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Captive Power in Indian Industries: A Review of Evolution, Adoption, Technology, Regulation, and Future Energy Systems

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Abstract

Captive power generation plays a vital role in Indian industry by reinforcing grid reliability, mitigating tariff volatility, and ensuring energy security. This review traces the evolutionary trajectory of Captive Power Plants (CPPs) in India—from fossil-fuel baseload units toward storage-augmented, renewable-rich industrial microgrids. We evaluate conventional, renewable, and hybrid captive architectures against techno-economic, power quality, and resilience metrics. Crucially, the paper evaluates the regulatory paradigm shift introduced by the Electricity (Amendment) Rules, 2026, analyzing its collective compliance framework, the revision of the Association of Persons (AoP) proportionality test, designated nodal verification via National Load Dispatch Centre (NLDC)/ State agencies, and the explicit recognition of Energy Storage Systems (ESS) within captive consumption limits. Significantly, we specify why these 2026 rules are transformative, highlighting how they overturn the fallout of strict judicial rulings—such as the Supreme Court's Gayatri Shakti precedent—by decoupling individual member non-compliance from overall captive plant disqualification. Finally, we examine digital energy management architectures—incorporating AI-driven forecasting and grid-forming inverter controls—and identify pressing research gaps across protection coordination, dynamic modeling, and regulatory settlement.

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1. INTRODUCTION

Electricity availability, reliability, and cost directly influence industrial productivity and competitiveness. Historical limitations in grid supply, voltage disturbances, and high industrial tariffs encouraged Indian industries — particularly energy-intensive and continuous-process sectors, where interruptions cause production losses, equipment trips, and restart costs — to develop captive generation[1,2]. The Electricity Act, 2003, the National Electricity Policy, 2005, and the Electricity Rules, 2005 established the statutory basis for captive generation, including the right to construct and operate a captive plant, group-captive arrangements, and the eligibility requirements of at least 26% ownership and 51% captive consumption by the user(s)[3-5]. Crucially, this policy landscape experienced a major paradigm shift with the notification of the Electricity (Amendment) Rules, 2026, which formally substituted Rule 3 of the Electricity Rules, 2005. This amendment provides immediate industrial relevance by streamlining the collective compliance framework for group-captive architectures, reforming the AoP proportionality test, and granting explicit statutory recognition to electricity consumed through ESS as eligible captive consumption[1].

Captive generation was historically dominated by coal, diesel, gas, biomass, and cogeneration, but the sector is diversifying rapidly toward solar PV, wind, hybrid renewable systems, BESS, and industrial microgrids. Firm-specific transaction costs, reliability requirements, and power quality continue to shape captive-generation decisions[6], while the Electricity (Amendment) Rules, 2026 have further reshaped ownership, verification, and storage-linked captive consumption[7]. Captive power is consequently evolving from a self-generation backup into an integrated industrial energy system combining generation, storage, grid interaction, and digital energy management.

This transition motivates the present review, which traces the evolution and present status of captive power in India, industrial adoption across major sectors, and the economic, reliability, technical, and strategic drivers behind it. It further compares conventional, renewable, and hybrid technologies and outlines a roadmap toward renewable-integrated, storage-enabled, and intelligent industrial energy systems, with attention to the regulatory implications of the 2026 amendment.

2. EVOLUTION AND PRESENT STATUS

The development of captive power in India tracks the growth of industrial electricity demand and the need for reliable, cost-effective supply. In the pre-reform period, industries built coal-, diesel-, and gas-based captive

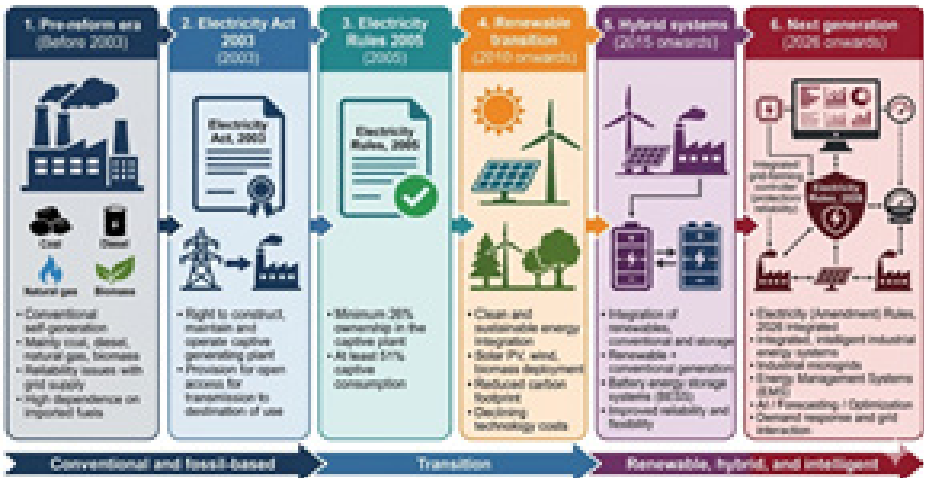


Figure 1. Evolution of captive power in India: from conventional to renewable, hybrid, and intelligent systems.

plants to supplement grid electricity, and cogeneration developed in sugar, paper, and chemical industries able to use process by-products for combined heat and power. The Electricity Act, 2003 (Section 9) and the Electricity Rules, 2005 formalized captive-plant eligibility and established the basis for group-captive arrangements[3,5].

According to the definitive data published in the Central Electricity Authority (CEA) General Review 2025, India's cumulative installed non-utility captive generating capacity (for units ≥ 0.5 MW) successfully reached 80,926.07 MW[8]. This substantial industrial self-generation infrastructure constitutes approximately 15.48% of India's aggregate utility and captive generating footprint[7]. In terms of fuel-mix configuration, heavy industrial facilities remain heavily reliant on traditional thermal baseload capacity, with steam-based (primarily coal) setups anchoring ~57% of the total captive matrix, followed by standby diesel configurations at 24%, and gas-fired units at 8%[8]. Concurrently, driven by strict industrial decarbonization targets and corporate green energy open-access routes, the integration of captive renewable energy has surged to comprise nearly 11% (~9.1 GW) of the non-utility power pool[8]. This capacity continues to be heavily consolidated across energy-intensive and continuous-process segments including iron and steel, cement, chemicals, fertilizers, aluminium, pulp and paper, and sugar[7].

The Electricity (Amendment) Rules, 2026 (notified 13 March 2026) substituted Rule 3 of the Electricity Rules, 2005, retaining the 26%/51% requirements while clarifying captive-user definitions and — significantly — recognizing electricity consumed through an energy storage system associated with a captive plant as captive use[7]. The sector is thus transitioning from conventional self-generation toward diversified, increasingly integrated industrial energy systems.

3. INDUSTRIAL ADOPTION

Captive adoption is strongest where electricity is simultaneously a major production input and a critical reliability requirement, and it varies substantially across sectors in intensity, technology, and renewable potential (Table 1). Iron and steel, aluminium, cement, and chemicals/petrochemicals account for the bulk of installed capacity, reflecting continuous processes and, often, access to process gases or waste heat. Sugar and pulp/paper industries have strong cogeneration

Table 1. Comparative captive-power characteristics across major Indian industries (condensed)[9,8].

Industry	Elec. intensity / adoption	Dominant technology	RE potential and key issue
Iron and steel	Very high / very high	Thermal CPP, Combined Heat and Powe (CHP), waste-gas	High; fuel cost, emissions
Cement	High / high	Thermal CPP, WHR, CHP	Moderate–high; WHR, emissions
Aluminium	Extremely high / very high	Large CPP (coal/gas)	High but technically hard; continuous load
Chemicals and petrochem.	High / high	CHP, gas/thermal CPP	High; process continuity
Sugar and pulp/paper	Medium–high, seasonal / high	Biomass CHP (bagasse, black liquor)	Moderate–high; feedstock seasonality
Mining	Medium–high / site-dependent	Diesel/thermal CPP, hybrid	Very high at remote sites; islanding

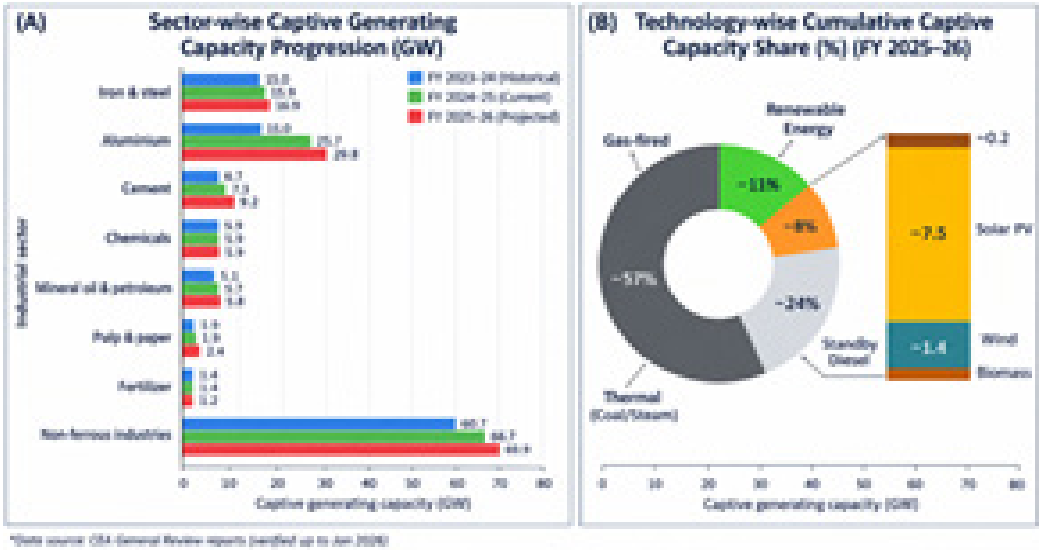


Figure 2. Industry-wise captive-power adoption in India.

opportunities via bagasse and black liquor, while mining depends heavily on diesel or hybrid systems owing to remote siting[9].

Installed capacity alone does not measure the share of an industry's electricity actually met by captive generation; a reliable sectoral adoption rate would require plant-level data on total consumption versus captive supply[8,10]. Thermal and diesel plants continue to dominate energy-intensive metals and chemicals, cogeneration concentrates in biomass-rich process industries, and renewable/hybrid captive systems are increasingly adopted through on-site and group-captive or open-access routes, driven by falling renewable costs and corporate decarbonization commitments[9,11].

4. DRIVERS OF ADOPTION

The captive-generation decision is a strategic "make-or-buy" evaluation shaped jointly by economic, reliability, technical, and strategic considerations rather than electricity price alone; the transaction-specificity of a firm's electricity use is a significant predictor of captive adoption in Indian manufacturing[10].

Economic: industrial tariffs — historically inflated by cross-subsidization of other consumer categories[12] — demand charges, fuel-price risk, and open-access costs (wheeling, banking, cross-subsidy/additional surcharge) together define a spectrum from grid supply to conventional/group-captive generation, renewable open access, and hybrid renewable-BESS systems, best compared on a levelized, long-term basis.

Reliability: historically the dominant driver — World Bank evidence documented significant production losses and equipment damage from outages and poor supply quality[13], and continuous-process industries face disproportionate restart costs even from short interruptions, underlying the concept of value of lost load.

Technical: load factor, waste-heat and cogeneration opportunities, local renewable-resource availability, and grid constraints (e.g., remote mining sites) determine feasibility; captive-renewable growth from ~1 GW to ~9.1 GW (2014–15 to 2024–25) reflects expanding technical relevance of solar and wind[9].

Strategic: energy-security through portfolio diversification, sustainability commitments reinforced by the Perform, Achieve and Trade (PAT) scheme[15],

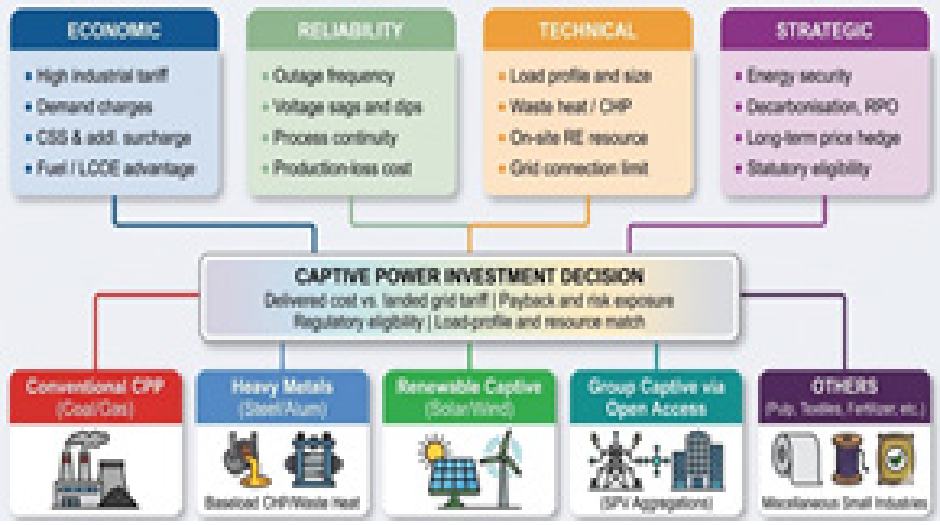


Figure 3. Key drivers influencing captive-power adoption and configuration.

corporate renewable-energy targets pursued via group-captive projects and open access[11], and long-term price management, since renewables shift expenditure from variable fuel cost toward fixed capital cost.

These categories interact rather than act independently: economic drivers determine competitiveness against purchased power, reliability drivers determine the value of continuity, technical drivers determine feasibility, and strategic drivers determine alignment with long-term energy-security and decarbonization goals — together forming a multidimensional optimization rather than a single cost comparison.

5. TECHNOLOGIES: CONVENTIONAL TO RENEWABLE

Captive technology has historically been dominated by coal, gas, diesel, biomass, and cogeneration, valued for controllability and continuity, but declining renewable costs and decarbonization pressure are steadily raising the renewable share[6].

Conventional: coal (~57% of 2024–25 capacity) dominates energy-intensive metals, cement, and chemicals for its dispatchability but faces rising emissions and ramping constraints; gas (~8%) offers faster load-following and cogeneration suitability but carries fuel-price risk; diesel (~24%) is increasingly confined to backup/emergency roles; biomass/CHP serves sugar, paper, chemical, and food-processing industries with simultaneous electricity and thermal demand.

Renewable: solar PV is the most widely adopted renewable captive technology given modularity and zero fuel cost, though variability requires complementary generation or storage at higher penetration — India's cumulative solar capacity reached ~168 GW by August 2026, with wind at ~58.5 GW and small hydro ~5.2 GW providing complementary or more-controllable profiles[16].

Hybrid and storage: solar-wind, renewable-plus-conventional, renewable-plus-grid, and renewable- plus-BESS configurations balance cost, reliability, and flexibility without displacing existing assets outright. BESS enables renewable time-shifting, peak reduction, ramp-rate control, and limited islanded operation; national storage requirement is projected to rise substantially, with Ministry of New and Renewable Energy (MNRE) estimating ~82.37 GWh (2026–27) rising to ~411.4 GWh (2031–32)[14,17]. The 2026 amendment's recognition of storage-associated

electricity as captive use underpins future renewable-plus-storage configurations[7].

The overall trajectory — conventional → hybrid → renewable → renewable-storage-integrated systems — requires coordinated operation of generation, storage, and grid interaction rather than a simple technology swap, given industrial loads' need for high availability, voltage/frequency support, and power quality.

6. WAY FORWARD: NEXT-GENERATION CAPTIVE POWER

A six-stage roadmap frames this transition: (1) conventional captive power (coal/gas/diesel/biomass); (2) hybrid captive power, pairing existing plants with solar/wind to cut fuel use while retaining firm capacity; (3) renewable-dominant captive power (solar+wind+grid); (4) renewable+BESS, addressing the temporal mismatch between renewable output and industrial demand; (5) the industrial microgrid stage, coordinating renewables, BESS, conventional generation, and flexible loads via an EMS, with limited islanded operation where designed and permitted[18,19]; and (6) the intelligent industrial energy system, where forecasting, AI/ML, optimization, digital twins, and advanced (including grid-forming) inverter control support predictive, multi-objective coordination[20,21].

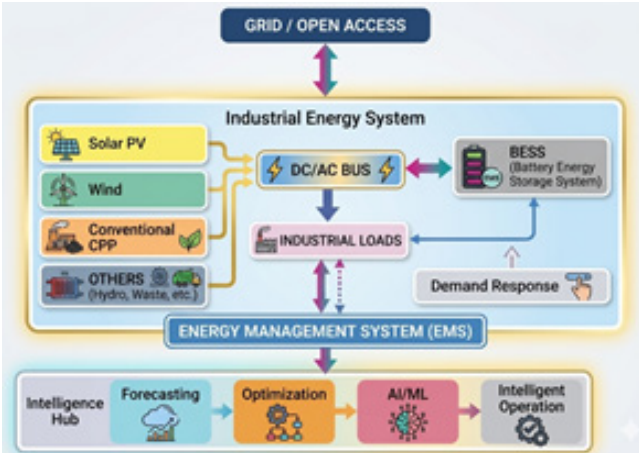


Figure 4. Next-generation integrated captive-power architecture for Indian industries.

Key research priorities include: dynamic/EMT modeling of inverter-based and grid-forming captive resources for protection and stability studies; industrial-load modeling capturing motor, power-electronic, and process-heating loads; multi-service BESS sizing (peak reduction, backup, frequency support, islanding) rather than energy arbitrage alone; adaptive, communication-assisted protection, since inverter fault currents are control-dependent rather than fixed by synchronous-machine impedance; cybersecurity built into EMS design; field-validated digital twins; and interoperability standards across multi-vendor equipment.

On policy, the 2026 amendment already clarifies captive ownership, verification, and storage-linked consumption[9], but further work is needed on transparent treatment of renewable-plus-storage systems, stable open-access/banking charges, microgrid and islanding standards, BESS financing support, and interoperability/cybersecurity standards — so that policy supports the transformation of captive power into flexible, renewable-integrated, digitally managed infrastructure, not merely additional capacity.

7. SUMMARY

Captive power in India has transitioned from an emergency reliability backstop into an agile, storage-enabled driver of corporate decarbonization. While dispatchable fossil and biomass generation continue to anchor energy-intensive baseload operations, declining solar-plus-storage costs and progressive regulatory clarity under the Electricity (Amendment) Rules, 2026 are accelerating the adoption of group-captive renewable hybrids. Crucially, industrial power resilience will depend on the coordinated operation of inverter-based resources, battery storage, and dynamic loads. Bridging this transition requires solving fundamental challenges in low-inertia system protection, grid-forming control stability, and multi-value storage optimization, ensuring captive microgrids satisfy cost, carbon, and compliance mandates in tandem.

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