

ECO FORGING

Energy Efficiency • Process Automation • Waste Heat Recovery • Green Metallurgy

Compendium of Clean Technologies and Use Cases for Resource Efficiency & Cleaner Production



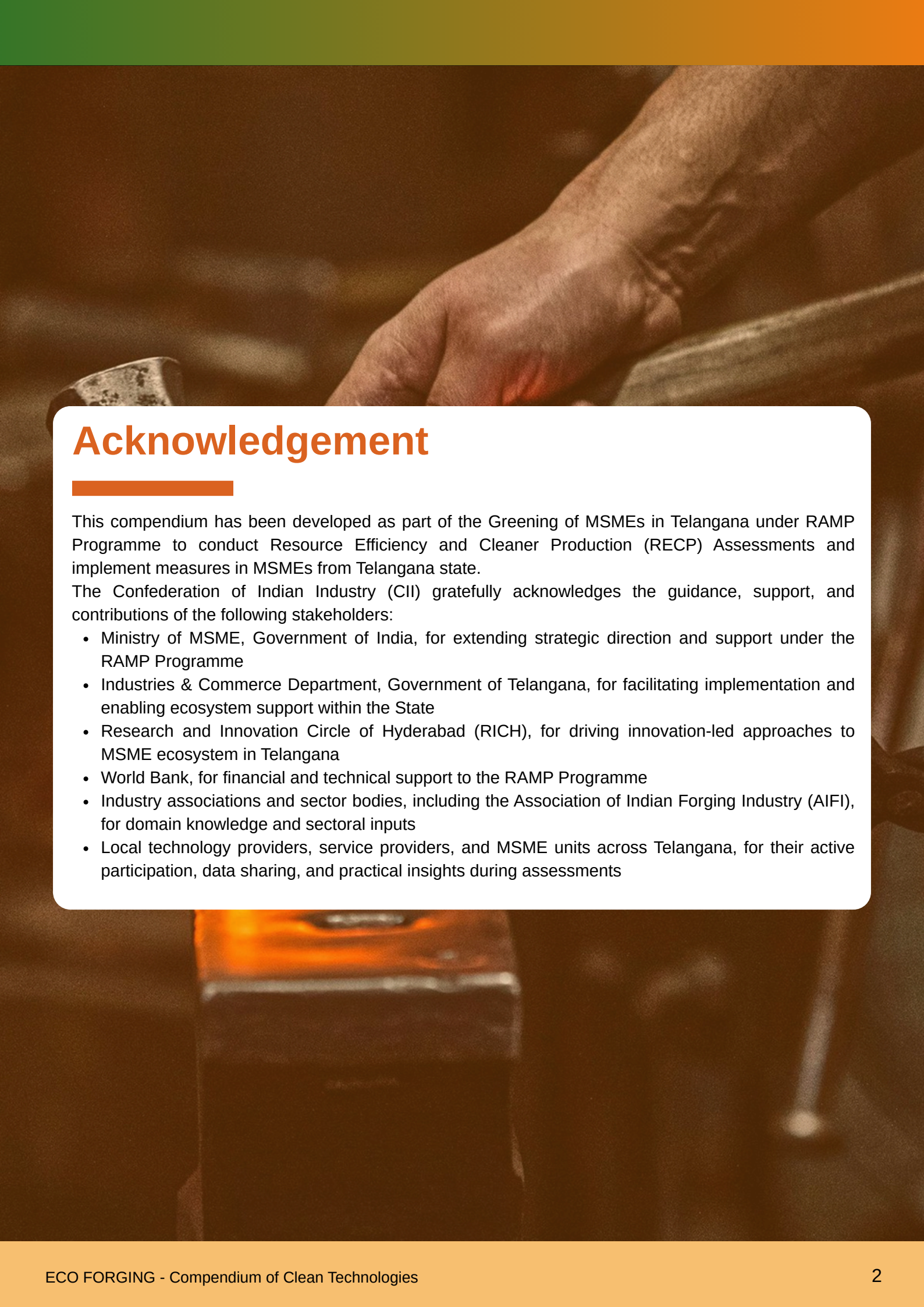
Prepared by CII for Research and Innovation Circle of Hyderabad (RICH) as part of the
RAMP Telangana Greening of MSME Initiative

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Disclaimer

The compendium has been prepared for the Raising and Accelerating MSME Performance (RAMP). Greening of MSMEs initiative being implemented by Research and Innovation Circle of Hyderabad (RICH) with technical assistance and field support from the Confederation of Indian Industry (CII). The RAMP program is a program for results under the Ministry of MSME, Government of India, with support from the World Bank. In Telangana the program is being overseen by the Industries & Commerce Department, Government of Telangana, and implemented by Research and Innovation Circle of Hyderabad (RICH), to guide MSMEs in Telangana clusters towards improved resource utilisation, energy efficiency, and cleaner production practices. The information presented in this document is intended as a reference guide for MSME owners, energy managers, plant operators, and policymakers. The technologies, performance parameters, and financial estimates provided are indicative in nature and may vary based on site-specific conditions. MSMEs are advised to undertake detailed technical, financial, and operational feasibility assessments prior to implementation of any recommended measures. The vendor or technology provider details included in this compendium are for informational purposes only and do not constitute an endorsement or recommendation by CII, RICH, the Industries Department of Telangana, or any other stakeholders under the RAMP Programme.

The energy savings potential, benchmarks, and case references presented are derived from secondary sources and cluster-level studies, including but not limited to studies conducted by the Bureau of Energy Efficiency (BEE), the Association of Indian Forging Industry (AIFI), the Government of Gujarat (Establishment of Forging and Casting Unit for Heavy Engineering Facilities Report, 2024), and the UNIDO–BEE Compendium for Eastern Zone Metal Industries (2020). While every effort has been made to ensure accuracy and relevance, CII, RICH, the Industries Department of Telangana, and associated stakeholders do not assume any responsibility or liability for decisions made based on the information contained in this document or for any consequences arising thereof.



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List of Abbreviations

Term / Abbreviation	Definition
BEE	Bureau of Energy Efficiency, Government of India
CBA	Cost–Benefit Analysis
CNC	Computer Numerical Control precision machining control system
EC Fan	Electronically Commutated motor fan variable-speed, high-efficiency fan
EOT	Electric Overhead Travel crane
FO	Furnace Oil heavy residual fuel oil used in industrial furnaces
GHG	Greenhouse Gas
HMC	Horizontal Machining Centre
HT	Heat Treatment
IE1/IE2/IE3/IE4	International motor efficiency classes (IE4 = highest efficiency)
IGBT	Insulated Gate Bipolar Transistor power semiconductor device used in induction heating and VFD systems
IoT	Internet of Things networked digital sensing and control technology
kWh	Kilowatt-hour unit of electrical energy
LPG	Liquefied Petroleum Gas
MT	Metric Tonne (1,000 kg)
NG	Natural Gas
Nm ³	Normal cubic metre gas volume at standard temperature and pressure
PF	Power Factor ratio of active to apparent electrical power
PV	Photovoltaic
SEC	Specific Energy Consumption energy consumed per unit of output
SPM	Special Purpose Machine
toe	Tonne of Oil Equivalent standard energy unit
VFD	Variable Frequency Drive electronic speed controller for AC motors
VMC	Vertical Machining Centre

About the Project

The Micro, Small and Medium Enterprises (MSME) sector plays a vital role in India's economic and social progress. As of July 4, 2025, MSMEs account for 30.1% of India's GDP, 35.4% of manufacturing and 45.73% of exports in the country. The Udyam Registration Portal, launched on July 1, 2020, and designed to provide a free, paperless and self-declared registration process, has recorded more than 3.80 crore MSME units. Additionally, the Udyam Assist Portal, introduced on January 11, 2023, to support informal micro enterprises and extend access to formal benefits such as Priority Sector Lending, has registered over 2.72 crore units. Together, these platforms cover around 6.5 crore MSME units across India, representing all eligible MSME category businesses, and collectively generating employment for nearly 28 crore people.

Despite its potential to drive entrepreneurship, economic growth and employment generation, the sector faces persistent challenges such as limited access to credit, technology and markets, infrastructure constraints, and delayed payments. The COVID-19 pandemic further exacerbated these issues, impacting liquidity, increasing non-performing assets, leading to unsold inventories, and disrupting supply chains.

To address these concerns, the Ministry of MSME, Government of India, introduced a new Central Sector Scheme called 'RAMP (Raising and Accelerating MSME Performance)', which is financially supported by the World Bank. The scheme is planned for implementation over a five-year period, starting from FY 23 till FY 27. The Cabinet approved the scheme on 30th March 2022 and the same was launched by the Hon'ble Prime Minister on 30th June 2022.

The RAMP programme is designed to have a nationwide impact, aiming to benefit all 63 million enterprises that fall under the MSME category, either directly or indirectly. However, the scheme specifically targets 5,55,000 MSMEs for measurable performance improvements. Additionally, it envisions expanding its reach to include service sector enterprises and aims to increase the participation of women-led MSMEs by approximately 70,500.

To operationalize RAMP, the central government directed all states and union territories to prepare and submit a Strategic Investment Plan (SIP) outlining their priorities and interventions under the programme. Telangana submitted its SIP identifying key objectives to strengthen the MSME ecosystem. One of the major priorities under Telangana's RAMP plan is Greening of MSMEs, which aims to:

- ❖ Promote energy efficiency, resource optimization, and cleaner production practices
- ❖ Reduce environmental impact and improve compliance
- ❖ Support MSMEs in adopting sustainable technologies and processes

The Industries Department, Govt. of Telangana, and RICH have entrusted CII to implement the "Greening of MSMEs" program in Telangana".

Executive Summary

Forged components are extensively used in applications requiring high mechanical strength, dimensional accuracy, fatigue resistance, and operational reliability. With India expanding its manufacturing capacity through initiatives focused on industrial growth, infrastructure development, localisation, and advanced manufacturing, the forging sector holds strategic importance in ensuring supply chain reliability and industrial self-reliance.

The forging sector is one of the most important pillars of India's manufacturing ecosystem, supplying critical components to industries such as automotive, railways, defence, aerospace, construction equipment, agricultural machinery, oil and gas, power generation, and heavy engineering. In Telangana, the forging industry is primarily concentrated in Hyderabad, Ranga Reddy, and Medchal districts, forming a vital part of both domestic and export-oriented industrial supply chains. The sector is highly energy intensive, with billet heating, forging operations, and heat treatment processes accounting for nearly 60–80% of total energy consumption in a typical forging unit. A significant number of MSME forging units continue to operate with conventional furnace systems, inefficient combustion practices, inadequate thermal insulation, compressed air leakages, poor electrical load management, and limited process monitoring systems. These operational inefficiencies result in excessive fuel consumption, higher operating costs, increased greenhouse gas emissions, productivity losses, and inconsistent product quality.

Global manufacturing markets are rapidly shifting towards low-carbon and sustainable supply chains, with international buyers and OEMs increasingly prioritising energy-efficient manufacturing, reduced carbon emissions, and sustainable sourcing practices. In this changing industrial environment, decarbonisation of the forging sector has become essential for improving competitiveness, strengthening export readiness, and ensuring long-term business sustainability. The transition towards energy-efficient and low-carbon forging operations not only reduces environmental impact but also improves productivity, product quality, process reliability, and operational efficiency. It further supports compliance with emerging environmental requirements and contributes to India's broader goals on industrial sustainability, energy efficiency, and emission reduction.

This Technology Compendium has been developed as a practical guide to support forging MSMEs in adopting resource-efficient and low-carbon technologies, enabling them to enhance competitiveness and build a future-ready sustainable manufacturing ecosystem. The compendium presents 23 energy efficiency and decarbonisation opportunities covering furnace systems, combustion optimisation, compressed air systems, electrical systems, waste heat recovery, process controls, utilities, and renewable energy applications. The identified technologies and practices are categorised according to implementation complexity, investment requirement, and energy-saving potential, supporting a phased and financially practical transition pathway for MSMEs.

Immediate Priority Actions for MSMEs: No-Cost and Low-Cost Measures

The compendium highlights several immediate implementation measures requiring minimal or low capital investment while delivering measurable operational and energy performance improvements:

- ❖ Optimisation of furnace temperature control and air-fuel ratio management
- ❖ Reduction of idle furnace operation through improved batch scheduling

- ❖ Peak load management and electrical demand optimisation
- ❖ Repair and strengthening of furnace insulation, refractory lining, and door sealing
- ❖ Identification and rectification of compressed air leakages
- ❖ Elimination of unnecessary compressed air usage during idle conditions
- ❖ Maintenance of power factor using thyristor-controlled Automatic Power Factor Correction (APFC) systems with detuned harmonic filters
- ❖ Adoption of energy-efficient LED lighting systems
- ❖ Installation of energy monitoring and consumption tracking practices
- ❖ Operator skill development and energy awareness programmes

Implementation of these measures delivers immediate operational benefits, including:

- ❖ Reduction in fuel consumption
- ❖ Reduction in compressed air energy losses
- ❖ Improved furnace efficiency and thermal stability
- ❖ Lower peak electricity demand charges
- ❖ Reduced maintenance requirements
- ❖ Improved equipment reliability and process consistency

In addition to these immediate operational measures, the compendium further includes medium investment and advanced technology interventions such as regenerative and recuperative burner systems, induction heating technologies, Variable Frequency Drives (VFDs), waste heat recovery systems, combustion automation, digital energy monitoring systems, thermal efficiency enhancement technologies, and rooftop solar integration to support long-term decarbonisation and sustainable manufacturing transformation within the forging sector.

Key Findings

Energy expenditure in MSME forging units typically accounts for 15–25% of total manufacturing costs, with thermal processing operations representing the largest share of energy consumption. Forging furnaces are the most energy-intensive systems, accounting for nearly 60% of total site energy use in a typical forging facility. Assessment of MSME forging units across the Telangana cluster has identified significant gaps between existing operating performance and achievable benchmark levels across major energy-consuming systems. These gaps highlight substantial opportunities for improving thermal efficiency, electrical performance, process reliability, and overall resource productivity through targeted technology interventions and operational optimisation.

Table 1. Energy Efficiency Potential in the Forging industry

System	Current Performance	Benchmark/post-implementation	EE Potential
Forging Furnace (Flue Gas Temp.)	900°C (flue out)	400°C (post recuperator)	15–25% fuel savings
Combustion Air Preheat	Ambient	250°C	5–10% fuel savings
Air Compressor (SEC)	0.22 kW/CFM	0.13 kW/CFM	~40%
Pumps (Motor Load)	30 kW	24 kW	~30–50%
Electric Motors (Efficiency)	~88% (IE1/IE2)	~93% (IE3/IE4)	5–8%
Cooling Tower Fans	11 kW/fan	9 kW/fan	30–50%
EOT Crane Energy	Baseline	Regenerative recovery	20–35%
Induction Heating (Efficiency)	40–50% (gas furnace)	75–85% (IGBT-based)	40–50%

The sector assessment indicates an overall potential for approximately 30–35% reduction in thermal energy consumption and 20–25% reduction in electrical energy consumption through implementation of energy-efficient technologies, process optimisation measures, and modern utility management systems. Metal heating and heat treatment operations account for nearly 60–80% of total site energy consumption, making thermal processing systems the primary focus area for energy efficiency improvement and decarbonisation in forging operations. Improvements in furnace efficiency, combustion control, insulation systems, waste heat utilisation, and process automation are essential for reducing fuel consumption, greenhouse gas emissions, and operating costs. This Technology Compendium presents key technology interventions covering furnace systems, forming equipment, utilities, renewable energy integration, and cleaner production practices. It outlines baseline operating conditions, proposed technological solutions, energy-saving potential, financial feasibility, and implementation considerations to support adoption across MSME forging units.

Technology Attractiveness Summary

Table 2. Technology Summary for the Forging Sector

Category	Technology	Savings / Benefit	Payback	Investment
Section A – Nil and Low Investment	Furnace Temperature Optimisation	5–8% fuel savings	Immediate	Nil
	Combustion Air-Fuel Ratio Control	5–10% fuel savings	Immediate	Nil
	Furnace Scheduling & Batch Optimisation	Variable savings	Immediate	Nil
	Load Scheduling / Peak Hour Avoidance	Direct bill reduction	Immediate	Nil
	Furnace Door Seal & Insulation Repair	Variable savings	<1 month	Minimal
	Compressed Air Leak Detection & Repair	20–30% compressor energy savings	<1 month	Minimal
	Pressure Optimisation in Compressed Air System	6–8% compressor energy savings	Immediate	Nil
	Level-Based Auto Drain Valve	2–5% compressor energy savings	Immediate	Minimal
	Automatic Power Factor Correction	Reduced kVA charges / kVAh bill	<2 months	Minimal
	Lighting Upgrades to LED	50–70% lighting energy savings	12–18 months	Low
	Energy Monitoring & Sub-metering	Foundation for future savings	12–18 months	Low
	Metallic Recuperator	₹25 lakhs/year savings	<2 months	₹2.0 lakhs

Section B – Medium Investment (up to ₹10 Lakhs)	Protective Anti-Scale Coatings	₹17 lakhs/year savings	6 months	₹9.0 lakhs
	Energy Efficient Pumps with VFD	₹2.9 lakhs/year savings	9 months	₹2.1 lakhs
	Thermo Ceramic Furnace Coating	₹4.2 lakhs/year savings	12 months	₹4.0 lakhs
	EC Fans for Cooling Towers	₹3.6 lakhs/year savings	13 months	₹4.0 lakhs
	IoT Energy Monitoring System	₹3.1 lakhs/year savings	20 months	₹5.0 lakhs
	IE3/IE4 Energy Efficient Motors	₹0.40 lakhs/year savings	45 months	₹1.5 lakhs
	Regenerative Drives for EOT Cranes	₹1.1 lakhs/year savings	42 months	₹4.0 lakhs
Section C – High Investment (above ₹10 Lakhs)	Self-Recuperative Burners	₹75 lakhs/year savings	2–4 months	₹15.0 lakhs
	IGBT-Based Induction Heating	₹90 lakhs/year savings	3–6 months	₹20.0 lakhs
	VFD Screw Compressor	₹20 lakhs/year savings	7–8 months	₹12.0 lakhs
Section D – Renewable Energy	Solar Rooftop PV System (500 kW)	₹67.5 lakhs/year savings	2.5–3 years	₹150.0 lakhs

Note: Financial parameters are directly sourced from cost–benefit analyses presented in this compendium. Actual values depend on plant-specific parameters, equipment sizing, utilization hours, and prevailing energy tariffs.

1. Forging Process Technical Overview

1.1 Overview

India has firmly established itself as one of the foremost metal forming economies in the world. The country currently holds the position of the second-largest forging industry globally, underpinned by an installed production capacity of approximately 38.5 lakh metric tonnes. The industry commands a broad material processing capability, encompassing carbon steel, alloy steel, stainless steel, superalloys, titanium, and aluminium enabling it to serve a wide spectrum of industrial applications with precision and reliability. Forging, defined as the shaping of metal through the application of compressive forces, is a foundational process in the manufacture of high-strength, structurally critical components. Its relevance spans multiple high-demand sectors, most notably the automotive industry and heavy engineering, where material integrity and dimensional accuracy are non-negotiable requirements.

The industry's output is anchored by a well-diversified demand base that mitigates exposure to any single sector's cyclical volatility. The automotive sector constitutes the dominant share, accounting for approximately 58% of total production. This segment drives consistent, large-volume demand for precision-forged components such as crankshafts, connecting rods, axles, gears, and suspension parts. The remaining 42% of production is attributable to non-automotive segments. This sector diversity is a structural advantage, providing resilience against demand downturns in any individual vertical and allowing the industry to pursue opportunities across multiple growth cycles simultaneously. These segments include:



Figure 1. Major End-User Industries for Forging Products

The forging market is estimated to reach USD 8 billion by 2029, growing at a compound annual growth rate (CAGR) of 10.69%. The casting market, meanwhile, is projected to attain USD 17 billion by 2028, at a CAGR of 6.7%. These projections are supported by multiple convergent factors, including rising infrastructure investment, accelerating defense procurement, the expansion of domestic manufacturing capacity, and increasing integration with global supply chains.

India's casting and forging industry is not uniformly distributed but is instead concentrated in strategic clusters aligned with major end-user industries. Key manufacturing hubs span, Maharashtra, Gujarat, Tamil Nadu, Punjab, Haryana, Delhi, Karnataka, Jharkhand, West Bengal, and Andhra Pradesh. This geographic configuration ensures proximity to both raw material sources and downstream consumers, enabling efficient supply chain management and reduced logistics costs.

Over the past two decades, the Indian forging industry has undergone a significant transformation in its technological capabilities. Manufacturers have progressively adopted advanced forging techniques, precision forging methods, computer-aided design, and automated quality control processes. These investments have enabled Indian producers to meet stringent international quality benchmarks and successfully compete for global supply contracts. Sustainability has increasingly become a dimension of technological advancement, with companies integrating energy-efficient furnaces, waste heat recovery systems, and cleaner production technologies into their operations. This dual focus on precision and sustainability is positioning the industry to meet the evolving requirements of both domestic and export customers who increasingly factor environmental performance into their procurement decisions.

Table 3. Major Growth Drivers Shaping the Indian Casting & Forging Sector

Category	Key Drivers (Short)	Impact on Industry
Government	Make in India, FDI	Manufacturing growth
Policies	Skill India, PLI	Higher local production
Technology	Modern sustainable tech	Better efficiency
Auto & Defense	Auto demand, Atmanirbhar	Strong component demand
Investments	Global OEM entry	Export expansion
Aerospace	Aviation growth, UDAN Scheme	Advanced material demand
Infrastructure	Urbanization, steel use	Higher forged product demand

1.2 State-Level Overview - Telangana

The forging industry in Telangana forms an integral part of the state's manufacturing ecosystem, contributing significantly to key downstream sectors such as automotive, railways, power equipment, and general engineering. The sector encompasses a range of processes including forging, pressing, stamping, roll-forming, and powder metallurgy, which are essential for producing high-strength and precision-engineered metal components. Based on annual survey of industries (Telangana) for FY 2022–23, the fabricated metal products segment in Telangana consists of approximately 591 registered factories, of which nearly 415 units are currently operational. This reflects a robust and active manufacturing base. A substantial share of these units is engaged in forging and related metal forming activities, with a strong concentration in and around Hyderabad, particularly across established industrial clusters such as Ranga Reddy and Medchal regions.

From an energy standpoint, the sector is distinctly electricity-intensive, driven by the widespread use of induction furnaces and electrically operated forging equipment. The total electricity consumption is estimated at approximately 862 million kWh annually, making electricity the dominant energy source for operations. In comparison, the use of coal is negligible, while petroleum-based fuels and other energy sources contribute a relatively smaller proportion to the overall energy mix. The overall energy consumption of the sector is substantial, with total energy expenditure placing it among the highest energy-consuming industrial segments in the state. This underscores the inherently energy-intensive nature of forging and metal forming processes, particularly in MSME-driven clusters where operational efficiencies vary significantly.

Table 4. Telangana's Overall Scenario for forging Sector; Source – Annual Survey of Industry (Telangana) for FY 2022-23

Category	Details
 Total Registered Units	~591
 Operational Units	~415 (~70% active base)
 Major Industrial Clusters	Hyderabad, Rangareddy, Medchal
 Key Application Sectors	Automotive • Railways • Power • General Engineering
 Primary Energy Source	Electricity (Induction-based operations)
 Electricity Consumption	~862 million kWh/year
 Coal Usage	~5 thousand tonnes (negligible)
 Other Fuels	Petroleum Products, LPG/PNG
 Energy Intensity Level	High (energy-intensive processes)
 Energy Consumption Status	Among top energy-consuming sectors in the state

1.3 Energy Consumption Profile

The energy scenario in the forging industry is characterized by high energy intensity and significant dependence on thermal processes, particularly furnaces. The forging furnace alone accounts for nearly 60% of total energy consumption in a typical unit, making it the most critical energy-consuming component. Additional energy is consumed in heat treatment, machining, and auxiliary utilities such as motors and compressors. The level of energy consumption varies across units depending on the range of operations performed, with larger integrated units consuming more energy due to multiple in-house processes, while smaller units focus on limited operations.

A key challenge in the sector is the continued use of outdated and inefficient technologies, such as old oil-fired furnaces, poorly insulated heat treatment systems, and rewound induction motors, all of which contribute to excessive energy consumption and higher operating costs. Inefficient temperature control systems further increase energy losses. However, this scenario also presents a strong opportunity for improvement. By adopting energy-efficient technologies, better process controls, and renewable energy solutions, forging units can significantly reduce energy consumption, lower costs, and enhance their environmental sustainability and global competitiveness.

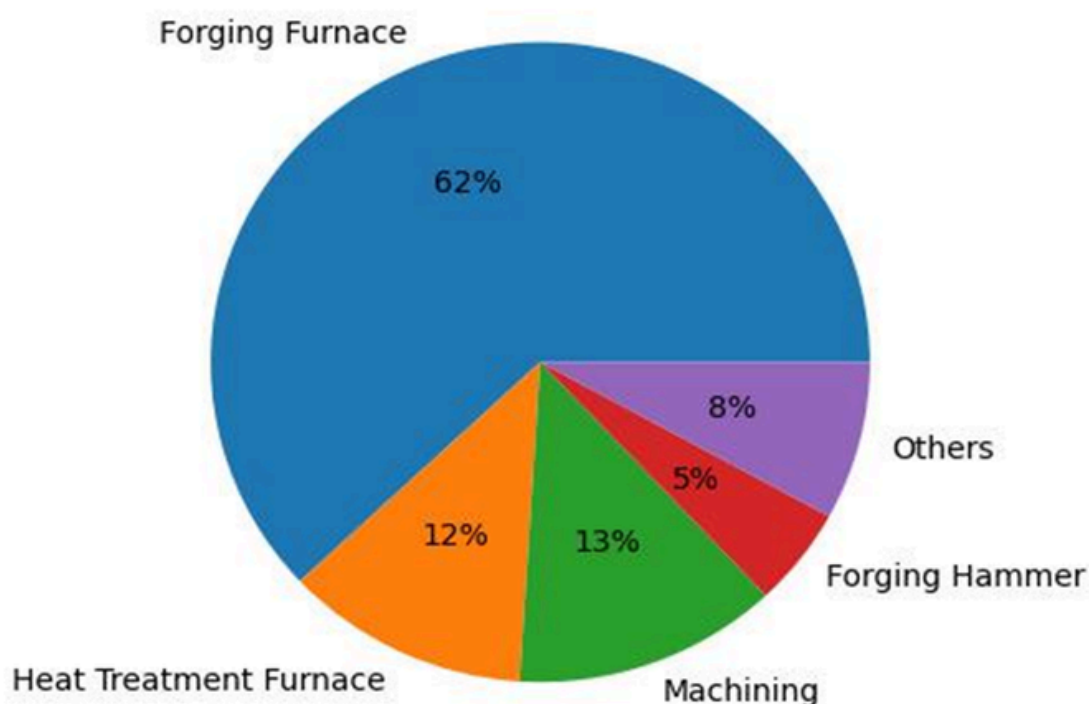


Figure 2. Energy share of critical equipment

1.4 Need for Resource Efficiency and Cleaner Production in the Forging Sector

The Indian forging industry, while globally competitive, remains energy-intensive, making resource efficiency and cleaner production a strategic necessity driven by rising input costs, tightening regulations, and growing international sustainability expectations. Forging enterprises, industry associations, and policy agencies have collectively recognized that improvements in energy consumption, material utilization, and emissions management are essential to sustaining long-term competitiveness. This need is reinforced by four key drivers:

1.4.1 Competitiveness

Energy constitutes one of the major recurring operating costs for forging plants, with particular intensity in heating and cooling operations. Reducing energy consumption yields a direct reduction in conversion cost, improving plant-level competitiveness in domestic and export markets.

1.4.2 Environmental Compliance and Emissions Reduction

Forging processes generate emissions of greenhouse gases (GHGs), particulate matter, and other combustion-related pollutants. Improving energy efficiency directly reduces the environmental footprint of the sector and supports compliance with evolving regulatory emission standards.

1.4.3 Technology Innovation and Quality Enhancement

The adoption of advanced energy-efficient technologies also delivers improvements in product quality, dimensional consistency, and process productivity. Technologies such as IGBT-based induction heating and IoT-enabled energy management systems simultaneously reduce energy consumption and improve process control.

1.4.4 Market Opportunity

Increasing customer preference for environmentally responsible and energy-efficient manufactured products is creating new market opportunities for forging enterprises. The automotive sector, which represents the dominant end-use segment for forged components, is undergoing a significant transition towards lightweight vehicles, improved fuel efficiency, and lower carbon emissions. This shift is encouraging forging units to adopt sustainable and energy-efficient manufacturing practices to remain aligned with evolving supply chain requirements.

In addition to the above strategic drivers, several technical gaps and operational deficiencies commonly observed in the forging sector contribute to excessive energy consumption and reduced process efficiency:

- ❖ Many oil-fired forging furnaces continue to operate with outdated designs and inadequate combustion control systems, resulting in significantly higher fuel consumption compared to industry best-practice benchmarks.
- ❖ Heat treatment furnaces frequently experience high surface heat losses due to deteriorated, damaged, or inadequate refractory insulation systems.
- ❖ Temperature measurement and control instrumentation is often absent, improperly calibrated, or non-functional, leading to inefficient furnace operation and inconsistent process control.
- ❖ A substantial portion of the installed motor fleet comprises old, rewound, or low-efficiency motors, resulting in avoidable electricity consumption and reduced operational performance.

1.5 Key Government Support Schemes for Sustainable Forging MSMEs

The Government of India and Government of Telangana has introduced several schemes and policy initiatives to support MSMEs in adopting sustainable and resource-efficient manufacturing practices. For the forging industry, these schemes provide financial assistance, concessional loans, technology upgradation support, and sustainability certifications to encourage cleaner production, energy efficiency, circular economy practices, and enhanced global competitiveness. Such initiatives help forging MSMEs to modernize operations while aligning with national goals of green industrial growth and sustainable manufacturing.

Table 5. National-Level Government Schemes for Forging Enterprises

Scheme	Support Provided
MSE Green Investment and Financing for Transformation	Interest subsidy on green technology loans
Technology Upgradation Support	Assistance for energy-efficient machinery
Second Loan for PMEGP and MUDRA Units	Subsidy for modernization and automation
MSME Innovative Scheme	Design and innovation assistance
Intellectual Property Rights Support	Patent reimbursement assistance
Incubation Support	Financial support for innovative ideas
MSE Scheme for Promotion and Investment in Circular Economy	Subsidy for circular economy projects
National Scheduled Caste and Scheduled Tribe Hub	Machinery subsidy for SC/ST enterprises
MSME Sustainable Zero Defect Zero Effect Certification	Sustainability and quality improvement support
MSME Tool Rooms	Tooling, consultancy, and technical training

Table 6. Telangana State-Level Government Schemes

Scheme	Support Provided
Telangana State Industrial Development and Entrepreneur Advancement	Capital investment subsidy
Telangana Program for Rapid Incubation of Dalit Entrepreneurs	Higher subsidy for SC/ST enterprises
Women Enterprise Incentives	Additional subsidy benefits for women-owned enterprises

2. Forging Process

The major steps involved in typical forging units include cutting steel rods in the form of billets, heating of billets in the furnace and forging in hammers or presses. The forged components are trimmed and sent for heat treatment. Forging is an energy intensive process, where energy is mainly consumed for metal heating and heat treatment processes.

The major process steps in a typical forging unit are classified under four broad functional categories:

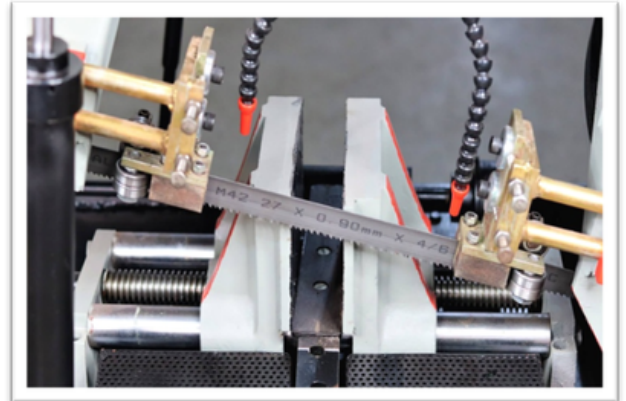
- Metal Preparation
- Metal Heating
- Metal Forming
- Machining and Finishing

Table 7. Summary of Forging Process Stages, Equipment, and Energy

Process Stage	Activity	Key Equipment	Energy Source
Metal Preparation	Cutting of rods/bars into billets	Bandsaw / Shearing Machine	Electricity
Metal Heating	Heating billets to 1,050–1,250 °C	Induction Heater / Box Furnace	Electricity / Furnace Oil
Metal Forming	Plastic deformation into desired shape	Belt Drop Hammer / Screw Press	Electricity / Pneumatic
Trimming	Removal of flash (excess metal at die parting line)	Trimming Die / Screw Press	Electricity
Heat Treatment	Stress relief and mechanical property enhancement	Heat Treatment Furnace	Furnace Oil / Natural Gas / LPG
Finishing & Machining	Final dimensional and surface-finish operations	CNC Lathe / VMC / Surface Grinder	Electricity

2.1 Metal Preparation

Raw material arrives at the forging unit in the form of billets, rods, or bars. These are cut to the required weight, cross-sectional size, and length using bandsaw or shearing machines, producing suitably sized billets for each specific component being produced. The sized metal pieces are subsequently transferred to the metal heating stage. Bandsaw machines and shearing machines are the primary tools employed at this stage. No thermal energy is consumed; the process is driven exclusively by mechanical (electrical) energy.



2.2 Metal Heating

Metal heating is the most energy-intensive stage in a forging unit, typically accounting for the largest share of total energy consumption. In this process, furnaces and billet heaters raise the metal temperature to around 1,050–1,250°C, which is approximately 75% of its melting point. The exact heating range depends on the alloy composition and carbon content, as different materials require specific temperatures to achieve the desired level of plasticity. At these elevated temperatures, the metal's crystalline structure softens, significantly reducing its resistance to deformation (flow stress). This enables the material to be shaped into complex geometries with relatively lower forming forces, improving process efficiency and die life.

Maintaining a uniform temperature distribution throughout the billet is equally critical for achieving consistent forging quality. Non-uniform heating can create thermal gradients within the material, leading to irregular metal flow during deformation. Such conditions may result in defects including surface cracks, internal stresses, dimensional inaccuracies, poor grain structure, and premature die wear or failure.

In addition, overheating of billets can lead to excessive oxidation and scale formation, causing material loss and deterioration of metallurgical properties. Conversely, insufficient heating increases forging loads, adversely affects material flow, and may cause damage to forging dies and equipment. Therefore, precise temperature control and efficient heat management are essential for ensuring product quality, operational reliability, and energy efficiency.

Given its significant contribution to overall energy consumption and its direct influence on product quality and productivity, optimization of the metal heating process represents a key opportunity for improving energy performance and reducing operational costs in forging operations.

Two primary heating technologies are commonly deployed across the forging cluster:

- ❖ **Electrical Induction Billet Heaters**
- ❖ **Box-Type Heating Furnace**

1. Electrical Induction Billet Heaters



These are widely adopted by medium-scale and larger forging units due to their superior energy efficiency and precise temperature control. Unlike conventional furnaces, induction heating works by generating heat directly within the billet through electromagnetic induction, resulting in significantly faster heating rates. This targeted heating method ensures uniform temperature distribution throughout the billet cross-section, which is critical for consistent forging quality. One of the most advantages is near-zero scale loss, as the billet surface is not exposed to prolonged oxidizing atmospheres, reducing material wastage considerably. The precise control over temperature also minimizes the risk of overheating or decarburization, preserving the metallurgical properties of the metal. Induction heaters are highly compatible with automated forging lines, allowing seamless integration with billet transfer and press operations for improved productivity.

2. Box-type Heating Furnace:

These are the traditional choices among smaller forging units, typically fired using Furnace Oil (FO) as the primary fuel source. These furnaces feature a box-shaped refractory-lined chamber into which billets are manually loaded and heated to the required forging temperature. Due to their conventional design, box-type furnaces tend to exhibit higher fuel consumption compared to modern induction systems, making them less energy-efficient over prolonged operations. The combustion atmosphere inside the furnace promotes significant oxidation on the billet surface, leading to the formation of mill scale and resulting in greater material losses. Temperature control in these furnaces is relatively less precise, which can lead to uneven heating across the billet length and cross-section,

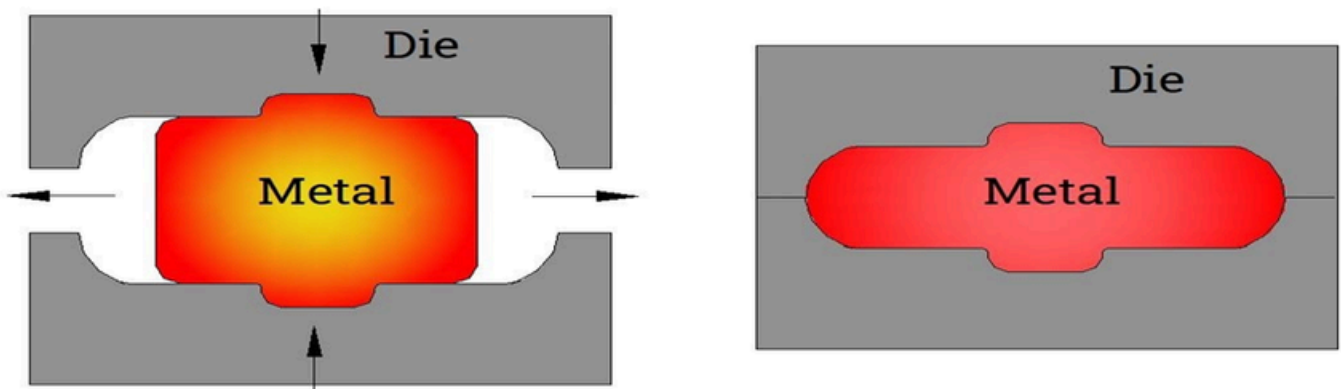


potentially affecting forging consistency. Despite these limitations, box-type furnaces remain widely used in smaller forging units due to their low initial capital cost, simple operation, and ability to handle a variety of billet sizes and materials. The progressive shift towards induction heating represents a significant energy conservation opportunity that a growing number of forging units across India have already acted upon.

2.3 Metal Forming

Metal forming involves the controlled plastic deformation of a pre-heated workpiece into the desired near-net shape through the application of compressive force. A working temperature of approximately 1,250 °C is maintained throughout the forging operation to preserve metal plasticity.

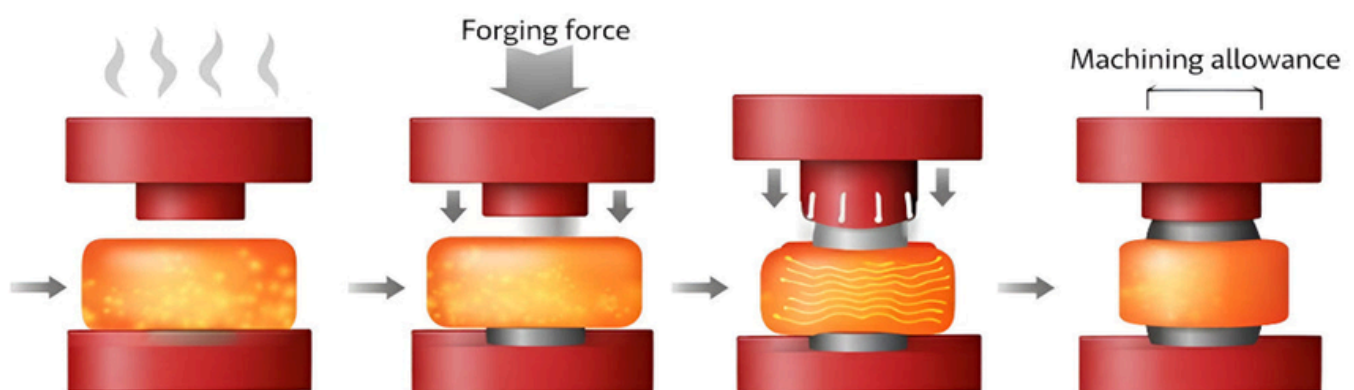
2.3.1 Closed Die Forging



In closed-die (impression-die) forging, a heated metal billet is compressed within enclosed dies to obtain the required component shape with high dimensional accuracy and improved mechanical properties. Key features of the process include:

- ❖ Suitable for components ranging from 500 g to 5 tonnes
- ❖ Produces complex near-net-shaped components
- ❖ May require multiple forging stages for intricate shapes
- ❖ Performed using hammers or mechanical/hydraulic presses depending on application

2.3.2 Open Die Forging



In open-die forging, the workpiece is deformed between dies that do not completely enclose the material, allowing free metal flow except at the points of contact. The process is used for larger and simpler components and can accommodate workpieces ranging from a few kilograms up to approximately 50 tonnes. Key features of the process include:

- ❖ Produces components with a refined grain structure, improved fatigue resistance, and superior microstructural characteristics
- ❖ Requires multiple controlled hammer blows to achieve the desired form and dimensions
- ❖ Primarily used for shaft forgings, flats, discs, and heavier bespoke forgings

2.3.3 Trimming

Upon completion of the finish-forging operation, the excess metal extruded at the die parting line is removed in a dedicated trimming operation. Electrically driven screw presses are also employed for trimming and coining operations.

2.4 Forming Equipment

2.4.1 Belt Drop Type Hammer

Belt-drop hammers are the most predominant forging tool found across the forging cluster, valued for their versatility in producing a wide range of components including shafts, flanges, gear blanks, pipe fittings, rollers, and wheel hubs. The operating principle is straightforward yet highly effective. The hammer ram is lifted to a predetermined height using a belt-drive mechanism and then released under the force of gravity, delivering a powerful compressive blow onto the hot billet placed within the die cavity. The energy of each blow is determined by the weight of the ram and the drop height, making it a reliable and repeatable forming method. Multiple successive blows are typically applied to progressively shape the heated billet



into the desired form, with the operator skillfully repositioning the workpiece between strikes.

Belt-drop hammers are well-suited for both open-die and closed-die forging operations, offering flexibility to accommodate different component geometries by simply changing the die set. Their relatively simple mechanical design translates into lower maintenance requirements and ease of operation, making them an economical choice for small to medium forging enterprises. Despite being conventional technology, they continue to remain the backbone of cluster-based forging operations due to their proven performance and low operating costs. Their adaptability to diverse product ranges and billet sizes further reinforces their dominant presence across the cluster.

2.4.2 Screw Press

Screw presses serve as an important complement to belt-drop hammers across the forging cluster, specifically deployed for applications demanding controlled and repeatable pressing force rather than impact-based forming. They are particularly well-suited for shaft-end heating operations and precision forming jobs where dimensional accuracy and consistency are critical requirements. Unlike drop hammers that rely on impact energy, screw presses deliver a slow, sustained squeezing force generated through a rotating screw mechanism, allowing better control over material flow and die fill. This characteristic makes them the standard equipment of choice for trimming operations, where excess flash formed during the forging process is cleanly removed from the component periphery.



2.5 Heat Treatment

After forging, the component carries residual stresses, a non-uniform grain structure, and subsurface irregularities that must be addressed before the part enters service. Heat treatment is therefore an indispensable stage in the production sequence, performed to relieve these stresses, improve machinability, and enhance the mechanical and structural properties of the forged component. Energy sources include Furnace Oil, Natural Gas, and LPG, and depending upon the material grade and property requirements, one or more of the following processes are employed.

Annealing -The forged component is heated to 750–900 degrees Celsius and cooled slowly within the furnace in a controlled manner, suppressing hard microstructures and internal stresses. This results in enhanced ductility and toughness, making the component suitable for further machining or relieving forging-induced residual stresses.

Normalising - The component is heated to 880–980 degrees Celsius, held for an adequate soaking period, and then cooled in still ambient air. The relatively faster air cooling encourages a finer, more homogeneous grain structure, improving strength, hardness, and machinability in preparation for subsequent processing.

Quenching - The forging is rapidly cooled from its austenitising temperature of 820–900 degrees Celsius by immersion in water, oil, or polymer solution, driving the transformation of austenite into martensite and significantly increasing surface hardness and wear resistance. Due to the brittleness and residual stresses introduced, quenching is invariably followed by tempering.

Case hardening - The component is heated to 850–950 degrees Celsius in a thermochemical atmosphere enriched with carbon or nitrogen, promoting diffusion of these elements into the outer surface layer. The enriched case is subsequently quenched to achieve high surface hardness while the core retains its original toughness, making it suitable for gear teeth, bearing surfaces, and cam profiles.

Tempering - The hardened component is reheated to 150–650 degrees Celsius, held below the lower critical transformation temperature, and then gradually cooled. This partially stabilises the brittle martensitic microstructure, relieving internal stresses and restoring a workable balance between hardness and toughness for the intended service application.

2.6 Finishing and Machining

Forged components typically carry excess metal at edges and surfaces and require several downstream operations depending on component type and intended application:

1. Trimming and Straightening: Flash removal and geometric correction
2. Shot Blasting: High-velocity steel abrasive impingement for scale removal
3. Machining Centers: Turning, shaping, boring, drilling, threading on CNC Lathes, VMCs, HMCs, or SPMs
4. Grinding and Finishing: Surface grinders delivering required surface roughness and dimensional tolerances

2.7 Utilities

Cooling Tower - Cooling towers dissipate heat loads generated by induction billet heaters and serve centralized cooling circuits for hydraulic hammer systems, air compressors, and other auxiliary equipment.

Air Compressor - Compressed air is an essential utility for pneumatic hammer operation and for automated control functions in machining and material handling applications.

Electric Motors - Electric motors constitute the primary mechanical power source across the plant driving screw presses, machining equipment, air compressors, fans, and pump sets. Motor selection, loading efficiency, and condition maintenance are critical determinants of the overall electrical energy balance.

Pump Sets - Pumps Sets circulate hydraulic oil within hydraulic hammer and press systems and convey cooling water and other process fluids. Pump sizing, operating efficiency, and control strategy directly influence auxiliary electrical energy consumption.

Energy Conservation and Resource Efficiency Context



Metal heating and heat treatment operations collectively account for 60–80% of total site energy consumption, establishing thermal processes as the single largest and most actionable lever for energy reduction across the forging cluster. The transition to induction heating, deployment of recuperative and regenerative burner systems for waste heat recovery, and systematic optimisation of furnace scheduling and batch utilisation collectively represent the highest-potential interventions for achieving measurable reductions in specific energy consumption at the plant level.

Beyond thermal energy, water usage in quenching and cooling operations constitutes a significant resource efficiency opportunity. The adoption of closed-loop cooling systems can substantially curtail freshwater withdrawal and minimise process effluent discharge, addressing both operational cost and environmental compliance imperatives simultaneously.

On the material front, solid waste streams generated through forging operations including mill scale, flash trimmings, and machining swarf represent recoverable ferrous material of commercial value. Systematic collection and channeling of these streams back into the steel supply chain reduces net raw material demand, lowers input costs, and contributes to a more circular material flow within the cluster.

Taken together, an integrated approach to energy, water, and material recovery rather than isolated, single-stream interventions offer the forging cluster its most robust and economically viable pathway toward resource efficiency, regulatory compliance, and long-term operational sustainability.

3. Technologies For Resource Efficiency And Cleaner Production In The Forging Sector

This section presents a structured compendium of energy efficiency and renewable energy technologies applicable to forging units across India, organised into four investment tiers. For each technology, a technical description and cost–benefit analysis (CBA) are provided.

3.1 Section A - Nil / Low Investment Measures

The following measures require minimal or zero capital outlay and can be implemented through improved operational practices, minor repairs, or low-cost instrumentation upgrades.

Table 8: Section A: Nil / Low Investment Measures: Summary Overview

Sr.No.	Technology	Description	Investment (₹ Lakhs)	Energy Savings
1	Furnace Temperature Optimisation	Avoid billet overheating	Nil	5–8%
2	Combustion Air-Fuel Ratio Control	Optimise burner tuning	Nil	5–10%
3	Furnace Scheduling & Batch Optimisation	Reduce idle heating	Nil	Variable
4	Compressed Air Leak Detection & Repair	Repair air leakages	Minimal	20–30%
5	Pressure Optimization in Compressed Air System	Reduce excess pressure	Minimal	6–8%
6	Level-Based Auto Drain Valve	Preventing air loss	Low	2–5%
7	Power Factor Correction (Capacitor Banks)	Improve power factor	Minimal	Reduced KVA charges
8	Load Scheduling / Peak Hour Avoidance	Avoid peak tariff	Nil	Direct bill reduction
9	Furnace Door Seal & Insulation Repair	Reduce heat loss	Minimal	Variable
10	Lighting Upgrades to LED	Install LED lighting	Low	Payback < 2 years
11	Energy Monitoring & Sub-metering	Track energy use	Low	Foundation for savings

3.1.1 Furnace Temperature Optimisation

- ❖ Maintaining the correct furnace temperature is critical to avoiding unnecessary fuel consumption.
- ❖ In many units, billets are overheated beyond process requirements, resulting in both energy wastage and increased oxidation losses.
- ❖ Calibrating temperature set-points and ensuring the functional integrity of control instrumentation eliminates excess heating.
- ❖ Typical savings range between 5–8% of furnace fuel consumption.

3.1.2 Combustion Air-Fuel Ratio Control

- ❖ Efficient combustion requires precise maintenance of the optimal air-to-fuel stoichiometric ratio.
- ❖ Excess combustion air increases heat loss through elevated flue gas enthalpy, while insufficient air causes incomplete combustion.
- ❖ Periodic burner tuning combined with continuous monitoring of flue gas oxygen levels maintains the ideal balance.
- ❖ Energy savings of 5–10% are achievable.

3.1.3 Furnace Scheduling & Batch Optimisation

- ❖ By grouping billets of similar cross-section and composition into planned production batches and scheduling furnace utilisation accordingly, thermal efficiency improves substantially.
- ❖ Proper production scheduling minimises fuel consumption, extends furnace refractory life, and improves overall shop-floor productivity.

3.1.4 Compressed Air Leak Detection & Repair

- ❖ Compressed air systems are among the most energy-intensive utilities in a forging plant, and air leakage is the dominant source of system-level energy loss.
- ❖ Regular inspection using calibrated ultrasonic leak detection equipment enables systematic identification and prioritised repair of leakage points.
- ❖ Documented savings of 20–30% of total compressor energy consumption are achievable.

3.1.5 Pressure Optimization in Compressed Air System

- ❖ Reducing compressor discharge pressure by 1–2 bar lowers compressor power consumption and minimizes artificial air demand in MSME plants.
- ❖ Maintaining optimum system pressure through pressure regulators, VFDs, and demand-based compressor operation improves overall compressed air system efficiency.
- ❖ Reducing pressure drop by fixing air leakages, cleaning filters, and optimizing pipeline layout decreases compressor loading and electricity consumption.
- ❖ Documented savings of 6–8% of total compressor energy consumption are achievable.

3.1.6 Level-Based Auto Drain Valve

- ❖ Automatically removes condensate only when required, preventing continuous compressed air leakage and reducing energy wastage.
- ❖ Improves compressed air quality and system efficiency by avoiding moisture accumulation in pipelines and pneumatic equipment.
- ❖ Reduces compressor running hours, maintenance requirements, and operational energy losses compared to manual or timer-based drain systems.
- ❖ Documented savings of 2–6% of total compressor energy consumption are achievable.

3.1.7 Power Factor Correction

- ❖ By optimising the operation of installed capacitor banks to maintain a power factor of 0.95 or above, reactive power drawn from the grid is minimised, reducing both utility penalty charges and internal distribution losses.

3.1.8 Load Scheduling / Peak Hour Avoidance

- ❖ By systematically scheduling energy-intensive operations particularly heavy press forging runs to off-peak tariff windows, significant direct reductions in electricity cost are achievable with no capital expenditure.

3.1.9 Furnace Door Seal & Insulation Repair

- ❖ Damaged door seals and degraded refractory insulation cause continuous heat losses through direct radiation and parasitic cold-air infiltration.
- ❖ Systematic repair of door seals and restoration of refractory lining integrity is a low-cost activity with high impact on furnace thermal efficiency.
- ❖ Payback is typically achieved in less than a month.

3.1.10 Lighting Upgrades to LED

- ❖ Replacement with LED luminaires designed for industrial environments reduces power consumption by 50–70%, provides superior illumination quality, and delivers service life of 50,000 hours or more.
- ❖ Simple payback is consistently achieved within 1–2 years.

3.1.11 Energy Monitoring & Sub-metering

- ❖ Installing calibrated energy sub-meters at major energy-consuming assets furnaces, presses, compressors, and heat treatment equipment provides detailed consumption data that enables identification of inefficiencies and verification of improvement measures.
- ❖ Energy sub-metering forms the essential analytical foundation for all further energy efficiency initiatives.

3.2 Section B- Medium Investment Measures (up to ₹10 Lakhs)

The following measures require moderate capital investment, typically in the range of ₹0.5 to ₹10 Lakhs, and offer payback periods from a few months to approximately four years depending on utilisation intensity and prevailing energy tariffs.

Table 9: Section B: Medium Investment Measures (up to ₹10 Lakhs): Summary Overview

Sr. No.	Technology	Description	Investment (₹ Lakhs)	Energy Savings
1	Metallic Recuperator	Recover flue gas heat to pre-heat combustion air	Up to ₹2L	15–25% fuel
2	Energy Efficient Motors (IE3/IE4)	Replace IE1/IE2 motors with premium efficiency models	Up to ₹2L	5–10% motor energy
3	IoT Energy Monitoring Solutions	Real-time dashboards, alerts, and automated load control	₹1–10L	~5% total energy
4	Protective Anti-Scale Coatings	Reduce billet oxidation losses and furnace fuel consumption	₹1–10L	0.5–2% yield gain
5	Thermo Ceramic Furnace Coating	High-emissivity coating on furnace interior walls	₹0.5–5L	5–8% fuel
6	Energy Efficient EC Fans	Variable-speed electronically commutated cooling tower fans	₹0.5–8L	30–50% fan energy
7	Regenerative Drives for EOT Cranes	Recover crane braking energy and feed back to bus bar	₹2–5L	20–35% crane energy
8	Energy Efficient Pumps with VFD	VFD-controlled hydraulic and cooling water pumps	₹2–6L	30–50% pump energy

3.2.1 Energy Efficient Metallic Recuperator

Current Practice in Industry

In most small and medium forging units, hot flue gases exiting the furnace at temperatures of 800-1000°C are directly discharged into the atmosphere through the stack without any heat recovery. This represents a significant and continuous loss of thermal energy, as a substantial portion of the fuel energy input leaves the system unutilised. The absence of any waste heat recovery mechanism results in higher fuel consumption, elevated operating costs, and increased greenhouse gas emissions per tonne of production.

Energy Efficient Option

A metallic recuperator installed on the furnace flue gas outlet captures the sensible heat from hot exhaust gases and transfers it to incoming combustion air through a counter-flow heat exchanger. The preheated combustion air, typically raised to 200–300°C, reduces the fuel requirement to achieve the same furnace temperature, delivering direct and measurable fuel savings.

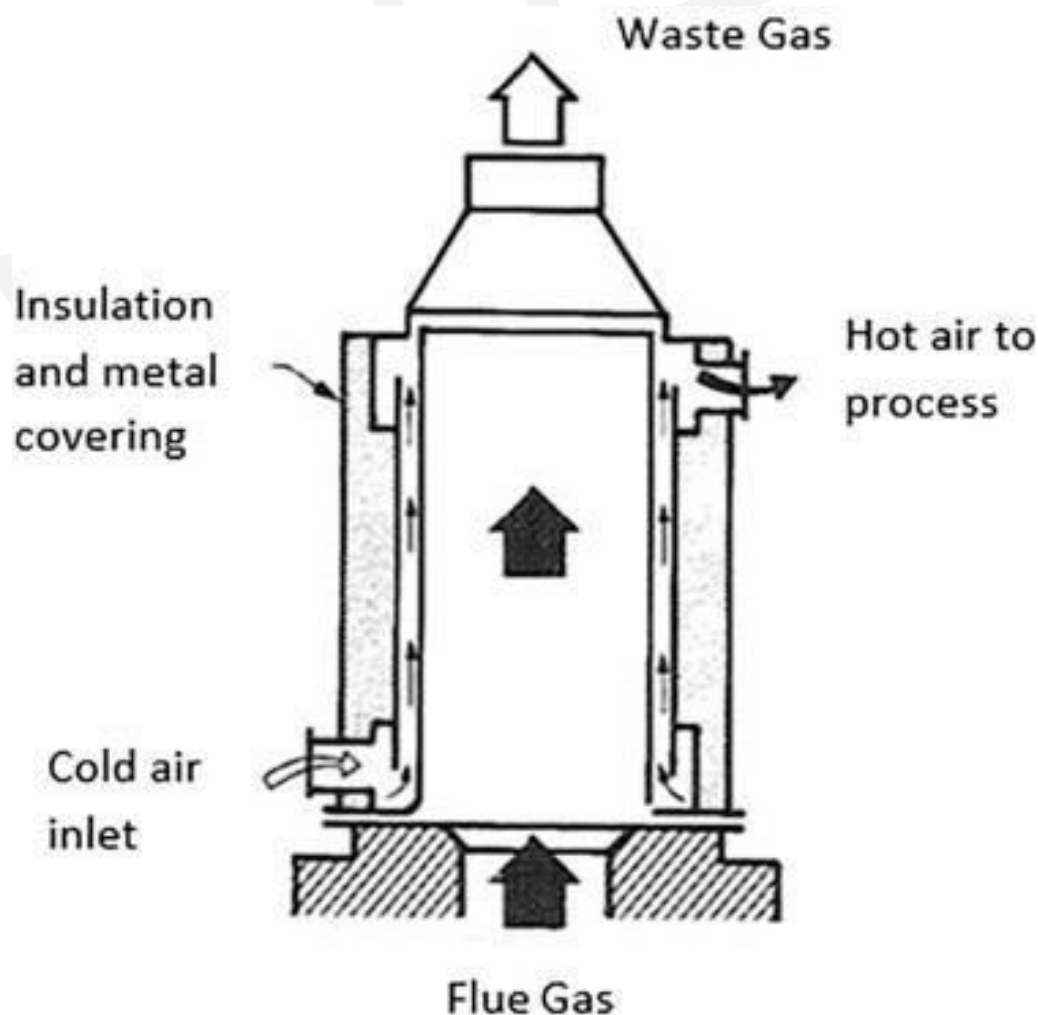


Figure 3. Diagram of metallic recuperator

Working Principle

The recuperator operates on the principle of counter-flow heat exchange. Hot flue gases exiting the furnace pass through one side of the metallic heat exchanger, while cold combustion air flows in the opposite direction on the other side. Heat is transferred through alloy steel walls separating the two streams, maximising thermal exchange efficiency. The preheated air then enters the burner, reducing the additional fuel energy required to reach the desired flame temperature.

Operating Parameters:

- ❖ Flue Gas Inlet Temperature: 800–1000°C
- ❖ Combustion Air Preheat Temperature: 200–300°C
- ❖ Heat Recovery Efficiency: 30–50%

Benefits

- ❖ Fuel consumption reduced by 15–25% depending on furnace conditions
- ❖ Higher flame temperature improves heat transfer and furnace productivity
- ❖ Reduced CO₂ and greenhouse gas emissions per unit of production
- ❖ Short payback period with minimal operational complexity
- ❖ Compatible with existing furnace configurations without major modifications

Case Study — Cost Benefit Analysis

A representative forging unit in the cluster operating a natural gas-fired billet heating furnace was assessed for metallic recuperator installation. Prior to intervention, the furnace was exhausting flue gases at approximately 900°C directly to atmosphere, with combustion air entering the burner at ambient temperature. Fuel consumption was recorded at 50 Nm³/hr against an annual operating schedule of 5,000 hours.

Following installation of a metallic alloy steel counter-flow recuperator on the flue gas outlet, the exhaust gas temperature at the stack was reduced to approximately 400°C, with combustion air being preheated to 250°C before entering the burner assembly. This preheating directly reduced the fuel energy required to achieve the target furnace temperature, bringing fuel consumption down to 40 Nm³/hr — a reduction of 10 Nm³/hr or 20% on the baseline.

Table 10: Cost–Benefit Analysis Metallic Recuperator

Parameter	Baseline	Post Implementation
Flue Gas Temperature	900 °C	400 °C
Combustion Air Preheat Temperature	Ambient	250 °C
Fuel Consumption	50 Nm ³ /hr	40 Nm ³ /hr
Operating Hours	5,000 Hr/Yr	5,000 Hr/Yr
Annual Fuel Saving	50,000 Nm ³ /Yr	
Fuel Cost	₹50/Nm ³	
Annual Savings	₹25 Lakhs	
Capital Investment	₹2 Lakhs	
Simple Payback Period	< 2 Months	

3.2.2 Energy Efficient Motors (IE3 / IE4)

Current Practice in Industry

The majority of forging units across the cluster operate with standard efficiency motors of IE1 or IE2 class, many of which have been rewound one or more times following burnout. Rewound motors typically suffer an efficiency loss of 1–3% per rewinding cycle due to degradation of lamination quality and increased winding resistance. These motors run continuously driving screw presses, compressors, fans, and pump sets, accumulating significant energy losses over thousands of operating hours annually.

Energy Efficient Option

IE3 (Premium Efficiency) and IE4 (Super Premium Efficiency) motors are designed with superior core materials, increased copper content, and optimised rotor geometry to deliver higher efficiency across all load conditions. Replacing old IE1/IE2 or rewound motors with IE3/IE4 equivalents at the point of failure or scheduled replacement offers an immediate and lasting reduction in electrical energy consumption.

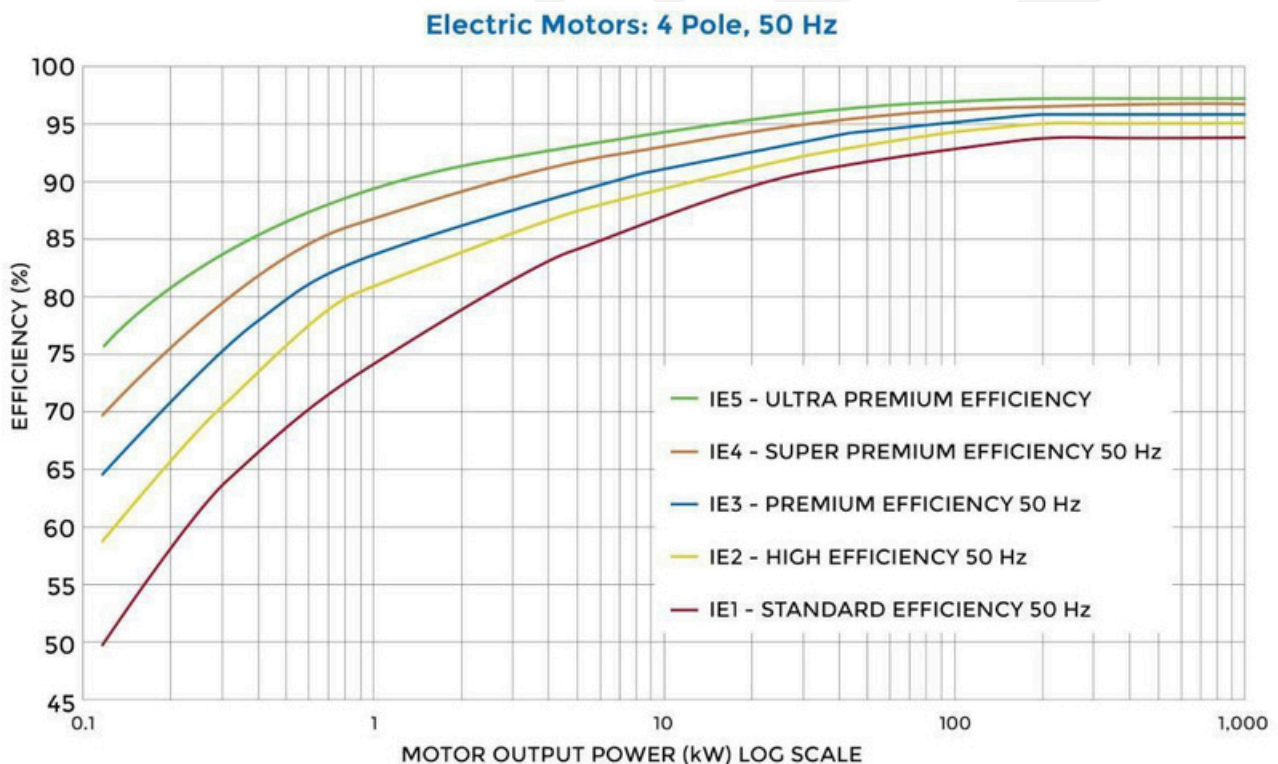


Figure 4 Efficiency Advantage of IE3 / IE4 Motors over IE1 / IE2 Across Load Conditions

Working Principle

IE3/IE4 motors operate on the same fundamental electromagnetic induction principle as standard motors but are optimised through the use of high-grade silicon steel laminations that reduce core losses, increased copper conductor cross-sections that minimise resistive winding losses, precision-balanced rotors with tighter air-gap tolerances that reduce mechanical and magnetic losses, and improved cooling designs that maintain lower operating temperatures and extend insulation life.

Benefits

- ❖ Energy consumption reduced by 3–8% compared to IE1/IE2 motors of equivalent rating
- ❖ Lower operating temperature improves insulation life and motor reliability
- ❖ Improved power factor reduces reactive power demand on the supply network
- ❖ Reduced heat generation lowers cooling load in the electrical room
- ❖ Longer service life reduces frequency of rewinding and replacement

Case Study — Cost Benefit Analysis

A forging unit operating multiple motor-driven systems including screw presses, cooling fans, and pump sets was assessed for motor replacement under a phased programme. A representative 15 kW motor driving a cooling water pump was selected for detailed analysis. The existing motor, a rewind IE1-class unit, was operating at a measured efficiency of 88% under normal load conditions, against an annual operating schedule of 6,000 hours.

Replacement with a new IE3-class motor of identical rating and frame size brought operating efficiency to 93%, with no changes required to the driven equipment or electrical supply infrastructure. The efficiency improvement of 5 percentage points translated directly into a reduction in annual energy consumption from 79,500 kWh to 75,000 kWh.

While the payback period for a single 15 kW motor appears extended at 45 months, the financial case strengthens considerably when viewed at fleet level. A typical forging unit operating 15–20 motors across presses, compressors, fans, and pumps would generate aggregate annual savings several times the single-motor figure. Furthermore, the avoided cost of rewinding, typically ₹0.3–0.5 Lakhs per motor and the reduced downtime risk associated with newer motors improve the overall economic case. The recommended strategy is fleet-level replacement at the natural end-of-life or next rewinding event, rather than forced early replacement, to maximise the return on investment across the plant.

Table 11: Cost–Benefit Analysis Energy Efficient Motors (IE3/IE4)

Parameter	Baseline	Post Implementation
Motor Rating	15 kW	15 kW
Motor Efficiency	88%	93%
Operating Hours	6,000 Hr/Yr	6,000 Hr/Yr
Energy Consumption	79,500 kWh/Yr	75,000 kWh/Yr
Annual Energy Saving	4,500 kWh/Yr	
Electricity Cost	₹9/kWh	
Annual Savings	₹0.40 Lakhs	
Capital Investment	₹1.5 Lakhs	
Simple Payback Period	45 Months	

3.2.3 IoT Solutions for Energy Efficiency

Current Practice in Industry

Energy monitoring in most MSME forging units is limited to monthly electricity billing data from the utility meter, with no granular visibility into consumption at equipment level. Furnaces, presses, compressors, and heat treatment systems operate without sub-metering, making it impossible to identify which assets are consuming excessively, when peak loads occur, or whether equipment is running inefficiently during idle periods. Decisions on energy management are largely reactive rather than data driven.

Energy Efficient Option

IoT-based energy management systems deploy wireless smart sensors and sub-meters at individual equipment level, transmitting real-time data to a cloud-based platform that provides dashboards, automated alerts, and consumption analytics. This enables plant managers to identify and act upon inefficiencies as they occur rather than discovering them weeks later through utility bills.

Working Principle

IoT energy management systems function through four integrated layers. Sensors and smart meters capture real-time data on electricity consumption, fuel flow, temperature, pressure, and compressed air flow at each major asset. Data is transmitted via wired or wireless networks to a central cloud platform. Analytics software processes data using algorithms to detect anomalies, benchmark performance, and generate actionable reports. The control layer enables automated responses such as load shedding during peak tariff periods or alerts when equipment deviates from set energy parameters.

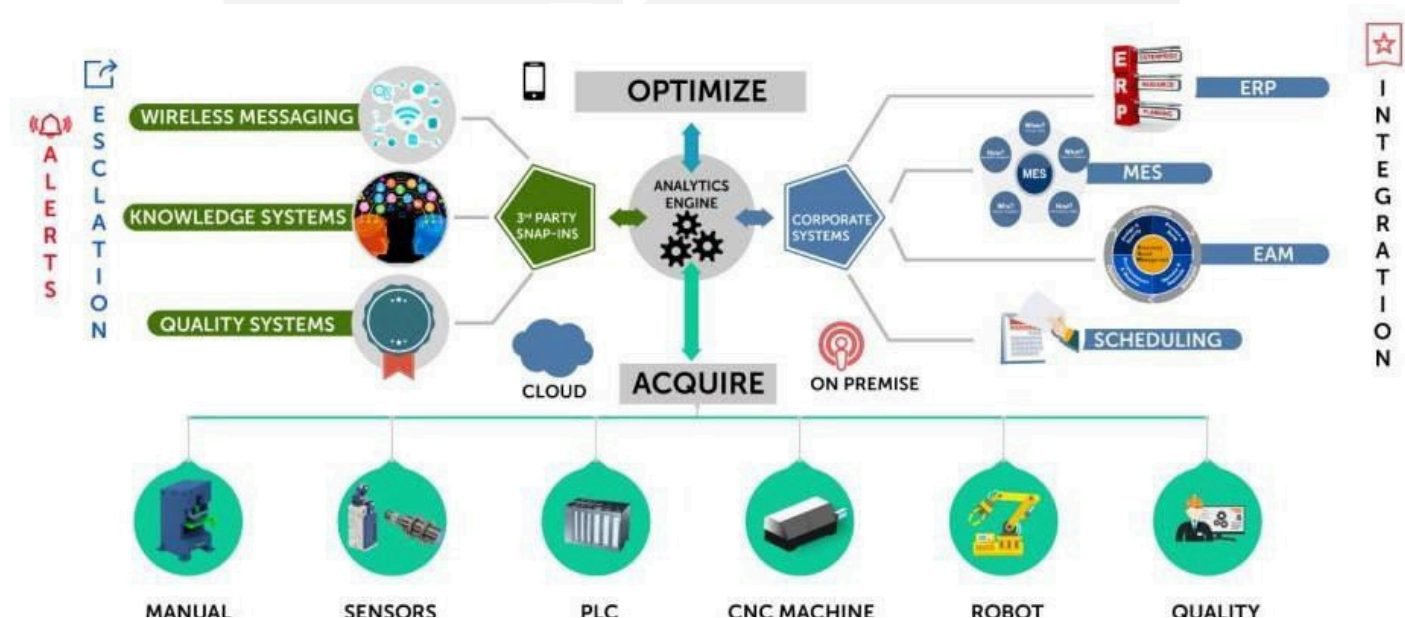


Figure 5 IoT Elements for Optimisation

Benefits

- ❖ Real-time visibility enables immediate identification and correction of energy losses
- ❖ Automated peak load alerts facilitate active electricity tariff management
- ❖ Predictive maintenance alerts reduce unplanned downtime and associated energy waste
- ❖ Consumption benchmarking across shifts and production batches drives operational accountability
- ❖ Provides verified data foundation to support investment decisions for further efficiency measures

Case Study — Cost Benefit Analysis

A medium-scale forging unit with a connected load of approximately 500 kW, operating furnaces, induction heaters, presses, compressors, and auxiliaries, was assessed for IoT energy monitoring deployment. Prior to implementation, the plant had no sub-metering beyond the main utility incomer, and the average recorded consumption was 140 kWh/hr across a 5,000-hour annual operating schedule, resulting in total annual consumption of 7,00,000 kWh.

An IoT monitoring system comprising 12 smart energy meters, 4 fuel flow sensors, and a cloud-based analytics dashboard was installed across all major energy-consuming assets. Within the first three months of operation, the system identified three significant inefficiency sources — a furnace running at elevated temperature during non-production shifts, a compressor cycling unnecessarily during lunch breaks, and a press motor consuming full load power during idle periods between forging batches. Corrective actions on these three findings alone reduced average consumption to 133 kWh/hr, a 5% reduction on baseline.

The 5% reduction documented here represents a conservative baseline estimate. Units that actively engage with IoT data, implement shift-level energy targets, and act on predictive maintenance alerts consistently report reductions of 10–15% on pre-monitoring baselines, which would reduce the payback period to under 12 months. Beyond direct energy savings, the IoT system also provides the verified consumption data required to apply for BEE star ratings, access green financing, and demonstrate progress against sustainability commitments to automotive OEM customers increasingly requiring supplier environmental disclosures.

Table 12: Cost–Benefit Analysis IoT Energy Monitoring Solutions

Parameter	Baseline		Post Implementation
Baseline Energy Consumption	140 kWh/hr		133 kWh/hr
Operating Hours	5,000 Hr/Yr		5,000 Hr/Yr
Annual Energy Saving	35,000 kWh/Yr		
Electricity Cost	₹9/kWh		
Annual Savings	₹3.1 Lakhs		
Capital Investment	₹5 Lakhs		
Simple Payback Period	20 Months		

3.2.4 Protective Coatings for Scale Prevention

Current Practice in Industry

In conventional box-type and oil-fired furnaces, steel billets are exposed to high-temperature oxidising atmospheres during the heating cycle, resulting in the formation of mill scale on the billet surface. Scale loss typically ranges from 1.5–2.5% of billet weight per heating cycle, representing a direct and recurring loss of purchased raw material. Beyond material wastage, scale formation leads to surface defects on forged components, increased descaling effort, and additional specific fuel consumption due to the insulating effect of scale buildup on heat transfer efficiency.

Energy Efficient Option

Protective anti-scale coatings applied to billet surfaces prior to furnace charging form a ceramic barrier layer that limits direct contact between the hot metal surface and the oxidising furnace atmosphere, significantly reducing scale formation, improving material yield, and lowering specific fuel consumption through enhanced billet surface heat transfer.



Figure 6. Coating application on billets

Working Principle

Anti-scale coatings are water-based formulations containing refractory oxides and glass-forming compounds. When applied to the billet surface and dried, they form a thin adherent ceramic barrier that limits oxygen diffusion to the metal surface at elevated temperatures, reducing the oxidation rate and minimising scale thickness. The application process involves surface cleaning of billets to remove loose scale, coating applications by spraying or dipping, and drying before furnace charging. The coating is consumed during the heating cycle and does not contaminate the forged product or die surfaces.

Benefits

- ❖ Scale loss reduced by 50–80%, directly improving material yield by 1–3%
- ❖ Improved billet surface quality results in better downstream component finish quality
- ❖ Reduced descaling and surface cleaning requirements lower auxiliary operating costs
- ❖ Enhanced heat transfer to billet core reduces specific fuel consumption by 2–5%
- ❖ Applicable to existing furnaces without any equipment modification or capital expenditure

Case Study — Cost Benefit Analysis

A forging unit producing automotive components with an annual throughput of 1,350 MT was assessed for anti-scale coating implementation. The unit operated box-type oil-fired furnaces and had measured scale losses of 1.7% of billet input weight equivalent to approximately 23 MT of ferrous material lost annually to oxidation. Surface finish defects attributable to heavy scaling were also causing a rejection rate of approximately 1.2% at the machining stage, adding further cost to the quality chain.

Following introduction of a water-based anti-scale coating applied by spray gun prior to furnace charging, scale loss was reduced to 0.8% of billet weight. This reduction of 0.9 percentage points on an annual throughput of 1,350 MT translated into a recovery of 6 MT of ferrous material per year. At prevailing steel input prices, this material recovery generated a gross annual saving of ₹17 Lakhs. The total annual cost of coating material and application was assessed at ₹9 Lakhs, yielding a net annual saving of ₹8 Lakhs.

The financial return is driven primarily by the recovery of ferrous material that would otherwise be lost as scale, valued at prevailing steel input prices. The intervention also delivered a secondary benefit through reduction of the machining stage rejection rate from 1.2% to 0.4%, further improving the overall cost of quality per component. Units with higher production volumes and currently elevated-scale loss rates above 2% will achieve proportionally greater returns from this intervention.

Table 13: Cost–Benefit Analysis Protective Coatings for Scale Prevention

Parameter	UOM
Scale Loss Baseline	1.7%
Scale Loss Post Application	0.8%
Annual Production	1,350 MT/Yr
Scale Reduction	6 MT/Yr
Gross Cost Savings	₹17 Lakhs
Coating Application Cost	₹9 Lakhs
Simple Payback Period	6 Months

3.2.4 Protective Coatings for Scale Prevention

Current Practice in Industry

In conventional box-type and oil-fired furnaces, steel billets are exposed to high-temperature oxidising atmospheres during the heating cycle, resulting in the formation of mill scale on the billet surface. Scale loss typically ranges from 1.5–2.5% of billet weight per heating cycle, representing a direct and recurring loss of purchased raw material. Beyond material wastage, scale formation leads to surface defects on forged components, increased descaling effort, and additional specific fuel consumption due to the insulating effect of scale buildup on heat transfer efficiency.

Energy Efficient Option

Thermo ceramic coatings are advanced insulating formulations applied directly onto refractory surfaces and furnace outer shells to restore and enhance thermal performance without the cost and downtime associated with full refractory replacement. These coatings contain hollow ceramic microspheres and infrared-reflective compounds that reduce both conductive and radiative heat losses from furnace surfaces.

Working Principle

Thermo ceramic coatings reduce heat loss through three complementary mechanisms. Low thermal conductivity of the ceramic microsphere matrix limits conductive heat transfer through the furnace wall. Infrared reflection from the coating surface redirects radiant heat back into the furnace chamber. Air pocket insulation within the hollow microsphere structure further impedes heat flow. The combined effect is higher heat retention within the furnace, reduced external surface temperature, and lower fuel requirement to maintain the target operating temperature.



Figure 7. Thermo Ceramic Coating-Before and After application.

Benefits

- ❖ Surface heat losses reduced significantly, improving overall furnace thermal efficiency by 5–15%
- ❖ External furnace shell temperature reduced, improving workplace safety conditions
- ❖ Fuel consumption and operating cost reduced without major capital expenditure on refractory
- ❖ Extended refractory service life through thermal protection of the underlying structure
- ❖ Can be applied during scheduled maintenance shutdowns without extended furnace downtime

Case Study — Cost Benefit Analysis

A forging unit operating two heat treatment furnaces — one electrically heated and one LPG-fired — was assessed for thermo ceramic coating application. Thermal imaging of the furnace shells indicated external surface temperatures in the range of 85–110°C, significantly above the acceptable benchmark of 55°C, confirming substantial heat losses through degraded refractory walls. Monthly energy records showed electrical consumption of 50,000 kWh and LPG consumption of 2,300 kg across the two furnaces.

Thermo ceramic coating was applied to all internal refractory walls and the external furnace shell surfaces during a scheduled two-day maintenance shutdown. Post-application thermal imaging confirmed external surface temperatures had reduced to 45–55°C. Monthly monitoring over the following quarter recorded electrical consumption falling to 48,000 kWh and LPG consumption reducing to 1,800 kg, representing reductions of 4% and 22% respectively on pre-application baselines.

The payback period of 12 months reflects savings from both electrical and thermal energy sources simultaneously. Beyond the direct financial return, the reduction in external surface temperature to below 55°C brought the furnace into compliance with occupational safety thermal standards, eliminating the risk of contact burns for operators working in proximity to the furnace shell. The coating is expected to retain its thermal performance for 3–5 years under normal operating conditions before reapplication is required, delivering cumulative savings substantially in excess of the initial investment over its service life.

Table 14: Cost–Benefit Analysis Thermo Ceramic Furnace Coating

Parameter	UOM
Electricity Consumption Baseline	50,000 kWh/month
Electricity Consumption Post	48,000 kWh/month
LPG Consumption Baseline	2,300 Kg/month
LPG Consumption Post	1,800 Kg/month
Combined Annual Savings	₹4.2 Lakhs
Capital Investment	₹4 Lakhs
Simple Payback Period	12 Months

3.2.6 Energy Efficient EC Fans for Cooling Towers

Current Practice in Industry

Cooling towers in forging units serve induction heater cooling circuits, hydraulic system heat exchangers, and air compressor aftercoolers. Conventional cooling tower fans are driven by standard AC induction motors operating at fixed speed regardless of actual cooling load. During periods of lower ambient temperature or reduced production intensity, the fan continues to run at full speed, consuming maximum power even when cooling demand is significantly lower. This results in persistent over-cooling and chronic energy overconsumption throughout winter and night-shift operating periods.

Energy Efficient Option

Electronically Commutated (EC) fans replace conventional fixed-speed AC motor-driven fans with brushless DC motors incorporating integrated electronic speed controllers. EC fans modulate their speed in direct response to actual cooling demand, consuming only the power required to maintain the desired cooling water outlet temperature under any given operating condition.

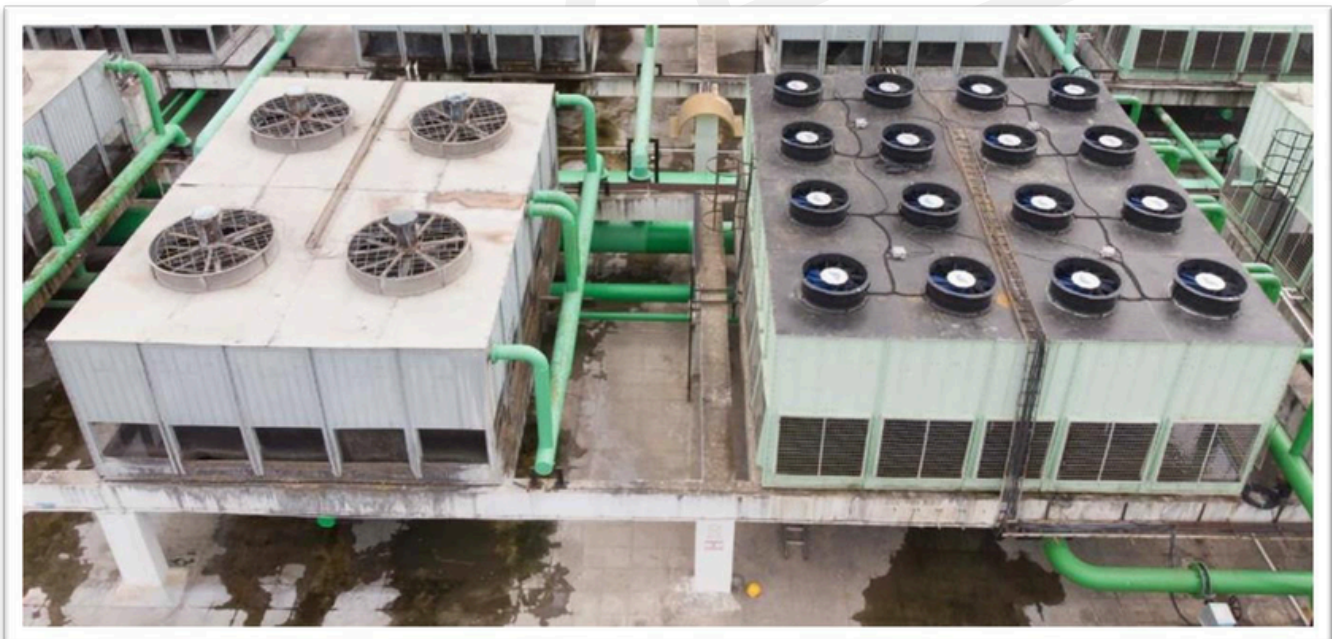


Figure 8. EC fans application on cooling tower

Working Principle

EC fans use a brushless DC motor with a permanently integrated electronic controller that converts incoming AC supply to DC internally and regulates motor speed through pulse-width modulation based on a temperature signal from the cooling circuit. As cooling demand decreases, fan speed reduces proportionally. Since fan power follows the cube law relationship with speed, even a modest reduction in fan speed delivers a disproportionately large reduction in power consumption, yielding 30–50% average energy savings across a full operating year.

Benefits

- ❖ Electricity consumption reduced by 30–50% compared to fixed-speed conventional fans
- ❖ Precise temperature control improves cooling circuit and process equipment efficiency
- ❖ Brushless motor design eliminates brush wear, significantly reducing maintenance requirements
- ❖ Reduced operating noise levels improve the working environment around the cooling tower
- ❖ Extended equipment life due to lower average operating speeds across the annual cycle

Case Study — Cost Benefit Analysis

A forging unit with a centralised cooling tower serving four induction billet heaters and two hydraulic hammer systems was assessed for EC fan conversion. The existing cooling tower was fitted with four 11 kW fixed-speed AC induction motor fans, all running continuously at full speed throughout the operating shift regardless of ambient temperature or production load. Energy metering confirmed that the four fans collectively consumed approximately 200,000 kWh annually at an average load factor of 91%.

Replacement with four EC fans of equivalent airflow capacity, each rated at a maximum of 9 kW but modulating between 3–9 kW based on cooling demand, reduced the collective average power draw significantly. Over the first full year of operation, metered consumption from the four fans totalled 160,000 kWh, a saving of 40,000 kWh representing a 20% reduction. The saving was most pronounced during the winter months and night shifts, when fan speed regularly reduced to 40–50% of maximum, delivering power reductions of over 80% during those periods due to the cube law effect.

The 13-month payback period documented here is based on conservative average savings. Units located in Telangana benefit from the pronounced seasonal temperature variation between summer and winter, which amplifies the part-load operating hours of the EC fan and strengthens the financial return beyond the baseline estimate. The elimination of brush maintenance and the extended motor service life further reduce the total cost of ownership over the 10–15 year expected service life of the EC fan assembly.

Table 15: Cost–Benefit Analysis Energy Efficient EC Fans for Cooling Towers

Parameter	Baseline	Post Implementation
Fan Motor Rating	11 kW	9 kW
Number of Fans	4 Units	4 Units
Annual Energy Saving	40,000 kWh/Yr	
Electricity Cost	₹9/kWh	
Annual Savings	₹3.6 Lakhs	
Capital Investment	₹4 Lakhs	
Simple Payback Period	13 Months	

3.2.7 Regenerative Drives for EOT Cranes

Current Practice in Industry

EOT cranes in forging shops are used extensively for loading billets, transferring hot forgings between stations, and handling finished components. In conventional crane drives, energy generated during lowering of heavy loads and braking of the crane bridge is dissipated entirely as heat through braking resistor banks. This represents a significant and recurring energy loss, particularly in high-cycle operations involving frequent load lowering from elevated heights. Braking resistors additionally generate considerable heat within the electrical panel room, increasing the panel cooling load and creating a maintenance item subject to periodic replacement.

Energy Efficient Option

Regenerative drives equipped with Active Front-End (AFE) converters replace conventional resistor-based braking systems and recover the electrical energy generated during load lowering and deceleration, feeding it directly back into the plant AC supply network for immediate use by other connected loads.

Working Principle

In EOT cranes, regenerative drives operate on the four-quadrant principle, where the hoist motor acts as a generator during load lowering, converting the descending load's potential energy back into electrical energy instead of dissipating it as heat through braking resistors. An Active Front-End (AFE) converter using IGBT switches enables bidirectional power flow, detecting back-fed energy on the DC bus and feeding clean power back into the plant's AC supply at near-unity power factor. This recovers energy during deceleration of travel motions as well, typically yielding 20–35% energy savings while eliminating resistor banks and improving overall power quality.

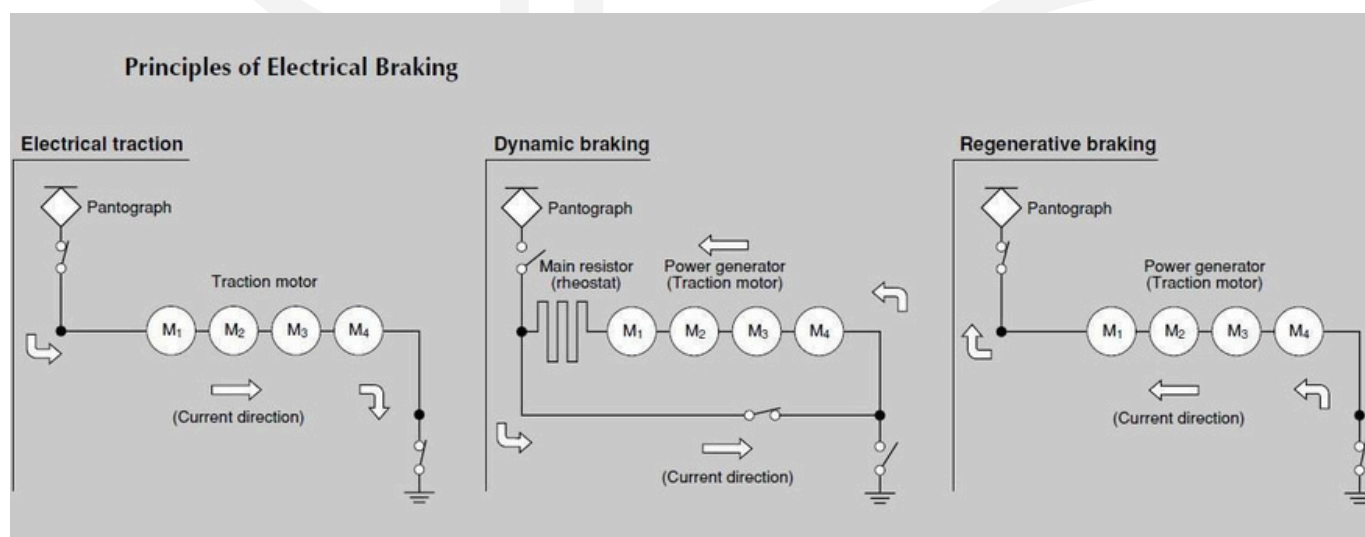


Figure 9 Regenerative Drive System in EOT Crane Showing Energy Recovery During Lowering and Braking

Benefits

- ❖ Recovery and reuse of braking energy reduces overall crane power consumption by 20–35%
- ❖ Elimination of braking resistors removes a recurring source of heat generation and a maintenance cost item
- ❖ Near-unity power factor operation improves plant-level power quality and reduces utility penalty charges
- ❖ Smoother speed control reduces mechanical stress on crane structure and drive components
- ❖ Reduced wear on mechanical braking systems lowers maintenance frequency and associated downtime

Case Study — Cost Benefit Analysis

A forging unit operating a 10-tonne EOT crane for billet loading and forging transfer was assessed for regenerative drive installation. The crane performed an average of 80 lift-lower cycles per shift across a 5,000-hour annual operating schedule, with typical lift heights of 4–5 metres and average loads of 6–8 tonnes. The existing drive system dissipated all regenerated energy through a bank of braking resistors, which required replacement every 18 months at a cost of approximately ₹0.8 Lakhs per replacement event. Following installation of a regenerative AFE drive system, the recovered energy measured over the first six months and annualized, totalled 12,600 kWh per year, representing the electrical energy that would previously have been lost entirely as heat in the resistor bank. At the prevailing electricity tariff, this recovery generated annual savings of ₹1.1 Lakhs. Additionally, with resistor banks eliminated, the panel room ambient temperature reduced by approximately 8°C, reducing the panel cooling load and extending the service life of other electrical components within the enclosure.

The 42-month payback period documented here reflects a moderate-duty crane cycle assumed in the analysis. Units with higher crane utilisation, greater average lift heights above 6 metres, and heavier average loads will achieve proportionally shorter payback periods. When the avoided cost of periodic braking resistor replacement of ₹0.8 Lakhs per 18-month cycle is incorporated into the financial model, the effective net payback reduces to approximately 30 months. The technology delivers maximum value in high-cycle forge shops where the crane is in near-continuous operation across multiple shifts.

Table 16: Cost–Benefit Analysis Regenerative Drives for EOT Cranes

Parameter	Post Implementation
Annual Energy Recovered	12,600 kWh/Yr
Electricity Cost	₹9/kWh
Annual Savings	₹1.1 Lakhs
Capital Investment	₹4 Lakhs
Simple Payback Period	42 Months

3.2.8 Energy Efficient Pumps with Variable Frequency Drive

Current Practice in Industry

Pump sets in forging units circulate hydraulic oil in press and hammer systems and convey cooling water through induction heater and compressor cooling circuits. Conventional pumps are driven by fixed-speed motors sized for peak demand conditions. During periods of lower demand, flow is regulated through throttle valves or bypass arrangements, which waste energy by artificially restricting flow while the motor continues to run at full speed. This results in chronic energy overconsumption and accelerated wear on pump internals, control valves, and seals.

Energy Efficient Option

Variable Frequency Drive (VFD) controlled pumping systems regulate motor speed in direct proportion to actual flow demand, eliminating throttling and bypass losses entirely. Since pump power consumption follows the affinity law — where power reduces as the cube of the speed reduction — even modest reductions in operating speed deliver substantial energy savings across the annual operating cycle.

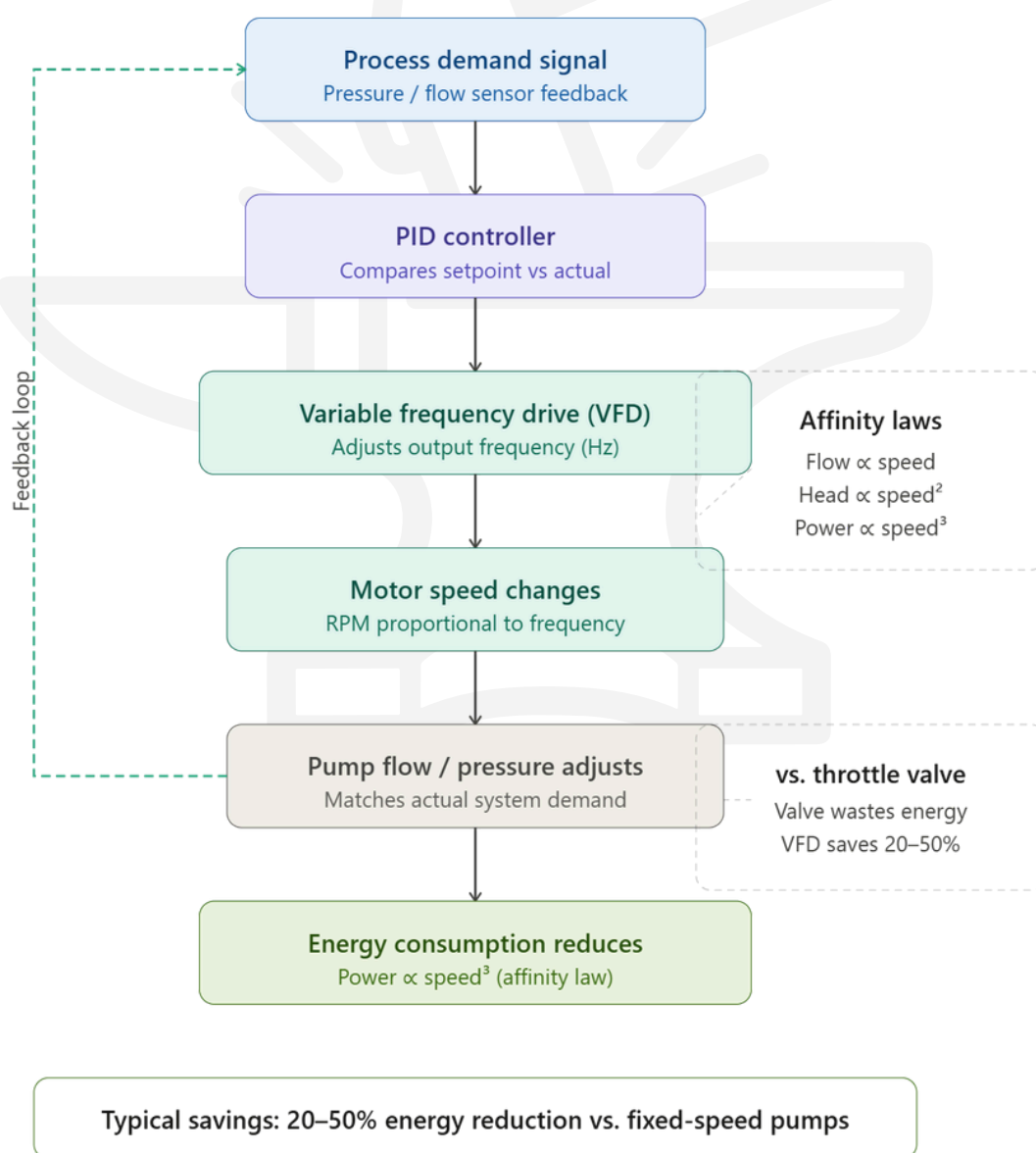


Figure 10. Energy saving with Energy Efficient pumps with VFD

Working Principle

A VFD controls the frequency and voltage supplied to the pump motor, directly regulating rotational speed and hence flow output. When process demand decreases, the VFD reduces motor frequency, lowering pump speed, flow, and power consumption proportionally. This eliminates the need for throttling valves and bypass lines, ensuring that energy input precisely matches process requirements at all operating conditions. According to affinity laws, a 20% reduction in pump speed results in approximately a 49% reduction in power consumption, making VFD control highly effective even for moderate flow reductions.

Benefits

- ❖ Energy consumption reduced by 30–50% in variable load pumping applications
- ❖ Elimination of throttling losses improves overall system hydraulic efficiency
- ❖ Reduced mechanical stress on pump impellers, seals, and bearings extends service life
- ❖ Smoother motor starting reduces electrical stress on supply infrastructure
- ❖ Improved process control with precise and responsive flow and pressure regulation

Case Study — Cost Benefit Analysis

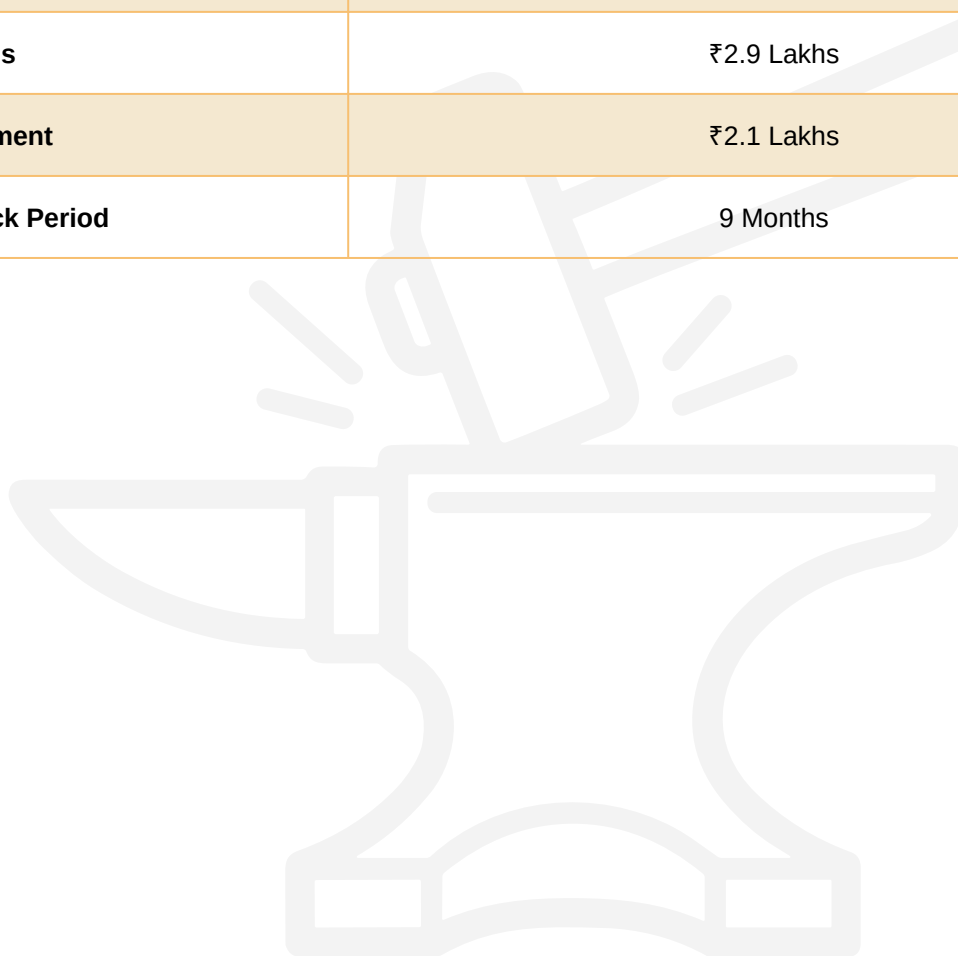
A forging unit operating a centralised hydraulic cooling water system for its induction heaters and press hydraulic circuits was assessed for VFD pump installation. The system comprised a 30 kW fixed-speed centrifugal pump running continuously throughout the production shift, with flow regulated by a partially closed throttle valve. Energy audit measurements confirmed that the pump was operating significantly away from its best efficiency point due to throttling, with actual hydraulic output representing only 58% of motor shaft input — a clear indication of avoidable energy waste through valve throttling losses.

Installation of a VFD on the existing 30 kW motor, combined with removal of the throttle valve and conversion to speed-based flow control using a pressure transmitter feedback signal, reduced average motor loading from 30 kW to approximately 24 kW — a 20% reduction in average power draw. Over 5,000 annual operating hours, this translated into an energy saving of 32,400 kWh per year. The relatively low capital cost of ₹2.1 Lakhs for the VFD unit and installation generated a payback period of just 9 months on annual savings of ₹2.9 Lakhs.

The 9-month payback period makes the VFD pump system one of the strongest financial performers in the medium investment category. Beyond the direct energy saving, the unit reported a measurable reduction in pump maintenance frequency following VFD installation, with the first impeller inspection at 18 months showing significantly lower wear compared to the pre-VFD baseline, attributable to the elimination of high-velocity throttling conditions that had previously caused accelerated erosion of pump internals. The intervention is recommended as a priority measure for all variable-flow hydraulic and cooling water circuits across the cluster.

Table 17: Cost–Benefit Analysis Energy Efficient Pumps with VFD

Parameter with VFD	Baseline	Post Implementation
Motor Power Rating	30 kW	24 kW
Annual Energy Saving	32,400 kWh/Yr	
Electricity Cost	₹9/kWh	
Annual Savings	₹2.9 Lakhs	
Capital Investment	₹2.1 Lakhs	
Simple Payback Period	9 Months	



3.3 Section C - High Investment Measures (above ₹10 Lakhs)

The following technologies represent capital-intensive investments that deliver the highest absolute energy savings and greenhouse gas emission reductions. Despite the larger initial outlay, the financial returns typically yield competitive payback periods.

Table 18: Section C High Investment Measures (above ₹10 Lakhs): Summary Overview

Sr.No.	Technology	Description	Investment (₹ Lakhs)	Energy Savings
1	IGBT-Based Induction Heating	Replace gas furnaces with medium-frequency induction heaters	₹11–25L	40–50% energy
2	Self-Recuperative Burners	Integrated flue gas heat recovery within burner assembly	₹5–20L	25–40% fuel
3	Screw Compressor with VFD	Variable frequency driven screw compressor replacing fixed-speed units	₹3–16L	20–35% compressor energy

3.3.1 IGBT-Based Electric Induction Heating

Current Practice in Industry

Most small and medium forging units across the cluster continue to rely on box-type or pit-type oil-fired or gas-fired furnaces for billet heating. These conventional furnaces heat billets through convection and radiation within a combustion chamber, exposing the billet surface to an oxidising atmosphere throughout the heating cycle. System thermal efficiencies for such furnaces typically range from 25– 45%, meaning more than half of the fuel energy input is lost through flue gases, furnace wall radiation, and scale formation. Billet scale losses of 1.5–2.5% per heat are routine, representing a direct and recurring loss of raw material value. Temperature control is manual or semi-automatic, resulting in significant billet-to-billet variation in heating uniformity and frequent over-heating to compensate for cold spots.

Energy Efficient Option

IGBT-based medium-frequency electric induction billet heaters replace conventional combustion furnaces with a contactless electromagnetic heating system that generates heat directly within the metal. System efficiencies of 75–85% are routinely achieved, compared to 25–45% for oil or gas furnaces. The complete elimination of combustion eliminates scale formation, reduces GHG emissions to zero at the point of use, and enables full integration with automated forging lines through precise temperature and feed rate control.

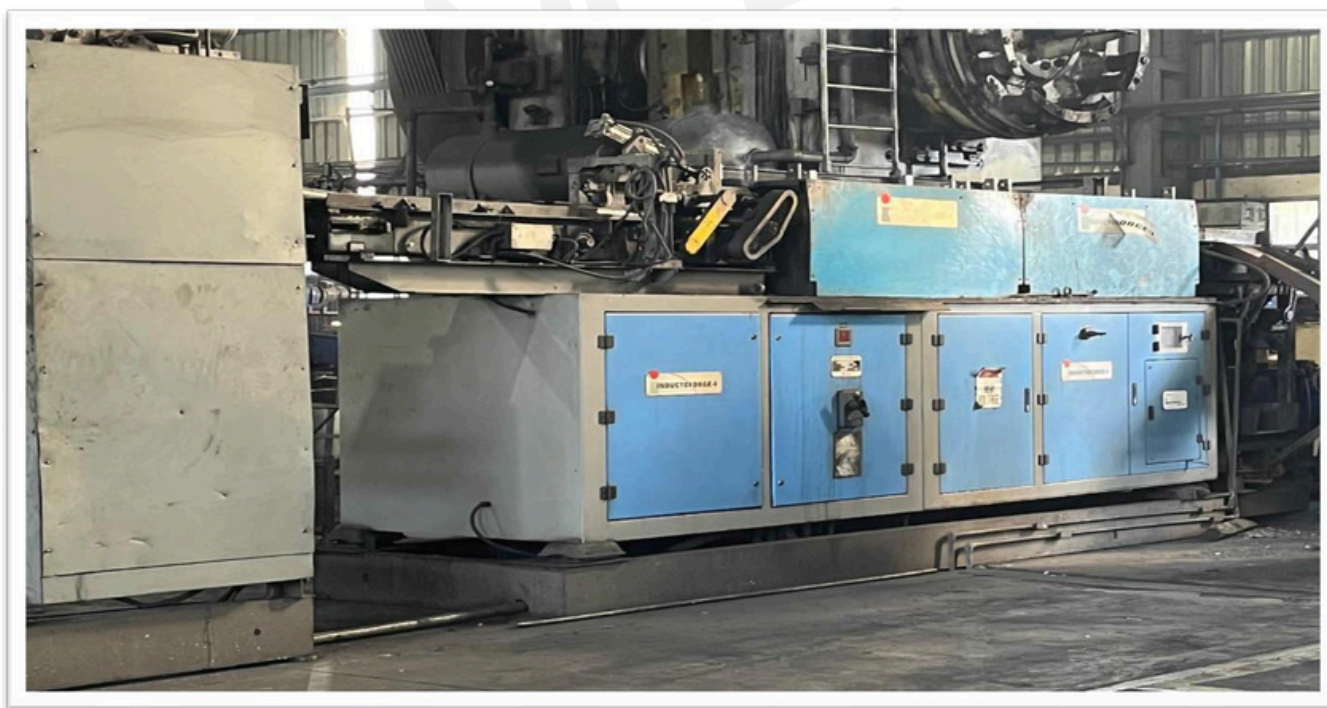


Figure 10. IGBT based electrical billet heater

Working Principle

The system uses Insulated Gate Bipolar Transistor (IGBT) modules to generate and precisely control high-frequency alternating current. The AC supply from the grid is first rectified to DC by a converter stage, then inverted back to high-frequency AC — typically in the range of 500 Hz to 10 kHz — by the IGBT inverter. This high-frequency AC current flows through a water-cooled induction coil surrounding the billet. The alternating magnetic field generated by the coil induces eddy currents within the electrically conductive billet. These eddy currents encounter the electrical resistance of the metal and generate heat directly within the billet cross-section through Joule heating. The frequency of the alternating field determines the depth of current penetration — lower frequencies produce deeper penetration suitable for larger billet diameters, while higher frequencies concentrate heating near the surface for smaller sections. This direct internal heat generation results in rapid, uniform, and precisely controlled heating without any oxidising atmosphere contact.

Benefits

- ❖ System efficiency of 75–85% compared to 25–45% for conventional gas or oil furnaces
- ❖ Scale loss reduced to near zero, improving material yield by 1.5–2.5% per heat
- ❖ Faster heating cycles increase press or hammer throughput and productivity
- ❖ Precise temperature control and uniformity improve forging consistency and die life
- ❖ Complete elimination of combustion removes on-site GHG emissions from heating operations
- ❖ Full integration with automated billet transfer and forging line controls
- ❖ Lower maintenance costs — no burners, refractory, or combustion controls to service

Case Study — Cost Benefit Analysis

A medium-scale forging unit in the Telangana cluster operating two natural gas-fired box furnaces for billet heating was assessed for conversion to IGBT-based induction heating. The existing furnaces were operating at a combined thermal efficiency of approximately 42%, consuming natural gas equivalent to 25,00,000 kWh of energy annually to heat the required billet throughput. Scale losses were measured at 1.8% of billet input weight, and the unit was experiencing periodic forging defects attributable to inconsistent billet temperature distribution from uneven furnace heating.

Following installation of a medium-frequency IGBT induction billet heating line sized to match the existing press capacity, total annual energy consumption for the heating operation reduced to 15,00,000 kWh of electrical energy — an energy saving of 10,00,000 kWh per year, representing a 40% reduction in heating energy. Scale loss was eliminated entirely, recovering the full 1.8% yield loss as productive output. Forging defect rates attributable to heating non-uniformity reduced to near zero, and the automated feed system increased effective press uptime by reducing manual billet handling time between heats.

Heating occurs directly within the material, ensuring efficient and uniform heating.

The annual financial saving of ₹90 Lakhs against a capital investment of ₹20 Lakhs produces a payback period of 3–6 months, making IGBT-based induction heating one of the most compelling investment opportunities in the entire forging sector energy efficiency landscape. This exceptional return is driven by the large absolute energy saving achievable when replacing a low-efficiency combustion system with a high-efficiency electrical system at scale. Beyond the direct financial return, the unit also recorded a significant improvement in material yield from the elimination of scale loss, and a reduction in downstream rejection rates attributable to improved heating consistency. When the value of yield improvement is incorporated alongside energy savings, the effective payback period reduces further. For units currently operating aged oil-fired furnaces with efficiencies below 35%, the financial case is even stronger than the baseline analysis presented here.

Table 19: Cost–Benefit Analysis IGBT-Based Induction Heating

Parameter	Baseline	Post Implementation
Fuel / Energy Type	Natural Gas	Electricity
System Efficiency	40–50%	75–85%
Annual Energy Consumption	25,00,000 kWh/Yr	15,00,000 kWh/Yr
Annual Energy Saving	10,00,000 kWh/Yr	
Energy Cost	₹9/unit	
Annual Financial Savings	₹90 Lakhs	
Capital Investment	₹20 Lakhs	
Simple Payback Period	3–6 Months	
Scale Loss	1–2%	~0%
GHG Emission Reduction	Significant	

3.3.2 Self-Recuperative Burners

Current Practice in Industry

Conventional forging furnaces across the cluster are typically fitted with standard open-flame burners that discharge hot combustion products directly into the furnace chamber and subsequently exhaust flue gases to atmosphere at temperatures of 700–1000°C without any heat recovery. This high flue gas exit temperature represents a substantial and continuous thermal energy loss — in many units, 30–40% of the total fuel input energy leaves the system through the flue. The absence of heat recovery not only increases specific fuel consumption per tonne of production but also results in higher combustion air requirements, elevated CO₂ emissions, and reduced flame temperature stability. Many older forging furnaces operate with hand-adjusted air-fuel ratios and periodic manual temperature checks, resulting in frequent over-firing to compensate for heat losses.

Energy Efficient Option

Self-recuperative burners integrate a compact counter-flow heat exchanger directly within the burner body assembly, enabling flue gas heat recovery and combustion air preheating within a single self-contained unit. Unlike external recuperators that require separate ducting and heat exchanger installation, self-recuperative burners are direct drop-in replacements for existing conventional burners, offering a compact and installation-efficient route to significant fuel savings without major furnace modifications.

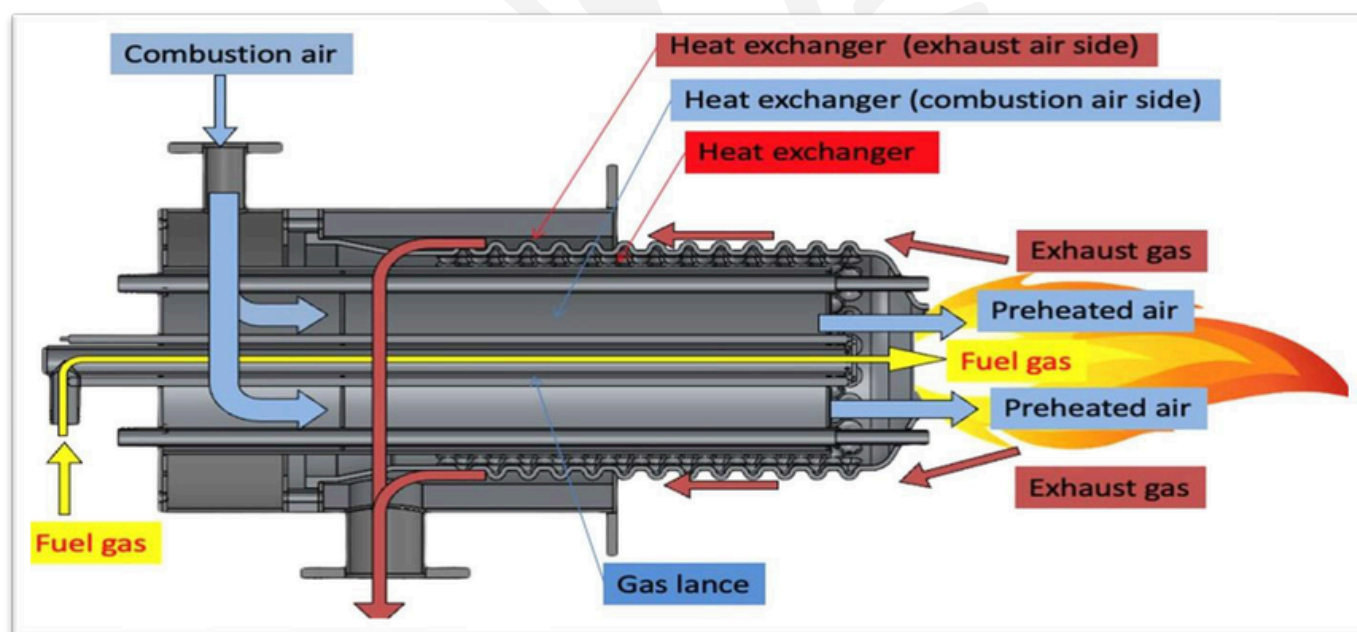


Figure 12. Self-Recuperative Burners cross sectional diagram

Working Principle

Self-recuperative burners combine combustion and heat recovery in a single integrated assembly. Hot flue gases generated in the furnace chamber are drawn into the burner body through an annular exhaust passage surrounding the central combustion air supply tube. As the hot exhaust gases flow outward through this annular passage, they transfer heat through the metallic wall to the incoming combustion air flowing inward in the opposite direction — a counter-flow arrangement that maximises heat transfer efficiency. The preheated combustion air, typically reaching 300–600°C depending on furnace temperature and burner design, then enters the combustion zone and mixes with fuel. The elevated air preheat temperature reduces the additional fuel energy required to reach the target flame temperature, delivering a direct and proportional reduction in specific fuel consumption. The cooled flue gases exit the burner body at significantly lower temperature before discharge to atmosphere.

Benefits

- ❖ Fuel consumption reduced by 25–40% through integrated combustion air preheating
- ❖ Improved furnace temperature uniformity due to stable and consistent flame characteristics
- ❖ Compact drop-in design simplifies installation and minimises furnace modification requirements
- ❖ Lower flue gas discharge temperature reduces thermal stress on chimney and stack
- ❖ Reduced CO₂ and NO_x emissions per unit of production
- ❖ Applicable to both new furnace installations and retrofit of existing furnaces

Case Study — Cost Benefit Analysis

A large forging unit in the cluster operating a continuous billet heating furnace fired by natural gas was assessed for self-recuperative burner conversion. The furnace was equipped with 8 conventional open-flame burners consuming a combined 80 Nm³/hr of natural gas, operating across 5,000 hours per year. Flue gas temperature measurements at the stack indicated exit temperatures of 820–880°C, confirming substantial heat loss through the exhaust. The unit had no existing heat recovery system on the furnace.

Replacement of all 8 conventional burners with self-recuperative burner assemblies of equivalent firing capacity was carried out during a scheduled furnace maintenance shutdown over 4 days, with no structural modification to the furnace required. Post-installation monitoring over the first production quarter confirmed fuel consumption had reduced from 80 Nm³/hr to 55 Nm³/hr — a saving of 25 Nm³/hr or 31% on the baseline. Stack flue gas temperature reduced from 860°C to 320°C, confirming effective heat recovery within the burner bodies. Annual fuel consumption fell from 4,00,000 Nm³ to 2,75,000 Nm³, yielding an annual fuel saving of 1,25,000 Nm³.

The annual saving of ₹75 Lakhs against a capital investment of ₹15 Lakhs yields a payback period of 2–4 months, establishing self-recuperative burners as one of the fastest-payback capital investments in the forging sector. The strength of this return is driven by the combination of high fuel unit cost, large absolute firing rate, and the significant flue gas temperature reduction achievable through integrated heat recovery. Beyond the direct financial return, the unit reported improved temperature uniformity across the furnace chamber length, which was a direct consequence of the more stable and hotter flame characteristics of the preheated-air burners — which translated into a reduction in billet temperature variation from 45°C to under 15°C across the furnace length. This improvement in

heating consistency reduced forging rejects attributable to cold billets by approximately 60%, providing an additional quality- related financial benefit not captured in the energy saving calculation alone.

Table 20: Cost–Benefit Analysis Self-Recuperative Burners

Parameter	Baseline	Post Implementation
Fuel Consumption	80 Nm ³ /hr	55 Nm ³ /hr
Operating Hours	5,000 Hr/Yr	5,000 Hr/Yr
Annual Fuel Consumption	4,00,000 Nm ³ /Yr	2,75,000 Nm ³ /Yr
Annual Fuel Saving	1,25,000 Nm ³ /Yr	
Fuel Cost	₹60/Nm ³	
Annual Financial Savings	₹75 Lakhs	
Capital Investment	₹15 Lakhs	
Simple Payback Period	2–4 Months	

3.3.3 Energy Efficient Screw Compressor with VFD

Current Practice in Industry

Compressed air is an essential utility in forging units, serving pneumatic hammer operation, automated control systems, billet ejection mechanisms, and cleaning operations. Most forging units operate fixed-speed screw or reciprocating compressors that run at constant motor speed regardless of the actual air demand at any given time. When air demand falls below compressor output capacity which occurs routinely during shift changes, machine setups, maintenance breaks, and partial production schedules, the compressor enters an unload-reload cycling mode, continuing to consume 25–40% of full-load power while delivering no useful compressed air output. This unloaded running represents a direct and significant energy waste that accumulates over thousands of operating hours annually.

Energy Efficient Option

Variable Frequency Drive (VFD) equipped screw compressors replace conventional fixed-speed units with a speed-modulated system that continuously matches compressed air output to actual demand. By varying motor speed between a minimum of approximately 25% and maximum 100% of rated speed, the VFD compressor eliminates unloaded running entirely, delivering precise pressure control and substantial energy savings particularly during the significant portion of operating time when demand is below peak.

Working Principle

A twin-screw compressor uses two precisely machined intermeshing helical rotors to trap and progressively compress air as it moves from the inlet to the outlet. In a VFD-based system, the frequency and voltage of the electrical supply to the compressor motor are continuously modulated by the drive controller in response to a system pressure feedback signal. When compressed air consumption in the plant increases and system pressure begins to fall, the VFD increases motor frequency to accelerate the rotors, increasing output flow and restoring pressure. When demand falls and system pressure rises toward the upper setpoint, the VFD reduces motor frequency, slowing the rotors and reducing output proportionally. This continuous modulation eliminates the pressure band swings and unloaded running cycles of fixed-speed compressors, maintaining stable system pressure within a narrow band while consuming only the energy required to deliver the actual air demand at each moment.

Benefits

- ❖ Energy consumption reduced by 20–40% compared to equivalent fixed-speed compressors
- ❖ Elimination of frequent load/unload cycling reduces mechanical stress and extends compressor life
- ❖ Stable system pressure within a narrow band improves quality of pneumatic operations
- ❖ Soft start capability of VFD reduces electrical inrush current at motor start-up
- ❖ Reduced noise levels during part-load operation improves forge shop environment
- ❖ Lower maintenance frequency due to reduced mechanical cycling stress on valve assemblies

Case Study — Cost Benefit Analysis

A forging unit operating a 110 kW fixed-speed screw compressor serving pneumatic hammer systems, control air circuits, and cleaning stations was assessed for VFD conversion. The existing compressor delivered a rated output of 500 CFM at 7 bar and operated at a fixed specific energy consumption of 0.22 kW/CFM. Energy monitoring over a two-week period confirmed that the compressor was in unloaded running condition for approximately 35% of its operating hours, consuming around 40 kW during these unloaded periods while delivering zero useful air output. Peak demand periods coincided with full production shifts, while unloaded running was concentrated during shift changeovers, lunch breaks, and weekend maintenance running.

Replacement with a VFD-equipped screw compressor of identical 500 CFM rated capacity eliminated all unloaded running by modulating motor speed to match actual demand at all times. Post-installation metering over the first quarter confirmed specific energy consumption had reduced from 0.22 kW/CFM to 0.13 kW/CFM — a 41% improvement — with average power consumption reducing from 110 kW to 65 kW. Over 5,000 annual operating hours, this delivered an energy saving of 2,25,000 kWh per year. System pressure stability also improved significantly, with pressure variation reducing from ± 0.8 bar under the fixed-speed load/unload regime to ± 0.1 bar under VFD modulation, improving the consistency of pneumatic hammer operation.

The annual saving of ₹20 Lakhs against a capital investment of ₹12 Lakhs produces a payback period of 7–8 months, making the VFD screw compressor a highly attractive investment for any forging unit with variable air demand patterns. The 41% improvement in specific energy consumption documented in this case study reflects the compressor spending a significant portion of operating time at part load — a condition that is common across MSME forging units where production schedules include regular breaks and shift changeovers. Units with even greater variability in air demand, or those currently operating aged fixed-speed compressors with higher specific energy consumption, will achieve proportionally stronger financial returns. The secondary benefit of improved system pressure stability has also delivered a measurable improvement in the consistency of pneumatic hammer strike energy, reducing component dimensional variation attributable to pressure-related forming force fluctuations.

Table 21: Cost–Benefit Analysis VFD-Driven Screw Compressor

Parameter	Baseline	Post Implementation
Compressor Capacity	500 CFM	500 CFM
Specific Energy Consumption	0.22 kW/CFM	0.13 kW/CFM
Power Consumption	110 kW	65 kW
Power Saved	45 kW	
Operating Hours	5,000 Hr/Yr	5,000 Hr/Yr
Annual Energy Saving	2,25,000 kWh/Yr	
Electricity Cost	₹9/kWh	
Annual Financial Savings	₹20 Lakhs	
Capital Investment	₹12 Lakhs	
Simple Payback Period	7–8 Months	

3.4 Section - D Renewable Energy Proposals

Table 22: Section D Renewable Energy Proposals: Summary Overview

Sr.No.	Technology / Description Measure		Investment (₹ Lakhs)	Energy Savings
1	Solar Photovoltaic (PV) System	Rooftop / ground-mounted captive solar power generation	₹40–200L	LCOE < grid tariff; ~600 tCO ₂ /yr

3.4.1 Solar Photovoltaic System

Current Practice in Industry

Forging units across the Telangana cluster are entirely dependent on grid electricity supplied by TGNPDCL at prevailing industrial tariff rates, currently in the range of ₹8–10 per kWh for HT and LT industrial consumers. This full dependence on grid power exposes units to tariff escalation risk, demand charge penalties, power factor surcharges, and supply interruptions during peak grid demand periods. Rooftop and ground-mounted areas available within industrial plots are largely unused for energy generation. Given Telangana's annual average solar irradiation of 5.5–6.0 kWh/m²/day — among the highest in India, this represents a significant and underutilised opportunity for captive renewable power generation that can directly offset grid electricity consumption at a levelised cost substantially below the prevailing grid tariff.

Energy Efficient Option

Rooftop and ground-mounted solar photovoltaic systems convert incident solar radiation directly into electricity using semiconductor PV modules, feeding the generated power into the plant's internal electrical distribution network to displace grid electricity consumption in real time. Grid-connected systems without battery storage — the most cost-effective configuration for industrial units with daytime operations — require no storage infrastructure and deliver maximum financial return by directly offsetting the highest-cost grid electricity consumed during production hours.

Working Principle

Solar PV systems operate on the photovoltaic effect, wherein photons from incident sunlight excite electrons in the semiconductor material of the PV cell typically mono or polycrystalline silicon, generating a direct current (DC) voltage across the cell junction. Individual cells are connected in series and parallel within modules to produce the required output voltage and current. Multiple modules are arranged in strings and connected to a DC combiner, which feeds a grid-tied inverter. The inverter converts DC output to AC at the plant distribution voltage and frequency, synchronising with the grid supply and injecting power directly into the plant's internal distribution system. The plant draws from the solar generation first, with the grid supplying only the balance of demand not met by solar output. Under Telangana's net metering policy, any surplus generation exported to the grid is credited against future consumption at the applicable rate.



Figure 13. Solar photovoltaic (PV) system installations

Types of Systems:

- Grid-connected system — Connected to utility grid without battery storage (most common and cost-effective for industrial use)
- Off-grid system — Fully islanded with battery storage for remote or backup applications
- Hybrid system — Combines grid connection with battery storage for peak shaving and backup supply

A typical solar PV system in Telangana generates 4.8–5.2 kWh per kW installed per day based on the region's solar resource, equivalent to approximately 1,500–1,600 kWh per kW per year of annual generation.

Benefits

- ❖ Direct displacement of grid electricity at a levelised cost of energy (LCOE) well below the prevailing grid tariff
- ❖ Protection against future electricity tariff escalation over the 25-year system life
- ❖ Zero emissions during operation — no fuel consumption, no combustion, no on-site GHG emissions
- ❖ Long system life of 20–25 years with low maintenance requirements — primarily periodic module cleaning
- ❖ Eligible for accelerated depreciation benefits under Indian Income Tax provisions, improving post-tax financial returns

- ❖ Supports sustainability credentials and green supply chain requirements of automotive OEM customers
- ❖ Potential for carbon credit generation under applicable certification frameworks

Case Study — Cost Benefit Analysis

A forging unit with an 800-kW connected load and annual electricity consumption of 35 lakh kWh implemented a 500-kW grid connected rooftop solar PV system to reduce grid electricity dependence and energy costs. The plant's daytime operating pattern aligned well with solar generation, and the available rooftop area of approximately 4,000 m² was sufficient for installation. The system was designed to generate about 7.5 lakh kWh annually using high-efficiency monocrystalline modules and string inverters, with actual first-year generation recorded at 7.48 lakh kWh. The entire solar power generated was consumed within the plant, resulting in annual electricity cost savings of approximately ₹67.5 lakhs through displacement of grid power at an industrial tariff of ₹9/kWh.

The project involved a capital investment of about ₹150 lakhs, including system supply, installation, and commissioning, and achieved a simple payback period of approximately 2.5–3 years. Over the 25-year system life, the project is expected to generate cumulative savings exceeding ₹1,500 lakhs while reducing annual CO₂ emissions by nearly 600 tCO₂ through replacement of coal-based grid electricity. The case demonstrates the strong technical and financial viability of rooftop solar PV for forging units and highlights opportunities for MSMEs to adopt solar energy through RESCO and other financing models with minimal upfront investment.

Table 23: Cost–Benefit Analysis Solar Photovoltaic System

Parameter	Baseline	Post Implementation
Installed Capacity	500 kW	
Annual Generation	7,50,000 kWh/Yr	
Grid Electricity Displaced	7,50,000 kWh/Yr	Reduced to near zero
Electricity Tariff	₹9/kWh	
Annual Financial Savings	₹67.5 Lakhs	
Capital Investment	₹150 Lakhs	
Simple Payback Period	2.5–3 Years	
System Design Life	25 Years	
Annual CO ₂ Emission Reduction	~600 tCO ₂ /Yr	

4. Conclusion and Roadmap

4.1 Summary

The forging industry in Telangana, concentrated across Hyderabad, Ranga Reddy, and Medchal industrial regions, represents a vital component of the state's manufacturing ecosystem, supporting key sectors such as automotive, railways, power equipment, and general engineering. At the same time, the cluster presents a substantial opportunity for improving energy efficiency and advancing cleaner production practices.

Based on cluster-level assessments and national benchmarking data from Bureau of Energy Efficiency and Association of Indian Forging Industry, the sector demonstrates the potential to achieve:

- ❖ **20–25% reduction in electrical energy consumption**

- ❖ **30–35% reduction in thermal energy consumption**

through systematic adoption of proven technologies and operational improvements.

The compendium presents **23 technologies interventions** across four key categories:

- ❖ **Furnace and thermal efficiency improvements**

- ❖ **Utility systems optimisation (motors, compressors, pumps, cooling systems)**

- ❖ **Advanced process technologies (induction heating, recuperative systems)**

- ❖ **Renewable energy integration (solar PV systems)**

These interventions range from **no-cost operational measures** (furnace optimisation, compressed air leak reduction, scheduling improvements) to **medium investment upgrades** (recuperators, VFD systems, IE3/IE4 motors) and **high-impact capital investments** (IGBT-based induction heating, self-recuperative burners, solar rooftop systems).

4.2 Recommended Priority Actions

For MSME forging units in Telangana, the following priority interventions are recommended based on **ease of implementation, financial attractiveness, and energy-saving potential**:

Priority	Technology	Energy Savings	Payback	Investment
1	Furnace temperature optimisation & air-fuel ratio control	5–10% fuel	Immediate	Nil
2	Compressed air leak detection & repair	20–30% compressor energy	<1 month	Low
3	Metallic recuperator	15–25% fuel	<2 months	Low
4	Furnace insulation & door seal repair	Variable	<1 month	Low
5	Energy-efficient pumps with VFD	30–50% pump energy	~9 months	Moderate
6	EC fans for cooling towers	30–50% fan energy	~12–13 months	Moderate
7	IE3/IE4 motor replacement (phased)	5–8% motor energy	2–4 years	Moderate
8	Self-recuperative burners	25–40% fuel	2–4 months	High
9	IGBT-based induction heating	40–50% heating energy	3–6 months	High
10	Solar rooftop PV system	15–30% grid offset	2.5–3 years	High

These measures collectively provide a balanced portfolio of quick wins and long-term investments, enabling MSMEs to progressively reduce operating costs and improve competitiveness.

4.3 Implementation Roadmap

A **phased implementation strategy** is recommended to ensure financial feasibility and smooth operational transition:

Phase 1 (0–6 Months): No / Low Investment Measures

- ❖ Furnace temperature optimisation
- ❖ Combustion air-fuel ratio control
- ❖ Compressed air leak detection and repair
- ❖ Furnace insulation and door seal maintenance
- ❖ Load scheduling and peak demand management
- ❖ LED lighting upgrades
- ❖ Power factor correction
- ❖ Energy monitoring and sub-metering

Outcome: Immediate cost savings with minimal capital investment

Phase 2 (6–18 Months): Medium Investment Measures

- ❖ Metallic recuperator installation
- ❖ Energy-efficient pumps with VFD
- ❖ EC fans for cooling towers
- ❖ IE3/IE4 motor replacement (at failure stage)
- ❖ IoT-based energy monitoring systems
- ❖ Thermo ceramic furnace coating
- ❖ Regenerative drives for EOT cranes

Outcome: Structured reduction in both thermal and electrical energy consumption

Phase 3 (18–36 Months): High Investment Measures

- ❖ IGBT-based induction heating systems
- ❖ Self-recuperative burner installation
- ❖ VFD-based screw compressors
- ❖ Solar rooftop photovoltaic systems

Outcome: Maximum energy savings, decarbonisation, and long-term cost stability

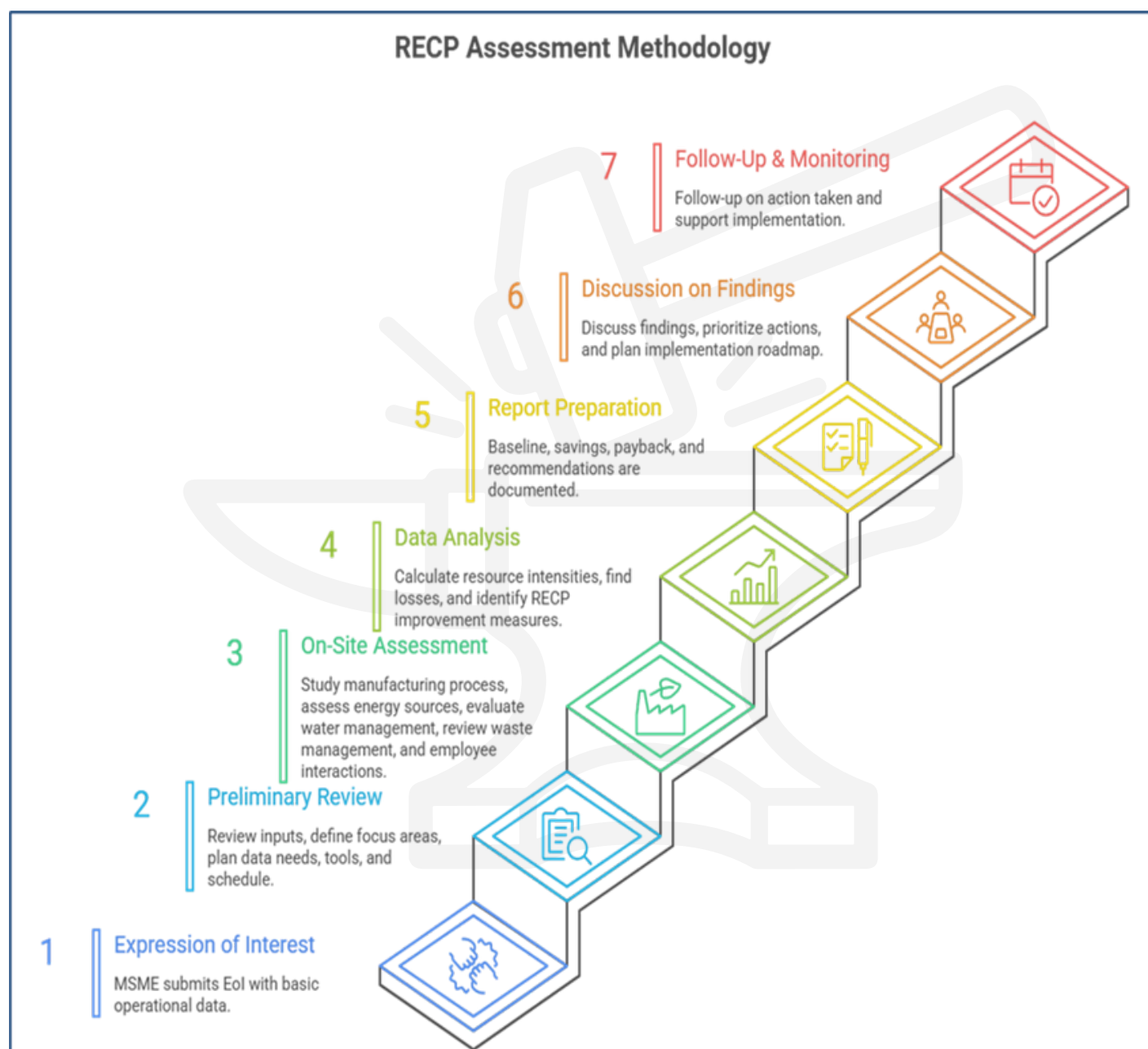
Ongoing Actions

- ❖ Continuous energy monitoring and benchmarking
- ❖ Periodic energy audits and RECP reassessments
- ❖ Integration of digital energy management systems
- ❖ Alignment with national best-practice standards and sustainability targets

4.4 About the RECP Assessment Process

RECP assessment follows a systematic, step by step approach to evaluate how efficiently an MSME utilizes its resources and to identify opportunities for reducing resource use, improving operational efficiency, and minimizing environmental impact. The focus is on reduction of energy, water, raw materials, waste, and emissions and helping units adopt cleaner and more sustainable practices.

The methodology adopted for conducting the assessment is outlined below



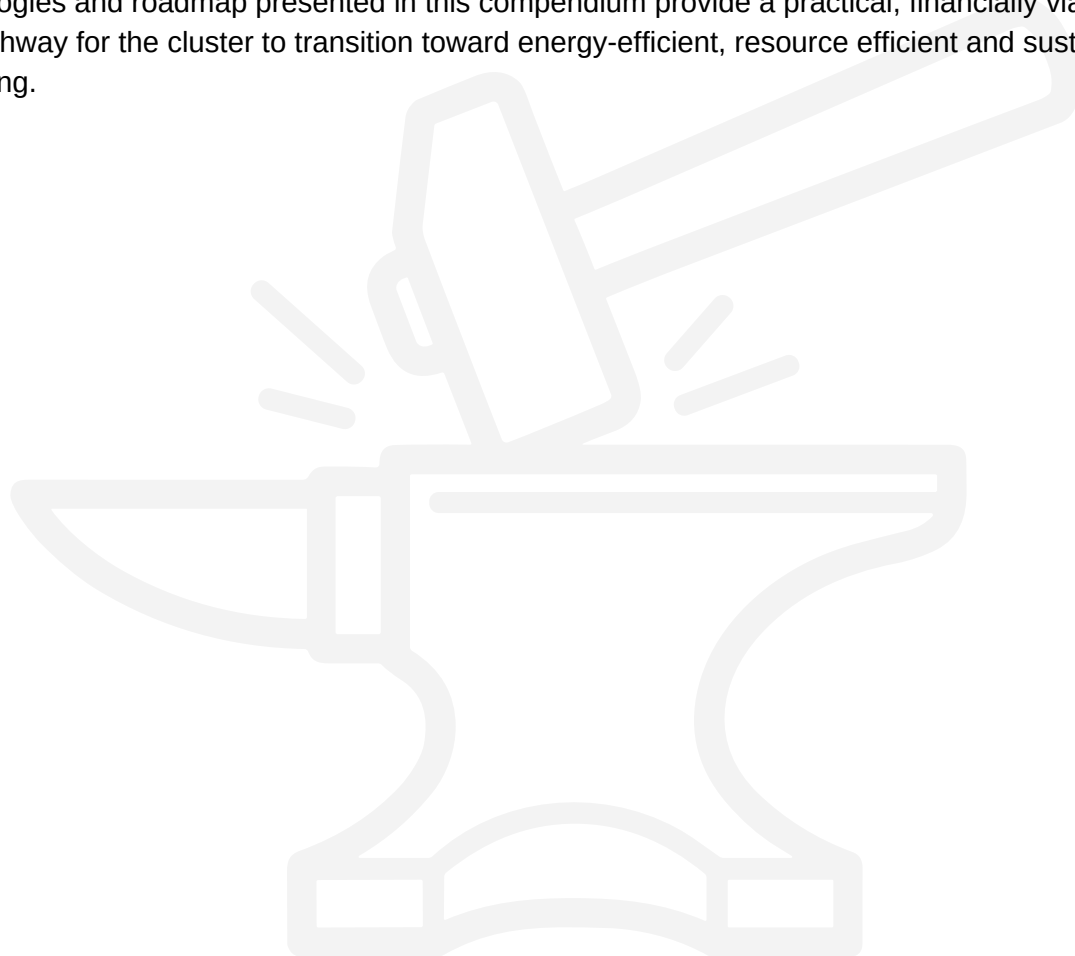
4.5 Final Outlook

The Telangana forging cluster stands at a critical juncture where energy efficiency is no longer optional but a strategic necessity. Rising energy costs, increasing environmental regulations, and evolving customer expectations particularly from automotive and export markets are driving the need for cleaner and more efficient production systems.

By adopting a phased, technology-driven approach, MSME forging units can:

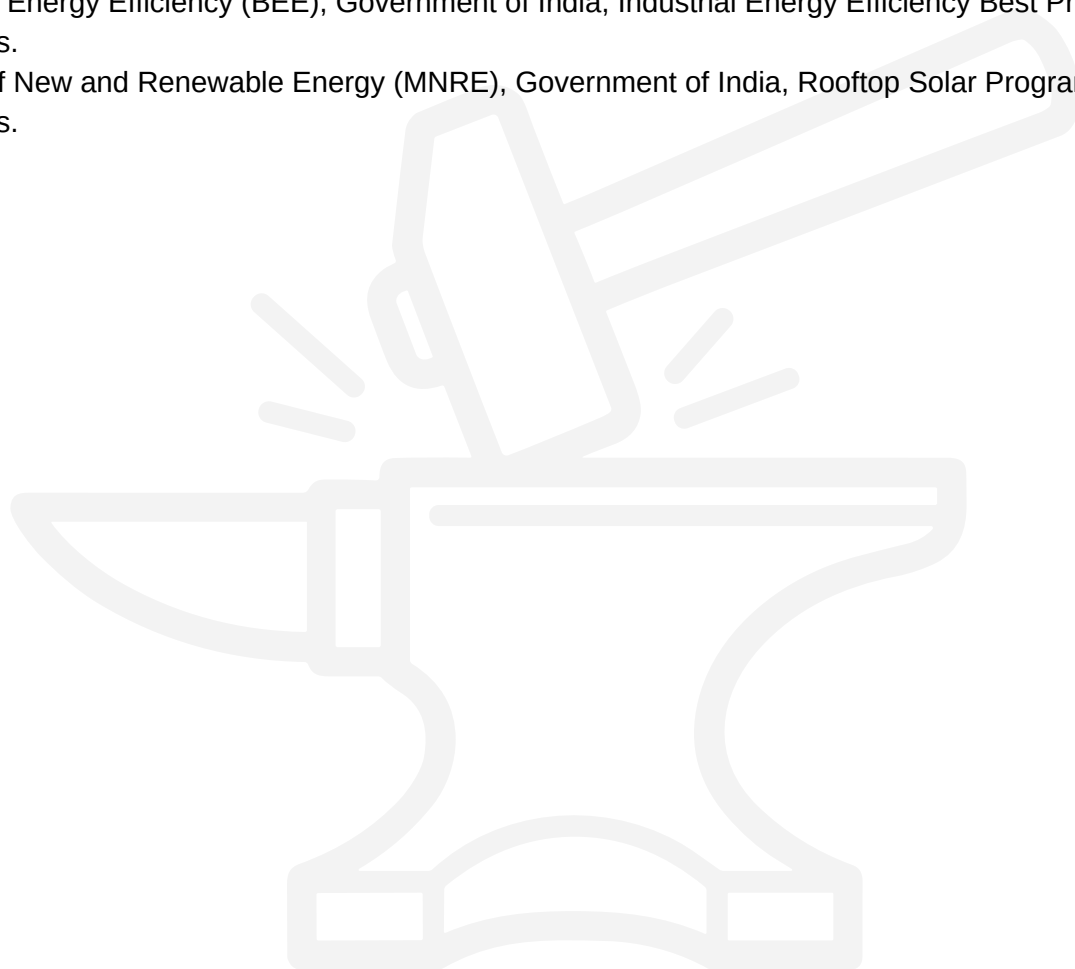
- ❖ Reduce operating costs significantly
- ❖ Improve product quality and process consistency
- ❖ Lower greenhouse gas emissions
- ❖ Strengthening global competitiveness

The technologies and roadmap presented in this compendium provide a practical, financially viable, and scalable pathway for the cluster to transition toward energy-efficient, resource efficient and sustainable manufacturing.



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Greening of MSMEs in Telangana

The Government of Telangana has taken up the “Greening of MSMEs” initiative, under the Raising and Accelerating MSME Performance (RAMP) Programme, with an intent to support MSMEs in adopting sustainable and resource-efficient industrial practices. Research and Innovation Circle of Hyderabad (RICH) is implementing the Greening of MSMEs program in Telangana with technical support and program delivery comprising awareness creation, energy audits, and handholding support being provided by CII. The initiative promotes cleaner technologies, energy and water conservation, waste reduction, and improved operational efficiency through Resource Efficient and Cleaner Production (RECP) assessments, awareness programs, and cluster-level interventions. By facilitating technical guidance and implementation support, the programme helps MSMEs reduce environmental impact, improve productivity, and enhance their competitiveness in both domestic and global markets.

Research and Innovation Circle of Hyderabad (RICH)

RICH was launched in 2017 as a first-of-its-kind initiative by the Government of Telangana. RICH was established to bridge the gap between research and real-world applications by enabling collaboration among research institutions, industry, startups, and government bodies. RICH also serves as Hyderabad's Science and Technology City Cluster, under a national initiative led by the Office of the Principal Scientific Adviser to the Government of India. In this capacity, RICH drives multidisciplinary projects to address complex local and national challenges. Working at the intersection of science, technology, and entrepreneurship, RICH focuses on three critical sectors “Life Sciences”, “Food & Agriculture”, and “Sustainability”. In the Sustainability area, RICH focuses on Clean Energy Transition, Industrial Decarbonization and Circularity through strategic partnerships, pilot initiatives, and policy engagement. RICH fosters a culture of innovation that delivers scalable and transformative solutions for long-term impact.

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