Ravi Krishnan

From Wikipedia, the free encyclopedia

Ravi Krishnan (born June 16, 1972 in India) is an author,[1][2] speaker[3] and marketing professional[4][5] in the electric power industry. He is the founder of Krishnan & Associates, Inc. a Connecticut United States based energy marketing, energy recruitment and strategy consulting firm. He is also the founder of Enstreet.com, a web portal providing information on energy markets and energy jobs.

Ravi Krishnan is most well known as a proponent for the use of pollution control technologies in the power generation[6][7] and transportation industries.[8] His work on the technology evaluation of Selective Catalytic Reduction techniques for NOx removal has been cited in rule-making by various state environmental protection agencies and the Environmental Protection Agency.[9][10][11]

He has written on personnel issues facing the U.S. electric power industry, such as combating the loss of highly specialized technical skills due to aging issues.[12][13] Ravi Krishnan is also known for his commentary on emerging market trends in India's Power and Coal-Mining industries.[14] He has been engaged in the recruitment of several power generation subject matter experts in countries experiencing significant growth in energy infrastructure such as India to construct, commission and operate large power projects.[15]

References [edit]

1. ^ A Comparison of Clear Skies Act and Clean power Act to control multi-pollutant emissions, Electric Light & Power, March 2003, by Ravi Krishnan [1]
2. ^ SCR Economics For Diesel Engines, Diesel Gas and Turbine World Wide, July–August 2001, by Ravi Krishnan [2]
3. ^ Pump & Valve Market Updates, Scenarios & Forecasts, Hydraulic Institute, August 2011 [3]
4. ^ Power Gen 2010 Competitive Power College Curriculum
5. ^ Coal-Gen 2009, Pre Conference workshop [4] [5]
6. ^ Case Study: Staying in compliance after expanding production capacity, Ethanol Producer Magazine, October 2004, By Ravi Krishnan & R. Gifford Broderick [6]
7. ^ SCR: California cleaning, Modern Power Systems online August 5, 2002 Archived July 14, 2011, at the Wayback Machine
8. ^ Economics of Emission Reduction For Heavy Duty Trucks, DieselNet Technical Report, January 2005, Ravi Krishnan and T.J. Tarabulski [7]
9. ^ EPA Final Regulatory Support Document: Control of Emissions from New Marine Compression-Ignition Engines, January 2003, p.130 [8]
10. ^ Non-Road Diesel Emission Reduction Study Prepared for Puget Sound Clean Agency Oregon Department of Environmental Quality and U.S. Environmental Protection Agency, October 14, 2003, p.173 [9]
11. ^ Climate Change Roadmap for New England and Eastern Canada, p.180 Archived 2012-03-26 at the Wayback Machine
12. ^ Easing the Exodus, Power Engineering, June 1, 2006
13. ^ The New Energy Crisis: Power Industry in for a Jolt as About Half of Workforce Readies for Retirement, University of Cincinnati, August 7, 2006, By M.B. Reilly [10]
14. ^ India: Can she make the most of her opportunities, Power Engineering international, March 2010, by Ravi Krishnan [11] Archived 2012-03-26 at the Wayback Machine
15. ^ Krishnan Consultants play part in power projects, Stamford advocate.com, March 20, 2010, by Richard Lee [12]

External links [edit]

- Krishnan & Associates, Inc.
- Webcast Experts

Categories: American energy industry businesspeople | American businessmen of Indian descent | American business writers | 1972 births | Living people

Fierce competition in Indian emissions control market

With revised compliance deadlines for coal plant emissions limits that are much more realistic than those proposed in 2015, emissions control technology suppliers are looking to the Indian market. Ravi Krishnan, Krishnan & Associates (ravi@krishnaninc.com)

In December 2015 the Indian Ministry of Environment and Forests introduced new emissions requirements for Indian coal plants requiring compliance within two years, giving plants very little time for implementation.

The regulations were challenged by the Indian power industry causing delays and eventual extension of the compliance deadline to 2022.

Among factors taken into account were:

- lack of compensatory tariffs for many IPPs for FGD capital & operating costs;
- capital, operating and auxiliary costs for scrubbers considered too high;
- short implementation timeline for FGD (when compared with estimated average installation times of about 30 months);
- lack of existing CEMS data from power plants for pollutants (eg, SO_x, NO_x);
- no infrastructure to supply limestone and for disposal of gypsum;
- no experience in the selection, procurement, commissioning, operation, maintenance or commercial evaluation of AQCS systems.

On 11 December 2017, the Indian Central Pollution Control Board (CPCB), after expiry of the original deadlines, issued notices to power stations asking them to take action to comply with the same limits specified in the 2015 notification, but with a new deadline, shifted to 2022.

India's economic growth is expected to be a driver for continued coal-fired generation as intermittent renewables are not expected to meet demand and will not be cost-competitive compared with fossil fuels for some time, even though prices for renewables are dropping.

Around 163 GW of coal generation capacity is subject to the new limits and will need to implement emissions control measures by 2022.

There are also limits on specific water consumption at coal plants, to be covered in next month's issue.

Favoured technologies

The current preferred approach for NO_x retrofit projects is generally to deploy combustion modifications and SNCR (selectively). SNCR is used as a trimming technology beyond in-furnace NO_x control. However, ammonia and urea, the primary reagents for SNCRs, are currently in short supply in India and largely imported, making it a relatively expensive option for Indian power plants.

Selective catalytic reduction is being specified for all new units and some existing units depending on their vintage. However, the ash impact on SCR catalyst deactivation and erosivity is under investigation, with many pilot programmes underway at NTPC power plants. The verdict on this issue will be known very shortly.

Particulate matter retrofits consist predominantly of ESP upgrades and rebuilds, especially in the case of older units having to meet a PM emissions target of 50 ppm.

For SO_x control, all units above 500 MW built after 2003 will require flue gas desulphurisation technology. Units below 500 MW may require FGD technology, especially those located in densely populated areas (defined as in excess of 400 people/km²), while there will be prioritised installation of FGD technology for power stations in states neighbouring Delhi.

The favoured technology for SO_x control is predominantly wet FGD, which is generally the preferred technology due to the size of the units. However, dry systems would be ideally suited to Indian market conditions, particularly for smaller units, ie, below about 600 MW. Dry FGD has lower initial cost compared with wet FGD. In addition, dry FGD has lower power and water utilisation costs. Indian coal also is low in sulphur content, typically less than 1%, a further advantage for dry systems in the Indian context.

There has been some discussion about the availability of lime, the primary reagent for dry FGD, but our research shows it is available in some rural parts of India where many of the mine mouth coal fired plants are located.

In many cases smaller units (600 MW and less) are also relatively old and require an ESP rebuild anyway. In this case a dry FGD system with a baghouse is worth considering because overall it can potentially be a cost effective option, depending on particular plant circumstances.

However, wet FGDs remain the dominant technology as the Indian market has very limited awareness of the potential benefits of the dry system in the Indian context.

Technology procurement

A number of companies with experience of markets where AQCS technologies are well established and have been deployed for many years (notably USA, Europe, China, Korea and Japan) have partnered with Indian companies through licensing/JVs or appointed distributors/agents to supply equipment to Indian power plants and to make technology available.

There have been many cases of technology licences being signed with Indian companies. For example BHEL has recently entered into a technology collaboration agreement with Babcock Power Environmental of the USA on SCR systems and with Nano of Korea for design and manufacture of SCR catalyst. BHEL already had a technology collaboration agreement with MHPS in the FGD area, and is a major player in the supply of wet FGD in India.

Another feature of the Indian market is the reverse auction, not widely used in the environmental market globally, but becoming common in India, especially with NTPC projects. India is a very price sensitive market and the global softening of the air pollution control market has prompted the use of reverse auctions in India where sellers are underbidding each other to get business.

For example, there are typically 10+ competitors bidding for wet FGD projects, and in one recent NTPC auction there were around 30 bidders.

NTPC has nearly 25 FGD projects that it is awarding in lots and five companies have been successful so far: GE; BHEL; MHPS; ISGEC; and L&T-Chiyoda. There are perhaps 30-35 emissions control technology vendors around the world focusing on the Indian market because of dwindling prospects globally for coal power and coal plant emissions technology.

Indian industry observers were surprised by the low price recorded in the reverse auction that led to the first Telengana award to GE – equivalent to about $35/kW.

As FGD reverse auctions have progressed, prices have been moving upwards, reaching $130/kW. The scope for each project varies somewhat but usually includes absorber system, limestone preparation system and gypsum dewatering system, along with material handling system and wet stack.

The bottom line: a lot of suppliers and a lot of price competition for NTPC projects (although for non-NTPC projects, mainly IPPs and state GENCOs, the story is slightly different, and we have not been seeing reverse auctions).

The Chinese are not being preferred yet and there are many Western suppliers in the race. BHEL has been winning the lion's share, although other companies, such as GE, ISGEC, etc, are winning some projects.

Biomass co-firing

A new factor likely to further influence emissions control strategies at India's coal fired plants in the coming years is biomass co-firing. NTPC, which has a total coal fired installed capacity of about 40 GW, has said it plans to adopt biomass cofiring at all its coal units.

It has already trialled 7% biomass cofiring at its Dadri power plant.

Another technology of potential interest in the Indian context for utility applications, due to its inherent low emissions design and multi-fuel firing capability, is the CFB, to be the topic of a future article.

MOEF notification of emissions limit requirements for Indian coal fired plants, issued December 2015

Pollutant	Units installed before 31 December 2003*	Units installed after 1 January 2004 up to 31 December 2016*	Units installed from 1 January 2017**
Particulate matter	100 mg/Nm³	50 mg/Nm³	30 mg/Nm³
SO_2	600 mg/Nm³ (units < 500 MW) 200 mg/Nm³ (units ≥ 500 MW)	600 mg/Nm³ (units < 500 MW) 200 mg/Nm³ (units ≥ 500 MW)	100 mg/Nm³
NO_x	600 mg/Nm³	300 mg/Nm³	100 mg/Nm³
Mercury	0.03 mg/Nm³(for units of 500 MW or more)	0.03 mg/Nm³	0.03 mg/Nm³

*Units required to meet the limits within two years from date of publication of the notification.
**Includes all units which have been given environmental clearance and are under construction.

Recent contract wins for GE and BHEL

GE Power reports that it has recently been awarded four orders by NTPC to supply and install wet FGD systems (combined value of INR 1783 crore (USD 247 million)) for four NTPC coal fired plants: Solapur - 2 x 660 MW; Tanda Stage II – 2 x 660 MW; Feroze Gandhi - 1 x 500 MW; and Meja – 2 x 660 MW (jointly owned by NTPC and UPRVUNL).

GE has completed installation and performance guarantee tests for wet FGD at NTPC's Vindhyachal Stage V Unit 13, 1 x 500 MW, plant and was awarded the contract for wet FGD at NTPC's 2 x 800 MW Telangana coal plant earlier this year.

GE has also just won its first order for its (formerly Alstom's) low NO_x firing system in India. The low NO_x combustion system, classified as a "primary" NO_x reduction measure, has been selected for installation on NTPC's 2 x 490 MW Dadri coal fired plant and on a 136 TPH Tata Chemicals coal fired boiler in Mithapur, Gujarat.

Meanwhile,"amidst stiff competitive bidding", Bharat Heavy Electricals also reports recent substantial orders (total value INR 2900 (USD 400 million)) from NTPC, for wet FGD systems at the following coal fired units: North Karanpura - 3 x 660 MW; Mauda Stage 1 - 2 x 500 MW; Barh Stage I - 3 x 660 MW; and Barh Stage II – 2 x 660 MW.

BHEL notes that it was "one of the earliest entrants in the Indian market for emission control equipment", having executed the wet FGD system at Tata Power's Trombay unit 8 in 2008. With these recent orders, BHEL is currently installing FGD systems for 17 units owned by NTPC and its JVs, other projects being at: Bongaigaon - 3 x 250 MW; National Capital Power Station, Dadri - 2 x 490 MW; and Maitree - 2 x 660 MW (Bangladesh).

Indian Market for Emission Control Expected to See Explosive Growth

By Ravi Krishnan, Krishnan & Associates, Inc.

Coal remains central to India's power needs primarily due to energy security issues. Coal accounts for 61% of the installed power generation base and 75% of the generation capacity. An estimated 70.5 GW of coal based power is in the pipeline under various stages of construction. Bowing to international pressures, Conference of Parties or COP 21 compliance requirements and India's own initiative to go green, the Indian Ministry of Environment & Forests (MOE&F) announced stringent emission standards to regulate Nitrogen Oxide (NOx), Sulfur Dioxide (SO_2), and Particulate Matter emissions. These emission norms announced in December 2015, are stringent by any yardstick and comparable with standards in most Western countries. For example: NOx emission targets will range from 600 mg/Nm³ to as low as 100 mg/Nm³ and will vary depending on the commissioning date and size of the plant. Such targets will have to be achieved in a fairly short period of time and call for some of the best available control technologies (BACT) to be installed at Indian Power Plants.

The new norms have impacted a number of utilities and Independent Power Producers (IPPs). A total of 175 GW of existing coal fired capacity have been impacted to varying degrees potentially requiring over $10 billion in Air Quality Control Systems (AQCS). Majority of the projects will be related to the removal of SO_2, NOx and PM control equipment upgrades. Consequently, the market will require a whole new eco-system of equipment, auxiliaries & consumables for primary NOx control measures, Selective Catalytic Reduction (SCR), Flue Gas Desulfurization (FGD), Electro-static Precipitators (ESPs), Baghouses, Consumables (ex: Urea, Ammonia, Limestone, Lime, etc.), Waste Disposal, Auxiliaries for Environmental Equipment etc. Nearly 2/3rd of India's installed coal fired capacity is made up of plants commissioned after 2003 and all of them will have to be upgraded to the new requirements for NOx, SO_2 and PM emissions. The remaining 1/3rd, primarily older plants commissioned before 2003 will have to at least upgrade their PM control systems, if not more.

Exhibit 1: New Environmental Standards Place Emission Limits Similar to US & Europe

	TPP installed before 31 December 2003		TPP installed after January 2004 up to 31st December 2016		New install from 1st January 2017
Capacity	Smaller than 500MW	500MW & Above 500MW	Smaller than 500MW	500MW & Above 500MW	Any Size
Particulate	100mg/Nm³		50mg/Nm³		30mg/Nm³
SO_2	600mg/Nm³	200mg/Nm³	600mg/Nm³	200mg/Nm³	100mg/Nm³
NOx	600mg/Nm³		300mg/Nm³		100mg/Nm³
Mercury	-	0.03 mg/Nm³	0.03 mg/Nm³		0.03mg/Nm³

Exhibit 2: Breakdown of Units by Commissioning Date

Unit Size	Installed before 31.12.2003		Installed after 31.12.2003	
	No. of Units	Total Capacity	No. of Units	Total Capacity
Up to 250 MW	313	47628	110	19014
From 250-500 MW	27	13500	49	15220
More than 500 MW	0	0	137	80495

Meeting NOx Emission Control Standards

In order to meet the 100 mg/Nm³ NOx standard, new Indian plants will have to utilize SCR to achieve compliance. However, existing plants required to achieve the 300 mg/Nm³ standard can potentially attain this through a combination of primary measures such as, combustion controls, Selective Non-catalytic (SNCR) technology and in some cases SCR technology.

SCR refers to a technology that is a proven and effective method to reduce NOx emissions from coal-fired power plants by 90%+. The technology injects ammonia into the flue gas and reduces NOx in the presence of a catalyst primarily made up of vanadium, tungsten and titanium. Primary measures refer to non-catalytic technologies such as Low NOx burners, Overfire Air and SNCR systems. SNCR refers to injecting a reagent such as urea into the furnace flue gas in an appropriate temperature window to lower NOx. In some cases, SCR may still be required to get the 300 mg/Nm³ standard depending on the size of units and the type of coal utilized. A major impediment in India for SCR and other NOx control systems is technology preparedness on high ash Indian fuels. Indian coals can have up to 40%-45% ash content and Indian utilities are keen to evaluate cases where SCR technology has been proven to be effective and cost-competitive on similar type fuels before making full-scale investments. Unfortunately, nowhere in the world are such high ash fuels burnt in utility applications and it appears that SCRs have not been installed on units exceeding 60 gms/m³ as compared to the Indian average of about 80 gms/m³ In order to overcome this impediment, SCR system & catalyst suppliers are piloting their technology on a split stream demonstration basis with major Indian Power Producers like National Thermal Power Corporation (NTPC) that burn Indian fuel to test the performance of the SCR catalysts (i.e. honeycomb, plate, corrugated, etc.) under Indian conditions.

India Emerging as the World's Largest FGD Market

For power plants burning low sulfur Indian coal until recently there were no SO_2 emission standards. However, coastal plants burning imported coals have always required FGD technology if they are importing coals with sulfur content in excess of 0.5%. Furthermore, all new plants nationwide were asked to allocate space for an FGD scrubber for potential future retrofits. At the end of 2015, approximately 24 Indian power plants mostly importing higher sulfur coal had installed FGD scrubbers. These units have been achieving SO_2 emission levels of approximately 150 mg/Nm³ after the FGD upgrade.

The new SO_2 standards in India require power plants to attain between 200 mg/Nm³ and 600 mg/Nm³ depending on their size and commissioning date. Therefore, all new and many older coal fired units will require an FGD. The most common technologies utilized would be wet scrubbing using slurry as absorbent usually Lime or Limestone and sea water scrubbing.

Majority of the new FGD systems are likely to be wet systems as seawater systems are more common in coastal areas. Given that India is increasingly getting self-sufficient in coal production, fewer power plants in the future are likely to be located in coastal areas, a factor that will favor wet FGD systems. Another key criterion that will drive technology selection is the quality of gypsum for which there is tremendous demand given India's building materials requirements. The market for FGD is expected to be an $8 billion+ retrofit and upgrade market.

ESPs Dominate India's PM Control Market

ESPs are widely used to control the PM emissions from power plants in India to meet the emission standard of 50-100 mg/Nm³ for existing power plants and 30 mg/ Nm³ for new units. Over 98% of India's installed coal-fired generation capacity utilizes ESP. In spite of the continuous deterioration of coal quality and increasing ash content affecting the effi-

ciency of ESPs, baghouses have not made inroads due to their higher O&M costs and some poor performing projects where baghouses have operated sub-optimally.
The new standards offer a series of retrofit opportunities for adding fields , rebuilding existing precipitator with taller systems, installing fabric filters and flue gas conditioning such as ammonia injection, SO_3 conditioning and water fogging.

Market Exploding but Highly Cost-Sensitive

The market for AQCS systems in India is exploding. However, the new regulations are not without considerable opposition from utilities & IPPs who are concerned about unrealistic compliance schedules, high capital & operating costs, inadequate environmental cost recovery mechanisms, and technology challenges concerning high ash Indian coals. These uncertainties and pressures coupled with the high capex associated with AQCS systems and their impact on tariff recovery, have created a highly cost-sensitive AQCS market. These increased capex costs were not anticipated by Indian power plants. Many of the existing Power Purchase Agreements (PPAs) do not have a pass through clause to the consumer. Therefore there is currently no mechanism to pass the additional capital cost to the rate payer or customer. All these factors are putting immense pressure on Indian plants to adopt a low cost approach to achieving compliance both in terms of capital cost and variable costs.
Competition is fierce with more 30 global suppliers consisting of boiler and environmental companies active in the Indian market. The plethora manufacturers, many of them experiencing a slow worldwide market demand for AQCS products are offering products in India at amongst the lowest prices in an attempt to get a piece of the market. This has put further downward pressure on ownership costs. In India it is expected that the price for environmental equipment will be close to 50% of global prices. Therefore, localized manufacturing becomes very vital to be competitive in the Indian market.

Implementation Delays

The new emission standards have taken the Indian power industry by storm, as none of the power producers have had much experience in the selection, procurement, commissioning, operations, maintenance or commercial evaluation of AQCS systems. Many of them are in a learning mode as the industry grapples from lack of standardization in specifications. Some of the IPPs are struggling from the lack of compensatory tariffs and government owned utilities are concerned about the short implementation timeline. Given all these factors there is a good chance that the deadline will be extended from 2 years to perhaps 3 or 4 years.

Exhibit 3: AQCS Price Comparisons

	Expected Indian Price	Global Prices	Pollutant Removed
Low NOx Burners	$10,000/MW	$20,000/MW	NOx
SNCR	$12,000/MW	$25,000/MW	NOx
SCR	$45,000/MW	$120,000/MW	NOx
FGD	$90,000/MW	$250,000/MW	SO_2
SCR Catalyst	$3,500/MW	$5,000- $6,000/MW	NOx
ESP Renovation	$25,000/MW	$30,000/MW	PM

Krishnan & Associates, Inc. has announced the release of its latest study Indian Power Generation Market – Strategic Review & Forecast, 2016. K&A's study takes an in-depth look at how new emission regulations and other market developments will shape the future of the Indian fossil-fuel fired power generation industry. For more information visit http://krishnaninc.com/analytics/power-market-reports/

About the Author

Ravi Krishnan of Krishnan & Associates has been consultant in the Power Industry for nearly 20 years. His expertise includes marketing, market analysis & business development for the global energy industry. His Stamford, Connecticut based marketing & strategy firm initiates marketing & business development programs for corporations seeking market expansion in Asia especially India. For more information Ravi Krishnan can be contacted at Ravi@krishnaninc.com or + 1-203-257-9232

Sadbhav Infrastructure signs EPC agreement with its four subsidiaries

Sadbhav Infrastructure Project, a leading road BOT company in India that specializes in the development, operation and maintenance of highways, roads and related projects, has signed EPC agreement with its four subsidiaries worth Rs. 283 crore for maintenance and repairs works.
The first agreement is with Sadbhav Rudrapur Highway for Rampur-Kathgodam (I) section of NH-87, length 43.45 kms valued at Rs. 69 crore. The second agreement is with Sadbhav Nainitat Highway for Rampur- Kathgodam (II) section of NH-87, length 49.78 kms valued at Rs. 73 crore. The third agreement is with Sadbhav Bhavnagar Highway for Bhavnagar-Talaja section of NH-8E, length 48.05 kms valued at Rs. 82 crore. The fourth agreement is with Sadbhav Una for Una-Kodinar section of NH-8E, length 40.95 Kms valued at Rs. 59 crore.

Petrochemical complex to be set up in Andhra Pradesh

Union minister for Petroleum and Natural Gas (independent charge) Dharmendra Pradhan has recently said that a petrochemical complex will be set up in Andhra Pradesh in the current (2016-17) fiscal year at a cost of Rs. 35,000Cr.
Speaking at a public meeting at the Vangali area under Sabbavarm mandal in Vizag district after Chief Minister N. Chandrabulu Naidu laid the foundation stone for Indian Institute of Petroleum and Energy (IIPE) in the presence of Union ministers M. Venkaiah Naidu, Y. Sujana Choudhary and P. Ashok Gajapathi Raju, Mr. Pradhan said the foundation stone for petrochemical complex would be laid in this year. "Though the UPA government had included the proposed petro-chemical complex in the AP Reorganisation Act-2014, it mentioned that it was subject to feasibility. But, we have taken a decision to set up the petrochemical complex in AP in be-tween Vizag and Kakinada region," he added.
Saying that his ministry has planned to invest crores of rupees to make AP a petro-chemical and gas hub, Mr. Pradhan said the capacity of HPCL-VR refinery in Vizag would be enhanced from 8.5 million tonnes to 15 million tonnes by December 2016 at an investment of Rs. 21,000Cr, and there were plans for LPG pipeline supply in the state at a cost of about Rs. 62,000Cr.
"The IIPE will produce top experts within four years in petroleum, oil and gas sector and the campus will be ready in three to four years at the Vangali area in around 200 acres," Mr. Pradhan added.

POWER

India’s Power Industry Struggles to Solve Pollution Problems

06/01/2018 | Sonal Patel

In a bid to tamp down pollution, India’s government in December 2015 notified the country’s coal generators they would need to meet—for the first time—new emissions limits for nitrogen oxides (NO_x), sulfur dioxide (SO_2), and mercury, as well as tightened limits for particulate matter (PM) and water consumption. The gazetted notification gave new plants until January 2017 and existing plants just two years—until December 2017—to curb those pollutants.

But on November 17, 2017, in an affidavit filed with the Supreme Court of India, the Ministry of Environment, Forest, and Climate Change (MoEFCC) recognized the timeframe wasn’t feasible. India produces 80% of its power with coal, and electricity is an “essential commodity and [an] uninterrupted power supply in the country needs to be ensured at all times, therefore, many units cannot be taken out for retrofitting at the same time and it has to be done in phases, so as to avoid [a] problem in the power supply,” it said, asking the high court for an “appropriate order” to extend compliance deadlines until at least 2022.

In the affidavit, the MoEFCC also urged the court to relax a ban it issued in October of pet coke and furnace oil use by power generators and the cement sector in three states (Uttar Pradesh, Rajasthan, and Haryana) that flank the National Capital Region, which is battling an unprecedented smog crisis (Figure 1). The MoEFCC noted that while state-owned natural gas processing and distribution company GAIL was looking into what it will take to make power generation through gas competitive with coal plants, it was clear that India does not have enough domestic natural gas to fuel its power sector. “Present availability of domestic natural gas is only 23 [million metric standard cubic meters per day],” it said. That’s enough to fuel 5 GW of power capacity, against a demand of 120 GW to 160 GW for the whole country.

1. **A pollution predicament.** New Delhi and neighboring areas in the National Capital Region of India are battling a debilitating air pollution crisis. In November 2017, fine particles suspended in the air shot up to maximum levels recorded, soaring beyond hazardous levels. New Delhi officials took drastic measures, curbing construction and demolition work, banning diesel generators, and temporarily shutting down a coal-fired power plant, while the Supreme Court ordered the Environmental Pollution Control Authority to come up with an immediate, "comprehensive" plan to tackle the issue. This image was taken at the New Delhi railway station on December 31, 2017. *Courtesy: Sumita Roy Dutta/Creative Commons*

'Compliance with New Norms Is Limited'

As the court contemplates these matters, coal generators across the country are exploring the most economic and technically feasible options to comply with the MoEFCC's new environmental rules. Dr. Rahul Tongia, a fellow with New Delhi–based Brookings India, explained to *POWER* that generators have asked the government to temper emissions limits stipulated in the original edict, as well as to phase them in, focusing first on PM and NO_x last. Currently, "compliance with the new norms is limited, especially for plants that need retrofitting, and it's not clear when these would get implemented in full," he noted. "If the past is any guide, then much of the benefits of a five-year delay could be lost—instead of testing, learning, and implementing in phases, there might be limited action at the beginning, and a scramble near the end."

In a paper he authored for Brookings India in February 2017, Tongia noted that India's environmental focus rests on PM, specifically, fine particulates (PM 2.5)—even though SO_2 and NO_x, which, emitted as gases, convert to PM after atmospheric reactions. "India used to claim that its coal was low-sulfur, and hence [flue gas desulfurization (FGD)] wasn't required," he noted. Meanwhile, the data for how many plants have actually installed SO_2 controls to comply with the new limits is scarce.

According to the International Energy Agency's (IEA's) Clean Coal Centre, many coal generators have individual deadlines for installation of pollution controls, but delays are expected owing to a number of issues as India attempts to introduce mass retrofits or new technologies. The country will need to tackle technical difficulties; financial issues associated with introducing multiple technologies at the same time; a lack of local suppliers; and a subsequent need to import technologies as well as all materials and reagents. Then it must grapple with a lack of local skills and expertise. "The utilities have no experience in continuous emissions monitoring," it noted in a February 2018 report.

NOx Compliance: A Pipe Dream?

The IEA Clean Coal Centre's report specifically highlights India's coming troubles associated with its stringent new NO_x limits. The new rules require coal plants built before 2004 to emit less than 600 milligrams (mg) of NO_x per cubic meter (m^3). Plants installed after 2003 and before 2017 must emit no more than 300 mg/m^3, and plants installed after January 1, 2017, must limit NO_x emissions to 100 mg/m^3.

Significantly, however, as Sanjeev Kumar Kassi, who serves as director for thermal engineering and technology development at India's Central Electricity Authority, noted: "Globally available [selective catalytic reduction (SCR)] system[s] for reducing NO_x emissions are not proven for Indian coal having high ash contents. No proven and established control technology suited to our high-ash Indian coals exists and pilot studies [are] needed before deploying any technology."

The IEA points out that many boilers in India already have overfire air and deploy fuel biasing, but only a few have low-NO_x burners. (That point has been contested by an expert on the Indian power market, who notes that because Indian plants did not have pollution standards before the 2015 announcement, no overfire air was ever used.) To meet the new limits, more than 300 units may require SCR, it said. Though SCR achieves the highest NO_x removal rates of all NO_x controls (at 80% to 90%), it is also the most expensive option. Installing SCR systems in existing units may also be technically difficult, owing to plant layout. "For example, an extensive change in duct work, an [induced draft] fan, and other equipment will be required, for which there will have been no provision made in the existing design. There will be a need for reagent storage, an injection grid, and the associated installations."

An SCR for a 500-MW unit could also consume 2,500 tons per year of ammonia, but the use of ammonia as a reagent will cause new environmental and safety concerns. An SCR system would also require extra outages for inspection and replacement of the SCR catalyst, which is subject to high rates of erosion due to the ash content of the coal, and it may not reach the three-year average lifetime achieved with international steam coals. Then, "installation of the new system will lead to changes in [operations and maintenance] and greater auxiliary power consumption due to the increased pressure drop in the system," it said.

The Challenge of Control System Supply

Beyond those challenges, India will likely need to import NO_x control systems "as they are not manufactured in India" and ensure they are suited to Indian conditions. Citing Kassi, IEA noted that India is already facing a limited supply of desulfurization systems. Consequently, the installation of NO_x control technology at a rate of 20,000 MW/yr for a total 256,000 MW capacity (made up of 175,200 MW of existing units plus 80,800 MW under construction) would take more than 10 years.

Cost increases are also inevitable, with implications for the country's power reliability, and grid operators will be forced to take into account plant outages needed for modifications and retrofits. The IEA suggests that a high demand for pollution control systems within the short timescale could raise the energy tariff by an estimated 1¢/kWh. For plants older than 15 years, any increase in tariffs could hamper recovery of the investment within their remaining lifetime. For plants whose construction began before the new limits were introduced, delays and cost increases related to redesign are inevitable.

However, Ravi Krishnan, founder of global consulting firm Krishnan & Associates, also cited in the report, told *POWER* that competition among pollution control manufacturers is fierce in India. "I personally don't believe that there's a shortage of suppliers because there are at least 30 to 35 emission control companies around the world who are all centered into India, because the market for worldwide coal-fired emissions control technologies are dwindling. Coal-fired power plants are no longer being built in many parts of the world and some are being shut down because of revenue pressures from gas." Krishnan said demand for emission control technologies is dependent on new markets like India. "In fact, at a recent bid at NTPC, I think there were close to 25 to 30 suppliers. There are a lot of Chinese, European, American, Korean, and Japanese suppliers with [joint ventures] in India," he said.

For now, despite several hurdles on the horizon, a few major players are evaluating NO_x control technologies. The country's largest power generator NTPC currently is carrying out eight pilot projects for installation of SCR and selective non-catalyst reduction (SNCR). Results for these projects are expected in 2019, and the IEA noted that "utilities are not expected to make decisions before the outcome of these tests is clear." Indian power equipment maker BHEL is also testing its own SCR catalyst on a pilot scale. Recognizing the market's potential, global equipment manufacturers have also jumped into the game. Doosan Babcock and Doosan Heavy Industries recently developed low-NO_x burners specifically for such applications.

However, SCR isn't the only option, noted the IEA. Generators may also consider multipollutant control technologies like ReACT (Regenerative Activated Coke Technology), which was conceived in Germany in the 1950s and has been used successfully in Japan and in the U.S. (Figure 2); Haldor Topsoe's SNOX, an FGD system that can remove NO_x and particulates from flue gas; Tri-Mer's UltraCat, a ceramic filter technology; and Linde's LoTOx, a process that uses low-temperature ozone injection to oxidize NO_x for capture in an FGD system. "Although, there are no multi-pollutant systems developed specifically for high ash coals, it appears that the existing ones can be applied successfully," the IEA noted. The potential of the ReACT system in particular for Indian high ash coals has reportedly been recognized by the Indian government and utilities. However, both cost and water availability should be important considerations in the technology selection process in India, it added.

***2.* A multi-pollution solution.** Wisconsin Public Service began commercial operation of the first-of-its-kind U.S. ReACT (Regenerative Activated Coke Technology) facility at the Weston Power Plant 321-MW Unit 3 in November 2016, after a three-year construction period. According to the utility, with the $345 million ReACT facility in service, Weston 3's emissions, including mercury, NO_x, particulate matter, and SO_2, are all well below legal and regulatory requirements. This image shows construction of the facility by Miron, which conducted superstructure work. *Courtesy: Miron*

Still, "It may be years before the exact effect is known of Indian coals on these systems. Hence contracts with potential suppliers should have some flexibility and there should be provisions for future possible technical changes," the IEA said.

*—**Sonal Patel** is a POWER associate editor*

Death Toll Rises at Indian Power Plant 7 Months After Start

Rajesh Kumar Singh

Published on November 02 2017, 6:44 PM
Last Updated on November 06 2017, 7:26 AM

(Bloomberg) -- An explosion at a newly commissioned unit of a coal-fired power plant in northern India killed 32 people, while about 80 are still recovering from injuries in one of the nation's worst industrial disasters in recent years.

Flue gases and steam were released by the blast Wednesday afternoon at NTPC Ltd.'s Unchahar power plant, India's biggest electricity producer said in a statement. NTPC has shut the unit, which was commissioned in March and began commercial operations in September, while the rest of the

NTPC has formed a committee to investigate the accident, Federal Power Secretary A.K. Bhalla said by phone Friday. Officials from Bharat Heavy Electricals Ltd., which supplied the boiler, are also at the site to investigate, he said.

"Until now we were busy with rescue operations," Bhalla said. "From today onward we will try to find out what went wrong and accordingly take action."

The death toll ranks among one of the highest from a power-plant accident in recent years. Seventy-five people lost their lives following an explosion at a hydropower station in Siberia in 2009. Dozens of fatalities have also been reported at Chinese plants.

Industrial Accidents

The Unchahar blast is the deadliest industrial accident in India since the 2009 collapse of an under construction power-plant chimney at Bharat Aluminium Co.'s Korba project that killed 45 people, according to the Hindustan Times. India reported 809 accidental explosion incidents in 2015, causing 831 deaths, federal home ministry data show.

NTPC was little changed at 180.40 rupees as of 2:36 p.m. in Mumbai on Friday. Bharat Heavy Electricals gained 2.6 percent to 100.15 rupees. The benchmark S&P BSE Sensex rose 0.3 percent.

While India relies on coal, Prime Minister Narendra Modi has made surprising progress on his ambitious goals for developing the country's renewable energy, said Jason Bordoff, director of Columbia University's Center on Global Energy Policy. Renewables are the fastest-growing form of power and stand to challenge coal's dominant position in the utility space.

"As a share of the total energy mix, renewables will grow and coal will fall," Bordoff said. "But that's a share of a pie that's getting massively bigger. That still means a lot more coal a decade or two from now than it does today."

The plant in Uttar Pradesh state has a total capacity of 1,550 megawatts, according to the company. NTPC has generating capacity of 51.7 gigawatts, almost 16 percent of India's total 329.3 gigawatts capacity.

While safety standards at Indian power plants have improved in recent years, there's still some way to go, said Ravi Krishnan, who runs a specialized energy consultancy with offices in the U.S. and India. NTPC has had an impressive safety record overall, he said.

"They have some of the best operating practices," he said. "It surprised me when I saw this, it doesn't happen very frequently."

India's new emissions rules: challenges and opportunities

The Indian power industry is now getting to grips with addressing new stringent emissions requirements for coal plants. The Indian market for air quality control equipment and supporting ancillaries is expected to enjoy explosive growth.

*Ravi Krishnan, Krishnan & Associates, Inc, Stamford, CT, USA (ravi@krishnaninc.com)**

Coal remains central to India's power needs primarily due to energy security issues. Coal accounts for 61% of the country's installed capacity and 75% of the power generated. An estimated 70.5 GW of coal based power is in the pipeline at various stages of construction. Bowing to international pressures, COP 21 compliance requirements and India's own initiative to go green, the Indian Ministry of Environment & Forests (MOE&F) has introduced stringent new standards to regulate NOx, SO2, particulate matter and mercury emissions from coal fired power plants. See Table 1.

Table 1. India's new emissions standards for coal plants (mg/Nm^3)

	Plants installed before 31 Dec 2003		Plants installed 1 Jan 2004 to 31 Dec 2016		New installs, from 1 Jan 2017
Capacity	Smaller than 500 MW	500 MW and above	Smaller than 500 MW	500 MW and above	Any size
Particulates	100	100	50	50	30
SO_2	600	200	600	200	100
NO_x	600	600	300	300	100
Mercury	-	0.03	0.03	0.03	0.03

The new requirements come into effect in 2017, creating a very tight timescale for compliance. Particulates were the only coal plant emissions controlled prior to the new regulations. The new regulations tighten the existing PM requirements.

The new emissions norms for NOx and SO2, announced in December 2015, are stringent and comparable with standards found in many Western countries.

For example, NOx emission targets will range from 600 mg/Nm3 to as low as 100 mg/Nm3 and will vary depending on the commissioning date and size of the plant. Such targets will have to be achieved in a fairly short period and call for some of the best available control technologies (BACT) to be installed at Indian power plants.

The new Indian standards introduce a requirement for mercury, although this is less stringent than US EPA requirements and the new European BREF levels. For example, the BREF level for mercury is 1-4 μg/Nm3, compared with the 30μg of the new Indian regulations.

The new norms have major implications for a number of Indian utilities and independent power producers (IPPs). A total of 175 GW of existing coal fired capacity will be impacted to varying degrees, potentially requiring a spend of over $10 billion on air quality control systems.

The majority of the projects will be related to the removal of SO2, NOx and PM, entailing control equipment upgrades, with mercury control largely achieved as a co-benefit of these measures.

The regulations are likely to give rise to the establishment of a whole new “eco-system” of equipment, auxiliaries, consumables and waste disposal arrangements to support primary NOx control measures, selective catalytic reduction (SCR), flue gas desulphurisation (FGD), electrostatic precipitators (ESPs), and baghouses. Consumables will include urea, ammonia, limestone and lime.

Nearly two-thirds of India’s installed coal fired capacity is made up of plants commissioned after 2003 and all of them will have to be upgraded to the new requirements for NOx, SO2 and PM emissions. The remaining one-third, primarily older plants commissioned before 2003, will have to at least upgrade their PM control systems, if not more.

Table 2 shows a breakdown of Indian coal units by size and commissioning date.

Table 2. Breakdown of Indian coal units by size and commissioning date

Unit size	Installed before 31 Dec 2003		Installed after 31 Dec 2003	
	No. of units	Total capacity	No of units	Total capacity
Up to 250 MW	313	47628	110	19014
From 250 to 500 MW	27	13500	49	15220
More than 500 MW	0	0	137	80495

Meeting NOx requirements

To meet the 100 mg/Nm3 NOx standard, new Indian plants will have to make use of SCR to achieve compliance. However, existing plants required to achieve the 300 mg/Nm3 standard can potentially attain this through a combination of primary measures, such as combustion controls and selective non- catalytic reduction (SNCR) technology, with SCR technology required in some cases.

SCR – entailing injection of ammonia into the flue gas and reduction of NOx in the presence of a catalyst primarily made up of vanadium, tungsten and titanium – can reduce NOx emissions from coal-fired power plants by 90% and above. Primary measures include fitting of low NOx burners and overfire air systems.

Whether SCR is needed or not to get to the 300 mg/Nm3 level depends on the size of units and the type of coal being used.

A major impediment in India limiting the applicability of SCR and other NOx control systems is technology preparedness for high ash Indian fuels.

Indian coals can have up to 40%-45% ash content and Indian utilities are keen to evaluate cases where SCR technology has been proven to be effective and cost- competitive on similar fuels before making full-scale investments. Unfortunately, nowhere in the world are such high ash fuels burnt in utility applications and it appears that SCRs have not been installed on units using fuel with an ash content exceeding 60 g/m3, well below the Indian average of about 80 g/m3. In order to overcome this impediment,SCRsystem&catalystsuppliers are piloting their technology on a split stream demonstration basis with major Indian power producers such as National Thermal Power Corporation (NTPC) to test the performance of various SCR catalyst configurations (honeycomb, plate, corrugated, etc) with Indian fuels under Indian conditions.

India becoming the world's largest FGD market

For power plants burning low sulphur Indian coal there were, until recently, no SO2 emission standards. However, Indian coastal plants burning imported coals have always required FGD technology if they are importing coals with sulphur content in excess of 0.5%. Furthermore, all new plants nationwide were asked to allocate space for an FGD scrubber for potential future retrofits. At the end of 2015 around 24 Indian power plants, mostly importing higher sulphur coal, had installed FGD scrubbers.These units have been achieving SO2 emission levels of approximately 150 mg/Nm3 after the FGD upgrade.

The new SO2 standards in India require power plants to attain between 200 mg/ Nm3 and 600 mg/Nm3 depending on their size and commissioning date. Therefore, all new and many older coal fired units will require an FGD system. The most common technologies to be deployed will be wet scrubbing, using slurry as absorbent, usually lime or limestone, and seawater scrubbing.

Most of the new FGD systems are likely to be wet systems as seawater systems are generally only used in coastal areas. Given that India is aiming for increased self- sufficiency in coal production, fewer power plants in the future are likely to be located in coastal areas, a factor that will favour wet FGD systems over seawater systems.

Another key criterion that will drive technology selection is the quality of gypsum, for which there is tremendous demand given India's building materials requirements.

Overall, the market for FGD is expected to be an $8billion+ retrofit and upgrade market.

ESPs dominate India's PM control market

ESPs are already widely used in India to control the PM emissions from power plants to meet the existing emissions standards.

Over 98% of India's installed coal- fired generation capacity makes use of electrostatic precipitators. In spite of the continuous deterioration of coal quality and increasing ash content affecting the efficiency of ESPs, baghouses have not made inroads due to their higher O&M costs and some poor performing projects where baghouses have operated sub-optimally.

To meet the new standards, 50-100 mg/ Nm3 for existing power plants and 30 mg/ Nm3 for new units, will entail, for many plants, substantial retrofitting, including adding of fields to ESPs, rebuilding existing precipitators with taller systems, installing fabric filters and flue gas conditioning such as ammonia injection, SO3 conditioning and water fogging.

Prices under pressure

The market for AQCS systems in India is exploding. However, the new regulations are not without considerable opposition from utilities and IPPs, which are concerned about unrealistic compliance schedules, high capital and operating costs, inadequate environmental cost recovery mechanisms, and technology challenges arising from high ash Indian coals. These uncertainties and pressures coupled with the high capex associated with AQCS systems and their impact on tariff recovery, have created a highly cost-sensitive AQCS market. These increased capex costs were not anticipated by Indian power plants. Many of the existing power purchase agreements (PPAs) do not have a pass through clause to the consumer. Therefore there is currently no mechanism to pass the additional capital cost to the rate payer or customer. All these factors are putting immense pressure on Indian plants to adopt a low cost approach to achieving compliance both in terms of capital cost and variable costs.

Table 3. Price comparisons for air quality control system equipment ($/MW)

	Expected Indian price	Global price
Low NO_x burners	10 000	20 000
SNCR	12 000	25 000
SCR	45 000	120 000
FGD	90 000	250 000
SCR catalyst	3500	5000-6000
ESP renovation	25 000	30 000

Competition is fierce, with more than 30 global suppliers, including boiler and environmental, companies active in the Indian market. The plethora of manufacturers, many of them experiencing weak worldwide market for their air quality control systems (AQCS) products, are offering products in India at amongst the lowest prices in an attempt to get a piece of the market. This has put further downward pressure on ownership costs. In India it is expected that the price for environmental equipment will be close to 50% of global prices (see Table 3). Therefore, localised manufacturing becomes very vital to be competitive in the Indian market.

Implementation delays looming

The new emissions standards have created shockwaves in the Indian power industry, as none of the power producers have had much experience in the selection, procurement, commissioning, operations, maintenance or commercial evaluation of AQCS systems. Many of them are in a learning mode as the industry grapples from lack of standardisation in specifications. Some of the IPPs are struggling from the lack of compensatory tariffs and government owned utilities are concerned about the short implementation timeline. Given all these factors there is a good chance that the implementation deadline will be extended from two years to perhaps three or four years.

BUSINESS

INSIDE:
THE WALL STREET JOURNAL SUNDAY
C3-5

REGIONAL NEWS

Juice for the lights of India

Krishnan firm plays part in power projects

By Richard Lee
STAFF WRITER

Enough electricity for the homes and businesses of India is the mission of one Stamford consulting firm that focuses on the power and energy industry.

Stamford-based Krishnan & Associates, led by Principal Consultant Ravi Krishnan, a native of Mumbai, India, is playing a major role in creating an electricity generation grid to meet the country's rising industrial demands. The firm recently released a detailed study on emerging trends in the Indian power generation industry, analyzing the current state and future of the Indian fossil fuel-fired power sector.

The Indian government has embarked on an aggressive plan to increase power generation capacity,

See KRISHNAN on C2

John Evans, a manager of business development for Krishnan & Associates, left, and the principal of Krishnan Associates, Ravi Krishnan, stand in the conference room of the office in Stamford. The firm specializes in "innovative solutions for the power industry," according to Krishnan.

BOB LUCKEY/STAFF PHOTOGRAPHER

Krishnan provides juice for the lights of India

Continued from C1

according to Krishnan. There is a rapidly growing need for reliable power in the vast rural areas of the country, where the public policy goal is increasing the average household income, he said.

India has four times the population of the United States but one-fifth of the power generation capacity.

"There's obviously a lot of catching up to do. For market suppliers, there is where the future is," Krishnan said, adding that during peak-demand periods there is a need for 20 percent more electrical power than currently provided.

Like other Indian businesses, Krishnan's staff at its office in Navi Mumbai have become accustomed to the periodic power shortages, making use of a battery and a stationary diesel generator.

"The government of India, through its Power Commission, has planned to increase capacity through a five-year plan. This is a great opportunity for power equipment suppliers and people who want to leverage their expertise in this market," said Krishnan, who previously was executive vice president and chief operating officer of RJM Corp., a global provider of environmental technologies for utility and industrial boilers.

India is working to bring 200,000 megawatts online in the next 12 years, but its native coal used in the interior of the country produces high levels of ash and has a lower heating value, Krishnan said. Its generating plants have access to Indonesian coal, which burns cleaner than the Indian variety.

The Indian government is implementing stricter air pollution standards, but there is room for improvement, Krishnan said.

"We think it may not be enough. We're educating the Indian government and power developers" about building facilities that can be retrofitted with environmental controls, he said.

Besides providing consulting advice to the power and energy industry, Krishnan's firm also places personnel at Indian power plants and projects.

"We're sending Americans to India to run large power projects. This is a very specialized skill set," he said, adding there aren't enough Indians with supervisory and vocational skills in the country's industry. His firm has placed more than a dozen American power and energy professionals in India, Krishnan said. Many of them have Indian roots and work on two- to three-year contracts.

The energy infrastructure side also is complex. While Indian companies, often through joint ventures, manufacture components for the power and energy industry, Chinese and Western manufacturers vie for Indian power construction contracts.

"The Chinese are very active in India supplying equipment. Chinese equipment is 30 percent less expensive than Western equipment but delivered more quickly," he said. "Western equipment has traditionally been more reliable. There are customers in India that value that, even if it is more expensive. The Chinese have been good at mass manufacturing, but when it comes to customer design they fall behind."

Krishnan founded his firm in 2005, timed to take advantage of the surge in India's economic growth. The business is among a wave of U.S.-based companies that see India's burgeoning economy as an opportunity to sell their products and services.

At the same time, Indian-based companies, fueled by an expansion in the nation's power generation capacity, are gearing up to become players in the global marketplace, said Thomas Abraham, founder of the Global Organization for People of Indian Origin, and president of Innovative Research & Products, a Stamford developer and marketer of industry research reports.

"There is a big need for power generation in India. There are a lot of opportunities for people of Indian origin because they have a network in India. There are a number of companies in Stamford that are doing business in India," said Abraham, a native of Kerala, India, adding that those contacts can result in Indian-based businesses seeking opportunities in Stamford.

As India's energy capacity improves, more companies will take advantage, empowering them to become participants in the international marketplace, said Abraham, who joined other Stamford business owners of Indian heritage recently in a meeting with Stamford Mayor Michael Pavia to discuss business connections between India and the city.

Indian companies will increasingly see opportunities in the United States, he said, as they grow within their home country.

Krishnan & Associates is filling a void as more Indians who have been living in the U.S. and expatriates travel to India to fill positions in the power and energy industry, and other key businesses, said Raj Mahale, a partner in the international corporate practice at the Stamford law office of Fox Rothschild.

"There is a huge need. I think they're serving an interesting niche model," he said. "Niche-focused advisory services are popping up all over."

PANKAJ NANGIA/BLOOMBERG

Cooling towers stand at the NTPC Ltd. power station in Dadri, India, earlier this month. Krishnan & Associates of Stamford is working with the Indian industry to increase power capacity and the capabilities of its personnel.

Energy equals economic strength

03/01/2013

Coal is the backbone of India's electricity generation sector, so it is essential that the long-running supply issue is addressed
Credit: World Coal Association

A power blueprint combining thermal, hydroelectric, nuclear and renewable generation must urgently be drawn up to ensure India's current energy crisis does not take a toll on the country's economic growth, argues Ravi Krishnan.

With projected long-term annual economic growth rates of more than 7 per cent, it is vital for India to plan for concurrent growth within its energy sector, combining thermal, hydroelectric, nuclear and renewable sources.

With the predominant use of domestic and imported coal as the country's primary fuel source, the government has embarked on ambitious plans to increase coal-fired power generation capacity.

Despite these aggressive plans, a number of factors including fuel and tariff considerations have led to capacity addition shortfalls, which will have to be addressed on a number of fronts immediately to ensure that the current energy crisis does not take a toll on India's economic growth.

India has experienced impressive GDP growth rates exceeding 7 per cent in the past. While recent trends indicate a slow down, long-term GDP growth of 7 per cent-plus is expected to continue through to at least 2020. To support India's expanding economy, large-scale power capacity additions in the range of 100-150 GW are projected over the next ten years. While this represents an impressive objective, in reality there has been - and will continue to be - shortfalls in capacity additions due to a variety of factors, including fuel constraints, regulatory and tariff issues, shortages of skilled manpower and construction equipment, infrastructure issues, and environmental and bureaucratic delays in obtaining clearances and permits.

Contributing to the energy capacity addition shortfall is a shortage in domestic coal production, price volatility for higher quality imported coal and natural gas. Bureaucratic and government delays associated with obtaining permits and clearances for pre-bid activities such as land acquisitions, water allocation, environmental clearances, and commercially viable power purchase agreements (PPAs) also contribute to the ongoing power generation capacity commissioning delays and shortfalls.

The lack of trained construction, commissioning, electrical and instrumentation personnel accounts for close to a 33 per cent shortage in technically skilled manpower.

Major efforts are currently underway to train local talent from villages in proximity to power projects, but this has led to non-availability and inadequate training procedures which can contribute to delays in commissioning and construction.

Also, major construction equipment such as rolling stock, cranes, tunnel boring equipment and welding machines are in short supply, and this has led to over-working of equipment, safety issues and project delays.

The Indian government, national and state-run utilities, and independent power producers (IPPs) are all taking measures to address these shortfall issues. It is expected that over the long-term many of these issues will be mitigated to a significant degree resulting in a decreasing gap in power demand and capacity.

Policy calls for more power

The energy policy of India can be characterised by five major economic and social drivers:

- A rapidly growing economy, with a growing need for a dependable and reliable supply of electricity, gas and petroleum products;
- Increasing household incomes, causing demand for affordable electricity;
- Limited reserves or bottlenecks to efficiently exploit fossil fuels, necessitating vast imports of crude oil, natural gas, petroleum products and coal;
- Adverse environmental impacts of rapid urban and regional development, necessitating the adoption of cleaner fuels and cleaner technologies.
- Increased investment in social and economic infrastructure, enhanced productivity in agriculture and a fresh impetus to the manufacturing sector.

The current electricity generation capacity in India is approximately 206,000 MW, and it ranks sixth in the world in terms of electricity generation, coming behind the US, China, Japan, Russia, and Canada.

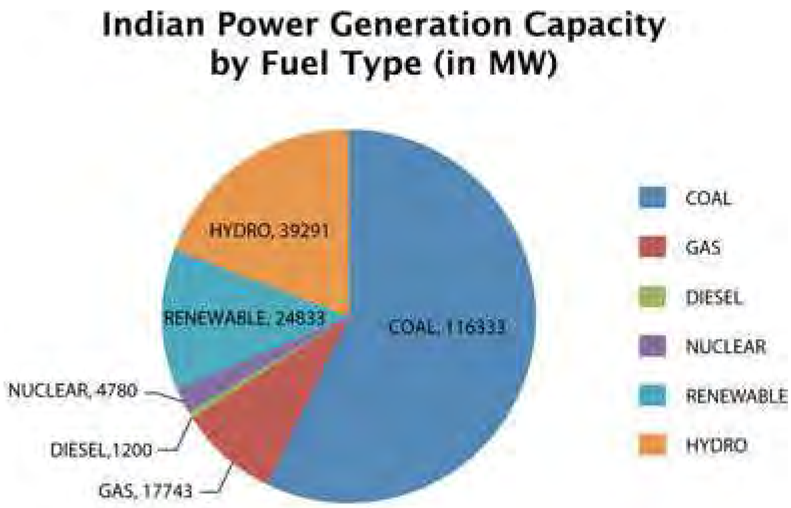
Today, India is on the same threshold of power generation capacity as was the case for China 15 years ago. Table 1 shows a comparison between installed generation capacity expansion in China and India.

Table 1: Comparing the 22-year installed capacity growth in India and China

	India	China
Installed capacity (FY 1990)	63 GW	118 GW
Installed capacity (FY 2000)	98 GW	319 GW
Current capacity (FY 2011)	206 GW	1040 GW
CAGR growth	6.7%	11.3%
Per capita power consumption (FY 2012)	0.16 kW	0.77 kW

Fossil fuels account for about 65 per cent of the total installed capacity with the remaining 35 per cent being hydroelectric, renewable and nuclear. Among the fossil fuels, coal accounts for about 56 per cent of the nation's generating capacity, with natural gas and oil accounting for 9 per cent and 1 per cent, respectively.

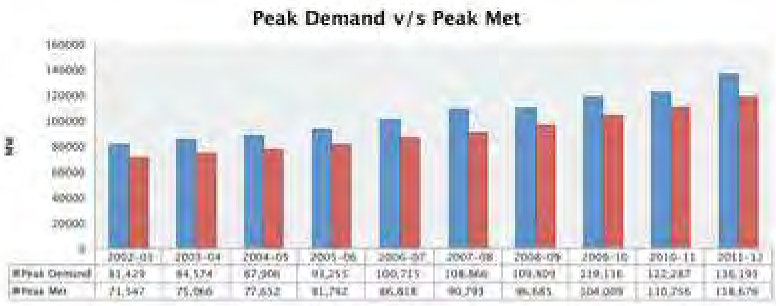
The central and state governments together own and operate approximately 73 per cent of the installed capacity in India. The participation of the private sector has however been increasing over time owing to power reforms. The full breakdown of generating capacity by specific fuels is shown in Figure 1.



Since India's independence from Britain in 1947, electric generating capacity has grown from 1400 MW to the current capacity of approximately 206,000 MW.

During the same period, India has witnessed a population growth from 250 million to over 1.3 billion. The growing population, combined with India's recent economic growth and inadequate supply and distribution infrastructure, has resulted in power supply shortages - both in terms of peak demand and overall energy supply.

An overall average peaking shortage of about 12 per cent has been typical on an all-India basis, as shown in Figure 2. The large energy deficit gaps have resulted in low per-capita consumption. Therefore, additional generating capacity will be required in order to serve the country's population and fuel economic growth.



This has prompted the government to embark on an ambitious plan to increase power generation capacity to bridge the growing power demand - capacity gap with low-cost power.

Five-year plans established by the government's Planning Commission lay out specific targets for new generation capacity. The 10th five-year plan (2002-2007) had a target of 41,100 MW of additional capacity.

However, only 18,000 MW of added capacity came on stream during this period, representing a slippage of 56 per cent. For the 11th five-year plan (2007-2012), the slippage decreased considerably as an estimated 67,000 MW was added against the 11th five-year plan target of 83 000 MW. For the 12th five-year plan (2012-2017), an additional 93,000 MW of new capacity has been targeted but less than 50% is expected to come on line due to current market pressures.

Generation alternatives

The primary fuel in India for power generation is coal becasue domestic resources are available in abundance in India. However, its coal production has remained low in comparison to reserves, a key issue that has to be resolved in order to accelerate power generation capacity additions in the future.

Natural gas is in short supply in India and supply to the existing gas-fired power stations has been inadequate. As such, the plants have been operating at 58-60 per cent load factor. Although India has identified a few domestic natural gas reserves and is in discussion with natural gas suppliers in Qatar, Iran, and Australia, gas is not expected to bridge the power generation deficits in the short-term. Furthermore the K-G basin projects in India is not producing enough gas at competitive prices to justify natural gas-fired generation.

Indian coal has a high ash content (between 35-45 per cent), silica and alumina, and highly abrasive with slagging characteristics. Given the high ash content and relatively weak coal transportation system in the country, Indian coal does not 'travel economically'. Therefore, locating power plants close to the pit heads is common.

Availability of coal for power production is a matter of serious concern in India. In order to meet the original 12th five-year plan requirements, coal supply is estimated at around 842 million tonnes (MT) for 2016-17.

India will be facing a shortage of in the region of 280 MT. Domestic coal production has not kept pace with recent power capacity additions. Many of the leading government-owned coal producers have not been able to produce enough coal because of the following reasons:

- Land acquisition, rehabilitation and inability to settle with landowners and villagers as per the Forest Rights Act;
- Delays in obtaining Ministry of Environment and Forest (ME&F) clearances;
- Deficient railway and mining infrastructure to move coal out from the mines and coal terminals;
- Poor mining technology/mechanisation;
- Various NGOs opposing deforestation and resettlement of tribes and villages.

A large portion of the indigenous coal in India is trapped under the few remaining forests in the central and eastern parts of the country, which are classified as protected areas. The Ministry of Coal is looking to increase the amount of coal-bearing land it has, and needs clearances from the ME&F to mine additional forest lands. However, the ME&F superimposed forest cover on 602 coal blocks in nine important coal fields in India, and recommended that 47 per cent of the blocks be kept off limits to mining.

The coal ministry however wants access to virtually all 602 blocks. This impasse is likely to hurt economic growth unless addressed immediately, and will require resolution at the highest level as it impacts sensitive issues and could affect the growth prospects for industry and the economy.

The coal mining sector in India has been privatised. However, delays in land acquisition norms, low-cost financing, inadequate skilled labor, misallocation of coal blocks to private companies with limited mining expertise, weak transportation and poor environmental permitting procedures are delaying the development of various private sector initiatives. The private sector is attempting to produce more than 200 MT of coal reserves annually by 2020.

All these factors have placed an increased dependence on imported coal. Some of the Indian power producers mitigated such issues by strategically locating plants in coastal areas and securing coal resources from countries such as Indonesia, South Africa, Mozambique and Australia.

However, recent initiatives by the Indonesian government to impose a 25 per cent tax on exported coal and mandatory benchmarking exports to international prices has slowed down several Indian power projects.

Many of the projects had aggressively bid in the tariff-based competitive bidding process, based on their agreements/arrangements they had made for fuel stock from Indonesia at significantly lower prices. Costlier imports are now impacting the commissioning rate of new Indian coal power plants that are dependent on Indonesian coal as many of the PPAs do not have an all-important 'fuel pass-through clause'.

Therefore, in many power projects firing Indonesian coal the generation cost itself is more than the PPA price resulting in a number stranded assets.

Indian power plants cannot run on such expensive coal imports. This will make power unaffordable in India. Therefore, some of the options are to ramp up domestic coal production, design equipment to burn a wider range of fuels and change the fuel mix with emphasis on renewable sources.

Furthermore, various state governments which purchase the power from the IPPs will have to raise consumer tariffs for the stranded projects that were originally bid for at a fixed rate. However, raising consumer tariffs can be extremely unpopular and politically sensitive, especially with national elections scheduled in 2014. This issue will be critical and will have to be carefully timed by various state governments.

Unrealised potential

The Indian power sector has traditionally faced a range of challenges in expanding generation capacity. India has added 91 GW in the past two five-year plans against a cumulative targeted capacity increase of 124 GW. The shortfall was largely attributed to a shortage of boiler, turbine and generator equipment manufacturing facilities. Additional factors that have adversely affected capacity additions causing slippages include shortages of both construction equipment and skilled manpower, availability of fuel, project financing, rail, port and other infrastructure bottlenecks, project safety issues and delays in environmental and governmental clearances.

Previously, Bharat Heavy Electricals Limited (BHEL) was the only major supplier within India. Although BHEL retains its leadership position, in the past few years several Indian boiler and turbine manufacturers have solidified alliances with major western companies to add substantial subcritical and supercritical boiler manufacturing capacity.
With this relatively new boiler capacity addition, shortfalls in generating capacity additions should be substantially mitigated in the current and following five-year plans. The new added Indian manufacturing capacity will also reduce an historical dependence on Chinese manufacturers.

Looking ahead into the next ten years, if India wishes to realise its full economic potential and achieve its goal of adding even 100,000 MW during this time, key issues such as coal availability and linkages, rail and port infrastructure, land acquisition reforms, PPA revisions and greater levels of foreign direct investment have to be achieved.

The industry is hopeful that national elections in 2014 will bring major regulatory and policy reform. If these shortcomings are overcome, the country will undoubtedly continue to represent the highest growth opportunity for new power generation capacity expansions in the world.

Ravi Krishnan runs US-based Krishnan & Associates, which initiates business development programmes for US and European OEMs seeking market expansion in India. For more information, visit www.krishnaninc.com.

Ravi Krishnan, Krishnan & Associates Inc

India: Can she make the most of her opportunities?

A fast growing economy and an appetite for energy to match mean India will be attractive to power companies and providers of environmental services equipment for some time. Where do the opportunities lie?

caption

India will remain a robust market for worldwide providers of power plant and environmental equipment at least until 2030. Demand for electricity in the country is high and India has aggressive targets for adding capacity. The country's potential in the power sector is yet to be fully realized and additions to its power generation capacity are expected to be substantial despite shortfalls resulting from factors internal and external to the country.

So what is driving India's demand for power and what opportunities does it open up to power companies and providers of environmental services equipment?

Four major economic and social drivers characterize the energy policy of India: a rapidly growing economy, increasing household incomes, limited domestic reserves of fossil fuels and the adverse impact on the environment of rapid development in urban and regional areas. Rapid economic growth has created a growing need for dependable and reliable supplies of electricity, gas and petroleum products. India's economy has expanded by above six per cent per year over the last five years, one of the fastest rates in the world. Projections are for it be more than eight per cent per year until 2020. Supplies of electricity, gas and water must keep up with this. India's economy has more than tripled in real terms since economic reforms began in 1991.

Part of the reason for this growth is the commitment successive governments have shown to continue economic liberalization, stance that has instilled confidence in investors and presented opportunities. The second driver of the country's energy policy, rising house hold incomes, has pushed up demand for affordable electricity. Consumer demand too has grown rapidly over the decades. India has a population of over a billion people and as a market for retail consumer goods it is already one of the largest, whose size is expected to grow to $600 billion per year by 2012, putting it among the top five in the world. Geographically speaking India is one of the largest countries in the world. Its area covers more than 3 million km^2, or roughly a third that of the United States.

India is a young nation. Some 70 per cent of its population is under the age of 36 and 20 per cent under 24. It produces over 15 million fresh university graduates each year, about 1.5 times as many as China and about twice as many as the United States. It has also made considerable progress on many socio-economic fronts. Since the 1950s, the fraction of the population below the poverty line has dropped from over 50 per cent to just over 25 per cent, and adult literacy

Table 1: Demand Supply Scenario in Western India for the period April 2008 to February 2009						
State/Union Territories	Peak Demand (MW)	Peak Deficit MW	Peak Deficit (%)	Energy Requirement (MU)	Energy Deficit (MU)	Energy Deficit (%)
Gujarat	11 841	3024	25.5	61 910	6654	10.7
Chhattisgarh	2887	57	2	13 682	395	2.9
Madhya. Pradesh	7,564	754	10	38 262	6,379	16.7
Maharashtra	18 049	4674	25.9	110 767	23 792	21.5
Daman and Diu	225	25	11.1	1630	202	12.4
Dadar and Nagar Haveli	466	32	6.9	3239	132	4.1
Goa	464	51	11	2532	40	1.6

rates have risen from the high 30 per cent range to the mid-60 per cent range. India will need a total capacity addition of 150-250 GW over the next 12 years to address its goal to alleviate poverty.

FOSSIL FUEL RESERVES

Low domestic reserves of fossil fuels form the third main driver in India's energy policy. As about 64 per cent of India's total installed capacity is fossil-fuel fired it has to import vast amounts of natural gas, crude oil and petroleum products. Coal accounts for about 53 per cent of the nation's generating capacity, while gas and oil account for 10 per cent and 1 per cent respectively.

India's domestic of coal resources are available in abundance. Most of these are in the states of Bihar, Jharkhand, Orissa, Madhya Pradesh, Chhattisgarh and West Bengal. Production of coal in India has traditionally been low compared with its reserves. One reason is because the past has seen restrictions on the entry of private sector players in the mining of this fuel in the country. These restrictions have been removed, encouraging private participation in coal mining.

Indian coal is high in silica and alumina and is highly abrasive, with high slagging characteristics. Its high ash content of 35-45 per cent and the weak coal transportation system in the country mean that it is economical to locate power plants close to pit heads. Most of the pit head stations have their own dedicated coal transportation system and do not depend on India's railways.

To address the need for a higher quality of coal many Indian power producers are now acquiring fields in the countries of east Asia, such as Indonesia, and erecting power plants in Indian coastal towns to tap into a more economical fuel supply. This should fulfill some of the country's need for higher quality coal, but domestic supplies will still fuel the bulk of the country's power generation.

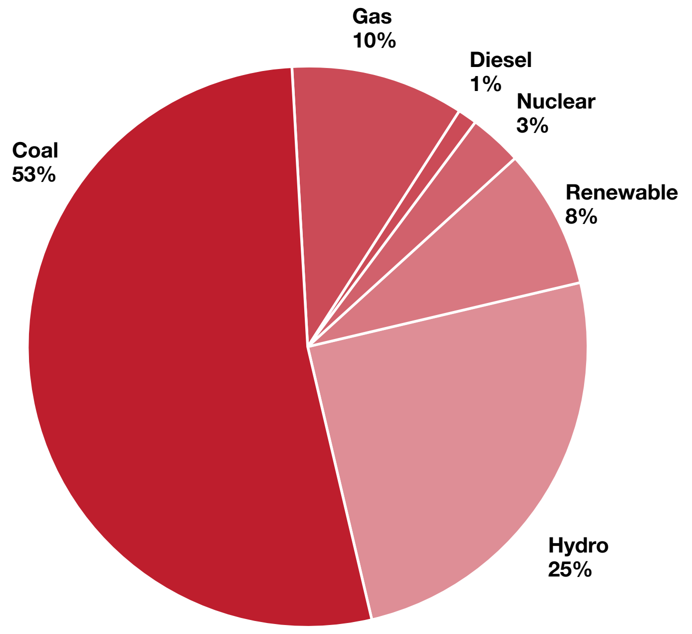
Table 2: India's Fuel Options	
Coal • Domestic coal resources are in abundance in India • Private participation in coal mining expected to result in greater production efficiencies • Economical imported coal is accessible for coastal locations • Coal is the most economical fuel for meeting base load demand • Clean coal technologies a priority by the Government of India	Natural Gas • Limited availability of domestic gas • High price of LNG in spite of growing production • Potentially a long-term fuel source for India
Nuclear • Ambitious plans for nuclear power face many challenges • Access to nuclear technology, fuel source and safety considerations	Hydro • Large amounts of hydro potential mainly in the North and Northeast India • High capital costs & long lead time • Seasonality effects of snow and rainfall
Wind • Not suitable for base load generation • Potentially low load factors • Moderate wind patterns.	Solar • Abundant sunlight and ideal for solar powered generation • Population density and space constraint • Supplement to coal-fired generation • Not suitable for large base-load operations

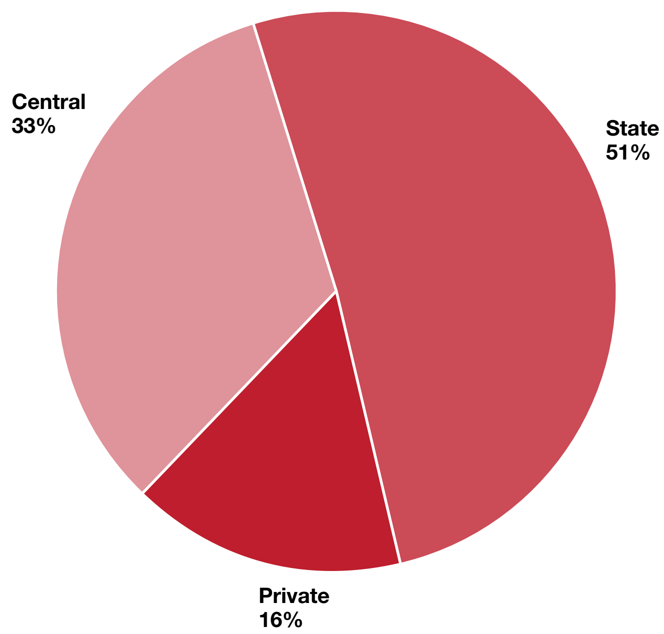
Natural gas is in short supply in India and supply to gas fired power stations has been inadequate, which has meant they have been operating at load factors of around 58-60 per cent. Gas is not expected to bridge the power generation deficits in the short-term although India has identified a few domestic natural gas reserves and is in discussion with suppliers in Qatar, Iran and Australia. Table 2 shows India's fuel alternatives.

The final main driver of India's energy policy concerns the environment, on which rapid urban and regional development has had a negative impact. India aims to adopt cleaner fuels and cleaner technologies to compensate. Projections are that coal fired power generation in India is likely expand rapidly. If this growth is uncontrolled it will be to the detriment of the environment. While India's focus is on generating low-cost power, the government recognizes the potential impact on air-quality that new coal plants would have.

In response, India has begun various initiatives at the national level that aim to bring in more stringent regulations for nitrogen oxides (NO_x), PM10, sulphur dioxide (SO_2) and, potentially, mercury emissions. For example, some of the plants burning high-sulphur coal now must either include an FGD scrubber, depending on the plant location, or make space provisions for a future retrofit of SO_2 removal technologies.

This is a major development for a country that has no official standard for major pollutants such as NOx, SO_2 and mercury but largely regulates





India's power generation by capacity

Breakdown of generation assets ownership

on a case-by-case basis. In the case of CO_2 emissions, no regulations exist.

India is not expected to accept a binding emissions reduction target as the initiative is considered too expensive and could double the cost of electricity generation. However, various measures are being considered to deploy cleaner coal technologies.

India's infrastructure has not kept up with its economic growth, despite progress on various fronts. Compared with western nations, the quality of the rail and road systems is poor and they fail to offer the same connectivity. Similarly the country's energy infrastructure is in continuous need of expansion to support increasing demand from consumers and industry.

Although infrastructure investment is on the rise, the government recognizes that future growth may be constrained without further improvements to infrastructure, the inadequacy of which is a key risk to the continued growth of the Indian economy. Since independence in 1947, electricity generating capacity has grown from 1400 MW to about 150 GW today, the sixth highest in the world behind the figures of the US, China, Japan, Russia, and Canada.

Over the same period, the population of India has grown from 250 million to over 1.1 billion. The rising population, India's high economic growth rate and its inadequate supply and distribution infrastructure have caused power supply shortages in terms of peak demand and overall energy supply. Peaking shortage has been about 13 per cent on an all-India basis with significantly greater shortages in selected regions such as the west of the country, where deficits are as high as 26 per cent, as Table 1 shows.

The large energy deficit gaps have resulted in low per-capita consumption, so India will need additional generating capacity to serve its population and fuel economic growth. To this end the government embarked on an ambitious plan to raise power generation capacity to bridge the growing power demand-capacity gap with low-cost power.

The Planning Commission has established five-year plans that lay out specific targets for new generation capacity.

The tenth five-year plan, covering 2002-2007, had a target of 41.1 GW of additional capacity. The 11th, covering 2007-2012, is slated to add 78 GW of capacity. Some 83 GW of new capacity is the target for the 12th plan, covering 2012-2017.

This expansion includes 14 Ultra Mega Power Projects that are awarded based on tariff-based competitive bidding. The projects are designed to be environmentally friendly. They will emit low amounts of greenhouse gases, employ supercritical technology and use 100 per cent of fly ash.

SHORTAGES CONTINUE

India's power sector has traditionally faced a range of challenges in expanding generation capacity. The country has added 30 GW in the past 7 years whereas China has added 303 GW over the same period. India needs to add 78 GW in the current five-year plan, essentially doubling the 78 GW added over the last 22 years.

Of the targets set across the last three five-year plans, only 50 per cent of the target capacity has been achieved, failures largely attributed to a shortage of boiler, turbine and generator equipment, long lead times, shortages of construction equipment, shortage of skilled manpower, fuel availability, a lack of project financing, rail and other infrastructure related issues, and delays in obtaining environmental and governmental clearances.

To accelerate capacity additions, the government has embarked on programmes to encourage foreign participation in the supply of power generation equipment supply. The result is that Western and Chinese manufacturers now actively provide equipment and services in India.

This has significantly eased the bottlenecks the industry previously faced. Various training and manpower development programmes and expedited processes to obtain various permits and clearances have also been initiated to address external delays.

Financing for power projects from world capital markets – a historical constraint – is less of an impediment for India today as many Indian Power Producers have started delivering results that match their earlier projections.

Confidence among the investment community is on the rise.

Prime Minister of India
Shri Narendra Modi

Digital India Technology Dinner
organized by
Embassy of India, Washington, DC
and
Consulate General of India, San Francisco

In partnership with

USINDIA BusinessCouncil

TiE

GITPRO
Global Indian Technology Professionals Association

Ambassador of India to the United States
Arun K. Singh
requests the pleasure of the company of

Ravi Krishnan

to Digital India Technology Dinner
with

Prime Minister of India
Shri Narendra Modi

on
Saturday, 26 September 2015
at 5.00 pm
at Regency Ballroom, The Fairmont San Jose
170 S Market Street, San Jose, CA 95113

RSVP by 18 Sept., 2015 by email to: digitalindia@indiagov.org

- Gates will open at 5:00 pm and close at 6:15 pm sharp. Guests are advised to arrive early to give sufficient time for security clearance
- Please carry a valid photo ID
- Please carry this invitation for security check
- This invitation is personal and non-transferable
- Invitation is for one person only
- Please indicate your dietary preference along with RSVP

CMI's MiRIS pilot project: batteries (both Li-ion and flow) are included

CMI Energy, well known as a global player in steam generation, has diversified into renewables, in particular CSP, and is now taking steps into the battery storage area with completion of the MiRIS facility at CMI Group's international headquarters in Seraing (Belgium). The aim of the MiRIS (Micro Réseau Intégré Seraing) pilot plant, which incorporates a microgrid and PV, is to look at a range of battery options and their integration with renewables. **Ravi Krishnan**, Krishnan & Associates*

Renewable energy has many environmental and economic benefits, but intermittency of solar and wind resources is by far the most formidable technical barrier to widespread system integration. Wind and solar generation are not dispatchable thus grid operators must wrestle with transmission and distribution system upgrades in addition to grid capacity constraints, spinning reserve margins, and frequency regulation to offset the effects of intermittency. Duplicate fossil-fired resources are often constructed to backstop renewables when the wind doesn't blow or the sun doesn't shine. The elegant solution to each of these problems is energy storage.

Small-scale energy storage projects are typically used in either high power, short duration applications such as frequency regulation or in low power, long duration applications such as time shifting of energy (kWh) and demand (kW) within a facility or local grid. Time shifting is the process of storing energy produced by an intermittent generating resource and releasing it at a later time when the energy and/or demand reduction is needed, typically during costly on-peak hours. Unfortunately, most energy storage technologies are unable to perform well in both roles.

There are many other economic advantages available to facilities with excess capacity to adopt energy arbitrage practices by storing low cost, off-peak energy for resale to the grid during on-peak hours at a premium price. A properly designed energy storage system may supply valuable grid ancillary services, such as grid voltage support, frequency regulation, and spinning reserve to the grid in some regions. This option is especially attractive for facilities with self-generated renewable energy that have with surplus capacity at certain times during the day.

As an alternative, energy storage may allow a facility with essential services to avoid the cost of expensive conventional backup power equipment.

Figure 1. The MiRIS pilot plant is under construction at CMI Group's international headquarters in Seraing (Belgium). The facility is expected to be completed in late 2018. Source: CMI Energy

* A global energy industry marketing firm, www.krishnaninc.com. Ravi can be reached at ravi@krishnaninc.com

Figure 2. PV panels, part of CMI Energy's MiRIS project. MiRIS will be integrated with the CMI Group's international headquarters complex, allow its engineers to perform detailed analysis of renewable integration with energy storage. Source: CMI Energy

From boilers to batteries

CMI Energy, part of CMI Group, a well established player in steam generation (notably HRSGs, as well as industrial and LNG boilers), is also active in renewable energy system design and integration, particularly concentrated solar power with thermal storage. The natural extension of that experience is battery energy storage, particularly when integrated with intermittent renewable energy resources, on either side of the meter. CMI Energy also acts as an EPC integrator within the energy storage sector, providing optimised solutions depending on each customer's specific needs and the best available technical-economic features.

CMI Energy is currently constructing the MiRIS (Micro Réseau Intégré Seraing) facility, Europe's largest industrial energy storage pilot, located adjacent to the CMI Group's international headquarters in Seraing (Belgium) (Figure 1). The purpose of the full-scale pilot plant is to demonstrate advanced integration of intermittent renewable energy resources with battery-based energy storage thereby producing a fully dispatchable renewable energy resource.

MiRIS, scheduled for completion in late 2018, consists of renewable power generation and energy storage systems. The renewable portion of the project includes a 2 MWp 1.75 GWh/y photovoltaic system consisting of 6500 roof top panels (Figure 2) and carports, and 36 inverters. The energy storage portion of the demonstration project includes two types of flow battery systems plus a lithium-ion battery system for a combined total of 4.2 MWh of storage capacity. The technology showcase will interconnect with the building's electrical network and its DSO 15 kV distribution service connection. The CMI complex consumes approximately 1.3 GWh/y.

CMI Energy plans to use the MiRIS project to investigate the interoperability of renewables and different energy storage technologies for a variety of energy user energy profiles, particularly with respect to renewable energy time shifting and energy resale to the grid. Another important goal is to demonstrate off-grid or "islanding" operation of the MiRIS microgrid. Potential ancillary services that may be provided to the local grid will also be evaluated as well as the impact of user demand response.

Jean-Michel Gheeraerdts, president of CMI Energy spoke to the importance of MiRIS when announcing the project: "We now have ways of use green energy sources that eradicate their major flaw: intermittent production. Energy storage and management can be applied in a number of fields as an alternative to diesel generators for unconnected regions, as a way of deferring investment in parts of the network, as a means of optimising existing photovoltaic or wind systems, and as an enabler of participation in the primary or secondary reserve markets."

Smart energy management

A single energy management system (EMS) ensures optimal energy flows within the MiRIS microgrid thus maximising the profitability of the overall system while contributing to its safe and reliable operation (Figure 3).

The EMS performs data management, modelling of alternative operating scenarios, as well as facility energy and demand forecasting. In addition, the EMS can evaluate the most economic combination of operating variables, electricity market signals, and weather projections in real-time to optimise the operation of the entire facility and its grid interconnection. CMI Energy developed the EMS in close collaboration with the University of Liège in Belgium.

The EMS is uniquely capable of adapting to a variety of different applications by employing a suite of sophisticated and innovative algorithms. System optimisation considers various inputs, such as forecast PV panel electricity production, expected loads, current and expected electricity tariffs, and grid constraints to derive optimal control decisions for each component, with both grid-tied and off-grid operation of the micro grid. Among the grid-tied applications are behind-the-meter segments, such as energy price arbitrage for consumer bill optimisation, self-consumption and peak shaving, including participation in reserve and capacity markets. The EMS will be enriched with added capabilities as experience is gained with operation of MiRIS.

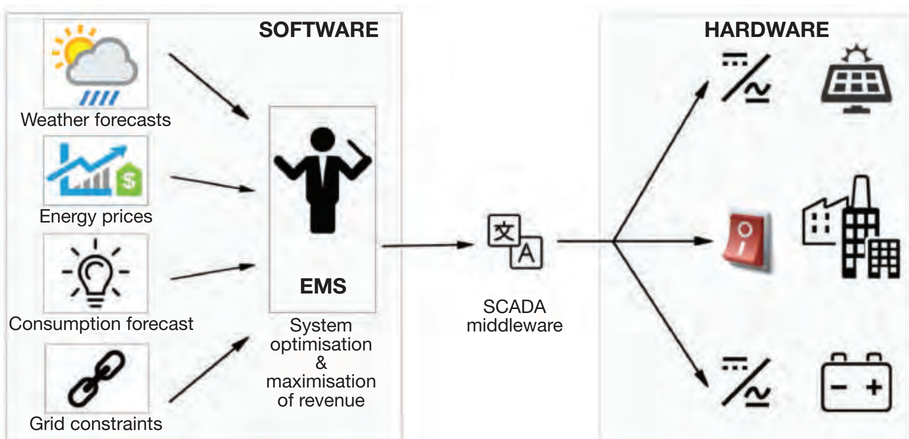
Lithium-ion battery option

Most energy storage projects today rely on packaging very large numbers, often tens of thousands, of individual lithium-ion (Li-ion) cells to meet a project's energy storage requirement. Li-ion batteries, commercialised in the early 1990s, have found many commercial and residential uses. Lithium-ion batteries have been the preferred energy storage technology for much of the past decade, particularly due to scale and manufacturing efficiencies from electric car production. Li-ion batteries are currently used in applications ranging from small-scale residential systems to grid-connected containerised battery systems that supply ancillary services.

The operation of a Li-ion battery, is in principle, the same as a conventional battery. However, instead of metallic electrodes and an acid-based electrolyte, lithium ions are injected into the structure of the electrode materials and lithium ions flowing between the electrodes produce current. The typical Li-ion battery used for energy storage applications uses a lithiated metal oxide positive electrode and a carbon negative electrode (Figure 4).

Modern Li-ion cells are generally available in different formats, such as prismatic and cylindrical. Depending on a project's energy density requirements, individual batteries are grouped into multi-cell modules in series/parallel arrays to form a battery string that will produce the desired voltage and capacity. Each string is usually controlled by a battery management system. Battery strings are then combined to provide the required amount of energy storage (kWh). For the MiRIS project, 1260 kW/1340 kWh of Li-ion batteries packaged within a single shipping container will be used.

Figure 3. The different roles of the energy management system. Source: CMI Energy



Two flow battery options

As an alternative to Li-ion, CMI Energy determined that flow batteries exhibit the best combination of life cycle cost, expected near-term economies of scale, and reasonable technology risk for bulk energy storage.

Navigant Research recently released a Leaderboard Report that examined the "strategy and execution" of 13 companies offering non-lithium-ion battery technologies for grid energy storage. The two companies judged to be market leaders were Sumitomo Electric Industries (Sumitomo vanadium redox flow battery) and ViZn Energy Systems (ViZn zinc-iron redox flow battery).

For the MiRIS project, CMI Energy concluded strategic partnership agreements in late 2017 with Sumitomo and with ViZn for the supply of flow batteries for the MiRIS and future projects.

Sumitomo Electric's redox flow battery (600 kW/1.75 kWh) uses vanadium dissolved in sulphuric acid as its electrolyte, with inert graphite electrodes.

The ViZn flow battery (400 kW/1200 kWh) uses a zinc-iron (hybrid) solution as its electrolyte.

Flow battery technology is distinctly different from conventional batteries. A flow battery stores energy in the electrolyte, unlike conventional lead-acid or Li-ion batteries, which store energy in the electrodes.

Modern flow batteries use two dissolved chemical components to form liquid electrolytes, positively or negatively charged, as energy carriers. The electrolytes are simultaneously pumped through two half cells separated by an ion-selective exchange membrane. The thin exchange membrane between the cells prevents the electrolytes from mixing but allows specific ions to pass through to complete the redox (reduction-oxidation) reaction and thus produce a flow of electric current.

For example, in Sumitomo's vanadium flow battery, the battery reactions change the valence of the vanadium in both the positive and negative electrodes (Figure 5). The valence change moves protons through the membrane, charging or discharging the battery. In a similar fashion, ViZn uses a zinc-iron electrolytic solution for its flow battery design.

The power rating (kW) of a flow battery is determined by the size, number, and configuration of electrodes in the cell stacks. A bipolar design describes cells stacked in a sandwich configuration so that the negative plate of one cell becomes the positive plate in the next cell. The voltage of a single cell is approximately 1.4 V. To obtain the design voltage, multiple layers of cells are connected in series to form a cell stack. The energy storage rating (kWh) is determined by the amount of electrolyte in the two electrolyte tanks (see Figure 5).

Unlike Li-ion batteries, redox batteries can be fully discharged with no impact on the life of the battery. Redox batteries are characterised by very high power output, capable of deep discharge and fast recharging of spent electrolyte, can undergo complex charge/discharge cycles (particularly attractive for remotely controlled grid ancillary services), very quick ramp rates, and have a long life because the electrolyte can be replaced. The electrolytes are also incombustible. ViZn's electrolyte has the added advantage of being globally abundant, non-toxic, and easily recycled. The output and capacity of a redox flow battery is expected to remain close to 100% of rated capacity for the first 20 years of operation. Li-ion batteries typically lose storage capacity with age and the charge/discharge cycles must be carefully managed in order to maximum battery life. Conversely, flow batteries are much more complex that conventional Li-ion batteries (except for the battery management system) and have a much lower energy density.

The capacity of a redox flow battery is also easily expandable as the power output (kW) and the energy storage capacity (kWh) may be independently specified because the number of cell stacks determine power output and the energy storage capacity is a function of available electrolyte (the size of the storage tanks). Flow batteries are also uniquely capable of providing both rapid, high-power discharges as well as long-duration low-power releases, ideal for grid-connected applications. In merchant applications, for example, flow batteries can provide two daily charge/discharge cycles and millisecond switching for wholesale grid regulation services, which are substantial economic advantages over conventional batteries.

Figure 4. Basic operation of a lithium-ion battery. Source: BYD

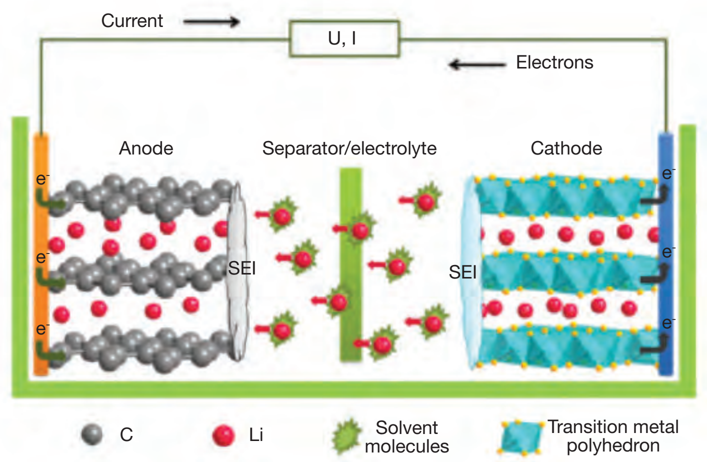
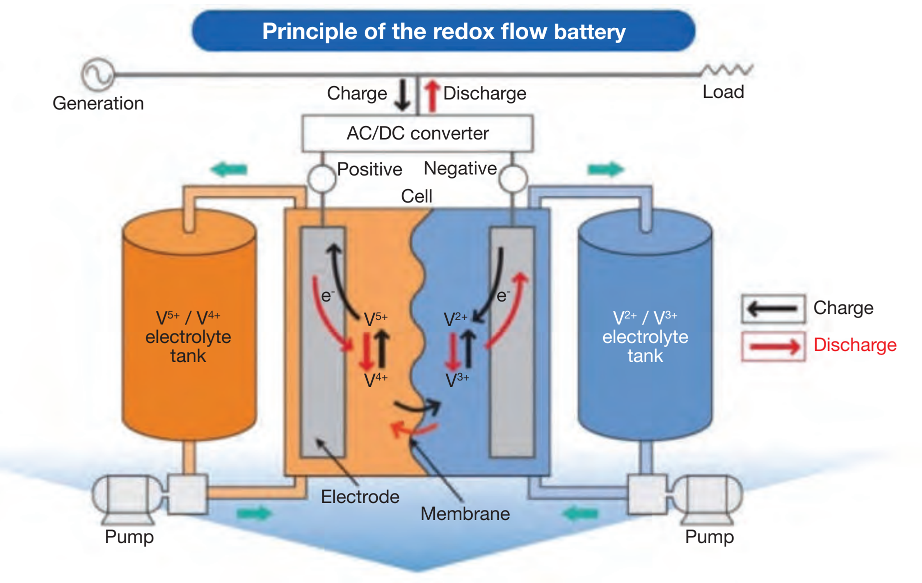


Figure 5. Flow batteries are an important technology option for grid-connected energy storage systems. Source: Sumitomo Electric Industries, Ltd.



Future plans

In the immediate future, CMI Energy will complete MiRIS and begin developing a deep understanding of how to economically optimise renewable energy sources coupled with energy storage for a range of users and demand load profiles. An added complexity in assessing the economics is the impact of grid interoperability (purchases, sales, and supply of ancillary services), which is site specific. Once these design and engineering hardware and EMS issues are well in hand, CMI Energy plans to expand its MiRIS project in the future by incorporating further energy storage and management innovations.

Ravi Krishnan Marketing Analytics Recruitment - Energy • 1st

Krishnan & Associates, Global Power & Energy Industry Consultants - Marketing | Market Analysis | Recruitment Services

Stamford, Connecticut

Message More...

Krishnan & Associates & Webcast Experts

Georgia State University

See contact info

500+ connections

Ravi Krishnan, Marketing, M&A, Market Analysis & Recruitment for the Power industry

Website : www.krishnaninc.com | Office: 203.921.1800 | Email: ravi@krishnaninc.com
Wiki: http://en.wikipedia.org/wiki/Ravi_Krishnan

Global Energy Market Expertise

Ravi brings nearly 2 decades of experience in power industry consulting services. His areas of expertise are marketing & sales to the energy industry, market research & analysis, M&A and executive recruitment in the power industry.

He is the founder of Krishnan & Associates (K&A) a global consulting firm providing:-
- Analytical & Advisory Services
- Marketing Communication & Sales
- Executive & Engineering Recruitment Services

He has initiated several relationships among large utilities and OEMs for a range of equipment and technologies resulting in new sales. K&A has over 200 clients for various marketing communication and business development programs. K&A has also successfully concluded sell side and buy side M&A transactions involving prospecting and deal structuring.

Previously, Ravi served as Executive Vice President & COO of RJM Corporation, a global provider of environmental technologies.Ravi began his consulting career at Southern Company.

Global Energy Recruitment Expertise (USA, Europe, Asia-Pacific)

K&A has placed 300+ senior executives for various power projects, OEMs in USA, Europe & Asia. Placements include positions in Construction, Commisioning, Power Plant O&M, Boilers, Turbines, etc. For OEMs, sales, project engineering, project managers and executive management.

India Power & Energy

K&A initiates business development programs for US and European OEMs seeking market expansion in India, including complete marketing and sales services. K&A initiates technology alliances between foreign companies and Indian firms. K&A also provides senior talent for new and existing energy projects in India. K&A releases an annual market study on the Indian Power Market interested in doing business in India.

Show less

Articles & activity

6,028 followers

CMI's MiRIS pilot project: batteries (both Li-ion and...

Ravi Krishnan Marketing Analytics Recruitment - Energy
Published on LinkedIn

Read the full article in the October 2018 Editon of Modern Power Systems Renewable energy has many environmental and economic benefits, but intermittency of solar and wind resources is by far the most formidable technical barrier to widespread system integration. Wind and solar gene ...see more

Like Comment Share

A very relevant topic for much of the Indian Sub-continent , China, Far Eas...

Ravi Krishnan commented

Exciting times at Sumitomo SHI FW Share, Like, Comment and Follow...

Ravi Krishnan commented

Great message David W. Arata Herschel Baxi Aaloki D....

Ravi Krishnan shared this
2 Likes

See all activity

See all articles

Experience

Managing Director
Krishnan & Associates & Webcast Experts
Jan 2005 – Present · 14 yrs 2 mos
Stamford, CT, USA

Krishnan & Associates, Inc. (K&A) is a full service technical consulting firm specializing in the power industry providing analytical and advisory services, product marketing & sales, and global recruitment & placement services. K&A's customers include major OEMs, domestic and international power producers, coal mining companies, EPC firms, consulting firms, and strategic & financial investors. K&A has over 100 customers and offices in USA and India and Europe.

K&A has practice heads for each of these disciplines and is uniquely focused on the power industry. K&A work and views on various energy markets have appeared in leading media & trad... See more

Vice President, Marketing
RJM Corporation
Jan 2001 – Sep 2004 · 3 yrs 9 mos

Marketing, Sales, Business Development, Market Analysis, Sales, Market Research, Recruitment, Mergers & Acquisition for Emission Control Products for Large Coal Fired Utilities, Industrial Facilities, Refineries, Chemical Plants, Waste-to-Energy plants, Pulp & Paper mills, etc.

Founder & President
Research & Solutions Group
Jan 1998 – Dec 2000 · 3 yrs
Greater Atlanta Area

Power Industry Market Research, Competitive Intelligence, Customer Intelligence, Market Surveys, Market Forecasts & Bench-marking Reports.

Customers included Georgia Power, Alabama Power, Georgia Power, Mississippi Power, ... See more

Various Internship Positions for a Large Electric Utility
Southern Company
Jan 1993 – Jan 1998 · 5 yrs 1 mo
Atlanta, GA

Various Paid Internship Positions between 1992 - 1998, as I completed my Bachelors & Masters degrees. Internship focused on Competitive Intelligence, Primary & Secondary Marketing Research, Electric Utility Customer Research and Regulatory Analysis in Regulated & Deregulated Electric Power Markets.

Education

Georgia State University
DCS, MBA, B.Com, Master of Science, Business Administration, Marketing, Engineering, Computer Science
1989 – 1997

Master of Science, 1994
Master of Business Administration, MBA, 1997

Lawrence School, Lovedale
High School
1983 – 1987

Skills & Endorsements

Energy · 99+
Endorsed by Dale Linaweaver and 26 others who are highly skilled at this
Endorsed by Bill Looman and 2 other mutual connections

Power Generation · 99+
Endorsed by Dale Linaweaver and 17 others who are highly skilled at this
Endorsed by Bill Looman and 2 other mutual connections

Strategy · 97
Endorsed by Nan [Nanette] Bulger and 2 others who are highly skilled at this
Endorsed by Kaival Shah and 2 other mutual connections

Show more

Recommendations

Ask for a recommendation | Recommend Ravi Krishnan

Received (1) | Given (3)

Pavan Ravulaparthy
International Business & Product Development
January 14, 2013, Pavan worked with Ravi Krishnan but at different companies

Ravi understands the power generation business with an extraordinary insight and very clear vision. His areas of strength include mergers & acquisitions with an exceptional market analysis skills.

Accomplishments

7 **Publications**
Krishnan Consultants play part in power projects • India: Can she make the most of her opportunities • Easing the Exodus • SCR: California cleaning • Economics of Emission Reduction For Heavy Duty Trucks • A Comparison of Clear Skies Act and Clean power Act to control multi-pollutant emissions • SCR Economics For Diesel Engines, Diesel Gas and Turbine World Wide

1 **Language**
Hindi, Tamil

Interests

ASME (American Society of Mecha...
219,578 members

Babcock & Wilcox
28,741 followers

CMI Cockerill Maintenance & Ingé...
17,169 followers

Energy Professionals
96,830 members

Marketing Communication
699,983 members

Adani Group
135,111 followers

See all