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Report on

Electrification Roadmap For Key Economic Sectors in India

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ABBREVIATIONS

AAT	**Advance Automotive Technology**	CY	**Calendar Year**
ASI	Annual Survey of Industries	DDUGJY	Deen Dayal Upadhyaya Gram Jyoti Yojana
ADB	Asian Development Bank	DG	Diesel Generator
ASEAN	Associations of Southeast Asian Nations	DRI	Direct Reduced Iron
BAU	Business as Usual	EAF	Electric Arc Furnace
BEE	Bureau of Energy Efficiency	EMMP	Environmental Mitigation and Monitoring Plan
BESS	Battery Energy Storage System	ESCO	Energy Service Company
BHEL	Bharat Heavy Electricals Limited	ESS	Energy Storage System
BMS	Battery Management System	EV	Electric Vehicle
BF	Blast Furnace	FAME	Faster Adoption and Manufacturing of Hybrid and Electric Vehicles
BOF	Basic Oxygen Furnace	FY	Fiscal Year
CAGR	Compound Annual Growth Rate	GHG	Green House Gas Emissions
CBAM	Carbon Border Adjustment Mechanism	GWh	Giga Watt hour
CCTS	Carbon Credit Trading Scheme	GVA	Gross Value Added
CCUS	Carbon Capture, Utilization, and Storage	HAP	Household Air Pollution
CEA	Central Electricity Authority	HP	Heat Pump
CHP	Combined Heat and Power System	HTHP	High-Temperature Heat Pump
CII	Confederation of Indian Industry	HSD	High-Speed Diesel
CO_2	Carbon Dioxide	ICM	Indian Carbon Market
COP	Coefficient of Performance	IEA	International Energy Agency
CPP	Captive Power Plant	IIT	Indian Institute of Technology
IRENA	International Renewable Energy Agency	IISc	Indian Institute of Science
ISTS	Inter State Transmission System	MOE	Molten Oxide Electrolysis
KWH	Kilo Watt Hour	MSME	Micro Small Medium Enterprises
KSRTC	Karnataka State Road Transport Corporation	MToE	Million Tones of Oil Equivalent

LPG	Liquified Petroleum Gas	MTPA	Million Tonnes Per Annum
MMT	Million Metric Tones	MVR	Mechanical Vapour Recompression System
MNRE	Ministry of New & Renewable Energy	MW	Mega Watt
MoEFCC	Ministry of Environment, Forest and Climate Change	MoRTH	Ministry of Road Transport and Highways
MoSPI	Ministry of Statistics and Program Implementation	PNG	Piped Natural Gas
MoP	Ministry of Power	NIC	National Industrial Classification
MoPNG	Ministry of Petroleum and Natural Gas	NITI Ayog	The National Institution for Transforming India
SAIFI	System Average Interruption Frequency Index	PAT Scheme	Perform Achieve Trade Scheme
SECI	Solar Energy Corporation of India	PEM	Polymer Electrolyte Membrane
SED	Sustainable Economic Development	PIB	Press Information Bureau
SIAM	Society of Indian Automobile Statistics	PSP	Pumped Storage Plants
SIDBI	Small Industries Development Bank of India	PSS	Pumped Storage System
SGHP	Steam Generating Heat Pump	PMUY	Pradhan Mantri Ujjwala Yojana
SNG	Synthetic Natural Gas	PPP	Public Private Partnership
TESS	Thermal Energy Storage System	RGGLVY	Rajiv Gandhi Gram LPG Vitrak Yojana
Th	Thousand	RE- RTC	Renewable Energy - Round the Clock
TRL	Technology Readiness Level	SAIDI	System Average Interruption Duration Index
TWH	Tera Watt Hours	ZEV	Zero Emission Vehicle
TCIL	Transportation Corporation of India	VAR	Volt Ampere Reactance

EXECUTIVE SUMMARY

This report presents a comprehensive assessment of the potential and roadmap for accelerating the electrification of India's industrial and commercial sectors as a critical strategy to reduce reliance on fossil fuels, enhance energy security, and meet the nation's climate commitments. Aligned with India's Nationally Determined Contributions (NDCs) under the Paris Agreement, the roadmap seeks to increase the share of electricity, particularly from renewable sources, in final energy consumption. It prioritizes interventions that are both technologically viable and economically feasible by 2030, setting the foundation for India's transition to net-zero emissions by 2070.

India's industrial sector accounts for nearly 49%[1] of the nation's total final energy consumption, yet only 18.7%[1] of this comes from electricity, significantly below the Asian average of 30.6%[2]. The commercial (building) sector fares better, with an electrification level of 88%, presenting near-term potential/opportunity for full electrification. The report identifies high-potential electrification industrial end-use sub-sectors such as cement, iron and steel, chemicals, textiles, paper, and aluminium. For these sectors, commercially available technologies, including high-temperature heat pumps (HTHP), mechanical vapour recompression (MVR) systems, electric boilers, and battery energy storage systems (BESS), can replace fossil fuel-based heating and captive power generation systems along with round-the-clock renewable energy procurement. In the commercial sector, applications in hotels, hospitals, malls, and office buildings can similarly transition from LPG, PNG, and diesel to electric alternatives such as heat pumps, electric boilers, induction cooking appliances, and BESS.

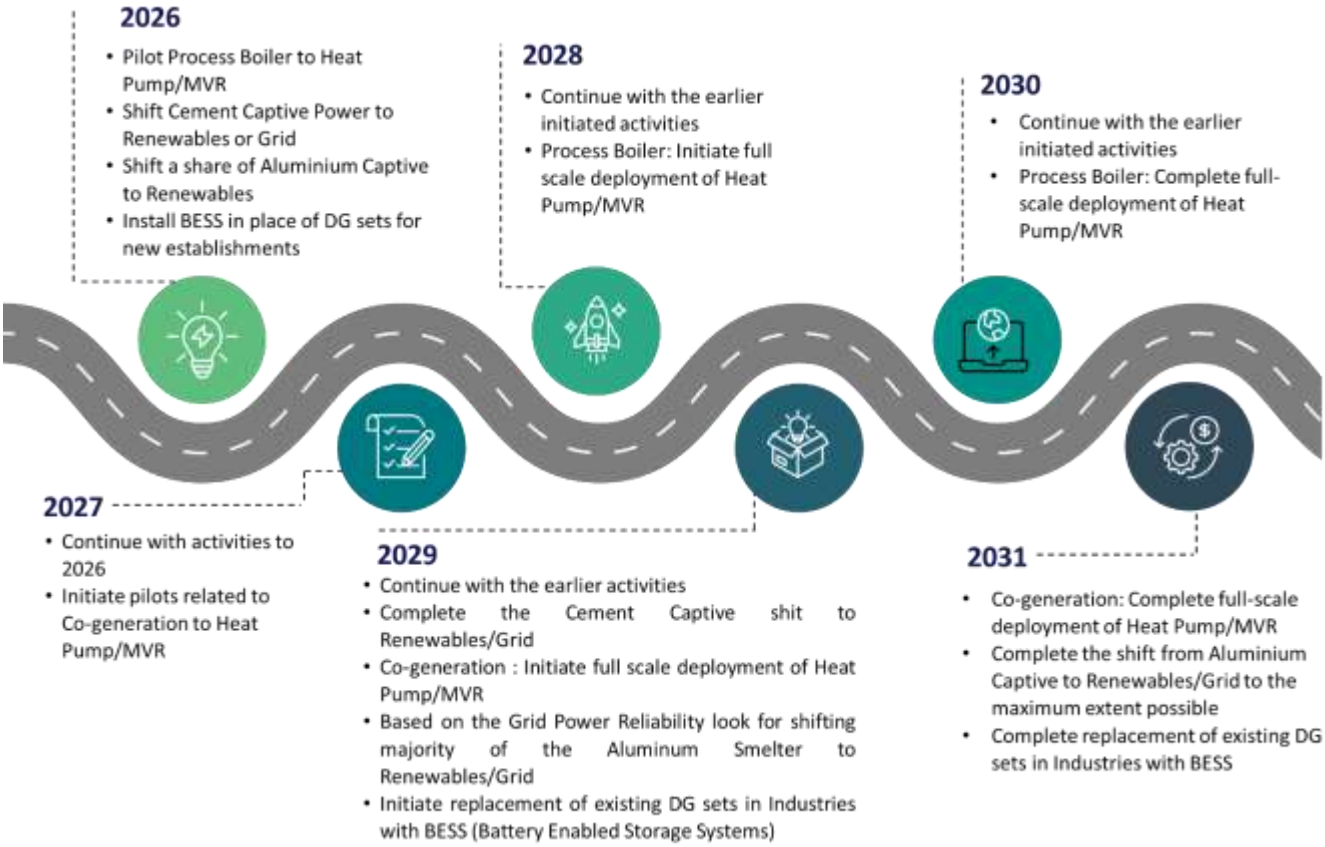
Moreover, the report forecasts that, with the proposed interventions, the industrial sector's electrification level can be raised from 18.7% to 25.3% by 2030. This would lead to significant reductions in greenhouse gas emissions, ranging from 47.7 million tonnes of CO_2 equivalent (CO_2e) if powered by the national grid (based on the current emission factor of 0.727 kg CO_2e/kWh), to 138.9 million tonnes CO_2e if powered by 100% renewable electricity. These transitions will result in additional electricity demand of approximately 125,558 GWh—representing about 9.5% of India's current electricity consumption—but will concurrently save over 139 million tonnes of coal equivalent (MToE) if the extra electricity required is sourced from renewables. The extra electricity demand created is equivalent to 23% of the electricity consumption of the industrial sector for the year 2021-22. The total extra installed renewable capacity required at a cumulative utilization factor (CUF) of 20%, and 17% T&D losses is 88 GW.

A phased implementation roadmap from 2026 to 2031 is proposed, beginning with pilot projects for HTHP, MVR, and BESS technologies in 2026–2027. This will be followed by full-scale deployment in small and medium process industries and captive power plants shift to renewable-powered grid supply (or round-the-clock renewable energy), particularly in energy-intensive industries like cement and aluminium.

[1] Energy Statistics 2024

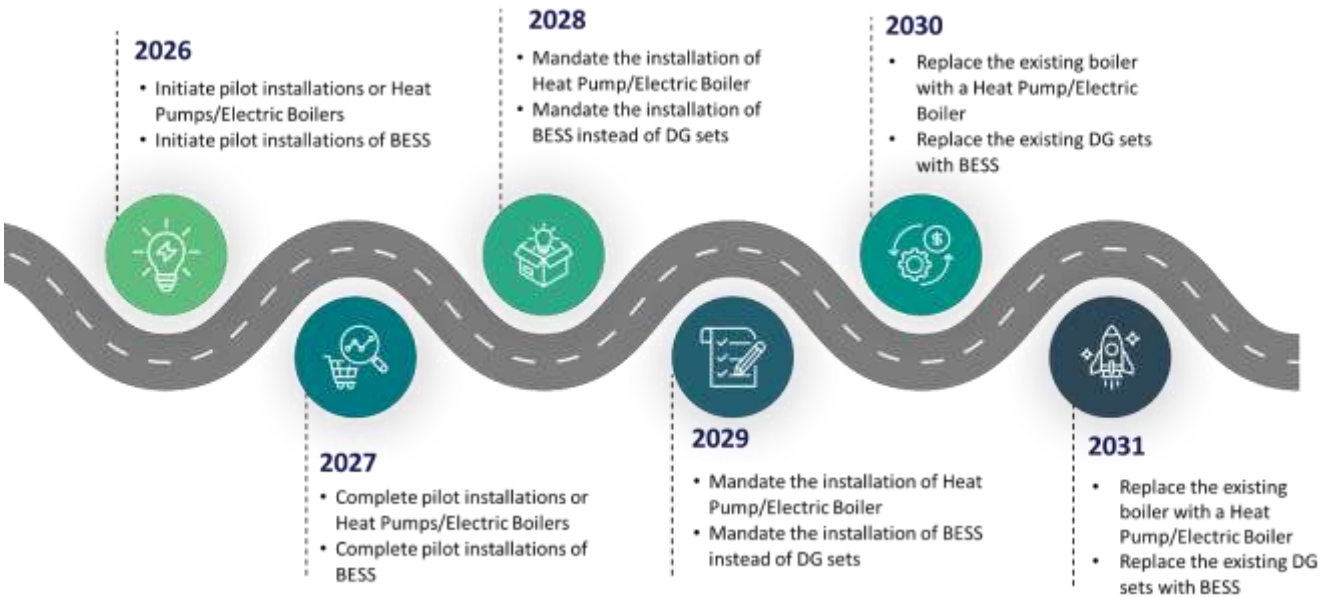
[2] Energy Statistics Pocketbook 2024

Figure 1: Industrial Sector Electrification Roadmap



For the commercial sector, the roadmap recommends mandating heat pump and BESS installations in new buildings by 2028 and retrofitting existing facilities by 2031.

Figure 2: Commercial Sector Electrification Roadmap



To support this transition, the report recommends key policy and regulatory reforms. These include mandating

enforceable minimum renewable procurement targets for industrial consumers, exempting electricity duties on captive solar, rationalising cross-subsidy and open access surcharges, and encouraging renewable captive power installations by easing restrictions. Financially, the roadmap proposes a ₹10,000 crore concessional loan facility, 100% accelerated depreciation for electrification investments, and exemption from GST and customs duties on critical electrification technologies. Funding mechanisms are to be supported through green bonds, public sector finance (e.g., REC, PFC, IREDA, SIDBI), blended finance, and international collaborations with institutions such as the World Bank and ADB.

An investment of ₹20,000 to ₹30,000 crore is required for the installation of heat pumps and mechanical vapor recompression (MVR) systems in process industries. An additional investment of ₹7,500 crore is needed for the installation of high-voltage step-down transformers to import the additional electricity required from the grid or renewable sources.

Approximately 20,000 direct jobs can be created in the heat pump and MVR sectors, with the majority of these new jobs related to installation and servicing. If India manages to support local manufacturing, the number of new jobs created could be significantly higher, which is around 50,000 direct jobs.

Despite the immense opportunities, the roadmap acknowledges several barriers—technological limitations in high-temperature processes, economic challenges due to high upfront costs and discouraging electricity tariff structures, regulatory inconsistencies, and grid infrastructure limitations. It outlines targeted strategies for each barrier, including greater R&D investment, regulatory harmonization across states, performance-linked incentives, and grid modernization.

In conclusion, industrial and commercial electrification is an essential pathway for India to meet its energy and climate goals while enhancing its global competitiveness and industrial resilience. This roadmap serves as both a strategic blueprint and a call to action, urging coordinated efforts across government, industry, financiers, and civil society to enable a just, efficient, and sustainable energy transition.

APPROACH & METHODOLOGY

A detailed analysis of the sub-sector level processes in the industrial and commercial sectors has been carried out to identify the current practice and match it with the electrification technologies, both commercially available and under research. To identify industrial sub-sectors with high potential for electrification, the Annual Survey of Industries (ASI) has been extensively used, based on which about sixteen sectors have been identified as having high potential. Further, these sectors have been ranked in terms of electrification potential and ease of implementation.

Since different sub-sectors have different processes and conditions under which they operate, there is no one-size-fits-all solution. After identifying the technologies, four sectoral workshops have been conducted, one for each of the sectors of industrial, commercial, residential, and transport, to validate the findings of the research and further seek inputs in terms of electrification opportunities. Consultation workshops were also useful to gather inputs regarding the stakeholders' concerns/challenges related to electrification technologies and the identification of possible mitigation measures.

The first report as part of the study is the "Primary Assessment Report," which focuses on the possible electrification opportunities across the four sectors: Industrial, Commercial, Residential, and Transport.

The second report of this study is "Comprehensive Assessment Report", which focuses on different electrification technologies related to industrial and commercial, cost-benefit analysis of the technologies, extra electricity demand analysis due to electrification, and analysis of the carbon emission reduction potential. Extensive secondary research, along with discussions with electrification technology providers and sub-sector-level industry experts, has been leveraged to make the study relevant and practical.

The final part of the study is the development of an electrification roadmap for the Industrial and commercial sectors. The roadmap talks about the specific recommendations across the industrial and commercial sectors with high potential for electrification. The roadmap focuses exclusively on technologies that are either already commercially available or anticipated to become commercially viable by 2030, and which are realistically implementable within the existing framework in India.

1. INTRODUCTION

The global climate emergency—driven by rising greenhouse gas (GHG) emissions—calls for urgent and deep decarbonization. India, as the third-largest carbon emitter globally, contributes about 7.4% of total global emissions[3] in the year 2022. The industrial sector alone accounts for nearly 49% of the total final energy consumption of India[4]. Coal remains dominant, supplying over 59% of India's primary energy demand, highlighting the critical need for cleaner alternatives[5].

In line with the Paris Agreement, India has submitted enhanced Nationally Determined Contributions (NDCs), pledging to reduce the emissions intensity of GDP by 45% by 2030 (compared to 2005 levels), and to achieve net-zero emissions by 2070. These targets reflect a strong global alignment but require bold transformation, particularly in energy-intensive sectors still reliant on coal, oil, and natural gas for heat, steam, and power.

The clean energy transition can be accelerated through **four key pathways:**

- Enhancing energy efficiency and conservation
- Expanding the share of renewable energy in the overall energy mix
- Advancing electrification across all major sectors
- Integrating alternative energy sources such as biofuels (including bioethanol from sugarcane, corn, and rice; biodiesel from vegetable oil, animal fats, and used cooking oil), compressed biogas, and green hydrogen.

A sustainable and inclusive energy transition requires decarbonization of both the electricity supply and fossil fuel-based processes in key economic sectors. While India is progressing toward decarbonizing its electricity grid, targeting 500 GW of renewable energy capacity by 2030, the electrification of fossil-fuel-consuming processes offers a complementary and necessary route. Electrifying industrial and commercial processes allows for greater utilization of renewables as their availability increases over time. Moreover, emphasizing energy efficiency during this transition can significantly reduce associated costs.

Presently, renewable electricity accounts for less than 4% of India's total primary energy consumption[4]. To genuinely pursue a net-zero, this figure must grow dramatically. India can seize this opportunity by designing and implementing policies that actively promote the expansion of renewables in both centralized and decentralized forms.

In tracking its net-zero trajectory, India must closely monitor two important indicators:

[3] https://www.iea.org/countries/india/emissions
[4] Energy Statistics 2024
[5] Energy Statistics 2024

1. **The share of renewable electricity in total primary energy consumption** – capturing how much of the country's overall energy demand is met by renewables.
2. **The share of electricity in final energy consumption** – indicating the extent to which electricity (ideally clean electricity) is being used in end-use sectors.

To increase the **share of renewable electricity in total primary energy consumption**, India should further increase efforts in the following areas:

- Increase solar, wind, and other renewables in total electricity generation
- Promote decentralized generation, including rooftop solar at demand centres
- Implement effective time-of-day tariffs and demand response programs
- Encourage the installation of energy storage systems to manage intermittency
- Expand off-grid renewable solutions, such as solar agricultural pump sets
- Promote waste-to-energy systems for alternative fuel production

To increase the **share of electricity in final energy consumption**, key steps include:

- Replacing fossil fuel-based processes with electric technologies
- Utilizing waste as an alternate energy source in industrial production
- Implementing waste heat recovery systems at the industrial level
- Promoting the use of ultra-efficient electrification technologies such as heat pumps (including high-temperature and steam-generating heat pumps), and Mechanical Vapour Recompression (MVR) systems
- Supporting solar thermal energy storage systems for process heating
- Reduce transmission and distribution (T&D) losses, especially in states with high inefficiencies

The Role of Electrification in Industrial and Commercial Sector Decarbonization: Industrial and commercial sector electrification—shifting from fossil fuel-based processes to electric alternatives—is poised to play a foundational role in India's decarbonization efforts. When paired with renewable energy sources, electrification offers multiple advantages:

- Reduction of direct emissions by eliminating fossil fuel combustion
- Improved energy efficiency, with electric technologies such as heat pumps and electric arc furnaces often surpassing conventional systems
- Potential for lower long-term energy costs due to decreasing renewable prices and reduced fossil fuel price volatility
- Enhanced energy security by lowering dependence on imported fuels

Policy and Regulatory Landscape: India's evolving policy framework reflects growing support for electrification and renewable energy development:

- **Energy Conservation (Amendment) Act, 2022**: Establishes an Indian Carbon Market (ICM) and enables trading through the **Carbon Credit Trading Scheme (CCTS)**. It has two key mechanisms – Compliance mechanism, which aims to address the emissions from its energy use and industrial sectors, and an offset mechanism to incentivize the voluntary actions from entities (not covered under compliance) for GHG reduction, thus providing a comprehensive approach to decarbonization of the economy.
- **Perform, Achieve, and Trade (PAT) Scheme**: Sets sector-specific energy consumption (SEC) targets and allows trading of energy-saving certificates.

- **National Hydrogen Mission**: Promotes green hydrogen as an alternative fuel, particularly for difficult-to-decarbonize sectors.
- **Renewable Energy Targets**: Aims to achieve 500 GW of non-fossil fuel-based capacity by 2030, including 450 GW from solar and wind. India's national Renewable Purchase Obligation (RPO) trajectory for designated consumers has been revised under the Energy Conservation (Amendment) Act, 2022, with the Ministry of Power notification dated 20 October 2023 specifying category-wise targets for the period FY 2024-25 through FY 2029-30. Over this span, the overall RPO rises from 29.91 percent to 43.33 percent of total energy consumption, apportioned across four sub-categories—wind, hydro, distributed renewable energy (e.g., rooftop solar), and other renewables (including biomass, small hydro, etc.)—to drive deeper decarbonization of India's power mix.

Table 1: Indian % RPO trajectory for designated consumers under Energy Conservation Act, 2022

Financial Year	Wind RE (%)	Hydro RE (%)	Distributed RE (%)	Other RE (%)	Total RPO (%)
2024-25	0.67	0.38	1.5	27.35	**29.91**
2025-26	1.45	1.22	2.1	28.24	**33.01**
2026-27	1.97	1.34	2.7	29.94	**35.95**
2027-28	2.45	1.42	3.3	31.64	**38.81**
2028-29	2.95	1.42	3.9	33.1	**41.36**
2029-30	3.48	1.33	4.5	34.02	**43.33**

Despite these positive strides, critical gaps remain. Notably, there is no unified national strategy specifically focused on industrial electrification. Furthermore, current policies are often skewed toward electricity generation, with insufficient attention to end-use electrification.

Socioeconomic and Environmental Drivers: Beyond climate considerations, several socioeconomic and environmental factors make electrification a compelling strategy:

- **Air Quality and Public Health**: Transitioning to electrified processes powered by renewables can significantly reduce emissions of particulate matter and nitrogen oxides (NOx), improving health outcomes
- **Global Competitiveness**: Electrification and clean energy adoption position Indian industries for access to emerging green markets while helping avoid carbon border taxes such as the EU's Carbon Border Adjustment Mechanism (CBAM).

2. VISION & OBJECTIVES

India has set a target to become net zero by 2070 with the aid of decarbonization pathways of renewable energy adoption, accelerated energy efficiency, deep electrification, and extensive biofuel consumption. The current focus of this study is to increase the electrification level at the end-use point, i.e., to increase the share of electricity in the final energy consumption. The other metric that can be used as an alternative is the share of renewable electricity in the total energy consumption at the endpoint. The advantage of this metric is that it reflects both electrification level and renewable electricity adoption, which is a critical aspect of electrification, considering the fact that to achieve the decarbonization goals, both the electrification of fossil fuel processes/operations and renewable adoption should go hand in hand. Nevertheless, considering that the focus of this study is to increase the electrification level at the end point of the industrial and commercial sector, this report will focus on the share of electricity in the final energy consumption. The share of electricity in the total final energy consumption of the industrial sector is 18.7%, and that of the commercial sector is 88% for the year 2022-23[6].

Table 2: Share of electricity in the total final energy consumption of the industry of different continents

REGIONS	*% SHARE*
WORLD	***29.68***
NORTH AMERICA	***27.16***
ASIA	***30.6***
EUROPE	***28.46***
LATIN AMERICA AND THE CARIBBEAN	***29.22***
INDIA (2021-22)	***18.7[6]***

Considering that the Asian industrial electrification level of 30.6% is significantly higher than India's level of 18.7%, this indicates a significant potential for electrification. In the case of the commercial sector, most of the technologies that are required for electrification are commercially available hence, there is a high chance to increase the commercial sector electrification level to nearly 100%.

2.1 Roadmap Objectives

This roadmap aims to identify pathways for electrifying India's industrial and commercial processes, align policies to accelerate the adoption of electric technologies, and mobilize investments for infrastructure, R&D, and workforce development. Industrial electrification is not merely a technical shift but a systemic transformation requiring coordinated action across policy, technology, finance, and society. By addressing challenges head-on and leveraging its renewable energy potential, India position itself as a lobal leader in sustainable industrialization while achieving its climate and development goals.

[6] Energy Statistics 2024

3. BARRIERS FOR ELECTRIFICATION

3.1 Technological limitations persist, particularly in high-temperature industrial processes where cost-effective electric alternatives are under development. Currently, only a small fraction of industrial heating uses renewable energy, mainly biomass. While existing electric technologies could address a significant portion of process heating, adoption is slow. There are limited manufacturers and demonstration projects for very high-temperature heat pumps, and supply chain challenges exist. Integrating new electric technologies into existing infrastructure may be challenging, potentially causing operational disruptions and impacting product quality. The long lifespan of existing equipment creates financial disincentives for early replacement. Diverse industrial sectors and processes necessitate tailored electrification solutions, but high-temperature direct electrification technologies for most sectors (except electric arc furnaces) have low Technology Readiness Levels (TRLs). Indirect electrification via hydrogen also lacks commercial viability and scale.

3.2 Economic barriers include high upfront capital costs and high industrial electricity tariffs in some states. Peak-hour surcharges and regional tariff disparities affect competitiveness. The financial viability and expected ROI of projects are key, but corporate payback expectations might not align with some technologies. Low-cost by-product fuels in some sectors reduce the incentive to electrify.

- High upfront capital costs for new electric equipment and infrastructure redesign are a major hurdle. This includes specialized electric heating solutions like electric boilers, heat pumps, and furnaces.
- Short payback period expectations in the industrial sector often clash with the longer timeframes for realizing electrification's financial advantages.
- The economic feasibility depends on electricity costs being competitive with or lower than fossil fuel costs, which is not yet widespread.
- Securing funding can be challenging due to high interest rates and a perceived lack of risk-sharing mechanisms.
- In India, high industrial electricity tariffs due to cross-subsidization for other sectors make electrification less competitive with cheaper domestic coal. Peak-hour surcharges in many states further increase costs for energy-intensive industries. Significant power rate disparities across Indian states create an uneven playing field.

3.3 Regulatory barriers include a lack of specific policies promoting industrial electrification, complex and lengthy approval processes, ineffective enforcement of RPOs for industrial consumers, inconsistencies in regulations across states and sectors, and policy conflicts. The current RPO framework's effectiveness needs examination. Variations in electricity tariffs and grid connectivity regulations across states create uncertainty. A lack of sector-specific regulations hinders targeted strategies. Policies promoting domestic manufacturing might increase the cost of imported electric technologies. Efforts to improve discom finances could lead to tariff hikes, discouraging electrification.

3.4 Infrastructure limitations include variable grid reliability and frequent power outages in some regions. Challenges in grid connectivity, especially in remote areas, and high transmission and distribution (T&D) losses (around 17.28% in FY2022- 23)[7] impact cost and availability. The high cost and limited deployment of energy storage solutions hinder the integration of variable renewables. Insufficient grid readiness for a high penetration of renewable energy is a concern. Significant differences in power supply reliability exist across Indian states. High T&D losses strain discom finances and may lead to higher tariffs. Adequate and affordable energy storage is needed for grid stability with increasing renewable energy. The grid needs strengthening to integrate more renewables without compromising reliability.

[7] Energy Statistics 2024

4. POLICY & REGULATORT FRAMEWORK

The Indian government has introduced several policies and regulations aimed at promoting the adoption of renewable energy and enhancing energy efficiency, which indirectly support the move towards industrial electrification.

One key policy is the implementation of **Renewable Purchase Obligations (RPOs)** for industrial consumers. These obligations mandate that a progressively increasing portion of an industrial consumer's electricity consumption must be met through renewable energy sources. This policy directly encourages industries to either procure renewable electricity from the grid or invest in their own on-site renewable energy generation facilities to power their operations, including electrified processes. By creating a guaranteed demand for renewable energy within the industrial sector, RPOs serve as a significant driver for investments in renewable energy projects and, consequently, support the use of green electricity for industrial electrification.

India's national Renewable Purchase Obligation (RPO) trajectory for designated consumers has been revised under the Energy Conservation (Amendment) Act, 2022, with the Ministry of Power notification dated 20 October 2023 specifying category-wise targets for the period FY 2024-25 through FY 2029-30. Over this span, the overall RPO rises from 29.91 percent to 43.33 percent of total energy consumption, apportioned across four sub-categories—wind, hydro, distributed renewable energy (e.g., rooftop solar), and other renewables (including biomass, small hydro, etc.)—to drive deeper decarbonization of India's power mix.

Table 3: Percentage of RPO targets notified by the Ministry of Power

Financial Year	Wind RE	Hydro RE	Distributed RE	Other RE	Total RPO
2024-25	0.67	0.38	1.5	27.35	**29.91**
2025-26	1.45	1.22	2.1	28.24	**33.01**
2026-27	1.97	1.34	2.7	29.94	**35.95**
2027-28	2.45	1.42	3.3	31.64	**38.81**
2028-29	2.95	1.42	3.9	33.1	**41.36**
2029-30	3.48	1.33	4.5	34.02	**43.33**

The National Green Hydrogen Mission, launched in 2023, represents another important policy initiative with implications for industrial electrification. The mission aims to establish India as a global hub for the production, utilization, and export of green hydrogen, targeting a production of 5 million tonnes annually by 2030, powered by approximately 125 GW of renewable energy[7].

The government is providing subsidies for the manufacturing of electrolysers and the production of green hydrogen under this mission. Green hydrogen can serve as a crucial energy carrier and feedstock for industrial processes where direct electrification is challenging or not yet feasible, offering an indirect pathway to decarbonize sectors like refineries, fertilizer plants, and steel manufacturing. The government is also actively considering mandating the purchase of green hydrogen for certain energy-intensive industries like fertilizer plants and oil refineries. The Green Hydrogen Mission, therefore, provides a long-term vision for decarbonizing hard-to-abate industrial sectors and stimulates the development of associated infrastructure and technologies.

Beyond these specific initiatives, the government has implemented a range of schemes to promote the broader adoption of renewable energy and improve energy efficiency across various sectors, which indirectly benefit industrial electrification efforts. These include **Production Linked Incentive (PLI)** schemes designed to boost the domestic manufacturing of high-efficiency solar photovoltaic (PV) modules and other critical renewable energy components. The **Perform, Achieve and Trade (PAT)** scheme focuses on reducing the specific energy consumption (SEC) of large energy-consuming industries through a market-based mechanism.

The **Carbon Credit Trading Scheme (CCTS)** is a market-based mechanism established under the Energy Conservation (Amendment) Act, 2022, to create India's domestic carbon market and issue **Carbon Credit Certificates (CCCs)** for verified greenhouse-gas reductions or removals. It transitions the existing Perform, Achieve & Trade (PAT) energy-efficiency scheme into a compliance-grade, intensity-based trading system covering nine energy-intensive sectors from FY 2026, while also embedding a voluntary offset arm for non-obligated entities to register and monetize carbon-reduction projects. The CCTS is jointly overseen by the Ministry of Power, MoEFCC, and administered by the Bureau of Energy Efficiency (BEE), with trading conducted via power exchanges under CERC regulation. Key benefits include incentivizing cost-effective emissions reductions, leveraging proven measurement, reporting, and verification (MRV) infrastructure, fostering liquidity in clean-technology investments, enabling firms to monetize beyond-compliance actions, and laying the groundwork for future linkage with global carbon markets.

Additionally, the **"Go Electric" campaign** aims to raise public awareness about the benefits of e-mobility, charging infrastructure, and electric cooking, signalling a broader government commitment to electrification across different sectors. These diverse policies and schemes collectively contribute to building a more conducive ecosystem for the adoption of clean energy technologies, including those required for industrial electrification.

Furthermore, the government has introduced regulations to promote open access to green energy and has provided temporary waivers on interstate transmission charges for renewable energy projects. These measures are intended to facilitate the direct procurement of renewable power by industrial consumers from off-site renewable energy projects. By reducing the cost and complexity associated with sourcing renewable electricity through open access, the government aims to make it a more competitive and attractive option for industrial consumers, thereby encouraging the electrification of their operations with cleaner energy sources.

4.1 Investment Priorities for Industrial Electrification: Achieving widespread industrial electrification in India necessitates substantial and well-directed investments across various segments of the energy

sector. Prioritizing these investments strategically will be crucial for overcoming existing barriers and accelerating the transition.

4.2 Renewable Energy Generation: A primary investment priority must be the significant expansion of renewable energy generation capacity. This includes sector, utility-scale solar and wind power projects, as well as the promotion of distributed generation within industrial premises. Investments in hybrid renewable energy projects, which combine the strengths of different renewable sources like solar and wind, should also be prioritized to ensure a more stable and reliable power supply [45]. Furthermore, exploring and investing in the potential of other renewable energy sources relevant to industrial applications, such as biomass and small hydro, can contribute to a diversified clean energy mix.

4.5 Grid Infrastructure Expansion and Modernization: Parallel investments in expanding and modernizing the electricity grid are equally critical. This includes the development of new high-capacity transmission lines, the establishment of advanced substations, and the strengthening of inter-regional grid interconnections to effectively transport the increasing volumes of electricity, particularly from renewable energy-rich regions. A significant portion of investment should also be directed towards the deployment of smart grid technologies, such as advanced metering infrastructure (AMI), distribution automation systems, and sophisticated grid management software, to enhance grid efficiency, reliability, and resilience. Exploring and implementing innovative financing models, such as Independent Transmission Projects (ITPs), can help attract much-needed private capital for these essential grid infrastructure upgrades.

4.6 Electrification Technologies: Substantial investments are needed to support the research, development, and widespread deployment of advanced electrification technologies suitable for various industrial applications. This includes technologies for industrial heating, such as high-efficiency electric boilers, industrial heat pumps, induction heating systems, and improved electric arc furnaces for specific industries like steel. Providing financial incentives, including capital subsidies, tax credits, and access to concessional financing, will encourage industries to adopt these cleaner technologies. Furthermore, fostering the development of domestic manufacturing capabilities for electrification equipment and components will not only reduce costs but also create new economic opportunities within the country.

4.7 Energy Storage Solutions: Investments in energy storage solutions are paramount for ensuring grid stability and the reliable integration of intermittent renewable energy sources that will power industrial electrification. This includes prioritizing investments in both battery energy storage systems (BESS) and pumped hydro storage projects, which can effectively manage peak demand and provide essential ancillary services to the grid. Implementing Viability Gap Funding (VGF) schemes and Production-Linked Incentive (PLI) schemes specifically targeted at the manufacturing and deployment of energy storage solutions will be crucial for scaling up capacity[8]. Additionally, exploring and investing in other emerging long-duration energy storage technologies, such as green hydrogen production and storage, will be important for ensuring long-term energy security and grid resilience.

[8] Unlocking India's Energy Transition: Addressing Grid Flexibility Challenges and Solutions

4.8 Research and Development: Increased funding for research and development (R&D) in the field of industrial electrification is essential for driving innovation and developing tailored solutions for the Indian context. This includes supporting R&D efforts focused on advanced electrification technologies for high-temperature processes, the development of more energy-efficient industrial processes, and the creation of smart grid solutions optimized for industrial loads. Promoting strong collaborations between academia, national research institutions, and the industrial sector will facilitate the crucial transfer of knowledge and accelerate the commercialization of innovative technologies. Supporting pilot projects and demonstration facilities will provide valuable real-world testing and validation of new electrification technologies, building confidence and encouraging wider adoption within the industrial sector.

Table 4: Investment Priorities for Industrial Electrification in India

Priority Area	Focus	Potential Funding Mechanisms
Renewable Energy Generation	Solar, Wind, Hybrid Projects, Biomass, Small Hydro	Public funding, private investment, FDI, green bonds
Grid Infrastructure	Transmission lines, substations, and smart grid technologies	Public funding, private investment (e.g., ITPs), and multilateral development bank loans
Electrification Technologies	Electric boilers, heat pumps, induction heating, electric arc furnaces domestic manufacturing	Capital subsidies, tax credits, concessional financing, PLI schemes
Energy Storage Solutions	Battery energy storage systems, pumped hydro storage, and green hydrogen	VGF schemes, PLI schemes, private investment, infrastructure bonds
Research and Development	Advanced electrification technologies, energy efficiency, and smart grid	Government grants, industry partnerships, venture capital

5. POLICY RECOMMENDATION

5.1 Regulatory Reform:

a) Rationalize Cross-Subsidy & Additional Surcharges: Exorbitant cross-subsidy surcharges (CSS) and additional open-access charges in states like Maharashtra, Karnataka, Tamil Nadu, and Gujarat inflate renewable procurement costs by 20–40%, negating cost savings for industries.

Proposed Measures:

- Cap CSS at 20% of the average cost of supply (as recommended by the Forum of Regulators)[9].
- Eliminate "additional surcharges" for third-party and group captive projects
- Harmonize inter-state open-access regulations to enable seamless RE procurement across state boundaries.

This would reduce the cost disparity between grid and renewable power, fostering competition and enabling industries to meet RPO targets cost-effectively.

b) Enhance Banking Facilities & Capacity Rules

Restricting the capacity of the on-site renewable energy plant as per the contract demand or the capacity of the distribution transformer/ feeder should be done away with. Discoms should provide banking facilities for captive and open access renewable energy consumers.

Proposed Measures:

- Permit yearly settlement/ accounting for the power generated from solar and wind plants, by providing banking facilities throughout the year
- Remove grid contract demand-linked capacity restrictions, allowing industries to size solar/wind projects to match actual load profiles (e.g., 100% of daytime demand).

c) Empower Electricity Regulatory Bodies

Weak enforcement of regulations (e.g., non-compliance with RPOs, green open access implementation) undermines investor trust and policy effectiveness. Amend the Electricity Act 2003 to empower regulators (CERC, SERCs) with statutory authority to:

- Impose proportionate penalties (e.g., ₹0.50–1.0/kWh for RPO non-compliance).
- Resolve disputes (e.g., open-access denials) within 60 days.
- Mandate quarterly public disclosure of DISCOM compliance with RE targets.

This will ensure timely enforcement of rules, improve the accountability of DISCOMs, and provide a predictable regulatory environment for renewable energy developers.

[9] https://forumofregulators.gov.in/Data/study/Final%20Report%20of%20FOR-GEOA.pdf

d) Compensate DISCOMs for Providing Banking Facilities

Banking facilities allow industries to "store" surplus solar power in the grid, but DISCOMs incur losses as the non-solar hours power exchange electricity charges are very high compared to solar hours. Rationalize banking charges so that DISCOMs could recover costs linked to banking service (e.g., grid balancing, administrative costs) through a transparent process approved by regulators.

This would incentivize DISCOMs to offer banking services, while industries retain the economic benefit of captive consumption of renewables.

5.2 Financial Incentives & Market Mechanisms:

i) Launch a Concessional Loan Window & Blended Finance Facility

High upfront costs and perceived risks deter MSMEs and first-time adopters from investing in energy-efficient electrification technologies like heat pumps, MVR, and Battery Energy Storage Systems (BESS). A dedicated financing mechanism is critical to bridge this gap.

Proposed Measures:

- Establish a ₹10,000 crore low-interest (5%) loan window under IREDA/SIDBI, specifically targeting electrification technologies. MSME loans to be backed by a 50% partial credit guarantee from the Government of India to de-risk lenders.
- Introduce a blended finance facility combining concessional loans (5% interest) and private equity to reduce the weighted average cost of capital (WACC) for MSMEs to below 8%.

ii) Accelerated Depreciation Benefit for Electrification Projects

Current depreciation rates delay ROI for industries, discouraging capital-intensive electrification upgrades. Amend the Income Tax Act to allow 80% accelerated depreciation in the first year for investments in:

- Electrification technologies (e.g., heat pumps, MVRs, BESS).
- Extend this benefit to group captive projects where multiple MSMEs collectively invest in shared electrification infrastructure.

iii) Custom Duty & GST Exemption on Electrification Technologies

Import duties (up to 25%) and GST (18%) on critical components like BESS inverters and heat pump compressors inflate project costs by 20–30%, discouraging accelerated adoption.

Proposed Measures:

- Waive customs duties for 5–7 years on technologies with limited domestic manufacturing (e.g., high-efficiency heat pumps, lithium-ion BESS).
- Reduce GST from 18% to 5% on all electrification technologies
- Link exemptions to phased Make in India milestones (e.g., duties reinstated gradually once domestic production meets 30% of demand).

This lowers upfront costs by 15–20%, attracting global OEMs to set up local manufacturing.

iv) Mobilise Funds via Clean Coal CESS

The National Clean Energy Fund (NCEF), funded by the ₹400/ton coal cess, has been underutilized since GST subsumed the cess in 2017. Reclaiming this revenue stream can fund electrification pilots. Post-GST compensation period (post-2026) and earmark coal cess revenues for:

- Grants covering 30–40% of the electrification project costs for industrial and commercial sectors, including MSMEs
- Fund pilot projects for the implementation of emerging high-impact electrification technologies
- GST compensation CESS may be imposed on an ad-valorem basis wherein the CESS would be directly related to the price and quantity of the coal, instead of the present levy of a fixed amount of Rs 400 per ton, as suggested by the inter-ministerial committee[10].

High investments required to upgrade the infrastructure related to shifting from captive power to grid/green open access can be compensated using the CCTS offset mechanism.

v) Expand Production-Linked Incentive (PLI) Schemes for more Electrification Technologies.

Extend the PLI scheme for advanced chemistry cell (ACC) batteries to cover industrial electrification technologies like heat pumps and mechanical vapour recompression (MVR) systems.

vi) Bulk Procurement of Electrification Technologies via EESL

Fragmented demand and small order volumes prevent economies of scale, keeping prices high for technologies like BESS and electric boilers.

Proposed Measures:

- Further empower Energy Efficiency Services Limited (EESL) to aggregate demand and execute bulk tenders for electrification technologies, replicating its successful LED and smart meter models.
- Establish technology-specific task forces (e.g., BESS, heat pumps) under EESL to standardize specifications, certify vendors, and negotiate 30–40% cost reductions through volume guarantees.

vii) Cluster-Based Approach for Renewable Power & BESS Deployment

MSMEs lack the scale to negotiate competitive renewable tariffs or invest in standalone BESS, leaving them dependent on expensive grid power.

Proposed Measures:

- Aggregate demand at the cluster level (e.g., Surat's textile cluster, Coimbatore's engineering units) and conduct reverse auctions for bundled solar/wind power at tariffs below ₹4/kWh.
- Deploy AI-driven demand forecasting to size BESS capacity accurately (e.g., 10–20% of cluster demand) and optimize daily load cycles.
- Offer central grants to states to subsidize 30% of BESS costs in clusters

[10]https://www.business-standard.com/industry/news/inter-ministerial-committee-suggests-higher-tax-on-imported-coal-124030701079_1.html

5.3 Sub-sector Specific Recommendations

a) Steel and Cement

Accelerate the Green Hydrogen Mission to decarbonize high-heat processes in the Iron & Steel and Cement sub-sectors. Promote electric arc furnaces (EAFs) and hydrogen-based direct reduction (like Sweden's HYBRIT project) in Odisha/Jharkhand, leveraging India's target of 5 million metric tons of green hydrogen by 2030.

b) Refinery, Petrochemical, and Fertilizer sectors

Provide adequate financial support and tax incentives in line with the earlier mentioned policy recommendations to the refinery, petrochemical, and fertilizer sectors to adopt commercial electrification technologies, which have good potential to reduce fossil fuel consumption. The electrification technologies like high temperature heat pumps, mechanical vapour recompression (MVR) systems, electric boilers, and battery energy storage systems (BESS) have good potential for electrification in these sectors.

Stakeholder Consultation Photos

Figure 3: Stakeholder consultation with sectoral experts in Hyderabad, and BEE, September 13, 2024

6. GRID MODERNIZATION & RENEWABLE ENERGY INTEGRATION

To enable large-scale industrial electrification, India must prioritize modernizing its grid infrastructure and harmonizing energy demand with renewable generation patterns. India should accelerate investments in smart grid technologies, such as advanced metering infrastructure and AI-powered demand forecasting systems, coupled with utility-scale energy storage solutions like battery parks and pumped hydro storage. These upgrades are critical to managing the intermittency of solar and wind energy, particularly during peak industrial demand cycles.

Adopting effective time-of-use (ToU) tariffs would incentivize industries to shift flexible operations, such as electric furnace runs or EV charging, to daylight hours when solar generation peaks, reducing reliance on fossil-fuel-based peak demand plants. By pairing grid modernization with dynamic pricing, India can lower industrial energy costs, minimize curtailment of renewables, and try to achieve 60% renewable grid reliability even under extreme demand fluctuations.

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7. FINANCIAL STRATEGIES

7.1 Sources for Industrial Electrification

Securing adequate funding is critical for the successful implementation of industrial and commercial electrification projects in India. A variety of funding sources are available, spanning the public and private sectors, as well as international collaborations.

a) Public sector entities play a vital role in providing financial support and driving the initial growth of renewable energy and electrification initiatives. Key non-banking financial companies (NBFCs) such as REC Limited and Power Finance Corporation (PFC) are major financiers across the entire power sector value chain, including the provision of substantial financial assistance to renewable energy projects and related infrastructure. The Indian Renewable Energy Development Agency (IREDA), a government-backed financial institution, specializes in offering concessional loans and other financial products specifically for renewable energy projects, making it a crucial source of funding for industries looking to adopt renewable power for their electrified operations. These public sector entities provide the long-term financing and stability often required for large-scale energy infrastructure development. SIDBI (Small Industries Development Bank of India) plays a crucial role in climate finance by providing concessional loans and supporting the adoption of green technologies by MSMEs (Micro, Small, and Medium Enterprises).

b) Private sector is also increasingly contributing to the funding landscape for clean energy and industrial technology through private equity and venture capital investments. These investments are flowing into various segments of the ecosystem, including the manufacturing of electric vehicles, the development of EV charging infrastructure, and the establishment of renewable energy generation projects.[11]. The International Finance Corporation (IFC) is significantly increasing its investments in India, with a specific focus on supporting the nation's climate goals, including initiatives in industrial decarbonization and renewable energy development. For example, IFC's funding to Grasim Industries Limited will help it accelerate its corporate-wide decarbonization measures, incentivizing a reduction in fossil fuel energy usage[12]. The growing interest from private equity and venture capital indicates a strong belief in the growth potential of the clean energy sector and its relevance to industrial electrification. Debt financing and loan options, including conventional bank loans, are vital for financing electrification projects.

c) International financial institutions, such as the World Bank and the Asian Development Bank (ADB), are also playing a crucial role in providing funding and technical assistance for India's low-carbon transition. The World Bank has approved financing to support India's efforts in developing a vibrant market for green hydrogen, scaling up renewable energy capacity, and stimulating finance for low-carbon energy investments[13]. Similarly, the ADB supports various infrastructure development projects

[11] https://evboosters.com/ev-charging-news/investment-in-indian-electric-mobility-industry-surges/

[12] https://www.ifc.org/en/pressroom/2024/ifc-ramps-up-investment-in-india-to-drive-financial-inclusion-create-jobs-and-unlock-climate-finance

[13] World Bank Approves Additional $1.5 Billion in Financing to Support India's Low-Carbon Transition

in India, including those in the energy sector, contributing to the financial resources available for industrial electrification-related initiatives[14]. These international collaborations provide access to concessional financing and global best practices in clean energy transition.

d) Green bonds have emerged as a significant funding instrument specifically for environmentally beneficial projects, including those related to renewable energy and potentially for industrial electrification. India has become a prominent issuer of green bonds, with both sovereign and corporate entities utilizing this mechanism to raise capital for green infrastructure and renewable energy projects.[15]. The proceeds from these bonds are directed towards projects with clear environmental benefits, such as the development of solar and wind power plants. Green bonds attract investors who prioritize environmental, social, and governance (ESG) factors in their investment decisions, providing a dedicated funding avenue for the green transition.

e) Development of a robust carbon market in India presents a potential future funding source for industrial electrification projects. India is in the process of establishing a national framework for a carbon market to incentivize the reduction of greenhouse gas emissions across various sectors.[16]. The existing Perform, Achieve and Trade (PAT) scheme demonstrates the potential of market-based mechanisms to drive emission reductions. As the carbon market matures, industries that invest in cleaner technologies like electrification and achieve verifiable emission reductions could potentially generate and trade carbon credits, creating a new revenue stream that can further improve the financial viability of these projects.

7.2 Innovative Financial Models for Industrial Electrification

Several innovative financial models, beyond conventional funding sources, show great potential for speeding up industrial electrification in India.

The Energy Service Company (ESCO)[17] model offers a comprehensive approach to implement energy efficiency and electrification projects in the industrial sector with minimal upfront investment from the industry itself [23]. ESCOs are companies that provide a complete package of energy efficiency solutions, including identifying opportunities, designing the project, arranging financing, and installing the equipment. Their earnings are directly linked to the actual energy savings achieved by the project through a performance-based contract. This model can be particularly beneficial for industries, especially SMEs, that may lack the technical expertise or capital to undertake such projects independently. Both shared savings models, where the ESCO and the client share the energy cost savings over a contract period, and guaranteed savings models, where the ESCO guarantees a certain level of savings, can be utilized. Energy Efficiency Services Limited (EESL) is a prominent example of a "Super ESCO", actively promoting energy efficiency across various sectors using this model. The ESCO model effectively transfers the technical and financial risks associated with energy efficiency and electrification projects from the industrial client to the ESCO.

[14] A Snapshot of the Public–Private Partnership Monitor: India

[15] India incorporates green bonds into its climate finance strategy

[16] Carbon Market | BUREAU OF ENERGY EFFICIENCY, Government of India, Ministry of Power

[17] ESCO contracts – Energy Service Companies (ESCOs) – Analysis - IEA

On-bill financing mechanisms offer another innovative way to fund industrial energy efficiency and electrification upgrades [18]. This approach allows utility customers to repay the cost of energy improvements through their regular monthly utility bills. On-bill financing can eliminate the need for a large upfront capital outlay from the industrial consumer, making upgrades more accessible. The repayment is often structured to be bill-neutral or even cash-flow positive for the customer, as the energy savings offset the financing costs. Distribution companies (Discoms) can play a crucial role in offering or facilitating on-bill financing programs for their industrial customers.

Public-Private Partnership (PPP) models present a viable strategy for developing large-scale infrastructure projects necessary to support widespread industrial electrification. PPPs involve collaboration between the government and private sector entities, leveraging the strengths and resources of both to achieve shared objectives[19]. In the context of industrial electrification, PPPs can be particularly effective for projects such as the modernization of the electricity grid to enhance reliability and capacity, the development of large-scale renewable energy generation facilities dedicated to industrial use, and the establishment of charging infrastructure for electric industrial vehicles [15]. PPPs have already been successfully implemented in India's power sector, especially in renewable energy generation and distribution [15]. The government is also exploring the potential of PPPs in emerging areas like nuclear power generation for industrial applications[20]. These partnerships can attract private capital, bring in specialized expertise, and enhance the efficiency of infrastructure development, crucial for supporting industrial electrification at scale.

Blended finance—the strategic use of development finance or philanthropic capital to attract greater private capital for key objectives—must be a part of the strategy. Blended finance instruments include grants, guarantees, concessional or subordinate debt, and equity. These instruments would allow development finance institutions such as the World Bank and major philanthropists—with higher tolerance for risk and access to patient capital—to instil confidence in, and adjust the risk downward for, private capital. The below tables contain examples of blended finance models from across the world.

Table 5: Blended Finance Models across the world

Country/ Project	Model Name	Key Players	Mechanism	Impact	Challenge
Pan-African	African Development Bank's R2RS	AfDB, Private Investors	$2B synthetic securitization transferring sovereign risk to private markets	Mobilized $2B for infrastructure/social projects	Complexity in risk-sharing structures
Kenya	Lake Turkana Wind Power	AfDB, European DFIs, Private Equity	Blended debt (public concessional loans + private equity) for wind farm	Supplies 15% of Kenya's electricity	High upfront costs, political risks

[18] Enhancing Energy Equity Through On-Bill Financing | EESI

[19] https://www.adb.org/sites/default/files/publication/994856/public-private-partnership-monitor-india-brochure.pdf

[20] India: Private Investments Power $125 Billion Clean Energy Push | Global Finance Magazine

Amazon Region	IDB's Amazon Sustainable Bonds	Inter-American Development Bank, Private Investors	Green bonds + philanthropic grants for rainforest conservation	Raised $200M for sustainable livelihoods	Long-term community engagement
Colombia	Green Growth Strategy	Colombian Govt, IFC, Private Banks	First-loss capital for renewables/sustainable agriculture	Leveraged $500M in climate investments	Scaling beyond pilot projects
India	National Investment and Infrastructure Fund (NIIF)	Indian Govt, Abu Dhabi Investment Authority	Sovereign fund blending public anchor investments with private capital	Mobilized $4.3B for infrastructure	Bureaucratic delays in approvals
ASEAN	ADB's ASEAN Catalytic Green Finance Facility	ADB, ASEAN Govts, Private Investors	Concessional loans + technical assistance for green infrastructure	Funded $1.4B in solar farms	Regulatory fragmentation
EU	European Fund for Sustainable Development (EFSD+)	European Commission, DFIs	Guarantees/blended finance for African/EU neighbourhood projects	Triggered €54B in investments	Balancing geopolitical vs. development goals
UK	British International Investment (BII)	BII, Private Equity Firms	Equity investments with concessional terms in SMEs	Supported 30,000 jobs (2022)	Measuring indirect social outcomes
Global (Africa focus)	U.S. DFC Blended Finance Program	U.S. DFC, Foundations	Grants/guarantees for health/energy access	Catalysed $1B for off-grid solar	Alignment with U.S. foreign policy

8. SECTORAL ANALYSIS & PRIORITIZATION

8.1 Industrial Sector Analysis

The current level of electrification at the national level is 21.9%, and that of the industrial sector is 18.7%. The industrial sector electrification level in India is much lower than the world average and the Asian average of 29% and 30%21, respectively. There are commercially available technologies that can increase the electrification level in the Indian Industrial sector, which will be discussed as part of this section. The fossil fuel usage in the industrial sub-sector can be divided into three main categories namely –**Direct heating systems** (where the target material is directly heated), **Indirect heating applications** use mediums like steam and thermic fluid heaters and **Captive power generation.**

8.1.1 Direct Heating

Direct heating applications generally need higher temperatures, and electrification technologies like induction furnaces, electric arc furnaces, and resistive furnaces are currently being used for multiple applications across sectors. Direct heating applications, especially related to the sub-sectors of Iron & Steel and Cement, are seeing significant action in terms of research and development due to significant decarbonization/electrification opportunities available. Cement kilns and blast furnaces use significant coal in India, but there are no commercially available technologies currently to electrify these processes. Liquid fuel-fired furnaces are increasingly being replaced with electricity-based furnaces in India.

8.1.2 Indirect Heating

Indirect heating is extensively used in all process industries, with the medium mostly being steam or thermic fluid. In the process industries, steam is produced either in co-generation mode or in non-cogeneration mode (exclusive process boiler). In the cogeneration mode, both the steam and electricity are produced simultaneously; hence, the heat rate of the electricity produced is much lower, and the overall system efficiency is much higher. In some cases, steam is produced only for the purpose of indirect heating, for example, in sub-sectors like pharma, dairy, small paper, small textile (wet process), etc. The temperature for these indirect electric heating processes is mostly less than 250 ° C. With the commercial availability of technologies like high-temperature heat pumps (HTHP) / steam-generating heat pumps and mechanical vapor recompression (MVR) systems, most of the indirect heating processes in the Indian Industry can be electrified.

A) Process Boiler-Based Indirect Heating (Textile, Pharma, Dairy, Chemical Etc.)

In sub-sectors where steam is produced only for indirect heating and co-generation is not in practice like in the case of small textile (wet processing), pharma, dairy, small chemical, and paper (medium and small) there is a good opportunity to move towards electrification with the help of technologies like HTHP/steam generating heat pumps and mechanical vapour recompression MVR) systems.

[21] https://unstats.un.org/unsd/energystats/pubs/documents/2024pb-web.pdf

A detailed analysis has been carried out as part of the study to estimate the process boiler coal consumption used for indirect heating purposes. The details of the analysis are provided below.

Table 6: Estimation of process boiler coal consumption used for indirect heating purposes

Sub-sectors	Coal consumption (Th tonnes)	Net captive power gen (GWh)	Heat rate* (kcal/kWh)	Coal calorific** value (kcal)	Estimated coal consumption of Captive incl. co-gen (Th tonnes)	Estimated process boiler coal consumption (Th tonnes)
Paper	4495	6441	1700	4000	2737	1758
Chemical	6906	7845	3000	4000	5884	1022
Textile	5797	2532	3000	4000	1899	3898
Pharma	1893	0	0	0	0	1893
Total						**8571**

 # Author analysis based on CEA and ASI data
**Assumed heat rate based on previous studies*
***Assumed calorific value*

Based on the above analysis, about 8,571 Th tons of coal is being consumed in the industry across sub-sectors of paper, chemical, textile and pharma for indirect heating which is not based on co-generation. There is a significant electrification opportunity available which can be achieved with focused and sustained efforts by all related stakeholders.

The opportunity also has significant challenges in terms of integrating the electrification technologies into the existing process in an efficient and economical way. The industrial processes/systems are different across sub-sectors and also within the sub-sector further complicating the implementation process.

Electrification technologies like high-temperature heat pumps (HTHP), mechanical vapor recompression (MVR) systems, electric boilers, and battery-energy storage systems (BESS) will be the key technologies that will enable the transition.

B) Co-generation-based indirect heating

Producing steam and electricity simultaneously has the advantage of higher system efficiency than producing steam for process use and producing electricity independently. However, this efficiency cannot be more than 100% instead of using electrification technologies like high-temperature heat pumps (HTHP) and mechanical vapor recompression (MVR) systems and integrating them into the process the overall efficiency can be more than 100%, which is as high as 300% to 500% based on the waste heat availability in the plant and temperature required for the process.

Since electrification technologies are much more efficient than even co-generation-based systems as discussed above, most of the indirect heating requirements in the industrial sub-sectors can be met by these latest electrification technologies like HTHP and MVR.

Since HTHP and MVR systems are more efficient than cogeneration systems, it may be technically possible to eliminate all coal consumption in sub-sectors such as paper, chemical, textile, dairy, and pharmaceuticals — including that used in cogeneration. However, actual implementation will depend on a cost-benefit analysis based on current fuel and electricity prices at the individual industry level.

Based on the coal consumption data available at the sub-sector level for these sectors as per the Annual Survey of Industries (ASI) data, it is estimated that about 18775 Th tonnes[22] of coal (this includes the coal savings mentioned in the previous section) can be saved in the above-mentioned industrial sub-sectors including the co-generation-based systems.

8.1.3 Captive Power Generation

Captive power generation refers to the process of producing electricity on-site rather than importing from the grid. While this approach meets local energy needs, it reduces the overall electrification level at both the industrial and national scale, as it increases fossil fuel use at the point of consumption. Theoretically, captive generation could be replaced by grid power or grid-based renewable energy, but practical challenges to this transition will be discussed in a later section.

In India, captive power generation has been a norm for all large process Industries for quite a long time due to various reasons including lower power costs of captive power plants (which is not the case currently), issues related to grid reliability, non-availability of grid infrastructure etc. The captive power generation capacity varies from sector to sector from as low as 1 MW to as high as more than 100 MW. The actual size-wise installed capacity of captive power in India as per CEA is given below.

Table 7: Installed capacity of Captive Power as per CEA

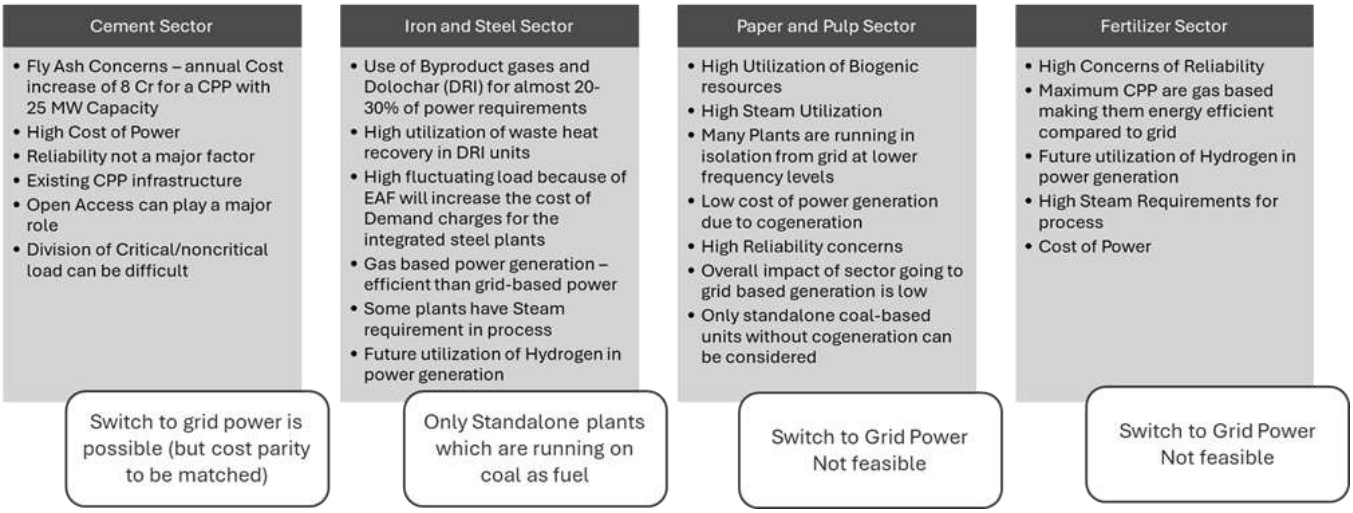
Range of Installed Capacity	No of Industries	% of total capacity	% of total Generation	Cum % of Gen	Cum Total no of Industries
1 to 10 MW	8544	24.69	5.38	100	9711
10 to 20 MW	510	9.63	5.66	94.62	1167
20 to 30 MW	254	8.32	6.4	88.96	657
30 to 40 MW	117	5.37	5.02	82.56	403
40 to 50 MW	82	4.97	5.44	77.54	286
50 to 100 MW	128	11.92	15.77	72.1	204

[22] Include coal consumption of paper, chemical, textile, dairy, and pharmaceuticals in the year 2021-22 as per the Annual Survey of Industries 2024

Over 100 MW	76	35.09	56.33	56.33	76
Total	**9711**	**100**	**100**		

There can be a two-pronged approach to shift from captive power plants to the grid. The first one is by shifting all the small captive power plants which generally have lower heat rates than average heat rate of large Utility Power Plant. The second is by taking a sectorial approach and focusing on addressing the challenges and barriers related to shifting from captive to grid power in that sector. The following figure summarizes insights from the earlier sectoral study conducted by CII (the consortium partner of the study).

Figure 4: Summary of sub-sector level analysis possibility of shifting from captive power to grid power based on CII's study



Under this study, further analysis and discussion have been conducted to identify the sub-sectors that can shift from captive to grid power. Based on the in-depth analysis of the industrial sub-sectors the sub-sectors of Cement and Aluminium are found to be good candidates for shifting to the grid, however sub-sector-specific and plant-specific concerns have to be addressed as a pre-requisite.

The Cement sector's captive power plants are generally smaller, with an average heat rate above 3,000 kcal/kWh compared to the grid's average heat rate of 2,375–2,600 kcal/kWh[23], as per technical studies by the Confederation of Indian Industry (CII).

With respect to the Aluminium Smelter sub-sector, since the associated captive power plants are of higher capacity, the heat rates are generally good. Hence, only the cases where the heat rates are relatively higher, should be considered for shifting from captive to grid from the energy efficiency point of view. In the short to medium term, the Aluminium smelter plants should look at moving a certain share of captive power to round-the-clock power. In the long run, all of them can be shifted to the grid in a phased manner as the grid becomes greener and the grid becomes more reliable.

[23] https://cea.nic.in/wp-content/uploads/tpp___d/2024/03/Report_on_finalization_of_Norms_for_ACQ_for_TPPs.pdf

Based on the data from CEA[24] and Annual Survey of Industries (ASI)[25] for the year 2021-22 the coal consumption has been bifurcated between captive power plant consumption and process consumption based on certain assumptions. This data will be used for future analysis in this report.

Table 8: Bifurcation of captive power plant and process coal consumption

Sub-sector	Coal quantity consumed (Th. Tonnes)	Net Stem power generation (GWh)	Heat rate (kcal/kWh)*	Coal calorific value (kcal/kg)	Coal consumption for captive generation including co-gen (Th. Tonnes)	Process coal consumption (Th. Tonnes)
Cement	27375	17247	3000	4000	12935	14440
Chemical	6906	7845	3000	4000	5884	1022
Textile	5797	2532	3000	4000	1899	3898
Paper	4495	6441	1700	4000	2737	1758

 # Author analysis based on CEA and ASI data
**Assumed heat rate based on previous studies.*
***Assumed calorific value*

8.2 Commercial Sector

The major fossil fuel-consuming sub-sectors in the commercial sector are hotels, hospitals, malls, and office spaces. Based on detailed analysis, all these sectors have significant potential to replace fossil fuel consumption with electricity. Some operations where fossil fuel consumption can be reduced or eliminated are outlined below for each of these high fossil fuel-consuming sub-sectors.

The study has focused on identifying the fossil fuel-consuming operations in these establishments and mapping them with technologies that can electrify those operations. The details of this mapping are provided below.

8.2.1 Commercial sector processes and technologies

a) Hotels: The hotel sub-sector consumes fossil fuels like LPG, PNG, HSD, etc. for generating steam using a boiler, DG set operations, cooking, etc. The steam generated in the hotels is used for multiple applications like cleaning, cooking, laundry, etc. The possible electrification technologies for hotels are hot water-generating heat pumps, steam-generating heat pumps, electric boilers, battery energy storage systems (BESS), and Induction stoves.

[24] All India Electricity Statistics
[25] Annual survey of industries for 2021-22

b) Hospitals: In hospitals, the major fossil-fuel-intensive equipment are boilers, DG sets, and cooking equipment. The applications where steam is being used in hospitals are for cleaning, laundry, food preparation, medical equipment sterilization, etc. The new key technologies that can electrify the fossil fuel consuming process in the hospital are hot water-generating heat pumps, steam-generating heat pumps, electric boilers, battery-energy storage systems (BESS), and Induction stoves.

C) Malls/Airports: The fossil-fuel-consuming equipment in the malls/airports are boilers, DG sets, and cooking equipment. Not all malls/airports would have boilers, but most of them would have DG sets and cooking equipment. Wherever boilers are available, the applicability of heat pumps and electric boilers can be explored, apart from battery-energy (BESS) storage in place of DG sets and induction stoves in place of LPG cooking equipment.

D) Commercial Office Space: Most of the commercial office spaces use fossil fuel-consuming equipment like DG sets and wherever the canteen facility is available, equipment like fossil fuel-based boilers and LPG-based cooking equipment is used. The major technologies for electrifying fossil fuel-consuming applications are battery-energy storage systems, heat pumps, electric boilers, and LPG stoves.

Table 9: Mapping commercial sector operations with electrification technologies

Sub-sector	Operations	Usage	Solution - Commercially available
Hotels	Food preparation	Steam from fossil fuel boiler	Steam generation heat pump up to 120°C, Electric boiler
	Laundry	Steam from fossil fuel boiler	High-temperature heat pump
	Cleaning	Steam from fossil fuel boiler	High-temperature heat pump
	LPG cook stove	LPG as fuel	Electric induction stove
Malls	Food preparation	Steam from fossil fuel boiler	Steam generation heat pump up to 120°C, Electric boiler
	Hot water	Steam from fossil fuel boiler	High-temperature heat pump
	LPG cook stove	LPG as fuel	Electric induction stove
Hospitals	Sterilization	Steam from fossil fuel boiler	Steam generation heat pump up to 120°C, Electric boiler
	Food preparation	Steam from fossil fuel boiler	Steam generation heat pump up to 120°C, Electric boiler

	Laundry	Steam from fossil fuel boiler	High-temperature heat pump
	Hot water	Steam from fossil fuel boiler	High-temperature heat pump
	LPG cook stove	LPG as fuel	Electric induction stove

Source: Author Analysis

Additionally, all commercial establishments use power generators, typically diesel-based, as backup power sources. These generators contribute to pollution in already densely populated commercial areas. The operation of diesel generator (DG) sets depends on the frequency and duration of power cuts/outages, which vary based on the region and the voltage of the distribution network.

As the price of Battery Energy Storage Systems (BESS) continues to decrease, replacing DG (diesel generator) sets with BESS is becoming more economical. This switch can reduce carbon emissions if the power is sourced from renewable energy. According to the Central Electricity Authority's general review report for 2023, there are 1,599 non-industrial captive generating plants above 0.5 MW, with a total installed capacity of 4,694 MW for 2021-22 and a total generation of 620 GWh[26]. By replacing DG sets with BESS, fossil fuel consumption for electricity generation can be reduced, and the electricity can be sourced from renewable energy and stored as backup power. The capacity of BESS needs to be designed based on the maximum load and backup duration required, depending on the nature of the business operations and power reliability in the operating region.

Considering that the commercial sector primarily uses diesel, LPG, and PNG, and many technologies required for electrifying fossil fuel-consuming processes are already commercially available, it is feasible for the commercial sector to target 100% electrification, provided the genuine concerns of commercial entities are addressed.

One specific technology that is not yet commercially available but could serve as a future power backup solution for the commercial sector is the compressed air-based power backup system. This was suggested during one of the stakeholder consultation workshops.

Almost all the fossil fuel consumption in the commercial sector can be electrified except for few processes in the cooking application.

As per the analysis in the study almost all the boilers in the commercial building sector can be replaced with electric technologies like heat pumps and electric boilers.

Some common barriers and challenges to the electrification of the commercial sector include power reliability & quality, high initial costs of electrification technologies, and reliability of the new electrification technologies.

[26] All India Electricity Statistics

9. RECOMENDATIONS & PROJECTIONS (BASED ON THE ROADMAP)

9.1 Industrial Sector Recommendations

The key study recommendations for the industrial sector electrification in order of priority are given below:

1. Electrify all process boilers using HTHP and MVR technologies.
2. Transition of the cement sector from captive power to grid power after addressing plant-specific challenges.
3. Shift from co-generation power to grid power and meet steam requirements using HTHP and MVR technologies.
4. Transition, Aluminium smelters from captive power to grid power in the long term, as the grid becomes greener and more reliable.
5. Replace diesel generator (DG) sets in industrial establishments with battery-energy storage systems (BESS).

In addition to the technologies mentioned above, other electrification technologies, such as infrared heating, microwave heating, radio frequency heating, and round-the-clock renewable energy solutions, can also be leveraged to enhance the electrification process.

With the implementation of these measures, the industrial electrification level can increase from **18.7% to 25.3%**, moving closer to Asia's average of 30%. This is a conservative estimate made based on the industrial sub-sector level energy consumption data provided by the Annual Survey of Industries (ASI) 2021-22 released in the year 2024.

The emission reduction potential by implementing the above recommendations in different scenarios for the current grid emission factor of 0.727 kg CO2e/kWh, CEA forecasted grid emission factor of 0.43 kg CO_2e/kWh for the year 2031-32, and a complete renewable power consumption scenario is given below:

Table 10: Carbon Emission Reduction in current scenario, 2030 scenario as per CEA emission forecast, 100% renewable scenario

Electrification options		Estimated share of electricity in industrial final energy consumption (%)	Reduction in emissions by shifting to renewable instead of grid power (Million-ton CO_2e)	Net emission reduction by shifting to grid power	
				At 0.727 grid emission factor (Million Ton CO_2e)	At 0.43 grid emission factor (Million-ton CO_2e)
A	Process Boilers	19.89%	18.01	2.62	8.91
B	Cogeneration	20.18%	22.01	0.38	9.22
C	*Cement Captive	19.95%	26.68	14.14	19.26
D	*Aluminium captive	21.93%	72.23	30.51	47.55
S1	Process Boiler + Cogen	21.08%	40.02	3.01	18.13
S2	Process Boiler + Cement Captive	20.85%	44.69	16.77	28.17
S3	Process Boiler + Cogen + Cement Captive	22.09%	66.70	17.15	37.39
S4	Process Boiler + Cogen + Cement Captive + Aluminium Captive	25.30%	138.92	47.66	84.94

*Cement captive means a captive power plant in Cement Mill, and Aluminium captive means a captive power plant in Alluminium manufacturing plant.

By implementing all four recommended measures, there is a potential to reduce emissions by 47.66 and 84.94 and 138.92 million tons of CO_2e under the different emission factors of 0.727, 0.43, and 0 (renewable power consumption) kg CO2e/kWh, respectively.

Figure 5: Emission reduction potential in different scenarios based on the current grid emission factor of 0.727 kg CO2e/kWh in Million-ton CO2e

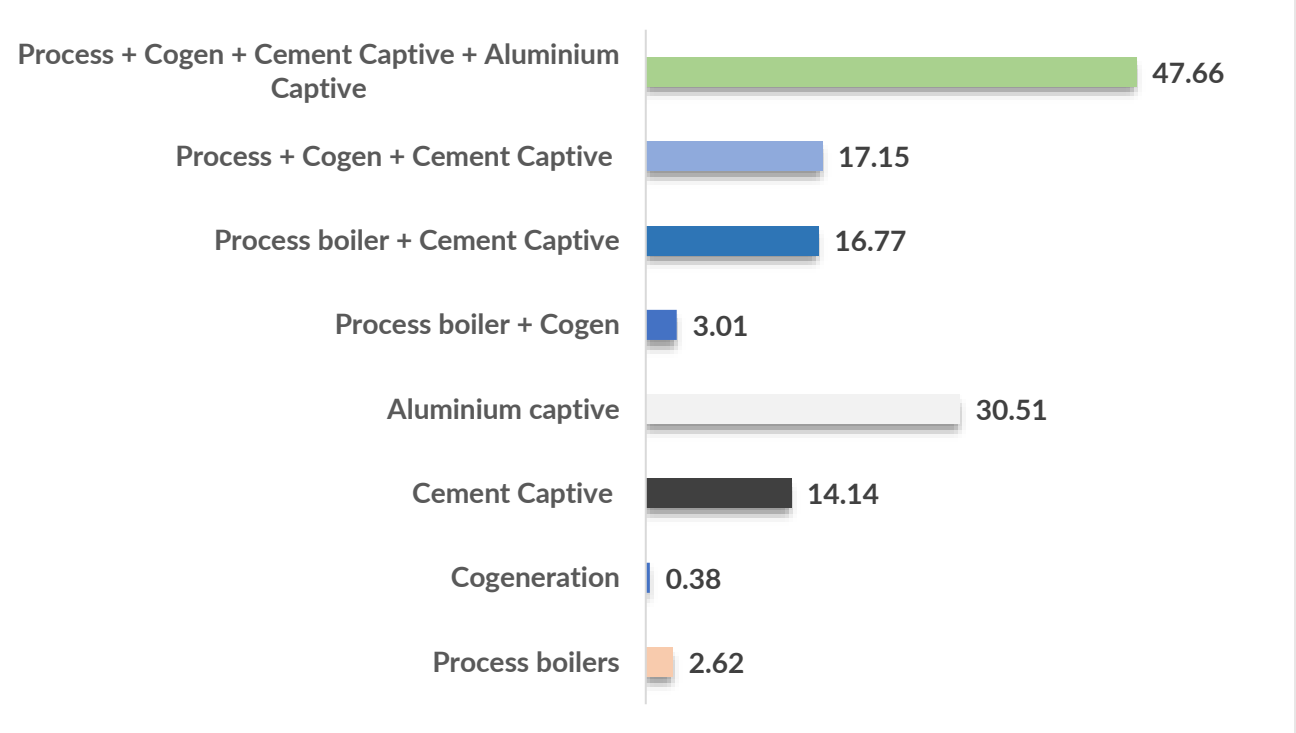


Figure 6: Emission reduction potential in different scenarios based on the grid emission factor of 0.43 kg CO2e/kWh projected for 2030 by CEA in Million-ton CO2e

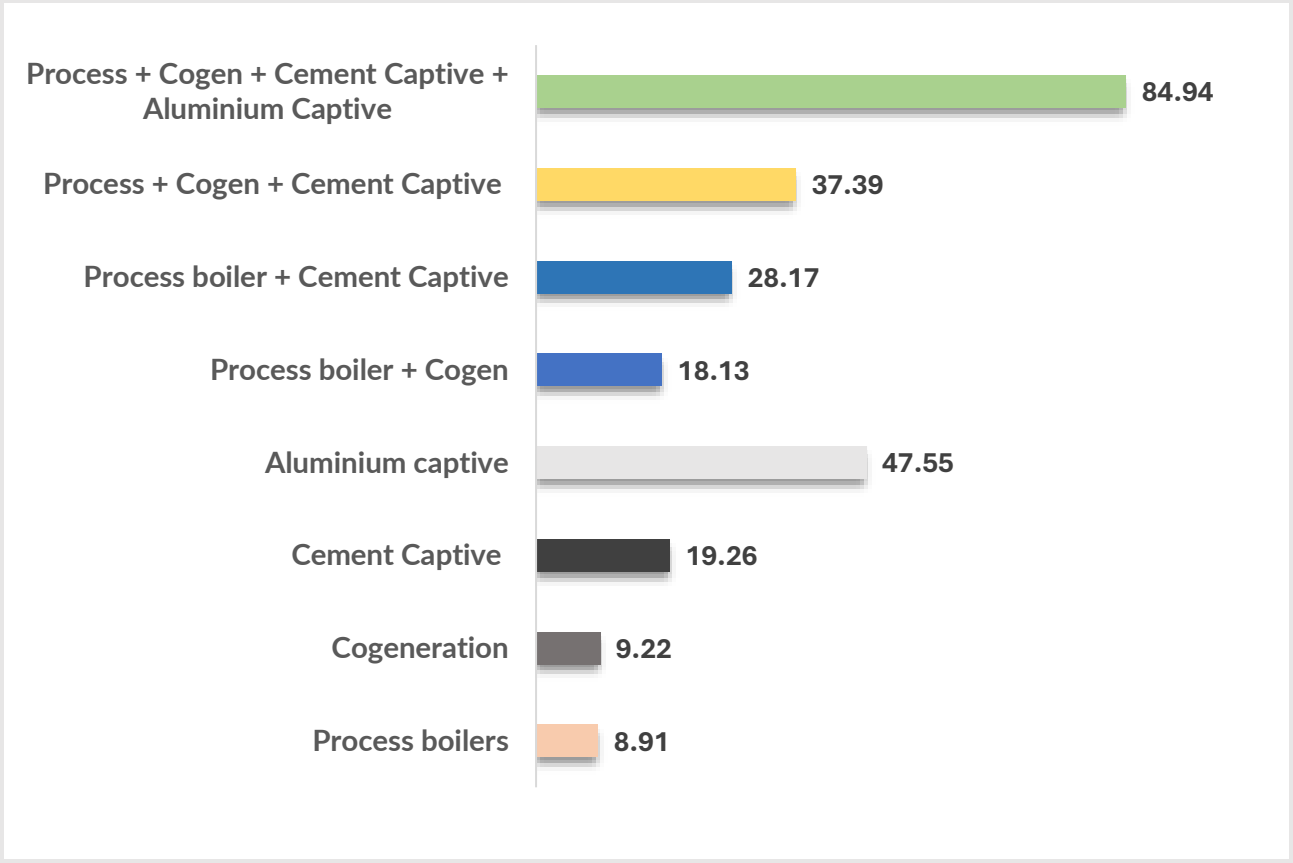
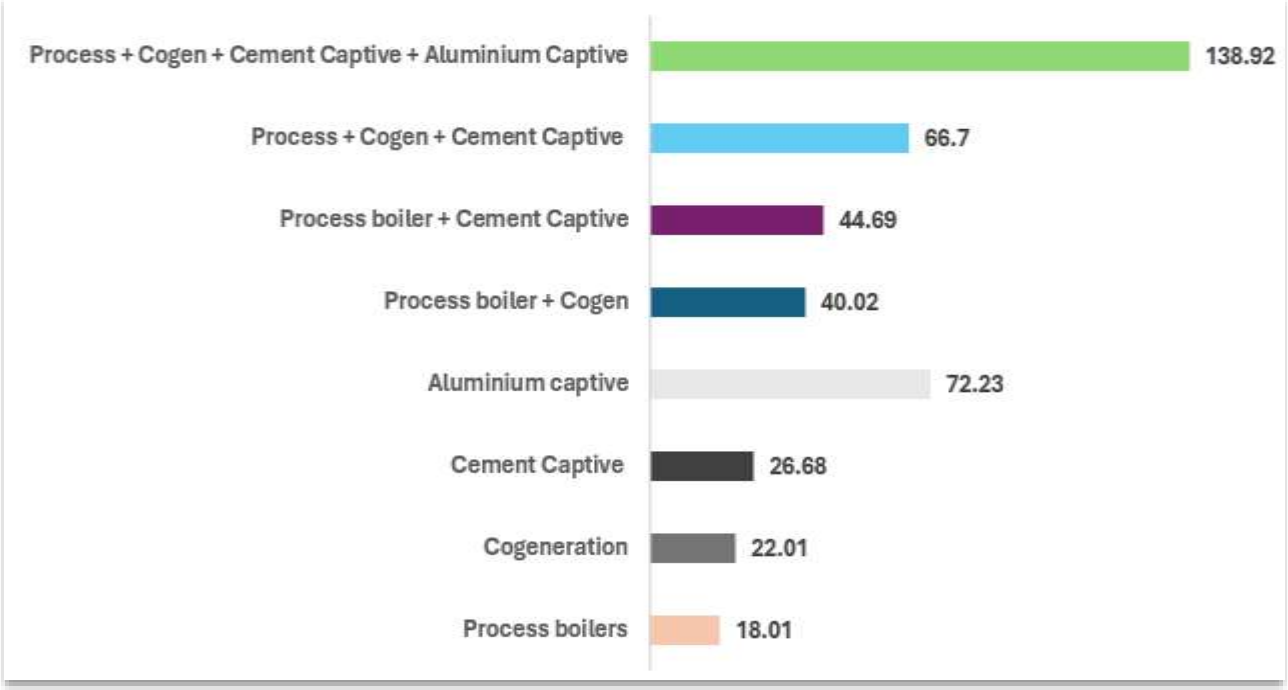


Figure 7: Emission reduction potential in different scenarios consuming renewable power instead of grid power in million tons of CO2e



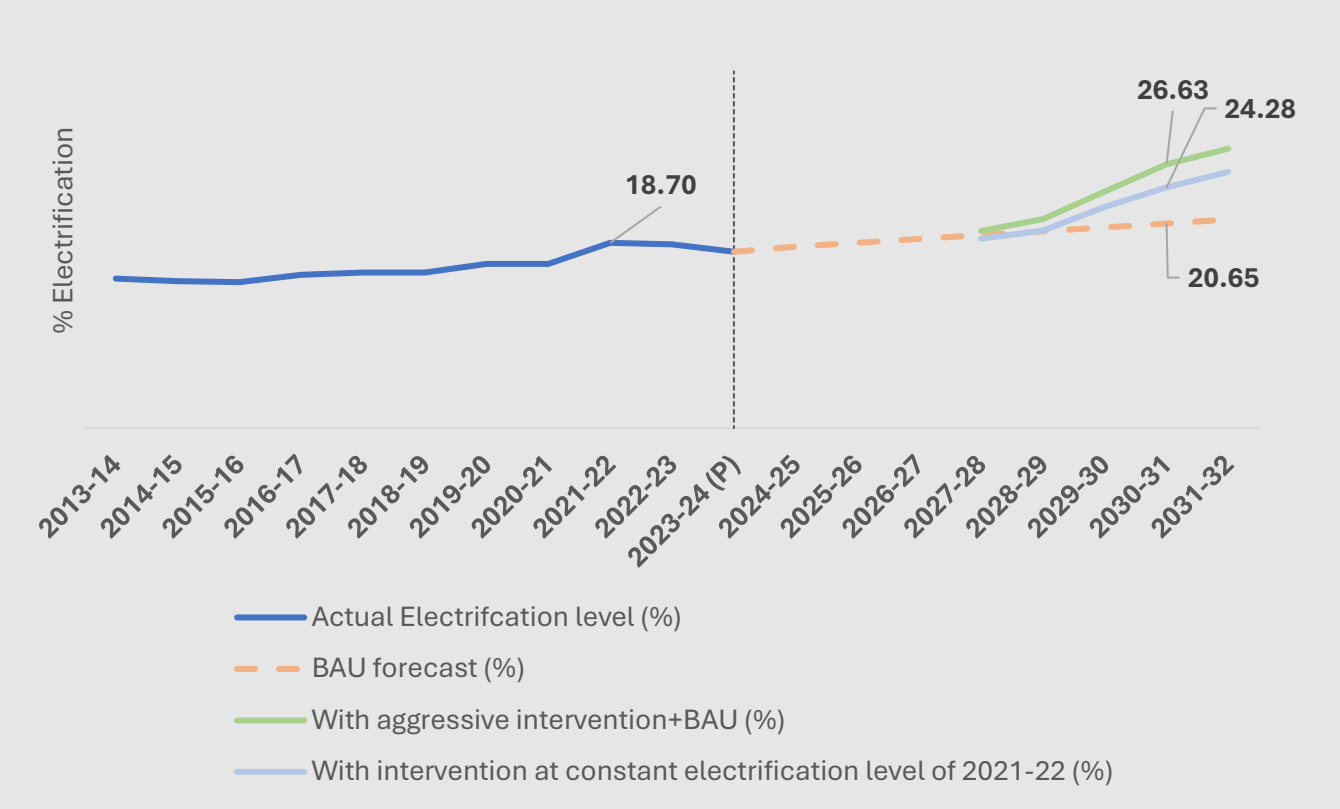
9.2 Forecasted Electrification Level of the Indian Industrial Sector

Based on the historical industrial sector electrification level derived from the Energy Statistics document of MoSPI, the BAU industrial electrification level is forecasted. Further, the industrial electrification level is derived based on the year-wise impact of interventions provided in the roadmap, considering both the BAU scenario and the constant electrification level of 2021-22.

Table 11: Forecasted and derived Industrial sector Electrification Levels based on roadmap interventions

	Actual Electrification level (%)	BAU forecast (%)	With aggressive intervention + BAU (%)	With intervention at the constant electrification level of 2021-22 (%)
2013-14	15.08			
2014-15	14.84			
2015-16	14.73			
2016-17	15.49			
2017-18	15.71			
2018-19	15.70			
2019-20	16.57			
2020-21	16.57			
2021-22	18.70			
2022-23	18.54			
2023-24 (P)	17.79	17.79		
2024-25		18.30		
2025-26		18.69		
2026-27		19.08		
2027-28		19.48	19.89	19.11
2028-29		19.87	21.10	19.93
2029-30		20.26	23.88	22.31
2030-31		20.65	26.63	24.28
2031-32		21.04	28.20	25.85

Figure 8: Year-wise actual, forecasted, and derived electrification level based on roadmap interventions



9.2.1 Extra Electricity Demand due to Electrification of the Indian Industrial Sector

While electrification of the industrial and commercial sectors is a major decarbonization intervention, it would require additional electricity demand in the country. Considering the growing renewable energy penetration into the grid, better load management systems, use of battery storage systems etc. will ensure that end-use sectors, especially industry & commercial, will transition towards a higher electrification level shortly. The study finds that the extra electricity demand might range from 21,165 GWh to 125,558 GWh in different electrification options as given below:

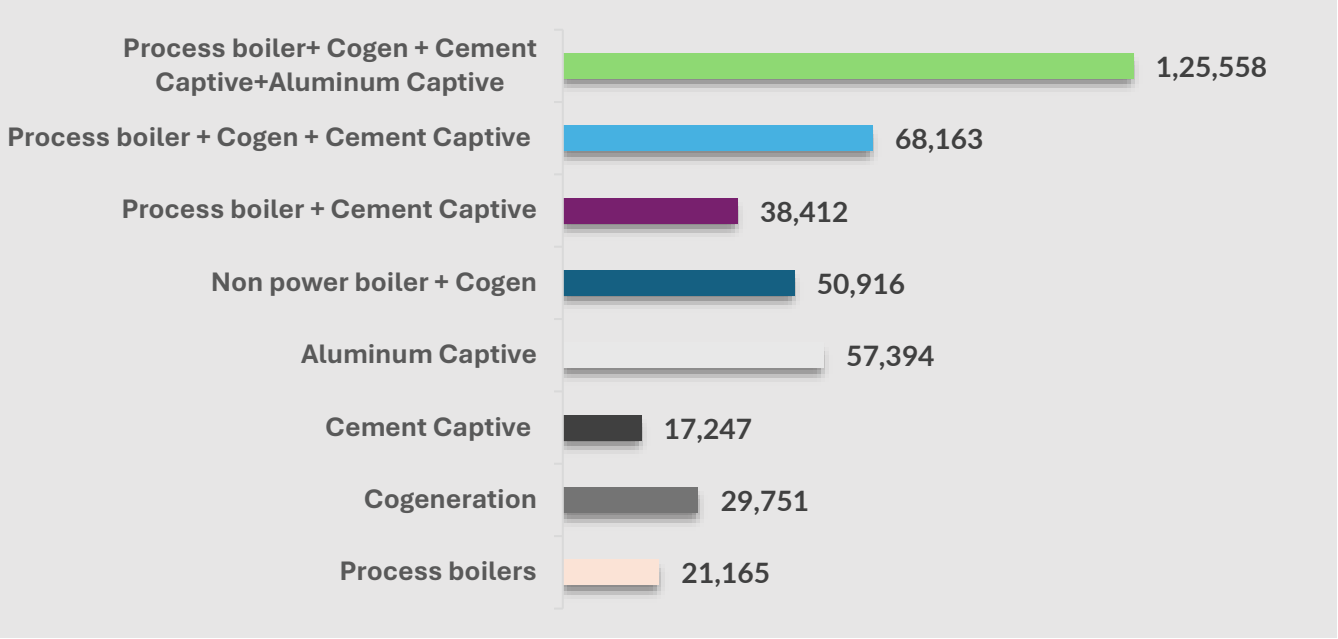
Table 12: Industrial electrification opportunities and different scenarios with coal savings and extra electricity demand

Option	Electrification options	Coal Saving percent	Extra Electricity demand (KToE)	Extra Electricity demand (GWh*)	Share of total electricity consumption of India 2021-22 (%)	Coal reduction (KToE)
A	Process boilers	2.70%	1,820	21,165	1.61%	4,550
B	Cogeneration system	3.30%	2,558	29,751	2.26%	5,561
C	Cement Captive	4.00%	1,483	17,247	1.31%	6,740

D	Aluminium Captive	10.83%	4,935	57,394	4.36%	18,248
S1	Process boiler + Cogen	6.00%	4,378	50,916	3.87%	10,110
S2	Process boiler + Cement Captive	6.70%	3,303	38,412	2.92%	11,290
S3	Process boiler + Cogen + Cement Captive	10.00%	5,861	68,163	5.18%	16,851
S4	Process boiler+ Cogen + Cement Captive + Aluminium Captive	20.83%	10,796	1,25,558	9.54%	35,099

**1 KToE=11.63 GWh*

Figure 9: Extra electricity demand related to different initiatives and scenarios in GWh



The additional electricity demand would translate to a renewable energy installed capacity of about 90 GW with an assumed capacity utilization factor of 20% and T&D losses of 17%. This extra electricity demand can be met from planned additional renewable capacity or otherwise.

9.3 Commercial (Building) Sector Recommendations:

Commercial Sector: The commercial sub-sectors that have a high potential for electrification are hotels, hospitals, malls/airports, and commercial office spaces. The top commercially available technologies that have high potential and high ease of adoption in the commercial sector are:

- Heat pump (HP)
- High-temperature heat pump (HTHP)
- Steam generating heat pump (SGHP)
- Electric Boiler
- BESS (battery energy storage system)
- Induction cook stove

The specific recommendations for the commercial sector are:

1. Replace all the fossil fuel boilers in the commercial sub-sectors with heat pumps (HP), high-temperature heat pumps (HTHP), steam-generating heat pumps (SGHP), or electric boilers (last priority)
2. Replace diesel generator (DG) sets in commercial establishments with battery energy storage systems (BESS).
3. Maximize the usage of electric appliances in the cooking process

The electrification level by electrification of the commercial sector has not been estimated because almost all the fossil fuel operations in the commercial building space can be electrified, except for a few processes in the cooking area. Further, the electrification potential in the commercial building sector is limited (0.43% based on available data) as compared to the industrial sectors.

© GGGI2025. Commercial Building

10 IMPLEMENTATION PLAN AND ROADMAP

10.1 Industrial Sector

The table below outlines a phased roadmap (2026–2031) for key industrial decarbonization and electrification initiatives. It presents sector-specific transitions from fossil fuel-based systems to cleaner, renewable electricity-powered technologies, aligned with the national net-zero pathway and industrial electrification goals.

Table 13: Industrial Sector Electrification Roadmap

Initiatives	2026	2027	2028	2029	2030	2031
Process Boiler to Heat Pump/MVR	Pilots		Full Scale Deployment			
Cogeneration to Heat Pump/MVR		Pilots		Full Scale Deployment		
Cement Captive to Grid	Captive renewables and grid					
Aluminium Captive to Grid/Renewables	Replace a share of captive power with renewable energy			Captive to the grid/Renewables		
Battery energy storage system	BESS instead of DG sets for new industries			Replace DG sets with BESS.		

The above table outlines a phased roadmap (2026–2031) for key industrial decarbonization and electrification initiatives. It presents sector-specific transitions from fossil fuel-based systems to cleaner, renewable electricity-powered technologies, aligned with the national net-zero pathway and industrial electrification goals.

10.1.1 Transition from Process Boiler to Heat Pump/MVR

This initiative begins with pilot projects in 2026–2027, demonstrating the feasibility of using high-temperature heat pumps in place of conventional fossil-fired process boilers. By 2028, these pilots will scale to full deployment, continuing through 2031. This shift promises significant efficiency gains and emissions reduction, particularly in small and medium-sized wastepaper mills, textiles wet processing plants, pharma, and chemical industries.

10.1.2 Transition from Cogeneration to Heat Pump/MVR

Cogeneration systems, which traditionally use fossil fuels to produce both electricity and process heat, are targeted for replacement by heat pumps/MVR starting with pilots in 2027. Full deployment is

scheduled for 2029–2031, especially in industries where combined heat and power (CHP) is currently prevalent, such as paper, textile, and chemical sub-sectors. The goal is to reduce direct emissions while enhancing grid integration.

10.1.3 Cement Industry – Shift from Captive Power to Grid/Renewables
From 2026, the cement industry is expected to begin sourcing power from a mix of renewables and the grid, moving away from captive coal-based generation. This reflects the sector's high electricity demand and the potential for flexible procurement under open access models. This transition also supports compliance with Renewable Purchase Obligations (RPOs).

10.1.4 Aluminum Industry - Shift from Captive Power to Grid/Renewables
Given aluminum's energy intensity, the roadmap starts with partial replacement of captive power with renewables in 2026–2028, followed by a full-scale transition to grid supply by 2029–2030. This will involve the use of group captive solar, wind, and hydropower, along with pumped hydro.

10.1.5 Battery Enabled Storage Systems (BESS)
The plan introduces BESS in 2026–2027 for new industrial setups as an alternative to diesel generator (DG) backup systems, aiming for complete replacement of DG sets by 2031. This aligns with the national BESS VGF scheme and strengthens resilience while supporting round-the-clock renewable power consumption.

By 2026–27, the focus is squarely on pilot demonstrations—validating high-temperature heat pumps in process boiler applications and replacing a share of captive fossil fuel Cogen with electric heat pump technology. At the same time, the Aluminum sector begins its initial shift from diesel and coal-fired captive power toward a mix of renewables and grid supply. Battery energy storage systems (BESS) are also introduced for new facilities, displacing backup diesel generators and ironing out intermittent renewable variability.

From 2028, full-scale deployment of heat pump systems replaces conventional process boilers and cogeneration plants across small and medium textiles, chemical, and paper industries, driving down on-site combustion emissions. The cement industry by then transitions to a hybrid model—blending captive solar and wind with grid procurement—to meet its high baseload needs under open access provisions.

Entering 2029–31, the roadmap culminates in a complete transition: Aluminum producers fully switch captive power to the grid, leveraging long-term renewable contracts; all diesel generator backup in new and existing plants is retired in favor of BESS; and industrial heat is supplied entirely by proven electric systems. This staggered approach—pilots, scale up, then full integration—ensures risk is managed, learning is captured, and each sector can adapt to the new energy paradigm without disrupting production.

10.2 Commercial Sector (Building)

The table below provides a phase-wise roadmap for the electrification of the commercial sector to achieve 100% from the current electrification level of 88% (based on the available data).

Table 14: Commercial Sector Electrification Roadmap

Initiatives	2026	2027	2028	2029	2030	2031
Heat Pump/Electric Boiler	Pilots		Mandate the installation of Heat Pump/Electric Boiler		Replace the existing boiler with a Heat Pump/Electric Boiler	
Install BESS instead of DG sets	Pilots		Mandate the installation of BESS in place of DG sets		Replace the existing DG sets with BESS	

10.2.1 Transition to Heat Pump/ Electric Boiler

The electrification of commercial sector heating begins with pilot demonstrations in 2026–2027, aimed at assessing feasibility across sub-sectors like hotels, hospitals, malls, and office spaces. Based on successful results, the installation of electric heat pumps and boilers becomes mandatory in new commercial facilities starting in 2028. Over the next two years, the focus shifts to retrofitting existing thermal systems in the commercial sector, with a target to fully replace conventional boilers with electric alternatives by 2031. This staggered approach allows for learning, capacity building, and infrastructure readiness before full-scale conversion.

10.2.2 Battery Enabled Storage Systems (BESS) in place of DG sets

In parallel, pilot deployments of BESS begin in 2026–2027, targeting new commercial units and high-reliability manufacturing clusters. From 2028, policies mandate BESS installations for all new industries in lieu of diesel generators, supporting cleaner power backup and grid balancing. By 2030, attention shifts to retrofitting existing facilities, aiming to completely replace DG sets with BESS by 2031. This not only reduces diesel dependency but also enhances power reliability and supports renewable integration.

10.3 Investment Plan and Employment Generation

To achieve the fossil fuel consumption savings estimated earlier, significant investment is required from the industries, primarily for the deployment of high-temperature heat pumps and mechanical vapor recompression (MVR) systems. This investment is estimated to be around ₹20,000 to ₹30,000 crore for the sub-sectors considered in the study. Additional investment is also necessary to import the extra electricity needed to power the new electrification technologies and replace existing captive power generation. Around ₹7,500 crore will be required for the installation of high-voltage step-down transformers within the industrial subsector.

In the initial phase, funding will be needed to support pilot projects, which can be provided in the form of grants to industrial subsectors. As the prices of electrification technologies decrease and adoption accelerates, concessional loans and other incentives, outlined in the policy recommendations section,

can be offered to further accelerate deployments. Funding for these electrification projects can be sourced from budgetary allocations, international financing mechanisms, and private capital, as detailed in the policy recommendations and financial strategies sections.

Investments related to renewable energy (as it is optional) and transmission and distribution (T&D) systems (which is an ongoing activity) have not been estimated, as these vary significantly on a case-by-case basis.

To realize the full coal savings potential, substantial investments in electrification technologies will be necessary, as discussed above. This transition is expected to create approximately 20,000 new direct jobs, primarily in the installation and servicing of high-temperature heat pumps and MVR systems. More jobs can be created in the heat pump or MVR manufacturing and components manufacturing if the actual manufacturing happens in India instead of importing. This will take the total new direct jobs generated to around 50,000.

This job estimate does not include employment opportunities arising from the increased installation of new step-down transformers, renewable energy infrastructure, and T&D system expansion.

Overall, electrification in the industrial and commercial sectors will enhance energy efficiency and significantly reduce carbon emissions across these sectors.

10.4 Monitoring Progress through KPIs

Monitoring the progress of industrial electrification requires a well-defined set of Key Performance Indicators (KPIs) that capture both environmental and economic outcomes. These KPIs should include the percentage share of electricity in total final energy consumption, the reduction in fossil fuel use, and associated CO_2 emission savings. In parallel, it is important to track cost savings and efficiency improvements achieved by industries/commercial units adopting electrified technologies, as well as the growth in investment and deployment of such technologies across sectors. Collecting and reporting this data in a transparent, timely manner will enable evidence-based decision-making and allow policymakers and stakeholders to assess the effectiveness of current initiatives. To support this, a centralized digital dashboard—hosted by institutions such as the Bureau of Energy Efficiency (BEE)—can be developed to visualize trends, provide access to performance data, and serve as a platform for public accountability.

10.5 Adaptive Planning

Complementing strong monitoring systems, adaptive planning is critical to ensure that industrial electrification strategies remain responsive to changing conditions and stakeholder needs. This approach involves continuous evaluation of policy outcomes, allowing for real-time course correction based on what is working and what is not. Establishing structured feedback loops—through industry consultations, surveys —can help capture on-the-ground insights from plant operators, equipment suppliers, and investors. These insights should feed into periodic policy reviews, ideally conducted quarterly or biannually, to reassess incentives, regulations, and implementation timelines. Adaptive planning ensures that the policy framework remains flexible and dynamic, enabling faster replication

11. COMMUNICATIONS & PUBLIC AWARENESS

...rventions, phasing out of ineffective measures, and alignment with technological ...d market conditions. This iterative model of governance is essential to achieving ...ial decarbonization goals while addressing short-term challenges effectively.

11. COMMUNICATION & PUBLIC AWARENESS

11.1 Awareness Programs for Industries on Cost Benefits and Incentives

To accelerate the adoption of industrial electrification technologies, it is essential to enhance awareness among stakeholders about the tangible economic and operational benefits. Many industries, especially MSMEs, remain unaware of the long-term cost savings, reliability improvements, and available government incentives associated with transitioning from fossil fuels to electricity-based systems like heat pumps, mechanical vapor recompression (MVR), or electric boilers. Structured awareness programs should be launched at the national and state levels through workshops, webinars, and industrial roadshows in collaboration with industry bodies. These programs should include practical tools such as sector-specific return-on-investment calculators, fact sheets on subsidies, and testimonials from early adopters. A digital knowledge hub should also be created to serve as a single-window resource for accessing real-time information on electrification-related financial incentives, technical guidelines, and support schemes offered by both central and state governments.

11.2 Technical Training for Workforce on Electrified Industrial Processes

Widespread electrification in industry will require a parallel investment in developing a skilled workforce that can install, operate, and maintain advanced electrical systems efficiently and safely. This calls for targeted capacity-building programs designed for plant engineers, technicians, and energy managers.

11.3 Promotion of Best Practices and Success Stories from Pilot Projects

Demonstrating real-world success stories is vital to building industry confidence in the feasibility and returns of electrification. Pilot projects that have successfully implemented technologies like high-temperature heat pumps, mechanical vapour recompression (MVR) systems, battery energy storage systems (BESS) etc. should be systematically documented and widely shared through public and private sector networks. These case studies should include technical configurations, cost-benefit analyses, energy savings, and challenges faced during implementation. A central repository of industrial electrification best practices should be established, and early adopters should be recognized through awards and publicity campaigns to encourage peer replication. Multimedia tools such as video case studies, interviews with plant managers, and virtual plant tours can be used to highlight success

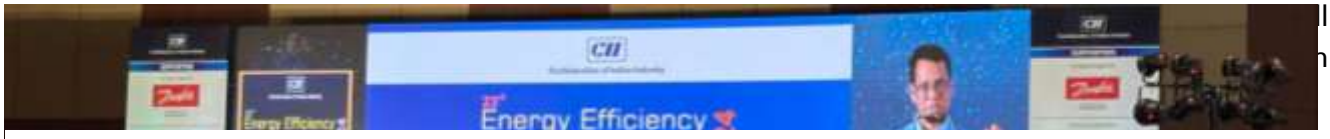


Figure 10: Energy Efficiency Summit 2024

12. RISK MANAGEMENT & RESILIENCE PLANNING

12.1 Grid Reliability Issues: Invest in Microgrids and Energy Storage

One of the key barriers to industrial electrification in India is the inconsistency of grid reliability, especially in industrial corridors that suffer from voltage fluctuations, load shedding, or frequent outages. This unpredictability discourages industries from shifting critical thermal and process loads to electricity. To address this, targeted investments must be made in decentralized energy solutions such as microgrids and behind-the-meter battery energy storage systems (BESS). Microgrids, particularly when integrated with renewable energy sources like solar or wind, offer localized power resilience and can serve as primary or backup sources for industrial operations. Public-private partnerships can be structured to develop industrial microgrids in high-potential clusters with policy support from state energy departments and central agencies like the Ministry of Power. Additionally, providing financial incentives or capital subsidies for the deployment of industrial-scale BESS can help stabilize demand peaks and improve load management, creating a robust ecosystem for electrification without overburdening the existing grid infrastructure.

12.2 Financial Risks: Develop Blended Finance Models and Risk-Sharing Mechanisms

Industrial electrification technologies often face high upfront capital costs and uncertain payback periods, particularly for small and medium enterprises. This financial risk impedes wider adoption. To overcome this, a structured blended finance approach must be adopted that combines concessional public capital with private investment, thereby lowering the cost of financing and sharing project risks. Institutions like IREDA, SIDBI, and multilateral agencies (e.g., World Bank, GCF) can jointly offer financing packages that include low-interest loans, equity support, and performance-linked grants. Simultaneously, the establishment of a risk-sharing facility, backed by sovereign or green climate funds, would help de-risk lending for commercial banks and NBFCs. Mechanisms like partial credit guarantees, first-loss cover, and project insurance can be included to address the concerns of lenders and unlock greater capital flows into industrial electrification. Encouraging project aggregation, where clusters of MSMEs apply collectively, can also improve creditworthiness and facilitate financing at scale.

12.3 Technology Gaps: Encourage Domestic Manufacturing and Innovation Hubs

Bridging the technology gap is critical to accelerating electrification in India's industrial sector. While many electrification solutions, such as heat pumps, MVR systems, etc., their adaptation and affordability in the Indian context remain limited. To tackle this, the government should incentivize domestic manufacturing of electrification technologies under schemes like Production Linked Incentives (PLI) and FAME-like frameworks for industrial decarbonization. Creating dedicated industrial electrification innovation hubs—possibly co-located with existing institutions like IITs or IISc—can drive R&D focused on adapting high-efficiency technologies to Indian operating conditions. These hubs should support startups and MSMEs working on components like high-COP compressors, thermal storage, smart controls, and hybrid systems, through grants, incubation support, and testing infrastructure. By fostering domestic innovation and reducing import dependence, India can develop a resilient, cost-effective technology supply chain that meets its industrial decarbonization goals.

13 POTENTIAL FOR UPTAKE OF ALTERNATE ENERGY SOURCES FOR ELECTRIFICATION IN INDIA

Alternate energy sources play a crucial role in achieving clean energy transition by reducing the reliance on imported fossil fuels, mitigating greenhouse gas emissions, enhancing energy security and independence, and creating green jobs and economic opportunities.

13.1 Potential of Renewable Energy Sources for Electrification

a) Solar Power:

India possesses a remarkable solar energy potential, with most parts of the country receiving high solar irradiance in the range of 4-7 kWh per sqm per day, and experiencing about 300 clear and sunny days annually[27]. The theoretical solar energy incidence on India's land area is approximately 5,000 trillion kWh per year (5 EWh/yr), which significantly exceeds the nation's total fossil fuel energy reserves[27]. The technical potential for solar power in India is estimated to be over 750 GW , with the National Institute of Solar Energy (NISE) assessing it at 748 GW assuming coverage of 3% of wasteland[27]. Certain states like Rajasthan, Gujarat, and Maharashtra exhibit particularly high solar radiation levels, making them optimal locations for large-scale solar installations. Annual solar radiation across India ranges from 1200 to 2300 kWh per square meter.

India has witnessed a rapid increase in solar power deployment, with an installed capacity reaching 105.6 GW by March 2025[28], positioning the country as one of the top solar power producers globally. Technological advancements, including the adoption of bifacial solar panels, high-efficiency photovoltaic cells, and solar tracking systems, are continuously enhancing the efficiency of solar energy generation. Floating solar technology is also gaining traction, especially in areas with high population density and limited land availability. The cost-effectiveness of solar energy, compared to other energy sources, has further propelled its adoption.

The government of India has set ambitious targets for solar energy of 500 GW of renewable energy by 2030, with at least 250 GW expected to come from solar power. Various government initiatives and schemes are in place to support solar energy adoption, including the Solar Park Scheme, PM-KUSUM, PM Surya Ghar: Muft Bijli Yojana, and the Grid Connected Solar Scheme. Financial incentives such as subsidies, rebates, grants, low-interest financing options, net metering policies, and income tax benefits are also provided to encourage investment in solar installations. Furthermore, the waiver of Inter-State Transmission System (ISTS) charges for solar power projects commissioned by June 2025 further incentivizes large-scale solar deployment.

[27] Solar Overview | MINISTRY OF NEW AND RENEWABLE ENERGY | India

[28] https://mnre.gov.in/en/physical-progress/

b) Wind Power:

India possesses substantial wind energy resources, with an estimated onshore potential of 695.50 GW at 120 meters and 1163.9 GW at 150 meters[29]. The country also has a significant offshore wind energy potential, with particularly promising potential in the regions off the coasts of Gujarat (36 GW) and Tamil Nadu (35 GW)[30]. The southern, western, and northwestern states of India are known for their high wind power potential.

As of March 2025, the total installed wind power capacity in India was 50.16 GW, making it the fourth largest in the world[31]. Technological advancements in the wind energy sector include the development of larger and more efficient turbines and the establishment of offshore wind farms.

The Indian government has set a target of achieving 140 GW of wind power capacity by 2030 and has implemented various policies to promote wind energy development. These include the National Offshore Wind Energy Policy, the Generation Based Incentive (GBI) scheme (which was available until March 2017), and the Renewable Purchase Obligation (RPO)[32]. Financial incentives such as Accelerated Depreciation benefits, concessional custom duty exemptions, and Viability Gap Funding (VGF) for offshore wind projects are also provided[33]. Additionally, a repowering policy has been introduced to encourage the replacement of older, less efficient wind turbines with modern ones. The government is also promoting hybrid wind-solar power projects to leverage the complementary nature of these energy sources.

c) Hydropower

Exploitable large hydro potential in India is estimated at 133 GW. Further, the identified pumped storage potential is 176 GW[34]. This includes a substantial potential for small hydropower projects (up to 25 MW capacity), estimated at 21,133 MW from 7,133 potential sites. Furthermore, 56 sites for pumped storage schemes have been identified, with an aggregate installed capacity of 94,000 MW. The Northeastern states and the Himalayan region hold the largest untapped hydropower potential.

As of Feb 2025, the installed capacity for large hydro projects was around 46,968 MW, with an additional 5,101 MW from small hydro[35]. However, hydropower generation in India is susceptible to climatic variations, and its share in the total power generation fell to a historic low of 8.3% in FY2023-24 due to low rainfall. The development of new hydropower projects faces several environmental and social challenges, including potential opposition from tribal populations, remote locations,

[29] Wind Overview | MINISTRY OF NEW AND RENEWABLE ENERGY | India

[30] Offshore Wind | MINISTRY OF NEW AND RENEWABLE ENERGY | India

[31] https://mnre.gov.in/en/physical-progress/

[32] Wind Overview | MINISTRY OF NEW AND RENEWABLE ENERGY | India

[33] Offshore Wind | MINISTRY OF NEW AND RENEWABLE ENERGY | India

[34] https://pib.gov.in/PressReleasePage.aspx?PRID=2040094

[35] https://powermin.gov.in/sites/default/files/uploads/power_sector_at_a_glance_Feb_2025.pdf

unpredictable geology, natural calamities, and issues related to environment, forests, rehabilitation, and inter-state coordination.

The government is actively supporting the hydropower sector, with large hydro projects now classified as renewable energy sources[34]. Financial incentives and budgetary support are being provided for the development of enabling infrastructure and flood moderation components of hydropower projects. There is a renewed focus on harnessing the hydropower potential of the Northeast region to enhance energy security and promote regional development. Pumped storage schemes are also being emphasized for their crucial role in grid stability and meeting peak power demands.

d) Other Renewable Energy Sources

Geothermal energy presents a promising avenue for clean energy generation in India, with an estimated potential of 10,600 MW[36]. The Geological Survey of India has surveyed approximately 381 geothermal hot springs across the country, most of which have low surface temperatures suitable for direct heat applications. While the power generation through geothermal resources is still in its nascent stages in India, pilot projects are being explored in regions like Puga Valley in Ladakh and Tatapani in Chhattisgarh. The development of geothermal energy in India faces challenges such as high upfront costs, limited exploration and data, lack of technical expertise, and absence of a comprehensive regulatory framework.

Other emerging renewable energy technologies like wave and tidal energy also hold potential for future electrification in India, given its extensive coastline. However, their current contribution to the energy mix is negligible, and further research and development are needed to assess their viability and scale of deployment.

e) Green Hydrogen

India has a significant potential for green hydrogen production, primarily due to its abundant renewable energy resources, including solar, wind, and hydropower. Estimates suggest that India could produce between 5 MTPA and 10 MTPA[37]. Green hydrogen can be utilized for electricity generation through fuel cells and potentially in gas turbines. Electrolysers used in green hydrogen production also offer grid flexibility, aiding in the integration of variable renewable energy.

Recognizing the importance of green hydrogen, the government of India launched the National Green Hydrogen Mission with the objective of making India a global hub for its production, usage, and export. The mission aims to achieve a production capacity of at least 5 MMT per annum by 2030, with a total outlay of ₹ 19,744 crore[38]. The mission encompasses various strategies, including providing incentives for the domestic manufacturing of electrolysers and the production of green hydrogen, supporting pilot projects in sectors like steel and shipping, developing green hydrogen hubs, fostering

[36] https://sansad.in/getFile/loksabhaquestions/annex/1712/AU2435.pdf?source=pqals

[37] SDIM: India's green hydrogen-fuelled industrial clusters | World Economic Forum

[38] Press Note Details: Press Information Bureau

infrastructure development for storage and transportation, promoting research and development, and facilitating skill development in this emerging sector.

The deployment of green hydrogen requires significant infrastructure, including electrolysers, storage solutions, transportation networks (pipelines and tankers), and refuelling stations. Key challenges for the widespread adoption of green hydrogen include high production costs, the need to reduce transportation costs, scaling up the necessary infrastructure, establishing supportive regulatory frameworks, and ensuring adequate water availability for electrolysis. However, green hydrogen also presents significant opportunities for India, such as decarbonizing hard-to-abate sectors like steel, cement, and heavy transportation, reducing the dependence on imported fossil fuels, and creating new avenues for exports.

f) Bio-CNG:

India has a vast potential for bio-CNG production, estimated at up to 62 million tons annually from various organic waste sources. The country generates over 1,000 MMT of biomass each year, including agricultural residues, animal manure, municipal solid waste, and industrial waste. Bio-CNG, produced through the anaerobic digestion of these biomass sources, can be used for electricity generation in gas engines. Its production also plays a crucial role in waste management by converting organic waste into clean energy and valuable bio-fertilizers.

The government of India is actively promoting bio-CNG through initiatives like the Sustainable Alternative Towards Affordable Transportation (SATAT) scheme, which aims to establish over 5,000 bio-CNG plants by 2030 and facilitate the procurement of bio-CNG by oil marketing companies. The scheme also mandates the phased blending of bio-CNG with compressed natural gas (CNG) for transport and piped natural gas (PNG) for domestic use. The National Bioenergy Programme also supports the setting up of bio-CNG plants and provides financial assistance to project developers.

Despite the significant potential and government support, the bio-CNG sector in India faces several challenges. These include ensuring a consistent and sufficient supply of feedstock, which can be affected by seasonality, logistics, and competition from other uses. The limited number of biogas plants and the need for technology upgrades also pose hurdles. Additionally, the development of adequate distribution infrastructure, including storage and refuelling stations, is crucial. High production costs and regulatory challenges, including complex approval processes, also need to be addressed to foster greater investment and deployment in the bio-CNG sector.

Figure 11: GGGI supported GoMP in setting up the 600 MW FSPV project on Omkareshwar Dam in Madhya Pradesh

14 IMPACT OF INDIAN CARBON MARKET ON INDUSTRIAL ELECTRIFICATION IN INDIA

14.1 Expected Impact on Costs and Benefits of Industrial Electrification

The implementation of the Indian Carbon Market (ICM) is anticipated to have a significant impact on the costs and benefits associated with industrial electrification in India. By placing a price on carbon emissions, the ICM is expected to increase the operational costs of energy sources that are carbon-intensive, such as coal, oil, and natural gas used for captive power generation or direct heating. This increase in the cost of fossil fuels will, in turn, enhance the economic competitiveness of electricity generated from renewable sources, making industrial electrification powered by clean energy a more financially attractive option for various sectors. Furthermore, the ICM provides a direct economic incentive for industries to reduce their emissions intensity. Entities that successfully lower their emissions below the targets set by the ICM will be eligible to receive carbon credit certificates (CCCs). These CCCs can then be traded on the carbon market, generating a potential revenue stream for the industries that have invested in emission reduction measures, including the adoption of electrification technologies. This revenue from the sale of carbon credits can help to offset the initial capital investments and operational costs associated with transitioning to electric systems and renewable energy sources.

While the long-term operational costs of electrified systems powered by renewable energy may be lower, the substantial initial capital investment required can deter many companies, particularly small and medium-sized enterprises (SMEs), without access to sufficient financing or clear visibility of returns. Furthermore, the intermittency of key renewable energy sources like solar and wind power poses a challenge for continuous industrial operations that require a reliable and uninterrupted power supply 24/7. The need for reliable and affordable energy storage solutions, as well as robust grid infrastructure to ensure grid stability and the integration of variable renewable energy, will be critical for supporting widespread industrial electrification powered by renewables.

14.2 Opportunities for Accelerated Electrification through the ICM:

The Indian Carbon Market (ICM) presents several significant opportunities to accelerate the electrification of India's industrial sector. The ICM can act as a strong financial incentive for industries to invest in energy-efficient electrical equipment and processes. By adopting more efficient electrical technologies, industries can reduce their overall energy consumption and consequently lower their emissions intensity, allowing them to earn and potentially sell valuable carbon credits. This creates a direct economic link between carbon pricing and the adoption of energy-efficient electrification. The offset mechanism within the ICM framework can also play a crucial role in promoting renewable energy adoption in the industrial sector. By incentivizing non-obligated entities to invest in renewable energy projects, the offset mechanism can increase the overall availability of green electricity in the grid. This increased supply of renewable power can then be accessed by industrial consumers to meet their growing electricity needs in a cleaner and more sustainable manner. The ICM has the potential to be a significant driver of innovation in both electrification technologies and related business models. As industries seek cost-effective strategies to reduce their emissions and capitalize on the opportunities presented by carbon credits, there will be an increased demand for new and improved electrification technologies, as well as innovative approaches to energy management and procurement. Finally, the ICM's focus on emissions intensity targets offers a degree of flexibility for

industries, particularly in a rapidly growing economy like India. By setting targets based on emissions per unit of output, the ICM allows industries to continue to grow their production while simultaneously reducing their carbon footprint, aligning economic development with environmental sustainability.

14.3 Potential Short-Term and Long-Term Impacts of the Indian Carbon Market on Electricity Adoption in Indian Industries:

The implementation of the Indian Carbon Market (ICM) is expected to have both short-term and long-term impacts on the adoption of electricity as a primary energy source in Indian industries, considering both economic and environmental perspectives. In the short term (next 3-5 years), the ICM is likely to create an initial impetus for industries, particularly those covered under the compliance mechanism, to assess their carbon emissions and explore relatively low-cost emission reduction opportunities. This may lead to increased investments in energy-efficient electrical equipment and processes, as these can directly lower emissions intensity and potentially generate carbon credits. The initial carbon price, expected to be modest, might not immediately trigger large-scale shifts to full industrial electrification, especially in sectors with high capital costs for technology transition like steel and cement. However, it will likely raise awareness and encourage preliminary steps towards electrification, particularly where it offers clear energy efficiency gains and opportunities to earn carbon credits. Environmentally, the short-term impact might be a gradual reduction in emissions intensity from the participating sectors, driven by efficiency improvements and some fuel switching to less carbon-intensive sources, including electricity, where economically viable. In the long term (beyond 5 years), as the carbon price is expected to rise and the emission reduction targets become more stringent, the economic rationale for transitioning to electricity, especially from renewable sources, will become significantly stronger. Industries will face increasing costs for their fossil fuel consumption under the ICM, making the stable and potentially lower operating costs of renewable electricity more attractive. This will likely drive substantial investments in industrial electrification technologies across a wider range of sectors, including those currently heavily reliant on thermal energy from fossil fuels. The long-term environmental impact is expected to be a significant reduction in direct and indirect GHG emissions from the industrial sector, contributing substantially to India's climate goals. The increased demand for electricity from renewable sources will also stimulate growth in the clean energy sector, fostering job creation and economic development. Furthermore, the alignment with global carbon norms and the potential avoidance of carbon border taxes like CBAM will enhance the international competitiveness of Indian industries in the long run.

CONCLUSION

Industrial electrification holds immense promise as a key strategy for India to achieve its ambitious energy transition and climate goals. By shifting away from fossil fuels towards cleaner electricity, industries can significantly reduce their environmental impact, potentially enhance their operational efficiency, and improve their long-term competitiveness. However, realizing this potential requires a concerted and strategic approach that addresses the existing challenges and leverages the available opportunities.

As this analysis indicates, the transition to widespread industrial electrification in India necessitates a multi-faceted strategy encompassing supportive government policies, robust financial incentives, substantial investments in grid infrastructure and technology development, and the active promotion of innovative financial models. Policymakers, financial institutions, and industries must collaborate

closely to create an enabling ecosystem that fosters this transformation. By addressing the issues of high tariffs, technological limitations, infrastructure gaps, and financial constraints, and by capitalizing on the growing affordability of renewable energy and the advancements in electrification technologies, India can accelerate the pace of industrial electrification.

The successful transition will not only contribute significantly to India's efforts in combating climate change and achieving its net-zero targets but will also lead to a more sustainable and resilient industrial sector, driving economic growth and enhancing India's standing as a global leader in clean energy and sustainable development. A forward-looking and proactive approach to financing industrial electrification is therefore crucial for securing a prosperous and sustainable future for India.

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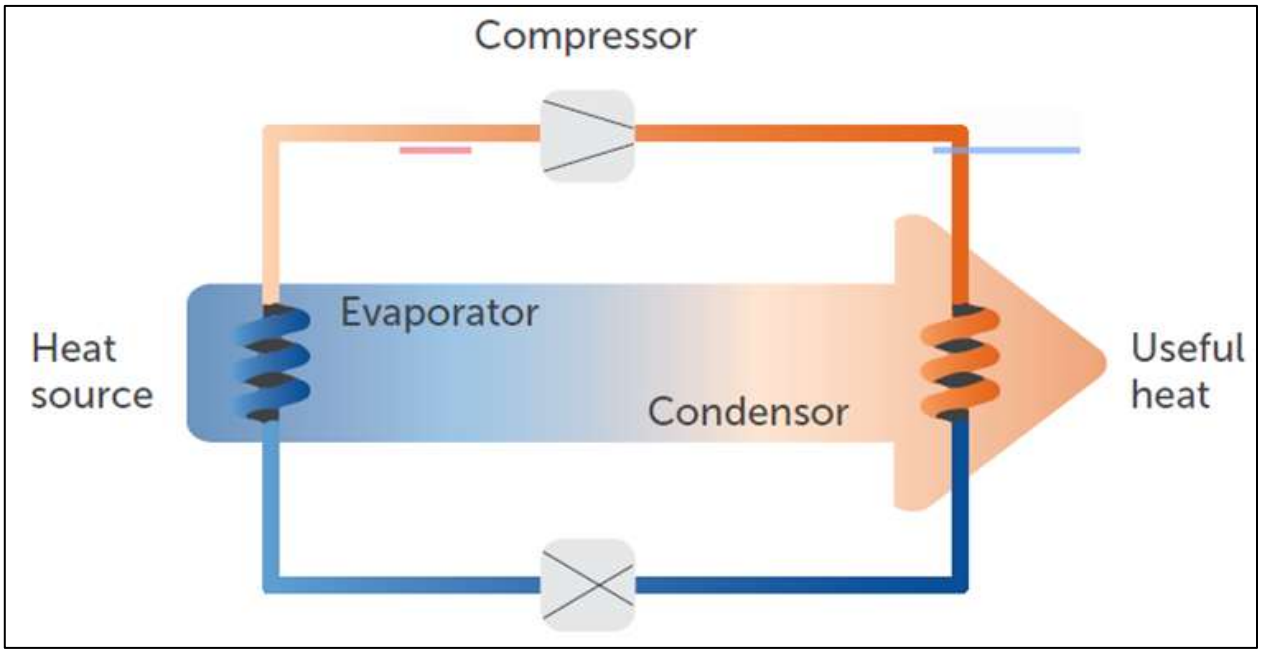
15. ANNEXURES

15. 1 Electrification Technologies

15.1.1 Heat Pump

A heat pump is a device that utilizes electricity or heat to transfer heat from a lower temperature to a higher temperature. In doing so, it recovers heat that would otherwise be wasted and makes it available for practical purposes such as process heating or other applications. Potential heat sources include the outside air or the ground, or waste heat from industrial processes. A heat pump is a key component in everyday appliances such as fridges, freezers and reverse-cycle air conditioners. Heat pumps create heat by compressing and expanding the refrigerant fluid. They exploit the property of the refrigerant to heat up when and cool when expanded. A heat pump moves a refrigerant between four key parts: compressor, condenser, expansion device, and evaporator.

Figure 12: Simple representation of a heat pump



Compressor: compresses working fluid causing temperature to increase (electrically powered).
Condenser: gas condensed to liquid - releasing heat
Expansion device: reduces pressure of gas
Evaporator: low-pressure refrigerant evaporated, absorbing heat from an external source
Heat source: waste heat or external air, water or ground

Heat pumps enable energy and cost savings due to their remarkable efficiencies – represented by their coefficient of performance (COP). The resulting operational savings will repay the capital costs associated with the installation of heat pumps. The case study below will provide further details.

As a rule of thumb, a heat pump with a COP of 4 will be cheaper to run than a fossil fuel boiler where the price of electricity is less than 4.5 times the price of the fossil fuel. Heat pumps are even more cost-effective when they can be used for simultaneous heating and cooling – for example in the pasteurization of milk.

Heat pumps have the added advantage that they can be installed in a modular fashion. Manufacturers can choose to replace just the most inefficient parts of the boiler/distribution system rather than needing to shut down and replace the entire boiler/steam system in one go. The heat pumps have significant growth potential in industrial processes where hot air, hot water, or steam is required including most food production processes, such as pasteurization, fermentation, distillation, washing, and drying.

14.1.1 a) Additional economic benefits of a heat pump

The major cost savings discussed above can be significantly enhanced by considering the additional benefits of a heat pump, which include:

- Improved ability to recover waste heat, including latent heat
- Better reliability – reducing maintenance costs and plant downtime. Heat pumps can run trouble-free for 15 years or more.
- Better heating control leading to improved product quality
- Increased plant output
- Increased space on the factory floor due to the smaller footprint of heat pumps and their potential to reduce space occupied by steam distribution systems.

14.1.1 b) Costs of purchase, installation, and maintenance

A heat pump system costs around $500-1000 per kilowatt of heating capacity for heat pumps with capacity below 500 kW, and around $275- 500 per kilowatt for systems of 1 MW and above. For example, the Mayekawa Eco Sirocco costs $75,000 for a unit with 120kW of heating capacity. Installation is an extra 25-100% of the purchase price, depending on numerous site-specific factors. The total cost might be two or even three times the up-front cost of an equivalent gas boiler, however, the heat pump can pay for itself in just a few years thanks to cheaper running costs.

14.1.1 c) High-temperature heat pumps (HTHP)

High-temperature heat pumps (HTHP) are advanced thermal systems that provide heat at temperatures exceeding 90 °C , making them suitable for a wide range of applications in industry. These heat pumps operate on the same principles as conventional heat pumps but employ modified components and potentially new working fluids that enable them to achieve high efficiency and performance at elevated temperatures.

Table 15: Cost-benefit analysis of replacing a gas boiler with a high-temperature heat pump

System	Heating Capacity (MW)	Equipment Cost ($/kW)	Total Equipment Capital Cost ($)	Cost of Energy	Annual Cost of Operation ($) *
Gas boiler (85% efficiency)	2	120	240,000	$13/GJ (gas)	660,706
Heat pump (COP of 4)	1.6	520	832,000	12 c/kWh (electric)	312,000

The above table compares the capital and operating costs of a gas boiler and a high-temperature heat pump. The heating capacity of the heat pump is lower as it minimizes distribution losses. The heat pump costs over three times more than the gas boiler including the installation cost. However, due to lower running costs, the heat pump pays for itself in less than two years. In some cases, heat pumps will be even more cost-effective as they can replace costly steam distribution systems along with the central gas boiler.

It is expected that various high-temperature heat pump technologies will become commercially available and implemented during 2024 to 2025 for supply at up to 120 °C, during 2025 to 2026 for temperatures up to 160 °C, and during 2026 to 2027 for even higher temperatures.

The integration of HTHP in industrial processes comes when a series of energy efficiency measures have already been considered. The efficiency of heat pumps (COP) makes their integration into industrial processes very attractive, either for operational costs or for decarbonization of the industrial processes. The industrial processes where HTHP can be applied are diverse, however, their feasibility depends mainly on the temperature range, the stability, the capacity, and the glide (temperature difference or range experienced by the working fluid) of both the source & the sink sides. Moreover, the type of process (batch or continuous), the annual operating hours and the type of energy carrier (fuel, electricity) used to heat the processes are important techno-economic factors.

To be economically viable the main requirement for a HTHP integration into an industrial process is to have an adequate heat source. Typical heat sources that a heat pump can utilize are as follows:

- Waste heat from industrial processes
- Refrigeration or cooling plant heat sink
- Cooling water (directed to cooling tower)
- Radiant heat from product
- Air with high moisture content
- Recirculation streams in processes
- Heat from renewable sources (low or zero cost) Solar thermal
- Geothermal
- Sea or river water

14.1.1. d) Ambient air

Generally, heat sink temperatures of HTHP units for industrial applications are high. Some of the main processes that have been identified for potential applications are drying, boiling, bleaching, pasteurization, sterilization, distillation, coloring etc. The main industries using these processes are pulp & paper, food & beverage, chemicals, metal, automotive, textiles, etc.

The sink side of closed-loop HTHP can be integrated into the process stream either directly using the condenser(s) and/or sub-cooler to heat the flow or to heat a utility stream (secondary loop) used as a heating medium to heat a process. Another way to integrate a vapor compression HTHP is with mechanical vapor recompression (MVR) systems.

Table 16: Potential developments related to high-temperature heat pumps for industrial applications

Year	2023	2025	2030	2035
Typical maximum temperature	165 ^{O}C	200 ^{O}C	200 ^{O}C	200 ^{O}C – 300 ^{O}C
Heat production efficiency	150-600%	150-600%	150-600%	150-600%
Capacity	20 MW	Modular, expandable	Modular, expandable	Modular, expandable
Advantages	Very high efficiency' existing operation experience in relevant applications			
Disadvantages	Higher investment costs than electric steam boilers More complex plant integration than electric steam boilers. Higher temperature lifts reduce efficiency			
Examples of relevant industries and processes	Steam generation in paper production, textile wet processing, the food industry, and the chemical industry			
Technology readiness level (TRL)	8 (at very high temperatures and high capacities) – 9 Established technology (small/medium capacities) Use in other applications (e.g. high capacities, high temperatures) requires further development			

The most important applications for heat pumps are to be found in industries with demand for low- to medium-temperature heat and steam. These include food processing (for cooking, sterilising etc.), pulp and paper (pulping, bleaching), chemicals (driving chemical reactions), textiles (drying, heat setting) and shaping metal parts for vehicles. In many applications, the required temperature level may be lowered by implementing appropriate efficiency and process optimisation measures at best- available-technology (BAT) level – thereby increasing the suitability and efficiency of heat pumps. However, modifying existing processes in this way is complex and entails specific challenges.

14.1.1. e) Simultaneous heating and cooling

The temperature difference between the source and the sink side of a HTHP is inversely proportional to the COP of the system. For HTHPs that are integrated into a process in which the source side is cooling down a process stream rather than using waste, the performance of the HTHP increases substantially. This type of configuration is highly recommended for higher COP values and therefore lower operational costs.

The need for simultaneous heating and cooling in the food industry is driving efficient installation of heat pumps. Cooling of products will produce waste heat at temperatures above ambient, which can be upgraded using a heat pump to satisfy the process heating requirements.

Coupling process heating and cooling needs using a heat pump will result in high process efficiencies and low operational costs.

14.1. 2 The growing potential of heat pumps

Most heat pumps in use today supply temperatures below 100°C. The efficiency, flexibility and reliability of heat pumps have improved considerably in recent years. Heat pumps are now available that can supply steam or hot water up to 165°C, or hot air up to 120°C. This means they can provide sufficient heat for a wide range of manufacturing processes, including food production, industrial washing and drying products such as timber, paper etc. Within a decade heat pump manufacturers expect to commercialize industrial systems capable of reaching 200°C. The heating capacity of single modules is also growing, with several available in the megawatt range.

For example, Sabroe's NS 355 HP, with a capacity of 12.5 MW, can produce more than 200,000 liters of hot water every hour. Most of the leading manufacturers are based in Europe, Japan or China.

14.1. 3 Different compressor types used in heat pumps

The compressor is the main component of a compression heat pump. It compresses the gaseous refrigerant from a lower to a higher pressure level. Therefore, the compressor highly impacts the efficiencies of the heat pump system. Different compressor types are available. The main compressor types currently used in HTHPs are piston (reciprocating), scroll, screw, and turbo compressors (including centrifugal compressors). Typically, these compressor types are driven by an electric motor.

a) Piston compressor: In this type, the gaseous refrigerant at lower pressure is sucked in through a valve when the piston moves downwards. When the piston moves upwards, the gas is compressed to a higher pressure. The disadvantages of this type of compressor are the pulsating volume flows and the possible occurrence of a liquid hammer.

b) Screw compressor: In this type of compressor, compression is accomplished by two counter-rotating screw-shaped rotors. The advantages of screw compressors are, for example, the compact design and the high speeds that can be realized. A disadvantage is the oil injection that is necessary for sealing. Moreover, it requires oil management systems, and oil degradation at high temperatures might be an issue limiting the application.

c) Scroll compressor: In scroll compressors, the gaseous refrigerant is compressed by means of two spirals moving into each other. The advantages of this type include low vibration, low noise level, and not sensitive to liquid hammers. However, the capacity range of the compressor type is very limited.

d) Turbo compressor: In contrast to the other compressors described above, the turbo compressor is a fluid-flow machine and does not operate on the displacement principle. In this type of compressor, the energy is transferred to the medium by means of rotating impellers. The pressure increase is achieved by means of a diffuser. The advantage of this type is the small space requirement, the large flow rates, the good speed control, and the low abrasion. However, the feasible pressure ratios per stage are low. Typically, water vapor recompression systems are operated using large compressors or high-speed oil-free turbo compressors with high flow rates and low-pressure ratios to compensate for the low density of the water vapor. A summary of heat pump characteristics based on the type of compressor is given below.

Table 17: Heat pump characteristics by compressor type

Compressor Type	Piston	Scroll	Screw	Turbo
Driving Force	Displacement	Displacement	Displacement	Flow machine
Compression	Static	Static	Static	Dynamic
Swept volume	Geometrical	Geometrical	Geometrical	Depending on the counterpressure
Production	Pulsing	Continuously	Continuously	Continuously
Volume flow	Up to 1,000 m3/h	Up to 500 m^3/h	100 to 10,000 m^3/h	100 to 50.000 m^3/h
Heating Capacity	U to 800kW	U to 400 kW	80 kW to 8 MW	80 kW to 40 MW
Pressure ratio (single stage)	Up to 10	Up to 10	Up to above 20	Up to 5
Controllable at constant speed	In stages	Difficult	Continuously	Continuously
Speed control	Possible	Possible	Possible	Possible
Sensitivity to liquid slugging	High	Low	Low	Low
Causes vibrations	Yes	No	No	No

The International Energy Agency (IEA) has collected many examples of industrial high-temperature heat pump installations and their performance. The table below presents some of these successful installations.

For example, Hokkaido Bioethanol installed a heat pump to recover heat from the distillation of ethanol. The heat pump captures heat at 65°C and returns it to the distillation process as steam at 120°C with a COP of 3.5. The company has reduced energy consumption by 40% and running costs by 54%. All the installations in the below table have achieved impressive energy and cost savings, and short payback periods. The International Energy Agency (IEA) reports that the typical payback period for a new heat pump is between 2 and 7 years.

Table 18: High temperature heat pump applications from across the world

Sector/ product	Company/ Location	Heat pump make	Heating capacity (kw)	Temperature uplift	Coefficient of performance	Energy /cost saving	Heat pump application
Food – frozen noodles	Shikoku Island, Japan		144	83°C > 98°C 100C > 30C	3.0 (heating) 2.1 (cooling)		Hot water for boiling noodles, and cold water for the cooling process before freezing.
Auto -painting	Hino Motors, Japan	HEM-150 II	566		5.1 (heating) 4.1 (cooling)	Payback 3-4 yrs Cost saving 63%	Simultaneous heating and cooling for drying paint on car parts.
Timber - Softwood timber	Germany		180	65°C > 90°C	4.5	Payback - 4 yrs	Recovers waste heat from the biomass power plant to dry timber.
Paper – packaging material	Smurfit Kappa, Netherlands	Bronswerk Heat Transfer and IBK		64°C > 115°C			Recovers heat from moist air released from paper-drying to produce steam at 115°C, which is used at different steps in production.
Chemicals - Bioethanol distillation	Hokkaido Bioethanol, Japan	Kobe Steel	9,250	65 > 120°C (steam)	3.5	Cost saving 54%	Recovers warm air from the distillation process and returns it as steam.
Electronics - transformer casings	Minami Electric, Japan		110	20°C > 80–120°C	4–6.5	Energy cost saving 12%	Pre-heats air to 80-120°C for drying casings. A gas burner completes the temperature uplift to 170°C.

15.2 Mechanical Vapor Recompression (MVR) system

Mechanical Vapor Recompression (MVR) system is a highly efficient technology used to recover and reuse energy in processes. Like a heat pump, an MVR system captures waste heat (low-pressure vapor) and repurposes it as a heating source for the process use. In MVR, a mechanical compressor plays a role like that of the compressor in a heat pump. It increases the vapor's thermal energy by compressing it.
Typically, components of MVR include a vapor compressor (e.g., centrifugal or rotary), heat exchanger, and process control systems. An MVR system is essentially a specialized industrial heat pump tailored for vapor-based processes.

Mechanical vapour recompression (MVR) is a special type of heat pump that compresses the vapour form of the fluid being processed (usually water), rather than a refrigerant. Compressing the vapour makes it hotter. MVR systems usually compress water vapour at 70-80°C and deliver steam between 110°C and 150°C, in some cases up to 200°C. Their performance is particularly impressive with COPs of 10 to 30. Common MVR applications involve the removal of water or water vapour in drying, dehumidification, distillation and concentration processes, and the recovery of heat for immediate reuse. Other potential industrial applications include:

- De-watering mixtures such as landfill leachate, oil emulsions and saline, acidic or other corrosive solutions
- Concentrating liquids such as fruit juices, milk, black liquor (in pulp and paper industry)
- Distilling of alcohol and organic chemicals.

- Re-injecting low-pressure steam into a high-pressure system.

Case study

Multinational utility and energy services provider Engie worked with a dairy factory in France to replace its two 5.5 MW gas boilers with heat pumps. Engie optimized a mechanical vapor recompression (MVR) heat pump to produce low-pressure steam at <95°C and high-pressure steam at 100-140°C by using an on-site waste heat stream. The optimized design has yielded a high efficiency of 400% (COP of 4). This has reduced CO2 emissions by 3,000 tons per year. It also lowered electricity consumption three times more than would have been possible if the boiler had been replaced with an electric boiler.

The below figure shows how a heat pump and MVR can be used in combination to produce very high-temperature steam for industrial process requirements up to 200OC using the currently available technologies.

Figure 13: Heat Pump and MVR used in combination to produce temperature as high as 200OC

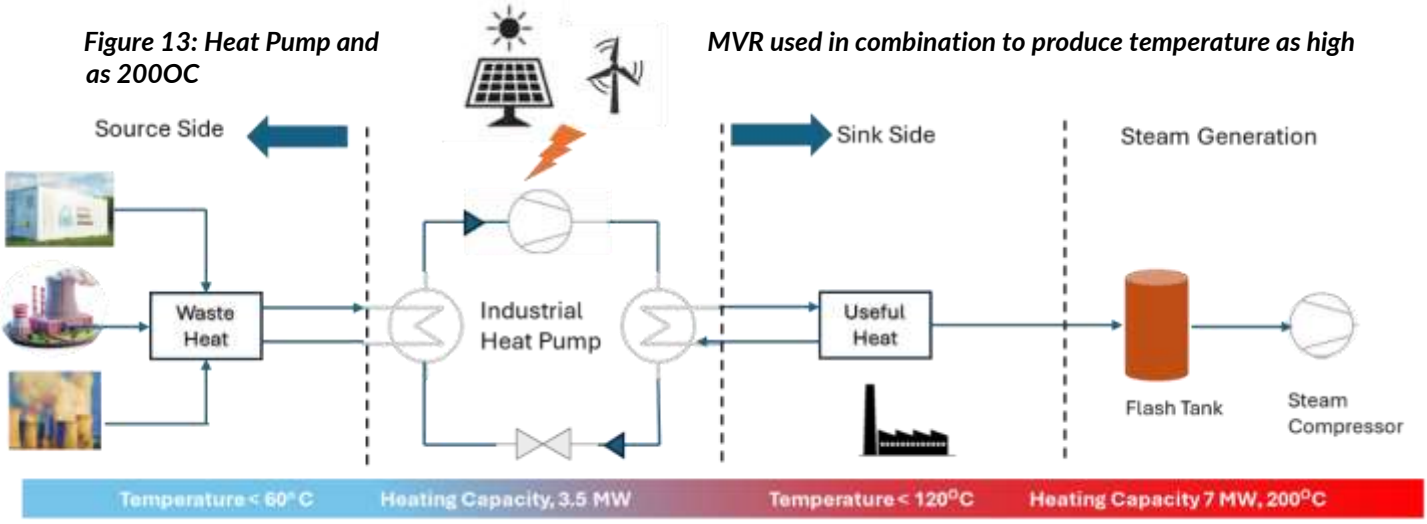


Table 19: MVR use cases from across the world

15.3 Electric Boiler

Electric boilers have emerged as an alternative to fossil-fired boilers. Their application and use are equivalent to those of conventional boilers.

Electric boilers come in two types: electrode and resistance boilers. In an electrode boiler, the current is introduced directly into the water via an anode and flows through the water to a cathode. In resistance boilers, an electric current heat a metal or ceramic heating element (i.e. via resistance heating) and the heating element transfers the heat to the water via conduction. Electric boilers are available in a range of capacities, accommodating various industrial demands. They typically provide capacities ranging from small-scale applications at around 10 kW to large-scale systems exceeding 10 MW. Furthermore, these boilers can attain maximum temperatures above 500 °C, facilitating processes that necessitate elevated heat levels which heat pumps cannot provide. Pressure levels can vary based on specific requirements, typically reaching up to 20 bar, though higher pressures can be achieved.

Table 20: Electric boilers and potential technical advancements

Year	2023	2025	2030	2035
Maximum temperature	500 °C	500 °C	500 °C	500 °C
Heat production efficiency	99%	99%	99%	99%
Capacity	up to 75 MW	up to 75 MW	up to 75 MM	up to 75 MW
Advantages	Compared to heat pump: higher achievable temperatures, easier to integrate into existing systems and lower investment costs, existing operation experience in relevant applications			
Disadvantages	Compared to heat pump: lower efficiency			

No.	Supplier	Industry	Process	Heat source			Heat sink			Refrigerant	Compressor	Capacity (KW)	COP_H	Op. hours [h/a]
				Unit Operation	T out [°C]	T in [°C]	Unit Operation	T_{out} [°C]	T_{in} [°C]					
1	**Kobelco**	sewage	sludge drying	exhaust drying air	93	93	steam generation	160	160	R718	twin-screw, roots blower	675	2.9	n. a.
2	**Piller**	plastics	thermal separation	exhaust vapour	60	60	steam generation	131	126	R718	turbo (8 blowers)	10,000	4.4	8,000
3	**Spilling**	pulp and paper	pulp drying	exhaust vapour	105	133	steam generation	201	n. a.	R718	piston (4 LT-, 2 HT-cylinders)	11,200	4.2	7,500
4	**Spilling**	chemical	chemical	exhaust vapour	105	152	steam generation	211	n. a.	R718	piston (4 LT-, 2 HT-cylinders)	12,000	5.3	7,500
5	**Rotrex, Epcon**	sewage	sludge drying	surplus steam	100	n. a.	steam generation	146	n. a.	R718	turbo (2 stages)	500	4.5	n. a.
6	**n. a.**	beverage	alcoholic distillation	product cooling	75	78.3	distillation	140	n. a.	n. a.	n. a.	350	5.2	n. a.
7	**Shanghai Nuotong**	beverage	alcoholic distillation	air	n. a.	18.9	steam generation	120	90	LT-C:R410a, HT-C:R245fa	screw	180	1.85	n. a.
8	**Shandong Zhangqiu Blower**	refinery	ethanol distillation	exhaust vapour	76	n. a.	steam generation	116	n. a.	R718	centrifugal	n. a.	7.68	7,000

Examples of relevant industries and processes	Steam generation in paper production, food industry and chemical industry
Technology readiness level	9 Established technology (small capabilities) Application for higher temperatures and capacities no big hurdle Economic Barriers

Electrification of boilers will require changes only in the boiler room to replace the existing boilers with electrified boilers. It will not require any changes to end-use processes and technologies. While there are benefits associated with the electrification of boilers as it does not require changes in the production process, the downsides are energy losses during steam distribution and use and the missed opportunities to take advantage of efficiency gains that some end-use electrified technologies (e.g., heat pumps) provide. The details of fossil fuel boilers currently used in different process industries are given below.

Table 21:Details of fossil fuel boilers used in different process industries

Industry	Plant Size	Boiler Capacity (TPH)	Pressure (Bar)	Applications	Estimated Plants in India (approx.)
Waste Paper-Based Paper Mills	Small	10–20 TPH	15–25 Bar	Pulping, drying, steam curing	300–400
	Medium	25–40 TPH			100–150
Chemical Plants	Small	5–15 TPH	10–20 Bar	Reactor heating, distillation, sterilization	1,500–2,000
	Medium	20–50 TPH			500–700
Textile Wet Processing Plants	Small	2–10 TPH	10–15 Bar	Dyeing, bleaching, washing, fabric drying	8,000–10,000
	Medium	15–30 TPH			1,500–2,000
Pharmaceutical Plants	Small	1–5 TPH	10–15 Bar	Sterilization, reactor heating, drying, formulation processes	8,000–10,000
	Medium	5–20 TPH			1,000–1,500

14.3 Battery Energy Storage System (BESS)

A battery energy storage system (BESS) is an electrochemical device that charges (or collects energy) and discharges that energy later to provide electricity. Several battery chemistries are available or under investigation, including lithium-ion, lead acid, redox flow, nickel cadmium, and Sodium-sulphur. Battery chemistries differ in key technical aspects, and each battery has unique advantages and disadvantages. Battery technologies available and their relative advantages are given in the table below.

Table 22: Availability Battery Technologies

Technology	Round trip efficiency	Lifespan	Advantages
Lithium-ion	88-90%	10-15 years	High Specific energy and high load capabilities with power cell
Sodium-Sulphur battery	75-85%	10-15 years	Low-cost potential: Inexpensive raw materials and sealed, no maintenance requirement
Nickel Cadmium Battery	60-80%	10-15 years	Rugged, high cycle count with proper maintenance

Vanadium Redox Flow Batteries	70-75%	5-10 years	Long Service. Versatility
Lead-acid Batteries	60-70%	3-6 years	Low-cost and simple manufacture Low cost per watt-hour

14.3.1 Components of BESS:

The battery system comprises the battery pack, which connects multiple cells to appropriate voltage and capacity; the battery management system (BMS); and the battery thermal management system. The BMS protects the cells from harmful operation, in terms of voltage, temperature, and current, to achieve reliable and safe operation and balances varying cell states-of-charge (SOCs) within a serial connection.

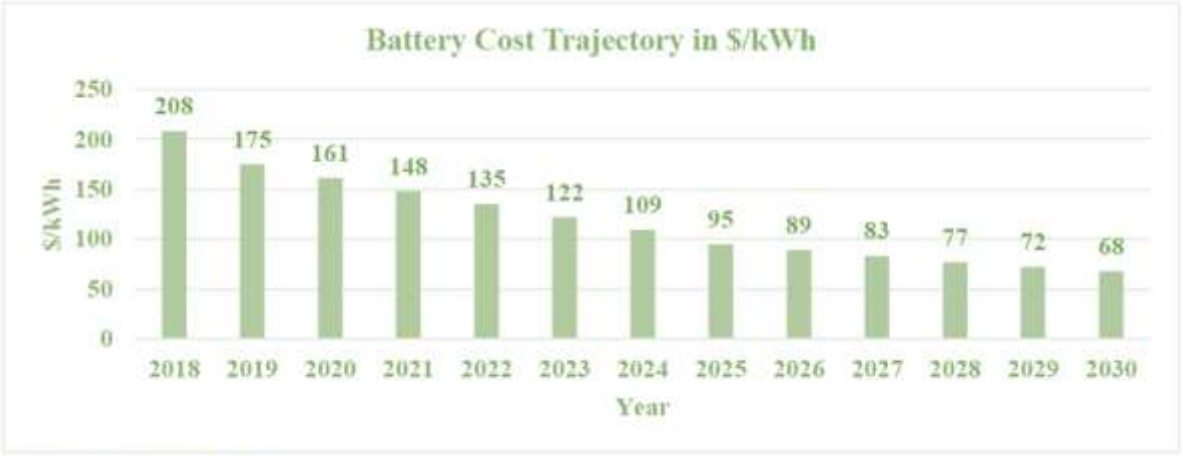
The Battery thermal management system controls the temperature of the cells according to their specifications in terms of absolute values and temperature gradients within the pack.

The inverter system, also called Power Conversion System, converts the DC power to AC power while discharging and converts AC power to DC power while charging the batteries.

14.4.2 Key characteristics of BESS:

- **Rated power** capacity is the total possible instantaneous discharge capability (in kilowatts (kW) or megawatts (MW)) of the BESS.
- **Energy capacity** is the maximum amount of stored energy (in kilowatt-hours (kWh) or megawatt hours (MWh))
- **Storage duration** is the time duration in which the stored energy can be discharged at its power capacity before depleting its energy capacity. For example, a battery with 1 MW of power capacity and 4 MWh of usable energy capacity will have a storage duration of four hours.
- **Cycle life/lifetime** is the time duration or cycles a battery storage system can provide regular charging and discharging before failure or significant degradation.
  Self-discharge occurs when the stored charge (or energy) of the battery is reduced through internal chemical reactions, or without being discharged for the application.
- **The state of charge**, expressed as a percentage, represents the battery's present level of charge and ranges from completely discharged to fully charged. The state of charge influences a battery's ability to provide energy or services at any given time.
- **Round-trip efficiency**, measured as a percentage, is a ratio of the energy discharged from the battery to the energy put into the battery.
- **Lithium-ion batteries:** Lithium-ion batteries are perhaps the most promising for both small and large-scale electricity storage in power generation. They currently offer superior performance and have dominated the market globally. For Li-ion battery applications industry is currently in the process of improving capacity, power, size, reliability, and safety for applications involving both electrical vehicles and power generation. Due to technological innovations and improved manufacturing capacity, lithium-ion chemistries have experienced a steep price decline since inception. The cost trajectory of the Battery Energy Storage system in future years is projected to decline, as per Bloomberg NEF projections shown below.

Figure 14: Future Battery Price Projections



Source: Bloomberg NEF

16. Legal Status to ESS

The Electricity (Amendment) Rules, 2022 provide that the Energy Storage Systems shall be considered as a part of the power system, as defined under clause (50) of section 2 of the Act. Further as per these Rules, ESS can be used independently or in conjunction with generation, transmission, and distribution infrastructure and would be accorded status based on its application area i.e. generation, transmission, and distribution. ESS owners or developers are permitted to lease or sell storage space to utility companies or Load Despatch Centres, as well as to use the storage space themselves to buy and store electricity for future sale. The independent energy storage system shall be a delicensed activity at par with a generating company in accordance with the provisions of section 7 of the Act. However, if an ESS owner or developer wishes to operate independently, they must register with CEA along with their capacity and location details and meet the safety requirements set by the CEA. Standalone ESS shall be provided connectivity under the Electricity (Transmission) System Planning, Development, and Recovery of Inter-State Transmission Charges Rules, 2021.

17. Energy Storage Obligations Trajectory till 2029-30

Ministry of Power has issued renewable purchase obligation (RPO) trajectory vide order dated 22nd July 2022 and corrigendum dated 19th September 2022. It specifies the RPO trajectory beyond 2021-22 (refer below table). Further, the order also specifies that a percentage of total energy consumed shall be solar/wind energy along with/ through storage.

Table 23: Energy storage obligations trajectory till 2029-30

Fiscal Year	Storage on an energy basis
2023-24	1.00%
2024-25	1.50%
2025-26	2.00%
2026-27	2.50%
2027-28	3.00%
2028-29	3.50%
2029-30	4.00%

The Energy Storage Obligation to the extent of energy stored from RE sources shall be considered as a part of the fulfilment of the total RPO. The Energy Storage Obligation above shall be calculated in energy terms as a percentage of total consumption of electricity and shall be treated as fulfilled only when at least 85% of the total energy stored in the Energy Storage System (ESS), on annual basis is procured from renewable energy sources.

18. Waiver of Inter State Transmission System Charges

Given the importance of facilitating RE integration in the grid and in pursuance of National Tariff Policy 2016, waiver of transmission charges for using Inter-State Transmission System has been made available to Energy Storage Systems, including BESS, vide Ministry of Power's order dated 23.11.2021, as amended from time to time. As per the said order, complete waiver of ISTS charges has been made applicable to BESS projects commissioned up to 30.06.2025, subject to certain conditions. The transmission charges for the ISTS network shall be levied gradually for the projects commissioned after 30.06.2025. The transmission charges shall be gradually increased by 25% annually starting from 1st July 2025 till 30th June 2028.

19. Rules for replacement of Diesel Generator (DG) sets with RE/Storage

The Electricity (Rights of Consumers) Amendment Rules, 2022 notified on 20th April 2022 mandates that the consumers, who are using the Diesel Generator (DG) sets as essential back up power, shall endeavour to shift to cleaner technology such as renewable energy with battery storage and the like in five years or as per the timelines given by the State Commission for such replacement based on the reliability of supply in that city covered under area of supply of the distribution licensee. This will encourage installation of ESS by Commercial and Industrial consumers who are using DG sets for enhancing reliability of power supply.

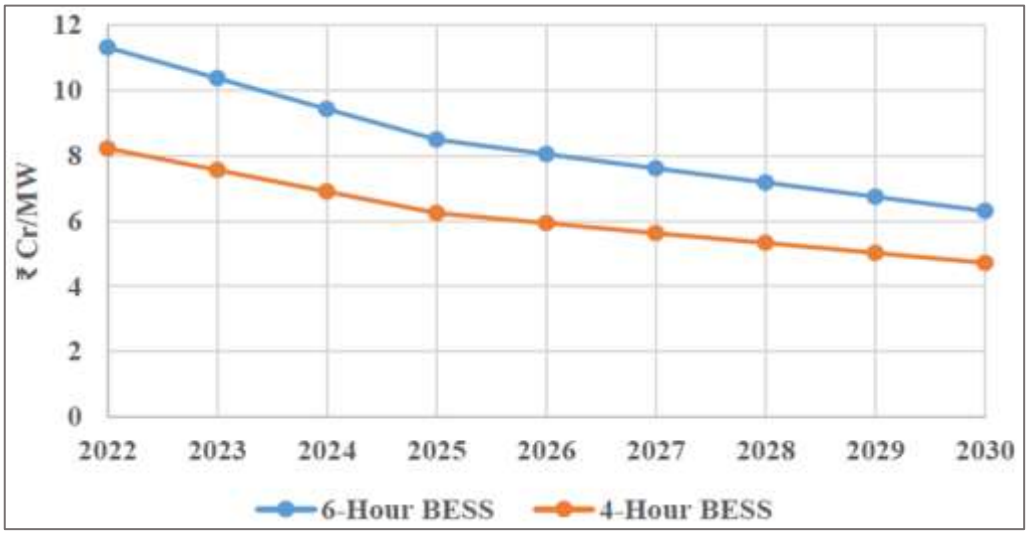
20. Introduction of High Price Day Ahead Market and Eligibility to ESS

Ministry of Power vide note dated 11.10.2022 has come up with a detailed framework for the High Price Day Ahead Market segment (HP-DAM) in the existing Integrated DAM (I-DAM), wherein sellers with high cost of generation would be allowed to participate. HP DAM has been launched on 9th March 2023. Battery Energy Storage Systems (BESS) have been included in the list of eligible generators that are allowed to participate in the HP DAM segment of the Energy Exchange. This would enable ESS asset owners to take suitable advantage of the price differential between Peak and Off-Peak tariffs.

21. Inclusion of ESS in Technical Standards for Connectivity to the Grid

Central Electricity Authority has notified CEA (Technical Standards for Connectivity to the Grid) Regulations, 2007 and its latest (Amendment) Regulations, 2019 on 6th February 2019 which provide the requirements to be complied with by BESS to get connectivity to the Grid at the voltage level 33kV and above. This will enable faster and smoother integration of BESS with the Grid.

Figure 15: BESS projected cost trajectory in Rs Crores/MW



22. Captive Power to Grid Power

Increasingly non-cogeneration power plants are showing interest in shifting from captive to the grid to meet the power requirements of the factory. Common challenges and concerns raised by the stakeholders during the consultations across sub-sectors related to shifting from captive power plants to the grid are as follows:

- Concerns about grid availability (including high voltage line and sub-station capacity), reliability, and power quality across different regions of the country
- Increased sensitivity of industrial equipment to fluctuations in power quality
- Additional investment is required to enhance power import capabilities at individual factory levels
- Higher electricity import tariff compared to the cost of captive power
- Potential waste of significant investments made in existing captive power plants
- Job security issues for employees working in captive power plants and associated cross-training costs if they need to be internally reassigned.

If these concerns are addressed the non-cogeneration-based captive power plants will readily shift to the grid power.

22.1Captive Power to Renewables

As Industries are installing more and more on-site and off-site renewable power for captive power consumption the adoption of renewable power is taking place at a faster pace. Today renewable power constitutes a significant share of many industries. The options available for renewable power generation in India are roof-top solar, onsite wind/ground-mounted solar, off-site wind/ground-mounted solar, open access renewable power, and renewable energy round-the-clock (RE-RTC).

As we are aware renewable power like and wind and solar are intermittent in nature hence cannot alone meet the renewable power requirement of Industries on a continuous basis hence there is a need to group all the renewable powers like solar, wind, hydro, biomass, etc. with energy storage systems like pumped hydro and battery enable storage systems (BESS) to provide round the clock power to large electricity consumers.

In October 2019, the Solar Energy Corporation of India (SECI) issued the first-ever RTC tender for 400MW (RTC-1). The following March, another SECI 5,000MW RE-plus-thermal (RTC-2) tender was announced (the capacity was reduced to 2,500MW in December 2020). In May 2020, for the RTC1 auction the lowest bid (L1) tariff discovered for the first year of the power purchase agreement (PPA) was Rs 2.9/kWh (3% annual escalation for first 15 years). Similarly, for RTC-2 auction conducted in October 2021, the L1 tariff discovered was Rs 3.01/kWh. Cost of some of the technologies that can enable RE RTC power in India as of 2022-23.

Table 24:Cost of technologies in India 2022-23

Name of Technology	Cost of Investment (Rs/MW) *
Solar	4.5 Cr
Wind	6 Cr
Hydro	8-10 Cr
PSP (6 hours)	4-6 Cr
Battery (5-Hour Storage)	8 Cr

**All prices considered are at the 2022-23 price level.*

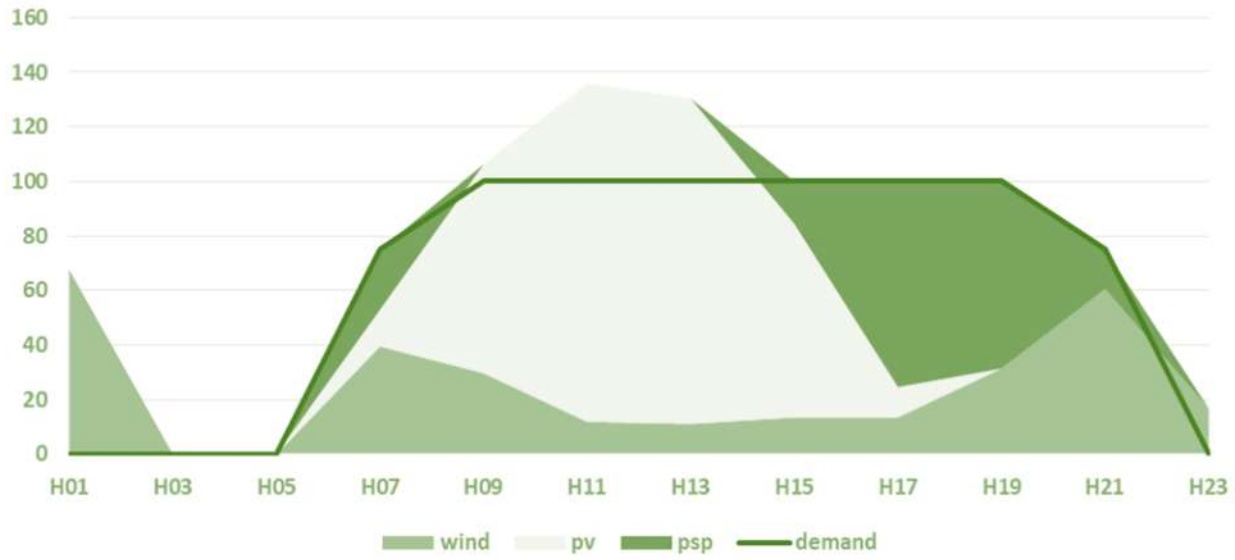
Case 1: RE RTC is suited for Industrial customers[39]

A case study for a 100 MW RE RTC for Industrial customers has been modeled. The capacity requirement and per-unit cost are shown in the table below. The demand pattern for Industrial customers with two-shift operations is shown in the figure below, along with the power dispatch scenario.

Table 25: Source-wise installed capacity requirement

Source	Installed Capacity requirement (MW)
Maharashtra Solar	189
Gujarat Wind	41
Karnataka Wind	78
Tamil Nadu Wind	34
PSP (6 Hours)	84
Annual Cost (in Cr)	2786
Energy in MWh	546000
Per Unit cost of generation in (Rs/kWh)	5.102

Figure 16: Power dispatch for 100 MW RE RTC Industrial customer



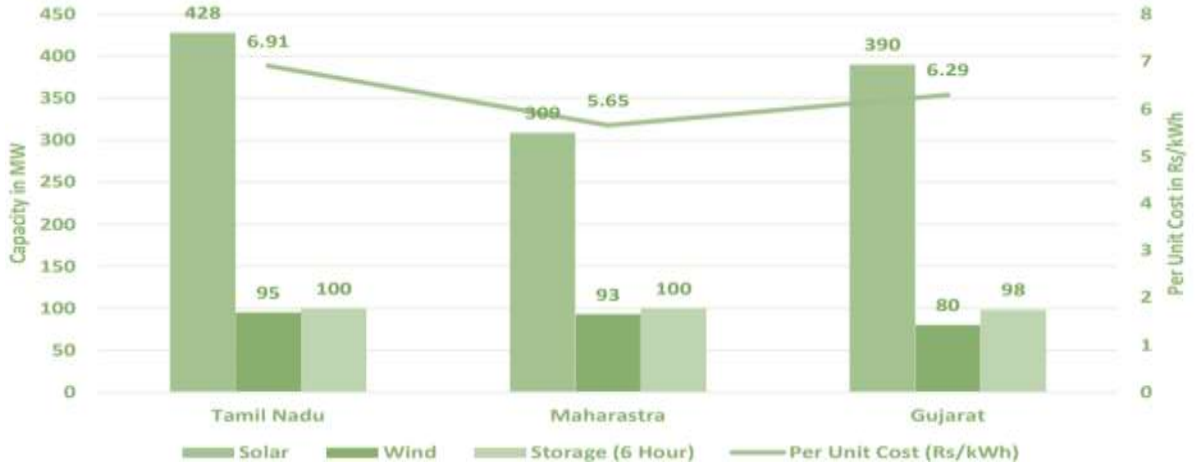
Case 2: 100 MW RE RTC for Industrial customers with State Specific Solar & Wind Profile[40]

A case study for 100 MW from RE RTC for C&I customers in different state scenarios considering the state-specific RE profile (Solar & Wind). The Capacity requirement and per unit cost for different example states of Gujarat, Maharashtra & Tamil Nadu are shown in the below figure.

[39] https://cea.nic.in/p-content/uploads/notification/2024/02/RE_RTC_Final_Report.pdf

[40] https://cea.nic.in/wp-content/uploads/notification/2024/02/RE_RTC_Final_Report.pdf

Figure 17: Effect of state RE profile on RE RTC cost and generation scenario



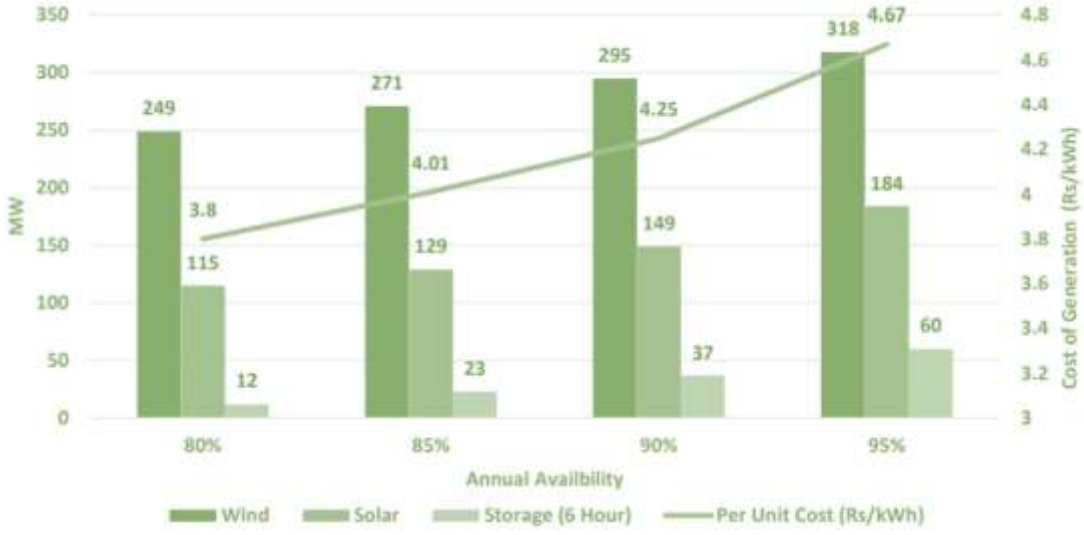
Case 3: Analysis of RE RTC annual availability (80%, 85%, 90%, 95%)[41]

A case study for a 100 MW RE RTC with annual availability varying in the range of 80-95% was considered for customers with the combination of Gujarat Solar and Maharashtra Wind. The capacity requirement and per unit cost are shown in below table/figure.

Table 26: Source-wise capacity requirement and per unit electricity cost for different availability cases

Description	Availability			
Source	**80%**	**85%**	**90%**	**95%**
Wind	249	271	295	318
Solar	115	129	149	184
Storage (6 Hour)	12	23	37	60
Per Unit Cost (Rs/kWh)	3.8	4.01	4.25	4.67

Figure 18: Source wise capacity requirement and per unit electricity cost for different availability cases



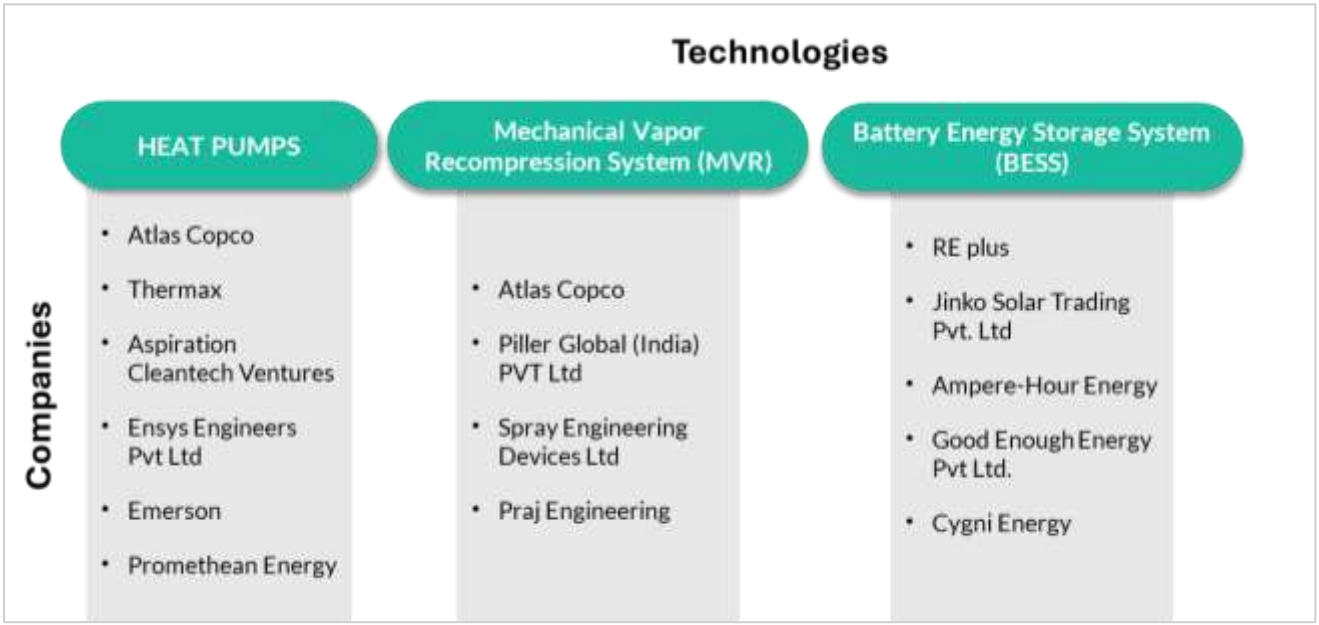
The following things can be noted from the above analysis:

[41] https://cea.nic.in/wp-content/uploads/notification/2024/02/RE_RTC_Final_Report.pdf

- With higher annual available requirements, the capacity and storage requirement increase significantly. This corresponds to higher investment requirement and higher per unit cost of generation.
- Comparison of annual availability of RE-RTC vs conventional sources with similar availability is difficult as for conventional sources the availability can be managed by planning the annual maintenance of the plant as per the requirement of utilities, while the availability of RE-RTC is solely dependent on the weather patterns and is subject to higher degree of seasonality across the year.

The present cost of generation of new coal plants is around 5-6 Rs/Unit with an annual escalation of 1-2% of fuel cost. Compared to this, RE-RTC presents an alternate green solution to meet the demand which is economically viable. The cost of RE-RTC is expected to decrease further which will make it more competitive to the conventional fossil generation source.

23. Summary Electrification Technology and Providers



ABOUT THE GLOBAL GREEN GROWTH INSTITUTE

The Global Green Growth Institute was founded to support and promote a model of economic growth known as “green growth”, which targets key aspects of economic performance such as poverty reduction, job creation, social inclusion, and environmental sustainability.

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