ECO WEAVES

Energy & Resource Efficiency | Effluent Management
Automation & Digitalization

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
May 2026

Confederation of Indian Industry

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), Gujarat Pollution Control Board (Best available techniques-Textile 2024), and the UNIDO RECP manual Textile sector. 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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Abbreviations

Abbreviation	Full Form
AHU	Air Handling Unit
CAGR	Compound Annual Growth Rate
CAD	Computer-Aided Design
CII	Confederation of Indian Industry
COD	Chemical Oxygen Demand
CMC	Carboxymethyl Cellulose
CNC	Computer Numerical Control
COD	Chemical Oxygen Demand
COP	Coefficient of Performance
CPCB	Central Pollution Control Board
CPB	Cold Pad Batch
CV	Calorific Value
DG	Diesel Generator
DLI	Disbursement Linked Indicator
EEM	Energy Efficient Motor
ESP	Electrostatic Precipitator
ETC	Evacuated Tube Collector
ETP	Effluent Treatment Plant
FBC	Fluidised Bed Combustion
FO	Furnace Oil
GDP	Gross Domestic Product
GLM	Grams per Linear Metre
GSM	Grams per Square Metre
HMI	Human Machine Interface

Abbreviation	Full Form
HP	Horsepower
IBEF	India Brand Equity Foundation
IC	International Cooperation (Scheme)
IoT	Internet of Things
KPI	Key Performance Indicator
KRA	Key Result Area
MEE	Multiple Effect Evaporator
MITRA	Mega Integrated Textile Region and Apparel
MLR	Material-to-Liquor Ratio
MRPS	Multi-Rotor Position Sensor
MSME	Micro, Small and Medium Enterprises
MSE-GIFT	Micro & Small Enterprises — Green Investment Financial Technology (Scheme)
MSE-SPICE	Micro & Small Enterprises — Sustainable and Profitable Industry through Circular Economy (Scheme)
MVR	Mechanical Vapour Recompression
NG	Natural Gas
NGT	National Green Tribunal
OE	Open End (Spinning)
PF	Power Factor
PLC	Programmable Logic Controller
PLI	Production Linked Incentive (Scheme)
PM-MITRA	Pradhan Mantri Mega Integrated Textile Region and Apparel
PMEGP	Prime Minister's Employment Generation Programme
PMS	Procurement and Marketing Support (Scheme)
PVA	Polyvinyl Alcohol
RAMP	Raising and Accelerating MSME Performance (Programme)

Abbreviation	Full Form
RECP	Resource Efficient and Cleaner Production
RICH	Research and Innovation Circle of Hyderabad
RMC	Residual Moisture Control
RO	Reverse Osmosis
RTD	Resistance Temperature Detector
SCADA	Supervisory Control and Data Acquisition
SEC	Specific Energy Consumption
SIP	Strategic Investment Plan
SITP	Scheme for Integrated Textile Parks
SOPT	Steam Operated Pumping Trap
STG	Steam Turbine Generator
T-IDEA	Telangana Industrial Development and Entrepreneur Advancement (Scheme)
T-PRIDE	Telangana Programme for Development of Industries for Dalit Entrepreneurs
TDS	Total Dissolved Solids
TFO	Two-for-One Twister
THDi	Total Harmonic Distortion — Current
THDv	Total Harmonic Distortion — Voltage
TIC	Temperature Indicating Controller
TPH	Tonnes per Hour
TTAP	Telangana Textiles and Apparel Policy
TUFS	Technology Upgradation Fund Scheme
VDR	Vertical Drying Range
VFD	Variable Frequency Drive
ZED	Zero Defect Zero Effect
ZLD	Zero Liquid Discharge

Units of Measurements

Unit	Description
°C	Degree Celsius
%	Percentage
% RH	Relative Humidity
cfm	Cubic Feet per Minute
COD	Chemical Oxygen Demand
CO_2e	Carbon Dioxide Equivalent
COP	Coefficient of Performance
den	Denier
GSM	Gram per Square Metre
h	Hour
HP	Horsepower
Hz	Hertz
kg	Kilogram
kg/cm^2	Kilogram per Square Centimetre
kg/h	Kilogram per Hour
kW	Kilowatt
kWh	Kilowatt-hour
kVA	Kilovolt Ampere
kW/TR	Kilowatt per Tonne of Refrigeration
kW/cfm	Kilowatt per Cubic Feet per Minute

Unit	Description
L	Litre
lakh	One Hundred Thousand (Indian numbering)
M^3	Cubic Metre
M^3/h	Cubic Metre per Hour
MT	Metric Tonne
MW	Megawatt
m^2	Square Metre
nos	Number
pcs	Pieces
ppm	Parts per Million
psi	Pounds per Square Inch
rpm	Revolutions per Minute
tex	Tex (Yarn linear density)
TDS	Total Dissolved Solids
TPH	Tonnes per Hour
TR	Tonne of Refrigeration
V	Volt
VFD	Variable Frequency Drive
yr	Year

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 people1.

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.

1 Press Release: Press Information Bureau, July 4, 2025

About the Technology Compendium

This Technology Compendium has been developed under the Greening of MSMEs initiative of the RAMP Programme in Telangana. Its purpose is to:

- Accelerate adoption of energy and resource-efficient technologies in textile MSMEs.
- Serve as a reference guide for MSMEs, consultants, and stakeholders to identify practical solutions for improving energy performance and reducing environmental impact.
- Provide case studies and best practices that can be adapted to specific plant conditions.

The compendium is intended for awareness, learning, and preliminary decision-making. Implementation of suggested measures should follow detailed technical and financial assessments tailored to individual units.

Structure of the Compendium

The compendium is structured to provide MSMEs with a clear roadmap for adopting sustainable practices. It begins with an overview of the textile industry and Telangana's sector profile, followed by detailed descriptions of textile processes and resource consumption patterns. The document then highlights the current technology status and presents case studies showcasing opportunities for Resource efficiency and cleaner production in utilities, process areas, water and effluent management, and renewable energy integration. Finally, it concludes with a summary of key technologies, an implementation roadmap, and information on policy and financing support, along with references for further guidance.

Executive Summary

The textile sector is a key contributor to India's economy, exports, and employment, with MSMEs serving as the backbone of the industry's value chain. However, rising energy costs, water scarcity, stringent environmental regulations, and increasing sustainability expectations from global buyers are creating significant challenges for MSME competitiveness and market access.

This compendium supports textile MSMEs in adopting Resource Efficient and Cleaner Production practices to improve productivity, reduce operating costs, and enhance environmental performance. It highlights opportunities to optimize energy, water, chemicals, and raw material use across spinning, weaving or knitting, wet processing, and garmenting operations.

The technologies presented demonstrate that MSMEs can achieve substantial reductions in energy consumption, water usage, waste generation, and emissions, while improving product quality and process reliability. These improvements directly enhance cost competitiveness, export readiness, and compliance with evolving sustainability requirements.

A range of interventions is covered, including energy efficiency measures, waste heat recovery, renewable energy systems, advanced process technologies, and digital solutions. These technologies offer varying levels of investment, savings, and payback periods, enabling MSMEs to prioritize actions based on feasibility and impact.

The following table summarizes the list of technologies included in the compendium:

Table 1: List of Technologies

S. No	Technologies	Investment (Rs. Lakhs)	Annual Savings (Rs. Lakhs)	Payback (Months)
Electrical				
1	Maximum Demand Controller and optimizing Contract Demand	0.5	0.6	10
2	High-Efficiency Atomisers instead of Nozzles in Humidification Plants	3.5	4.3	10
3	Energy Efficient Pnuemafil Fans in Ring Frames	4	7.8	6
4	Variable Frequency Drive for Water Circulating Pump of Jet Dyeing Machine	1.25	1.5	10
5	Temperature Controller in Processing Machine	0.2 - 0.3	0.2 - 0.3	12
6	Energy Efficient Automatic Spreading cum Cutting Machine	100	80	15

S. No	Technologies	Investment (Rs. Lakhs)	Annual Savings (Rs. Lakhs)	Payback (Months)
7	Servo Winder & Two for One (TFO) Machine	42	16.8	30
8	Micro-turbine	130	65	24
9	Grid-Connected Rooftop Solar PV System	25	6.4	46
Thermal				
10	System for control of excess air in Boiler/Thermic Fluid Heater	4	9.5	5
11	Residual Moisture control in Drying Cylinders	2 - 2.5	1 - 1.25	24 - 30
12	Heat Pump System for Hot Water Generation in Textile Wet Processing	8.5	6.22	16
13	Waste heat recovery system in stenters	13.5	7.5	22
14	Waste heat recovery through economizer in thermic fluid heater/boiler	1.7	0.95	21
15	Condensate recovery pump in jet dyeing machine	4	4.5	11
Process				
16	IoT-Based Water Management System for Textile Processing Units	1.7	1.12	8
17	Airflow Jet Dyeing Machine	2000 - 3000	2500 - 3500	12 - 15
18	Auto/Rapier Loom	50 - 52	25 - 30	24 - 30
19	Gas Fired Stenters	35 - 40	38 - 40	10-12
20	Waterless dyeing technology	2000 - 3000	2500 - 3500	12-15

The summarized technologies indicate that a wide spectrum of opportunities exists, ranging from low-cost operational improvements with short payback periods to advanced process technologies offering significant improvements in productivity, quality, and sustainability.

The compendium also emphasizes the importance of transitioning toward low carbon and resource efficient manufacturing through renewable energy integration, process optimization, and adoption of advanced technologies. A phased implementation roadmap is provided to guide MSMEs from immediate efficiency improvements to long term modernization and decarbonization.

1. Textile Sector Overview

1.1 Indian Textile Sector:

India's textile sector is one of the country's oldest and most diverse industries, with origins dating back several centuries. It spans a wide spectrum, ranging from traditional hand-spun and handwoven craft clusters to large-scale, technologically advanced mill operations. The industry derives its strength from a broad raw material base, including cotton, jute, silk, and wool, along with a growing range of man-made fibres such as polyester, viscose, and acrylic.

According to the latest available data from the Annual Survey of Industries (ASI) for FY 2023–24, a total of 23,835 textile factories are operating in India. The state-wise distribution of these factories reflects regional concentrations and varying levels of industrial development within the textile sector. This distribution is illustrated in the figure below. It is important to note that ASI data covers only registered factories within the organized manufacturing sector and does not include all MSMEs and informal textile enterprises operating across the country.

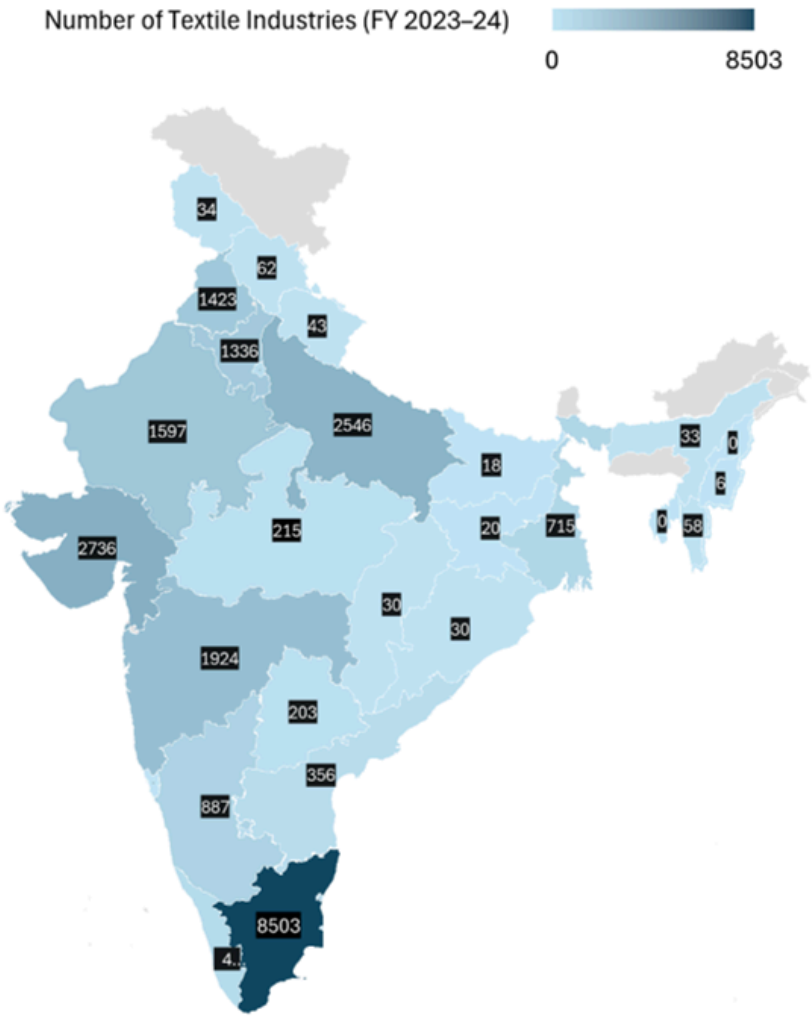


Figure 1: State-wise Distribution of textile industries[2]

[2]Press Release Page | Press Information Bureau

1.1.1. Sector Economic Contribution

The textile and apparel sector contributes 2.3% to India's GDP, accounts for 13% of the country's industrial output, and constitutes 12% of total exports. The industry is also the second-largest source of employment in the country after agriculture, providing direct employment to over 45 million people, including a significant share of women and rural workers. Notably, nearly 80% of the sector's production capacity is concentrated within MSME clusters[3].

In 2023–24, India's textile exports reached USD 34.4 billion. Apparel accounted for the largest share at 42%, followed by raw and semi-finished materials at 34%, and finished non-apparel products at 30%.

1.1.2. Growth targets

The overall market size, currently estimated at USD 174 billion, is projected to reach USD 350 billion by 2030, reflecting the sector's strong growth trajectory and increasing global competitiveness. The industry is closely aligned with several national priorities, including Make in India, Skill India, women's empowerment, rural youth employment, and the broader objective of inclusive growth.

Table 2: Growth Targets

Segment	Current	Target	Growth Rate
Textiles & Apparel market	$174B (current)	**$350B by 2030**	10% CAGR
Total exports	$34.4B (FY24)	**$100B by FY30**	~17% CAGR required
Technical textiles	$10B (est.)	**$23.3B by 2027**	High growth sub-sector
Cotton production	~6M tonnes	**7.2M tonnes by 2030**	Agricultural expansion

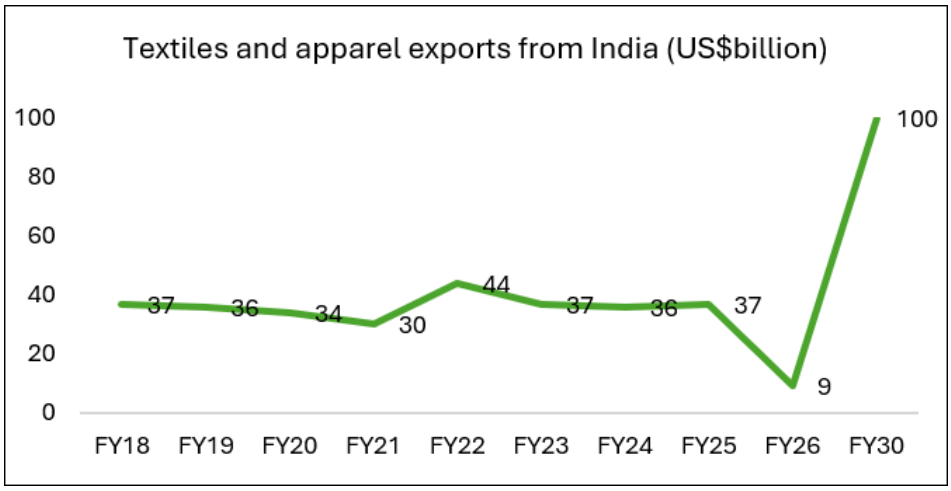


Figure 2: Textile and apparel exports from India[4]

Note: The partial figure shown for FY26* represents exports recorded up to June 2025, not a full-year total.

[3] doc202541530401.pdf

[4] Textile Industry in India, Leading Yarn Manufacturers in India - IBEF

1.1.3. Key Government Interventions

- **Scheme for Integrated Textile Parks (SITP)** — Promotes the development of world-class infrastructure for textile manufacturing units.
- **Technology Upgradation Fund Scheme (TUFS)** — Provides subsidized credit to facilitate technological upgradation across the textile value chain.
- **Mega Integrated Textile Region and Apparel (MITRA) Parks** — Envisions the establishment of seven greenfield parks with plug-and-play infrastructure to attract large-scale investments.
- **Production Linked Incentive (PLI) Scheme for Textiles** — Incentivizes the production of MMF fabrics and technical textiles.

1.2 Telangana Textile Sector:

Telangana's textile ecosystem combines a strong raw material base with rich artisanal capabilities. The state is among India's leading cotton producers, with an annual output of approximately 5 million bales (accounting for about 15% of the country's production). It also supports an installed spinning capacity of nearly 1 million spindles, enabling seamless fibre to yarn integration for both power loom and handloom clusters[5]

Table 3: Telangana - Textile Infrastructure

Infrastructure / Resource	Scale / Status	Significance
Cotton production	5 million bales/year	Among India's leading cotton-producing states
Spinning capacity	1 million spindles	Enables fibre-to-yarn continuity
Power looms	50,000 units	Supports industrial weaving segment
Handlooms	17,000 units	Preserves heritage craft traditions
PM MITRA Park	Warangal (1 of 7 nationa	Vertically integrated textiles value chain
Kakatiya Mega Textile Park	Warangal	Planned for spinning, weaving, processing & garme

1.2.1. Enterprise Landscape:

According to UDYAM registration data for FY 2022–23, Telangana had a total of 19,521 textile enterprises. These enterprises span a range of activities, including spinning, weaving, finishing, and the manufacture of various textile products.

[5]Textiles – Invest Telangana

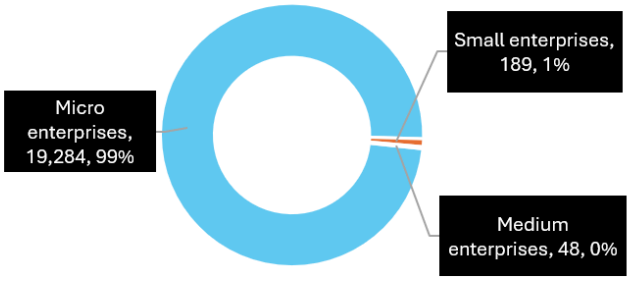


Figure 3: Telangana - Share of MSME Enterprise type

1.2.3. District-wise Distribution:

Hyderabad leads the state with 2,456 enterprises, followed by Yadadri Bhuvanagiri (1,822), Ranga Reddy (1,676), and Medchal–Malkajgiri (1,632). Collectively, these four districts account for over 38% of the total textile enterprises in the state. A detailed district-wise distribution is presented below.

Table 4: Telangana - District-wise Industrial Enterprise Count

District	Enterprises	District	Enterprises
Hyderabad	2456	Sangareddy	285
Yadadri Bhuvanagiri	1822	Peddapalli	263
Ranga Reddi	1676	Siddipet	251
Medchal Malkajgiri	1632	Mahabubnagar	249
Nizamabad	1209	Vikarabad	246
Rajanna Sircilla	1173	Medak	231
Karimnagar	1099	Khammam	224
Nalgonda	986	Suryapet	192
Mancherial	891	Bhadradri Kothagudem	159
Nirmal	734	Narayanpet	112
Jogulamba Gadwal	615	Mahabubabad	106
Hanumakonda	536	Komaram Bheem Asifabac	67
Jangoan	517	Jayashankar Bhupalapally	54
Warangal	497	Nagarkurnool	47
Kamareddy	422	Wanaparthy	38
Jagitial	384	Mulugu	18
Adilabad	330		

1.2.3. Heritage Textile Clusters

District clusters such as Pochampally, Gadwal, Narayanpet, and Warangal serve as key hubs for heritage textiles, supporting value-added fabric and apparel production. These clusters play a significant role in preserving cultural traditions while also contributing to export earnings.

Table 5: Telangana - Heritage Textile Sectors[5]

Cluster / Product	District	Specialty
Pochampally	Nalgonda / Yadadri	Ikat weaving — geometric patterns, silk & cotton
Gadwal	Jogulamba Gadwal	Gadwal sarees — silk borders on cotton body
Narayanpet	Narayanpet	Narayanpet sarees — distinctive check patterns
Warangal	Warangal / Hanumakonda	Durries, carpets, wool weaving
Karimnagar	Karimnagar	Silver filigree, carpet weaving

1.2.4. Policy Framework: T-TAP

Policy incentives under the Textile and Apparel Policy (T-TAP) are designed to attract private investment, reduce logistics costs, and enhance export potential while generating employment across both traditional and modern segments of the sector. Alongside the PM MITRA Park at Warangal and the Kakatiya Mega Textile Park, these initiatives position Telangana as a strategic destination for integrated textile investments[6].

[6]PM Mitra | Ministry of Textiles

2. Textile Manufacturing Process:

The textile manufacturing process comprises a series of interconnected stages that transform raw fibres into finished textile and apparel products. It begins with fibre preparation, followed by yarn production, fabric formation, and subsequent processing to enhance both appearance and performance. Each stage plays a critical role in determining the quality and value of the final product.

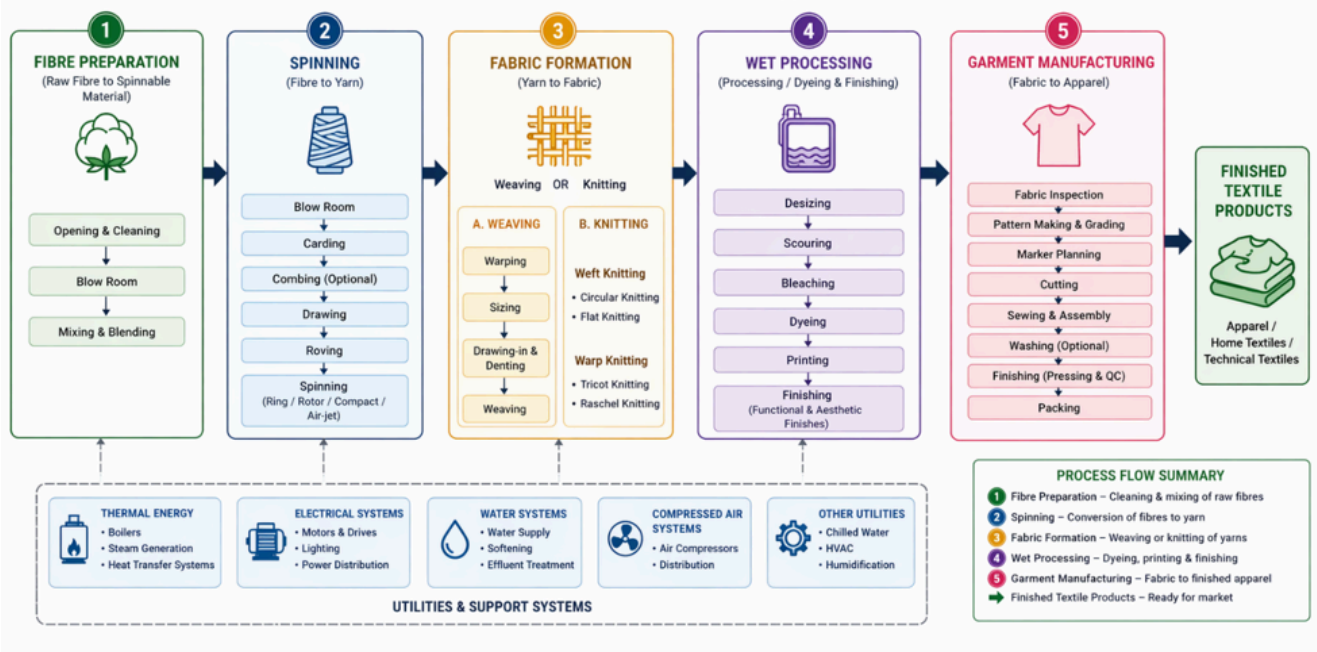


Figure 4: Textile Manufacturing Process

The textile manufacturing process begins with the conversion of fibres into yarn through spinning. Cotton fibre serves as the primary raw material for this stage and is sourced from cotton ginning mills.

2.1 Spinning

Spinning is the process of transforming loose, short, and discontinuous fibres into a continuous and strong yarn suitable for subsequent fabric formation.

Objective:

- To convert fibres into a consistent, strong, and uniform yarn
- To align and parallelise fibres
- To introduce the required level of twist
- To remove impurities and short fibres

Detailed Spinning Stages

1. Blow Room

- Fibres are opened, cleaned, and thoroughly mixed
- Dust, trash, and other impurities are removed using air currents and mechanical beaters
- Uniform blending ensures consistent yarn quality

2. Carding

- Commonly referred to as the “heart of the spinning process”
- Converts a tangled mass of fibres into a thin web, which is then formed into card sliver
- Removes neps, short fibres, and residual impurities
- Aligns fibres into a partially parallel arrangement

3. Combing (Optional – for premium yarn)

- Applied in the production of high-quality yarns
- Eliminates very short fibres (less than 12 mm in length)
- Produces smoother, finer, and stronger yarn with fewer imperfections
- Essential for high-end applications such as shirting, hosiery, and export-quality yarns

4. Drawing

- Multiple slivers combined to improve blending and reduce irregularity.
- Fibres are further parallelised.
- Results in a highly uniform sliver.

5. Roving

- Converts sliver into a finer strand with slight twist
- Prepares the material for the final spinning process

6. Spinning (Final Yarn Formation)

- **Ring Spinning:** Produces high-quality, versatile yarn using the traditional method
- **Rotor/Open-end Spinning:** Offers higher productivity, generally used for coarser yarns
- **Compact Spinning:** Produces premium-quality yarn with reduced hairiness
- **Air-jet Spinning:** Produces cleaner yarn with lower twist levels

Block Diagram:

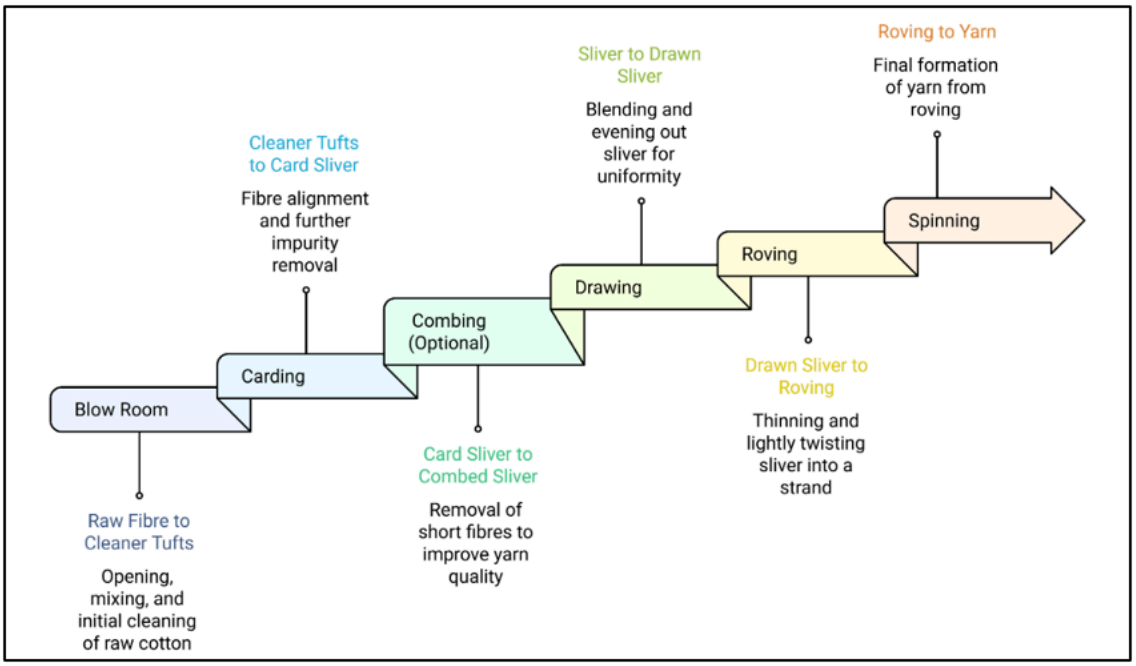


Figure 5: Spinning Process

2.1 Fabric Formation: Weaving & Knitting (Yarn → Fabric)

Fabric formation is the stage in textile manufacturing in which yarn is converted into planar textile structures. This transformation is primarily achieved through two distinct methods, namely weaving and knitting, each producing fabrics with specific structural characteristics and performance properties.

A. Weaving – Interlacing of Warp & Weft

Weaving involves the interlacement of two sets of yarns: warp (longitudinal) and weft (transverse). Prior to weaving, warp yarns undergo several preparatory operations to ensure efficient loom performance and consistent fabric quality.

Warping

- Conversion of yarn packages or cones into warp beams
- Ensures uniform yarn count, required length, and consistent tension across all warp ends
- Facilitates smooth and continuous yarn delivery during weaving

Sizing

- It involves the application of a protective adhesive coating (such as starch, PVA, or CMC) to warp yarns
- Enhances yarn strength and abrasion resistance
- Reduces yarn breakage and improves weaving efficiency

Drawing-in and Denting

- Threading of warp yarns through heddle (heald) eyes and reed dents
- Determines fabric width, weave structure, and design configuration
- Ensures proper alignment and spacing of warp yarns

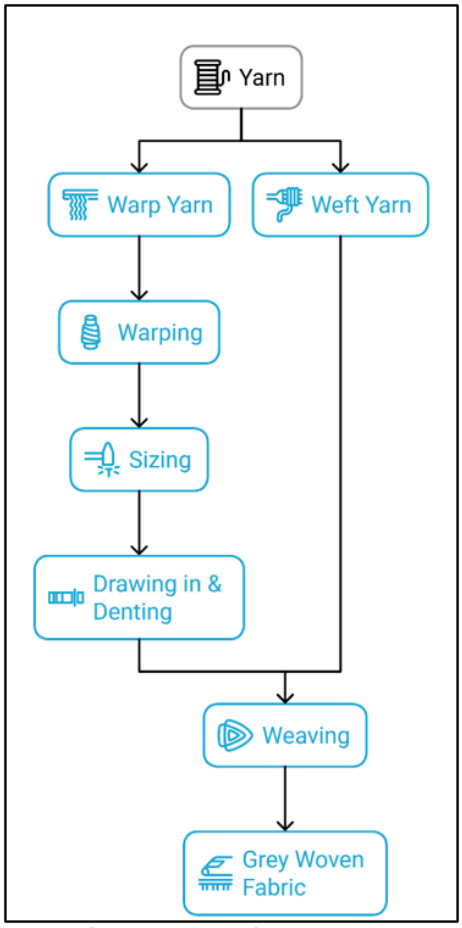


Figure 6: Weaving Process

B. Knitting – Fabric Formation by Looping of Yarns

Knitting is a fabric formation process in which yarns are converted into fabric through inter-looping, rather than interlacement. As a result of this structure, knitted fabrics typically exhibit higher elasticity, improved softness, and better drape compared to woven fabrics

Types of Knitting

1. Weft Knitting

- In weft knitting, a single yarn is fed horizontally and formed into loops across the width of the fabric
- This method is widely used due to its flexibility and versatility
- Common machine types and applications include:
    - o Circular knitting: Used for products such as T-shirts, sportswear, and leggings
    - o Flat knitting: Used for sweaters, collars, cuffs, and trims

2. Warp Knitting

- In warp knitting, multiple yarns are fed simultaneously in the lengthwise direction
- The resulting fabrics exhibit greater dimensional stability and are less prone to deformation compared to weft-knitted fabrics
- Common machine types and applications include:
    - o **Tricot knitting**: Used for lingerie, activewear, and sportswear
    - o **Raschel knitting**: Used for nets, laces, curtains, and technical textile applications

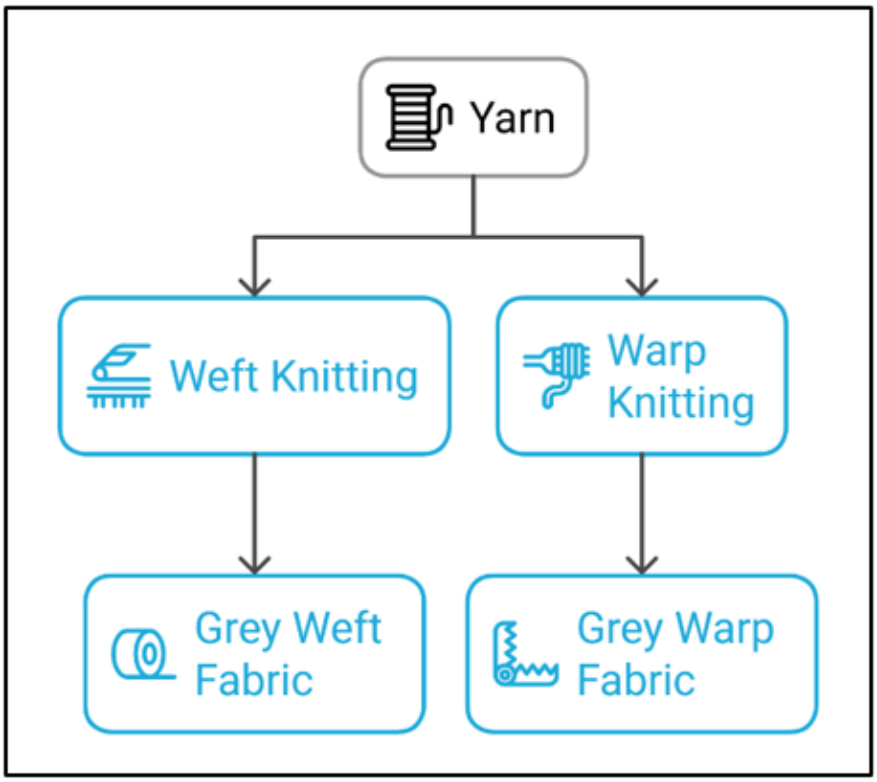


Figure 7: Knitting Process

2.3 Wet Processing (Textile Processing / Dyeing & Finishing)

This stage of textile manufacturing enhances the aesthetic appeal, functional properties, and overall performance of the fabric. It transforms grey fabric into a market-ready, value-added textile suitable for apparel, home textiles, and technical applications.

Major Processing Steps:

1. Desizing

- Removal of sizing agents applied to warp yarns during the weaving stage
- Restores fabric softness and improves absorbency, enabling effective subsequent wet processing

2. Scouring

- Eliminates natural impurities such as waxes, oils, fats, and residual contaminants
- Renders the fabric clean and hydrophilic, ensuring uniform dye uptake

3. Bleaching

- Enhances fabric whiteness and brightness by removing natural colouring matter
- Prepares the substrate for uniform dyeing or high-quality printing

4. Dyeing

- Imparts uniform and durable color to the fabric.
- Common dyeing methods include:
    - Jet dyeing
    - Jigger dyeing
    - Soft-flow dyeing
    - Continuous dyeing ranges

5. Printing

- Applies decorative designs and patterns to the fabric surface.
- Widely used printing techniques include:
    - Rotary screen printing
    - Flatbed screen printing
    - Digital textile printing

6. Finishing

Finishing is the final and most critical stage of wet processing, in which the fabric is treated using a combination of mechanical and chemical processes to achieve the desired functional performance, appearance, handle, and dimensional stability, based on end-use requirements. These treatments have a significant influence on the comfort, durability, safety, and overall market value of the textile product.

Block Diagram – Wet Processing

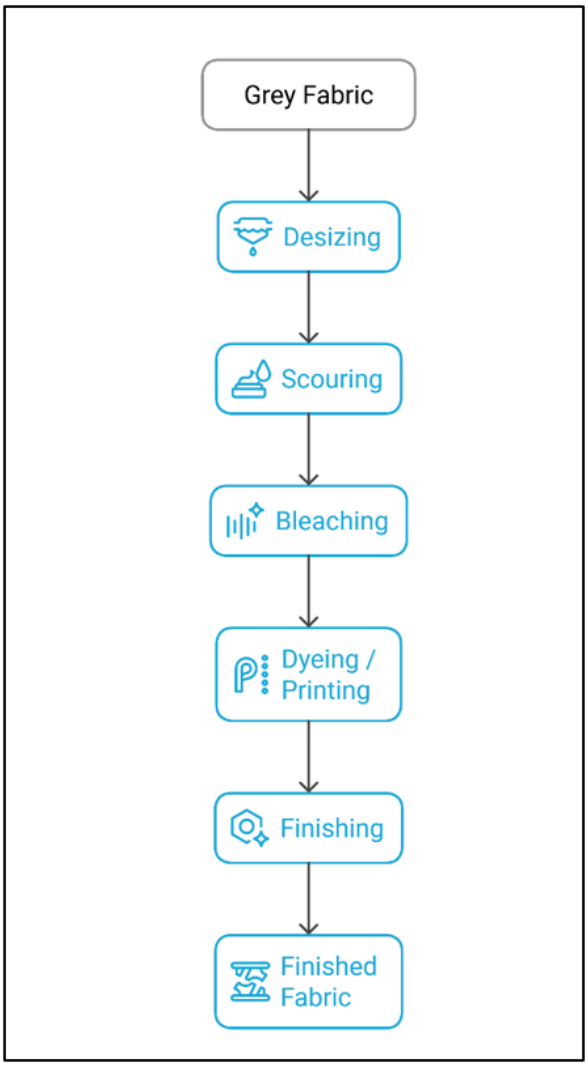


Figure 8: Wet Processing

2.4 Garment Manufacturing (Fabric → Apparel)

Garment manufacturing involves the conversion of finished fabric into ready-to-wear apparel and represents one of the most labour-intensive and value-adding stages of the textile value chain. It plays a critical role in the fashion, retail, and export sectors by influencing garment quality, fit, appearance, and overall market competitiveness.

Major Processing Steps:

1. Fabric Inspection

Finished fabric is carefully inspected to evaluate parameters such as grams per square meter (GSM), colour consistency, surface defects, shrinkage behaviour, and overall fabric uniformity. This process ensures that only approved-quality fabric is released for production, thereby reducing defects in finished garments and minimizing production losses.

2. Pattern Making and Grading

Patterns are developed based on garment design specifications and standardized measurement requirements. The base pattern is subsequently graded into multiple sizes to ensure proper fit, dimensional consistency, and uniformity across the entire size range.

3. Marker Planning

Marker planning involves the efficient arrangement of pattern pieces on the fabric spread to maximize material utilization and minimize wastage. Computer-aided design (CAD) systems are commonly employed to optimize marker layouts, thereby enhancing efficiency and reducing overall production costs.

4. Cutting

Fabric is spread in multiple layers and cut into garment components using methods such as manual cutting, straight-knife machines, die-cutting equipment, or computer numerical control (CNC) cutting systems. Precise cutting is critical to maintaining garment dimensions, ensuring proper fit, and achieving accuracy during subsequent assembly.

5. Sewing and Assembly

The cut components are stitched together using specialized sewing machines to produce complete garments. This stage represents the core manufacturing operation and requires skilled labour to ensure seam quality, strength, appearance, and production efficiency.

6. Washing (Optional)

Depending on fashion and design requirements, garments may undergo processes such as enzyme washing, stone washing, or distressing to achieve the desired texture, softness, and aesthetic appearance.

7. Finishing

Finishing operations include thread trimming, pressing, and final quality inspection. This stage ensures that garments meet the required standards of appearance, performance, and compliance prior to packaging.

8. Packing

Garments are systematically folded, tagged, labelled, and packaged for domestic retail or export distribution in accordance with buyer specifications and compliance requirements.

Block Diagram – Garmenting

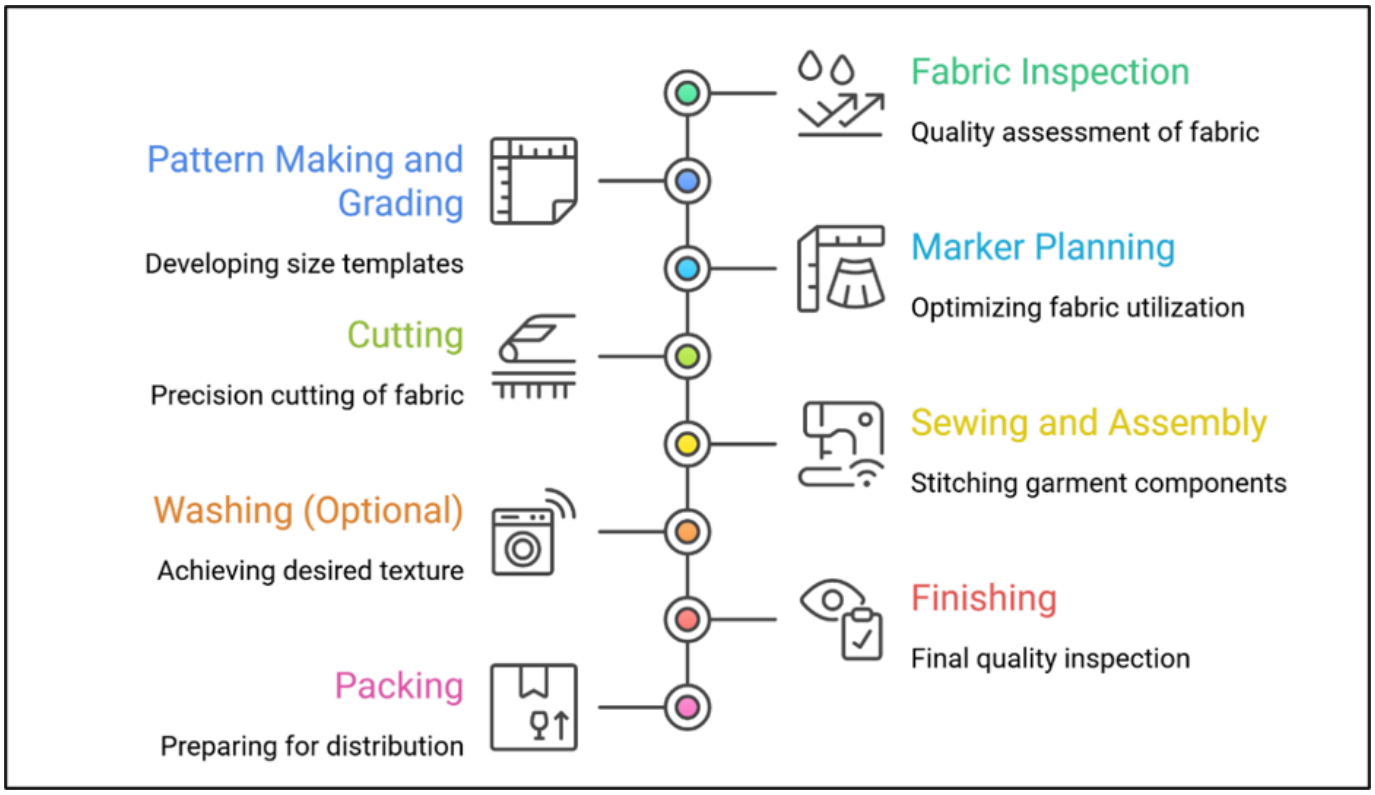


Figure 9: Garment Manufacturing Process

3. Energy Consumption Profile

3.1. Energy Consumption

The overall energy consumption in the textile sector is typically dominated by thermal energy, while electrical energy constitutes a comparatively smaller share. On average, thermal energy accounts for approximately 55-60% of the total energy consumption,primarily due to its extensive use in steam and heat-intensive processes such as scouring, bleaching, dyeing, drying, and finishing.

Electrical energy contributes around 40-45% of the total consumption and is mainly utilized to power machinery involved in spinning, weaving, and knitting, as well as various utility systems including compressors, pumps, and humidification units.

The section-wise distribution of energy consumption is illustrated in the figure below.

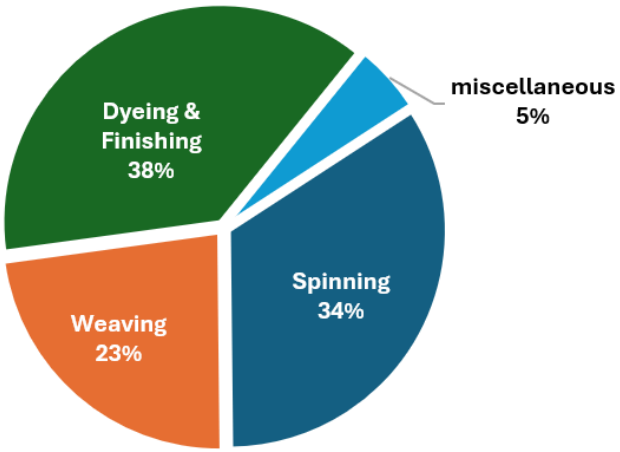


Figure 10: Section-wise energy consumption

The table below presents a section-wise overview of typical equipment used in textile manufacturing, along with their corresponding energy requirements.

Table 6: Spinning – Equipment details

Section	Equipment Category	Equipment Name	Process Requirement	Energy
Spinning	Fiber opening	Blow Room Line	Opening, cleaning, mixing fibers	Electricity
	Fiber alignment	Carding Machine	Sliver formation, impurity removal	Electricity
	Fiber refinement	Comber	Removal of short fibers, quality improvement	Electricity
	Sliver processing	Drawing Frame	Blending & parallelization	Electricity
	Intermediate stage	Roving Frame (Simplex)	Sliver to roving conversion	Electricity
	Yarn formation	Ring Frame / Rotor / Air jet	Final yarn production	Electricity
	Post-processing	Winding Machine	Yarn winding & packaging	Electricity
	Utilities	Humidification Plant	Maintain RH	Electricity

Table 7: Weaving – Equipment details

Section	Equipment Category	Equipment Name	Process Requirement	Energy
Weaving	Yarn preparation	Warping Machine	Warp beam preparation	Electricity
	Yarn treatment	Sizing Machine	Strengthening warp yarn	Steam + Electricity
	Looming	Shuttle / Airjet / Rapier Loom	Fabric formation (interlacing)	Electricity
	Utilities	Air Compressor	Compressed air for looms	Compressed air, Electricity

Table 8: Knitting - Equipment details

Section	Equipment Category	Equipment Name	Process Requirement	Energy
Knitting	Fabric formation	Circular Knitting Machine	Loop formation	Electricity
		Flat Knitting Machine	Garment panels knitting	Electricity
		Warp Knitting Machine	Stable fabric formation	Electricity

Table 9: Wet Processing - Equipment details

Section	Equipment Category	Equipment Name	Process Requirement	Energy
Wet Processing	Pre-treatment	Desizing Unit	Remove sizing chemicals	Steam + Electricity
		Scouring Machine	Remove impurities (oils, waxes)	Steam + Electricity
		Bleaching Unit	Increase whiteness	Steam + Electricity
	Dyeing	Jet / Jigger Dyeing Machine	Fabric dyeing	Steam + Electricity
	Printing	Printing Machine (Rotary/Digital)	Apply designs	Electricity
	Washing	Washing Range	Remove excess chemicals	Steam + Electricity
	Drying	Dryers	Moisture removal	Steam / Gas
	Finishing	Stenter Machine	Drying, heat setting	Gas / Thermic oil
		Calendaring Machine	Surface finishing	Electricity
		Padding Mangle	Chemical finishing	Electricity
	Utilities	Boiler	Steam generation	Coal / Gas / Biomass
		Thermic Fluid Heater	Heat generation	Coal / Gas / FO
		Effluent Treatment Plant	Wastewater treatment	Electricity

Table 10: Garmenting - Equipment details

Section	Equipment Category	Equipment Name	Process Requirement	Energy
Garmenting	Inspection	Fabric Inspection Machine	Quality checking	Electricity
	Design	CAD System	Pattern making & grading	Electricity
	Cutting	Cutting Machine (Manual/CNC)	Fabric cutting	Electricity
	Sewing	Sewing Machines	Stitching & assembly	Electricity
	Washing	Washing Machine	Garment washing	Electricity + Water
	Finishing	Steam Iron / Pressing Machine	Wrinkle removal	Electricity / Steam
		Thread Trimming Tools	Final finishing	Electricity
	Packing	Packing Line	Folding & packing	Electricity

4. Cleaner production, Energy, Water and Waste Management

The textile sector is one of the most resource intensive industries. Across its value chain, including fibre preparation, spinning, wet processing, and garmenting. It consumes substantial quantities of energy, water, and chemicals, while also generating significant amounts of solid waste, effluent, and air emissions.

As discussed in Chapter 3, the distribution of resource consumption and environmental impact varies considerably across different manufacturing stages. Wet processing, which includes scouring, bleaching, dyeing, printing, washing, and finishing, represents the most resource intensive segment of textile production. It accounts for the highest share of thermal energy consumption, freshwater usage, and pollutant generation.

In contrast, spinning and weaving are the primary consumers of electrical energy, whereas garment manufacturing, although comparatively less intensive in terms of energy and water use, contributes significantly to fabric cutting waste.

Cleaner Production (CP) is a preventive and integrated environmental strategy that focuses on minimizing waste and emissions at the source, rather than relying solely on end of pipe treatment solutions. In the context of the Indian textile sector, particularly among MSMEs which often operate with ageing machinery, labour intensive processes, and limited environmental management systems, Cleaner Production offers a practical and cost-effective pathway to improve operational efficiency, reduce production costs, enhance product quality, and ensure compliance with increasingly stringent environmental regulations.

4.1. Energy Consumption

Textile manufacturing is highly energy intensive, with thermal energy primarily required for wet processing operations and electrical energy consumed in spinning, weaving, and various utility systems. Inefficiencies such as poorly performing boilers, steam distribution losses, outdated motors, compressed air leakages, and inadequate heat recovery practices contribute to increased energy consumption and higher operating costs.
In addition, a high dependence on fossil fuels leads to elevated greenhouse gas emissions and air pollution. As a result, improving energy efficiency is a critical priority within Cleaner Production initiatives in the textile sector.

4.2. Water Management

Water consumption in textile wet processing is substantial and varies with fabric type, dyeing technology, process recipes, equipment, and chemicals used. Longer processing sequences further increase water demand, with a significant share consumed during washing operations at each stage.

Water pollution can be reduced through the optimization of dyeing and washing formulations, minimization of auxiliary chemicals, and substitution of hazardous substances with environmentally safer alternatives. The Indian textile industry typically consumes approximately 200 to 250 m^3 of water per ton of cotton cloth, which is significantly higher than the global average of less than 100 m^3 per ton[7].

Key sources of water waste:

- High liquor ratios in conventional jet and jigger dyeing machines, resulting in excessive water consumption per unit weight of fabric
- Excessive washing between process stages due to the absence of optimized wash sequences and effective process control
- Inefficient rinsing practices arising from inadequate design of countercurrent washing systems
- Loss of steam condensate due to discharge instead of recovery and reuse in the boiler system
- Unregulated freshwater supply to wet processing equipment in the absence of metering and automatic control mechanisms
- Leakages in steam, water, and compressed air distribution networks
- Discharge of cooling water from singeing machines and compressors, despite its potential for direct reuse

4.3. Effluent Treatment and Chemical Management

Textile effluent in India typically contains high concentrations of colour, dissolved salts, chemical oxygen demand, and surfactants, particularly from reactive dyeing operations. Inadequate treatment of such effluents can lead to serious degradation of water quality and adverse environmental impacts. To address these concerns, regulatory bodies such as the Central Pollution Control Board and the National Green Tribunal mandate the implementation of Zero Liquid Discharge systems in water stressed and pollution sensitive regions.

In addition to liquid effluents, the textile industry generates various forms of solid waste, including fibre waste, fabric cutting waste, effluent treatment plant sludge, and boiler ash. Among these, effluent treatment plant sludge is classified as hazardous waste and must be handled and disposed of through authorized channels in accordance with applicable regulations. Wet processing operations are highly chemical intensive due to the extensive use of dyes, salts, surfactants, and auxiliary chemicals. This not only increases operational costs but also adds to the complexity and load on effluent treatment systems.

[7]Understanding and addressing the water footprint in the t...

5. Resource efficiency and cleaner production Measures

5.1. Electrical:

Maximum Demand Controller and optimizing Contract Demand

Background & Problem:

Maximum demand charges form a significant component of industrial electricity bills. These charges are based on the highest demand recorded during any consecutive 30 minutes interval within a billing cycle. Peak demand typically occurs during plant start up or when multiple high load equipment operate simultaneously.

In most DISCOM tariff structures, maximum demand charges are applied on the higher of the actual recorded demand or 75 to 80 percent of the contracted demand. In textile industries, exceeding the contracted demand leads to penalty charges. Conversely, when actual demand remains consistently below this threshold, industries still incur higher charges based on the minimum billing criteria. This results in avoidable increases in electricity costs.

Technology Intervention – Maximum Demand Controller:

A maximum demand controller is an energy management device used to monitor and control peak power consumption within a predefined limit

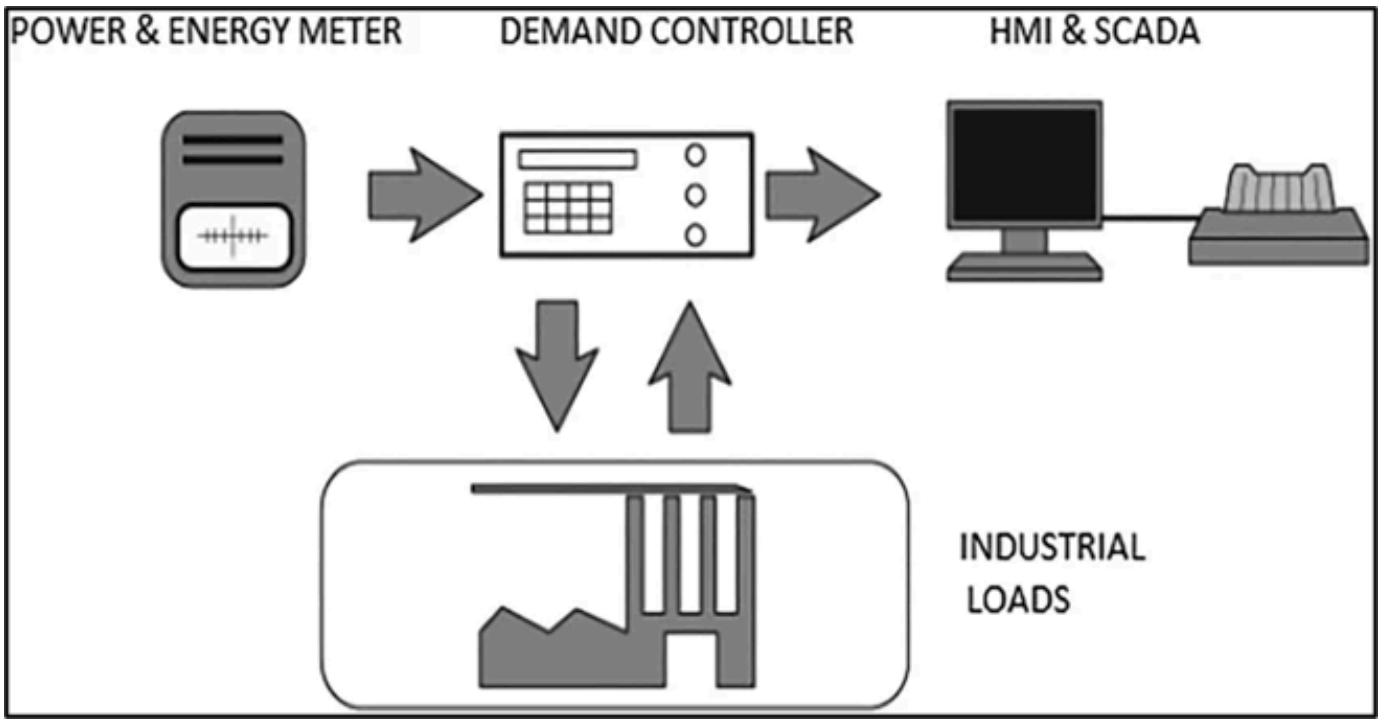


Figure 11: Demand Controller – Working Principle[8]

[8]Power demand control algorithm for single controllable load with parametric and variable load factors | Request PDF



Figure 12: Demand Controller[9]

Working Principle:

- The controller continuously receives real time energy consumption data from the main energy meter at the incoming power supply point.
- It calculates the ongoing demand and estimates the likely maximum demand at the end of the demand interval based on the consumption rate.
- The predicted demand is compared with the preset demand limit agreed with the utility.
- If the predicted demand exceeds the limit, the controller initiates corrective action by temporarily disconnecting non critical loads according to a predefined priority sequence.
- These actions are executed through relays or contactors. System status, demand levels, and alarms are displayed on the human machine interface and supervisory control system for monitoring.
- Once demand reduces below the set limit, the controller restores the disconnected loads automatically.

Cost-Benefit Analysis:

Estimated Investment: 0.5 lakhs

Estimated Annual Savings: 0.6 Lakhs

Payback: 10 months

Benefits:

- ✓ Reduces electricity cost by controlling maximum demand charges
- ✓ Avoids penalties due to excess demand
- ✓ Improves load management through prioritization of critical equipment
- ✓ Enhances overall electrical system efficiency and reliability

[9]Indus Electronics India (P) Ltd

High-Efficiency Atomisers instead of Nozzles in Humidification Plants

Background & Problem:

Humidification is a critical utility in textile plants. It maintains yarn quality by controlling relative humidity, typically in the range of 50 to 75 percent depending on the process. Humidification is required across spinning, weaving, and processing operations.

Conventional systems use multiple small spray nozzles. These systems face several operational challenges:

- High friction losses due to small orifice diameters
- Requirement of high-water flow rates and pumping pressure
- Uneven mist distribution affecting humidity control
- Frequent nozzle clogging, resulting in maintenance downtime
- Excessive energy and water consumption

Technology Intervention: High-Efficiency Atomisers

High efficiency atomisers are advanced humidification devices designed to produce fine and uniform mist. They replace multiple conventional spray nozzles and improve system performance through better fluid dynamics.

Working Principle:

- Pressurised water is supplied to the atomiser at a controlled pressure.
- Water passes through a precision designed orifice and interacts with internal air turbulence
- This interaction process generates very fine and uniform droplets compared to conventional systems
- The mist is carried through the Air Handling Unit (AHU) and distributed evenly across the process area.



Figure 13: High Efficiency Atomizer

Cost-Benefit Analysis:

Estimated Investment: 3.5 Lakhs

Estimated Annual Saving: 4.3 Lakhs

Payback: 10 Months

Benefits:

- ✓ One atomiser replaces 50 conventional nozzles, resulting in significant system simplification
- ✓ Water consumption is reduced to one third, leading to substantial savings in pump energy
- ✓ Ultra fine mist enables uniform and accurate humidity control across the process area
- ✓ Reduces yarn static electricity and thread breakage, thereby improving product quality
- ✓ Eliminates clogging issues and reduces maintenance requirements, lowering operating costs
- ✓ Prevents wetting of floors and machinery, enhancing workplace safety

Energy Efficient Pnuemafil Fans in Ring Frames

Background & Problem:

Pneumafil fans in ring frame machines are used to remove fibre waste and fluff generated during spinning. This helps maintain yarn quality and supports the preparation of yarn packages for subsequent processes.

Conventional pneumafil fans have the following issues:

- High power consumption
- Large fan diameter and heavy construction
- Non-uniform suction across spindle positions
- Increased electrical operating cost

Technology Intervention: Energy-Efficient Pneumafil Fans

Energy efficient pneumafil fans are designed with optimized impeller geometry and improved suction system design. These enhancements provide higher suction efficiency with lower power consumption. Energy savings of at least 20 percent can be achieved while maintaining or improving cleaning performance.

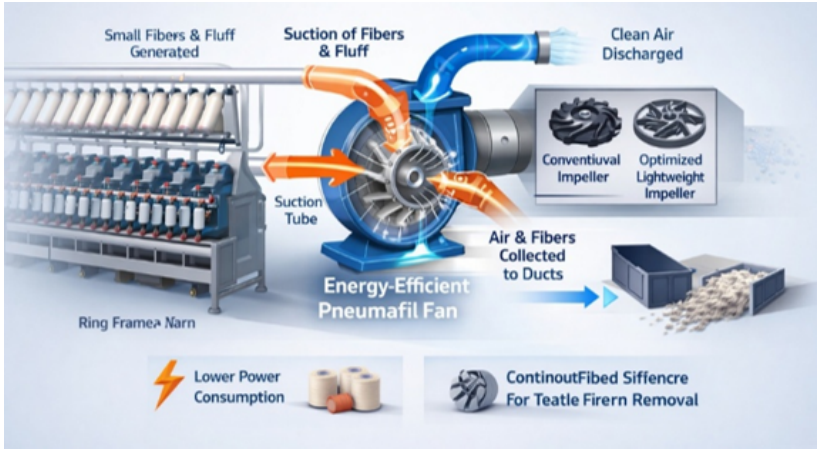


Figure 14: Energy Efficient Pneumafil Fans

Working Principle:

- Fibre generation at ring frame: Small fibres and fluff are generated during spinning
- Suction through pneumafil tube: A continuous suction line removes fibre waste along the machine
- High efficiency impeller operation: The optimized impeller creates negative pressure, drawing air and fibre into the system
- Air and fibre separation: Fibre waste is conveyed through ducts and separated for disposal, while clean air is released
- Improved aerodynamics: Advanced blade design and reduced fan size improve airflow efficiency and suction performance

Comparison

A comparison between conventional pneumafil fans and energy efficient models for G 5/1 ring frames is shown below.

Table 11: Comparison of Conventional and Energy-Efficient Pneumafil Fans

Special features	Conventional Pneumafil fans	Energy Efficient Fans	
Weight	14 kgs	6.5 kgs	6.2 kgs
Fan Diameter	490 mm	460 mm	420 mm
kWh consumed	5	3.97	2.41

Cost-Benefit analysis

Estimated Investment: 4 Lakhs
Estimated Annual Savings: 7.8 Lakhs
Estimated Payback: 6 months

Benefits

- ✓ Reduced power consumption
- ✓ Improved suction efficiency
- ✓ Uniform airflow across all spindle positions
- ✓ Compact and lightweight design
- ✓ Smaller fan diameter with better aerodynamic performance
- ✓ Improved fibre collection efficiency
- ✓ Cleaner working environment and enhanced yarn quality

Variable Frequency Drive for Water Circulating Pump of Jet Dyeing Machine

Background & Problem:

Jet dyeing machines are used for washing and dyeing fabrics. Hot water is circulated within the machine using a dedicated centrifugal pump, which operates continuously during the process.

Process pressure requirements vary at different stages of the batch. During nearly 30 to 35 percent of the operating time, excess pressure is controlled by throttling the outlet valve. This results in pressure loss and avoidable energy consumption. It also leads to inefficient pump operation and higher electricity use.

Technology Intervention:

Variable Frequency Drive (VFD):

A Variable Frequency Drive is an energy efficient motor control system. It regulates motor speed and torque by varying the input frequency and voltage.

In textile plants, pumps and other motor driven systems often operate at constant speed, even when full capacity is not required. Installing a Variable Frequency Drive allows the pump speed to match the actual process requirement, such as pressure and flow.

Working Principle:

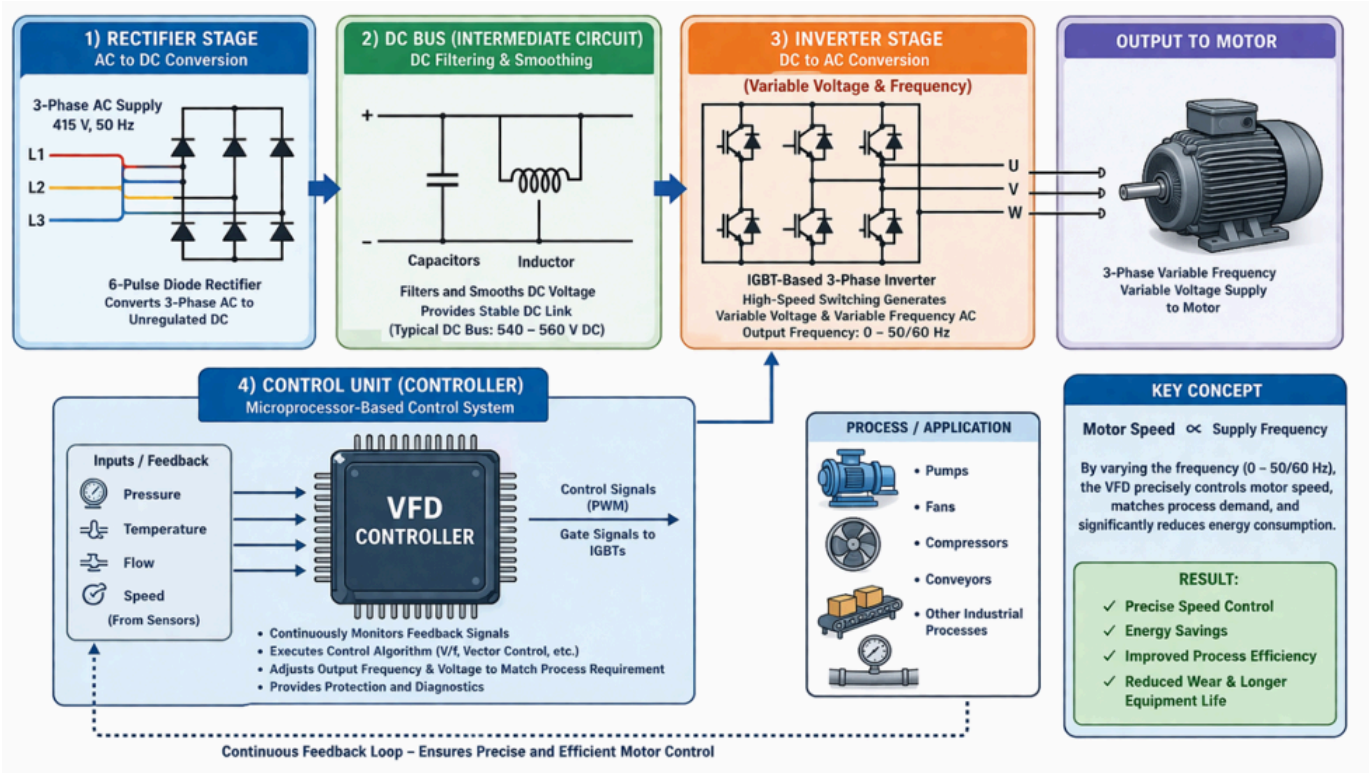


Figure 15: VFD - Working Principle

Working Principle:

- The VFD controls the speed of the jet dyeing machine pump by varying the frequency and voltage supplied to the motor.
- The required process pressure or flow rate is set through the machine control system, and the VFD continuously monitors the operating conditions.
- Based on the process requirement, the VFD automatically adjusts the pump speed to deliver only the flow and pressure needed for each stage of the dyeing cycle.
- During stages requiring lower circulation pressure, the pump operates at a reduced speed rather than maintaining full speed and restricting flow through valve throttling.
- As the pump speed decreases, power consumption reduces significantly in accordance with the pump affinity laws, resulting in substantial energy savings

Cost-Benefit analysis

Estimated Investment: 1.25 Lakhs
Estimated Annual Savings: 1.5 Lakhs
Payback: 10 months

Benefits

- ✓ Achieves approximately 35 percent energy savings during 30 percent of operating time
- ✓ Eliminates pressure losses associated with valve throttling
- ✓ Improves pump efficiency under varying load conditions
- ✓ Reduces mechanical stress on pumps and valves
- ✓ Lowers overall energy consumption and environmental impact

Temperature Controller in Processing Machine

Background & Problem:

In textile processing operations, equipment such as washers and jiggers require hot water at around 85°C. This temperature is typically achieved through direct steam injection.
In the absence of proper control, temperature regulation is often carried out manually. As a result, the process temperature frequently exceeds the required level and may reach up to 95°C. This leads to unnecessary steam consumption and increased energy costs.

Technology Intervention – Temperature Controller:

A Temperature Indicating Controller operates on a closed loop control system. It continuously measures, compares, and regulates the process temperature to maintain it at the desired set point.

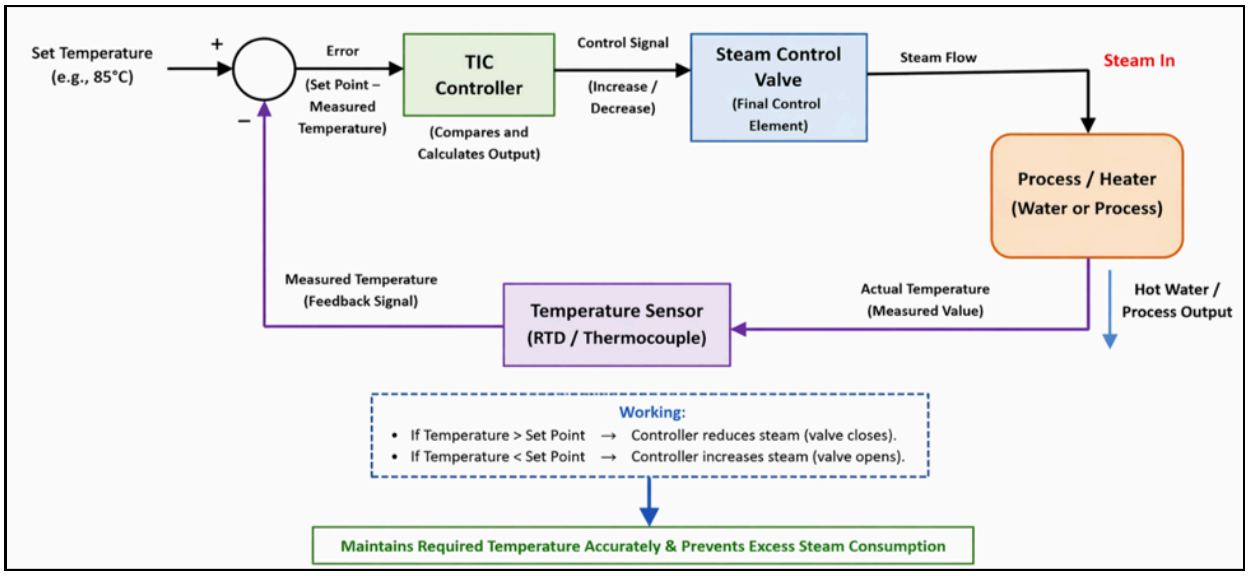


Figure 16: Temperature Controller - Block Diagram

Working Principle:

- A temperature sensor, such as an RTD or thermocouple, continuously measures the actual process temperature
- The measured value is transmitted to the controller for evaluation
- The controller compares the measured temperature with the predefined set value
- When the temperature exceeds the set value, the controller signals the steam control valve to reduce or stop steam flow
- When the temperature falls below the set value, the valve opens to increase steam supply
- This continuous feedback mechanism ensures stable temperature control and prevents overheating
- By maintaining the required temperature, the system minimizes excess steam usage

Cost-Benefit Analysis:

Estimated Investment: 0.2 – 0.3 Lakhs

Estimated Annual Savings: 0.2 – 0.3 Lakhs

Payback: 12 months

Benefits:

- ✓ Reduces steam consumption by preventing temperature overshoot
- ✓ Ensures consistent and accurate process temperature control
- ✓ Improves energy efficiency and reduces operating costs

Energy Efficient Automatic Spreading cum Cutting Machine

Background & Problem:

In textile garment manufacturing, fabric spreading and cutting are often performed using multiple semi-automatic or conventional machines. These processes are typically carried out in sequence.

Such systems involve high manual handling and dependence on labour. Production rates remain low due to separate spreading and cutting operations. Fabric wastage is also high due to misalignment and cutting inaccuracies. In addition, energy consumption per unit of production is relatively high. Variations in cutting quality further affect downstream stitching and finishing processes.

Technology Intervention – Energy Efficient Automatic Spreading cum Cutting Machine

It integrates fabric spreading and precision cutting into a single automated operation. It replaces multiple conventional machines with a high capacity and efficient solution.



Figure 17: Energy Efficient Automatic Spreading cum Cutting Machine[10]

[10] https://img.directindustry.com/images_di/photo-mg/55072-3625743.jpg

Working Principle:

- Fabric rolls are automatically spread in layers on the cutting table with controlled tension and alignment to avoid wrinkles and material distortion.
- Sensors ensure accurate control of fabric length, width, and number of layers
- The system follows predefined marker layouts through a programmable control unit
- Spreading and cutting operations are carried out in a synchronized manner
- An automated cutting unit, such as a straight knife, rotary knife, or laser cutter, cuts the fabric stack with high precision

Cost-Benefit Analysis:

Estimated Investment: 100 Lakhs
Estimated Annual Savings: 80 Lakhs
Payback: 15 months

Table 12: Energy Efficient Automatic Spreading cum Cutting Machine - Comparison for Conversion and Automatic system

Parameter	Conventional System	Automatic System
Power consumption (kWh/hour)	32	19
Production output (pieces/hour)	420	3000
Specific energy consumption (kWh / 100 pieces)	8	1
Daily production (pieces/day)	5000	36000

Benefits:

- ✓ Significantly increases production output through integrated and automated operation
- ✓ Reduces fabric wastage through precise alignment and controlled cutting
- ✓ Improves consistency and quality of cut pieces
- ✓ Enhances overall productivity and operational efficiency

Servo Winder & Two for One (TFO) Machine

Background & Problem:

In conventional textile yarn manufacturing, polyester yarn passes through multiple stages, including winding, twisting, doubling, and rewinding. Each stage is carried out on separate machines for functions such as package preparation, strength enhancement, count adjustment, and final winding.

This multistage arrangement requires repeated handling of yarn. It increases the risk of yarn damage, knot formation, and breakages. In addition, conventional mechanical machines lack precise control over tension and speed, leading to variations in yarn quality.

Technology Intervention - Servo Winder & Two for One TFO:

The Servo Winder is an advanced winding system that uses servo motor control to regulate yarn tension, speed, and package formation with high accuracy.

The Two for One Twisting Machine is an efficient yarn processing technology that introduces two twists in a single spindle rotation. It combines twisting and doubling into one operation. Together, these technologies simplify the process, reduce handling, and improve overall efficiency.

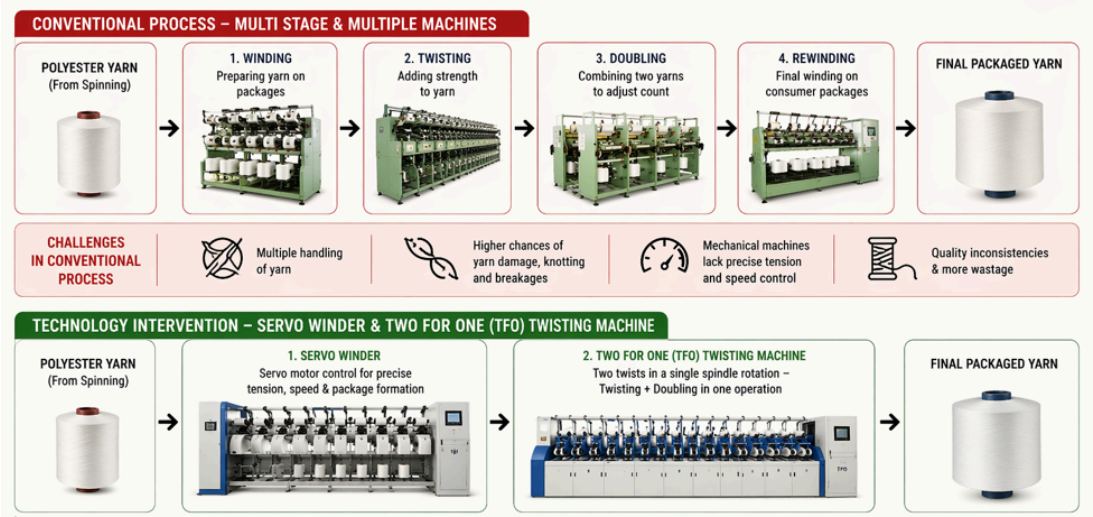


Figure 18: Servo Winder & Two for One TFO

Working Principle:

- The servo winder uses a servo motor to precisely control yarn speed and tension during winding
- The system continuously adjusts motor speed based on real time feedback to ensure uniform and stable package formation
- The yarn is then fed into the Two for One twisting machine
- The spindle inserts two twists in a single rotation, combining twisting and doubling in one step
- The processed yarn is directly wound into final packages
- This integrated operation reduces yarn handling and improves overall process efficiency

Cost-Benefit Analysis:

Estimated Investment: 42 Lakhs

Estimated Annual Savings: 16.8 Lakhs

Payback: 30 months

Benefits:

- ✓ Reduces the number of machines, leading to lower overall power consumption
- ✓ Enables precise control of yarn tension, reducing damage and material loss
- ✓ Minimizes yarn breakages and defects, reducing reprocessing requirements
- ✓ Improves process efficiency and product quality
- ✓ Lower energy consumption contributes to reduced indirect carbon emissions

Micro-turbine

Background & Problem:

In textile industries, high pressure steam generated from boilers is used for process heating applications such as dyeing, drying, washing, and finishing. The steam pressure is typically reduced through pressure reducing stations to match process requirements.

During this pressure reduction, a significant portion of pressure energy and enthalpy is dissipated without any useful recovery. This results in a loss of potential energy and reduced overall system efficiency.

Technology intervention – Installation of Micro Turbine:

A micro turbine of about 125 kW capacity can be installed in the bypass line of the pressure reducing system. The turbine reduces steam pressure to the required level while simultaneously generating electrical power.

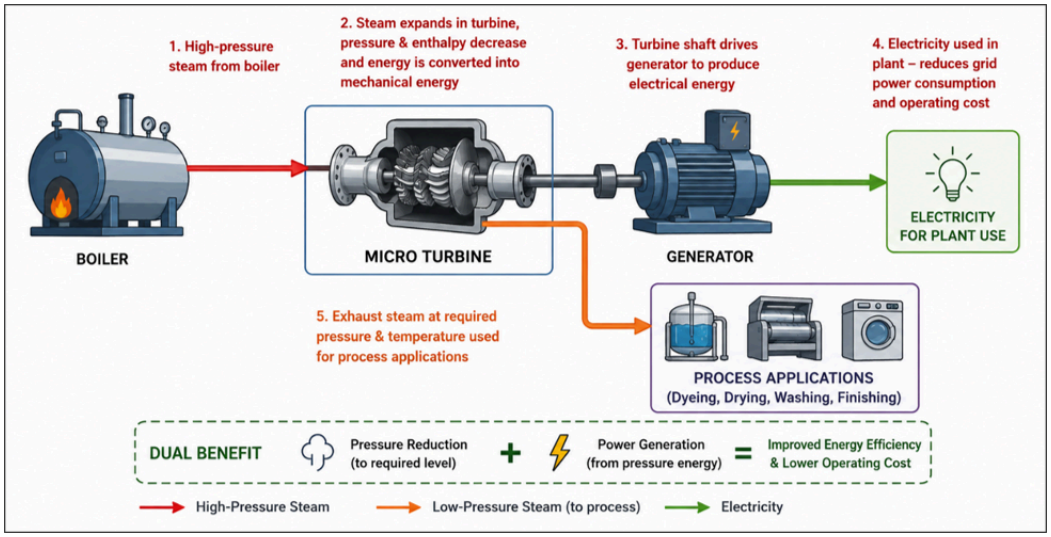


Figure 19: Micro Turbine-Working Principle

Working Principle:

- High-pressure steam generated in the boiler is directed through the micro turbine instead of passing through a conventional pressure reducing valve (PRV).
- As the steam expands through the turbine, its pressure and enthalpy decrease. The energy released during this expansion is converted into mechanical energy, causing the turbine shaft to rotate.
- The rotating turbine shaft is coupled with an electrical generator, which converts the mechanical energy into electrical energy.
- The generated electricity can be utilized within the textile plant, reducing the demand for grid electricity and lowering operating costs.
- After passing through the turbine, the exhaust steam is discharged at the required pressure and temperature and is subsequently used for process applications such as dyeing, drying, washing, and finishing.
- The system therefore performs the dual function of steam pressure reduction and power generation, improving the overall energy efficiency of the steam distribution network.

Cost-Benefit Analysis:
Estimated Investment: 130 Lakhs
Estimated Annual Savings: 65 lakhs
Payback: 24 months

Benefits:

- ✓ Recovers energy from steam pressure reduction that would otherwise be lost
- ✓ Generates electricity from existing steam, reducing grid power consumption
- ✓ Improves overall steam system efficiency
- ✓ Reduces energy costs through in house power generation
- ✓ Lowers greenhouse gas emissions and environmental impact

Grid-Connected Rooftop Solar PV System

Background & Problem:
Textile industries consume significant amounts of electrical energy for operations such as spinning, weaving, dyeing, humidification, compressors, pumps, lighting, and other utilities. Rising electricity tariffs and dependence on grid power increase operating costs and carbon emissions.
At the same time, most textile plants have large unused rooftop areas that can be utilized for renewable energy generation.

Technology intervention – Installation of 50 kWp Rooftop Solar PV System:
It is proposed to install a 50 kWp Rooftop Solar PV System at the textile plant.

The proposed system will consist of:

- Solar PV modules,
- Grid-connected inverter,
- Module mounting structures,
- AC/DC distribution panels,
- Protection and monitoring systems,
- Net metering arrangement.



Figure 20: Rooftop solar PV system

Working Principle:

- Solar photovoltaic modules convert incident solar radiation directly into direct current (DC) electricity through the photovoltaic effect.
- The DC power generated by the PV modules is collected through DC cabling and routed to a grid-connected inverter.
- The inverter converts the DC power into alternating current (AC) power synchronized with the plant's electrical system and utility grid parameters.
- The generated AC power is supplied directly to the plant loads, offsetting a portion of the electricity that would otherwise be drawn from the grid.
- During periods when solar generation exceeds the plant's instantaneous demand, surplus electricity is exported to the utility grid through a net metering arrangement.
- When solar generation is insufficient, such as during nighttime or low solar irradiance conditions, the required power is automatically imported from the grid to ensure uninterrupted plant operation.
- The monitoring and protection systems continuously supervise system performance, energy generation, voltage levels, and safety parameters to ensure reliable and efficient operation.

Cost-Benefit Analysis:

Estimated Investment: 25 lakhs
Estimated Annual Savings: 6.4 lakhs
Payback: 46 months

Benefits:

- ✓ Reduces grid electricity consumption and operating cost.
- ✓ Utilizes renewable solar energy for industrial operations.
- ✓ Reduces carbon emissions and supports sustainability initiatives.
- ✓ Improves energy security by reducing dependence on grid power

5.2. Thermal:

System for control of excess air in Boiler/Thermic Fluid Heater

Background & Problem:

Boilers and thermic fluid heaters in textile industries account for a major share of thermal energy consumption. They are used for processes such as dyeing, drying, washing, and finishing.

Efficient combustion requires an optimum air to fuel ratio. In conventional systems, excess air is maintained at higher levels to ensure complete combustion and safe operation. However, higher excess air results in heat losses and reduced thermal efficiency.

Technology Intervention - Installation of an Automatic O_2 Trim Control System:

An oxygen trim control system continuously monitors oxygen concentration in flue gases and automatically adjusts combustion air supply to maintain optimum excess air levels.

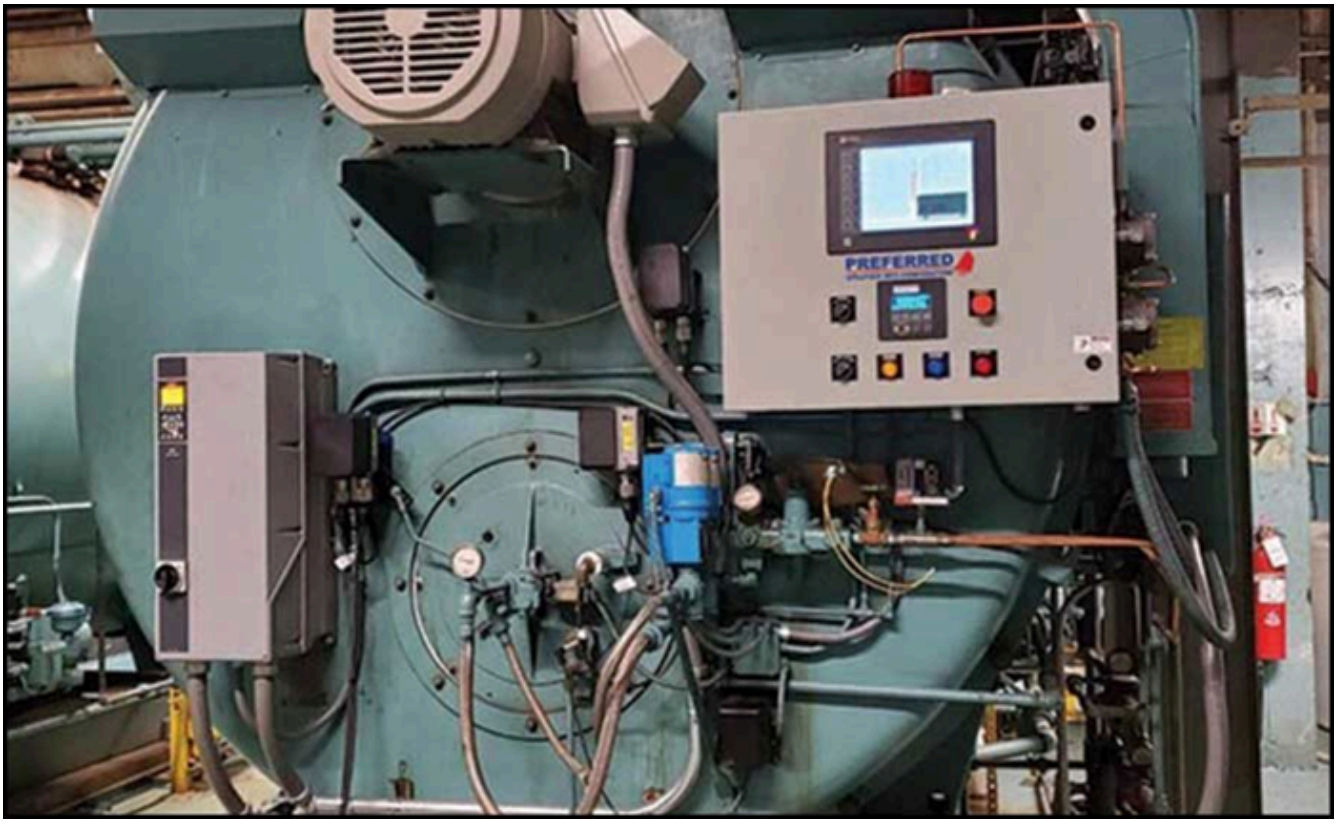


Figure 21: Oxygen trim control system[11]

[11] Why Oxygen Trim Should Be Part of Your Boiler Room – The Preferred Pyroscope

Working Principle:

- An oxygen (O_2) sensor is installed in the flue gas path of boiler or thermic fluid heater to continuously measure oxygen levels in the exhaust gases.
- The sensor sends the measured O_2 signal to a PLC/controller.
- The controller compares the actual oxygen level with the predefined optimum oxygen set point.
- If excess oxygen is detected, the controller adjusts the combustion air supply.
- The air flow is controlled through a Variable Frequency Drive connected to the forced draft fan or through damper actuators
- This maintains the optimum air-to-fuel ratio for efficient combustion.
- The system continuously responds to changes in boiler load, fuel quality, atmospheric conditions and temperature variations.
- Additional features include monitoring of flue gas temperature, alarms, combustion efficiency, and emission levels

Cost-Benefit Analysis:

Estimated Investment: 4 Lakhs
Estimated Annual Savings: 9.5 Lakhs
Payback: 5 months

Benefits:

- ✓ Reduces fuel consumption by maintaining optimum excess air levels.
- ✓ Improves combustion efficiency and reduces stack losses.
- ✓ Minimizes emissions, soot formation, and fouling of heat transfer surfaces
- ✓ Provides continuous monitoring and automatic control of combustion
- ✓ Enhances overall reliability and performance of the heating system

Residual Moisture control in Drying Cylinders

Background & Problem:
Vertical Drying Ranges are widely used in woven dyeing and printing operations. These systems are typically designed for maximum production capacity. As a result, fabrics of different GSM are subjected to the same drying conditions.

This often leads to over drying of lighter fabrics, causing unnecessary steam consumption and energy loss. Cotton fabric, being hygroscopic, absorbs moisture from the surrounding air after excessive drying. This results in uneven moisture distribution within the fabric roll.The outer layers regain moisture, while the inner layers remain over dried.

Such variations in residual moisture can affect downstream processes such as dyeing and may lead to quality issues.

Technology Intervention - Residual moisture Control:
The Residual Moisture Control system is an advanced control solution installed at the exit of the Vertical Drying Range. It ensures that the fabric retains the required level of moisture after drying.

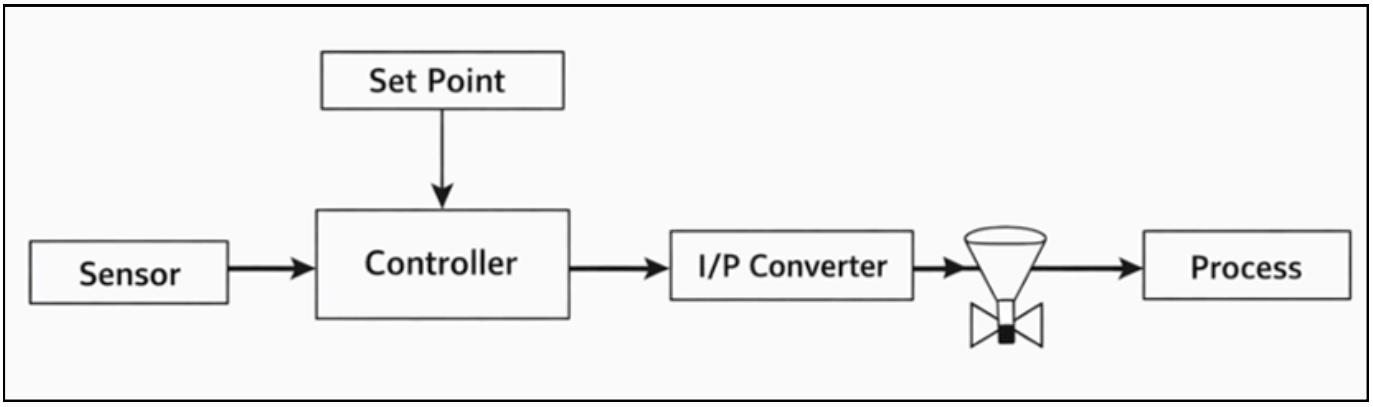


Figure 22: Residual Moisture Control - Block Diagram

Working Principle:

- A moisture sensor, typically infrared or microwave based, measures the moisture content of the fabric at the dryer exit
- The measured value is transmitted to the control system
- The system compares the actual moisture with the preset value based on fabric type and GSM
- Based on the deviation, the controller adjusts steam supply or fabric speed
- This closed loop control maintains consistent moisture levels during operation

Cost-Benefit Analysis:

Estimated Investment: 2-2.5 Lakhs

Estimated Annual Savings: 1-1.25 Lakhs

Payback: 24-30 Months

Benefits:

- ✓ It will save 5-15% of energy consumption
- ✓ Reduces steam consumption by avoiding over drying
- ✓ Ensures uniform moisture content and improves product quality
- ✓ Improves energy efficiency and process control

Heat Pump System for Hot Water Generation in Textile Wet Processing

Background & Problem:

Textile wet processing operations such as dyeing, scouring, washing, and bleaching require large volumes of hot water and steam. These requirements are typically met using furnace oil or natural gas fired boilers, which involve high operating costs and significant greenhouse gas emissions. In addition, a considerable amount of heat is lost through hot effluent and warm ambient air, resulting in inefficient energy utilization.

Technology Intervention – Heat Pump:

Heat pumps provide an energy efficient solution by recovering low grade waste heat and upgrading it to useful hot water temperatures up to 80°C. This reduces the thermal load on boilers, lowers fuel consumption, and decreases operating costs.

With a high coefficient of performance, for example 2.5, the system produces 2.5 units of heat for every unit of electrical energy consumed. This makes it significantly more efficient than conventional heating methods. The system is well suited for facilities with continuous hot water demand, such as dyeing and processing units.

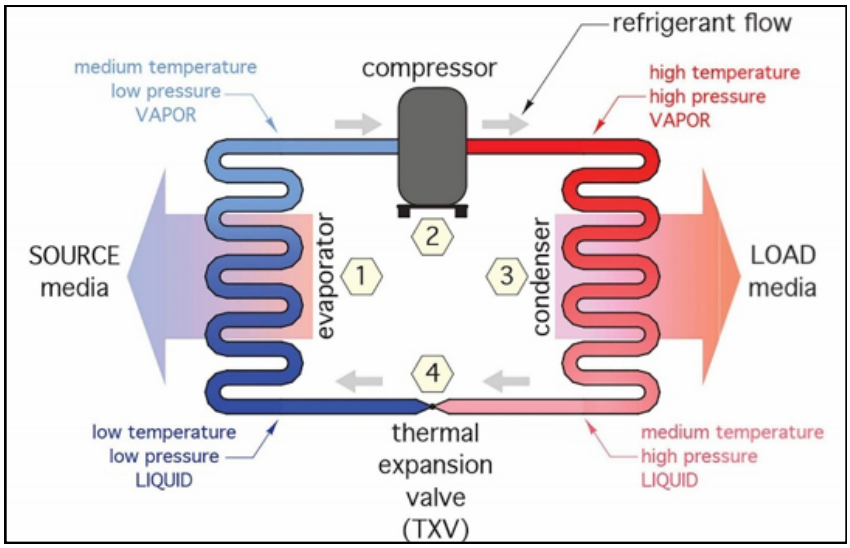


Figure 23: Heat Pump

The system operates through four main components:

Evaporator: The refrigerant absorbs heat from a low temperature source such as wastewater in the evaporator and changes into vapour

Compressor: The vapour is compressed to increase its pressure and temperature

Condenser: The high temperature refrigerant transfers heat to water in the condenser and condenses back into liquid

Expansion Valve: The pressure of the refrigerant is reduced through an expansion device before returning to the evaporator

Cost-Benefit Analysis:

Estimated Investment: 8.50 lakh

Estimated Annual Savings: 6.22 lakh

Payback: 16 months

Benefits:

- ✓ Reduces furnace oil or natural gas consumption, leading to lower fuel costs
- ✓ Decreases carbon emissions by reducing dependence on conventional heating systems
- ✓ Provides high energy efficiency due to favorable coefficient of performance
- ✓ Utilizes waste heat, improving overall energy utilization
- ✓ Compact design allows installation near point of use, such as near dyeing machines.

Waste heat recovery system in stenters

Background & Problem:

Stenters in the textile processing section are among the major consumers of thermal energy. They are used for drying, stretching, and finishing of fabric.

Fabric enters the stenter after pre drying with a moisture content of about 60-65%. This moisture is removed during the stenter process and expelled as hot exhaust air. A significant amount of heat is lost through this exhaust, leading to inefficient energy use.

This presents a strong opportunity for waste heat recovery and reuse within the process.

Technology Intervention – Waste heat recovery system:

A waste heat recovery system is installed in the stenter exhaust line to capture heat from hot exhaust air. The recovered heat is reused within the process, improving overall energy efficiency.

The system typically includes heat exchangers made of corrosion resistant materials such as glass tube bundles or coated finned tubes, which are suitable for handling contaminated exhaust gases.

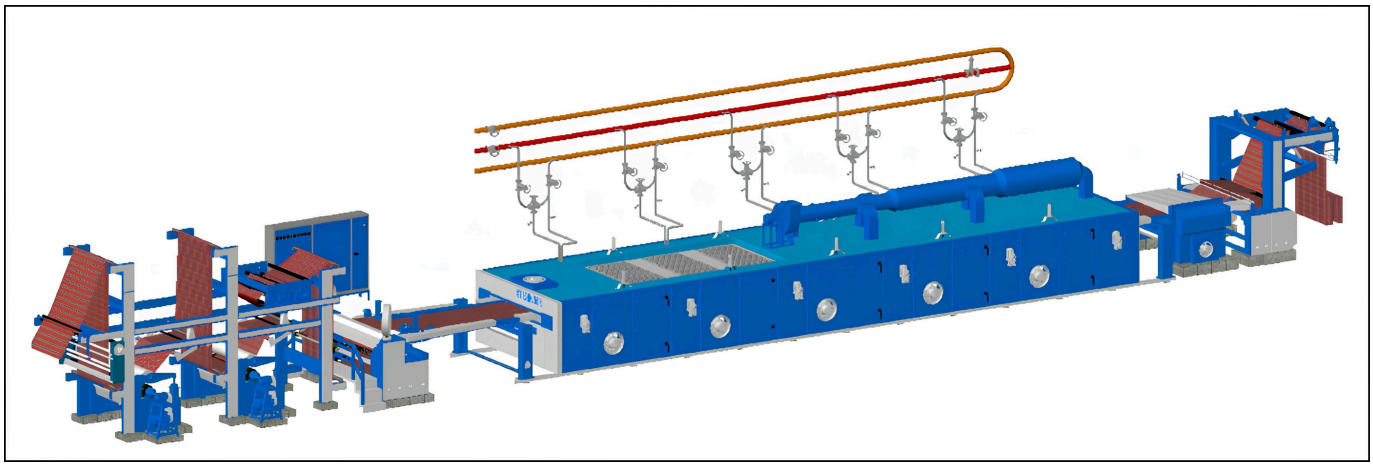


Figure 24: Hot air stenter design[12]

[12] stenter machine, textile processing machinery, stenters, padding mangle, float dryer, india

Working Principle:

- Hot exhaust air from the stenter passes through a heat exchanger
- Heat from the exhaust air is transferred to a secondary medium such as fresh air or water
- Preheated air is supplied back to the stenter as make up air
- Alternatively, the recovered heat is used to generate hot water for process applications
- The system operates continuously alongside the stenter, recovering heat during operation

Cost-Benefit Analysis:

Estimated Investment: 13.5 lakhs

Estimated Annual Savings: 7.5 lakhs

Payback: 22 months

Benefits:

- ✓ Reduces fuel consumption by recovering heat from stenter exhaust air.
- ✓ Lowers energy costs through preheating fresh make-up air.
- ✓ Generates hot water for dyeing, washing, and other textile processes.
- ✓ Improves overall energy efficiency and reduces greenhouse gas emissions.

Waste heat recovery through economizer in thermic fluid heater/boiler

Background & Problem:

In boilers and thermic fluid heaters, a significant amount of heat is lost through high temperature flue gases discharged into the atmosphere. Typical flue gas temperatures range from about 230°C to 270°C in boilers and from 330°C to 360°C in thermic fluid heaters.

This heat loss results in higher fuel consumption, reduced thermal efficiency, and increased environmental emissions. There is considerable potential to recover this waste heat and improve overall system performance.

Technology Intervention – Waste heat recovery through economizer:

An economizer is installed in the flue gas line of the boiler or thermic fluid heater to recover heat from hot exhaust gases. It is typically a shell and tube heat exchanger designed to operate under high temperature conditions.

[13]Economizers and heat recovery units - UNITERM SRL



Figure 25: Economizer and heat recovery units[13]

Working Principle:

- Hot flue gases from the boiler or thermic fluid heater pass through the economizer
- Water flows through tubes arranged inside the economizer
- Heat is transferred from the flue gases to the water through the tube surface
- The temperature of the water increases before it enters the boiler or is used in the process
- The flue gas temperature reduces before it is released to the atmosphere
- This continuous heat exchange improves thermal efficiency and reduces fuel consumption

Cost-Benefit Analysis:

Estimated Investment: 1.7 lakhs
Estimated Annual Savings: 0.95 lakh
Payback: 21 months

Benefits:

- ✓ Reduces fuel or biomass consumption by utilizing waste heat from flue gases
- ✓ Improves efficiency of boilers and thermic fluid heaters
- ✓ Generates hot water for process applications and reduces process time
- ✓ Minimizes heat loss and reduces thermal pollution
- ✓ Improves overall energy utilization in the system

Condensate recovery pump in jet dyeing machine

Background & Problem:

Jet dyeing machines require large quantities of steam for heating the dye liquor and maintaining the desired dyeing temperature. During heat transfer, steam condenses into hot water (condensate), which still contains a significant amount of thermal energy. In many textile processing units, this condensate and the associated flash steam are discharged instead of being recovered, resulting in substantial heat loss, increased boiler fuel consumption, and higher freshwater requirements.

Technology Intervention – Condensate recovery pump:

A condensate recovery pump is installed to collect, transport, and return hot condensate generated in the jet dyeing machine back to the boiler feed water system.

Working Principle:

- Steam is supplied to the heat exchangers of the jet dyeing machine, where it transfers heat to the dye liquor and condenses into high-temperature condensate.
- The condensate is discharged through steam traps and collected in a condensate receiver tank, while preventing the escape of live steam.
- When the condensate level reaches a predetermined limit, the condensate recovery pump is automatically activated to transfer the collected condensate.
- The pump utilizes steam pressure to actuate a diaphragm mechanism, enabling the efficient transfer of condensate to the boiler feed water tank.
- The recovered condensate, which retains substantial thermal energy, is reused as boiler feed water, thereby reducing freshwater consumption and boiler fuel requirements.

Cost-Benefit Analysis:

Estimated Investment: 4 lakhs
Estimated Annual Savings: 4.5 lakh
Payback: 11 months

Benefits:

- ✓ Saves energy by recovering hot condensate and flash steam
- ✓ Reduces boiler fuel and freshwater consumption
- ✓ Improves system efficiency and reduces steam losses
- ✓ Low maintenance and no electrical power needed
- ✓ Cuts operating cost and emissions significantly

5.3. Process:

IoT-Based Water Management System for Textile Processing Units

Background & Problem:

Textile processing units, especially dyeing, bleaching, washing, mercerizing, and finishing are highly water-intensive operations. Large volumes of water are consumed across multiple processes such as:

- Dye bath preparation
- Washing/rinsing cycles
- Bleaching and scouring
- Soft-flow and jet dyeing
- Boiler feedwater
- Cooling water circulation

In most textile mills, water consumption is monitored manually. This leads to measurement errors, unaccounted usage, leakages, and inefficiencies. Real time visibility of water usage at the section, machine, or shift level is generally unavailable, making effective control difficult

Technology Intervention – IoT based Water Management System:

An IoT based water management system enables real time monitoring, control, and optimization of water usage across the plant. It improves transparency, supports informed decision making, and reduces water consumption and operating costs.

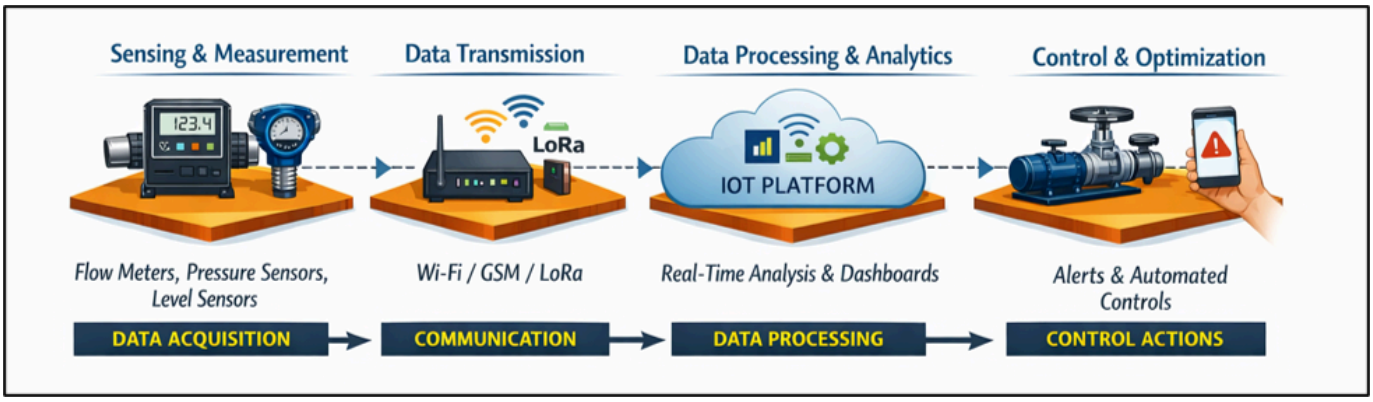


Figure 26: IoT based Water Management System

Working Principle:

The IoT-based water management system operates on a data acquisition, communication, and control loop:

Sensing and Measurement: Flow meters, pressure sensors, and level sensors are installed at key points such as dyeing machines, ETP, boiler feed, etc. to continuously measure water usage and system parameters.

Data Transmission: The collected data is transmitted through an IoT gateway using communication protocols such as Wi-Fi, GSM, or LoRa to a central server or cloud platform.

Data Processing and Analytics: The cloud platform processes the collected data in real time to generate insights such as consumption patterns, abnormal usage, and potential leakages. This information is presented through dashboards for effective monitoring by operators and management.

Control and Optimization: Based on the analysis, the system can trigger alerts or automatically control actuators like valves and pumps to regulate water flow, ensuring optimal usage

Cost-Benefit Analysis:

Estimated Investment: 1.7 lakh

Estimated Annual Savings: 1.12 lakh

Payback: 8 months

Benefits:

- ✓ Minimizes water losses by detecting leakages, overflow, and abnormal usage in real time
- ✓ Improves process efficiency through monitoring at section and machine level
- ✓ Supports optimization of water usage in dyeing and washing processes
- ✓ Reduces energy consumption associated with pumping, heating, and effluent treatment

Airflow Jet Dyeing Machine

Background & Problem:

Conventional jet dyeing machines are widely used for polyester fabric dyeing with disperse dyes. These machines rely on large volumes of dye liquor to transport the fabric. Fabric movement is achieved through liquid circulation, resulting in high consumption of water, chemicals, and energy.

High liquor ratios lead to:

- Increased steam demand for heating
- Large effluent generation
- Higher environmental impact and operating costs

Technology Intervention – Airflow Jet Dyeing Machine:

Airflow dyeing is an advanced and environmentally efficient technology that uses air instead of liquid as the primary transport medium. In this process, dye liquor is atomized into fine droplets and carried by high pressure airflow to the fabric surface.

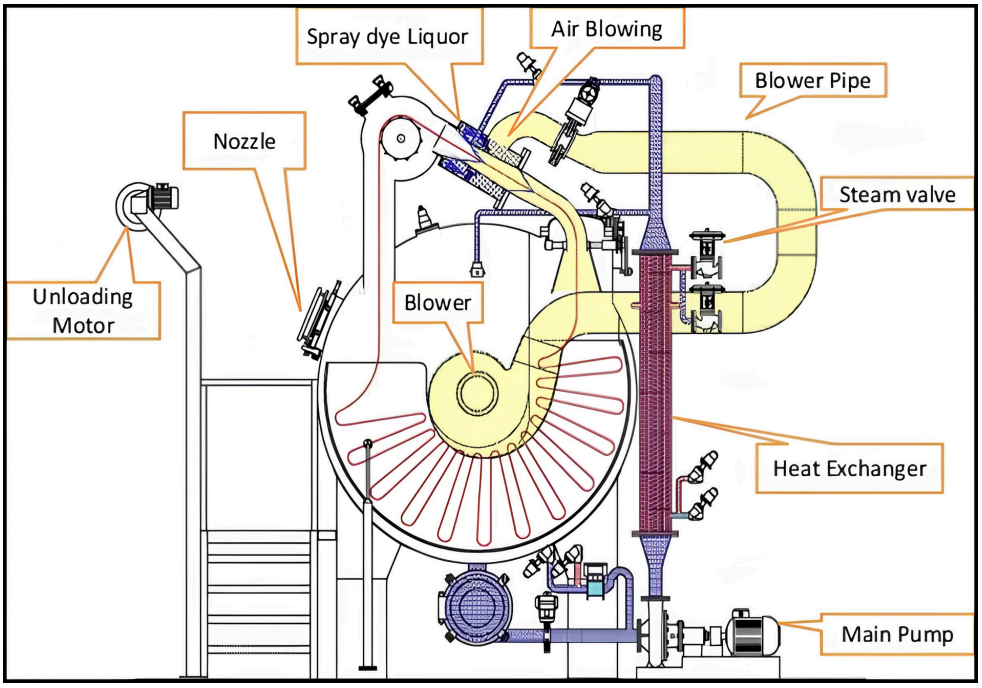


Figure 27: Airflow Jet Dyeing Machine[14]

Working Principle:

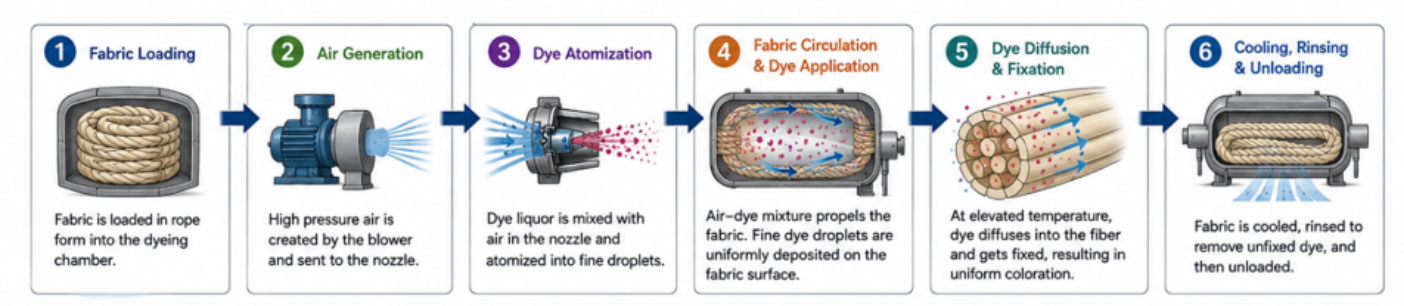


Figure 28: Air flow Jet Dyeing - Working Principle

Fabric Loading and Dye Liquor Preparation: The fabric is stitched into a continuous rope form and loaded into the dyeing chamber. Simultaneously, dyes and auxiliaries are dissolved in a small quantity of water to prepare the dye liquor required for coloration.

Generation of High-Velocity Airflow: A centrifugal blower generates high-pressure air, which serves as the primary medium for fabric transportation. This airflow replaces the large volume of dye liquor used in conventional jet dyeing systems.

Atomization of Dye Liquor: The dye liquor is injected into a specially designed airflow nozzle, where it is atomized into fine droplets by the high-speed air stream. The increased surface area of the droplets enhances dye transfer efficiency and promotes uniform dye distribution.

Fabric Transportation and Dye Application: The air-dye mixture propels the fabric continuously through the transport tube and dyeing chamber. During circulation, the atomized dye droplets are uniformly deposited onto the fabric surface.

[14]Air-Flow Dyeing - an Eco-friendly water preserving fabric dyeing technology - Textile School

Dye Diffusion and Fixation: Under controlled temperature conditions, the fibers swell and become more receptive to dye molecules. The dye diffuses into the fiber structure and becomes permanently fixed within the fiber matrix, producing the desired shade and color fastness.

Cooling, Rinsing, and Unloading: After dye fixation, the fabric is gradually cooled and rinsed to remove any unfixed dye and residual chemicals. The dyed fabric is then unloaded and transferred for subsequent finishing operations.

Cost-Benefit Analysis:

Estimated Investment: 2000 – 3000 Lakhs

Estimated Annual Savings: 2500 - 3500 Lakhs

Payback: 12-15 months

(Note: For equipment capacity 400-450 kg)

Benefits:

- ✓ Ensures uniform and high-quality dyeing due to continuous fabric movement
- ✓ Reduces water and chemical consumption and lowers effluent generation
- ✓ Improves energy efficiency compared to conventional dyeing systems
- ✓ Minimizes fabric stress, resulting in better fabric quality and finish

Auto/Rapier Loom

Background & Problem:

Conventional shuttle and power looms operate at low speeds and require significant manual intervention. They involve higher maintenance and deliver lower productivity.

These looms also have limitations in handling complex fabric designs, multiple colour weft insertion, and modern weaving requirements. This results in higher production costs and reduced competitiveness.

Technology Intervention – Auto/Rapier looms:

Conventional shuttle looms are replaced with modern rapier looms equipped with advanced control and automation features. These include microprocessor based control systems, multiple weft insertion capability, improved shedding mechanisms, and centralized lubrication systems.

COMPARISON: CONVENTIONAL LOOMS vs AUTO / RAPIER LOOMS

	CONVENTIONAL SHUTTLE LOOMS (POWER LOOMS)	AUTO / RAPIER LOOMS
	  Shuttle	  Rapier Head
Weft Insertion System	Uses shuttle to carry the weft yarn across the shed.	Uses rapier (flexible or rigid) to carry the weft yarn across the shed (shuttle-less).
Speed (RPM)	Around 120 RPM (normal speed)	**Up to 220 RPM** (actual speed) High efficiency up to 95%
Productivity	Low – Standard productivity	Up to 3 times more productivity
Fabric Capability	Limited – Difficult to weave fancy fabrics & multiple color weft.	High – Can weave fancy fabrics with up to 8 Color Pick-at-Will weft insertion.
Start Mark Prevention	Start marks common in many fabrics.	HT-Drive motor with 150% torque for first pick prevents start marks.
Labor Requirement	High – More operators and helpers required.	Low – Immediate reduction in man-power and laborers.
Infrastructure	Upgradation often needs more space or changes.	Fits in place of existing shuttle looms. No need for new buildings or major changes.
Maintenance	Higher wear & tear due to more moving parts and vibrations.	Lower vibrations, less wear & tear. Centralized lubrication reduces maintenance.
Power Consumption	Higher	Lower power consumption
Take-Up System	Conventional take-up mechanisms.	Universal 7-wheel Wretchet-n-Pawl semi-positive take-up (4–120 picks per inch).
Let-Off Options	Limited options.	Multiple options – Ruti-Type, Positive Cam, Negative Cam, Electronic Let-Off.
Control System	Mechanical / Basic controls.	Advanced Microprocessor Controller – monitors breaks, cloth length, pick programming, weft control, etc.
Cost & Incentives	No specific benefits.	20% subsidy under TUFS (on certified looms) + State Government Incentives.
	LESS PRODUCTIVITY | HIGHER COST | HIGHER MAINTENANCE MORE LABOR | LIMITED CAPABILITIES	HIGH PRODUCTIVITY | LOWER COST | LOW MAINTENANCE LESS LABOR | ADVANCED FEATURES | BETTER QUALITY

Figure 29: Comparison between Conventional and Auto looms

Working Principle:

Warp Preparation, Shedding, and Weft Feeding: Warp yarns are drawn through the heald frames and reed. During weaving, the heald frames move according to the weave pattern to create an opening called the shed, through which the weft yarn is inserted, while the required weft yarn is simultaneously selected and fed to the rapier mechanism.
Weft Transfer and Insertion: The rapier carries the weft yarn across the shed. In double-rapier looms, the weft is transferred from the giver rapier to the receiver rapier at the center before being inserted across the fabric width.
Beat-Up Mechanism: After weft insertion, the reed moves forward and pushes the newly inserted weft yarn against the fabric edge (fell of the cloth), forming the woven structure and determining fabric density.
Take-Up and Let-Off Motion: The woven fabric is continuously wound onto the cloth roller, while warp yarn is simultaneously released from the warp beam at a controlled rate to maintain uniform tension.
Electronic Monitoring and Continuous Weaving: Sensors and control systems monitor warp tension, weft insertion, and yarn breakages to ensure fabric quality. The sequence of shedding, weft insertion, beat-up, take-up, and let-off is continuously repeated to produce fabric.

Cost-Benefit Analysis:
Estimated Investment: 50-52 lakhs
Estimated Annual Savings: 25-30 lakhs
Payback: 24-30 months
(Note: For equipment capacity – 220 rpm)

Benefits:

- ✓ Increases productivity up to three times compared to conventional power looms
- ✓ Reduces labour, maintenance, and overall production costs through automation and efficient operation
- ✓ Enables weaving of complex and multi colour fabrics with up to eight colour weft insertion and programmable pick systems
- ✓ Improves fabric quality and operational efficiency through reduced vibration and prevention of start mark defects

Gas fired stenters

Background & Problem:

In conventional stenters and dryers, heat is supplied through thermic fluid heaters. Hot thermic fluid circulates through pipelines and radiators to transfer heat to the drying chambers.

This system results in heat losses due to long piping networks and heat transfer surfaces.

These losses reduce overall thermal efficiency and increase fuel consumption.

Technology Intervention – Gas fired stenters:

The system replaces thermic fluid-based heating with direct gas fired heating in the stenter.

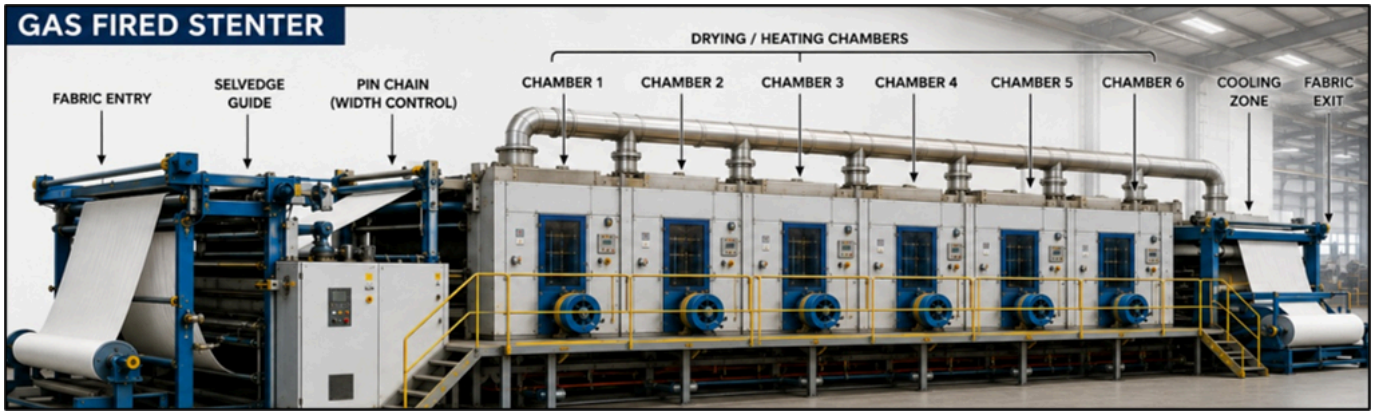


Figure 30: Gas fired stenters

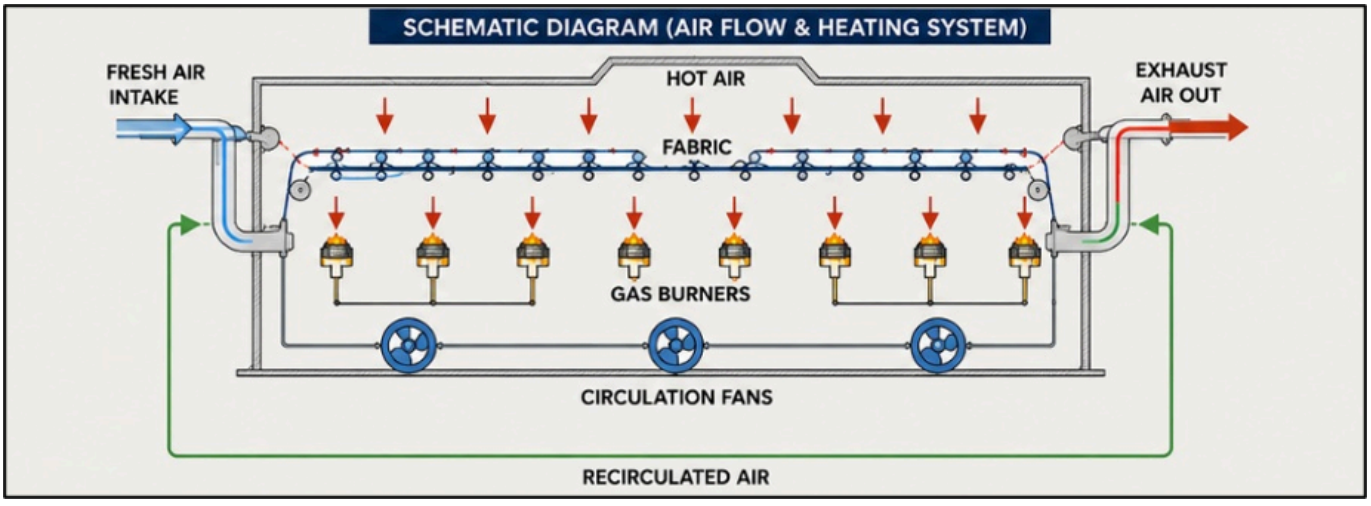


Figure 31: Gas fired stenters (Schematic diagram)

Working Principle:

- The wet fabric enters the stenter through the fabric entry section. Selvedge guides align the fabric edges to ensure proper positioning before width setting.
- The fabric edges are gripped by pins or clips attached to continuously moving chains. The chain rails can be adjusted to stretch the fabric to the required width and maintain dimensional stability throughout processing.
- Natural gas is supplied to burners installed within each stenter chamber.
- The gas is mixed with air in a controlled ratio and ignited to produce a stable flame, generating the thermal energy required for fabric drying and heat setting.
- Fresh and recirculated air passes over the burner system and is heated to the required temperature. This hot air acts as the primary heat transfer medium for drying the fabric and carrying out thermal treatments.
- High-capacity circulation fans distribute the heated air uniformly throughout the drying chambers.
- A portion of the exhaust air may be recirculated and reheated, reducing fuel consumption and improving thermal efficiency.
- Temperature and airflow are continuously monitored and controlled through automated systems.

Cost-Benefit Analysis:

Estimated Investment: 35-40 lakhs
Estimated Annual Savings: 38-40 lakhs
Payback: 10-12 months

(Note: For equipment capacity 1600 mm stenters)

Benefits:

- ✓ Faster heating and improved temperature control
- ✓ Reduced fuel consumption and improved productivity
- ✓ Energy saving potential: 30-40% over thermic fluid-based stenter systems
- ✓ Lower emissions compared to conventional systems

Waterless dyeing technology (Supercritical CO_2 Dyeing)

Background & Problem:

Conventional textile dyeing processes use large volumes of water for dyeing and washing. This leads to high water consumption, significant wastewater generation, and increased treatment costs. These processes also require substantial energy for heating water and drying fabrics. In addition, chemical effluents from dyeing operations contribute to environmental pollution and regulatory challenges.

Technology Intervention – Waterless Dyeing Technology:

Waterless dyeing technology uses supercritical carbon dioxide as a dyeing medium instead of water. This eliminates the need for water and reduces environmental impact.

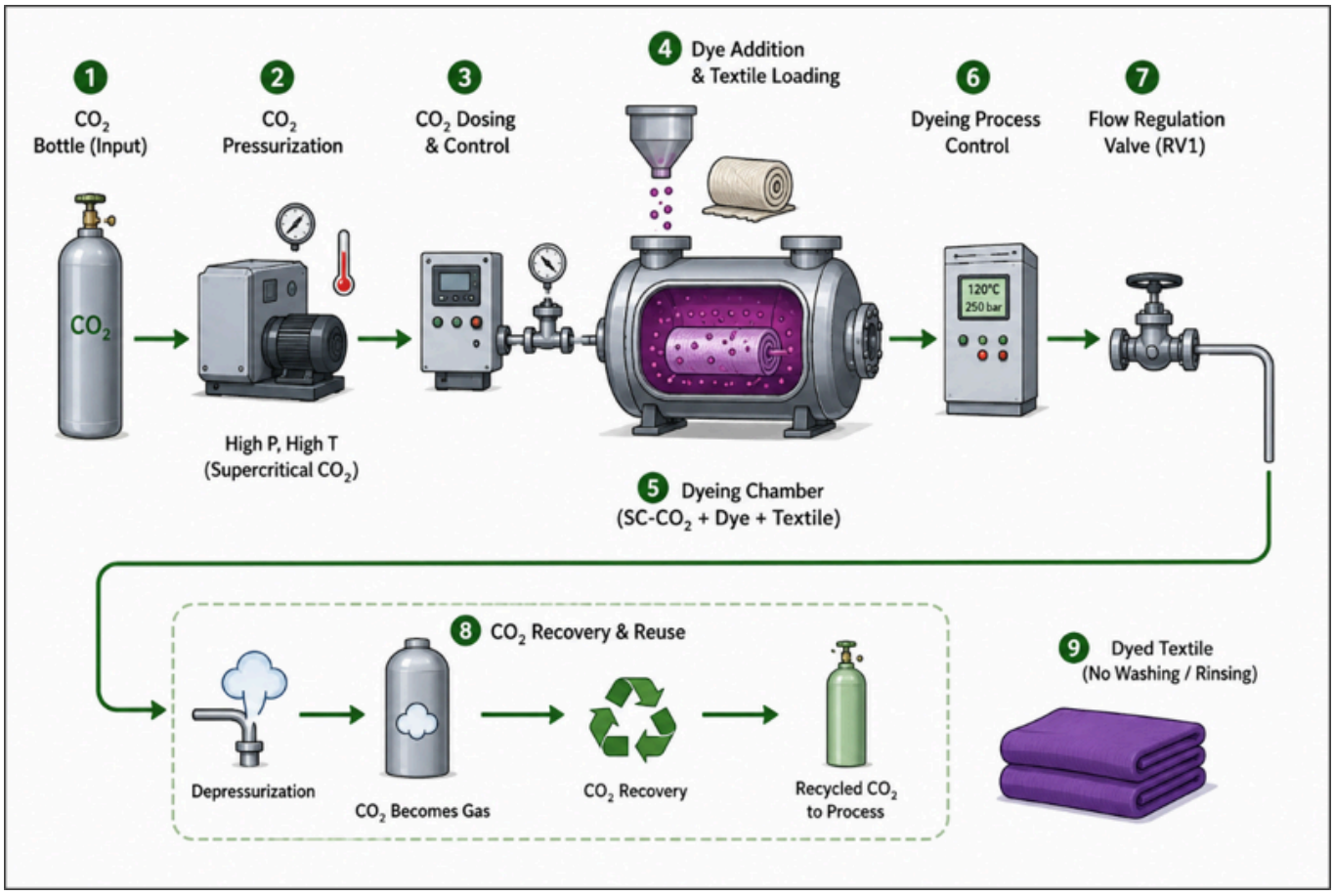


Figure 32: Waterless dyeing technology[15]

[15] Supercritical CO2 Dyeing of Textiles: Dye Properties, Technical Requirements, and Industrial Perspectives | IntechOpen

Working Principle:

CO_2 Bottle (Input)

- Liquid carbon dioxide is stored in a high-pressure cylinder and supplied to the dyeing system.
- It serves as the dyeing medium, replacing water used in conventional dyeing processes.

CO_2 Pressurization

- The supplied CO_2 is compressed to a high pressure and heated above its critical temperature (31.1°C).
- Under these conditions, CO_2 reaches its supercritical state, where it exhibits both liquid-like solvent properties and gas-like diffusivity.

CO_2 Dosing and Control

- The pressure, temperature, and flow rate of the supercritical CO_2 are carefully regulated.
- Maintaining stable supercritical conditions ensures efficient dye dissolution and uniform dye transport throughout the system.

Dye Addition and Textile Loading

- The textile substrate (fabric, yarn, or fiber) is loaded into the dyeing chamber.
- Disperse dye is introduced into the system either by preloading onto the textile or by direct addition into the vessel.
- The supercritical CO_2 dissolves the dye and acts as a carrier medium.

Dyeing Chamber

- The textile material is exposed to the dye-laden supercritical CO_2 inside a high-pressure vessel.
- Due to its high diffusivity, the supercritical fluid penetrates deep into the fiber structure.
- Simultaneously, the fibers undergo swelling and plasticization, creating pathways for dye molecules to enter the polymer matrix.

Dyeing Process Control

- Dyeing is typically carried out at approximately 120°C and 250 bar for about 120 minutes.
- Temperature, pressure, and residence time are continuously monitored and adjusted to achieve uniform dye penetration and optimum color development.
- During this stage, dye molecules diffuse into the amorphous regions of the fibers and become permanently fixed.

Flow Regulation Valve

- The valve controls the circulation and discharge rate of supercritical CO_2 within the system.
- It helps maintain the required operating pressure and ensures stable dyeing conditions throughout the process.

Post-Treatment and CO_2 Recovery

- After completion of dyeing, the system is gradually depressurized.
- The supercritical CO_2 returns to its gaseous state and is separated from the dyed textile.
- The recovered CO_2 is collected and recycled for reuse in subsequent dyeing cycles.
- Any residual dye particles are removed from the system.

Dyed Textile Removal

- The dyed textile is removed from the chamber after depressurization.
- Since no water is used, washing, rinsing, and drying operations are generally unnecessary.
- The final product exhibits excellent color strength, levelness, and fastness properties.

Cost-Benefit Analysis:

Estimated Investment: 2000 – 3000 lakhs

Estimated Annual Savings: 2500 – 3500 lakhs

Payback: 12 - 15 months

(Note: For equipment capacity 20-200 kg)

Benefits:

- ✓ Energy and resource saving potential of approximately 60 - 65%
- ✓ Eliminates water usage in dyeing process
- ✓ Avoid wastewater generation and reduces effluent treatment requirements
- ✓ Improved dye penetration and color uniformity
- ✓ Enables reuse of CO_2 reduces operating cost

6. Additional Measures

Additional Resource Efficiency and Cleaner Production measures are broadly classified into the following three categories based on investment requirement, implementation complexity, and level of analysis needed:

Low Cost - Easy to implement options:
Minimal or nil investment measures that can be implemented quickly with short payback periods. These include operational improvements and minor modifications aimed at achieving immediate efficiency gains.

Medium Investment - Options requiring further information and detailed analysis:
Medium investment interventions that involve the adoption of advanced process technologies require in-depth technical analysis, performance assessment, and financial feasibility studies.

High Investment - Options for consideration at a later stage (Resource Dependent):
Capital-intensive measures require major changes and long-term planning. Suitable for future expansion or phased implementation.

6.1. Low Investment

Table 13: RECP Opportunities - Low Investment

S. No	RECP Opportunities
1	Mitigating idle operation of Motors (Stop Motion Circuit)
2	Installation of Transvector Nozzle for the Cleaning Applications
3	Reuse of Vapor Condensate of Caustic Recovery Plant
4	Reuse of Cooling Water from Singeing Machines
5	Reuse of Post Bleaching Washes as Pre-Washes at Pre-treatment Machine
6	Installation of Automatic Water Shut-Off Valves at Rotary and Flatbed Printing Machines' Blanket Washing Water
7	Utilization of RO Reject Water
8	Installation of kVAr energy compensator at load end to reduce the line losses
9	Automation in Jet Dyeing and Drum Machine
10	Replace Reciprocating Compressor with Screw Compressor and Installation of Air Pressure Monitoring to reduce air leakages and maintain optimum pressure

6.2.Medium Investment:

Table 14: RECP Opportunities - Medium Investment

S. No	RECP Opportunities
1	Installation of energy efficient airline system in compressed air distribution network
2	Heat Recovery from Hot Wastewater in Continuous Process.
3	Installation of desuperheater for chiller compressor to recover the waste heat
4	Heat Recovery from Hot Wastewater in Jigger Dyeing Machine
5	Heat recovery from exhaust dyeing bath
6	Partial/Full Wastewater Recovery in Rotary Relax Drum Washer
7	Convert V-belt drives to synthetics flat belt drives for the TFO machines
8	Replacement of open jigger with closed maxi jigger

6.3. High Investment

Table 15: RECP Opportunities - High Investment

S. No	RECP Opportunities
1	Replace Old Conventional Motors with Energy Efficient Motors
2	Cogeneration with low-pressure steam turbine
3	Digital Printing
4	Automated colour kitchen for dyeing section
5	Automated colour kitchen for printing section

7. Financial Mechanism and Support Schemes

Textile MSMEs in India, particularly those transitioning towards sustainable and advanced manufacturing practices, can avail a range of financial incentives offered by central and state governments. These schemes support technology upgradation, energy efficiency, environmental compliance, and market expansion.

7.1. Technology Upgradation and Green Incentives

Textile units investing in energy efficient technologies and modern machinery can access the following support mechanisms:

- **MSE-GIFT (Green Investment Financial Technology):** This scheme provides a 2% interest subvention per annum for up to 5 years on term loans up to INR 2 crores. Eligible technologies must be listed under the approved technology catalogue, which includes equipment such as air dyeing systems, auto or rapier looms, PLC based dyeing machines, and energy efficient fans.
- **MSE-SPICE (Circular Economy):** offers a credit linked capital subsidy of 25 percent for existing brownfield units adopting circular economy solutions. The subsidy is capped at INR 12.5 lakhs for projects exceeding INR 50 lakhs.
- MSME Sustainable Certification under the Zero Defect Zero Effect framework provides financial assistance of up to INR 3 lakhs for technology upgradation after certification.

7.2. Telangana State Incentives (For units in Telangana)

Textile units located in Telangana clusters, such as Warangal (Powerloom) or Karimnagar (Sirsilla Powerloom), are eligible for significant capital support:

- T IDEA offers a capital subsidy ranging from 15-25 % for general category micro and small textile units, with a maximum limit of INR 30 lakhs.
- T PRIDE provides enhanced support for SC and ST entrepreneurs, with a capital subsidy of 35 percent and a proposed increase up to 50 %, subject to a maximum of INR 1 crore.
- Women owned enterprises are eligible for an additional capital subsidy ranging from 10 to 20 percent under state schemes.

7.3. General Central Government Subsidies

- **National SC-ST Hub:** Textile units owned by SC/ST entrepreneurs can avail of a 25% subsidy on the purchase of plant, machinery, and equipment, capped at INR 25 lakh.
- **MSME Innovative (Design Component):** If a textile unit initiates a design-led manufacturing project, the government contributes 75% (for Micro) or 60% (for Small & Medium) of the project cost, up to INR 40 lakh.
- **PMEGP (New Units):** For new textile ventures, the Prime Minister's Employment Generation Programme offers a Margin Money subsidy of 15-35% on projects up to INR 50 Lakh.
- **Khadi Vikas Yojana:** For Khadi-specific textile institutions, a subsidy of 35% on prime cost is provided for Cotton/Muslin, Wool, and Polyvastra.

7.4. Marketing and Export Support

- **Procurement and Marketing Support (PMS) Scheme:** Textile MSMEs can receive funding for adopting Modern Packaging Techniques, barcode implementation, and participating in national/international trade fairs.
- **International Cooperation (IC) Scheme:** Units looking to export can get reimbursed for stall charges (up to INR 3 lakh) and airfare (up to INR 1.5 lakh) for participating in international exhibitions.

7.5. Eligible equipment under MSME GIFT Scheme: Textiles

Table 16: Eligible equipment under MSME GIFT Scheme: Textile

Eligible Equipment / Technology	Energy Saving Min (%)	Energy Saving Max (%)
High efficiency atomizers in humidification plant no cleaning required	10	20
Energy efficient fans lesser heat generated	20	25
Variable frequency drive for auto core suction motor smooth start / stop operation	15	30
Transvector nozzle for cleaning application sucks atmospheric air along with air jet	5	10
Yarn conditioning machine noncorrosive stainless steel used for construction	15	20
Automatic rotor spinning machine with mrps system every spinning position shows production rate	20	25
Open-width continuous scouring and bleaching range with microprocessor control controlled cloth tension	15	20
Speed frame machine smooth start / stop operation	10	15
Extrusion lamination line with frequency control motors smooth start / stop operation	10	30
Warp / raschel knitting machine (manufacturing of knitted fabric) inverters to control speed	25	30
Modern industrial humidification system (for controlling relative humidity & temperature) ease to maintain	50	60
Wet fabric spreading and squeezing machine (dyeing) excellent squeezing and spreading performance	20	30
Washing range with arrangement of tension free fabric drying and reduced water consumption / water reuse system (dyeing)	5	10
Hydro extractor (dyeing) very high speed results in quick and maximum hydro extraction	15	20
Tumble dryer (dyeing) fully programmable electronic control	15	20
Multi chamber stenter (min 4 chambers) with arrangement of oil / gas heating (finishing) close circuit air circulation chamber	10	20
Radio frequency / infrared radiant gas fired / microwave / loop / relax dryer (finishing) optimum residual shrinkage with softer	15	20
Balloon padding machine compact in size	10	15
Slit opener with squeeze mangle excellent squeezing performance	30	40

Eligible Equipment / Technology	Energy Saving Min (%)	Energy Saving Max (%)
Plc based compacting machine sensitive load cells	20	30
Plc based mercerizing machine saving of dyestuff in subsequent processing	20	30
Airtight hot air stenter machine (using	25	30
Energy efficient boiler with combustion control system (steam heating system) measures & monitors for design parameters	10	15
Thermo pac (heating system) easy access to parts for maintenance	10	25
Interlock knitting machines higher production rate	5	20
Rib pointel jacquard machines higher production rate	10	30
Rib knitting machines higher production rate	20	30
High speed single jersey knitting machines higher production rate	10	25
Single jersey machines with open width take up system higher production rate	15	30
Single jersey auto striper machines faster pattern setting	5	10
Float plating denim machine higher production rate	15	30
Woven like corduroy machine higher production rate	5	15
High speed circular knitting machines higher production rate	20	25
High speed flexible chip shooter sixth generation high- speed modular chip shooter	30	40
Soft flow / jet flow dyeing machine (low mlr of 1:5 or lower) variable frequency drive for centrifugal pump in jet-dyeing machine	30	35
Squeezer with slit opener	15	30
Balloon padding compact in size	10	25
Relax dryer optimum residual shrinkage with softer	5	25
Float plating denim machine higher production rate	15	30

Eligible Equipment / Technology	Energy Saving Min (%)	Energy Saving Max (%)
Automatic hank / yarn dyeing machine variable conveyor speed	15	20
Lockstitch machine with automatic thread trimmer easy to operate	5	10
Servo-motor stitching machines clutch-less operation	50	60
Clutch motor stitching machines with 3-phase motor accurate clutch operation permits instant start / stop	7	10
Computerized embroidery machine advance dahoo program gives high quality performance	15	20
Automatic printing machine auto start / stop with auto counters	10	30
Industrial washing / drying machine / tumble dryers programmable electronic control	10	15
Draw winder inverter driven motor drive system offers stepless parameter setting in	40	50
Air draw texturizing machine inverter driven motor drive system offers stepless parameter	40	50
Draw texturizing machine inverter driven closed loop speed control for individual drives	40	50
Automatic cone winder variable frequency drive controlled	15	20
Yarn guided machine with precision crossing with inverter control	10	30
High speed shuttle less velcro machine even feeding of yarn and efficient operation	5	20
Water jet looms	40	50
Jacquard machine with electronic control easy to adapt and versatile	40	50
Heat recovery systems for boilers (economizer	5	10
High efficiency diesel generating sets	5	10
Energy efficient fan	25	30
Automatic power factor controller	5	10

Eligible Equipment / Technology	Energy Saving Min (%)	Energy Saving Max (%)
Circular weaving machine optimum output of fabric and quality from the machine	20	25
Tape extrusion line	25	30
Cheese winder capable of producing high quality packages even at the highest operating speed	20	30
Automatic stitching machine	20	25
Bridge guiding machine	20	25
Blow room machinery higher efficiency rates	15	20
Open width knitted inspection machine for fabric with inverter control variable speed drives	25	30
Circular grain knitting machine excellent design	20	25
Four needle chain stitch machine micro adjustment for needle feeding amount	10	15
Automatic saddle stitchers (with variable frequency drive) reduced energy consumption	10	15
Armflat lock machine different sewing patterns	10	15
Automatic package winder	10	15
Ultrasonic cutting machine efficient performance	10	15
Heading machine with semi cover	10	15
Sludge combustion boiler easy and flexible operation	2	5
Synthetic flat belt drives (replace v-belts) extraordinary tensile and high frictional co- efficient	4	8
Water-tube boilers (by replacing conventional smoke-tube boiler) higher steam output	2	5
Energy efficient motor longer life	3	7

8. Implementation Roadmap

The implementation roadmap for Resource Efficient and Cleaner Production (RECP) in the textile sector is structured into four progressive categories based on the priority and maturity of interventions. The roadmap begins with immediate efficiency improvement measures and gradually advances toward renewable integration and long-term technological upgradation. This phased approach enables textile units, particularly MSMEs, to improve operational performance, environmental compliance, and sustainability systematically.

8.1. Phase-wise Implementation Roadmap

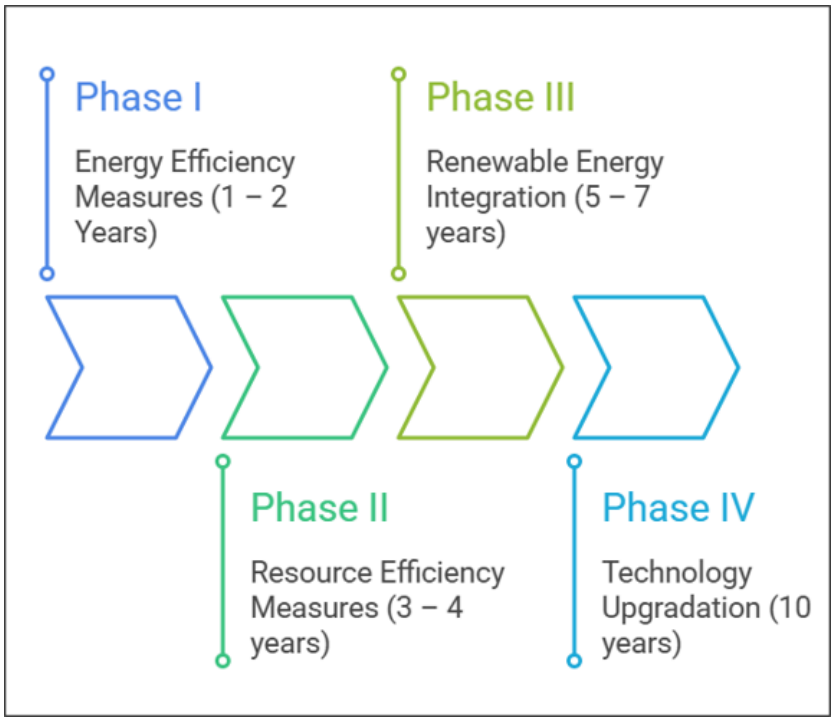


Figure 31: Implementation Roadmap

Phase I: Energy Efficiency Measures (1 – 2 Years)

MSMEs initiate their RECP journey by improving energy efficiency in existing systems and utilities. These measures are prioritized as they deliver immediate cost savings and improve process reliability with minimal disruption.

Key Measures:

- Utility system optimization and preventive maintenance
- Monitoring and controlling energy consumption
- Improvement in thermal insulation and heat utilization
- Installation of energy-efficient equipment and controls
- Process optimization to reduce unnecessary energy consumption
- Awareness and training programs for operators and maintenance personnel

Phase II: Resource Efficiency Measures (3 – 4 years)

This phase focuses on improving the efficient use of water, chemicals, and raw materials. The objective is to reduce waste generation and enhance process efficiency.

Key Measures:

- Water conservation and reuse practices
- Optimization of chemical and process inputs
- Reduction of process waste and material losses
- Improvement in wastewater and effluent management
- Recovery and reuse of heat and process resources
- Strengthening of monitoring and data management systems
- Adoption of cleaner production and waste minimization practices

Phase III: Renewable Energy Integration (5 – 7 years)

This phase emphasizes the transition toward renewable and low carbon energy sources. The objective is to reduce dependence on fossil fuels and improve long term sustainability.

Key Measures:

- Rooftop solar photovoltaic (PV) systems
- Solar thermal systems for hot water generation
- Biomass based boilers and cleaner fuel substitution
- Cogeneration and waste heat utilization systems
- Heat pump based hot water and thermal systems
- Renewable energy procurement through open access or green power agreements
- Battery energy storage and smart energy management systems

Phase IV: Technology Upgradation (10 years)

This phase focuses on long term modernization and transformation toward advanced, sustainable, and globally competitive manufacturing systems.

Key Measures:

- Modernization of production and processing technologies
- Adoption of automation and digital manufacturing systems
- Implementation of advanced water and waste treatment systems
- Integration of circular economy and recycling practices
- Strengthening of sustainability reporting and ESG frameworks
- Adoption of internationally recognized sustainability standards and certifications
- Continuous workforce development and technical capacity building
- Transition toward low impact and climate aligned manufacturing systems

8.1. Role of stakeholders:

Successful implementation of Resource Efficient and Cleaner Production requires coordinated efforts from multiple stakeholders. MSMEs often face constraints related to finance, technology adoption, and technical expertise. Therefore, a strong support ecosystem is essential for effective implementation.

The Government of Telangana, through the Director of Industries and Research and Innovation Circle of Hyderabad, plays an important role in policy support, awareness generation, and capacity building. It also facilitates access to financial incentives and schemes.

Financial institutions support MSMEs by providing credit, subsidies, and green financing options for adopting RECP measures.

Technology providers and clean technology startups contribute by offering efficient technologies, process optimization solutions, and digital tools. These stakeholders collectively enable MSMEs to improve resource efficiency, reduce environmental impact, ensure regulatory compliance, and enhance long term competitiveness.

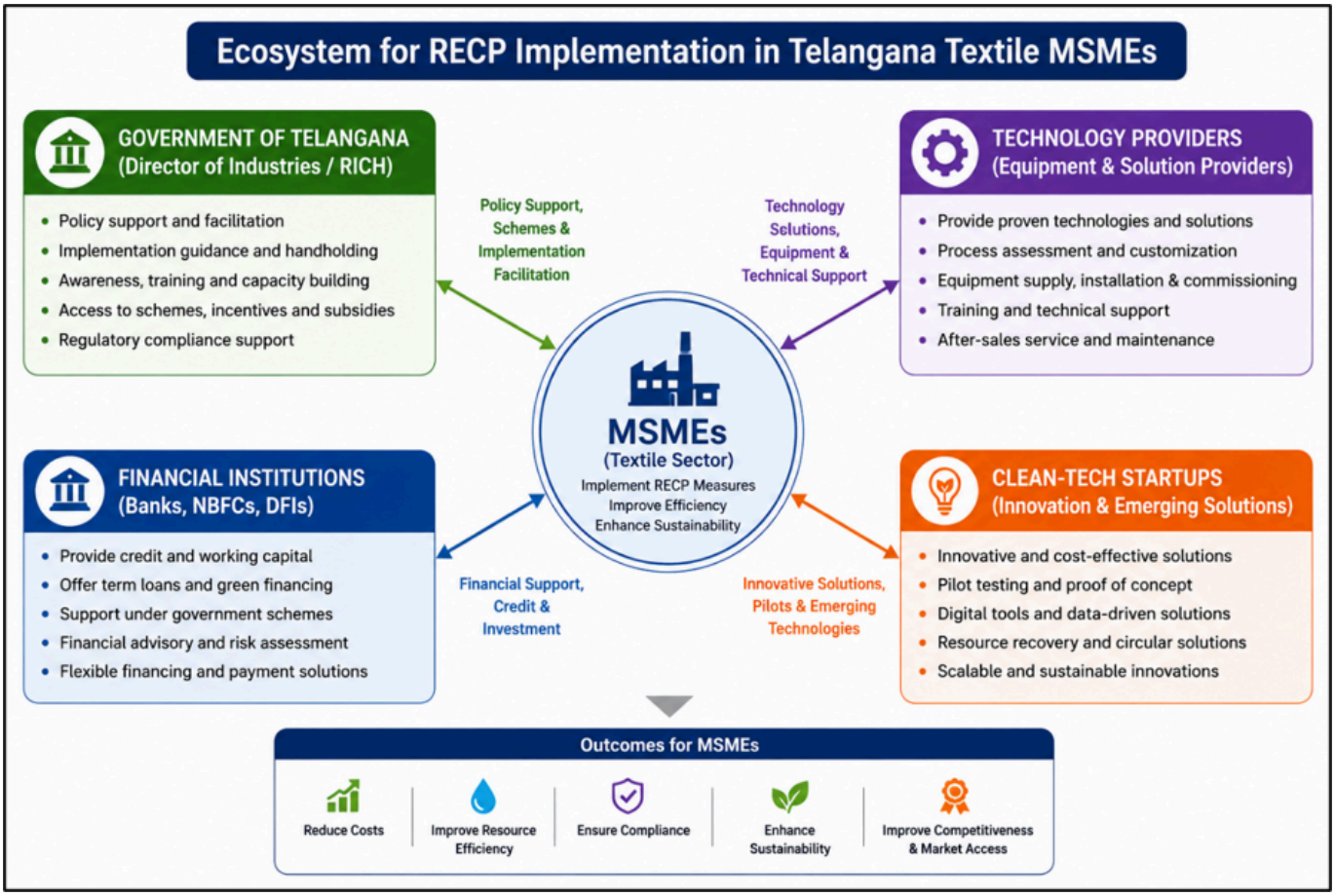


Figure 32: Role of stakeholders in Implementation Roadmap

9. Conclusion

The Indian textile sector plays a critical role in economic growth, employment generation, and export earnings. This compendium presents a comprehensive overview of the sector, including manufacturing processes, resource consumption patterns, cleaner production opportunities, water and waste management practices, financial support mechanisms, and implementation strategies.

The analysis highlights that although the sector faces challenges related to energy use, water consumption, environmental compliance, and global competitiveness, there is strong potential for transformation through technology adoption and efficient resource utilization.

Key insights from this compendium include:

- Wet processing remains the most resource-intensive stage, accounting for maximum thermal energy use, water consumption, and pollutant generation.
- Resource Efficient and Cleaner Production (RECP) interventions can typically achieve 10 - 30% savings in energy and water with short payback periods.
- Advanced technologies such as airflow dyeing, waterless dyeing, heat pumps, automated colour kitchens, and digital printing offer step-change improvements in productivity, quality, and environmental performance.
- Telangana, supported by PM MITRA parks, T-TAP policy incentives, and strong raw material availability, is well positioned to emerge as a competitive and sustainable textile manufacturing hub.

The transition toward resource-efficient and cleaner production is no longer optional. Market pressures from global buyers, regulatory mandates such as Zero Liquid Discharge (ZLD), rising fuel and water costs, and climate commitments necessitate a structured and phased implementation approach across the textile value chain.

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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 Decarbonisation 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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