Confederation of Indian Industry

ADVANCING EFFICIENCY, INNOVATION & FLEXIBILITY IN THERMAL POWER

A Guidebook for Indian Thermal Power Plants

September 2025

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While every care has been taken in compiling this guidebook, CII- Godrej GBC does not accept any compensation claim, if any entry is wrong, abbreviated, omitted, or inserted incorrectly either as to the wording space or position in the Advancing Efficiency, Innovation and Flexibility guidebook for Indian Thermal Power Plants. It is a store of information so that it will be useful to the plant personnel involved in production, operations, energy conservation and can be used by them readily. The source of the guidebook for Indian Thermal Power Plant is data from the annual CII National Awards for Excellence in Energy Management, case studies shared by suppliers in CII conferences and other data collected by the team.

This document is an attempt to bring out all the innovative and best practices adopted by the thermal power plant.

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FOREWORD

India's energy sector stands at the threshold of a transformative era, where the dual imperatives of reliable electricity supply and environmental stewardship shape every operational decision. This guidebook, developed by the Confederation of Indian Industry Sohrabji Godrej Green Business Centre in close collaboration with the nation's leading thermal power plants, emerges as both a compendium and a catalyst for change. It reflects the collective knowledge, innovation, and practical experience that drive our industry's continuous improvement.

In compiling this guidebook, we sought to capture the essence of sector-leading initiatives—from flexible plant operations and accelerated ramp rates to emissions reduction, integration of digital technologies, and adoption of sustainable business models. Each chapter not only documents proven solutions and replicable strategies but also presents the exciting cross-sector innovations poised to redefine standards in plant efficiency, safety, and reliability.

As renewable energy's contribution to the grid expands and climate goals become ever more urgent, the role of thermal power plants in providing balance and resilience remains critical. The practices, technologies, and insights detailed herein are indispensable for plant operators, engineers, policymakers, and stakeholders committed to building a world-class, future-ready power sector.

It is our hope that this guidebook will serve as a trusted reference, inspire new collaborations, and help accelerate India's journey toward global leadership in clean, flexible, and sustainable energy

Bidya Nand Jha
Executive Director- (Operation Services)
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ACKNOWLEDGEMENT

Confederation of Indian Industry - Sohrabji Godrej Green Business Centre (CII-Godrej GBC) extends its heartfelt gratitude to all the contributors involved in the development of this guidebook. We are especially thankful to the thermal power plants, their management teams, and technical personnel who generously shared data, operational insights, and best practices. The active participation and collaborative spirit shown by these companies during the detailed data collection, and energy audit exercises have been instrumental in creating a resource that truly reflects the sector's current excellence and innovation.

We would like to acknowledge the distinguished jury panels and expert judges of the CII's National Award for Excellence in Energy Management, whose rigorous evaluation and unbiased assessment ensured recognition of truly impactful projects and initiatives. Their collective expertise and dedication have elevated the standards of energy conservation and operational efficiency in the thermal power sector. Special thanks are due to the companies that presented their pioneering projects and innovations at the CII's National Award for Excellence in Energy Management; their commitment to sustainability and energy optimization serves as inspiration for the entire industry.

The valuable inputs and case studies shared by the technology providers have enriched these best practices guidebook. Their continued support and knowledge sharing are vital to building an ecosystem of continuous improvement.

Finally, we express our sincere appreciation to all the stakeholders of the thermal power industry. The collaborative effort reflects a shared vision to foster cleaner, smarter, and more flexible energy sector practices, supporting India's ambitious climate and clean energy goals.

EXECUTIVE SUMMARY

India's power sector is undergoing a dynamic transformation driven by ambitious clean energy targets and the need for grid reliability. With an installed capacity nearing 490 GW as of mid-2025, renewable energy now accounts for nearly half of the mix, positioning India as a global leader in energy transition. Despite this progress, coal-based thermal power plants remain critical, fulfilling over 70% of electricity demand and providing essential grid stability and round-the-clock supply.

To meet the challenges posed by increasing renewable penetration, thermal power plants are rapidly adopting flexible operation strategies. These strategies enable units to reliably operate at reduced minimum technical loads (MTL), achieve faster ramp rates, and minimize start-up and shutdown times without compromising equipment integrity or efficiency.

The sector is leveraging advanced technologies such as AI-driven digital twins, predictive maintenance, and automated control systems to optimize fuel consumption, reduce emissions, and lower auxiliary power consumption. Proven best practices from Indian thermal plants demonstrate substantial operational savings and emission reductions, highlighting the value of replicable innovation.

Looking forward, the integration of biomass co-firing, green hydrogen production, and emerging carbon capture, utilization, and storage (CCUS) technologies will be pivotal in decarbonizing the thermal fleet. Strategic policy support, targeted investments, and coordinated implementation are essential to accelerate these transitions.

To support the India's net-zero ambitions by 2070 this guidebook recommends to:

Accelerate Flexible Operation deployment by prioritizing to achieve 40% MTL across the fleet by 2030 following CEA's roadmap.

Scale AI-based performance monitoring, economic load dispatch optimization, and IoT-enabled utility management to maximize efficiency and reduce operational costs.

Encourage wider adoption of biomass co-firing and streamlined supply chains to meet mandated co-firing targets and reduce coal dependency while ensuring reduced emissions per unit generated.

Leverage existing hydrogen infrastructure in thermal plants by shifting electrolysis power supply to renewable sources and exploring hydrogen co-firing combustion feasibility.

Support pilot projects for implementation of technologies like CCUS, Energy Storage and institute continuous knowledge sharing through platforms like CII's Flex India Conference and Power Plant Summit.

This guidebook serves as a comprehensive resource and a call to action, emphasizing that India's thermal power sector can remain a robust, flexible, and sustainable backbone in the country's clean energy future.

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LIST OF ABBREVIATIONS

Abbreviation	Full Form
ACW	Auxiliary Cooling Water
AET	Air Extraction Tank/Tower
AI	Artificial Intelligence
APC	Auxiliary Power Consumption
APH	Air Pre-Heater
BESS	Battery Energy Storage System
BFP	Boiler Feed Pump
BMCR	Boiler Maximum Continuous Rating
BTL	Boiler Tube Leakage
CCPI	Clean Coal Power Initiative
CCUS	Carbon Capture, Utilization & Storage
CEA	Central Electricity Authority
CHP	Combined Heat and Power
CII	Confederation of Indian Industry
CNG	Compressed Natural Gas
CRH	Cold Reheat
CV	Calorific Value
CW	Cooling Water
DC	Direct Current
DM	Demineralized Water
DPT	Differential Pressure Transmitter
DSM	Demand Side Management
EMS	Energy Management System
EPRI	Electric Power Research Institute
ESS	Energy Storage System
ESP	Electrostatic Precipitator
ETP	Effluent Treatment Plant
FD FAN	Forced Draft Fan
FGD	Flue Gas Desulfurization
FMS	Flue Gas Monitoring System

LIST OF ABBREVIATIONS

GEF	Grid Emission Factor
GEF	Global Environment Facility
GHG	Greenhouse Gas
GW	Gigawatt
HP	High Pressure
HVAC	Heating, Ventilation & Air Conditioning
ID FAN	Induced Draft Fan
IE	International Efficiency
IEA	International Energy Agency
IHI	Ishikawajima-Harima Heavy Industries Co., Ltd
IOT	Internet of Things
JERA	Japan Energy Regeneration Authority
KLD	Kilo Litres per Day
kW	Kilowatt
LMT	Log Mean Temperature difference
LP	Low Pressure
MDBFP	Motor Driven Boiler Feed Pump
MLD	Million Liters per Day
MMT	Million Metric Tons
MoEFCC	Ministry of Environment Forest & Climate Change
MoP	Ministry of Power
MOV	Motor Operated Valve
MTL	Main Transmission Line
MTL	Minimum Technical Load
MUs	Million Units
MW	Megawatt
MWt	Megawatt thermal
NDT	Nondestructive Testing
NEP	National Electricity Plan
NEP	National Electricity Policy

LIST OF ABBREVIATIONS

NGO	Non-Governmental Organization
NGT	National Green Tribunal
NHR	Net Heat Rate
NOGS	Naturally Occurring Gamma Ray Sensor
NREL	National Renewable Energy Laboratory
NRG	National Regulatory Group
NRV	Non-Return Valve
NTPC	National Thermal Power Corporation
O&M	Operation and Maintenance
OED	Oil & Energy Department
OEM	Original Equipment Manufacturer
OEM	Original Equipment Manufacturer
PA FAN	Primary Air Fan
PAPH	Primary Air Pre-Heater
PHE	Plate Heat Exchanger
PLC	Programmable Logic Controller
PRD	Pressure Reducing Device
PRDS	Pressure Reducing & De-superheating Station
PSP	Pumped Storage Plant
PSD	Product Service Data / Pollutant Standard Declaration
PTW	Permit-To-Work
PV	Photovoltaic
QR	Quality Report / Quick Response
RAPH	Rotary Air Pre-Heater
RCO	Renewable Consumption Obligation
RDF	Refuse Derived Fuel
RFET	Remote Field Eddy Current Testing
RH	Reheater
RLNG	Re-gasified Liquefied Natural Gas
RMD	Rotor Metal Displacement

LIST OF ABBREVIATIONS

RPM	Revolutions Per Minute
RTD	Resistance Temperature Detector
SA FAN	Secondary Air Fan
SCADA	Supervisory Control & Data Acquisition
SCAPH	Steam Coiled Air Pre-Heater
SDS	Safety Data Sheet
SGPT	Standard Gross Plant Test
SH	Super Heater
SHAKTI	Scheme for Harnessing and Allocating Koyala (Coal) Transparently in India
SHK	Surface Hydrokinetic
SLT	Solar Land Type
SP	Set Point
STP	Sewage Treatment Plant
SUF	Sulfur Unit of Fuel
T&D	Transmission & Distribution
TDBFP	Turbo Driven Boiler Feed Pump
TDG	Technical Design Guide
TEG	Triethylene Glycol
TEO	Thermal Energy Output
TFF	Thermal Treatment Facility
TGT	Turbine Generator Transformer
TML	Thermal Minimum Load
TMCR	Turbine Maximum Continuous Rating
TMCR	Turbine Maximum Continuous Rating
TPM	Total Productive Maintenance
TPP	Thermal Power Plant
TPR	Turnaround Period
TQM	Total Quality Management
TRH	Turbine Reheat
TPS	Thermal Power Station

LIST OF ABBREVIATIONS

TSS	Total Suspended Solids
TSP	Total Suspended Particulates
TTF	Thermal Treatment Facility
TPD	Tons Per Day
UMP	Unit Maintenance Program
VFD	Variable Frequency Drive
VGF	Viability Gap Funding
VM	Volatile Matter
WBG	Wide Band Gap
WH	Waste Heat
WTP	Water Treatment Plant
WWTP	Waste Water Treatment Plant

1 OVERVIEW OF INDIAN POWER SECTOR: A COMPREHENSIVE ANALYSIS

Introduction

India's power sector has emerged as one of the world's most dynamic and rapidly evolving energy landscapes, positioning the country as a global leader in both conventional and renewable energy deployment. As of 31st July 2025, India's total installed power generation capacity reached 490 GW, cementing its position as the third-largest power producer globally after China (2,510 GW) and the United States (1,330 GW). This remarkable achievement reflects the country's sustained commitment to energy security, economic growth, and environmental sustainability, with renewable energy now accounting for almost half of the nation's total installed capacity.

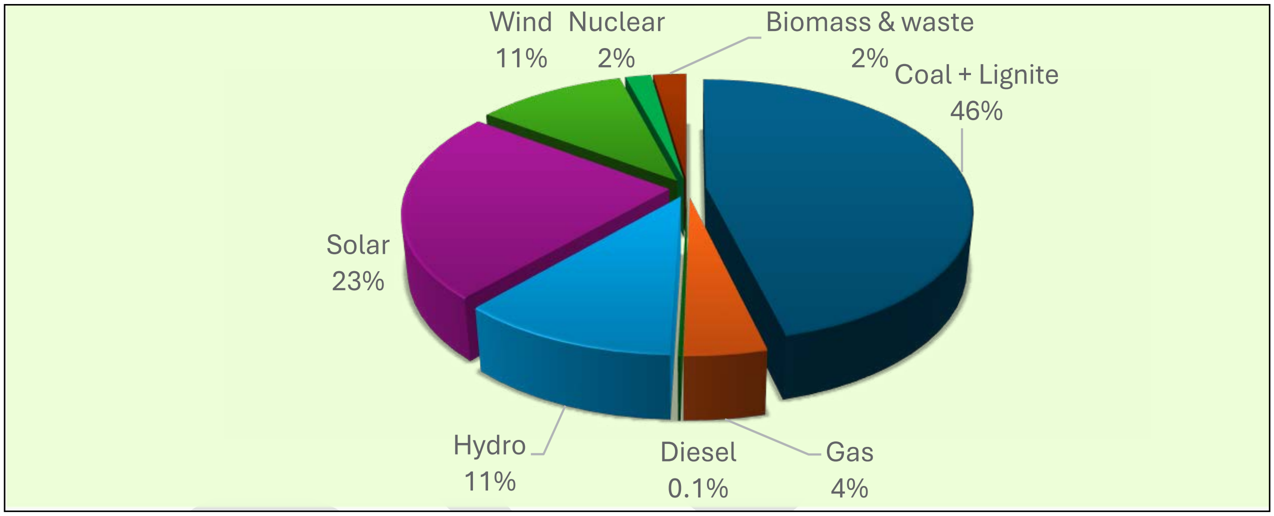


Figure 1: All India installed capacity as on July 2025

Table 1: All India installed capacity as on July 2025

	Source of ProductionGeneration	Total Installed Capacity in GW	Share in total Installations (as on 31.07.2025)
Thermal Source	Coal + Lignite	223.07	45.52%
	Gas	20.13	4.11%
	Diesel	0.59	0.12%
	Total (Fossil- Based Sources)	**243.79**	**49.75%**
Renewable Energy Sources	Solar PV	119.02	24.29%
	Wind	52.14	10.64%
	Biomass & Waste to Energy	11.60	2.37%
	Hydro	54.74	11.17%
	Nuclear	8.78	1.79%
	Total (RE Sources)	**246.27**	**50.25%**
	Total Installed Capacity (From all sources)	**490.06**	

1.1 India's Power Generation Mix: A Balanced Transition

1.1.1 Thermal Power: The Reliable Backbone

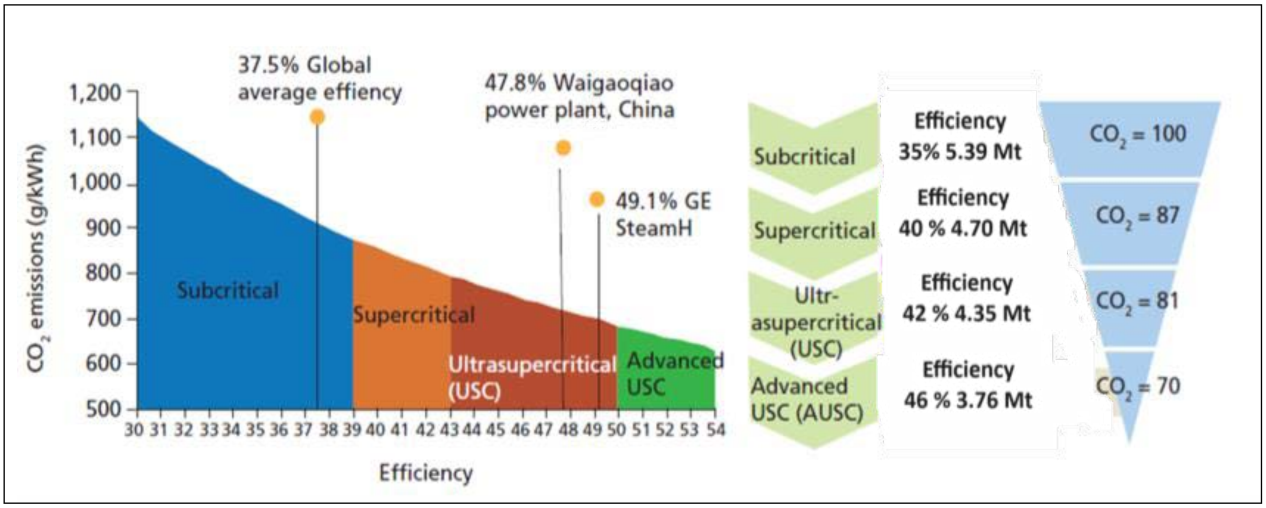
Thermal power continues to serve as the backbone of India's electricity infrastructure, despite the rapid expansion of renewable energy, accounting for 244 GW (49.75% of the total installed capacity), reflecting India's abundant domestic coal reserves and high dependency on coal for electricity needs. Despite accelerating green energy goals and policy shifts, thermal power plants remain essential for grid reliability, industrialization, and supporting socioeconomic growth.

Thermal power plants, earlier designed for base load operations, are now playing a major role in grid stabilization and bridging the supply demand gap arising due to challenges associated with RE. They are supporting grid stability through spinning reserves and flexible operations. Despite having a share of 49.75% in the total installed capacity, thermal power contributes to over 70-75% of the total electricity generation.

Considering the abundant domestic coal reserves and being the cheapest source of energy in India, thermal power plays a vital role in energy security and as an enabler in economic development.

Key Trends & Developments:

- India added 13,495 MW of new generating capacity in Q1 2025 (Jan to Mar- 2025) but most additions were renewables. Thermal additions were just 3.8 GW versus a 15 GW planned goal.
- The sector is moving towards more efficient units with new projects in pipeline all based on Super critical (SC) and Ultra Super Critical technologies (USC). These newer technology plants have a better cycle efficiency as compared to the sub-critical units. The efficiency for SC units can be as high as 40% while for USC units can reach up to 42% versus 35% for the sub-critical technology units.
- With the SC & USC technology, the emissions can be reduced by 20% causing reduced CO_2 emission per unit generated. Additionally, these projects tend to favour in-built features to achieve higher levels of flexibility by incorporating better combustion technologies, better pressure part materials, extended AI based monitoring etc.
- Bharat Heavy Electricals Limited (BHEL) , Ministry of Heavy Industries (MHI) in association with Indira Gandhi Centre for Atomic Research (IGCAR) and National Thermal Power Corporation Limited (NTPC) has developed an indigenous Advanced Ultra Super Critical (AUSC) technology which can yield plant efficiency of 46%. AUSC R&D project was approved with a total outlay of INR 900 crores out of which MHI has contributed a major share of INR 470 crores.



1.1.2 Emission Scenario in Thermal Sector

India ranks 3rd globally in total CO_2 emissions, with the largest share of 39% coming from electricity generation through thermal power sources—primarily coal, along with gas and diesel-based plants. As seen from the installed capacity mix presented in the previous section, generation from gas and diesel sources is minimal compared to coal. Consequently, coal remains the dominant contributor to power sector emissions.

The carbon footprint of a grid can be measured in terms of Grid Emission Factor (GEF). GEF is a measure of the amount of carbon dioxide emissions produced per unit of electricity generated by an electrical grid, usually expressed in kg of CO_2/kilowatt-hour (kg CO_2/kWh). Essentially, the GEF quantifies the environmental impact of electricity consumed from a particular grid.

Higher the dependence over the fossil-based power generating sources caused higher GEF while integration with renewable energy sources helps to reduce the same. Following line graph shows the average Grid Emission Factor (kg CO_2/kWh) of India year on year while the bars represent the electricity consumption in GW during the particular year.

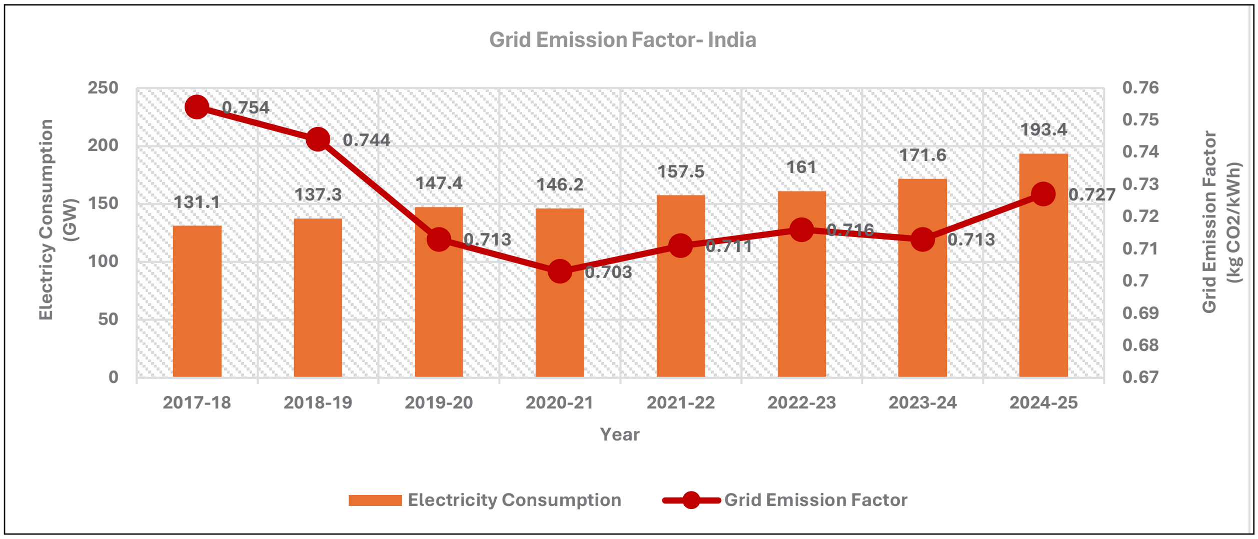


Figure 2: Grid Emission Factor India

There was steady decline in the GEF due to integration of green energy from RE sources in the grid from 2017 onwards. The rapid decline in the year 2019-20 to 2021-22 is due to the covid pandemic causing reduction in electricity demand following which the generation and hence the emission was reduced considerably. A rise in GEF post covid can be observed post 2021-22 due to rise in electricity demand.

In the year 2024-25, a slight increase in GEF was observed as there was increase in electricity demand but the generation from renewable energy sources failed to meet the rise in demand due to delay in projects and climatic issues causing reduced generation.

Following bar graph shows where India stands in terms of the GEF as compared to the other countries that operates thermal power plants.

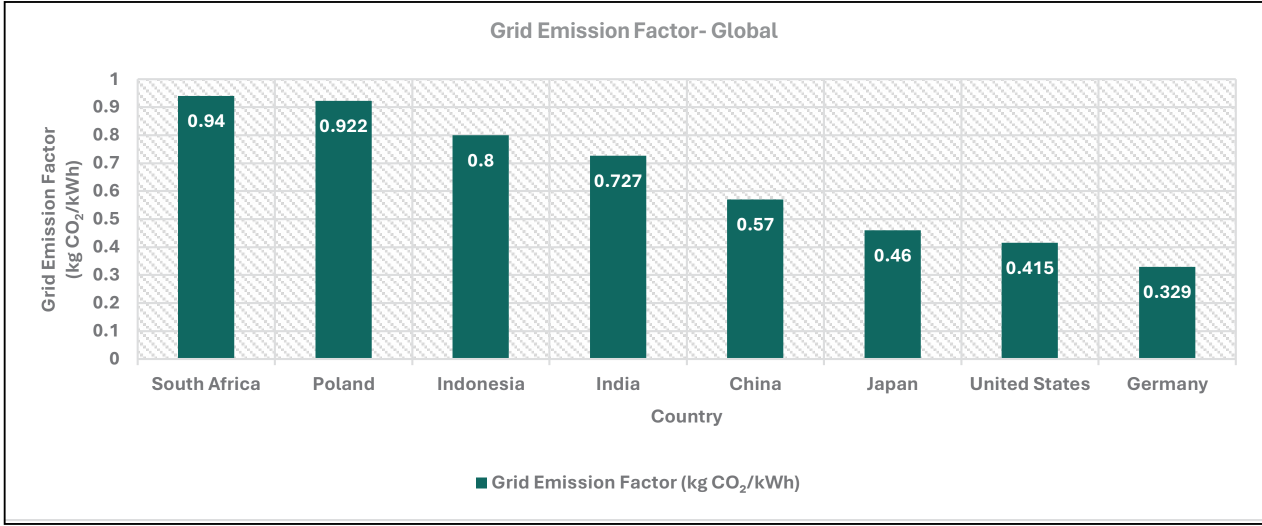


Figure 3: Grid Emission Factor (kgCO_2/kWh)

The GEF in countries like China, Japan, US & Germany has dropped drastically due to rapid RE installations and expansion in nuclear energy projects providing the grid with greener sources of electricity. While India is rapidly expanding its RE portfolio, it is expected that the GEF will fall in between 0.55-0.6 kgCO_2/kWh with 500 GW of RE capacity by the end of 2030. South Africa is heavily dependent on coal with 80% of the installed capacity from thermal assests.

1.2 Regional and State-Wise Distribution

1.2.1 Regional Power Landscape

India's power infrastructure exhibits significant regional variations, reflecting diverse resource endowments, industrial development patterns, and policy priorities.

- The Western Region (Gujarat, Goa, Madhya Pradesh, Chhattisgarh and Maharashtra) leads with 158.87 GW of total installed capacity, driven primarily by Gujarat's 57.7 GW and Maharashtra's 53.33 GW. This concentration reflects the region's industrial development, favourable policies, and abundant renewable energy resources.
- The Southern Region (Andhra Pradesh, Telangana, Karnataka, Kerala, Tamil Nadu, Puducherry) demonstrates the highest renewable energy concentration with 72.99 GW of RE capacity, benefiting from excellent wind and solar resources, progressive state policies, and strong industrial demand for clean energy.

- In contrast, the lowest total installed capacity is in Islands 0.16 GW (Andaman & Nicobar and Lakshadweep Islands) followed by North Eastern region- 5.2 GW.

1.2.2 State-wise Leadership Patterns

Gujarat emerges as India's power capacity leader with 57.7 GW of total installed capacity, demonstrating balanced development across thermal and renewable sources. The state's success stems from proactive industrial policies, abundant solar and wind resources, and strong institutional frameworks supporting power sector development.

Rajasthan leads in renewable energy deployment with 35.7 GW of RE capacity, primarily driven by its exceptional solar potential and supportive state policies. The state has experienced remarkable growth, with solar capacity increasing by 33% from 21.35 GW to 28.29 GW between 2023-24 and 2024-25.

Maharashtra demonstrates strong thermal capacity leadership with 29.57 GW of thermal installations while simultaneously building substantial renewable capacity. This balanced approach reflects the state's diverse industrial base and commitment to energy security.

1.3 Investment and Financial Leadership

India has emerged as the largest recipient of development finance institution funding for clean energy, receiving approximately $2.4 billion USD in project-specific funding in 2024 . This financial leadership reflects international confidence in India's clean energy transition and policy frameworks. The country attracted 83% of power sector investments toward renewables in 2024, demonstrating the sector's attractiveness to both domestic and international investors.

1.4 Grid Integration and Infrastructure

India operates one of the world's largest synchronized power grids, with over 4 lakh circuit kilometres of transmission lines supporting the "One Nation, One Grid, One Frequency" system. This integrated infrastructure enables efficient power sharing across regions and supports renewable energy integration challenges.

The National Electricity Plan (2022-32) outlines comprehensive grid modernization strategies, including AI-based forecasting, hybrid project promotion, and battery storage development. Inter-regional electricity transfer reached 259,937 MU during FY 25, representing a 4.2% increase from the previous year .

1.5 Evolving Indian Policies & Regulations

The section highlight the Indian polices and regulations related to the power industry. This includes polices such as SHAKTI (Scheme for Harnessing and Allocating Koyala Transparently in India), CCTS (Carbon Credit and Trading Scheme), RCO (Renewable Consumption Obligations) and others.

1.5.1 SHAKTI

The policy was introduced in 2017 and aimed at reforming coal allocation to thermal power plants to promote transparency, efficiency and ease of doing business. The policy was recently revised in May-25. The Revised SHAKTI Policy streamlines coal allocation into two main windows- Window-I supplies coal at notified prices mainly to Central and State government-owned power plants. Window-II allows all thermal power producers, including Independent Power Producers (IPPs) and imported coal-based plants, to secure coal through auctions at a premium over the notified price.

- This revision provides flexibility in contract duration, from short-term (up to 12 months) to long-term (up to 25 years), and importantly, removes the previous requirement of having Power Purchase Agreements (PPAs) to access coal, allowing producers greater freedom in electricity sale and market participation.
- The policy encourages pithead thermal capacity addition, promotes domestic coal usage to reduce imports, improves transparency, and aims to lower electricity tariffs by rationalizing coal sourcing and reducing logistics costs.
- It supports energy security and economic growth by facilitating increased coal availability and production, creating employment opportunities, and aiding revival of stressed power assets.

1.5.2 Relaxation for Universal Installation of FGD System

The Ministry of Environment Forest and Climate Change (MoEFCC) has exempted most of the thermal power plants from installing the flue gas desulphurisation (FGD) system. Instead of mandating the installation of FGD across all the power plants in India, the MoEFCC has mandated for the plans falling in Category-A only. The details are as under:

Category	Details	Compliance	Installation By
A	Plants within 10 km radius of NCR or cities having million plus population	Mandatory	31 Dec 27
B	Plants within 10 km radius of non-attainment cities or critically polluted areas	To be decided on case-to-case basis.	31 Dec 28
C	Other than those included in Category A and B	Exempted	-

Out of the total 600 coal-based power stations in India, 22% falls in the Category-A & B. while the remaining 78% of the plants that comes under Category-C are exempted from installation. There are 72 plants in Category- B (11%) out of which only four has installed FGD while there are 462 plants in Category- C out of which 32 units has completed installation.

- With the current relaxation, the additional financial burden of FGD installation and operation has been reduced. The FGD retrofitting cost is estimated to be around INR 2.5 lakh crore nationally. The downtime to connect the unit to connect the FGD system with the exiting plant is also avoided.
- The additional auxiliary power required to run FGD auxiliaries has been avoided which would have caused additional CO_2 emission per kWh generated.
- By saving on large retrofit and maintenance costs for pollution control equipment, plants could help prevent increases in electricity tariffs. This exemption potentially reduced tariff hikes by about 25-30 paise per unit, benefiting end consumers.

1.5.3 56th GST Council Decision

The 56th GST Council meeting held on 3rd September 2025 brought significant reforms affecting the coal sector and power tariffs, with the changes effective from 22nd September 2025. The GST rate on coal was increased from 5% to 18%, leading to an estimated increase in coal cost by approximately INR 166.27 per metric tonne for G-12 grade coal. For the power sector, this would translate to a rise in generation cost by about INR 0.12 to INR 0.15 per kWh.

However, the substantial positive offset comes from the complete removal of the GST Compensation Cess of INR 400 per tonne previously levied on coal. This removal more than offsets the cost increase due to the GST rate hike and results in a net reduction of coal cost by about INR 233 per metric tonne. Consequently, this translates into a decrease in power generation cost by approximately INR 0.17 per kWh.

- The reforms will also help in rationalization of tax burden on coal vis-à-vis its pricing. Previously, a flat rate of Rs. 400 per tonne was imposed as GST compensation cess without considering coal quality. This disproportionately affected low-quality and low-priced coal.
- The reforms will also help in promoting Aatmanirbhar Bharat by import substitution. Earlier, due to flat rate of GST compensation cess, landing cost of High Gross Calorific value imported coal was lesser as compared to Indian Low-grade Coal. This used to place Indian Coal in disadvantageous position. The removal of cess levels the playing field, strengthening India's self-reliance and curbing unnecessary imports.

1.5.4 Renewable Consumption Obligation

The Renewable Consumption Obligation (RCO) notification issued by the MoP in August 2025 marks a significant policy shift in India's clean energy transition by mandating designated consumers, including captive power plants, distribution licensees, and open access consumers, to consume a minimum and gradually increasing share of their electricity from renewable sources. The RCO replaces the earlier Renewable Purchase Obligation (RPO) by focusing on actual consumption — both grid-based and behind-the-meter renewable energy — rather than only procurement, thereby promoting a more comprehensive integration of renewables. The annual RCO targets start at 29.9% for FY 2024-25 and rise to 43.33% by FY 2029-30, with sub-targets for wind, hydro, distributed renewable energy, and other sources.

- Promotes integration of RE in grid, giving rise to grid operational challenges. The coal plants are required to be flexible in handling the fluctuations.
- Thermal plants need to become more flexible to accommodate variable renewable generation integrated under RCO. This requires operational changes such as cycling and ramping that can increase wear-and-tear, reduce efficiency, and raise maintenance costs.
- Meeting RCO targets increases costs that may pressure coal plant economics, especially in regions with stronger renewable resource availability and cheaper solar or wind options. This can impact plant viability, tariff competitiveness, and investment attractiveness.

1.5.5 National Electricity Plan (2023-32)

India has committed to achieving 500 GW of non-fossil fuel-based energy capacity by 2030, representing one of the world's most ambitious clean energy targets. As of July 2025, the country has already achieved 246.27 GW from non-fossil fuel sources, comprising 237.49 GW of renewable energy and 8.8 GW of nuclear power.

The National Electricity Plan's (NEP) projections indicate peak electricity demand will reach 277.2 GW by 2026-27 and 366.4 GW by 2031-32 , requiring total installed capacity of approximately 900 GW by 2031-32. These projections reflect India's sustained economic growth trajectory and increasing per capita energy consumption.

Currently, coal accounts for around 45% of India's installed power capacity. However, its share is expected to decline to 39% by 2027 and further to 29% by 2032. The average Plant Load Factor (PLF) for thermal power plants during 2024-25 stood at 67.15%, slightly lower than 67.90% recorded in 2023-24. According to the National Electricity Plan- 2023 , the PLF is projected to further reduce to 58.4% by 2026-27 and will remain at the same level till the end of 2032.

Due to the large scale RE integration in coming years, the average GEF is expected to reduce to 0.548 kg CO^2/kWh in the year 2026-27 and to 0.430 kg CO^2/kWh by the end of 2031-32 .

1.6 Key Takeaways

India's power sector is among the most dynamic globally, balancing energy security with an ambitious clean energy transition. Strong policies, technological innovation, major investments, and institutional capacity have propelled India to 3^{rd} in total power production and 4^{th} in renewable capacity worldwide. It is also the largest recipient of clean energy development finance. Ambitious plans for 500 GW non-fossil capacity by 2030, alongside green hydrogen and nuclear expansion, will cement its leadership. The sector's evolution will be pivotal for global climate goals and sustainable development.

While India is witnessing a rapid expansion in renewable energy capacity, the inherent challenges associated with renewables pose significant threats to grid stability. These challenges include variability, intermittency, and concentration issues, which cause generation from renewable assets to become highly unpredictable. Addressing these challenges requires enhanced flexibility in thermal power plants.

Given the rapid transformation of India's energy sector, flexible operation of thermal power plants has become critical to managing the challenges of renewable energy sources. This publication highlights the importance of modernization and technological upgrades in improving plant flexibility—enabling faster ramp rates, lower minimum load operation, and enhanced control mechanisms. These adaptations not only support grid stability but also improve operational efficiency, reduce emissions, and extend equipment life. By showcasing best practices implemented by thermal power plants and exploring technologies popular in other sectors, this guidebook encourages power plants to embrace flexibility as a strategic imperative. Such advancements are essential for thermal plants to effectively complement renewable integration, sustain reliability, and contribute to India's broader climate and energy goals.

2 BEST PRACTICES IN THERMAL POWER SECTOR

Introduction

The Best Practices in Thermal Power Sector highlights pioneering initiatives and breakthrough solutions demonstrated by thermal power plants across India. These projects represent practical, field-proven interventions that have emerged from presentations delivered by participating power plants during previous editions of the CII's prestigious National Awards for Excellence in Energy Management . The showcased innovate projects were shortlisted for their proven ability to deliver significant operational improvements and energy savings within thermal power sector. The selection criteria emphasized not only the magnitude of savings but also the scalability and replication potential of these innovations across the national fleet of thermal power plants.

Recognizing the evolving challenges faced by the Indian power sector—including fluctuating load demands, rising renewable integration, and the imperative to optimize energy efficiency—these innovative projects showcase diverse approaches to reduce auxiliary power consumption, enhance equipment reliability, improve process controls, and mitigate emissions. Featuring successful case studies ranging from equipment modifications and system integrations to digital and automation-enabled solutions, this chapter serves as a comprehensive knowledge base encouraging wider adoption. By sharing these replicable success stories and associated benefits, the chapter aims to accelerate the modernization and sustainability agenda of India's thermal power industry. It reinforces the industry's commitment to operational excellence, cost-effective energy conservation, and alignment with national clean energy goals.

2.1 AHP-LP Pump Header Directly Connected with Recovery Pump Header

Details of Plant

Plant	D B Power Limited
Capacity	2 x 600MW
Location	Champa, Chhattisgarh

In thermal power plants, coal combustion produces ash that is collected in two forms: bottom ash and fly ash, typically distributed as 20% bottom ash and 80% fly ash. Fly ash is collected in dry form using electrostatic precipitators, while bottom ash settles in hoppers at the boiler bottom and is usually conveyed in wet slurry form to ash ponds. To conserve water, plants install ash water recovery pumps that reclaim water from ash ponds and recycle it back to the plant, storing it in ash water tanks for reuse. Low-pressure pumps then maintain the water levels in bottom ash hoppers by pumping water from ash water tanks to ensure proper wet conditions. These systems work together to maintain the required water levels in both bottom ash hoppers and ash water tanks, thereby enabling zero liquid discharge and minimizing water loss from the plant.

Details of existing system:

- For operation of bottom ash system, water requirement is met through LP pumps which supply water from ash water sump to respective unit's bottom ash hoppers.
- LP Pump-1 operates continuously while LP Pump-2 runs for 08 hrs daily. In total the operating time is 32 hrs/day.
- Additionally, ash water recovery pumps are installed for recovering the waste water from ash dyke and pump it back to the ash water sump.
- The flow of the ash water recovery pump is equal to the designed flow of LP water pump

Details of modification:

- The ash water recovery pump discharge is directly connected to the LP water pump discharge header
- Valves are installed to isolate both the systems when required to ensure isolation in case of breakdowns or maintenance.
- With the interconnection, the recovered ash water is directly pumped to the bottom ash without going to ash water sump hence the operation of LP water pump is reduced.

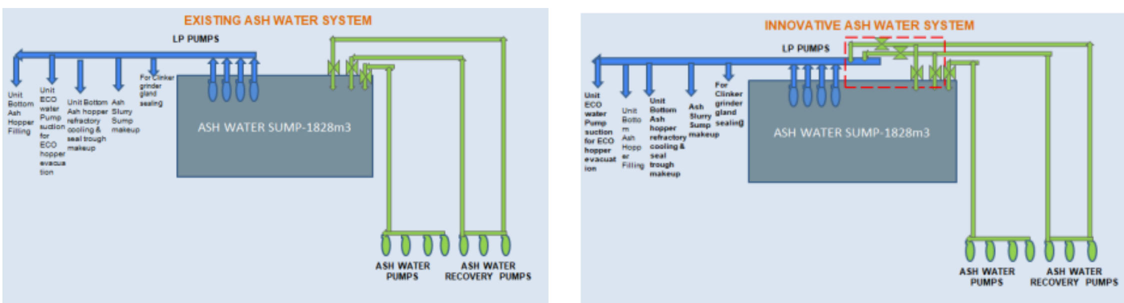


Figure 5: Ash water system before & after modification

Benefits:

- The modification helps to reduce the power consumption required due to double pumping.
- Post modification, the operation of LP water pump is reduced.
- Only 1 pump operates for 08 hours daily while the operation of other pump for 24 hours is saved. This has additionally increasing the pump life while reducing maintenance cost.

Table 2: Ash Water System Post Modification Saving Details

Investment Required	INR 5.00 Lakhs (for piping & valves)
APC Saved	8,19,060 kW/year
Annual Operation Cost Savings	INR 28.50 Lakhs (considering INR 3.5/kWh)
Annual Maintenance Cost Savings	INR 2.00 Lakhs
Total Annual Savings	INR 30.50 Lakhs

Applicability:

- The modification is applicable to the plants where the ash water recovery pump is of similar or higher capacity than the LP water pump.
- The plants should have a remote operation logic for the ash water recovery pump to effectively control the bottom ash level.

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2.2 CHP-Enhancement of Crusher Throughput by Modification in Hammer Weight

Details of Plant

Plant	D B Power Limited
Capacity	2 x 600MW
Location	Champa, Chhattisgarh

In a thermal power plant, the crusher plays a vital role in the coal handling system by breaking down large coal chunks into smaller, manageable sizes up to 20mm suitable for further pulverization in coal mills. The coal crusher ensures efficient fuel pulverization and reduces coal mill power consumption which otherwise would have required for pulverizing larger size lumps. Typically, ring granulator crushers are used, combining impact and compression to crush coal with high throughput and lower power consumption. Wear and tear are common issues due to abrasive coal, causing degradation of crusher components such as hammers, liners, and rotors. This also results into downtime and reduced crusher throughput.

Details of existing system:

- The crusher is installed in line to the bunker feeding conveyor to reduce the size of coal to smaller one for better handling and efficient grinding in pulveriser.
- As per design, each crusher was having 50 numbers of hammers in a rotor. The weight of each hammer was 39.5 kg. The design throughput is 5 Lakh MT/month but in actual the plant was getting reduced output of 4-4.5 Lakh MT/month.
- Due to lower throughput, frequent maintenance needs to be done including hammer replacement for 8 to 9 times in a year.
- The crusher availability was only 80% due to breakdowns and downtime for maintenance.
- Details of modification:
- The plant has developed a new hammer by increasing the weight by 5.5 kg per hammer. Each hammer weight is increased to 45 kg from 39.5 kg (13% increase in weight).
- Trials were taken to ensure that the system is capable of taking the weight of new heavier hammer along with measuring the power consumption.

- With the increase in hammer weight the wear is reduced and efficient coal crushing was achieved compared to the earlier hammers.

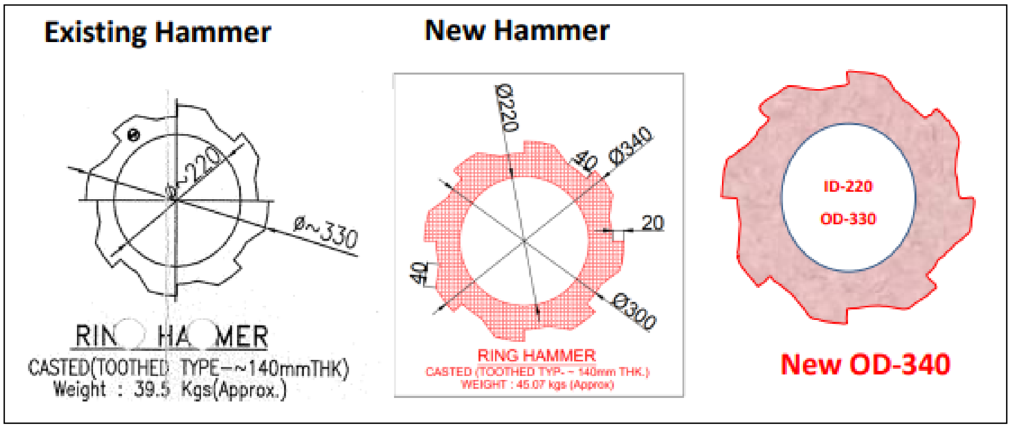

Figure 6: Hammer Details

Benefits:

- With the increase in weight of hammer, the crusher is able to deliver higher outputs. The capacity is increased to 6.5 Lakh MT/month .
- The rise in motor current was found to be minimal.
- The instances of hammer breakdown is drastically reduced to 1-2 cases annually. The crusher availablily is also increased to 95%.

	Before Modification	After Modification
Coal Throughput	4.5 LMT	6.5 LMT
Motor Ampere	37.01A	37.2A
Hammer consumption (yearly)	500 nos	400 nos
Hammer Breakdown	08-09 cases/yr	01-02 cases/yr
Crusher Availability	80%	95%
Cost Savings	INR 8 Lakhs/yr (including maintenace cost INR 5 Lakhs)	

Applicability:

- The project can be implemented in the plants where the crusher shaft is capable enough to handle higher weights of the hammer, which can be determined through trials.
- The crusher should have sufficient clearances to accommodate higher weight and size of hammers.

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2.3 Interconnection of CW & ACW Pipeline Header

Details of Plant

Plant	Prayagraj Power Generation Company Limited
Capacity	3 x 660MW
Location	Bara, Uttar Pradesh

Cooling Water (CW) and Auxiliary Cooling Water (ACW) systems are critical components of a thermal power plant's cooling infrastructure. The CW system primarily removes heat from the condenser by circulating water byabsorbing latent heat of condensation heat from the steam turbine exhaust, which is essential for maintaining condenser vacuum & cycle efficiency. The ACW system supplies cooling water to PHE to extract heat from DMCW which in turn provides cooling to auxiliary equipment such as boiler feed pumps, lubrication oil coolers, compressors and other heat exchangers within the plant. In some cases, the suction of ACW is from the CW discharge while in other cases both operates independently. CW & ACW operates in closed loops but depend heavily on weather conditions. During winters, as the ambient temperature is low, the cooling is more efficient while in summers it is less effective.

Details of existing system:

- The plant has independent CW & ACW system. CW is supplying cooling water to condenser while ACW is supplying cooling water to plant PHE for cooling of DM water.
- The source of both the pumps is forebay water which is the outlet of the cooling tower.
- Both the pumps are not having VFD due to which the flow of the pumps cannot be controlled. They always operate as per the designed flow.
- The plant used to run both CW & ACW pumps to meet the cooling water requirements for condenser as well as for PHE irrespective of the weather conditions and cooling water requirements.

Details of modification:

- It was observed that during the winters and low laod operations the cooling water requirements is reduced in condenser as well as for the ACW system.
- The ACW header is connected with the CW header through a MOV and a NRV.
- For all the operating units, only 1 ACW pump is kept in operation during summers while during winters, all the ACW pumps are shutdown.
- During winters, as the requirement of cooling water in condesor is less, the same water was diverted as ACW in PHE.

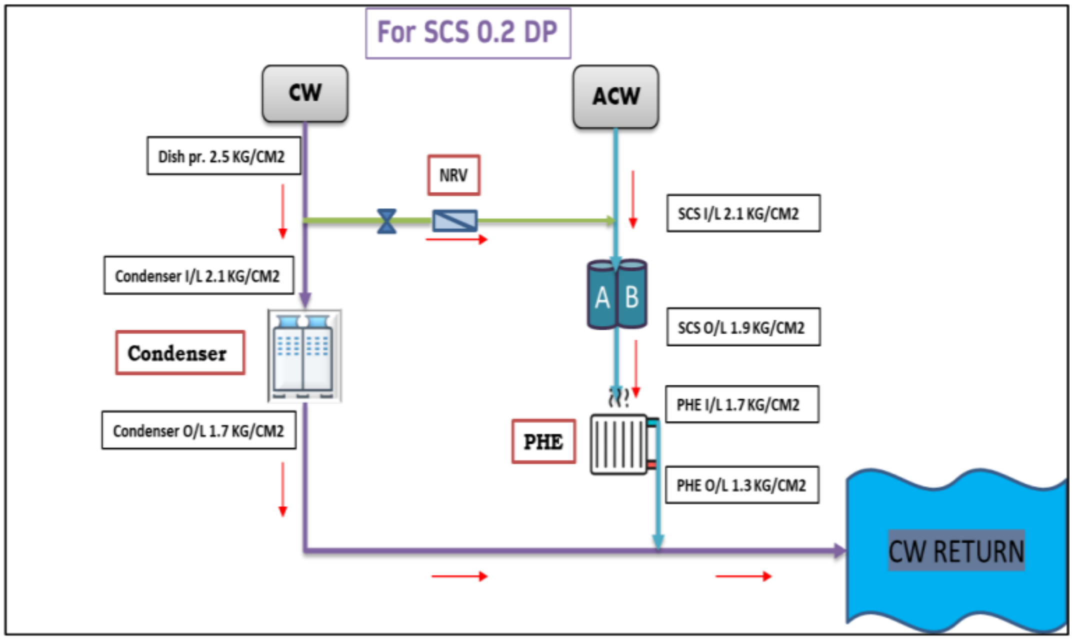

Figure 6: Modification Detail

Benefits:

- Improved system reliability as during failure of ACW system, there is minimal or no effect on system operations as CW is running and supplying cooling water to PHE.
- The increase in CW power is minimal as the flow of the CW is same while only some of the flow is diverted to the ACW system.
- Maintenance and downtime of ACW pump is reduced.

	Winters	Summers
Investment required	INR 5.00 Lakhs for pipes and valves	6.5 LMT
ACW operation before modification	2 Pumps Running	2 Pumps Running
ACW operation after modification	Stopped	1 Pump Running
Cost of Power Saved	INR 331 Lakhs	INR 165 lakhs
Total Annual Savings		INR 496 Lakhs

Applicability:

- The project can be readily implemented in the plants where the ACW suction is from CW discharge. This does not require any investment.
- The project applicability is very high for the plants located in the areas where the winters are extreme.
- During lower load operation (mainly at MTL) the cooling water requirement is less for condensers due to reduced steam quantity. The plants which are mostly operating at MTL can implement the project to reduce the ACW power consumption.

Contact Details:

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2.4 NOGS Type Ash Level Sensor for ESP Hoppers

Details of Plant

Plant	NTPC Ltd- Ramagundam Super Thermal Power Station
Capacity	3 x 200MW, 4x 500 MW
Location	Bilaspur, Chhattisgarh

Effective monitoring of ESP hopper ash levels is critical, as it directly impacts plant emissions. Most plants rely on level probes for this purpose. Typically, an ESP contains 28 to 36 hoppers, making individual ash level monitoring a challenging task for operators. Furthermore, contact-type probes are prone to malfunction due to ash deposition, leading to field outages and increased emissions.

Level probes are generally installed at 70–90% of the hopper height and only detect ash when it comes into direct contact with it. This limitation means that if the ash level drops below the probe, for instance to 50%, the system is unable to detect the presence of ash, resulting in inaccurate monitoring.

Details of modification:

- Plant has installed NOGS type level sensors for 1st field of ESP
- Field tripping is provided by the sensors which is user configurable

Details of NOGS type fly ash level measurement technology:

NOGS Sensor (Naturally Occurring Gamma Ray Sensor) is the most advanced continuous level measurement device for ESP fly ash hoppers. It is installed outside the hopper plate without any cut out or shut down for the ESP hopper.

NOGS Sensor, based on “NOGS” γ-ray detection technology, used for level measurement of ESP fly ash hoppers, measures the trace amounts of natural radionuclides present in the fly ash. It can effectively extract the low amounts of changing of Gamma rays sensed by the device adopting random signal recognition technology.

NOGS Sensor has a dedicated built-in processor, which can effectively distinguish the γ-ray of fly ash from those of the noises in the background environment, and then translate the intensity of gamma ray to precise material level measurement.

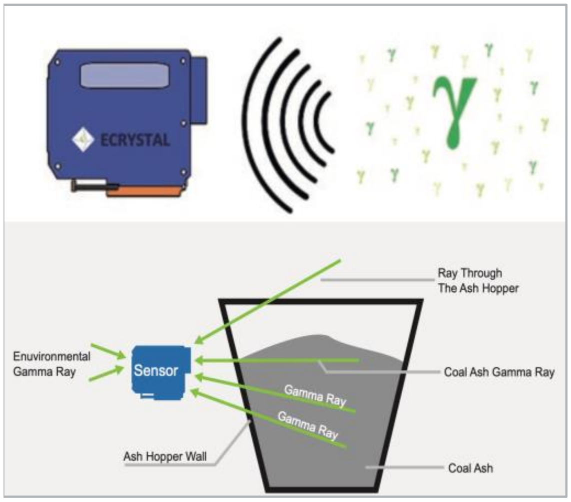

Figure 8: Working principle of NOGS level sensor

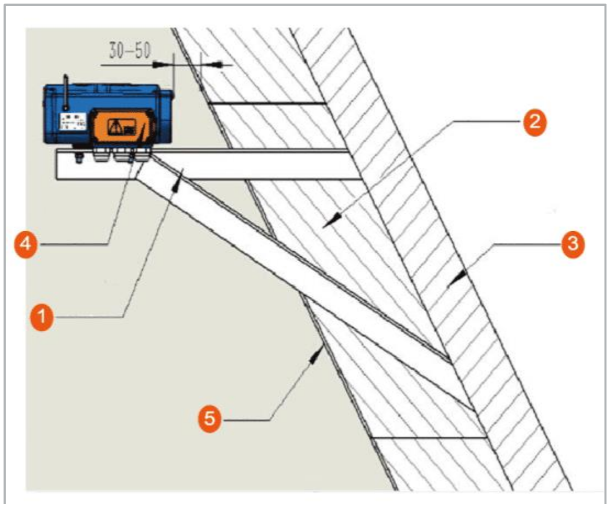

Figure 9: Installation of NOGS level sensor

Features of NOGS type level measurement:

Non-contact measurement	No radioactive sources.
Provide accurate level signals	Operating temp -40 to +85°C (sensor is installed outside the hopper)
Analog signal (4-20 mA)	Easy to modiy preset working parameters via display panel or remote calibrator.

Benefits:

- The plant personnel can have an accurate idea of the level of ash inside the hopper which in case of level probe is not possible. This will also help the plant personnel to prioritize the selection of hopper for ash evacuation.
- Increased availability of ESP fields and reduced emissions.
- Improved safety of ESP structures and field manpower.
- Reduced maintenance cost and ESP field downtime.

Field Downtime saved	4 hrs considering time required for manual evacuation
Emissions reduced	SPM maintained < 50 mg/Nm^3 if the outage is considered in 1st field
Analog signal (4-20 mA)	Easy to modiy preset working parameters via display panel or remote calibrator.

Applicability:

- The NOGS type level sensors are mostly applicable to the large stations where the distance of the unit is far from the main control room so that the accurate monitoring can be ensured wirelessly.
- The plants where the hopper evacuation system is automatic which works with the setpoint from the hopper level, the accurate level measurement becomes of prime importance.

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2.5 Harnessing Hydro Power from Cooling Tower Discharge

Details of Plant

Plant	NTPC Ltd- Sipat
Capacity	3 x 660, 2 x 500MW
Location	Bilaspur, Chhattisgarh

The condenser is a major heat sink in a thermal power plant. The latent heat of condensation is transferred to the circulating cooling water inside the condenser. This heat is in turn released into the atmosphere through the Cooling Towers. The cooled water is collected into the cooling tower basin and flows by gravity through canals to the forebay where the cooling water pumps are installed for circulation. The water flowing through the canal has an approximate velocity of 1 m/s which can be utilized for generating useful work or energy.

Details of modification:

- The plant has a canal dimensions of 4.5m (width) x 3.5m (depth) x 85m (length).
- The plant has installed fixed type SHK (Surface Hydrokinetic) turbines in the water canal at a distance to generate hydropower from the flowing cooling water.
- Modules of SHK turbines are installed in every canal.
- The SHK turbine is fitted with Auto Submergence Adjuster to ensure that the turbine is always submerged in the water due to changes in water level.

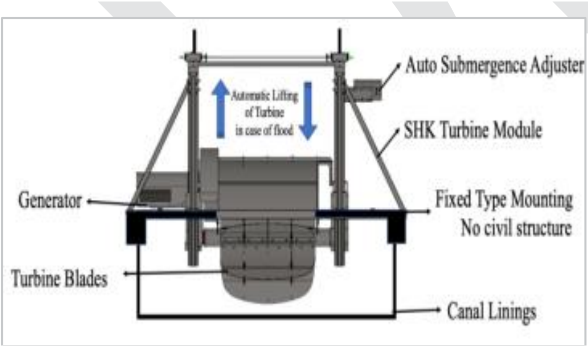

Figure 11: SHK Turbine

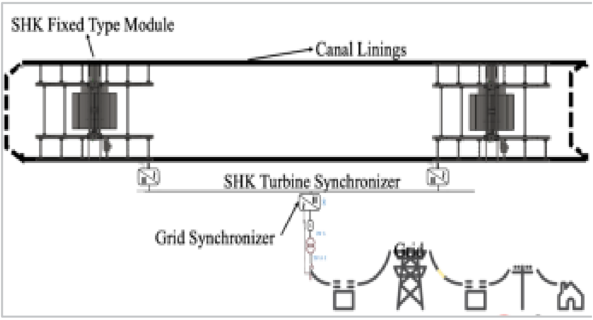

Figure 12: SHK Power Evacuation Scheme

Benefits:

- The potential energy in water flowing freely due to gravity in the forebay can be utilized for the power generation.
- The evaporation losses from the forebay is slightly reduced.
- Helps in reducing emission within the boundary.

Table 5: Saving Details for SHK Turbine Installation

Module in each canal	3 X 10 kW
Capex (including maintenance cost for 5 years)	INR 2.5 Lakh/kW (for 18 modules)
Capacity	180 kW (Total 6 X 3 X 10 kW)
Annual Energy generation	1.44 MUs
Unit Cost	INR 3.17/unit
Simple Pay-back period	9.9 years
Useful life of Hydro turbine	40 years

Applicability:

- SHK turbines are applicable to the plants with open forebay connecting cooling towers with CW pump houses.

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2.6 APH Soot blowing Line Modification

Details of Plant

Plant	IB Thermal Power Station Ltd
Capacity	2 x 210MW, 2 x 660MW
Location	Jharsuguda, Odisha

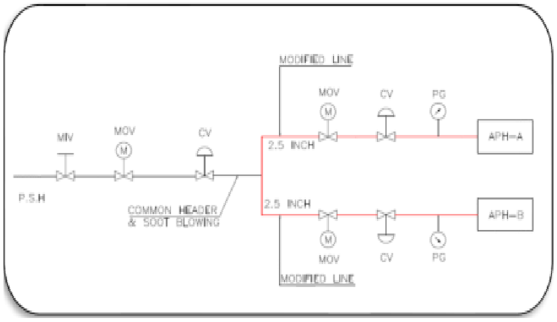
Air Pre-heater (APH) in provided for heating the secondary as well as primary air using the heat of the exit flue gases. It is also the last heat recovery equipment in boiler hence its performance largely affects the boiler efficiency. Since every 22 deg. C of rise in flue gas exit temperature from APH reduces boiler efficiency by 1%, it is of utmost importance that the heat transfer in the APH should be as per the designed. Challenges associated with APH such as soot deposition, inadequate soot blowing and cold end corrosion can cause reduced heat transfer in the basket.

Details of existing system:

- After commissioning, the APH soot blowing system was ineffective due to lower soot blowing steam pressure. The plant was getting 6-8 kg/cm2 against the designed 12-14 kg/cm2 steam pressure.
- This was causing higher flue gas exit temperature from APH (4-5 deg. C higer than the designed). Additionally, due to lower heat transfer, the rated SA & PA air temperature at APH outlet is also not achieved causing reduced boiler efficiency.

Details of modification:

- Post Root Cause Anlysis (RCA), it was decided to modify the Soot Blower line & replace it with larger size with proper valve arrangements to increase the APH SB pressure.
- The branch line which was earlier 1.5" have been replaced with 2.5" new pipeline with modified MOV and CVs.
- The CVs are tuned to maintain the required pressure between 12-14 kg/cm2 for effective soot blowing.



Benefits:

- Due to better soot blowing, the boiler efficiency is increased due to reduction in dry flue gas losses.
- With better heat trasfer area cleaning, the performance of the APH improved

	Before Modification	After Modification
Soot Blowing Pressure	6 kg/cm^2	12 kg/cm^2
Exit Flue Gas Temp	145 deg C	140 deg C
Investment required	INR 12.00 Lakhs (for bigger pipe, MOVs & CVs)	
Cost Savings	INR 277 Lakhs (due to better heat recovery)	

Applicability:

- The project is highly applicable to the plants which are getting lesser APH soot blowing line pressure resulting into increased flue gas outlet temperature as per the design.
- If the plants is using higher ash coal as compared to the designed, it becomes of prime importance that there should be systems in place to remove the soot deposition effectively from the heat transfer surfaces.

2.7 QR Code System for Electrical Isolation of Equipment

Details of Plant

Plant	Adani Dahanu Thermal Power Station
Capacity	2 x 250MW
Location	Dahanu, Maharashtra

In a power plant, equipment isolation is carried out not only during breakdown maintenance but also as part of preventive maintenance activities. Proper and accurate isolation plays a critical role in ensuring the safety of workmen working in the field. In a typical power plant with two operating units, the number of daily isolation activities can range between 30 to 40. The process becomes even more complex when the plant has a larger number of units with similar capacities and symmetrical layouts, as this increases the likelihood of overlapping systems and potential risks.

Details of existing system:

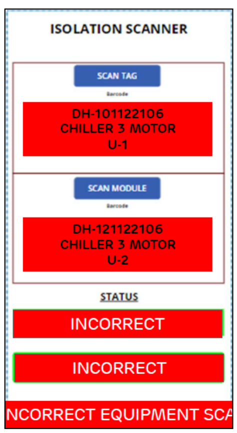
- The maintenance engineer approaches the operation executive with a permit-to-work (PTW) for isolation equipment.
- Operation executive, taking into account the availability of parallel system, stops the running equipment and issues instruction to electrical engineers to isolate the equipment. The isolation tag is sent to the electrical engineer.
- Electrical engineers manually search for the breaker (feeder) of the equipment, isolate the breaker and place a tag on it with information like date of isolation, name of person working on drive and department.
- Send feedback to the operation engineer regarding isolation of equipment followed by the release of PTW by operation engineer to the maintenance engineer.
- Issues with the existing system:
- Confusion in understanding the correct equipment. For example: PA fan-A & PA fan-B
- Confusion in understanding the correct Unit. For example: Unit-1 PA fan-A & Unit-2 PA fan- A.
- Incorrect tagging if the electrical engineer is handling multiple tags of different units/ equipment.
- Incorrect feedback of isolation by electrical engineers to the operation engineer. For example: Isolation of Unit-2 PA fan- A done but feedback of isolation of Unit-1 PA fan-A given to operation engineer.

Details of modification:

The plant has adopted QR code based electrical isolation system for equipment. All the equipment feeders are provided with exclusive QR codes. The tag, while printing, will also print the QR code at the top matching the QR of that particular drive. Electrical engineers are provided with a mobile app which can read and match the QR code mentioned on the tag as well as on the feeder to ensure correctness.

Procedure of isolation:

- The operations engineer prints the tag along with the QR code and send the same to the electrical engineer.
- The electrical engineer goes to the equipment feed and scan the QR code on the tag and equipment feeder as well. If the QR code is a perfect match, the application shows a match, and the engineer can go ahead with the isolation followed by the tagging of the feeder.
- If the QR code does not match, the electrical engineer comes to know that he is at the wrong location and can go to the correct location for isolation.
- Post isolation, the feedback is shared with the operation engineer via mobile app.

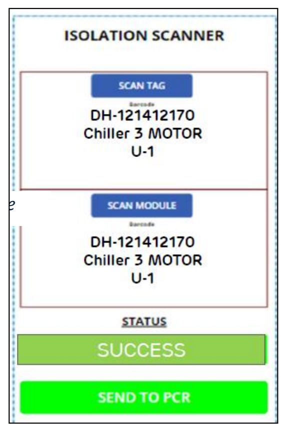


Figure 13: Isolation Procedure

Benefits:

- Improves safety and avoids human errors in isolation by ensuring correct equipment isolation.
- Eliminates the risk of accident and equipment damage.
- Reduces isolation time by avoiding errors and ensures accurate feedback to the operation engineer.

Applicability:

- The project is applicable broadly to all the plants as human errors are unavoidable even if utmost care is taken.
- The stations with symmetrical unit layout are more suitable as the chances of errors are high.
- The stations where the LOTO (Lock Out Tag Out) system is not implement and multiple permits are issued daily for preventive maintenance.

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2.8 Optimization of Compressed Air System

Details of Plant

Plant	JSW Energy (Barmer) limited
Capacity	8 x135MW
Location	Barmer, Rajasthan

The compressed air system is one of the costliest utilities in a power plant, and among the most frequently misused. Studies indicate that out of 100% of the input energy supplied, only about 7% is effectively utilized for productive work, while the remaining energy is lost primarily in the form of heat of compression, artificial demand, and leakages. At times, when the power sector is focusing heavily on emission reduction, optimization of compressed air systems assumes critical importance. Efficiency improvements in this area not only help in lowering the auxiliary power consumption (APC) of thermal power plants but also contribute to reduced maintenance costs, extended life of compressors, and enhanced system availability.

Details of existing system:

- The plant required compressed air which comprises of service air and instrument air system for operations.
- While instrument air is required for control and operation of field instrument critical for the process, the service air is mostly used for purpose such as man cleaning, filter cleaning and in some cases cooling purpose.
- Additionally, the service air was used for atomization of oil during oil firing.

Details of modification:

- The plant has assessed the usages of service air in the facility and identified that the service air is being used for oil gun atomization and filter cleaning.
- Plant has installed separate portable blowers at various places for filter cleaning and for man cleaning. It was strictly mandated not to use compressed air for man cleaning.
- Oil gun atomization tapping taken from instrument air compressor.
- By arresting leakages, the instrument air pressure is reduced from 6 kg/cm^2 to 4.8 kg/cm^2.
- 1 compressor stopped and required pressure is achieved by 1 compressor only.

Benefits:

- APC of 3.35 MU/year is reduced due to stopping of 1 compressor.
- The maintenance cost of the compressor was reduced due to reduced operating time.
- Monetary savings of INR 105 Lakhs annually.
- Improved compressor availability.

Investment required	INR 5.00 Lakhs (for piping & valve)
APC reduced	3.35 MU/year
Monetary Savings	INR 105 Lakhs

Applicability:

- The project can be readily implemented at the stations where the service air is kept charged and used only for filter or man cleaning. The station can restrict the usage of compressed air and can install portable blowers for similar applications.
- The plants where the service air is used additionally for gun cooling or atomization of oil in guns, the project can be implemented with a minor modification by interconnecting the atomizing air line with the instrument air line.

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2.9 Installation of In-house Biomass Pellet Plant

Details of Plant

Plant	Jindal Power Limited
Capacity	4 x 250MW, 4 x 600MW
Location	Raigarh, Chhattisgarh

Biomass pellet consumption in India's thermal power plants has gained significant momentum due to both environmental necessity and strong policy directives. The push for co-firing biomass with coal stems from the need to reduce carbon emissions, tackle air pollution caused by stubble burning, and help meet climate targets. The Government of India has mandated a minimum of 5% biomass co-firing in all coal-based thermal power plants equipped with appropriate mills starting from FY 2024–25, with a further increase to 7% from FY 2025–26.

Nationally, while about 71 power plants are now co-firing with biomass, and an estimated 814,000 tonnes of agro-residue-based pellets have helped prevent close to a million tonnes of CO_2 emissions, the implementation still struggles with supply chain, manufacturing, and technical challenges.

Details of modification:

The plant has installed in-house biomass pellet plant to address the challenges such as availability, transportation and quality of the biomass pellets. The details of the project are as follows:

Table 6: Bio mass Pellet Plant Project Details

Capacity of the Bio mass pellet plant	160 TPD
Feedstock	Paddy Straw, Forest waste, Firewood, Bamboo, Subabool, Rice husk, Horticulture waste etc.
Pellet Plant Equipment	Shredder, Chipper, Rotary Dryer, Hammer Mill, Pellet Machine (Ring Die type), Cooler & Material Handling equipment
Biomass Pelleting Process	Raw material selection-Shredding/chipping-Drying with the rotary dryer- Grinding with Hammer mill- Pelleting with Pellet machine- Cooling with discharge belt conveyors and coolers-Bagging/Packing
Air Pollution Control	Bag filters are provided to control dust and this dust free air is discharged to atmosphere through 15 m heigh stack.
Water Requirement	1000-1500 Litres per week (mostly water is reused)
Land required	1200 sq. m

Benefits:

- Substitution of fossil-based energy source.
- Reduction in GHG emissions.
- Utilization of waste and by-products
- Enhanced energy security.
- High replication potential- based on the availability of biomass in the plant vicinity.

Applicability:

- The biomass pellet plant is applicable to the plants where there is easy availability of raw biomass. Additionally, the transportation cost of the biomass also needs to be considered.
- The stations, where the biomass pellets are readily available in the market at a cheaper rate than the cost of production, the plant should consider purchasing the same from market.

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2.10 Air Leakage Reduction in RAPH with Improvised Control of Sector Plate Movement with Load Variation

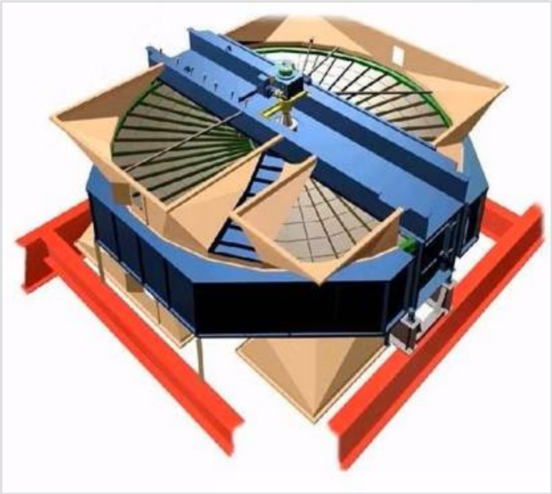
Details of Plant

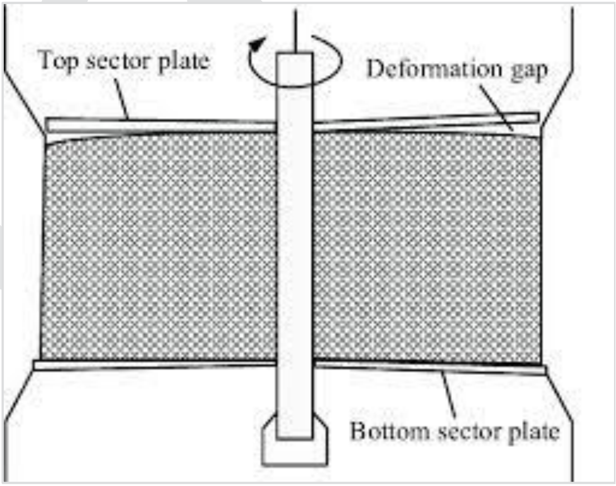
Plant	Nabha Power Limited
Capacity	2 x 700MW
Location	Rajpura, Punjab

APH leakage is one of the pressing issues in the thermal power plants. The typical range of leakage for trisector rotary regenerative APH is 7-10%. With increase in APH leakage, there is increase in power consumption of ID fan as the fan has to perform more work for creating the same amount of draught. Sector plates are provided to prevent unwanted mixing of fresh air. These plates are adjustable during the running which prevents the leakage in the APH.

Details of existing system:

- PLC based control through temperature measurements.
- The delay in temperature stabilization during load change resulted in heavy motor current fluctuations requiring frequent manual interventions and affecting overall efficiency.





Details of modification:

- The plant has reviewed the existing PLC logic for sector plate movement setpoint generation and collected field data of rotor displacement through manual operations of actuators.
- The data was collected at different load conditions for rotor displacement and motor current
- With real-time data integrations, the actuator positions are now available in DCS.
- The logic is modified for full retraction in case the load is < 40% TMCR or if there is any abnormal temperatures or runback in the system.
- Biasing is provided in each actuator for better controlling and higher flexibility to the control room operators.
- Alerts are incorporated in the system.

Benefits:

- Air leakage is maintained below 5.2% with 0.07% reduction in APC.
- Monetary savings of INR 240 Lakhs per year due to savings in APC and coal.
- Reduction is emissions to the tune of 28 Tonnes/day due to reduced APC and coal consumption.

	Before Modification	After Modification
Air leakage	8-12%	5.2%
APC reduced	0.07%	
Investment	10 Lakhs	
Monetary Savings	INR 2.4 crore annually	
Emission Reduction	28 tonnes/day	

Applicability:

- The project is applicable to the plants which has online sector plate adjustment mechanism.
- The plants with manual seal adjustment is not fit for this kind of project as the seal adjustment mechanism requires shutdown of boiler while in contrast the sector plate works online.

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3 FLEXIBLE OPERATION OF THERMAL POWER PLANTS

Introduction

India's Nationally Determined Contributions target a substantial RE capacity of 500 GW by 2030, constituting over 50% of the total installed capacity. The same is projected to increase to 596 GW by 2032 dominating the installation of 304 GW from fossil-based sources. Although, this accelerated growth of RE is pivotal to India's energy transition, it poses operational challenges to thermal power plants. The intermittency & variability of RE generation calls for enhanced flexibility in TPP operations to ensure grid stability.

In FY 2024–25, India's thermal power plant's average PLF remained at 69.45%, which is further expected to decrease with rising RE penetration. Moreover, advancements in technologies, like pumped storage and battery energy storage systems, are anticipated to further reduce PLFs.

In India, most of the plants are traditionally designed for a 55% MTL considering the base load operation but same must be lowered to 40% MTL to accommodate the growing generation from RE sources. Additionally, it is also required to have steeper ramp rates of up to 6% per minute and shortened startup/shutdown cycles for addressing variability & intermittency of RE. These adaptations strain equipment reliability and efficiency, escalating operational costs.

3.1 Demand Scenario and Flexibilization Requirements

As per the National Electricity Plan- 2023 which was released by Central Electricity Authority (CEA), the projected load factor of the thermal power plants considering the peak demand scenarios in the year 2026-27 and 2031-32 is shown in Table 7.

1. 1^{st} Sep 2023: At 2 PM: 65% of Peak demand met by Coal & 14% by Solar. Solar variation 34 GW (14%) absorbed by Wind (5 GW), Hydro (8 GW) Gas (2 GW), coal (8 GW) & demand variation (11 GW).
2. 2026-27: At 2 PM: 37% from Solar & 45% from Coal. With 37% Solar Generation share, Solar Generation varies by 104 GW which is to be accommodated by Wind (10 GW), Hydro (10 GW) Gas (3 GW), Coal (56 GW) & demand variation (25 GW).
3. 2031-32: At 2 PM: 55% from Solar & 26% from Coal. With 55% Solar Generation share, Solar Generation varies by 204 GW which is to be accommodated by Wind (15 GW), Hydro (12 GW) Gas (3 GW), Coal (125 GW) & demand variation (42 GW). Storage Solutions to supply 10 to 20 GW.

With the rapid increase of power generation from renewable energy, fossil fuel power plants are required to play a more important role in maintaining load balance and providing the grid frequency control service as they are considered as dispatchable power generation units. They are now required to be more flexible and to respond faster with more frequent start-ups or shutdowns for maintaining power network stability. In Indian coal-based power plants, several effective pilot studies and test runs have been carried out in recent years. NTPC has been leading the way in this area, conducting trials at its several coal-fired power facilities.

Table 7: Peak Demand of 1 September 2023 (240 GW), 2026 - 27 (281 GW), 2031 - 32 (374 GW)

	1 September 2023 (Peak Demand Day – 240 GW)				2026 – 27 (Peak Demand Day – 281 GW)				2031 – 32 (Peak Demand Day – 374 GW)			
	Afternoon (2 PM)		Night (2 AM)		Afternoon (2 PM)		Night (2 AM)		Afternoon (2 PM)		Night (2 AM)	
Fuel Type	**LF**	**MW Delivered**	**LF**	**MW Delivered**	**LF**	**MW Delivered**	**LF**	**MW Delivered**	**LF**	**MW Delivered**	**LF**	**MW Delivered**
Coal+Lig	86%	156263	88%	160832	63%	127395	94%	190082	44%	98249	100%	223293
Gas	55%	8263	65%	9765	42%	4170	65%	6454	42%	4170	65%	6454
Hydro	70%	26236	50%	18740	36%	15104	50%	20978	36%	17907	50%	24871
Nuclear	75%	4488	75%	4488	75%	7848	75%	7848	75%	11808	75%	11808
Solar	70%	34861	0%	0	80%	103917	0%	0	80%	204157	0%	0
Wind	30%	9227	45%	13841	40%	20411	45%	22962	40%	34131	45%	38397
Other RE	20%	1311	20%	1311	20%	2052	20%	2052	20%	3811	20%	3811
Total		**240649**		**208977**		**280897**		**250376**		**374233**		**308634**

3.2 Challenges of Renewable Energy Integration

Integrating high shares of renewable energy (RE) like solar and wind into the grid presents several complex challenges that directly impact flexible operation strategies of conventional power plants. These challenges largely stem from the physical and operational characteristics of renewables, as well as the limitations of existing grid infrastructure and technologies. These challenges broadly fall into four categories:

- Uncertainty – Output depends on weather conditions, which cannot be forecasted with complete accuracy. Sudden changes in wind speed or cloud cover can lead to imbalances between expected and actual generation.
- Variability – Solar output peaks at midday and drops to zero at night, while wind generation fluctuates hourly and seasonally, often without correlation to demand patterns.
- Concentration – Large renewable installations tend to be located far from consumption centres, creating transmission bottlenecks and curtailment risks.
- Forecasting Difficulties – Despite improving analytical tools, renewable generation predictions remain imperfect, requiring backup reserves and rapid-response resources.

3.2.1 Duck Curve Phenomenon

A practical manifestation of these challenges is the duck curve, first widely observed in systems with high solar PV penetration. The term describes the shape of the daily net load (system demand minus renewable generation):

- Midday Dip ("Belly" of the Duck): Solar generation is abundant while demand remains moderate, leading to very low net demand (net demand is the electricity demand from the coal plants). In some cases, net demand even turns negative, necessitating curtailment of renewables.

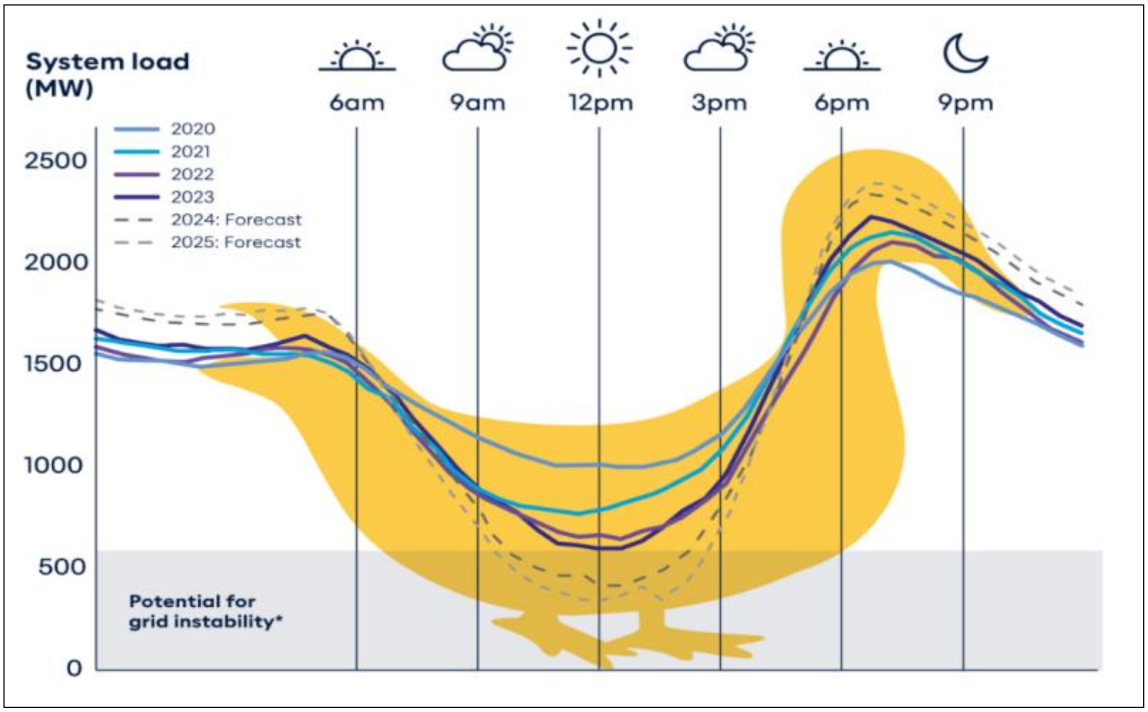


Figure 14: Duck Curve Phenomenon

- Steep Evening Ramp ("Neck" of the Duck): As solar output falls rapidly in the late afternoon, net demand simultaneously increases, requiring a large and fast ramp-up of dispatchable generation to maintain reliability.

This stresses existing thermal plants, which were not originally designed for frequent, steep, or fast load changes. The issue intensifies as more solar capacity is added, making the "belly" deeper and the evening ramp sharper.

India is experiencing the emergence of the "duck curve" phenomenon, particularly pronounced in renewable-rich states like Rajasthan and Gujarat, where solar generation creates midday surplus and sharp evening demand spikes.

In Rajasthan with 35.7 GW of RE capacity, the duck curve severity correlates strongly with solar penetration, with evening ramping rates reaching 2.5 GW/hr. Net load ramping requirements have increased by 60-80% between 2018-2023, necessitating thermal plants to operate with greater flexibility and faster response times.

3.3 Basic Definition related to Flexibility

3.3.1 Flexibility

The term and concept of power system flexibility have evolved over time to reflect the way technology and power markets have evolved. The term was first introduced in IEA (2008) as: "… The ability to operate reliably with significant shares of variable renewable electricity."

A more specific definition was put forward in IEA (2011): "the extent to which a power system can modify electricity production or consumption in response to variability, expected or otherwise. In other words, it expresses the capability of a power system to maintain reliable supply in the face of rapid and large imbalances, whatever the cause."

EPRI, the Electric Power Research Institute, defined flexibility in 2016 as: "the ability to adapt to dynamic and changing conditions, for example, balancing supply and demand by the hour or minute, or deploying new generation and transmission resources over a period of years."

3.3.2 Minimum Load

The minimum load is the lowest possible net load a generating unit can deliver under stable operating conditions. It is measured as a percentage of normal load or the rated capacity of the unit. Graphical representation of minimum load is depicted in the chart.

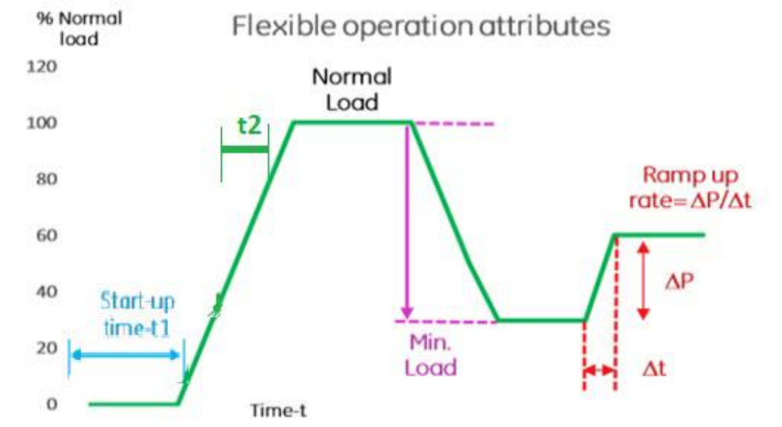


Figure 15: Detail of Minimum Load

3.3.3 Start-up time

The start-up times are defined as the period from starting plant operation from light-up to synchronisation (t1) & further from synchronisation to 90% base load (t2). The startup time of different generation technologies varies greatly. The other factors influencing the start-up time are, down time (period when the power plant is out of operation) & the cooling rate.

The start-ups can further be defined as hot, warm and cold as per the time the units are out of operation or as per the turbine casing metal temperatures. However, defining start-up types and the criteria will depend on the OEM/OED. Traditionally, the OEMs used the criteria of turbine casing metal temperature. But it is important to understand that a hot or warm start-up on a turbine may not necessarily be the same for boiler. The boiler can cool down faster and it may be a cold start for the boiler, while the criteria for the turbine may be hot or warm start. Some OEM/ OEDs have included the boiler metal temperatures also in the start-up criteria. Type of start-up for power plants is given below:

Table 8: Startup Time Detail

Criteria			Time	
Start - up Type	Shut down period (hrs)	Steam turbine metal temperature, °C	Light-up to Sync (Min)	Sync to 90% load (Min)
Hot	< 8	> 400	50 - 90	60
Warm	8 - 48	250 - 400	100 - 300	80
Cold	> 48	205	300 - 480	90

3.3.4 Ramp Rate

The ramp rate describes how fast a power plant can change its net power during operation. Mathematically, it can be described as a change in net power, ΔP, per change in time, Δt. Normally the ramp rate is specified in MW per minute (MW/min), or in the percentage of rated load per minute (% P/min). In general, ramp rates greatly depend on the generation technology.

3.3.5 Minimum Technical Load (MTL)

The MTL is the ratio of actual minimum load on the prime mover of a thermal power station and its rated capacity. E.g. if a 200 MW plant runs at minimum load of 120 MW during a day, then the MTL for that plant is 120/200 i.e. 60%.

3.3.6 Part Load Efficiency

Efficiency decreases (i.e. HR and APC) with decreasing load. The Heat Rates and Auxiliary power consumption measured at reducing loading rates of the unit is referred to as part load efficiency. During flexible operation, units are subjected to long hours of low load operation (part load) and optimizing the efficiency at low loads becomes important for maintaining the economic viability of utilities. In regulated tariff markets, lower efficiency would lead to higher marginal costs and direct reduction of profits of the stations. In real time markets, lower efficiency will increase the variable costs, and the power may not get dispatched.

3.3.7 Flexibilization Cost

The recurring costs incurred by the unit for running the unit on flexible operation modes (Variable cost) and the costs/investments incurred by the unit for enhancing the flexibilization capability of the unit (CAPEX) together are the flexibilization costs. The increase variable costs are incurred by the units on flexible operation due to the deterioration of efficiency, equipment life consumption, increased O&M expenses, extra oil consumption and decreased reliability (increase in outages & boiler tube leakages (BTL)). Start-up and shutdown operations are the most expensive mode of operation because of additional life consumption of components, extra primary and secondary fuel consumption, chemical consumption and DSM charges (specific to Indian markets), besides other costs.

3.4 Evolving Role of Coal Plants in Indian Grid

While the coal power plants are basically designed for the base load operation, the higher renewable energy penetration in the grid calls for doubling the role of coal power plants as a spinning reserve to support grid during transient fluctuations in renewable energy generation. Despite the share of 49.75% of the thermal power in current installed capacity, the share in electricity production is 75% showcasing the importance of thermal in country's electricity sector.

This year in India, the peak electricity demand reached about 241 GW on 9th June 2025 at 3:00 PM. This peak was successfully met with zero shortage reported on that day. Interestingly, the coal plant catered 73% of the requirement compared to the 23% share of renewable energy. On the other hand, there are frequent instances when the coal power needs to operate at MTL or sometime even shutdown for creating extra space to accommodate renewable energy. These dual requirement of ramping up during the peak hours and rolling back generation during non-peak hours has completely turned the way India used to look at coal power plants.

To address the challenges associated with renewable energy integration, the coal power plants are focusing to improve in the following areas:

- **Low load operation up to 40% TMCR:** To accommodate the rising generation from the renewable energy sources, the coal plants are required to reduce the generation down to 40% TMCR. It is required that the plants should deliver efficient & reliable power while running on lower loads. The phasing plan released by CEA details about the requirements which is explained in the next section.

- **Higher ramp rates:** Besides achieving lower loads, the ramp rates also play an important role in grid stability by rapidly filling the gaps between the generation and demand arising due to variability in renewable energy. The higher ramp rates ensure the availability of dispatchable power during frequency fluctuations.
- **Cyclic operation:** Instead of operating at a stable load, as designed, the coal power is now required to undergo cyclic load changes throughout the day. Cyclic operations put a lot of stress on components like boiler pressure parts, turbines and plant equipment. These cyclic stress calls for higher failure rates of components and ultimately increases the unit downtime. To address these issues, it becomes of prime importance that the industry should start looking at the maintenance activities from a new perspective while considering increased overhauling frequency, changing maintenance strategies and switching to better condition monitoring techniques.
- **Quick Startup & Shutdown:** With further renewable energy penetration, the coal plants are not only required to operate at MTL, but some plants are required to operate in shifts called the Two Shift Operation. This operation is increasingly necessary for grid flexibility, helping to balance demand variations especially when solar power is abundant during the day and demand spikes in morning/evening. Regulatory bodies like India's CERC have initiated pilot projects for two shift operation with incentives to encourage its adoption to address grid frequency challenges and renewable energy integration.

While the power producers are taking various steps to ensure that requirements for higher level of plant flexibility are addressed, they are also actively looking after potential technologies that can help the facilities to minimize the challenges associated with flexible operations. One such promising technique is the Energy Storage System (ESS) either in the form of Battery Energy Storage System (BESS) or Pump Storage System (PSP). The ESS can support the coal plants by storing the energy during the non-peak hours and releasing the same during the peak hours reducing the stress of high ramp rates on coal plants.

On 10th June 2025, Ministry of Power (MoP) has approved a Viability Gap Funding (VGF) scheme for 30 GWh of Battery Energy Storage Systems (BESS), in addition to the 13.2 GWh already underway. The INR 5,400 Crore scheme aims to attract Rs 33,000 Crore in investment, meeting the country's BESS requirement by 2028.

In a recent development, National Thermal Power Corporation (NTPC) has released a tender for BESS project at thermal power station in Uttar Pradesh. The company is seeking EPC contractors for a total 1,700MW/4,000MWh, comprising 300MW of 4-hour duration energy storage (1,200MWh) and 1,400MW of 2-hour duration storage (2,800MWh), to be deployed across 11 locations.

As per the NEP (2022-32) , the projected installed capacity of by the end of 2027 for PSP will be 7.4 GW while for BESS will be 8.6 GW/34,720 MWh and the same is expected to increase to 26.7 GW for PSP and 47.2 GW/236,220 MWh of BESS by the end of 2032.

3.5 CEA's Phasing Plan – Progress Towards Achieving 40% MTL

The Central Electricity Authority (CEA) has outlined a phased roadmap for enabling thermal power plants to operate at a Minimum Technical Load (MTL) of 40%. As per the notification dated 15th December 2023, forms a crucial step in enhancing grid flexibility and integrating renewable energy into the national power system.

The implementation is structured into five phases, starting with a Pilot Phase followed by four expansion phases spanning until December 2030.

Phase	Number of Units	Total Capacity	Timeline
Pilot Phase	10	5,850 MW	March 2024
Phase- 1	91	51,080 MW	July 2024 - June 2026
Phase- 2	100	46,825 MW	July 2026- June 2028
Phase- 3	101	37,215 MW	July 2028- Dec 2029
Phase- 4	191	55,767 MW	Jan 2030- Dec 2030

3.5.1 Ramp-Rate Requirements

To achieve 40% MTL, power plants are required to implement operational and technological measures that allow units to meet specified ramp-rate targets:

- 1% per minute: 40% to 55% & 55% to 40% of TMCR- this slow ramp rate accommodates stable operations without thermal stress on lower loads.
- 2% per minute: 55% to 70% & 70% to 55% of TMCR- this faster ramp-rates enables quicker responses, needed during more substantial grid changes, such as rapid RE output shits or sudden demand spikes.
- 3% per minute: 70% to 100% & 100% to 70% of TMCR- this capability is critical during peak hours when demand or RE variability can change rapidly, helping avoid under or over generation scenarios.

These ramping capabilities are essential for managing load fluctuations while ensuring grid stability. These ramp rates are pivotal during periods of abrupt changes such as the "duck curve" phenomenon, mentioned in the earlier section, when grid frequency and stability can be most vulnerable. Technological upgrades like advanced control systems, dynamic boiler tuning and improved turbine management are required for meeting these targets without sacrificing plant safety or efficiency.

3.5.2 Current Status of Phasing Plan

As of 30.06.2025 , the 10 units totalling 5,850 MW under the pilot phase are at different stages of execution of pilot phase. A summary of same is as under:

Organization	Name of Project	Unit No.	Capacity (MW)	40% Status
NTPC	Mauda TPS	1	500	Successfully completed
NTPC	Simhadri	3	500	Successfully completed
NTPC	Dadri	6	490	Successfully completed
DVC	Meja TPS	8	500	Successfully completed along with the required ramp rates
Neyveli Lignite	Neyveli New TPP	2	500	Under progress
KPCL	Yermarus TPS	1	800	Successfully completed
GSECL	Wanakbori TPP	6	800	Successfully completed
RRVUNL	Suratgarh SCTPP	8	660	Successfully completed
WBPDC	Sagardighi TPS	3	500	Successfully completed
APL	Raigarh TPS	2	600	Pending

3.6 Statistics- Low Load Operation

As per the CII's National Award for Excellence in Energy Management 2025 a study of low load operations on various critical parameters like Net Heat Rate, APC, Boiler exit flue gas temperature and Wind box pressure was conducted. The findings are as under:

3.6.1 Net Heat Rate

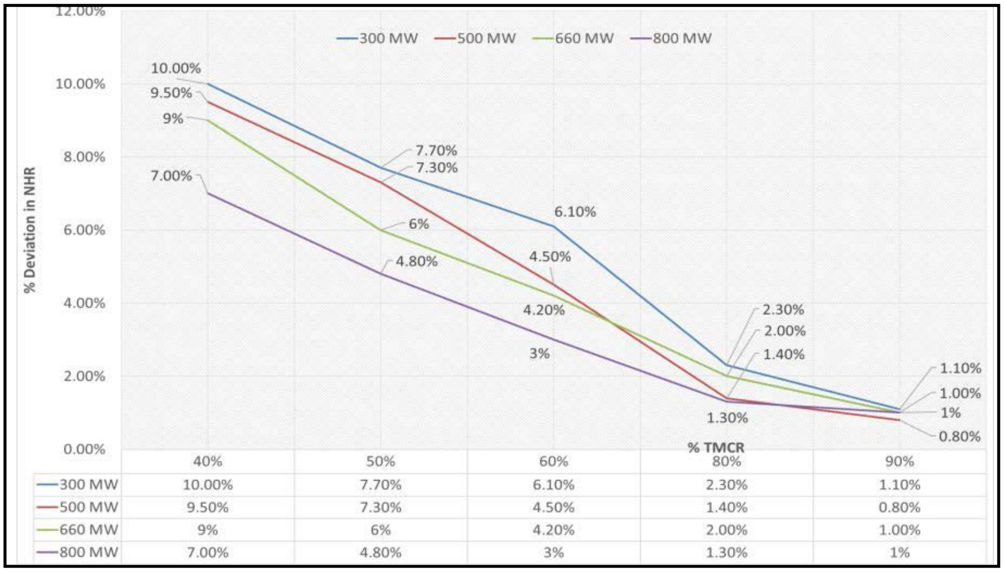


Figure 16: Net Heat Rate - Deviation from 100% TMCR

Findings:

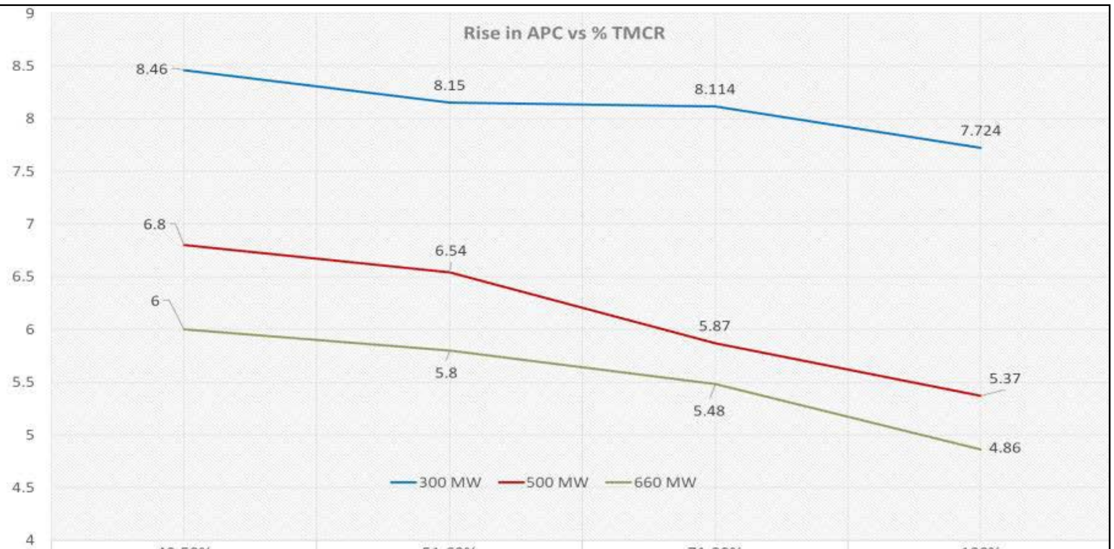
- The degradation in NHR becomes steep at <80% TMCR. This is the region where most of the plants are operating for most of the time.
- The degradation in NHR is higher for 300 MW units (10%) as compared to the 800 MW units (7%) due to the inherent inefficiencies in the sub-critical plant cycle.
- Higher capacity super critical units are more flexible compared to subcritical units.

Possible Solutions:

- During low load operations, the fluctuation in the critical parameters like MS temperature, MS pressure, RH temperature etc. are found to be high causing adverse effect on the cycle heat rates. Fine tuning of field instruments and control logics can help tighter control of critical parameters.
- Advanced combustion controls can helps maintain flame stability while ensuring complete combustion of the fuel resulting in near rated boiler efficiency while optimizing the unburnt carbon losses.
- The advanced combustion controls also help to achieve better combustion with lower excess air which is one of the leading causes of higher dry flue gas loss during part loading.
- Retrofitting & Digitalization of the unit can help achieve better unit flexibility.
- Real-time monitoring of critical parameters and heat rates using AI based tools can help the operator to take necessary corrective actions in real-time to bring the affecting parameters within the operating range.
- AI-based monitoring can also help in reducing the incidence of metal temperature excursions leading to the tube failures.

3.6.2 Auxiliary Power Consumption

Figure 17: Auxiliary Power Consumption - Deviation from 100% TMCR



	40-50%	51-60%	71-80%	100%
300 MW	8.46	8.15	8.114	7.724
500 MW	6.8	6.54	5.87	5.37
660 MW	6	5.8	5.48	4.86

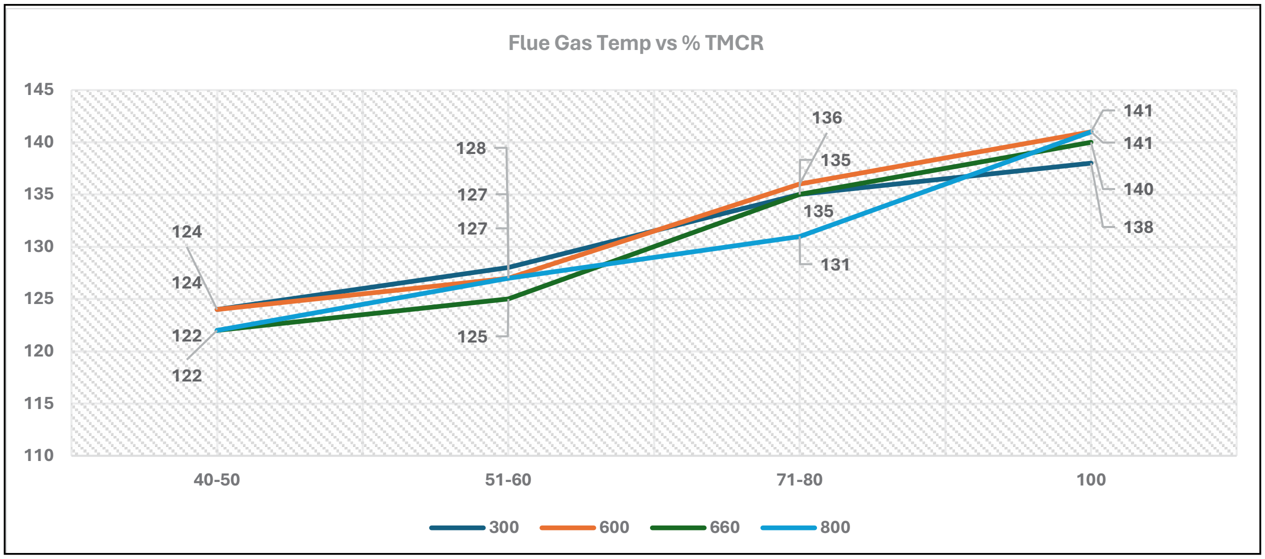
Findings:

- APC as a percentage of gross generation rises as the load decreases, with smaller units facing higher relative auxiliary demands.
- The rise in APC is more for higher capacity units as compared to the lower capacity units however, the actual APC is lower during partial load operations for higher capacity units

Possible Solutions:

- During partial load operation the equipment Shutdown such as Pulverizers, BFP, Fans, CT fans, ESP fields (if emissions are within limits) should be considered.
- Boiler Single pass isolation can be considered based on the reliability of the running equipment.
- Energy efficiency solutions- VFDs for variable flow, efficient motors, pumps & compressors
- Energy Audits- Can help identify energy saving opportunities and adoption of best practices
- Implementation of Energy Management System (EMS) in plant

3.6.3 Flue Gas Exit Temperature



Findings:

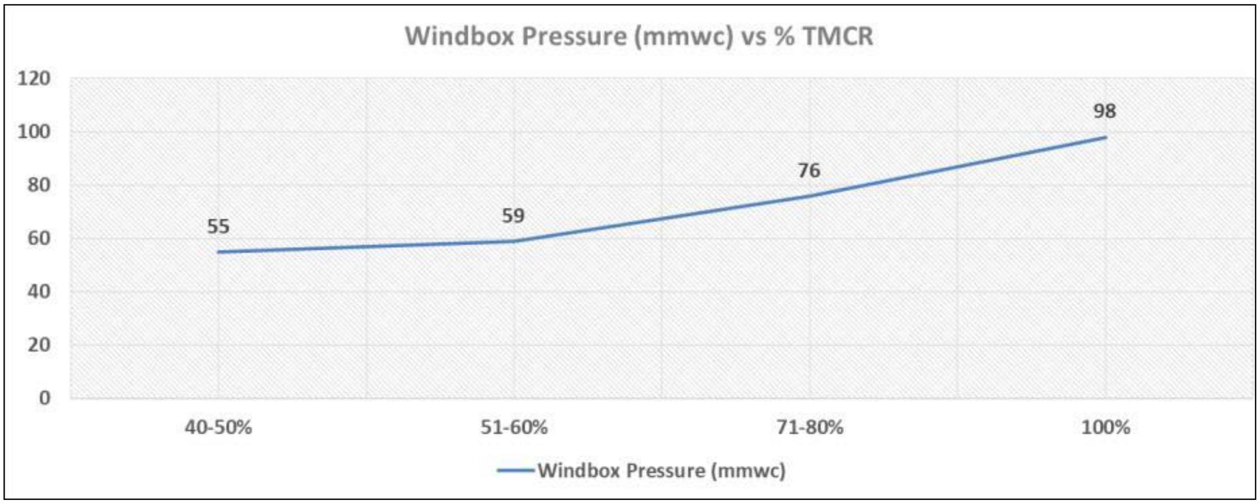
- The drop in flue gas exit temperature remains almost identical irrespective of the unit capacity. This is due to the reduced heat in the furnace during low load.
- It was also observed that, there is further drop in temperature in APH due to higher excess air compared to the fuel supplied to boiler.
- It is of prime importance to maintain the flue gas outlet temperatures above the acid due point as it can result in cold end corrosion. Although, Indian coal is having less sulfur the problem is critical for the plants which are operating with imported coal with high values of sulfur.

Possible Solutions:

- SCAPH is nothing but the Steam Coiled Air Pre Heater which located in the secondary air duct entering in the APH. SCAPH utilizes the auxiliary steam from PRDS to heat the secondary air resulting in reduced heat transfer in APH.
- SAPH is basically designed to be used during the startup to maintain the flue gas exit temperature well above the acid dew point, but during the low load operation, its application is found to be effective in maintaining the flue gas exit temperature.
- Reducing secondary air while ensuring flame stability can also help maintain the flue gas exit temperature as reduced secondary air will cause less heat transfer in APH.

3.6.4 Wind Box Pressure

Figure 17: Auxiliary Power Consumption - Deviation from 100% TMCR



Findings:

- Although not depicted for all the capacities, the drop in wind box pressure is found to be uniform across all the capacities.
- The major reason is due to the reduced load; the secondary air is reduced causing a reduction in wind box pressure.
- Additionally, the generally malfunctioning dampers at each firing corner also plays a vital role in dropping the wind box pressure.

Possible Solutions:

- Fine tuning of wind box dampers should be done to operate as per the logic. There are various types of dampers in a wind box like Fuel Air Damper & Auxiliary Air Damper. They all operate at various logics. The logic and operations should be fine-tuned to match the low-load operation of the unit.
- Flue air dampers and auxiliary air dampers to be closed for the pulverizes not in service.
- In most cases, the plant is not equipped with the actual position feedback of each individual damper, rather the feedback of the setpoint is shown in the control room. This deprives the operator from knowing the actual position of each damper in the field. Installing position feedback for each individual damper instead of common

3.7 Major Concerns During Flexible Operation

Almost all the thermal power plants are designed for base load operation, but they are often required to operate as balance service plants, that is, they frequently change the generation and operation to follow the demand changes. This causes many operational challenges which are as follows:

At 55% Load	At 40% Load
1. In transient load condition, drum level fluctuation due to opening of BFP recirculation valve.	1.Flame instability.
2. Higher APC due to marginal condition for BTG & BOP auxiliaries	2. Low wind box pressure hence chance of overheating in water wall.
3. Load increase will take longer time if one CW pump is taken out from service.	3. Less reliability with single FD fan, BFP, and CEP as any tripping may cause unit tripping.
4. Reduction of operating coal mill takes higher time at higher ramp and quantum.	4. Any tripping of coal mill @ 30% Load, possibility may increase of malfunctioning of control loop including drum Level.
5. Frequent load cycles increase fatigue loading of component and may causing boiler tube leakage in attachment weld failure.	TDBFP steam source from CRH: at low load it works good but at higher load with higher CRH pressure, control by TDBFP aux control valve is difficult.
6. Coal pipe choking & ash accumulation in ducts.	6. Proper tuning of control system required especially SH temp, Drum level.
7. Severe deposition on turbine blades.	7. Supercritical plants may operate very near to Benson point. The feedwater flow control is also very challenging in this zone.

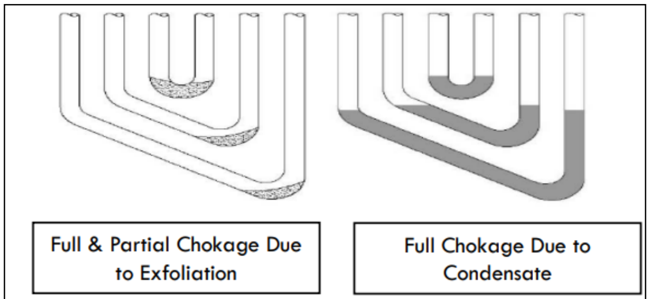
8. Damage to turbine valves.	8. The available domestic coal at some mines is having Low volatile matter (even less than 15%). It will be quite challenging to have a stable flame with low VM coal against design.
9. Excessive exhaust hood spray leading to LP blade erosion.	9. There may be a chance of a high exhaust temperature in the HP Turbine because of the low steam flow through it.
	10. Final main steam and reheater temperatures significantly reduced at 40% load condition. There was a more than 15 degree C differential temperature between MS and HRH.
	11.CRH supply steam to TDBFP through aux PRDS. Line during 40% load. This leads to limit value of NPSH of TDBFP, so deaerator need to be charged from aux PRDS. This may cause less RH flow through reheater coil.

3.8 Practical Solutions for Flexible Operation

The thermal fleet's variable operation presents several operational issues. For thermal power plants (TPPs) to operate at peak efficiency and preserve the equipment's health, proper operations and maintenance (O&M) practices are essential which are described as below.

3.8.1 Boiler-Fatigue Failure Control

Fatigue failure was experienced in the super heater tubes. Fatigue failure is the formation and propagation of cracks due to a repetitive or cyclic load. Most fatigue failures are caused by cyclic loads significantly below the loads that would result in yielding of the material. The failure occurs due to the cyclic nature of the load which causes microscopic material imperfections (flaws) to grow into a macroscopic crack (initiation phase). The crack can then propagate to a critical size that results in structural or pressure boundary failure of the component.



Source: EPRI

The damage mechanism identified is large variation in steam temperatures. The metal temperature of super heater bound to rise during the ramp up & ramp down. Super heater steam temperature variation was observed with 25 to 40 deg. C. To control the metal temperature within limit, SH spray is being done. Pendant tubes are arranged vertically. It was observed that the bottom loops of the pendant assembly having condensate blockage during high spray to control metal temperature.

Mitigation measures

During unit operation

- Control loop tuning.
- Optimum scheduling: Engagement with grid agency to optimize load variations.

During unit shutdown

- Identifying incipient defects by cyclic hydro test.
- Dry air preservation to prevent tube pitting.

During unit overhaul

- Attachment modifications as per EPRI guidelines.
- Both side fin welding (earlier if only one side).
- Checking of attachments by DPT.
- Checking of innermost bend for cracks.
- Adoption of RFET, AET, Exfoliation, Ther Flow, Thermovision test.

Implementation of Fatigue monitoring system (FMS)

Fatigue Monitoring System (FMS) is designed to provide managers with constant information for right operational decisions. Through pre-configured, key performance indicators (KPIs), FMS monitors highly stressed components from a boiler, displaying their fatigue and lifetime status which is fundamental for understanding component's reaction to different plant loads, reducing time for component replacements and avoiding sudden fatigue and outage days.

- Collection of temperature and pressure data is automated for fatigue calculation.
- Creep and low-cycle fatigue in the boiler components is calculated.
- Calculation is done component specific according to standards DIN EN 12952.
- FMS calculates online & stores the results long term.

3.8.2 Boiler Drum Level Control

Ensuring constant level in drum during the flexible operation is very difficult. There can be issues in TDBFP pumps during load changes, when change in steam source is required (from extraction steam to CRH or Auxiliary steam). Recirculation valves of BFP can pose problems like passing. Many of the stations have a recirculation valve which is full open/close type, and they pose problems during rapid load changes when the recirculation valves open with a jerk and at times causes disturbance in feed water flow and thus change in drum level. When R/C valves or feed regulating stations malfunction, as when thrust bearings fail, serious problems might occur. Under low load, there might be issues with overheating and leak-off.

The TDBFP's reliability is compromised when there is a large temperature differential between the sources, since it regularly has issues when switching its steam source (from extraction steam to CRH or Auxiliary steam).

During the flexible operation, the drum level variation was observed. The biggest deviations occurred when switching off a boiler feed pump. These deviations, however, did not appear to cause any problems.

Mitigation measures

For proper drum level control, ensuring smooth operation of BFP at low load is required. The boiler feed pumps have recirculation valves which are full open/ closed. At lower feed flow they are required to operate at intermediate positions. Modifications of BFP recirculation valve from on/off type to regulating type along with changes in operating logic is required.

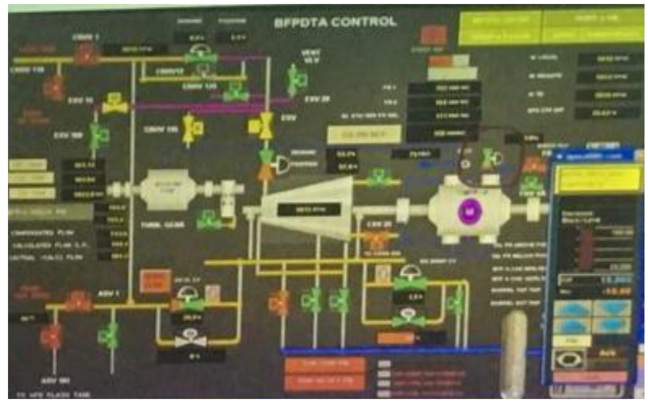


Figure 20: DCS Screen Shot of TDBFP

One TDBFP can supply the required amount of feed water at 40% load. It is necessary to make sure the driving steam source is changed. Make that the MDBFP is prepared for hot standby.

The manual operation of the drum level control was necessary for switching off the TDBFP only.

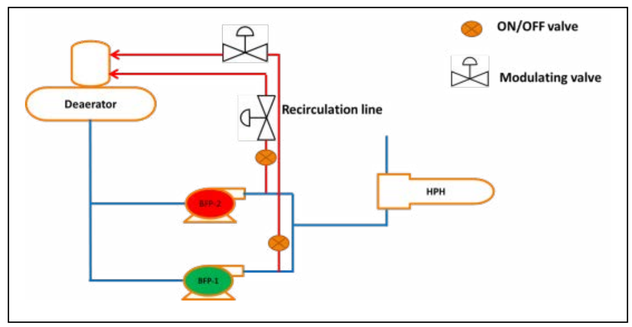


Figure 21: Line Diagram of Recirculation Valve

BFPs can be automatically brought into and taken out of operation based on the required load. Every BFP will feature an automated starting and shutdown procedure. An automated master group controller will create commands to start and stop the BFPs. The projected future load, which is primarily dictated by the intended load set-point, will also be used to bring the BFPs into and out of service in addition to the actual load.

3.8.3 Auto Mill Scheduling

Setting the steam generator and turbine's set points to fulfil operator or load dispatcher-specified criteria is the primary function of the unit control. Steam pressure and unit load are the two primary factors that need to be managed by the fast-acting turbine and the slow-acting boiler. During load ramps, the unit control also has to automatically turn on fans, boiler feed pumps, and mills to provide seamless and continuous load shifts.

To achieve completely automated load operation, burners or coal mills must be turned on and off automatically based on the load and the real number of burners and mills operating. A backup plan decides automatically which part to start or stop if a burner or mill

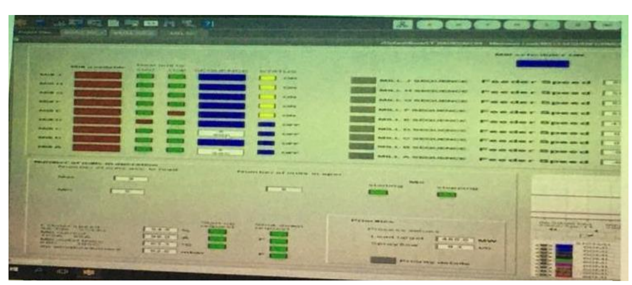


Figure 22: DCS Screen Shot

that is meant to be turned on or off malfunctions. Lastly, additional criteria can be assessed to identify the suitable component if more than one mill or burner can be started or stopped.

Mitigation Measures in a 500 MW unit

A coal mill scheduler operates autonomously, responding to the number of firing devices actually in use as well as the firing demand, and is subservient to the unit control. Additionally, if a mill fails while in use or does not start up, the system features an automated replacement plan.

A few parameters, including bunker filling and furnace fire distribution, are specified and ranked for every burner and mill. A priority for turning on and off each mill or burner is continually determined based on these factors.

Mill will auto start if

- Feeder loading more than 80%
- Average mills motor current >105 A
- Mill outlet temperature of all running mill <60 deg. C

Mill will auto shutdown if (500 MW)

- Feeder loading less than 60%
- Average mills motor current <65 A
- Any mill outlet temperature >105 deg. C

3.8.4 Condensate Throttling for Improved Ramp Rates

It has proven difficult in many coal-fired units to fulfil the primary frequency response or quickly changing supply/demand gaps, frequently as a result of plant design. Since frequency control is not offered by renewable energy generators, fossil fuel-fired units will continue to be required for both primary and secondary response in the future. Even though main frequency response (5% of load) is required for many stations in India, it might be challenging to comply with the requirement.

The fast-acting steam turbine control valve and the slow-acting power plant boiler are required to regulate the two primary control variables: electrical generator power and main steam pressure. Due to the steam generator's sluggish action, steam production can only follow the rapid adaptation of electrical output and, in turn, of steam flow, which is necessary during rapid load changes. As a result, there is an imbalance in the amount of steam produced by the boiler and extracted by the turbine. As a result, the steam pressure decreases. For this reason, a brief increase in fuel must be used to stabilize the steam pressure.

Mitigation measures

The main steam valves' opening and throttling, condensate throttling, feed water heater bypass, and HP stage bypass are among the techniques used for primary frequency control. Additionally, adding a thermal storage system can expand the range of loads.

Condensate throttling is a tried-and-true method of primary frequency control that allows for a rapid increase in turbine output in the event that grid frequency drops sharply. Condensate flow is decreased when more power is required, generally by throttling the condensate control valve.

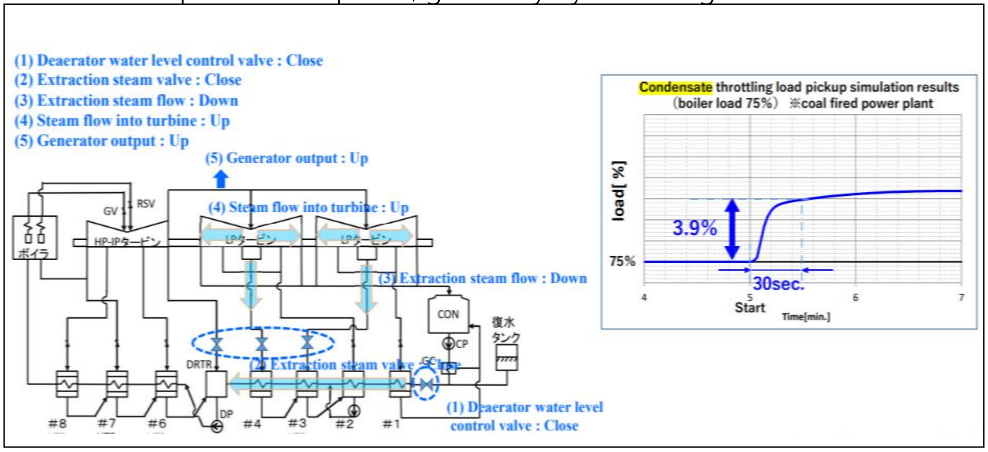


Figure 23: Details of Condensate Throttling

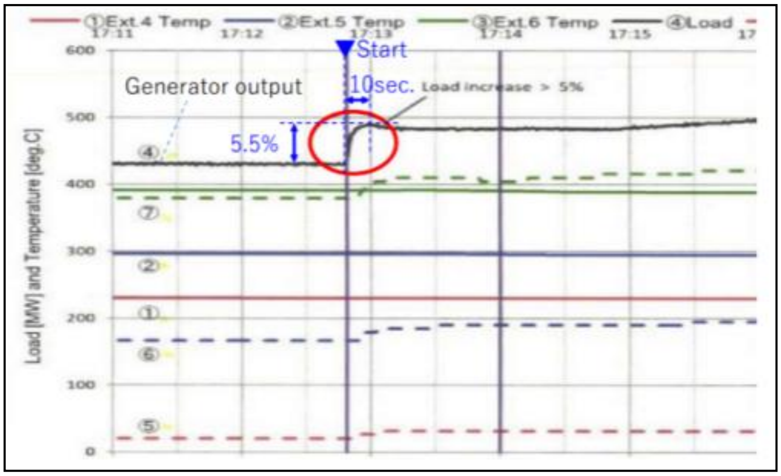


Figure 24: 5.5% load pickup in about 10 sec at 40% load

In comparison to the flow from turbine to condenser, the throttled condensate lowers the condensate flow via LP heaters. The feed water tank and LP heaters' extraction flow is decreased after a certain response time. In order to react to the frequency shift, more power is produced by the turbine's leftover excess steam.

The deaerator level will decrease and the hotwell level will rise simultaneously. Before the hotwell or deaerator's limitations are exceeded, the condensate throttling must be halted (reverted to normal). Either the deaerator level will drop or the hotwell level will rise with time.

Condensate throttling at one of the NTPC Plants has allowed for a reaction time of 20 seconds for a 7% power increase at 100% load.

Condensate throttling is used to generate extra power quickly—within a minute. Typically, frequency regulation is accomplished with this extra power.

3.8.5 Low Boiler Flue Gas Exit Temperature

When the units are required to operate below 50% load, there it may be required to switch off one set of fans. In this case, the flue gas exit temperature may drop below acid dew point temperature and thus low PA & FD air temperature. In one the supercritical plant, it was observed to be 104 deg. C at 40% load, it may go below 100 deg. C if the low load operation would have continued.

Low flue gas temperature cause corrosion problem to cold end baskets. First of all, the air preheater on the structure is easy to accumulate and block up. The heat transfer elements are often very thin metal plates, and the gap between the plates is very small. At the same time, in terms of sediment, due to the relatively low temperature at the cold end of the air preheater, sulfuric acid and ammonium bisulphate vapours are prone to condense here, resulting in fouling and clogging.

Coal's sulphur content controls how much corrosion is predicted to occur in the boiler's high- and low-temperature areas. The sulphur level of the coal determines how much SO_2 will be generated. A tiny portion of the sulphur in coal (between 2 and 3 percent) changes to SO_2, and the quantity of SO_2 generated and held in the flue gas controls both the flue gas's dew point and the precipitator's accumulation efficiency. Moreover, APH, duct, and ESP corrosion are impacted by SO_2 emissions and sulphur concentration. Even after washing, organic sulphur is difficult to extract because it is coupled with other molecules. However, the mineral sulphur component, or pyritic sulphur, may be substantially removed by coal washing.

Figure 25: DCS Screen Shot

Mitigation measures

The steam coiled air preheater (SCAPH) should be taken into operation automatically. In case flue gas temperature at APH outlet is maintaining less than acid dew point (say 110 deg. C).

Although SCAPH is included in the standard design of most of the newer stations, in many cases it is not used. For plants which do not have a SCAPH it is worthwhile to install it if it will be operated on cycling mode.

Air preheater baskets will need to be corrosion-resistant (enamelled or Corten) for future cycling, and the replacement of the cold end baskets will be more frequent than for baseload operation and will increase the cost of the system, as well as reduce the efficiency due to metal loss and corrosion fouling.

Maintain adequate steam parameters for APH soot blowers and operate periodically, more frequently during oil firing.

3.8.6 Startup / Shutdown of ID / FD / PA Fans Through Auto Sequence

In all the coal utility plants, major energy consuming auxiliaries like FD fan, PA fan, ID fan, BFP & CEP are provided with each 2 nos. (Say 2 x 60%). One set of fans may need to be turned off when the units must run at less than 50% load. For energy consumption point of view and to avoid its extreme low load operation, it is required. However, reliability is the issue at this zone if the operating equipment fails to run.

One of the most frequent issues with PA (Primary air) fans is their stalling at low load. This is typical in a setup where each mill has two PA fans, and the PA header carries the PA flow to the mills. The flow reduces under low load, but the PA header pressure must remain constant at a certain level. There has been a rise in the frequency of valve failures under increasing cyclic operations.

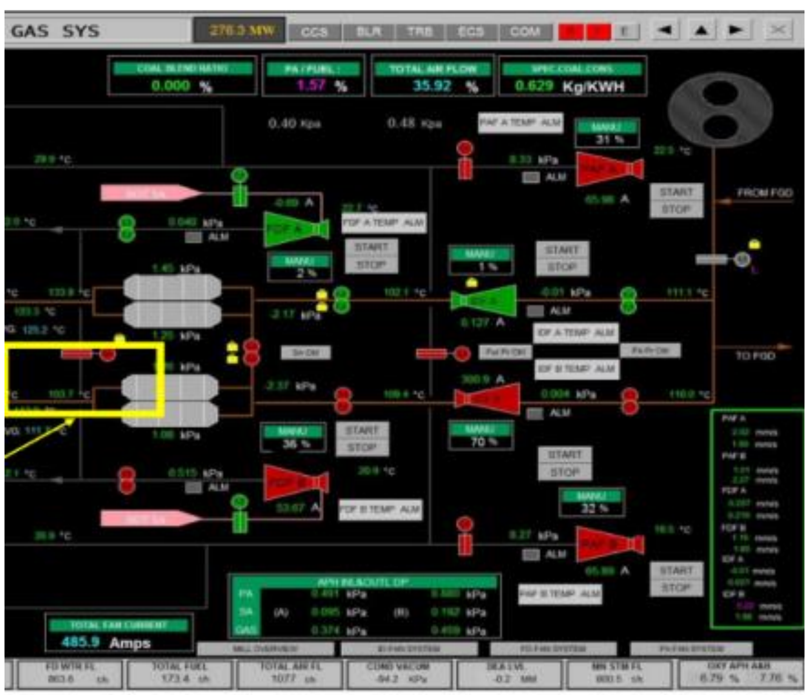


Figure 26: DCS Screen Shot

Mitigation measures

Fans can be taken in and out of service automatically depending on the required load. An automatic master group controller can create start and stop orders to the fans (ID, FD, PA). The fans will be taken in and out of service not only by actual load, but also by predicted future load, mainly based on the target load set-point.

ID/FD fan individual auto start/stop sequence for loading/unloading in load <300 MW (In a 490 MW plant). Both PA fan auto start/stop sequence for loading/unloading in load <300 MW (In a 490 MW plant).

To avoid stalling issue, run as per the PA fan flow-pressure curve supplied by the OEM. Before starting PA fans ensure that air and gas dampers of PAPH are open.

3.8.7 Plasma Ignitor Technology for Flexible Operation in Coal-Fired Power Plants

Flexible operation of coal-fired power plants is now a critical requirement due to increasing renewable penetration, stringent emission norms, and the need for fast start-ups and low-load running. Existing lignite and hard-coal fired units typically rely on auxiliary fuels such as heavy fuel oil or natural gas for ignition and flame stabilization during start-ups and low-load conditions. These fuels contribute to significant operational costs and CO_2 emissions.

To reduce dependency on support fuels and improve start-up reliability, Microwave-Induced Plasma Ignitors from GE (Plasma Combustion Stabilization System) were tested and integrated into plant operation.

Technology description

Two principal plasma ignition technologies exist:

1. Microwave Plasma (up to 6 kWe input)

- Plasma generated via microwave excitation.
- 90% electrical efficiency.
- Simple infrastructure: compressed air & low-voltage supply.
- Negligible electrode wear.

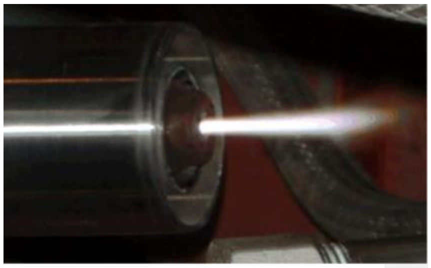


Figure 27: Microwave Plasma

2. DC Plasma (up to 300 kWe input)

- High-temperature plasma generated via high-voltage supply.
- 40–60% electrical efficiency.
- Requires more demanding infrastructure (HV supply, cooling water, compressed air).
- Limited electrode life (100–600 hours).

Figure 28: DC Plasma

Principle of Operation

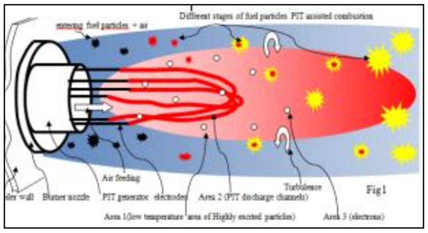


Figure 29: Plasma Ignitor

- The ignitor generates a high-energy plasma jet (ionized air) which is highly conductive.
- This plasma initiates rapid volatile release from coal particles.
- The released volatiles ignite and sustain further devolatilization.
- Full flame is quickly established at the burner mouth, eliminating the need for oil or gas ignition support.

Field Demonstration

- Plasma ignitors were installed and operated for over two years, accumulating >1000 hours of successful service.
- Demonstrated electrode life >2000 hours, exceeding design expectations.
- Provided stable flame at 25% feeder speed without support fuel, with potential for further turndown.
- No negative impact on boiler load response or unit performance observed.
- Overall performance of the plasma system has been excellent The plasma igniters are working reliably in day-to-day operation as a direct replacement for oil igniters. The plant operators see no noticeable difference between using the original oil igniters or the new Plasma system.

4 LATEST TECHNOLOGIES

Introduction

The Latest Technologies chapter explores cutting-edge solutions that have gained widespread acceptance in hard-to-abate industrial sectors such as cement manufacturing, pulp and paper production, and iron and steel processing. These industries have long grappled with energy-intensive operations and stringent environmental regulations, prompting adoption of advanced technologies to optimize energy consumption, reduce emissions, and improve overall sustainability. However, many of these mature technologies remain underutilized or absent within India's thermal power sector despite their proven advantages.

This chapter highlights such promising technologies—with demonstrated success in analogous heavy industries—that provide opportunities for cross-sector learning and technology transfer. Examples include advanced digital monitoring, heat recovery systems, smart automation, efficient motor drives, and innovative material applications. By assimilating these technologies into thermal power plants, significant reductions in auxiliary power consumption (APC) can be achieved, alongside improvements in operational reliability and environmental performance.

The objective of this chapter is to create awareness about these emerging yet well-established industrial technologies as potential enablers for the modernization and decarbonization of India's thermal power fleet. Emphasizing their replicability and potential impact on efficiency and cost savings, it encourages power sector stakeholders to proactively explore and pilot these innovations. Stimulating such cross-pollination of sustainable technologies from related industries will empower India's thermal power plants to enhance competitiveness while supporting the nation's ambitious energy transition and climate commitments. Through this knowledge sharing, the chapter envisions accelerating the deployment of next-generation clean technologies, driving a sustainable, resilient, and flexible power sector for the future.

4.1 Technology 1: Economic Load Dispatch

Most Indian coal power plants have 2–9 generating units per station, often of identical make and capacity, yet their real performance varies due to differences in coal quality, weather, and operational factors. Despite this, operators typically load units equally without real-time performance data, resulting in the inefficient units often handling as much load as the best ones. This practice can lead to higher coal consumption and operating costs, especially when a mix of unit sizes and conditions is involved.

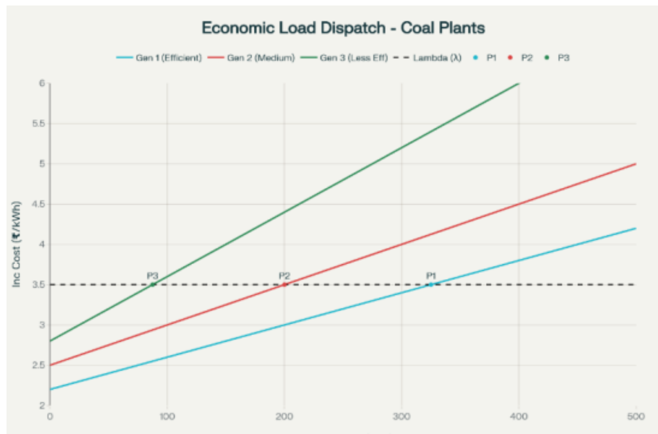
Need for digital solutions:

Given these realities, there is a clear operational and economic imperative for power plants to move away from uniform loading strategies and toward dynamic, performance-based dispatch. The deployment of digital twin technology using real-time monitoring, advanced analytics, and predictive modelling provides operators with actionable insights about the current performance of each unit. Such systems can optimize unit-level scheduling and load allocation in real time, ensuring that the most efficient units take on a higher share of generation as per their prevailing performance, and that the station meets demand using the least fuel and financial outlay.

By embedding digital twin solutions, Indian coal power plants can make significant strides in operational optimization, reducing unnecessary fuel usage, minimizing emissions, and enhancing overall profitability and sustainability.

Details of Economic Load Dispatch System

The primary objective of economic load dispatch is to determine the optimal power output of each generating unit in a power system such that the total fuel cost is minimized while meeting the system load demand and satisfying all operational constraints. This optimization problem can be mathematically formulated using a digital twin technology.



TThe chart shows explains an example of the plant where λ represents the marginal cost- the cost of producing one additional unit of electricity. Generator-1 (most efficient) produces 325 MW because its incremental cost reaches INR 3.50/kWh at this output. Generator-2 (medium efficiency) produces 200 MW while Generator-3 (least efficient) produces only 87 MW. When all generators operate at the same incremental cost, the system achieves minimum total fuel cost. The most efficient units produce more power, while less efficient units produce less, ensuring optimal economic dispatch across the station.

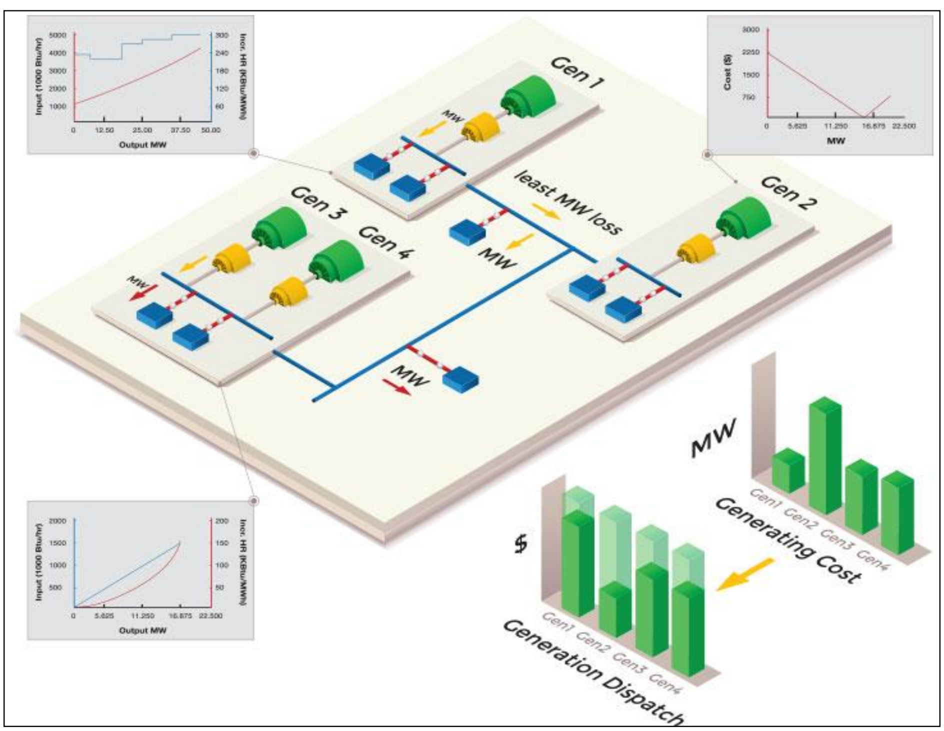


Figure 30: Overview of the Economic Load Dispatch

Advantages of the Solution:

The software can be further used to create a digital twin to simulate the unit's actual operating performance in comparison to its OEM's design performance, analyse the impacts of varying operating conditions on plant thermal performance and evaluate the impact of various critical parameters. Below table shows the outcome of one such implementation in one of the sub-critical coal power plants in China .

Table 11: Research article: case study of digital-twin-modelling analysis on power-plant-performance optimizations

Parameter	Unit	Design	Operation	Deviation
Plant gross output	MW_e	320.04	320.46	0.13%
Plant electric efficiency (gross)	%LHV	41.83	40.17	-1.66%pts
Plant electric efficiency (net)	%LHV	39.27	37.81	-1.46%pts
HP steam flow	tph	976.9	1011.6	+3.55%
HP steam temperature	°C	538	538.7	+0.1%
IP steam temperature	°C	538	537.3	-0.1%
Boiler feed-water temperature	°C	280	276.5	-1.25%
HP steam pressure	MPa	16.7	16.45	-0.25 MPa
IP steam pressure	MPa	3.46	3.55	+2.6%
Condenser pressure	MPa	0.049	0.092	+0.05 MPa
Air-heater exit-gas temperature	°C	134	147	+13 °C
Ambient temperature	°C	15	38	+23 °C
Cooling-water temperature	°C	15	30	+15 °C

- The software highlights the parameters that are deviating from the design conditions and can help the operator to take necessary decisions to bring them in acceptable range to achieve designed efficiency.
- The software supports various optimization objectives including economic dispatch for cost minimization, emission dispatch for environmental compliance, and multi-objective optimization that balances economic and environmental considerations.
- Economic Load Dispatch remains a cornerstone of modern power system operations, providing the mathematical and computational foundation for cost-effective electricity generation while maintaining system reliability and security. The evolution from simple lambda iteration methods to sophisticated optimization algorithms integrated with advanced software platforms demonstrates the continuous advancement in this critical field. As power systems continue to evolve with increasing renewable integration, market deregulation, and smart grid technologies, the principles and methods of economic dispatch continue to adapt and expand, ensuring their continued relevance in achieving efficient and sustainable

power system operation. Understanding these concepts and their practical implementation through modern software tools is essential for power system engineers, operators, and planners working to optimize the complex, interconnected electricity networks that power our modern world.

4.2 Technology 2: ECO STP

Background:

Several thermal power plants are linked to adjacent residential colonies, supplying water and supporting sewage treatment through dedicated facilities. Traditional sewage treatment plants process wastewater to produce clean water that can be reused for various purposes. However, the process is energy-intensive and relies on chemical usage. It also requires significant infrastructure investment, including equipment such as blowers, motors, aerators, diffusers, fans, and pumps. Additionally, there are safety risks involved, and the system demands high operating costs, maintenance, including regular tank cleaning and weekly sludge removal.

About ECO STP:

ECO STPs (Ecological Sewage Treatment Plants) offer a sustainable alternative to conventional sewage treatment plants (STPs) by leveraging natural processes for wastewater treatment. Here's a detailed process of ECO STP.

Stage 1 – Rumen Digester Filter (RDF)

Primary Sedimentation Chamber, Mesophilic anaerobic reactor to breakdown water pollution

Stage 2 – Rumen Digester Filter (RDF)

Up flow baffled reactor chambers, stage 1 wastewater is forced to pass through active bacteria chambers

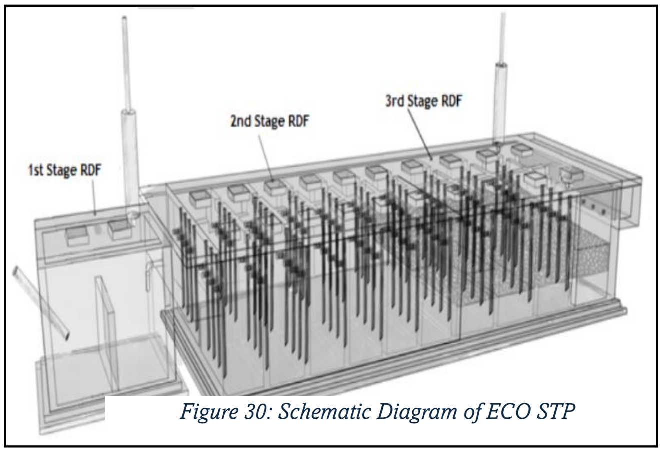


Figure 30: Schematic Diagram of ECO STP

Stage 3 – Rumen Digestor Filter (RDF)

Attached Growth biological filters with a high surface area, stage 2 wastewater is forced to pass through filter mass with bacteria lawn/ film

Benefits:

- Zero Power Consumption: The system operates entirely without electricity, making it ideal for off-grid and energy-conscious installations.
- No Use of Chemicals: It uses only natural biological processes, avoiding any harmful chemical inputs for safe and eco-friendly treatment.
- Risk-Free Operation: A fully sealed tank ensures there is no manual handling, cleaning, or need for operators, making it safe and hassle-free.
- Minimal Sludge Removal: Sludge is generated in very small quantities and needs to be removed only once in two years, reducing maintenance efforts.
- No Mechanical Components: With no motors, pumps, or exhaust fans, the system functions silently and without the risk of mechanical failure.
- Maintenance-Free Design: Built for simplicity and durability, the system requires virtually no maintenance throughout its operation.

Figure 32 Eco-STP under cafeteria & Parking

Cost Benefits (considering 200 KLD Plant):

Table : Saving Details of ECO STP

	Conventional STP	ECO STP
ECO STP CAPEX	INR 80 Lakhs	INR 100 Lakhs
ECO STP OPEX (For 2 years)	INR 25 Lakhs	INR 3 Lakhs
Annual Savings	-	INR 17 Lakhs
Total Space Required	5,000 sq. ft	8,200 sq. ft
Pay-back Period	-	2 years

4.3 Technology 3: High Efficiency Turbo Blower

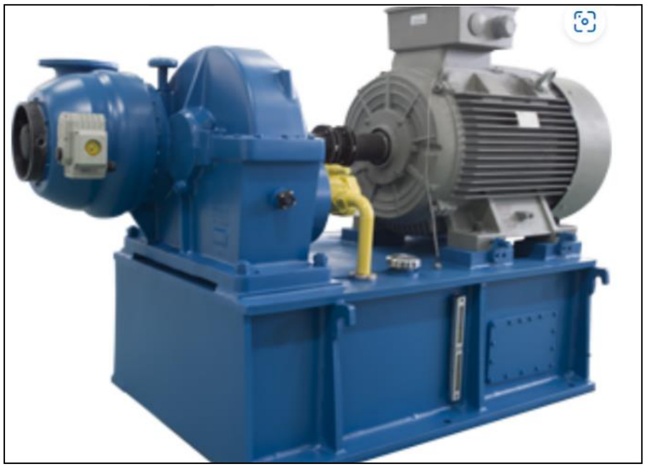
Background:

In power plants, effluent treatment plants (ETPs) have traditionally relied on twin lobe roots blowers as the primary air supply equipment. These positive displacement machines provide a constant volume of low-pressure, oil-free air (0.1–1 bar) required for aeration and equalization tanks, where oxygen supports microbial activity to break down organic pollutants from cooling tower blowdown, boiler blowdown, and ash handling wastewater. Their rugged construction, reliability, and ability to operate continuously made them the default choice for decades in ETP applications. However, in power plants where energy consumption and operating costs are critical, the limitations of twin lobe blowers—such as lower efficiency, pulsating airflow, and higher noise levels—make them less suitable compared to advanced technologies.

About Highly Efficient Turbo Blower:

A High Efficiency Turbo Blower is a high-speed, oil-free, energy-efficient blower widely used in power plant ETPs. It works on the dynamic principle, where a high-speed impeller (driven by a permanent magnet motor) accelerates air, and the diffuser converts this velocity into pressure to deliver continuous, pulsation-free airflow. With VFD-based control, it adjusts flow and pressure as per process demand. Compared to twin lobe blowers, high efficiency turbo blowers provide 30–40% energy savings, lower noise, minimal maintenance, and compact design, making them ideal for reliable and cost-effective aeration in wastewater treatment.

Figure 36: High Efficiency Turbo Blower



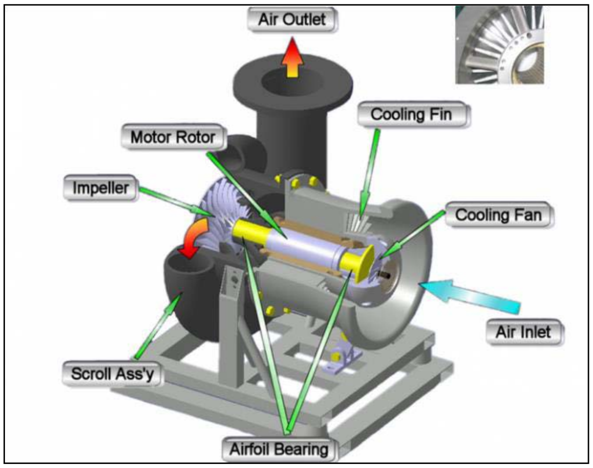


Table : Comparison between Twin Lobe & Turbo Blowers

Parameters	Twin Lobe Roots Blower	Turbo Blowers
Efficiency	Lower (20-40% more power usage)	High (Energy Efficient)
O & M Costs	High (Requires oil changes, frequent checks)	Low (air bearing, oil-free)
Noise & Vibration	High (>95 dB) – needs acoustic enclosure	Very low (<80 dB)
Air Flow Control	Fixed speed or limited VFD compatibility	8,200 sq. ft
	VFD/Inbuilt controls – variable speed	2 years
Turndown Ratio	10-15% only (inefficient at low flow)	40-65% of design flow (good flexibility)
Discharge Pressure	0.4 – 0.6 bar (drops at higher flows)	0.5 – 1.2 bar (customizable, stable)
Footprint & Design	Bulkier, with external accessories	Compact, integrated system
Service Life	Medium (frequent rebuilds every 3–5 years)	Long (10–15 years with minimal wear)
Initial Investment	Lower (INR 5–7 lakh for same capacity)	Higher (INR 10–15 lakh for 2200 m^3/hr)
Recommended For	Small or budget-constrained setups	Medium to large ETP / STP plants
CO2 Emissions	80 tons/year	48 tons/year

Cost Benefits (considering 800 KLD System):

Table : Saving Details with high efficiency Turbo Blower

	Twin Lobe Roots Blower	High Efficiency Turbo Blower
Annual Energy Consumption	3,17,196 kWh/year	1,93,842 kWh/year
Annual Cost	INR 23 Lakhs	INR 14 Lakhs
Annual Savings	-	INR 9 Lakhs
Investment	-	INR 15 Lakhs
Pay-back Period	-	1.7 years
Applicability	Very High for fresh installation projects.	40-65% of design flow (good flexibility)

	0.4 – 0.6 bar (drops at higher flows)	0.5 – 1.2 bar (customizable, stable)
Footprint & Design	Bulkier, with external accessories	Compact, integrated system
Service Life	Medium (frequent rebuilds every 3–5 years)	Long (10–15 years with minimal wear)
Initial Investment	Lower (INR 5–7 lakh for same capacity)	Higher (INR 10–15 lakh for 2200 m^3/hr)
Recommended For	Small or budget-constrained setups	Medium to large ETP / STP plants
CO2 Emissions	80 tons/year	48 tons/year

4.4 Technology 4: Compressor Waste Heat Recovery

Background:

Compressed air is a vital utility in industrial and power plants, supporting functions such as conveying, instrumentation, pneumatic actuation, cooling, and various auxiliary systems. Despite its wide use, air compression is highly energy-intensive—only about 10–15% of input energy is converted into useful compressed air, while 85–90% is lost as heat, leakage and artificial demand. This waste heat presents a significant opportunity for energy recovery through systems like heat exchangers, which can repurpose it for space heating, boiler feedwater preheating, or other thermal processes. Recovering this energy improves overall plant efficiency, reduces operational costs, and supports sustainability goals.

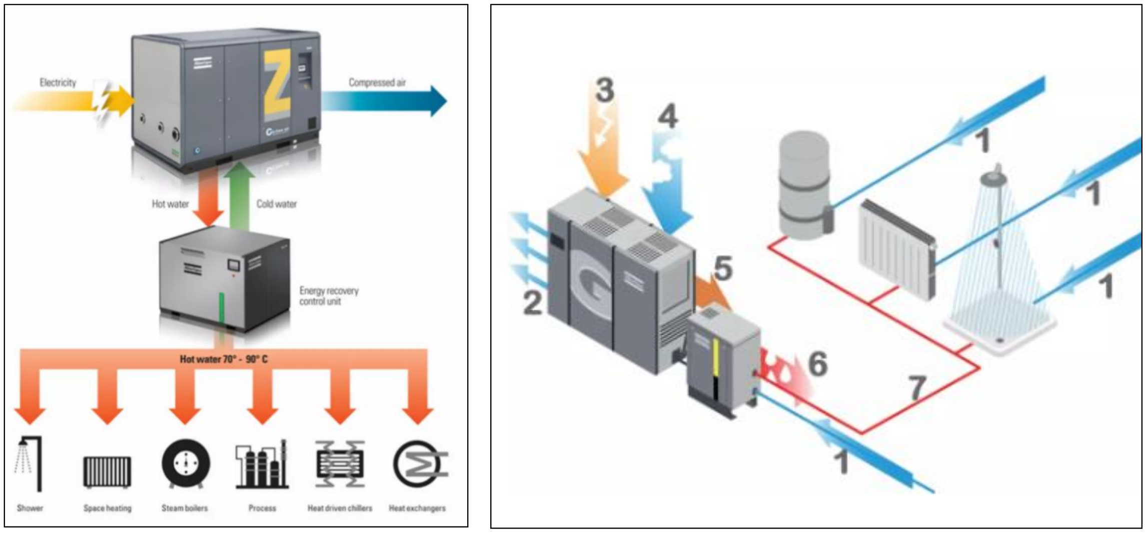
About Compressor Waste Heat Recovery:

Compressor waste heat recovery is a process that recovers waste heat generated during the operation of an air compressor. The waste heat recovery equipment introduces high-temperature circulating oil and high-temperature compressed air into the heat water unit, which absorbs the heat generated during the operation of the air compressor. About 70-94% of the energy supplied to the air compressor can be recovered, which leads to a huge lowering in carbon footprint and reducing energy consumption.

Levels of Waste Heat Recovery from Compressors

1. Cooling Water Jacket Heat (Low Temp ~70–90 °C)
    - o Captured from water-cooled compressor jackets.
    - o Used for boiler feed water preheating, space heating, process hot water.
2. Intercooler / Aftercooler Heat (Medium Temp ~90–120 °C)
    - o Heat from cooling compressed air between stages.
    - o Recovered via heat exchangers for hot water generation or process heating.
3. Lubricating Oil Heat (Medium Temp ~80–100 °C)
    - o Waste heat removed by oil cooling system.
    - o It can be used for water heating.

Figure 37: Waste Heat Recovery System



Benefits:

- Saves fuel & electricity by reducing additional energy needs.
- Improves efficiency by utilizing heat that would otherwise be wasted.
- Provides hot water, steam, or power for process or utility use.
- Reduces cooling load on chillers and cooling towers.
- Cuts CO_2 emissions through lower fuel consumption.
- Ensure fast payback and boosts profitability.

Challenges and Constraints in Implementation:

- High initial investment cost – WHR systems like waste heat boilers, heat exchangers, and piping require significant upfront capital, which may discourage industries.
- Low-grade or difficult-to-capture heat – Many processes release heat at low temperatures, making it less useful and harder to recover economically.
- Limited space for equipment – Industries often face space constraints that make installation of WHR units challenging.

Cost Benefits:

Table : Cost Benefits of Waste Heat Recovery

	Twin Lobe Roots Blower	High Efficiency Turbo Blower
Annual Energy Consumption	3,17,196 kWh/year	1,93,842 kWh/year
Annual Cost	INR 23 Lakhs	INR 14 Lakhs
Annual Savings	-	INR 9 Lakhs
Investment	-	INR 15 Lakhs
Pay-back Period	-	1.7 years

4.5 Technology 5: Mist Cooling Towers (HVAC & Compressors)

Background:

In thermal power plants, cooling towers are not only used for the main condenser system but also play a vital role in supporting HVAC systems and large air compressors. In HVAC, cooling towers reject heat from chiller condenser water, ensuring proper air conditioning and ventilation of control rooms, switchgear halls, and other critical areas. For compressors, they cool jacket water, intercoolers, and aftercoolers, preventing overheating and maintaining efficient, reliable operation. These cooling towers typically use the evaporative cooling principle, where part of the circulating water evaporates, removing heat from the system and lowering the return water temperature. Generally designed as induced draft mechanical towers. For evaporation, the cooling tower uses a series of fans and fills for splitting the water droplets. The fans consume power while the issues such as clogging and chocking of fills can reduce the effectiveness of cooling tower.

About Mist Cooling Tower:

A mist cooling tower (also called a spray or fog cooling tower) is a compact cooling system that uses fine water droplets (mist) sprayed into the air to achieve heat rejection. Unlike conventional cooling towers that rely on large surface films or splash fills, mist cooling relies on atomized micro-droplets produced by high-pressure nozzles. These droplets greatly increase the surface area for heat and mass transfer, enabling rapid evaporation and effective cooling of circulating water.

The system works by forcing water through high-pressure pumps and fine mist nozzles (with orifices as small as 5 micrometres), creating a micro-fine water vapor. When these tiny droplets are introduced into hot air, they flash evaporate almost instantly, absorbing heat and lowering the air and water temperature. This process can reduce temperatures by up to 25°C within seconds, making mist cooling towers especially useful where space is limited and fast cooling is required.

Table : Comparison between Conventional Cooling Tower and Mist Cooling Tower

Aspect	Conventional Cooling Tower	Mist Cooling Tower
Cooling principle	Uses evaporative cooling with large surface area from fills (splash or film type)	Uses fine water droplets (mist) sprayed directly by nozzles
Design	Large structure, requires fills, drift eliminators, fans	Compact design, no fills required, only mist nozzles

Heat transfer area	Provided by packing/fills inside tower	Provided by surface area of atomized droplets
Cooling efficiency	High, suitable for large-scale continuous duty (power plants, industries)	Moderate, best for small to medium loads
Space requirement	Large footprint and tall structure	Small footprint, compact installation
Maintenance	Fills prone to scaling, fouling, and clogging	Less fouling (no fills), but nozzles may clog
Applications	Power plants, petrochemicals, large industries	HVAC cooling, compressors, small industries, space-limited sites
Cost	Higher initial and maintenance cost	Lower cost, easier to install
Noise level	Moderate to high (due to fans and waterfall)	Low noise (fine spray system)

Benefits:

- No fills required - mist nozzles directly spray water.
- Compact design - smaller size compared to traditional cooling towers.
- Faster heat rejection due to large surface area of fine droplets.
- Lower drift loss is fitted with drift eliminators.
- Used for smaller to medium heat loads (industries, HVAC, compressors).

Challenges and Constraints in Implementation:

- Limited capacity - not suitable for large heat loads.
- Nozzle clogging - needs clean, treated water.
- Wind & humidity sensitive - efficiency drops in humid or windy conditions.
- Higher maintenance - frequent nozzle/pump checks.
- Limited scope - best for small to medium cooling loads.

Cost Benefits:

Table : Cost Benefits of Mist Cooling Towers

	Conventional Cooling Tower	Mist Cooling Tower
CAPEX	INR 20 - 25 Lakhs	INR 25 - 30 Lakhs
OPEX (annually)	INR 6 Lakhs	INR 1.92 Lakhs
Annual Savings	-	INR 4 Lakhs
Space Required	Large (civil & structural)	30 – 60% smaller
Pay-back Period	-	2 years
Applicability	Very High for utilities like HVAC, Compressor, AHP, CHP	

4.6 Technology 6: Carbon Capture, Utilisation and Storage (CCUS)

Background:

Power plants are one of the largest sources of carbon dioxide (CO_2) emissions because they rely heavily on fossil fuels such as coal and oil for electricity generation. Coal-fired plants are highly carbon-intensive, releasing close to 1 kg of CO_2 per unit of electricity produced, while gas plants emit roughly half that amount. Globally, the power sector accounts for nearly 35–40% of total CO_2 emissions, making it a key driver of climate change. Since these plants are large, concentrated point sources, capturing their emissions is both practical and essential. Implementing carbon capture technologies not only prevents millions of tonnes of CO_2 from entering the atmosphere but also plays a vital role in meeting international climate commitments, safeguarding the environment, and enabling a sustainable transition to a low-carbon energy future.

About CCUS:

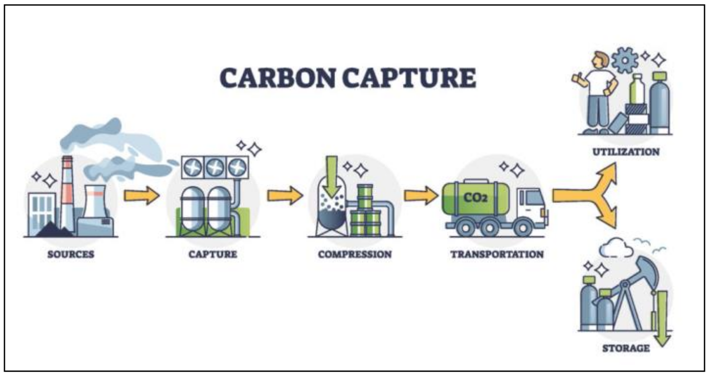
Carbon Capture, Utilization, and Storage (CCUS) is a suite of technologies designed to reduce carbon dioxide (CO_2) emissions from large sources such as power plants. Following is the process of carbon capture:

- For power generation the coal is burned and flue gases are generated.
- The flue gas is first cleaned to remove dust, sulphur oxides, and nitrogen oxides before entering the capture unit.
- Inside the absorber, special solvents bind with the CO_2, which is then released in concentrated form during solvent regeneration using heat.
- The captured CO_2 is cooled, purified, and compressed into a dense state for easy transport through pipelines or other means.
- Finally, it is either utilized in applications like enhanced oil recovery, chemicals, and building materials, or permanently stored in deep geological formations, with continuous monitoring to ensure safe and secure containment.

CCUS Technologies:

Carbon Capture, Utilization, and Storage (CCUS) incorporate a range of technologies across its three stages. In the capture stage, methods include post-combustion capture using solvents or membranes, pre-combustion capture during fuel gasification, oxy-fuel combustion producing pure CO_2 streams, and direct air capture systems. Utilization technologies convert CO_2 into useful products such as methanol, urea, synthetic fuels, and carbonated building materials, or employ it for enhanced oil recovery and food-grade applications. For storage, the main options are geological sequestration in depleted oil and gas reservoirs or deep saline aquifers, as well as mineralization where CO_2 reacts with rocks to form stable carbonates. Together, these technologies provide pathways to significantly reduce emissions from energy-intensive industries and support climate change mitigation goals.

Figure 39: CCUS System



Benefits:

- Captures up to 90% of CO_2 emissions from power plants and industries.
- Helps achieve global net-zero and climate goals.
- Enables continued use of existing fossil-fuel infrastructure with lower emissions.
- Decarbonizes hard-to-bate sectors like power, cement, steel, and chemicals.
- Converts CO_2 into fuels, chemicals, plastics, and building materials.
- Supports Enhanced Oil Recovery (EOR) while storing CO_2 underground.
- Creates jobs, investment opportunities, and economic growth.
- Improves energy security during the clean energy transition.

Challenges and Constraints in Implementation:

- Technology is still in very early phase.
- High cost – both capital investment and operating expenses are very high.
- Energy penalty – capture and compression reduce plant efficiency.
- Infrastructure needs – pipelines and storage sites are limited.
- Regulatory & policy gaps – weak carbon pricing and complex permitting slow adoption.
- Public acceptance – concerns about safety, leakage, and environmental impacts.

Cost Benefits:

Table : Cost of Carbon Capture

Parameter	CCUS (Incremental Cost for 500 MW Plant)
CAPEX	INR 6,000 – 10,000 Cr (capture unit, compression, transport pipeline, storage site)
Annual OPEX	INR 800 – 1,500 Cr (operation & maintenance, energy penalty, CO_2 handling)
Annual Savings / Revenue	INR 400 – 1,000 Cr (carbon credits, incentives, CO_2 utilization like EOR/ chemicals)
Net Additional Cost	INR 500 – 800 Cr per year (depends on credit price vs capture cost)
Pay-back Period	8 – 12 years (only possible if carbon price > \$50/tCO_2 and incentives apply)
Total CO_2 Captured	~2.5 million tCO_2 per year (for 500 MW at 70% capacity factor)
Applicability	High for coal/gas plants located near storage/utilization hubs

4.7 Technology 7: Floating Solar Panel

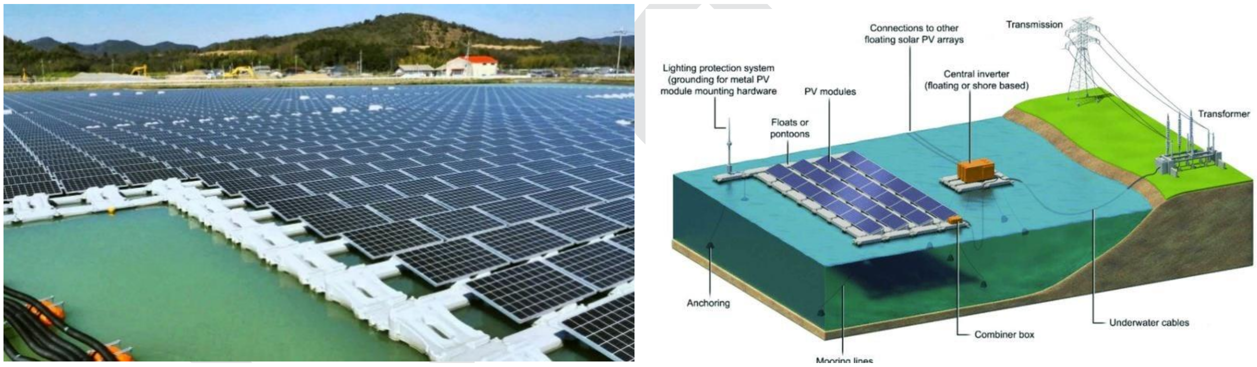
Background:

Renewable energy (RE) adoption in power plants is increasing due to the need to reduce greenhouse gas emissions, enhance energy security, and ensure sustainable electricity generation. Unlike fossil fuels, renewable sources such as solar, wind, hydro, biomass, and geothermal are naturally replenished and have minimal environmental impact. Integrating RE into power plants helps cut carbon emissions, lower operational costs over time, and diversify the energy mix, making power generation more resilient. In India, the government has played a key role in promoting RE adoption through initiatives like the National Solar Mission and Renewable Purchase Obligations (RPOs). India moves toward its 500 GW renewable capacity target by 2030 while integrating clean energy into conventional generation systems.

About Floating Solar Panel:

Floating solar panels (also called floatovoltaics) are solar photovoltaic (PV) systems installed on water surfaces such as reservoirs, lakes, ponds, or irrigation canals, instead of traditional land-based installations. They are mounted on buoyant platforms or pontoons that keep the panels afloat and stable.

Figure 40: Floating Solar



Floating solar panels work like conventional PV modules but are mounted on buoyant platforms on water bodies. Sunlight is converted into DC electricity, which is sent to an inverter to produce AC electricity for the grid. The floating structure keeps panels stable, while the water naturally cools the panels, improving efficiency by 5–15%. They can also be integrated with hydropower reservoirs for hybrid renewable generation.

First Installation in Thermal Power Plant:

With the commissioning of the 100 MW Solar PV Project at NTPC Ramagundam, the total operational floating solar capacity in the Southern Region has increased to 217 MW. Developed at a cost of INR 423 crores, the project spans 500 acres of the reservoir. It is expected to prevent nearly 32.5 lakh cubic meters of water evaporation annually, while also reducing coal consumption by about 1.65 lakh tons and avoiding approximately 2.1 lakh tons of CO_2 emissions each year.

Benefits:

- Saves Land – Installed on water, reducing the need for land in crowded areas.
- Improved Efficiency – Water cools the panels, boosting output by 5–15% compared to land-based systems.
- Reduces Water Evaporation – Helps conserve water in reservoirs and tanks.
- Integrates with Existing Infrastructure – Can be combined with hydropower dams or irrigation reservoirs.
- Environmentally Friendly – Generates clean energy without significant land disruption.
- Scalable & Flexible – Can be installed on small ponds to large reservoirs.

Challenges and Constraints in Implementation:

- High Initial Cost – Floating structures, anchors, and corrosion-resistant materials make installation more expensive than land-based systems.Complex Installation & Maintenance – Requires boats or specialized equipment for assembly, cleaning, and repairs.
- Environmental Impact – Potential disruption to aquatic ecosystems, including sunlight penetration and oxygen levels.
- Water Body Requirements – Not all reservoirs or ponds are suitable; water depth, currents, and waves must be considered.

Cost Benefits:

Table : Cost Benefits of Floating Solar Panels

Parameter	Floating Solar Panels
CAPEX	INR 5.5 – 7 crore per MW
OPEX	Slightly higher than land-based systems
Efficiency Gain	5–15% higher than land-based systems
Land Savings	Utilizes water bodies, preserving land
Water Savings	Reduces evaporation in reservoirs
Payback Period	Approximately 5–7 years
Applicability	High for coal/gas plants located near storage/utilization hubs

4.8 Technology 8: Green Hydrogen Production

Background:

Almost every large capacity thermal power plant (> 250 MW) uses H_2 for generator cooling. Using H_2 for cooling has various advantages like high cooling efficiency, reduced windage loss, improved generator efficiency and extended equipment life. To cater the need of H_2, power plants install H_2 generation plants to which generates H_2 by splitting the water molecules into H_2 and O_2 through the process called electrolysis. The H_2 is stored in bottles or storage tanks while the O_2 is vented to the atmosphere. The process of electrolysis requires electricity which is sourced from the plant generation.

If hydrogen is produced using electricity generated from a coal-fired power plant, it is classified as grey hydrogen. This category includes hydrogen produced from fossil-fuel-derived electricity, whether through water electrolysis or coal/lignite gasification, and is characterized by a high carbon footprint due to emissions from coal-based power generation.

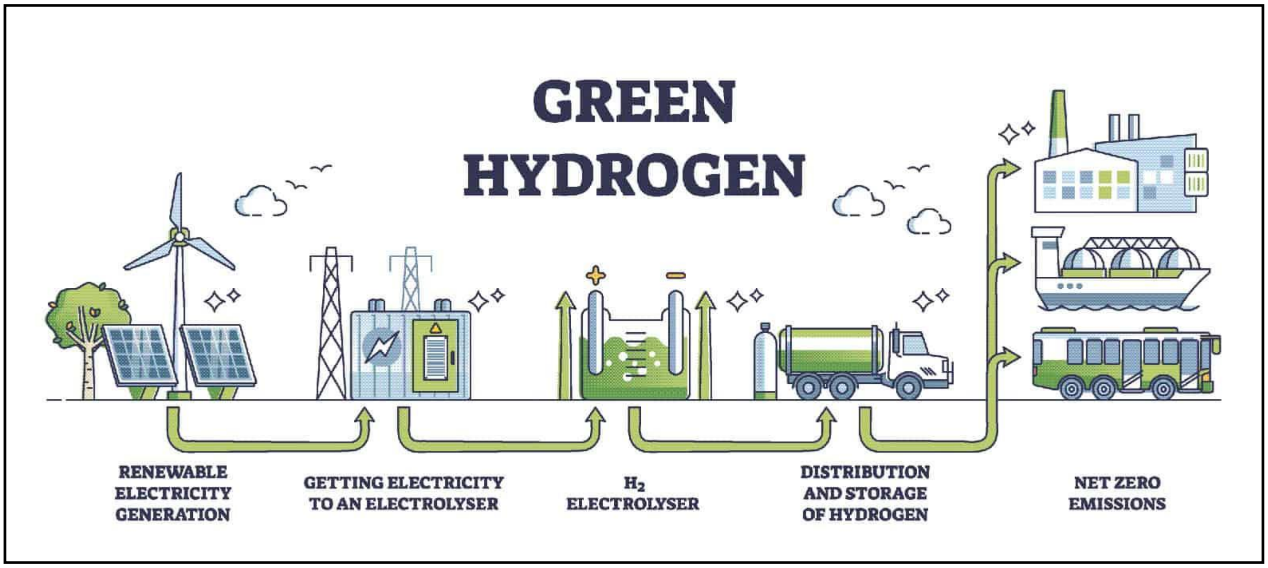
On the other hand, H_2 is categorized as green when it is produced using renewable energy sources such as solar, wind, hydropower, geothermal, or other non-fossil energy, and when its lifecycle greenhouse gas emissions are below a specific threshold. According to recent standards set in India, green hydrogen must have total emissions (including water treatment, electrolysis, purification, drying, and compression) of no more than 2 kg CO_2 equivalent per kg H_2.

National Green Hydrogen Mission[16] :

India's National Green Hydrogen Mision represents India's ambition to emerge as a global leader in the production and export of green hydrogen. The mission is launched in 2023 with INR 19, 744 crore budgets, aims to make the country a global hub for green hydrogen by 2030. Key details are as under:

- Targets 5 MMT of green hydrogen production per year by 2030 and adds 125 GW renewable capacity.
- Incentivizes domestic electrolyser manufacturing and creates green hydrogen hubs.
- Strategic focus on replacing hydrogen from fossil sources in existing industries.

Figure 41: Green Hydrogen Production Process



Advantage for Thermal Power Plants:

- It is easier for existing power plants to generate green hydrogen because they already have most of the necessary infrastructure for hydrogen production and handling, built for generator cooling and operations.
- Thermal power plants already have electrolysers for on-site hydrogen production.
- Systems for storage, purification, compression and piping to feed hydrogen for cooling large turbine generators.
- Safety systems, training and protocols for hydrogen management.

Transition from brown hydrogen to green hydrogen is simple for thermal power plants with the following changes required:

- The main change required is to reroute the power supply for electrolysis from conventional (coal/fossil) electricity to renewable sources such as solar or wind that can be generated on-site or sourced from off-site assets.
- No heavy capital expenditure is needed for new hydrogen handling or safety systems, since those are already operational.
- The retrofit involves minimal engineering- simply source and certify renewable electricity and possibly upgrade electrolyser technology for higher efficiency.

Application of Green Hydrogen in Power Plants:

- Generator Cooling: Direct replacement of conventional hydrogen with green hydrogen will help reduce production cost and coal savings.

- Mobility (internal transport): For internal movement and transportation of goods, coal, ash etc hydrogen vehicles can be used. It can also be used as fuel for buses for employee commuting. This will directly help to reduce the Scope-1 & 3 emissions of the facility. This will also help to reduce the cost of fossil fuels consumption for internal and external movement of employees and commodities.

- Cofiring in Boilers: Although cofiring of hydrogen along with the coal is not yet considered in thermal power plants but green hydrogen, if available, can have promising opportunities in co-firing. Further, studies related to effect of hydrogen combustion in boiler on the boiler performance need to be done for establishing the feasibility of the same.
- Sale of Green Hydrogen: Green Hydrogen if produced in excess, can be sold to nearby industries such as fertilizers plants and refineries. These sectors are significant consumers of hydrogen for their process, making them natural off takers of green hydrogen. This also brings benefits such as creating new revenue streams, reducing carbon footprints for off takers and aligning with India's clean energy and decarbonization targets. It encourages industrial clusters and power plants to collaborate, accelerating green hydrogen adoption and the transition to a sustainable economy.

Cost Benefits:

Table : Cost Benefits for a 1 MW

Aspect	Conventional H_2 (Coal)	Green H_2 (RE)
Energy Source	Fossil electricity	Solar/Wind/RE
Carbon Footprint	High	Near Zero
Production Cost (power cost only)	Depends on fuel cost	No cost if produced from onsite RE generated power
Capex	-	Safe infrastructure, only RE connection to be added
Opex	Water, maintenance, fossil fuel cost	Water, maintenance of RE
Policy Support	Minimal	Strong- Mission subsidies, guaranteed offtake

4.9 Technology 9: Energy Efficient Motors

Background:

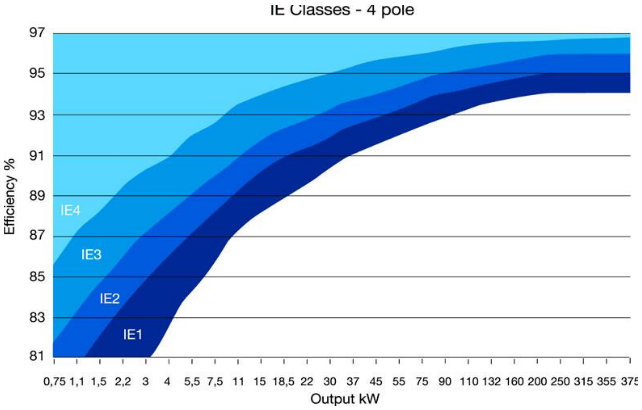
Electric motors are a core component in industrial operations, converting electrical energy into mechanical work for pumps, fans, compressors, and conveyors. They are classified by efficiency under the International Efficiency (IE) standard. Currently, most industries use IE2 (high efficiency) and IE3 (premium efficiency) motors. IE2 motors offer a balance of moderate upfront cost and reasonable efficiency, while IE3 motors, though slightly more expensive, provide 2–3% higher efficiency, resulting in significant electricity savings over their operational life. Many regulations now mandate IE3 as the minimum efficiency for motors above 0.75 kW.

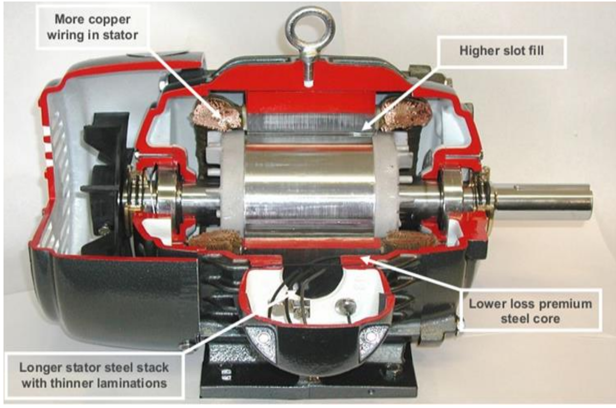
About IE4 & IE5 Motors:

The energy efficient motors are available at efficiencies as high as 94-95% depending upon the capacities which are relatively prominent with respect to the standard counterparts. The motors also retain the same efficiencies in the range of 50-100% loading. Energy efficient motors have four characteristics over lower efficient motors.

- More Cu wire in stator and rotor to cut resistance losses
- Precision air gaps to reduce current requirements
- Improved winding and lamination design to minimize energy consumption
- Special steel processing in the stator to minimize core losses

Figure 43: Energy Efficient Motors





IE4 and IE5 motors convert electrical energy into mechanical energy through electromagnetic induction, like standard AC motors. IE4 uses optimized designs and materials to reduce losses, while IE5 adds permanent magnets for ultra-high efficiency, resulting in lower energy consumption, less heat, and better performance for industrial applications.

Benefits:

- Higher Efficiency – IE4 and IE5 motors reduce energy losses by 3–5% (IE4) and 5–8% (IE5) compared to IE3/IE2, leading to lower electricity consumption.
- Lower Operational Costs – Reduced energy use directly translates into significant annual savings, especially for long-running motors.

- Reduced Heat Generation – Less heat improves reliability, motor lifespan, and reduces cooling requirements.
- Better Environmental Impact – Lower energy consumption means reduced CO_2 emissions, supporting sustainability goals.
- Higher Torque Density – Advanced designs allow more compact motors with the same power output.

Challenges and Constraints in Implementation:

- Higher Initial Cost – IE4 and IE5 motors are more expensive than IE2/IE3, which can be a barrier for plants with tight budgets.
- Specialized Maintenance – Advanced designs, especially with permanent magnets in IE5, may require skilled technicians for servicing.
- Limited Availability – Not all sizes and ratings are readily available in IE4/IE5, especially in some regions.
- Compatibility Issues – Existing drive systems, coupling, and space constraints may need modification to accommodate higher-efficiency motors.

Cost Benefits:

Table : Cost Benefits of Energy Efficient Motors

Parameter	IE2 Motor	IE3 Motor	IE4 Motor	IE5 Motor	Benefit / Savings
CapEx (Initial Cost)	INR 1,00,000	INR 1,15,000	INR 1,30,000	INR 1,50,000	Higher upfront for IE4/IE5, ~15–30% more than IE2
OpEx (Annual Energy + Maintenance)	INR 40,000/ year	INR 36,000/ year	INR 32,000/ year	INR 28,000/ year	Annual savings: IE4 saves INR 8,000/year vs IE2; IE5 saves INR 12,000/ year vs IE2
Cooling / Heat Loss Costs	INR 5,000/ year	INR 4,500/year	INR 4,000/ year	INR 3,500/ year	Reduced heat - lower energy for cooling
Net Annual Savings vs IE2	–	INR 8,500	INR13,000	INR 17,500	Cumulative savings over lifetime
Payback Period	–	~3 years	~5 years	~6–7 years	Depending on usage hours and energy cost

4.10 Technology 10: IOT Based Monitoring of Utilities

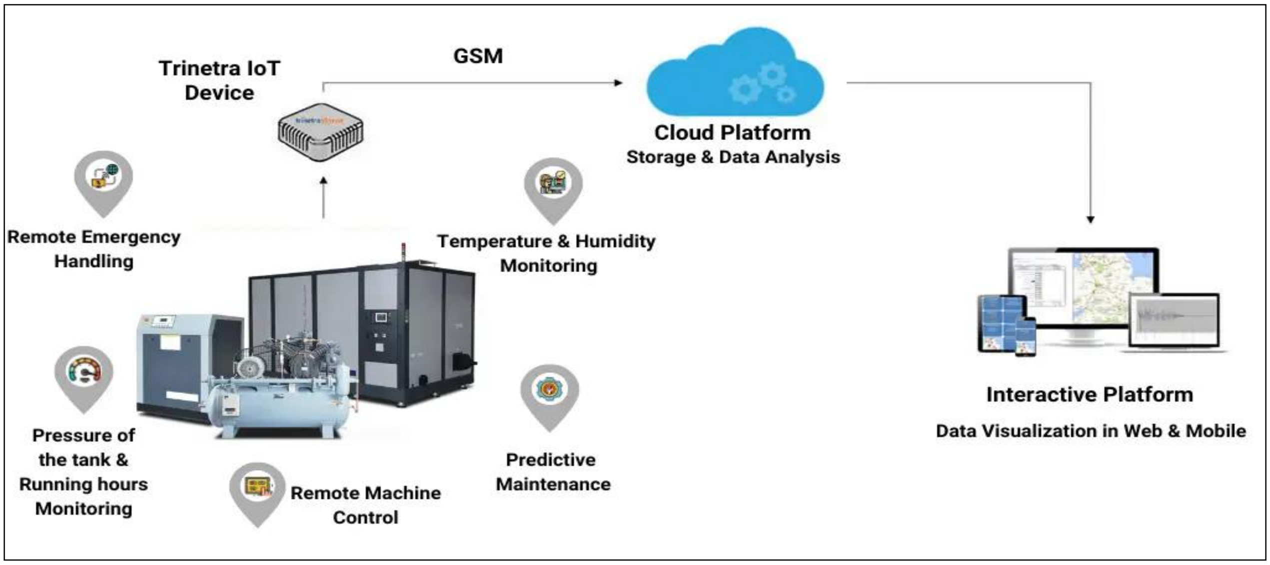
Background:

In thermal power plants, monitoring of steam, water, electricity, and other utilities like compressed air is critically important because inefficient usage directly increases auxiliary power consumption and operational costs. Continuous tracking of these utilities allows operators to identify energy losses, optimize the performance of boilers, turbines, pumps, fans, and other auxiliary systems, and ensure that resources are used efficiently. Effective monitoring also supports predictive maintenance, reduces downtime, and helps the plant meet environmental and efficiency standards. By closely observing utility consumption, plants can significantly improve overall efficiency, reduce fuel and energy costs, and extend the life of equipment.

About IoT based monitoring:

IoT (Internet of Things) based monitoring involves using a network of smart sensors, meters, and connected devices to continuously collect real-time data from equipment and systems across a plant. In thermal power plants, IoT devices can monitor steam, water, electricity, fuel, compressed air, and auxiliary systems, providing instant insights into operational performance.

Figure 44: IOT Based Monitoring System



Steps involved in IOT based monitoring:

- Identify Utilities – Select key systems like steam, water, electricity, fuel, and auxiliary equipment.
- Install IoT Sensors – Deploy smart meters and sensors on equipment and utility lines.
- Collect & Transmit Data – Sensors send real-time measurements to a central dashboard or EMS.
- Analyze & Optimize – Use data analytics to detect inefficiencies, enable predictive maintenance, and optimize operations.
- Continuous Monitoring – Maintain real-time oversight, generate alerts, and improve plant efficiency continuously.

Benefits:

- Real-Time Data Access – Continuous monitoring of steam, water, electricity, fuel, and auxiliary systems allows operators to make instant decisions.
- Energy Efficiency & Cost Savings – Identifies inefficiencies, reduces auxiliary power consumption, and optimizes resource usage, lowering operational costs.
- Predictive Maintenance – Detects anomalies early, preventing unexpected equipment failures and reducing downtime and repair expenses.
- Process Optimization – Enables better load management, flow control, and resource allocation for improved plant performance.
- Enhanced Reliability & Safety – Early alerts and data-driven insights improve system reliability and reduce operational risks.

Challenges and Constraints in Implementation:

- High Initial Investment – Setting up sensors, communication networks, and analytics platforms requires significant capital expenditure.
- Integration Complexity – Existing plant equipment and legacy systems may need modifications to interface with IoT devices.
- Data Security & Privacy – Connected systems are vulnerable to cyberattacks, requiring robust security measures.
- Skilled Workforce Requirement – Staff must be trained to operate, maintain, and analyze IoT systems effectively.
- Network Reliability – Continuous data transmission depends on stable and robust communication networks.

Cost Benefits:

Table : Cost Benefits with IoT based Monitoring

Parameter	Without IoT	With IoT Monitoring	Benefit / Savings
Capex (Initial Investment)	–	INR 2,00,00,000	–
Opex / Annual Costs	INR 2,80,00,000	INR 2,25,00,000	INR 55,00,000/year
Auxiliary Power Consumption	INR 1,00,00,000	INR 85,00,000	INR 15,00,000/year
Fuel/Energy Wastage	INR 2,00,00,000	INR 1,80,00,000	INR 20,00,000/year
Maintenance Costs	INR 50,00,000	INR 40,00,000	INR 10,00,000/year
Downtime Losses	INR 30,00,000	INR 20,00,000	INR 10,00,000/year
Total Annual Savings	–	–	INR 55,00,000/year
Payback Period	–	3.6 years	–

4.11 Technology 11: Bio CNG

Background:

Bio-CNG is a renewable fuel produced by purifying biogas from organic waste, agricultural residues, or wastewater. In power plants, it can be used in various places like canteens, gas cutting applications or even in boilers to co-fire with primary fuel or during startup to reduce oil consumption. Using Bio-CNG reduces fossil fuel consumption and greenhouse gas emissions, while also enabling waste-to-energy solutions by converting organic waste into usable energy. This makes it a sustainable, carbon-neutral option that improves energy security and supports environmental goals in power generation.

About Bio CNG:

Bio-CNG is produced by first collecting organic waste materials such as agricultural residues, horticulture waste, canteen or colony food waste, animal manure, or sewage sludge. These are fed into an anaerobic digester, where microorganisms decompose the organic matter in the absence of oxygen, producing biogas, a mixture of methane (CH_4) and carbon dioxide (CO_2). The biogas is then purified using techniques like water scrubbing, pressure swing adsorption, or membrane separation to remove CO_2, H_2S, and moisture, resulting in high-purity methane. Finally, this methane is compressed under high pressure to form Bio-CNG, which can be stored, transported, and used as a renewable, carbon-neutral fuel in power plants, engines, or industrial applications, offering both energy generation and environmental benefits.

Figure 42: Bio CNG System

Benefits:

- Renewable & Sustainable – Produced from organic waste, it provides a carbon-neutral fuel source, unlike fossil fuels.
- Waste Management – Converts agricultural residues, food waste, and manure into useful energy, reducing landfill and pollution.
- Environmental Benefits – Significantly lowers CO_2, SOx, NOx, and particulate emissions, improving air quality.
- Energy Security – Reduces dependence on imported fossil fuels by providing a domestic, decentralized energy source.
- Economic Savings – Offers lower fuel costs compared to conventional CNG/diesel and supports captive power generation.

Challenges and Constraints in Implementation:

- High Capital Cost – Setting up biogas purification and compression units requires significant initial investment.
- Feedstock Availability & Consistency – Continuous supply of organic waste, crop residues, or manure can be uncertain and seasonal.
- Collection & Logistics – Gathering and transporting waste from multiple locations is costly and logistically complex.
- Technology Challenges – Biogas purification, upgrading, and compression systems require skilled operation and maintenance.
- Storage & Distribution Infrastructure – Lack of widespread pipelines, filling stations, and storage facilities limits large-scale adoption.

Cost Benefits:

Table : Cost Benefits of Bio- CNG

Parameter	Conventional Fuel (Diesel/FO)	Bio-CNG	Benefit
Fuel Cost	INR 65 – 80 per kg (diesel equivalent)	INR 40 – 50 per kg	~30–40% savings
Calorific Value	10,000 –11,000 kcal/kg	11,000 –12,000 kcal/kg	Comparable / Slightly higher
OPEX (Operating Cost)	High (fuel + emission treatment + maintenance)	Lower (fuel + simpler emission handling)	15–20% lower
CAPEX (Plant Setup)	Minimal (only for diesel/gas systems)	INR15 – 25 crores for 10 TPD Bio-CNG plant	Higher CAPEX
Annual Fuel Cost (10 TPD equivalent)	INR 45 – 50 crores	INR 28 – 32 crores	Savings of INR15 – 18 crore/year
CO_2 Emissions	2.6 kg CO_2 per liter diesel	Negligible net CO_2 (carbon-neutral)	Environmental credits possible
Payback Period	–	3–4 years (through fuel savings + carbon credits)	Attractive ROI

5 FUTURE OUTLOOK: THERMAL POWER IN INDIA'S NET-ZERO JOURNEY

FUTURE OUTLOOK: THERMAL POWER IN INDIA'S NET-ZERO JOURNEY

As India advances toward its ambitious net-zero emissions goal by 2070, the thermal power sector- currently responsible for over half of the nation's electricity generation- faces a fundamental transformation. Rather than simply phasing out thermal power plants, India is charting a strategic pathway that leverages multiple decarbonization technologies to transform existing assets into cleaner, more flexible generation sources by mainly focusing on adoption of SC & USC technologies for upcoming projects, biomass co-firing, and adoption of technologies like Carbon Capture Utilization and Storage (CCUS)

Biomass co-firing represents the most mature and immediately deployable decarbonization technology for India's thermal power sector. The Ministry of Power has mandated that all coal-based plants co-fire at least 5% unmixed biomass by 2025, scaling to 7% by 2025-26. As of Aug 2025, 71 thermal power plants across India are actively implementing biomass co-firing, utilizing approximately 30,42,000 tonnes of biomass and preventing 36,50,000 tonnes of CO_2 emissions. The biomass co-firing has increased almost four times in the FY 2024-25 when compared to FY 2023-24. Despite progress, biomass co-firing faces implementation challenges including limited biomass pellet production capacity, supply chain constraints, and technical barriers at some facilities. Regional variations are significant—in Delhi-NCR, biomass share often remains below 1% with intermittent operations. The government has introduced the SAMARTH scheme to support agro-residue utilization, funding pellet manufacturing and creating vendor listings with long-term supply agreements.

Hydrogen and ammonia co-firing represent a more advanced decarbonization pathway with significant long-term potential. Japan leads global development, with Japan Energy Regeneration Authority (JERA) and Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI) achieving 20% ammonia co-firing at the 1,000 MW Hekinan Thermal Power Station . The project demonstrated stable combustion with near-zero unburned ammonia emissions and controlled nitrogen oxide levels. In India, ammonia blending with coal offers an opportunity to reduce the emissions linked with power generation from coal by 10-50% depending on the blending ratio. However, the cost of production of green ammonia will play a crucial role in determining the viability of the large-scale implementation.

Carbon Capture, Utilization, and Storage (CCUS) represents the most comprehensive decarbonization technology for thermal power plants, offering 85-95% CO_2 reduction potential. India's approach to CCUS has evolved significantly, with NITI Aayog developing a comprehensive CCUS policy framework targeting 750 million tonnes per annum of carbon capture by 2050 . NTPC is leading with India's first CCUS implementation in thermal power plant with a project of 20 TPD capacity already operational, complemented by multiple pilot-scale projects. Plans are also underway for large-scale capture units to further reduce emissions from the company's coal-based generation fleet. This integrated approach enables NTPC to systematically advance from proof-of-concept projects to full-scale deployment.

India's thermal power sector stands at a transformation inflection point where technological innovation enables continued asset utilization while achieving deep decarbonization. The three-pronged approach of biomass co-firing, hydrogen/ammonia blending, and CCS/CCUS readiness provides a comprehensive pathway for thermal plants to contribute meaningfully to India's net-zero journey by 2070.

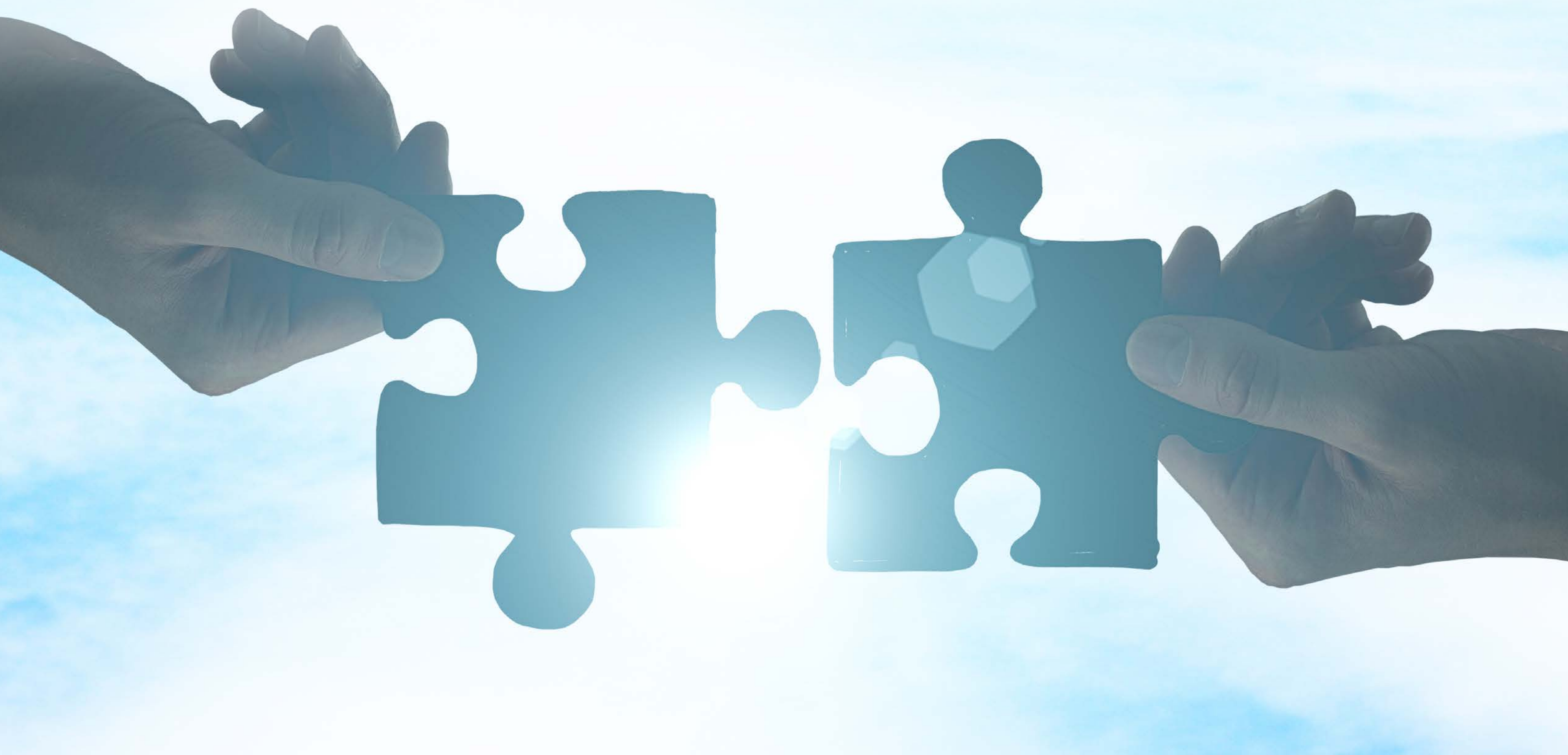
Success depends on coordinated policy support, strategic investment, and technology integration that leverages existing infrastructure while building future capabilities. The transformation preserves energy security, maintains grid stability, and supports socio-economic objectives while delivering substantial emissions reductions. This approach positions India's thermal power sector not as a sunset industry, but as a critical enabler of the clean energy transition—demonstrating that existing assets can be part of the solution rather than simply problems to be solved.

Call for Collaboration

As the energy landscape continues to evolve rapidly, this guidebook serves not only as a guide but as a call to action for all stakeholders—power producers, technology developers, policymakers, and researchers—to come together and accelerate the transition towards cleaner, more efficient energy systems. The challenges of tomorrow demand integrated solutions that blend operational excellence with technological innovation and environmental stewardship.

To sustain momentum, continual updates to this guidebook will be essential, incorporating emerging technologies like advanced hydrogen utilization, carbon capture and storage, digital twin simulations, and real-time IoT-driven optimizations. We strongly encourage thermal power plants to pilot projects, undertake collaborative research programs, and actively participate in industry forums to keep pioneering best practices that align with India's net-zero ambitions.

Together, through shared knowledge and joint efforts, the Indian thermal power sector can exemplify a successful balance of reliability, flexibility, and sustainability in the global energy transition.



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About CII-Godrej GBC

CII- Sohrabji Godrej Green Business Centre (CII-Godrej GBC) was established in the year 2004, as CII's Developmental Institute on Green Practices & Businesses, aimed at offering world-class advisory services on the conservation of natural resources. The Green Business Centre in Hyderabad is housed in one of the greenest buildings in the world and through Indian Green Building Council (IGBC) is spearheading the Green Building movement in the country. The Green Business Centre was inaugurated by His Excellency Dr. A. P. J. Abdul Kalam, the then President of India on 14 July 2004.

The Services of Green Business Centre include - Energy ManagementEfficiency Services, Green Buildings, Green Companies, Renewable Energy, GHG Inventorization, Green Product Certification, Waste Management and Cleaner Production Process. CII- Godrej GBC works closely with the stakeholders in facilitating India to emerge as one of the global leaders in Green Business by the year 2026.

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About CII

The Confederation of Indian Industry (CII) works to create and sustain an environment conducive to the development of India, partnering Industry, Government and civil society through advisory and consultative processes.

CII is a non-government, not-for-profit, industry-led and industry-managed organisation, with around 9,700 members from the private as well as public sectors, including SMEs and MNCs, and an indirect membership of over 365,000 enterprises from 318 national and regional sectoral industry bodies.

For more 130 years, CII has been engaged in shaping India's development journey and works proactively on transforming Indian Industry's engagement in national development. CII charts change by working closely with the Government on policy issues, interfacing with thought leaders, and enhancing efficiency, competitiveness, and business opportunities for industry through a range of specialised services and strategic global linkages. It also provides a platform for consensus-building and networking on key issues.

Through its dedicated Centres of Excellence and Industry competitiveness initiatives, promotion of innovation and technology adoption, and partnerships for sustainability, CII plays a transformative part in shaping the future of the nation. Extending its agenda beyond business, CII assists industry to identify and execute corporate citizenship programmes across diverse domains, including affirmative action, livelihoods, diversity management, skill development, empowerment of women, and sustainable development, to name a few.

For 2025-26, CII has identified "Accelerating Competitiveness: Globalisation, Inclusivity, Sustainability, Trust" as its theme, prioritising five key pillars. During the year, CII will align its initiatives to drive strategic action aimed at enhancing India's competitiveness by promoting global engagement, inclusive growth, sustainable practices, and a foundation of trust.

With 70 offices, including 12 Centres of Excellence, in India, and 9 overseas offices in Australia, Egypt, Germany, Indonesia, Singapore, UAE, UK, and USA, as well as institutional partnerships with about 250 counterpart organisations in almost 100 countries, CII serves as a reference point for Indian industry and the international business community

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