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ON GREEN ECONOMY



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MINISTRY OF
TEXTILES



INDIA TEXTILE TECHNOLOGY AND INNOVATION ROADMAP

2047

FROM FARM TO FUTURE





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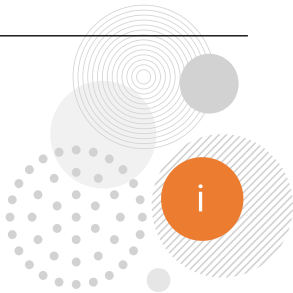
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ACRONYMS

Acronym	Full Form
AI	Artificial Intelligence
BAT	Best Available Techniques
BEE	Bureau of Energy Efficiency
CAGR	Compound Annual Growth Rate
IIoT	Industrial Internet of Things
IoT	Internet of Things
LCA	Life Cycle Assessment
MES	Manufacturing Execution System
MRSL	Manufacturing Restricted Substances List
PAGE	Partnership for Action on Green Economy
PM-MITRA	Mega Integrated Textile Region and Apparel Parks
R&D	Research and Development
TTTF	Textile Technology Transition Fund
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
UNITAR	United Nations Institute for Training and Research
ILO	International Labour Organization
ZLD	Zero Liquid Discharge
ZDHC	Zero Discharge of Hazardous Chemicals



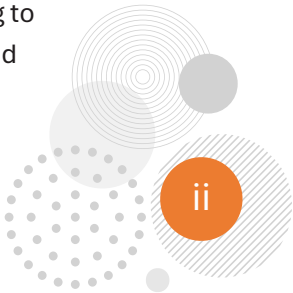
EXECUTIVE SUMMARY

India's textile and apparel sector is one of the country's most strategically important industries, contributing approximately **8.2% of industrial production**, generating **US\$175.7 billion** in domestic production, supporting **more than 45 million direct jobs**, and exporting **US\$35.8 billion** worth of textiles and apparel. Ranked as the **world's sixth-largest textile exporter**, India is also one of the few countries with an integrated textile value chain spanning natural fibres, yarn, fabric, garments, technical textiles, and global markets. These strengths provide a strong foundation for future growth. However, the basis of global competitiveness is changing rapidly. Technology, sustainability, traceability, and innovation are increasingly determining market access, investment decisions, and long-term industrial competitiveness, alongside traditional advantages of scale and cost.

The global textile industry is undergoing its most significant structural transformation in decades. Three converging forces are reshaping the sector. First, automation, artificial intelligence, digital manufacturing, and connected production systems are transforming productivity and operational performance. Second, sustainability has evolved from a voluntary commitment into a prerequisite for market access, with buyers and regulators increasingly requiring verified environmental performance, resource efficiency, and supply chain transparency. Third, advances in bio-based materials, textile-to-textile recycling, advanced processing technologies, and smart manufacturing are creating new competitive frontiers. These changes are already influencing sourcing decisions and investment flows, presenting India with a significant opportunity to strengthen its position within global textile value chains.

India enters this transition with considerable structural advantages. It possesses one of the world's largest manufacturing bases, abundant natural fibre resources, a diversified industrial ecosystem, growing technical capabilities, and an expanding domestic market. At the same time, the Baseline Assessment undertaken as part of this programme identifies several systemic constraints. Technology maturity remains uneven across manufacturing segments, digital adoption is limited, productivity gaps persist, and the commercialisation of research and innovation remains constrained. Resource-intensive manufacturing, fragmented digital infrastructure, and dependence on imported advanced machinery further limit competitiveness. The assessment concludes that future leadership will depend not on isolated technology upgrades but on coordinated transformation across the entire textile value chain.

This **India Textile Technology and Innovation Roadmap 2047** provides the strategic framework to guide that transformation. Developed under the Partnership for Action on Green Economy (PAGE) programme in collaboration with the Ministry of Environment, Forest and Climate Change (MoEFCC) and the Ministry of Textiles, Government of India, the roadmap adopts a future-back planning approach. Rather than projecting current trends forward, it begins by defining the capabilities India must possess by 2047 and identifies the technological, institutional, financial, and policy interventions required to achieve that vision. The roadmap builds upon extensive secondary research, technology horizon scanning, stakeholder consultations, industry workshops, structured questionnaires, cluster analysis, and international benchmarking to establish an evidence-based



pathway for sectoral transformation.

The roadmap identifies six strategic transformation directions that together define India's long-term technology and innovation agenda.

- **Natural Fibre Leadership** aims to transform India's diverse natural fibre base into a globally recognised advantage through improved productivity, quality, traceability, and sustainability credentials.
- **Resource-Intelligent Manufacturing** focuses on reducing water, energy, chemical, and material intensity by accelerating adoption of best available technologies and circular manufacturing practices.
- **Manufacturing Capability** seeks to improve productivity, automation, operational excellence, workforce capability, and quality consistency across textile manufacturing.
- **Digital Infrastructure and Traceability** establishes trusted digital systems that enable end-to-end traceability, lifecycle assessment, compliance reporting, and transparent supply chains.
- **Innovation and Technology** strengthens the ecosystem for research translation, commercialisation, and development of next-generation textile technologies, materials, and manufacturing processes.
- **Technology Sovereignty** builds domestic capabilities in advanced textile machinery, automation systems, and manufacturing technologies to reduce dependence on imported equipment while strengthening India's innovation ecosystem. iiThese six transformation directions are implemented

through the 5F value chain framework, recognising that competitiveness depends upon coordinated progress from **Farm** and **Fibre** through **Factory**, **Fashion**, and **Foreign Markets**. Improvements at one stage strengthen performance throughout the value chain, while gaps in technology, data, or capability create cumulative constraints on productivity, sustainability, and market access. The roadmap therefore approaches transformation as an integrated national system rather than a collection of independent interventions.

Recognising that transformation of this scale must occur progressively, the roadmap adopts a phased implementation pathway.

Align (2026–2030) establishes the foundations for transformation through policy alignment, technology modernisation, digital readiness, financing mechanisms, standards development, skills enhancement, institutional strengthening, and pilot implementation across priority clusters.

Amplify (2030–2035) focuses on scaling successful interventions through widespread deployment of advanced manufacturing technologies, resource-efficient production systems, digital traceability, innovation networks, cluster-based technology programmes, and expanded public-private collaboration.

Accelerate (2035–2047) positions India as a global leader in textile technology and innovation through mature digital infrastructure, advanced manufacturing, circular production systems, domestic technology development, globally competitive machinery capabilities, and sustained innovation-led growth.

Supporting this transformation is a



comprehensive enabling framework comprising investment mechanisms, regulatory reforms, research and innovation partnerships, skills and institutional capacity, digital infrastructure, and collaborative governance. The roadmap emphasises that technology alone will not transform the sector. Long-term competitiveness will depend upon aligning policy, finance, institutions, research organisations, technology providers, and industry around shared national priorities and measurable outcomes.

Successful implementation of the roadmap is expected to position India to achieve its national ambition of **US\$100 billion in textile and apparel exports by 2030**, expand the **technical textiles sector to approximately US\$309 billion by 2047**, and contribute around **US\$1.5 trillion**, representing approximately **5% of a projected US\$30 trillion Viksit Bharat economy**, through technology-led manufacturing, higher productivity, increased value addition, innovation, and sustainable industrial growth.

Transformation at this scale will be measured over decades rather than years.

By **2030**, India should have established the policy, institutional, technological, and financing foundations necessary for large-scale industrial modernisation.

By **2035**, advanced manufacturing, digital systems, resource-intelligent production, and innovation ecosystems should be embedded across major textile clusters, delivering measurable improvements in productivity, sustainability, and competitiveness.

By **2047**, India should have evolved into a globally recognised leader in textile technology and

innovation, characterised by low-carbon manufacturing, circular production systems, trusted digital infrastructure, globally competitive domestic technology capabilities, and resilient, future-ready value chains.

This roadmap is more than a technology strategy. It is a national transformation framework that aligns technology, innovation, investment, policy, and institutional development to strengthen India's global competitiveness while advancing the country's vision of **Viksit Bharat 2047**. By acting decisively during the present window of opportunity, India can move beyond being one of the world's largest textile manufacturers to becoming the world's most trusted, innovative, sustainable, and technology-driven textile economy.



APPROACH & METHODOLOGY

Approach: A Foresight-to-Action Methodology

Textile transformation cannot be planned through extrapolation of current trends alone. Recognising this, the study was developed using a Foresight-to-Action Methodology that integrates empirical evidence, stakeholder intelligence, technology horizon scanning, and systems-level strategic analysis. This future-back planning approach begins by defining the requirements and aspirations for 2047 and works backwards to identify the transformations required today.

Operationally, this methodology follows a diagnostic-to-strategic framework commonly employed in industrial transformation roadmaps and is, structured across three sequential phases:

1. Current State Diagnostic (“Where We Are”).

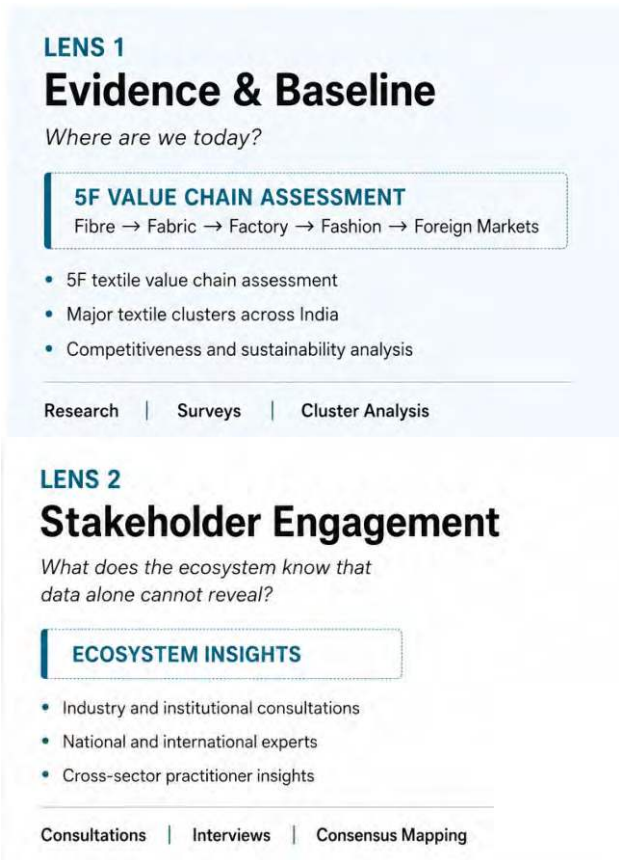
Comprehensive assessment of technology adoption, capacity, resource efficiency, and competitive positioning across India's textile value chain, establishing the baseline against which progress is measured.

2. Gap Analysis and Benchmarking (“Where We Need to Be”). Systematic identification of technology, infrastructure, skills, policy, and financial gaps through comparison against global best such as (EU manufacturers; leading exporters from China, Vietnam, Bangladesh, Turkey), sustainability requirements (India's NDCs, SDGs, ZLD mandates, energy efficiency targets), and market standards (export compliance requirements for the USA, EU, and UAE).

3. Roadmap Development (“How We Get There”). Translation of identified gaps into phased technology pathways (2026-2030-2035-2047), with enabling mechanisms, investment requirements, and implementation frameworks.

Architecture: The Four-Lens Transformation Framework

The above three phases are structured around four complementary analytical lenses, each addressing a distinct question and drawing on a distinct evidence stream. The lenses are not sequential silos; rather, each phase draws on multiple lenses, as shown below.



BREF).

PRIMARY STAKEHOLDER CONSULTATION

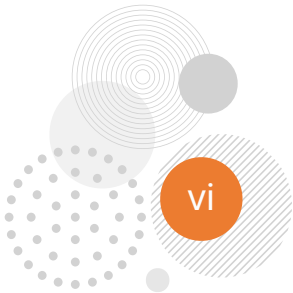
Primary evidence was gathered through three complementary methods, chosen to balance breadth of reach with depth of insight:

Workshops

Three cluster-based workshops were held in Ahmedabad, Surat, and Delhi, with average attendance of 50–60 participants per workshop. The workshops brought together local manufacturers, cluster associations, and allied industry members, who assessed whether issues identified within one segment were recognised as shared concerns across a broader cross-section of the ecosystem.

Interviews

In-depth interviews were conducted with representatives from 24 organisations across seven stakeholder categories. Participants were selected to ensure that the value chain, policy, verification, research, and academic dimensions of the ecosystem were adequately represented:



Data Collection Methodology

The study adopts a multi-method approach, combining secondary research, primary stakeholder consultation, structured questionnaires, and geographic cluster analysis, to capture the diversity of India's textile sector and to allow cross-verification between independent sources.

SECONDARY RESEARCH

Analysis of literature and secondary sources, including government reports (Ministry of Textiles Annual Report 2024–25, production/export statistics), industry reports (AEPC, TEXPROCIL, CITI data), technology documentation (machinery specifications, ITMA data), international best practices (EU BREFs, OECD reports, UNIDO case studies), and regulatory documents (CPCB/GPCB

Category	Organisations consulted
Industry associations ¹	TMMA, ITME, CMAI, SGCCI, SGTPA, GATS, CITI
Manufacturers	Gokaldas Images, Arvind Limited, Sulochana Cotton Spinning Mills, NHDC, SAN International
Brands	H&M Group, ABFRL
Verification / assurance bodies	Bureau Veritas Consumer Product Services, ZDHC Foundation
Textile Research Associations (TRAs)	SITRA, ATIRA, MANTRA
Academia	NIFT, IIT
Cluster associations	Ahmedabad, Surat, Delhi (Okhla)

Questionnaires

Comprehensive structured questionnaires were deployed across the TMMA members to capture equipment inventory and specifications, resource consumption patterns (water, electricity, steam and chemicals), technology modifications and retrofits (VFDs, sensors and heat recovery), resource savings achieved, CAPEX ranges and government support utilised, operational challenges and technology needs.

Coverage:

Each cluster was analysed for fibre type, value chain stage, scale of operations, technology adoption patterns, environmental compliance, and infrastructure availability.

Triangulation, Convergence, and Validation

Reliability across the multi-method design was established through:

1. Cross-verification across sources — primary data (consultations, questionnaires, site visits) checked against secondary data (government statistics, industry reports, vendor studies, research).

2. Convergence criterion for stakeholder findings — a finding was treated as convergent and included in the evidence base only where it was corroborated across at least two of the three most directly affected stakeholder categories (e.g., raised independently by both manufacturers and a verification body, or by both an industry association and cluster-level workshop participants). Where possible, findings were also cross-checked against secondary data or technology horizon scanning (Lens 3). Findings raised within a single stakeholder category are flagged as illustrative rather than representative where cited.

3. Expert validation and stakeholder feedback — preliminary findings were shared back with a subset of consulted stakeholders for confirmation prior to finalisation.



Scope and Limitations

- **Sectoral scope** - Focus on manufacturing technologies, while agricultural, logistics, and retail segments are outside the scope.
- **Coverage** - Organised and semi-organised sectors are covered; informal-sector coverage is limited.
- **Sampling** - Representative, purposive sampling was used rather than an exhaustive census. Workshop participation may be skewed towards organisations with existing cluster-association membership, while interview coverage, although spanning seven stakeholder categories, remains purposive rather than exhaustive within each category.
- **Characterisation** - Findings are qualitative and strategic in character, not detailed engineering specifications.
- **Disclosed institutional interest** - Verification and assurance bodies (Bureau Veritas Consumer Product Services and ZDHC) hold an institutional stake in compliance and traceability infrastructure that may shape their framing of adoption barriers. This is disclosed rather than treated as disqualifying, and such inputs are cross-verified per Section 0.4 before inclusion as findings.

This methodology provides the evidence-based foundation for the priority technology interventions presented from the baseline through the 2030 milestones to the 2047 vision.

This roadmap focuses on the technology transformation of India's textile and apparel manufacturing value chain, covering the stages

from raw material processing through to export readiness. It does not address upstream agricultural production, logistics and distribution, retail, or consumer behaviour.

The analysis primarily covers the organised and semi-organised manufacturing sectors. While the informal sector constitutes an important part of India's textile ecosystem, particularly 7in powerloom weaving and small-scale processing, its transition requires dedicated policy instruments and implementation approaches that fall beyond the scope of this roadmap.

The roadmap takes a strategic rather than an engineering perspective. It defines the priorities, sequencing, and enabling conditions required to accelerate technology adoption across the sector. Detailed technology specifications, equipment assessments, and technical evaluations are presented separately in the accompanying Technology and Innovation Compendium.

Purpose and Positioning

This document is India's Technology and Innovation Roadmap for the textile sector.

A STRATEGIC INSTRUMENT DESIGNED TO DEFINE WHAT THE SECTOR MUST BECOME BY 2047 AND WHAT MUST BE DONE, AND IN WHAT SEQUENCE, TO ACHIEVE THE VISION.

This roadmap draws on the Baseline Assessment conducted and the Technology & Innovation Roadmap and translates their findings into a strategic architecture: a connected set of technology pathways, institutional actions, enabling conditions, and governance mechanisms that together constitute a



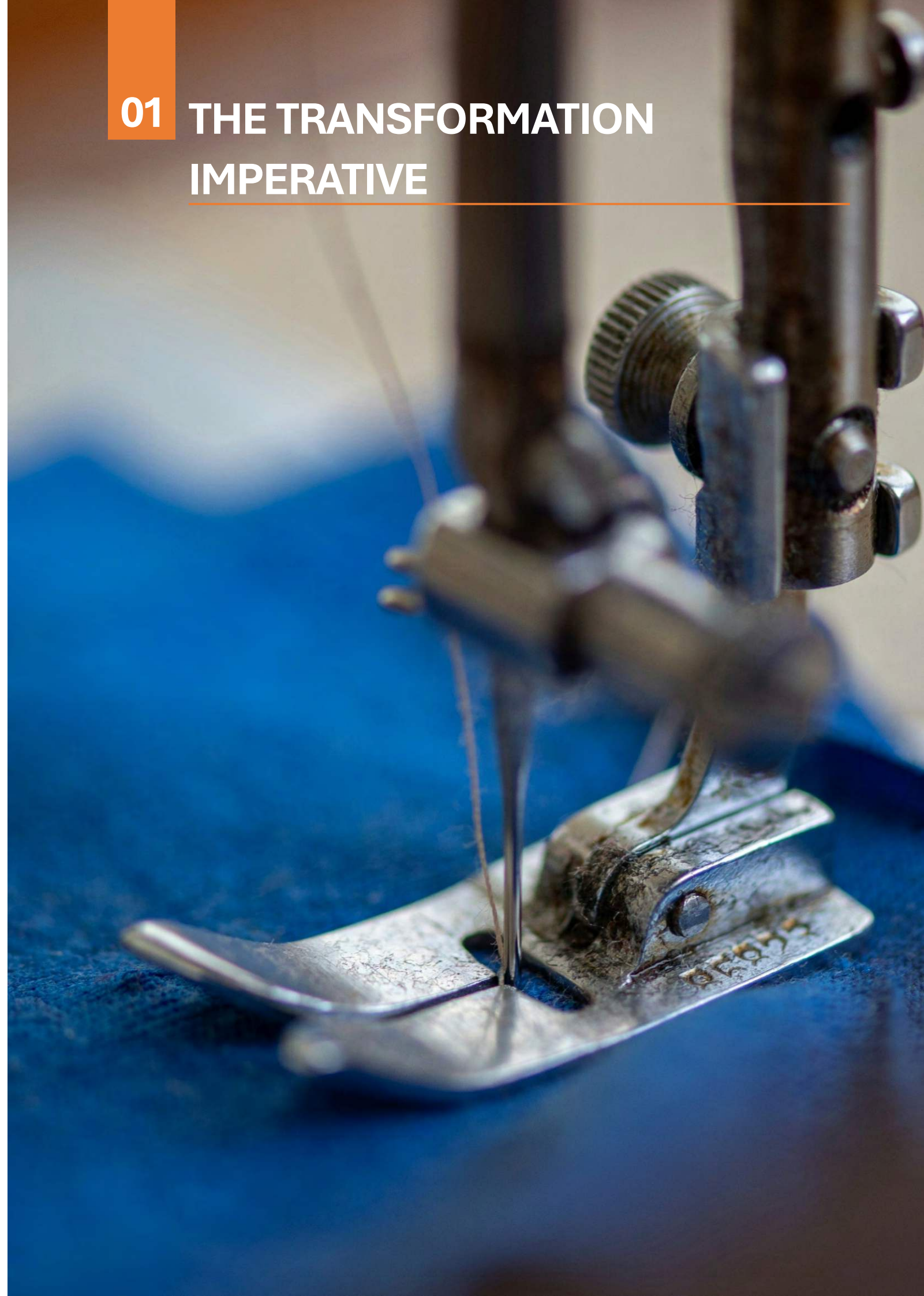
credible transformation programme.

The roadmap has been developed under the Partnership for Action on Green Economy (PAGE) India programme, implemented by UNIDO with the Ministry of Textiles, Government of India, and the Centre for Environment Education. Its primary audience is the Ministry of Textiles and associated government bodies. Its findings are intended to feed into India's broader green manufacturing vision for the sector and to provide a foundation for subsequent policy instruments, investment programmes, and institutional actions.

One positioning note that matters: this document is deliberately forward-looking. It does not begin with the current state of the sector and project existing trends forward. Instead, it starts from what India's textile sector must be in 2047 - a low-carbon, circular, globally competitive, and technologically sovereign and works backwards to identify the transformations required in the present. This represents a distinct analytical approach from that of a conventional sector study and, consequently, leads to a different set of recommendations.



01 THE TRANSFORMATION IMPERATIVE



Sector Profile and Strategic Importance

India's textile and apparel sector is the country's largest manufacturing employer, the world's sixth-largest textile exporter, and one of the few globally with an integrated value chain. The figures presented below are not future ambitions; they represent the scale, capability, and competitive foundation upon which this Vision 2047 roadmap is built.

SECTOR AT A GLANCE



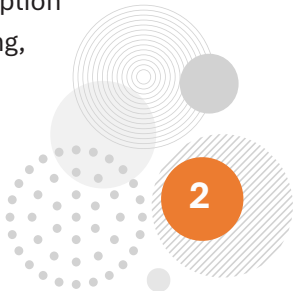
Source: Ministry of Textiles - Annual Report 2024-25

What makes India's position distinctive is not scale alone but breadth. Bangladesh is a garment economy. Vietnam is an assembly economy. Turkey is a speed-to-market economy. India is all of these simultaneously, and more: a raw material base that holds first position globally in cotton acreage, a craft heritage unmatched anywhere, and a technical textiles frontier that sits at \$29 billion today and is projected at \$309 billion by 2047. No single competitor can replicate this span.

But breadth without modernisation is width without depth, and in the decade ahead, depth is what buyers, regulators, and the competitive landscape are demanding. India exports 840 textile products, but 52% of exports come from just 134 items. That concentration is not the signature of a sector capitalising on its breadth. It is the signature of a sector that has not yet unlocked it. The global landscape that India is entering as a \$37.7 billion exporter is materially different from the one it must navigate as a \$100 billion exporter by 2030. Three forces are already reshaping the rules of this evolving global environment.

Value Chain Technology Baseline (2026)

The Baseline Assessment undertaken under this programme evaluated technology adoption across India's textile value chain consisting: Spinning, Weaving, Knitting, Wet Processing, and Ready-Made Garments.



The assessment combined stakeholder consultations, equipment-level assessments, and cluster-based field studies to establish the evidence base for the technology transformation pathway presented in this roadmap.

A clear pattern emerged across all five segments. India possesses one of the world's largest textile manufacturing bases, but its technology profile is highly heterogeneous, ranging from globally competitive facilities to ageing conventional equipment

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	SPINNING	WEAVING	KNITTING	WET PROCESSING	GARMENTING
Current Position	Large manufacturing base with mixed technology maturity	Productivity constrained by legacy technologies	Competitive manufacturing base with uneven technology adoption	Highest resource and compliance intensity across the value chain	Labour-intensive production with uneven automation
Technology Maturity	Moderate	Moderate-Low	Moderate	Moderate	Moderate-Low
Digital Maturity	Limited	Limited	Limited	Developing	Limited
Primary Transformation Priority	Manufacturing Capability at Scale	Manufacturing Capability at Scale	Manufacturing Capability at Scale	Resource-Intelligent Manufacturing	Manufacturing Capability at Scale
Key Transition Required	Improve quality consistency and process visibility	Improve productivity and production visibility	Expand advanced manufacturing capability	Improve resource performance and compliance	Improve productivity, digital operations and workforce capability
Downstream Contribution	Higher-quality yarn	Better fabric quality	Consistent fabric production	Verified sustainability and compliance data	Production and traceability records



These gaps compound across the value chain. Technology limitations at one stage reduce the performance potential of the subsequent stages creating cumulative impacts on quality, productivity, resource efficiency, and competitiveness. As a result, downstream performance is constrained not only by the technologies deployed at individual facilities, but by the capabilities established upstream. Strengthening the sector therefore requires coordinated transformation across the entire value chain rather than isolated technology upgrades.

The Baseline Assessment also examined technology adoption across major textile clusters, revealing substantial differences in industrial structure, technology maturity, and compliance readiness. These findings reinforce a central conclusion of this roadmap: transformation must be delivered through cluster-based implementation rather than uniform sector-wide interventions. Financing, common infrastructure, technology support, and skilling are most effective when designed around the specific needs and capabilities of each cluster.

The Global Technology and Market Shift

The global textile industry is undergoing its most significant structural shift since the introduction of synthetic fibres. Three forces are reshaping what it means to be a competitive textile manufacturer — and all three are moving faster than India's current response.

1

Automation and Digitalisation
Digitalization is becoming a prerequisite for competitiveness. IoT, AI, Manufacturing Execution Systems (MES), and digital twins are increasingly embedded across global textile supply chains. Beyond productivity gains, these technologies generate the operational data required for traceability, sustainability reporting, compliance, and buyer verification. In a data-driven market, digitally enabled manufacturing is rapidly becoming the baseline rather than a competitive advantage.

2

Sustainability as a Manufacturing Standard
Sustainability is shifting from voluntary commitment to market requirement. Regulations, buyer expectations, and emerging disclosure frameworks increasingly link market access to environmental performance, traceability, and responsible production. Competitiveness will depend not only on cost and quality, but on the ability to demonstrate credible sustainability outcomes.

3

New Materials and Process Paradigms
Bio-based fibres, textile-to-textile recycling, advanced processing technologies, and AI-enabled manufacturing are moving from pilot projects to commercial reality. The strategic question for India is no longer whether these technologies will shape the sector, but whether India will lead their development, accelerate their adoption, or remain dependent on innovation developed elsewhere.



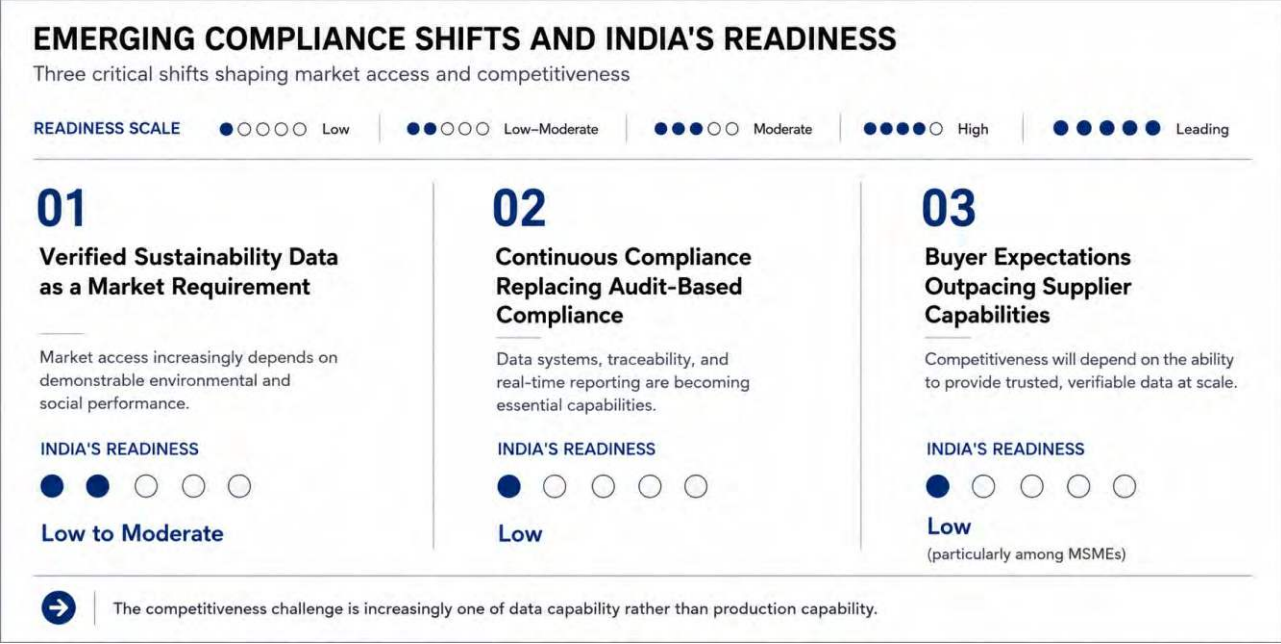
These forces are not external to India's sector. They are already arriving in the form of procurement requirements, regulatory timelines, and sourcing decisions. Buyers have translated all three into contractual language, and that language is landing on Indian suppliers now.

Evolving Market and Regulatory Requirements

Buyer sustainability requirements have crossed a threshold. They are no longer limited to sustainability programme commitments reviewed annually in ESG reports. Instead, they are procurement conditions embedded in purchase contracts, enforced through supplier audits, and backed by brand-level net-zero commitments that cannot be achieved without supply chain decarbonisation.

The direction of going forward is clear. Global brands are moving from periodic certification and audit-based approaches toward continuous, data-driven models of compliance, traceability, and performance verification. Circularity, emissions reduction, and supply chain transparency are increasingly being integrated into sourcing decisions rather than treated as standalone sustainability requirements.

Consultations also revealed a significant implementation gap within the Indian ecosystem, where financing constraints, limited technology adoption, and organisational readiness continue to slow the pace of transformation despite growing market expectations. Three findings from consultations converge here:



India's Competitive Position

The competitive picture is specific, not abstract. India's principal competitors did not stumble into their export positions. They built them through deliberate, sustained technology investment in defined domains, and they are continuing to invest ahead of India on precisely the dimensions that will determine the next decade of global textile trade.



The competitive landscape is evolving rapidly. China continues to advance automation and digital manufacturing, Vietnam is leveraging trade agreements and technology adoption, while Bangladesh and Turkey are strengthening sustainability and market responsiveness.

FOR INDIA, THE OPPORTUNITY LIES IN COMBINING ITS INTEGRATED VALUE CHAIN, MANUFACTURING SCALE, AND INNOVATION POTENTIAL TO LEAD THE NEXT PHASE OF TEXTILE TRANSFORMATION.



Strategic Learnings from Global Leaders

The policy learning from competitor trajectories is specific, not generic. The selected countries are among the world's leading textile and apparel exporters and represent key export competitors for India, each offering a distinct lesson in technology adoption, industrial capability, or market positioning. However, none offers a model India should replicate wholesale.



The lessons from global competitors extend beyond individual technologies or business models. China's experience demonstrates the importance of sustained investment in innovation, R&D, and technology deployment at scale. Bangladesh's evolution highlights the growing importance of sustainability and value addition alongside manufacturing competitiveness. Vietnam's progress illustrates how coordinated policy support, market access, and enterprise-level transformation can accelerate sectoral growth.

The common thread across these experiences is institutional alignment. Successful textile economies have created mechanisms that connect policy, technology, finance, data systems, and industry implementation within a coordinated framework. For India, strengthening this integration represents one of the most significant opportunities to accelerate transformation and maximise the impact of existing strengths and initiatives.



TECHNOLOGIES ARE AVAILABLE. THE FINANCING SCHEMES EXIST. WHAT IS MISSING IS THE INNOVATIVE MECHANISM THAT CONNECTS THEM.

Understanding where India's own gaps are concentrated is therefore the necessary next step.

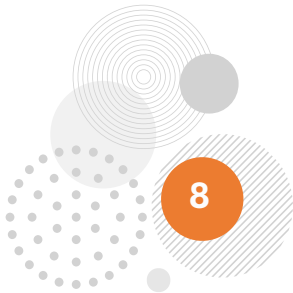
Six Transformation Directions

The gap analysis undertaken through the Baseline Assessment and stakeholder consultations reveals not six isolated weaknesses, but six strategic dimensions where India's textile sector must undergo structural transformation.

Each dimension has a current position, a documented gap, and a transformation destination. Together they constitute the technology and innovation agenda this roadmap is built around, and the thread that runs through every section that follows.

Six gaps define where transformation must concentrate:

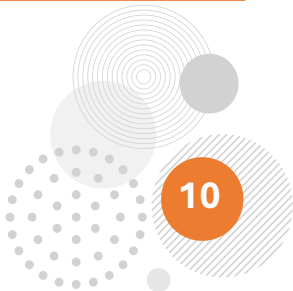
1.	Natural Fibre Leadership	Challenge: India possesses one of the world's most diverse natural fibre ecosystems, spanning cotton, silk, jute, wool, and emerging bio-based materials. Yet this advantage remains under-realised due to productivity gaps, inconsistent quality, and limited adoption of traceability and sustainability credentials. Strategic Imperative: Transform India's natural fibre advantage into a globally recognised and verifiable market proposition. Transformation Direction: Establish India as the global leader in certified, traceable, and high-quality natural fibres by integrating productivity improvement, quality assurance, and sustainability credentials across major fibre value chains. Primary 5F Linkage: F1 Farm and F2 Fibre
2.	Resource-Intelligent Manufacturing	Challenge: Resource inefficiency remains one of the largest constraints on competitiveness across the textile value chain. High consumption of water, energy, chemicals, and materials continues to increase production costs while intensifying environmental and regulatory pressures.



		Strategic Imperative: Transform resource efficiency into a source of competitiveness. Transformation Direction: Make resource-intelligent manufacturing the industry norm through best available technologies, efficient process design, renewable energy, and circular resource management, improving competitiveness, sustainability, and compliance simultaneously. Primary 5F Linkage: F3 Factory
3.	Manufacturing Capability	Challenge: India possesses substantial manufacturing capacity but continues to face productivity, automation, and operational excellence gaps in comparison to leading global competitors. Technology investments frequently underperform because workforce capability, management systems, and digital integration have not advanced at the same pace. Strategic Imperative: Combine technology adoption with operational excellence. Transformation Direction: Build globally competitive manufacturing capability by integrating advanced technologies, digital operations, skilled talent, and data-driven decision-making to deliver higher productivity, quality, responsiveness, and reliability at scale. Primary 5F Linkage: F3 Factory and F4 Fashion
4.	Digital Infrastructure and Traceability	Challenge: Global competitiveness increasingly depends on trusted data, traceability, and transparency. Yet digital readiness and lifecycle data infrastructure remain fragmented across much of India's textile Strategic Imperative: Make trusted data a strategic asset.



5.	Innovation and Technology	Transformation Direction: Establish an integrated digital infrastructure that enables end-to-end traceability, lifecycle assessment, and interoperable information systems, strengthening compliance, sustainability reporting, and buyer confidence.
		Primary 5F Linkage: All 5F Stages
		Challenge: India has a strong research base but limited translation of research into commercially deployed textile technologies. As a result, much of the sector remains dependent on innovations developed elsewhere.
		Strategic Imperative: Shift from technology adoption to technology origination.
6.	Technology Sovereignty	Transformation Direction: Build a nationally coordinated innovation ecosystem that connects industry, academia, research institutions, and start-ups to develop, validate, commercialise, and scale next-generation materials, manufacturing technologies, and digital solutions within India.
		Primary 5F Linkage: All 5F Stages
		Challenge: India remains highly dependent on imported textile machinery, advanced components, and manufacturing technologies. This dependence limits long-term competitiveness and creates strategic vulnerabilities across the sector.
		Strategic Imperative: Strengthen domestic technological capability.
		Transformation Direction: Develop globally competitive capabilities in textile machinery, automation systems, advanced components, and manufacturing technologies through targeted R&D, strategic partnerships, and ecosystem development, reducing dependence on imported technologies while strengthening innovation capacity.
		Primary 5F Linkage: Cross-Cutting Enabler



These gaps are not reasons for hesitation. Each one is a map coordinate. And every gap closed becomes a competitive credential, a cost saving, a compliance asset, and a market access enabler at the same time.

The 5F Dependency

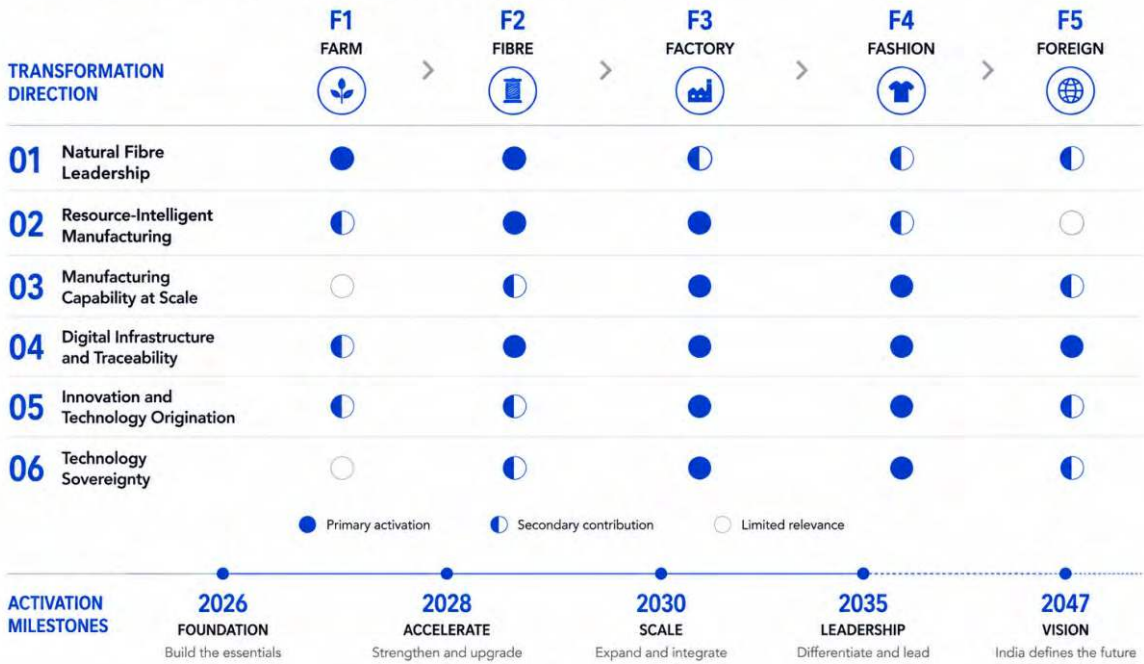
THE SIX TRANSFORMATION DIRECTIONS ARE INTERCONNECTED ACROSS THE 5F VALUE CHAIN.

- **Natural Fibre Leadership** establishes the foundation of quality, traceability, and sustainability credentials.
- **Resource-Intelligent Manufacturing** and **Manufacturing Capability** generate the efficiency, productivity, and operational data required for competitiveness.
- **Digital Infrastructure and Traceability** connect these capabilities into trusted value chains, while
- **Innovation and Technology Origination** and **Technology Sovereignty** ensure that future technologies are developed, commercialised, and deployed within India.

As a result, weaknesses in any one direction propagate across the value chain and ultimately affect competitiveness, compliance, market access, and value creation. The roadmap therefore approaches transformation as a coordinated system rather than a collection of independent initiatives.

INDIA'S TRANSFORMATION ACTIVATION MAP

Where each transformation direction activates across the 5F value chain



The export, sustainability, innovation, and value-addition ambitions outlined in this roadmap can only be achieved when all six directions advance together across the five stages of the 5F framework. The milestone pathways, enabling conditions, and governance mechanisms presented in subsequent sections are designed to support this integrated transformation journey.

The 2047 Opportunity

The case is not that India is falling behind. The case is that India is standing still while the conditions for transformation are open, and windows of this kind do not stay open indefinitely.

Buyers are actively diversifying away from China

and seeking supply bases with the scale, fibre diversity, workforce depth, and democratic legitimacy to sustain long-term sourcing relationships. No competing market simultaneously offers all of these. India does. That is not a permanent advantage. It is a window, and it is open now.

THE TABLE BELOW PRESENTS THE LONG-TERM OUTCOMES THAT DEFINE INDIA'S TEXTILE TRANSFORMATION BY 2047. TOGETHER, THESE TARGETS POSITION THE SECTOR TO CONTRIBUTE APPROXIMATELY US\$1.5 TRILLION, OR AROUND 5% OF A PROJECTED US\$30 TRILLION VIKSIT BHARAT ECONOMY, THROUGH TECHNOLOGY-LED AND GLOBALLY COMPETITIVE GROWTH.

2030	2047	
\$100 Billion - Exports	\$309 Billion - Technical Textiles	\$1.5 Trillion - Total Textile Sector
The government's stated target, requiring 16% CAGR from today's \$37.7 billion. Achievable, only through technology-led transformation, and not through volume expansion of current product mix.	The highest-value, fastest-growing segment of global textile demand, where India's material base, institutional capacity, and manufacturing depth give it genuine structural advantages that no single-stage competitor can replicate.	Representing 5% of a \$30 trillion Viksit Bharat economy, making textiles one of the largest individual sectoral contributions to India's centenary vision.

Source: Ministry of Textiles, Government of India; NITI Aayog; analysis

None of this trajectory is automatic. It runs directly through the technology and innovation investments this roadmap describes. It does not run through business as usual, and it does not reward a reactive posture. India's current approach of responding to buyer audits, regulatory deadlines, and export rejections is insufficient to achieve the ambition of \$100 billion in exports by 2030, let alone \$1.5 trillion by 2047. What will deliver it is a proactive transformation programme: designed now, funded now, governed now.

The next section defines what that programme is committed to: the vision India's textile sector is building toward, the convictions that shape how it gets there, and the milestone targets that make the commitment measurable

02 VISION & STRATEGIC DIRECTIONS



Vision 2047

BY 2047, INDIA'S TEXTILE SECTOR WILL BE THE WORLD'S MOST COMPETITIVE AND SUSTAINABLE TEXTILE ECONOMY, TRANSFORMING ITS SCALE, DIVERSITY, AND RESOURCE BASE INTO A SOURCE OF TECHNOLOGICAL LEADERSHIP, CIRCULAR GROWTH, AND ENDURING GLOBAL ADVANTAGE.

The previous section established the external conditions.

- Buyers are mandating transformation.
- Competitors are investing ahead of India.

The gaps are real and systemic. But a gap analysis without a destination is only diagnosis. This section names the destination.

That is not a rhetorical aspiration. It is a strategic commitment with **four specific dimensions**.

LOW-CARBON <i>From Carbon Liability to Carbon Value</i>	CIRCULAR <i>Material Remain in Circulation</i>	GLOBALLY COMPETITIVE <i>Competing on Trust</i>	TECHNOLOGY ORIGINATOR <i>Creating, Not Importing Innovation</i>
• Resource efficiency becomes a core source of competitiveness. • Emissions intensity declines significantly across the value chain. • Carbon markets create new value streams alongside compliance benefits. • Decarbonisation strengthens both environmental and business performance.	• Fibre-to-fibre recycling operates at commercial scale. • Closed-loop material systems become embedded across the value chain. • Agri-waste emerges as a strategic feedstock for textile applications. • Dependence on virgin resources is progressively reduced.	• Verified sustainability, transparency, and traceability becomes sources of market advantage. • India differentiates itself through reliability, quality, and sustainability. • Fibre diversity, manufacturing depth, and heritage strengthen global positioning. • Trusted value chains support access to premium markets.	• Strong innovation ecosystems connect industry, academia, and startups. • Advanced materials, processes, and technologies are developed and scaled in India. • Research, validation, and commercialization capabilities are strengthened. • India emerges as a source of textile innovation and technology exports.

THE 2047 VISION SHIFTS INDIA FROM A REACTIVE TO A PROACTIVE POSITION, SETTING THE PACE ON COMPLIANCE, TECHNOLOGY ADOPTION, AND SUSTAINABILITY PERFORMANCE RATHER THAN ADAPTING TO STANDARDS DEFINED ELSEWHERE.

Historically, much of the sector's transformation has been driven by external triggers, including buyer requirements, regulatory changes, and technology developments originating elsewhere. The next phase of growth requires a different approach: anticipating change rather than responding to it, shaping market expectations rather than adapting to them, and building capabilities that position India at the forefront of global textile transformation.

Six Transformation Directions: India's Strategic Bets

In the previous section, the six transformation directions were introduced through the evidence: where India's textile sector stands today, where the gaps lie, and what must change to remain competitive in a rapidly evolving global landscape.

The 2047 vision commits India to four attributes: Low-Carbon, Circular, Globally Competitive, and Technology Originator. These are not four separate programmes. They are four qualities that the six transformation directions build simultaneously.

01

NATURAL FIBRE LEADERSHIP

From Natural Fibre Advantage to Verified Market Leadership

- India's diverse natural fibre base becomes a globally differentiated competitive advantage.
- Quality, traceability, and sustainability credentials become standard across major fibre streams.
- Natural fibres command greater market confidence and premium value.
- Farmers, manufacturers, and exporters benefit from stronger value addition.

02

RESOURCE-INTELLIGENT MANUFACTURING

From Resource Consumption to Competitive Advantage

- Water, energy, materials, and chemicals are used more efficiently across manufacturing.
- Resource efficiency strengthens productivity, profitability, and sustainability together.
- Lower environmental impacts improve regulatory compliance and market access.
- Circular resource flows become standard manufacturing practice.

3

MANUFACTURING CAPABILITY AT SCALE

From Manufacturing Capacity to Manufacturing Excellence

- Productivity, quality, and responsiveness improve across the value chain.
- Automation and digital systems enhance operational performance.
- Workforce capability evolves alongside technology adoption.
- India competes on reliability, speed, and manufacturing excellence.

5

INNOVATION & TECHNOLOGY ORIGATION

From Technology Adoption to Technology Creation

- Industry, academia, and research institutions innovate together.
- New materials, processes, and manufacturing technologies are developed in India.
- Research is translated into commercial products and industrial adoption.
- India becomes a recognised source of textile innovation.

The six transformation directions form an integrated system that advances competitiveness, sustainability, innovation, and resilience across the textile value chain. Progress in one direction reinforces progress in others, while gaps in any one area constrain the performance of the whole system.

For this reason, the roadmap treats the six directions as mutually reinforcing pillars of sector transformation rather than independent programmes. The milestone pathways, enabling conditions, and governance mechanisms presented in subsequent sections are designed to advance them in a coordinated manner.

4

DIGITAL INFRASTRUCTURE & TRACEABILITY

From Fragmented Data to Trusted Digital Value Chains

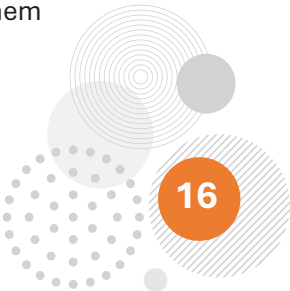
- End-to-end traceability becomes embedded across the textile value chain.
- Operational data supports compliance, lifecycle assessment, and buyer confidence.
- Sustainability performance becomes measurable and verifiable.
- Digital infrastructure strengthens transparency and global market access.

6

TECHNOLOGY SOVEREIGNTY

From Import Dependence to Indigenous Capability

- Domestic capability in textile machinery and advanced technologies expands.
- Strategic dependence on imported technologies is progressively reduced.
- Indian firms strengthen their position in global technology value chains.
- Technology development creates new manufacturing and export opportunities.

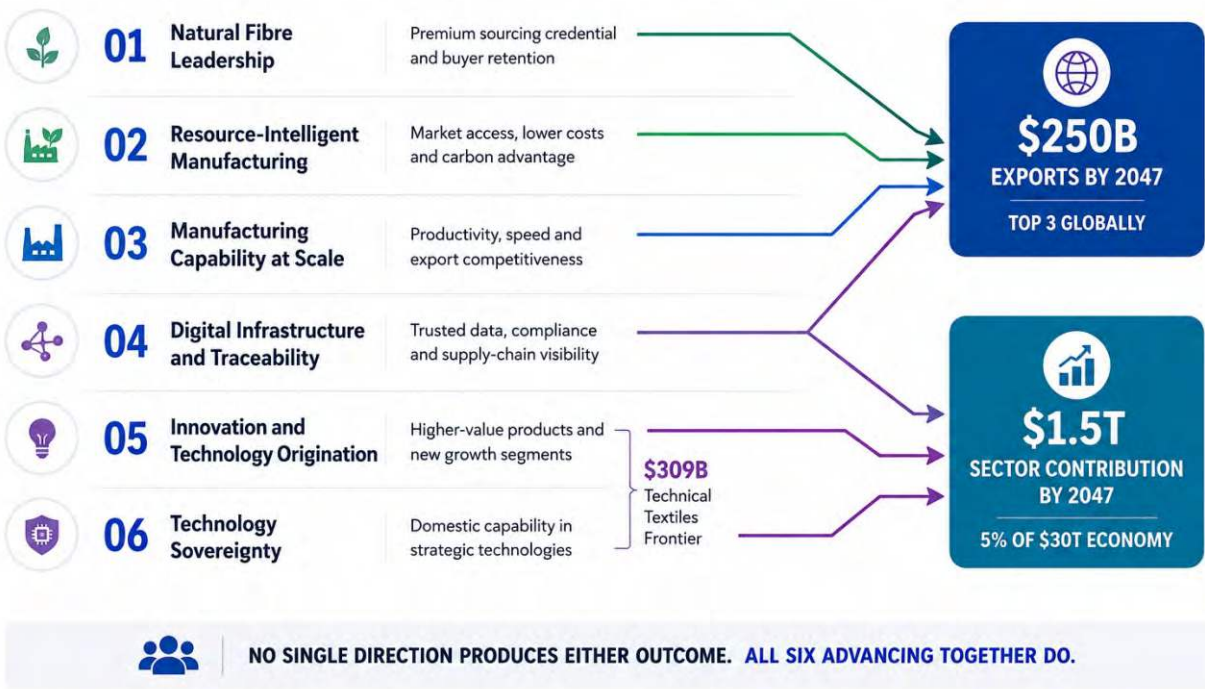


Milestone Targets - From Transformation Directions to Headline Numbers

Before the milestone targets, the connection between the six transformation directions and the two headline numbers must be stated explicitly. The \$250 billion export target and the \$1.5 trillion sector contribution do not emerge from any single direction. They are the compounded output of **all six directions advancing together**.

SIX TRANSFORMATION DIRECTIONS. TWO BIG OUTCOMES.

All six advancing together will deliver India's textile future.



THE AMBITIONS OUTLINED IN THIS ROADMAP ARE THE CUMULATIVE OUTCOME OF ALL SIX TRANSFORMATION DIRECTIONS WORKING TOGETHER.

Natural Fibre Leadership, Resource-Intelligent Manufacturing, and Manufacturing Capability at Scale strengthen India's ability to compete in global markets by improving quality, productivity, sustainability performance, and buyer confidence. Together, they form the foundation for sustained export growth and enhanced global competitiveness.

Innovation and Technology Origination and Technology Sovereignty position India to capture greater value from emerging opportunities in technical textiles, advanced materials, and next-generation manufacturing. These directions strengthen domestic technology capabilities while reducing dependence on imported solutions, enabling India to compete increasingly on innovation rather than cost alone.

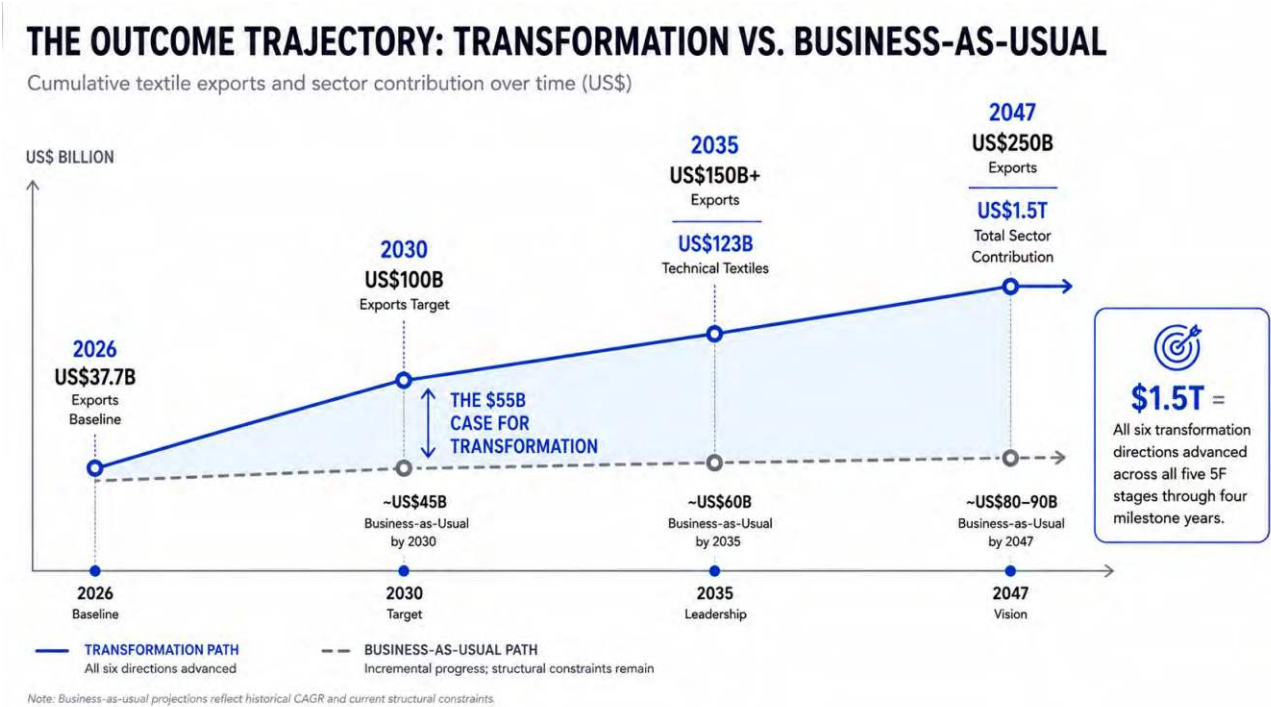


Digital Infrastructure and Traceability serve as the connective layer across the entire ecosystem.

It transforms quality, sustainability, and productivity achievements into verifiable market credentials, enabling compliance, transparency, and trusted access to global value chains. In this sense, digital infrastructure is not a standalone

capability but the mechanism through which the benefits of all other transformation directions become visible and commercially valuable.

THE MILESTONE TARGET MATRIX



The milestones outlined above represent the capabilities that must be built for the sector to move from its current trajectory to the Vision 2047 pathway. Under a business-as-usual scenario, textile exports are projected to reach approximately US\$45 billion by 2030. Achieving the Government's US\$100 billion exports ambition requires a fundamentally different trajectory, one defined by higher productivity, greater sustainability performance, stronger traceability, accelerated

technology adoption, and enhanced manufacturing competitiveness.

The same principle applies to technical textiles and advanced manufacturing. Long-term leadership in these segments depends on sustained investment in innovation, research commercialisation, and domestic technology capability. The institutions, partnerships, and innovation ecosystems established during the current

decade will determine India's ability to capture future opportunities in advanced materials, technical textiles, and next-generation manufacturing.

FOR THIS REASON, THE 2030 MILESTONE IS MORE THAN A GROWTH TARGET. IT IS THE

FIRST STRATEGIC VALIDATION POINT FOR THE TRANSFORMATION PATHWAY OUTLINED IN THIS ROADMAP. PROGRESS ACHIEVED BY THIS STAGE WILL LARGELY DETERMINE THE PACE, SCALE, AND CREDIBILITY OF THE SECTOR'S JOURNEY TOWARD ITS 2047 AMBITIONS

TRANSFORMATION DIRECTION	2026	2030	2035	2047
	Baseline	Scale	Leadership	Vision
NATURAL FIBRE LEADERSHIP	Yield & Traceability Gap	Certified Fibre Growth	Global Competitiveness	Global Leadership
RESOURCE-INTELLIGENT MANUFACTURING	Below Global BAT	BAT-Aligned	Global Best Practice	Global Benchmark
MANUFACTURING CAPABILITY AT SCALE	Industry 2.0–3.0	Digitally Enabled	Advanced Manufacturing	Global Benchmark
DIGITAL INFRASTRUCTURE & TRACEABILITY	Limited Adoption	Exporter Ready	End-to-End Traceable	Digital-by-Default
INNOVATION & TECHNOLOGY ORIGATION	<0.3% Revenue Invested in R&D	1% Revenue Invested in R&D	2% Revenue Invested in R&D	3%+ Revenue Invested in R&D
TECHNOLOGY SOVEREIGNTY	Technology Adoption	Applied Innovation	Technology Development	Technology Origination

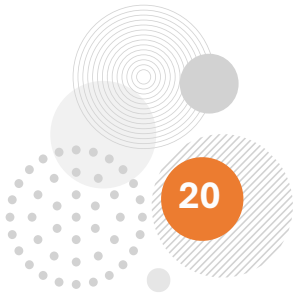
The milestones presented above should be read as a connected progression rather than a collection of independent targets. Each transformation direction builds capabilities that enable progress in others, creating a cumulative pathway from today's baseline to the Vision 2047 outcome.

Natural Fibre Leadership strengthens the foundation of traceability and sustainability credentials. Resource-Intelligent Manufacturing

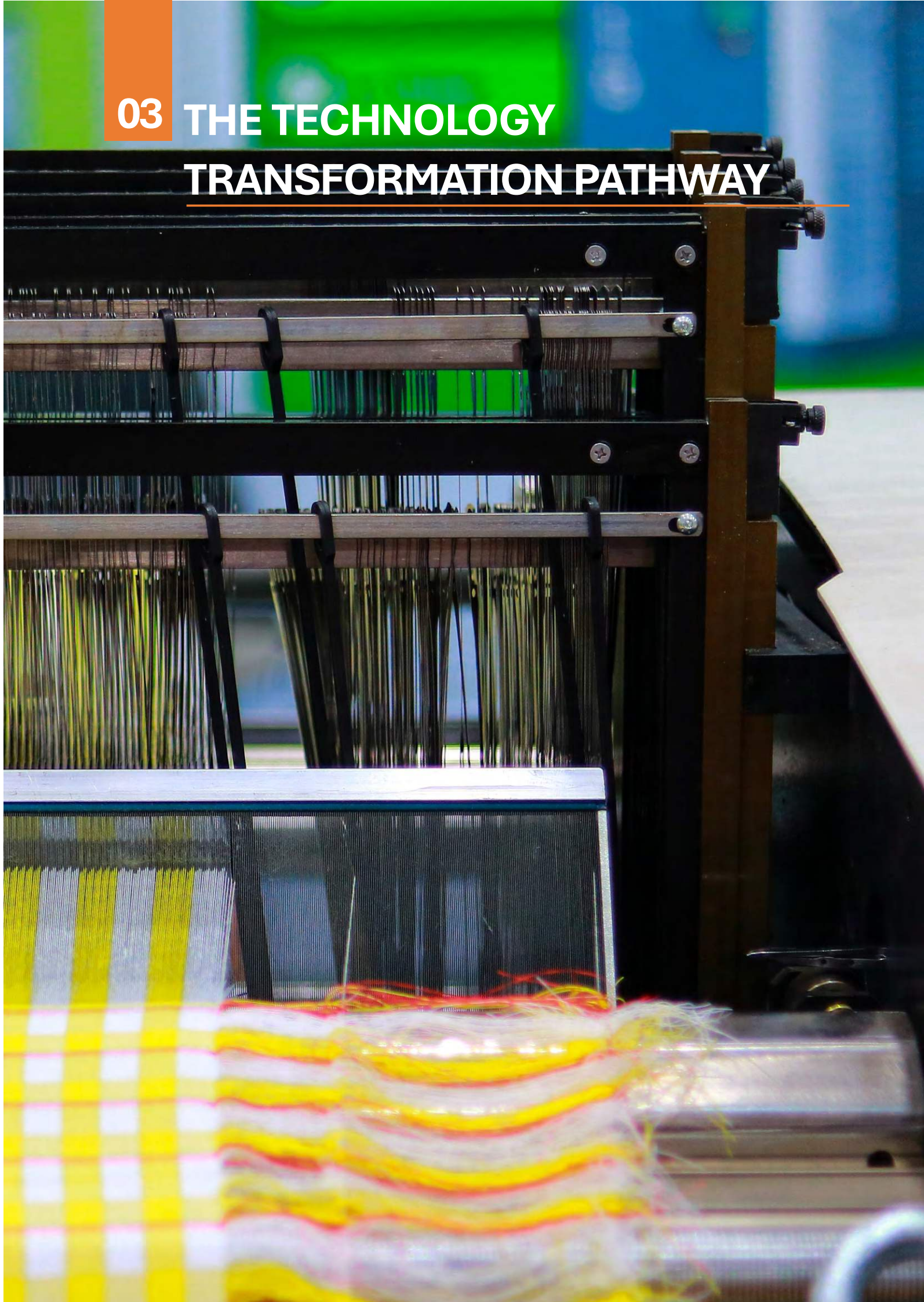
and Manufacturing Capability at Scale improve competitiveness, productivity, and operational performance. Digital Infrastructure and Traceability convert these capabilities into trusted and verifiable market credentials. Innovation and Technology Origination and Technology Sovereignty ensure that future growth is increasingly driven by technologies developed, commercialised, and deployed within India.

Taken together, these six directions define the pathway through which the sector can achieve its export, sustainability, innovation, and value-addition ambitions. The milestone gates outlined above provide the checkpoints through which progress can be monitored, validated, and course-corrected over time.

In this section, we defined the destination and the milestones. The next section outlines the transformation pathway required to reach them, organised around the six transformation directions advancing through the 5F value chain across three horizons of change.



03 THE TECHNOLOGY TRANSFORMATION PATHWAY



This section outlines the pathway for delivery, translating the six transformation directions into a sequence of technology upgrades, capability development, institutional reforms, and strategic investments across the 5F value chain.

The pathway is organised across three horizons aligned to the sector's transformation journey. Each builds the capabilities, infrastructure, and institutional foundations required for the next. The six transformation directions remain constant throughout; what evolves is the depth, scale, and ambition of intervention as the sector progresses toward Vision 2047.

The three horizons are cumulative rather than sequential. Each builds the capabilities required for the next. Align establishes the foundation, Amplify scales adoption, and Accelerate positions India for global technology leadership. Progression through the horizons is therefore determined by capability, not chronology.



Transition Logic: Why This Sequence, Why This Order

The three horizons are sequenced around dependency rather than chronology. Capabilities established in one horizon create the conditions required for the next. Resource-intelligent manufacturing generates the operational data that enables traceability. Manufacturing modernisation builds the productivity and management capability needed for advanced digital systems. Innovation ecosystems depend on demonstration platforms, skilled talent, and industry pathways before new technologies can be commercialised at scale.

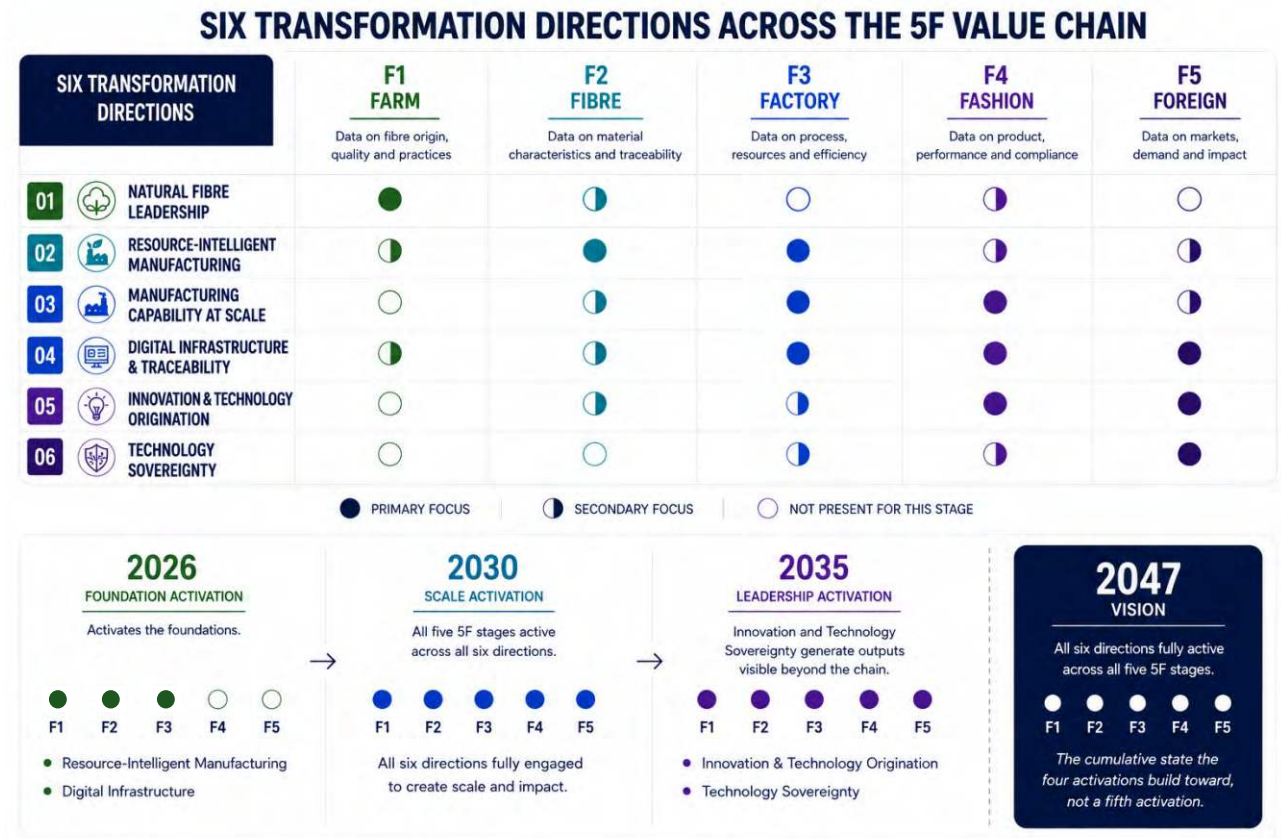
The same principle applies across the 5F value chain. The six transformation directions do not begin at the same stage or progress at the same pace. **Natural Fibre Leadership** starts at the farm and fibre stages. **Resource-Intelligent Manufacturing** and **Manufacturing Capability at Scale** become



most significant during processing and production. **Digital Infrastructure and Traceability** connects the entire value chain by generating, integrating, and verifying operational data, while **Innovation and Technology Origination** and **Technology Sovereignty** strengthen the sector's long-term capacity to create and deploy future technologies.

TRANSFORMATION THEREFORE CANNOT BE ACHIEVED THROUGH ISOLATED INTERVENTIONS. PROGRESS AT EACH MILESTONE DEPENDS ON CAPABILITIES ESTABLISHED IN PRECEDING HORIZONS AND EARLIER STAGES OF THE VALUE CHAIN. COORDINATED ADVANCEMENT ACROSS THE SIX TRANSFORMATION DIRECTIONS AND THE 5F VALUE CHAIN IS THEREFORE ESSENTIAL TO ACHIEVING THE 2047 VISION.

The next chapter translates this strategic framework into value chain-specific technology priorities, illustrating how transformation unfolds from **Farm** to **Fibre**, **Factory**, **Fashion**, and **Foreign**.



Align (2026–2030)

THE ALIGN HORIZON FOCUSES ON CLOSING THE GAP BETWEEN CURRENT INDUSTRY PRACTICE AND GLOBALLY ACCEPTED OPERATING STANDARDS.

The technologies required are largely proven, commercially available, and already deployed by leading manufacturers in India and abroad. The challenge, therefore, is not technology availability but adoption at scale through the right combination of financing, capability development, regulatory alignment, and management commitment.

The objective of this horizon is to *establish the foundations upon which all subsequent transformation depends. Resource efficiency baselines, operational data systems, traceability infrastructure, workforce capability, and institutional mechanisms for innovation must all*

be put in place during this period. Without these foundations, the scale, circularity, digitalisation, and technology leadership, ambitions of the next horizon cannot be achieved.

Across the six transformation directions, the Adopt horizon prioritises four outcomes:

- Improving the quality and traceability of natural fibres;
- Accelerating adoption of resource-efficient and digitally enabled manufacturing practices;
- Establishing the institutional infrastructure required for innovation and technology development;
- Building the data systems necessary for compliance, traceability, and future digital product passport requirements.

THE YEAR 2026 SERVES AS THE SECTOR'S FIRST CRITICAL CHECKPOINT. ITS PURPOSE IS NOT TO DEMONSTRATE LEADERSHIP, BUT TO ENSURE READINESS FOR THE SCALE-UP



PHASE THAT FOLLOWS.

The Align horizon should be viewed as a foundation, not an end state. The objective of this horizon is not to achieve leadership, but to establish the capabilities, systems, and data infrastructure required for the next stage of transformation.

Organisations that treat these investments as compliance measures are likely to realise limited returns. Those that view them as strategic capabilities will be better positioned to capture the productivity gains, market opportunities, and innovation benefits that emerge in subsequent horizons. The value of the Align horizon therefore extends beyond immediate outcomes; it creates the platform upon which the Scale and Leadership horizons are built.

Amplify (2030–2035)

The Advance horizon shifts the sector's focus from compliance to competitiveness. By this stage, the foundations established during the Adopt horizon should be in place: operational data systems functioning, sustainability and traceability programmes underway, and core resource-efficiency measures embedded within business operations. The challenge now is not meeting the standard but differentiating from it.

This horizon is defined by scale. Resource-efficient manufacturing must become mainstream rather than exemplary. Traceability systems must evolve from pilot projects to market-facing capabilities. Manufacturing productivity improvements must translate into measurable gains in quality, reliability, and responsiveness. At the same time, the institutional foundations established for innovation and technology development must begin generating tangible outputs that support long-term competitiveness.

The year 2028 serves as the mid-course validation point for this transition. It confirms that the capabilities established during the Align horizon are translating into measurable performance improvements and that progress across the six transformation directions remains balanced. Advancing in one area while neglecting others creates bottlenecks that ultimately constrain the performance of the entire system.

The 2030 year is the first major accountability milestone of the roadmap. It tests whether India has moved beyond incremental improvement and established the capabilities required for sustained export growth, technical textile expansion, technology development, and global market differentiation.

SUCCESS AT THIS STAGE DETERMINES WHETHER INDIA ENTERS THE NEXT HORIZON WITH THE CAPABILITIES REQUIRED TO SHAPE EMERGING MARKETS, TECHNOLOGIES, AND STANDARDS, RATHER THAN ADAPTING TO THEM AFTER THEY ARE ESTABLISHED.

Accelerate (2035–2047)

The Originate horizon marks the transition from technology adoption to technology leadership. While the specific technologies that will define 2047 cannot be predicted with certainty, the areas where global innovation is concentrating are already visible.

THE OBJECTIVE OF THIS HORIZON IS THEREFORE NOT TO FORECAST FUTURE TECHNOLOGIES, BUT TO BUILD THE INSTITUTIONAL, RESEARCH, AND

INDUSTRIAL CAPABILITIES THAT ENABLE INDIA TO PARTICIPATE IN THEIR CREATION.

The 2035 year serves as the first proof point that this transition is underway. By this stage, the institutions, partnerships, and innovation ecosystems established during the previous horizons should be generating tangible outputs, including commercial technologies, intellectual property, advanced manufacturing solutions, and globally competitive business models.

The Originate horizon is built around five emerging domains expected to shape the future of the global textile industry:

- *Bio-based and bio-fabricated materials,*
- *Waterless and near-waterless processing,*
- *Closed-loop recycling systems,*
- *Digital and physical integration at production scale,*
- *Advanced functional and technical textiles.*

India's long-term competitiveness will depend not only on its ability to adopt innovations in these domains, but increasingly on its ability to develop, commercialise, and export them.

INDIA ORIGINATES

Five domains where global disruption and Indian advantage intersect.

01 BIO-BASED AND BIO-FABRICATED MATERIALS	GLOBAL R&D Next-generation bio-materials INDIA ADVANTAGE Biomass diversity and scale	02 WATERLESS AND NEAR-WATERLESS PROCESSING	GLOBAL R&D Near-waterless manufacturing INDIA ADVANTAGE Process innovation and manufacturing scale
03 CLOSED-LOOP CHEMICAL, MECHANICAL, AND ENZYMATIC RECYCLING	GLOBAL R&D High-purity fibre recovery INDIA ADVANTAGE Large feedstock base and frugal engineering	04 DIGITAL AND PHYSICAL INTEGRATION AT PRODUCTION SCALE	GLOBAL R&D AI-enabled production systems INDIA ADVANTAGE Digital talent depth and IT-OT convergence
05 FUNCTIONAL AND TECHNICAL TEXTILES	GLOBAL R&D High-performance, application-driven textiles	INDIA ADVANTAGE Engineering capability and manufacturing scale	

By 2047, the ambition is for India to be recognised not only as a leading textile manufacturing nation, but also as a source of technologies, materials, standards, and innovations that influence the future direction of the global textile industry.

04 TECHNOLOGY TRANSFORMATION ACROSS VALUE CHAIN

Previous section described the transformation pathway. This section shows how that pathway unfolds across the five stages of the textile value chain. Drawing on industry consultations, technology assessments, and sector evidence, it identifies the key constraints, opportunities, and actions required at each milestone gate.

The value chain should be read as an integrated system. Progress achieved at one stage enables progress at the next, while unresolved gaps can propagate downstream and affect competitiveness, sustainability, traceability, and market access.

Each stage is linked to the six transformation directions introduced earlier, providing a practical view of how the Vision 2047 pathway translates into actions across the textile ecosystem.

Farm: Natural Fibre Leadership

THE QUALITY CEILING FOR INDIA'S ENTIRE TEXTILE VALUE CHAIN IS SET AT THE FARM GATE. WHAT CANNOT BE CORRECTED AT GINNING CANNOT BE CORRECTED DOWNSTREAM.

The farm stage determines the quality, productivity, and traceability potential of the entire textile value chain. Fibre characteristics established here influence every downstream process.

India enters this stage with significant structural advantages. It has the world's largest cotton acreage, is the only country producing all four commercial silk varieties, and possesses a diverse natural fibre base spanning cotton, silk, wool, jute, and emerging bio-based alternatives. Yet these strengths are not consistently translated into premium market positioning, productivity, or

verified sustainability credentials.

Industry consultations revealed a recurring theme: quality must precede certification.

Sustainability labels and traceability systems create value only when supported by consistent fibre quality and performance. Today, productivity gaps, contamination, limited certification coverage, and fragmented traceability systems continue to constrain India's ability to fully leverage its natural fibre advantage.

The challenge is not technological availability. Contamination detection systems, certification frameworks, digital traceability platforms, and advanced reeling technologies are already commercially proven.

The greater opportunity lies in deploying these solutions at scale through stronger aggregation models, cluster-level implementation, and integrated farm-to-fibre traceability systems that convert natural resource advantages into globally recognised market credentials.

Primary transformation direction: Natural Fibre Leadership

Secondary transformation direction: Digital Infrastructure & Traceability through origin, quality, and certification data generated at farm and ginning level.



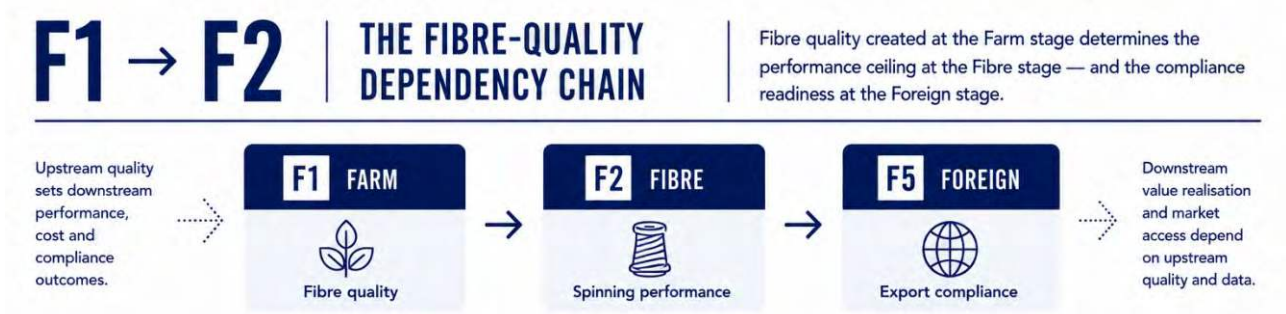
F1: FARM – RAW MATERIAL

2026 - 2030 ALIGN	2030 - 2035 AMPLIFY	2035 - 2047 ACCELERATE
- Strengthen fibre quality through modernisation of ginning, contamination control, and silk reeling infrastructure. - Expand sustainability certification through cluster-based models to improve smallholder participation. - Establish interoperable fibre traceability systems across priority natural fibres, including Kasturi Cotton. - Build institutional capacity for quality assurance, fibre testing, and digital provenance.	- Scale nationally recognised traceability and certification systems across cotton, silk, wool, jute, and other priority fibres. - Develop organised value chains for alternative natural fibres such as banana, hemp, PALF, bamboo, and other agricultural residues. - Integrate digital provenance with domestic and export compliance requirements, including Digital Product Passports. - Position Indian natural fibres as premium, verified, and sustainable materials in global markets.	- Establish India as a global leader in sustainable, traceable, and climate-resilient natural fibre systems. - Commercialise next-generation bio-based textile materials derived from agricultural residues and emerging feedstocks. - Integrate natural fibre production with advanced biomaterials and circular bioeconomy value chains. - Transform the agricultural sector from a raw material supplier into a global innovation hub for future textile materials.

The fibre that leaves this stage determines the performance potential of every stage that follows. Quality, consistency, and traceability established at the farm and fibre stages influence productivity in manufacturing, sustainability outcomes in processing, and credibility in export markets. No downstream investment can fully compensate for weaknesses introduced at the source.

By this point, Natural Fibre Leadership has established the foundation of the value chain. The quality and origin information generated here becomes the basis for efficient processing, trusted traceability, and premium market positioning throughout the remainder of the textile ecosystem.





Fibre: Manufacturing Capability

INDIA'S SPINNING SECTOR IS THE SECOND-LARGEST IN THE WORLD, WITH MORE THAN 54 MILLION INSTALLED SPINDLES AND A STRONG PRESENCE ACROSS COTTON, BLENDED, AND SYNTHETIC YARN PRODUCTION.

It includes globally competitive mills operating advanced compact, rotor, and air-jet technologies, alongside substantial capacity based on older-generation equipment. The defining characteristic of this stage is not a lack of capability, but the wide variation in productivity, quality, and technology adoption across the sector.

The fibre stage acts as the bridge between raw material quality and manufacturing performance. Yarn characteristics established here, including strength, evenness, and consistency, directly influence fabric quality, processing efficiency, dyeing performance, and finished product quality downstream. As a result, gains achieved at the farm stage can be amplified or diluted depending on the capabilities present at this stage.

Industry consultations highlighted two recurring challenges. The first is the limited availability of financing mechanisms tailored to MSME-scale technology upgrades. The second is the underutilisation of operational and quality data.

While many mills generate significant production and quality information, digital monitoring and data-driven decision-making remain uneven, limiting the returns from existing technology investments.

The opportunity therefore extends beyond machinery modernisation. It lies in combining technology upgrades with digital quality management, workforce capability, and stronger integration between fibre quality, recycled material streams, and downstream manufacturing requirements.

Transformation Focus: Manufacturing Capability at Scale and Natural Fibre Leadership
Enabling Capabilities: Digital Infrastructure & Traceability; Resource-Intelligent Manufacturing

F2: FIBRE - SPINNING, TEXTURING, RECYCLED FIBRE

2026 - 2030

ALIGN

- Modernize spinning and texturing operations to improve yarn quality, productivity, and manufacturing efficiency.
- Strengthen digital quality assurance and process monitoring across organized spinning operations.
- Expand certified recycled and sustainable fibre processing with robust chain-of-custody systems.
- Build the foundation for traceable yarn production supporting downstream value chain requirements.

2030 - 2035

AMPLIFY

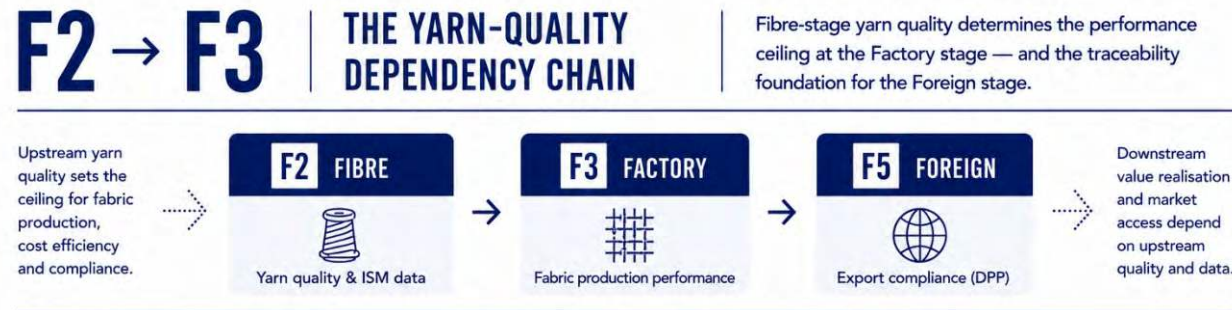
- Accelerate adoption of rotor, vortex, and air-jet spinning technologies where commercially appropriate.
- Expand recycled, regenerated, and alternative fibre processing capabilities to diversify raw material sources.
- Introduce MSME-focused technology leasing and upgrade financing mechanisms.
- Strengthen circular fibre ecosystems through fibre-to-yarn innovation and certified material platforms.

2035 - 2047

ACCELERATE

- Establish commercial-scale closed-loop fibre-to-fibre recycling systems.
- Develop advanced recycled and bio-based yarn platforms.
- Integrate next-generation materials into mainstream spinning operations.
- Position India as a global source of high-performance, circular, and traceable fibre systems.

Manufacturing Capability at Scale begins to take shape here through quality monitoring, automation, process control, and digital management systems. The capabilities established at the fibre stage are further amplified in manufacturing and garment production, where productivity, quality, and responsiveness become increasingly important sources of competitiveness.



Factory Dry: Productivity and Automation

India's weaving sector combines one of the world's largest handloom ecosystems with approximately 26 lakh powerlooms, creating a manufacturing base of exceptional scale and diversity. However, a high dependence on shuttle loom technology continues to constrain productivity, efficiency, and responsiveness relative to competing textile economies. The challenge is not capacity, but the ability to consistently convert capacity into globally competitive manufacturing performance.

The defining gap at this stage is increasingly digital rather than mechanical. While modern shuttleless technologies have expanded across parts of the organised sector, real-time production monitoring, predictive maintenance, and data-driven production management remain limited. As a result, many manufacturers are unable to fully realise the productivity gains that existing machinery is capable of delivering.

Industry consultations consistently highlighted a common challenge: technology adoption must be accompanied by digital capability and operational discipline. Investments in advanced equipment generate only a fraction of their potential value when production data is not actively used to improve efficiency, quality, scheduling, and maintenance decisions.

The opportunity therefore extends beyond loom modernisation. It is about building digitally enabled manufacturing systems that combine advanced machinery, operational visibility, skilled supervision, and data-driven decision-making to improve productivity, quality, and speed-to-market.

Transformation Focus: Manufacturing Capability at Scale
Enabling Capabilities: Digital Infrastructure & Traceability; Technology Sovereignty

F3: FACTORY DRY - WEAVING AND KNITTING

2026 - 2030
ALIGN

- Accelerate modernisation of weaving and knitting operations through high-productivity manufacturing systems.
- Establish real-time production monitoring and digital performance management as the baseline for modern manufacturing.

2030 - 2035
AMPLIFY

- Complete the transition towards modern weaving and knitting infrastructure across organised manufacturing.
- Expand advanced fabric production capacity for technical, functional, and engineered textile applications.

2035 - 2047
ACCELERATE

- Deploy AI-enabled quality prediction and process optimisation systems.
- Advance autonomous and highly connected manufacturing environments.

- Expand manufacturing capability for value-added fabrics, technical textiles, and specialised applications.
- Strengthen workforce capability in digital manufacturing, production optimisation, and quality management.
- Integrate design, production planning, and manufacturing operations through connected digital platforms.
- Scale intelligent manufacturing systems enabling predictive maintenance, resource optimisation, and operational excellence.
- Develop indigenous weaving technologies and digital manufacturing solutions.
- Position India as a leader in high-performance, technical, and digitally enabled fabric production.

The fabric produced at this stage determines both the quality and the resource profile of the processes that follow. Fabric characteristics influence dye uptake, chemical consumption, water use, processing efficiency, and ultimately the environmental footprint of the finished product.

For this reason, the next stage represents one of the most consequential points in the value chain. Decisions made during wet processing have a disproportionate impact on cost competitiveness, sustainability performance, regulatory compliance, and market access, making it a critical lever in the sector's transformation journey.



Factory Wet: Resource-Intelligent Manufacturing

WET PROCESSING SITS AT THE CENTRE OF THE SECTOR'S TRANSFORMATION CHALLENGE. THIS IS WHERE ENVIRONMENTAL IMPACT, OPERATING COST, REGULATORY COMPLIANCE, AND MARKET ACCESS INTERSECT, MAKING IT THE HIGHEST LEVERAGE STAGE IN THE ENTIRE VALUE CHAIN.

It represents one of the largest opportunities for value creation. Improvements in water efficiency, energy performance, chemical management, and process control simultaneously reduce operating costs, strengthen compliance readiness, improve sustainability outcomes, and enhance buyer confidence. Few investments elsewhere in the value chain deliver benefits across all four dimensions at once.

Industry consultations consistently identified wet processing as the stage where sustainability expectations are rising fastest and where data quality is becoming increasingly important. Buyers are seeking greater transparency on water, chemistry, carbon, and effluent performance, while emerging regulatory frameworks are making verified environmental data a prerequisite for market access. The challenge is therefore no longer limited to technology adoption; It is the ability to measure, manage, and demonstrate performance continuously.

The technologies required for transformation are largely proven and commercially available. The more significant barrier is accelerating adoption through financing mechanisms, performance-linked incentives, and stronger utilisation of operational data. The opportunity is not only to improve environmental performance, but to convert sustainability investments into measurable competitive advantage.

Transformation Focus: Resource-Intelligent Manufacturing and Digital Infrastructure & Traceability
Enabling Capability: Innovation & Technology Origination

F3: FACTORY WET - DYEING, PRINTING, FINISHING

2026 - 2030
ALIGN

- Establish real-time energy, water, and process monitoring as the digital foundation for resource-intelligent manufacturing.
- Modernise dyeing, printing, and finishing operations through advanced process automation and digital process control.
- Expand adoption of sustainable chemistry and MRSL-compliant chemical management across processing facilities.
- Upgrade wastewater treatment, water recycling, and resource recovery infrastructure in major processing clusters.

2030 - 2035
AMPLIFY

- Scale low-resource manufacturing practices across organised wet processing operations.
- Integrate production, environmental, and resource performance through connected manufacturing systems.
- Accelerate industrial decarbonisation through renewable energy integration and verified carbon performance programmes.
- Enable performance-based financing and carbon market participation to accelerate technology adoption.

2035 - 2047
ACCELERATE

- Demonstrate and scale next-generation processing technologies, including waterless and near-waterless systems.
- Deploy advanced chemical recovery, circular water management, and near-zero-emission technologies.
- Position India as a leader in resource-intelligent and low-carbon textile processing.
- Establish PM-MITRA parks and innovation platforms as demonstration platforms for breakthrough processing technologies.

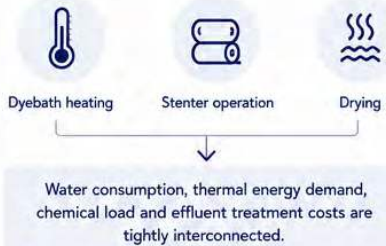
Wet processing is India's highest-leverage intervention point and of the sector's highest-risk stages for competitive exclusion.

**Act here, and gains compound.
Delay here, and risks multiply.**

01 THE UNIQUE CHALLENGE OF WET PROCESSING

Unlike other 5F stages where energy demand is primarily electrical and substitutable with renewable sources, wet processing depends on **thermal energy — steam** for dyebath heating, stenter operation, and drying.

THERMAL ENERGY DEPENDENCY CANNOT BE SWITCHED. IT CAN ONLY BE REDUCED BY CUTTING PROCESS DEMAND.



WHY THIS STAGE DRIVES COMPETITIVENESS

- Highest share of operating cost
- Largest environmental footprint
- Most exposed to compliance risk
- Greatest potential for multi-parameter improvement

02 THE CENTRAL STRATEGIC ISSUE: LIQUOR RATIO

High liquor-ratio dyeing increases water use, steam demand, salt consumption, and effluent load simultaneously.

REDUCING LIQUOR RATIO CREATES COMPOUNDING GAINS



03 RISING CHEMICAL MANAGEMENT PRESSURES

Conventional processing chemistries face increasing restrictions under evolving buyer and regulatory frameworks.

REGULATORY LANDSCAPE IS TIGHTENING

- ZDHC MRSL compliance
- EU chemical regulations
- National and regional norms evolving rapidly

BUYER EXPECTATIONS ARE RISING

- Process transparency
- Better wastewater performance
- Lower-carbon manufacturing systems

This is the highest-leverage stage in the textile value chain. It is where environmental performance, operational efficiency, compliance readiness, and market access converge. The chemistry, water, energy, and effluent data generated at this stage form the foundation of lifecycle assessment, sustainability reporting, and future Digital Product Passport requirements. No other stage has a greater influence on both the environmental footprint and the competitive position of the sector.

F3 WET → F4 FASHION | THE WET-PROCESSING TO FASHION LINKAGE

Wet-stage process performance sets the ceiling for fashion-stage reliability, speed, and market competitiveness.



The information generated during wet processing becomes the evidence base for downstream traceability and compliance systems. Without verified process data, sustainability claims cannot be substantiated, and market-access requirements cannot be met. Success at this stage therefore extends beyond resource efficiency alone; it determines the credibility of the entire value chain.

Fashion: Manufacturing Capability at Scale

India's apparel sector is demonstrating strong growth momentum, supported by expanding exports, increasing buyer diversification, and a deep manufacturing base.

THE SECTOR SPANS GLOBALLY INTEGRATED EXPORT FACILITIES, LARGE DOMESTIC MANUFACTURERS, AND EXTENSIVE MSME NETWORKS, PROVIDING BOTH SCALE AND RESILIENCE. HOWEVER, SIGNIFICANT DIFFERENCES IN PRODUCTIVITY, DIGITAL ADOPTION, AND OPERATIONAL CAPABILITY CONTINUE TO LIMIT THE SECTOR'S ABILITY TO FULLY CAPTURE EMERGING OPPORTUNITIES.

At this stage, competitiveness is determined less by machinery alone and more by how effectively technology, people, and processes operate together. Industry consultations consistently

highlighted that productivity gains depend on supervisory capability, production planning, workforce management, and the effective use of digital systems. Technology can accelerate performance, but only when organisational capability evolves alongside it.

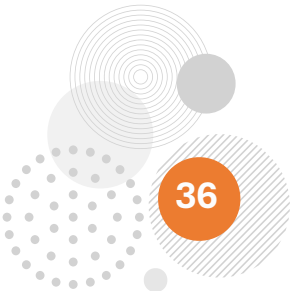
The opportunity is substantial. Global supply chains are increasingly demanding shorter lead times, greater flexibility, higher quality consistency, and stronger compliance performance. These requirements favour manufacturers that combine scale with digital capability, operational excellence, and skilled talent. For India, improving productivity is not only a cost imperative but also a pathway to higher-value products, stronger buyer relationships, and greater resilience against future competitive pressures.

Transformation Focus: Manufacturing Capability at Scale

Enabling Capabilities: Digital Infrastructure & Traceability; Technology Sovereignty

F4: FASHION - GARMENTING

2026 - 2030 ALIGN	2030 - 2035 AMPLIFY	2035 - 2047 ACCELERATE
Modernise garment manufacturing through digitally enabled cutting, sewing, and production systems.	Scale digital product development and virtual sampling across apparel manufacturing.	Establish highly flexible, digitally integrated, and demand-responsive apparel manufacturing ecosystems.



- Strengthen production quality, process standardisation, and operational efficiency across manufacturing units. - Improve manufacturing consistency through digital production management and quality assurance systems. - Build workforce capability in digital manufacturing, production optimisation, and quality management.	- Integrate production planning, shop floor operations, and quality management through connected manufacturing systems. - Expand intelligent manufacturing through AI-enabled quality assurance and production optimisation. - Strengthen workforce resilience through structured skilling, retention, and career progression programmes.	Scale AI-driven planning, scheduling, and autonomous production optimization across garment manufacturing. Establish India as a leader in responsive, digitally enabled apparel manufacturing. Build the capability to continuously evaluate, adopt, and commercialize next-generation apparel manufacturing technologies.
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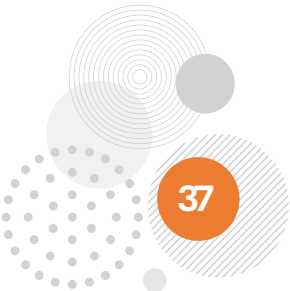
The records generated at this stage complete the manufacturing traceability chain. By this point, information on fibre origin, yarn production, fabric processing, environmental performance, and garment manufacturing has been created across the value chain. Together, these records form the foundation of credible traceability, sustainability reporting, and product transparency.



The final stage of the value chain is not primarily about generating new information. It is about verifying, integrating, and translating the information generated upstream into trusted market credentials. The competitiveness of India's exports will increasingly depend on how effectively this information can be transformed into buyer confidence, regulatory compliance, and market access.

Foreign: Digital Infrastructure and Traceability

THE EXPORT STAGE IS NO LONGER SIMPLY THE ENDPOINT OF THE VALUE CHAIN. IT HAS BECOME THE POINT AT WHICH QUALITY, SUSTAINABILITY, TRACEABILITY, AND COMPLIANCE PERFORMANCE ARE VERIFIED AND TRANSLATED INTO MARKET ACCESS.



Increasingly, global buyers are not only evaluating what products are made, but also how they are made, where they originate, the working conditions, how workers are treated and whether these claims can be supported by credible data.

Industry consultations consistently highlighted a common challenge: while many manufacturers have invested in machinery and sustainability initiatives, the systems required to capture, verify, and utilise operational data remain uneven. As a result, the gap is no longer limited to production capability. It is increasingly a gap in visibility, transparency, and evidence.

This stage reveals a critical reality of the modern textile economy: export readiness cannot be created at the export gate. Traceability, sustainability credentials, environmental performance, and product provenance must be established throughout the value chain and carried forward through each stage of production. By the time a product reaches export markets, the underlying information must already exist.

The opportunity is therefore not only compliance. It is the ability to convert operational performance into commercial advantage. Verified traceability, credible sustainability credentials, lifecycle data, and transparent supply chains are becoming important differentiators in global sourcing decisions, particularly in premium and regulated markets.

Transformation Focus: Digital Infrastructure & Traceability

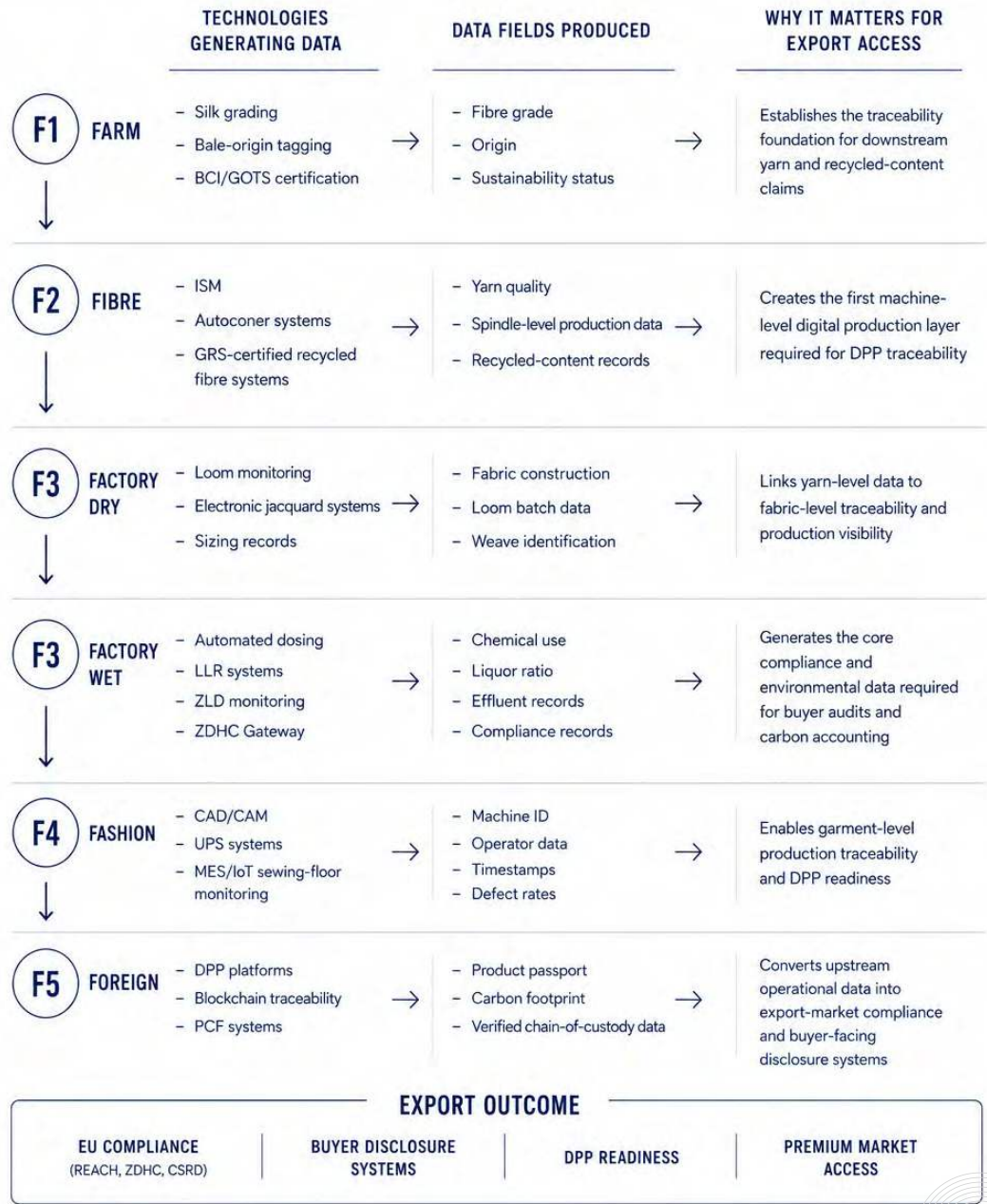
Enabling Capability: Resource-Intelligent Manufacturing; Manufacturing Capability at Scale; Natural Fibre Leadership

F5: FOREIGN - TRACEABILITY AND EXPORT READINESS

2026 - 2030 ALIGN	2030 - 2035 AMPLIFY	2035 - 2047 ACCELERATE
- Establish Digital Product Passport readiness across major export-oriented value chains. - Transition compliance systems from periodic reporting to continuous monitoring and verification. - Expand accredited testing, certification, and verification infrastructure across major textile clusters.	- Operationalise end-to-end traceability systems across priority export value chains. - Scale digitally verified chain-of-custody systems and trusted data exchange across supply networks. - Expand product-level environmental reporting, lifecycle assessment, and sustainability disclosure capabilities.	- Establish intelligent traceability systems integrating real-time production, environmental, and supply chain data. - Position India as a global leader in transparent and trusted textile supply chains. - Embed lifecycle intelligence into product development, sourcing, and export systems.

- Build product-level environmental data systems to support traceability and export compliance.
- Integrate traceability, compliance, and sustainability reporting into export workflows.
- Transform traceability from a compliance requirement into a source of market differentiation and competitive advantage.

The six segments above complete the 5F value chain. Technical textiles occupy a different position altogether. They are not a stage in the chain, but a strategic layer that cuts across it, drawing on advances in materials, manufacturing, traceability, and innovation to create the highest-value growth opportunities in the sector.



By this stage, the information generated across the value chain is transformed into trusted market credentials. The competitiveness of India's textile exports will increasingly depend not only on manufacturing capability, but on the ability to demonstrate quality, sustainability, and traceability with confidence and credibility.

Foundational Technologies: Digital Foundation for Competitive Manufacturing

NO SINGLE TECHNOLOGY CAN TRANSFORM THE TEXTILE SECTOR. COMPETITIVENESS EMERGES WHEN DIGITAL, OPERATIONAL, AND SUSTAINABILITY CAPABILITIES ARE EMBEDDED ACROSS THE ENTIRE VALUE CHAIN.

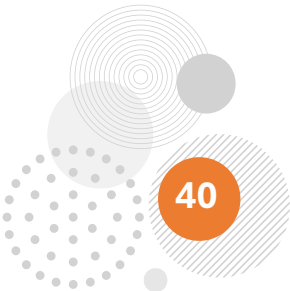
Foundational technologies provide the enterprise capabilities that enable transformation across every stage of the textile value chain. Unlike stage-specific technologies, these capabilities establish the digital infrastructure, operational discipline, resource intelligence, and enterprise systems that support connected, efficient, and resilient manufacturing.

India's textile sector enters this transformation with significant structural strengths, including one of the world's largest integrated textile manufacturing ecosystems, a diverse industrial base, and expanding policy support through initiatives such as PM MITRA, TEEM, and Tex Eco. However, technology adoption remains uneven. While leading manufacturers have embraced digital enterprise systems, automation, and sustainability platforms, many facilities continue to operate with fragmented information systems, limited operational visibility, and reactive production management.

Industry consultations consistently highlighted that digitalisation is no longer optional—it is the foundation for future competitiveness. Real-time production visibility, resource monitoring, predictive maintenance, enterprise-wide data integration, and sustainability reporting are increasingly becoming prerequisites for productivity, operational excellence, regulatory compliance, and participation in global value chains.

The challenge is not the availability of technology. Enterprise systems, Industrial Internet of Things (IIoT), Manufacturing Execution Systems (MES), artificial intelligence, industrial automation, and enterprise sustainability platforms are already commercially mature. The greater opportunity lies in integrating these capabilities across manufacturing operations, enabling connected decision-making, resource optimisation, industrial decarbonisation, and continuous improvement throughout the textile value chain.

Primary transformation direction: Digital Infrastructure & Traceability
Secondary transformation directions: Manufacturing Capability at Scale and Resource-Intelligent Manufacturing through connected enterprise systems, operational intelligence, and industrial decarbonisation.

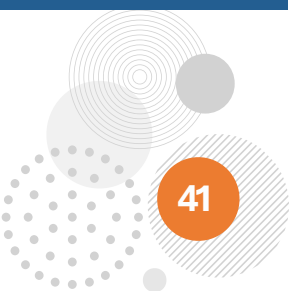


F0: FOUNDATIONAL TECHNOLOGIES

2026 - 2030 ALIGN	2030 - 2035 AMPLIFY	2035 - 2047 ACCELERATE
- Establish integrated digital enterprise systems as the foundation for connected textile manufacturing. - Strengthen operational excellence through real-time production, energy, water, and asset performance monitoring. - Accelerate adoption of resource-efficient manufacturing practices to improve productivity, reliability, and sustainability. - Build enterprise capability in digital manufacturing, data-driven decision-making, and industrial cybersecurity.	- Scale intelligent manufacturing through connected factories, industrial automation, and advanced analytics. - Accelerate industrial decarbonisation through renewable energy integration, process electrification, and enterprise-wide resource optimisation. - Expand enterprise sustainability platforms supporting carbon management, ESG reporting, and supply chain transparency. - Strengthen innovation ecosystems enabling industry-wide technology adoption and digital transformation.	- Establish autonomous, AI-enabled manufacturing ecosystems across the textile value chain. - Achieve deep industrial decarbonization through next-generation clean energy and circular industrial systems. - Build technology sovereignty through indigenous digital manufacturing platforms, advanced industrial technologies, and innovation ecosystems. - Position India as a global leader in intelligent, resilient, and sustainable textile manufacturing.

Every subsequent stage of the roadmap depends on the capabilities established here. Digital infrastructure enables traceability from farm to export, operational intelligence improves manufacturing performance across spinning, weaving, wet processing, and garmenting, while enterprise sustainability platforms provide the trusted environmental data increasingly required by global markets.

Without these foundational capabilities, investments in stage-specific technologies cannot realise their full productivity, sustainability, or competitiveness benefits.





05 FACILITY TECHNOLOGY UPGRADE PATHWAYS



The preceding chapters have examined technology transformation at the sector and value chain levels. They have established the six transformation directions, the three implementation horizons, and the technology priorities across the five 5F stages.

Transformation, however, occurs at one facility at a time. Every improvement in productivity, resource efficiency, compliance, traceability, and competitiveness ultimately depend on investment decisions made by individual mills, processing units, and manufacturing facilities.

INDIA'S TEXTILE SECTOR DOES NOT BEGIN FROM A COMMON BASELINE. FACILITIES DIFFER SIGNIFICANTLY IN TECHNOLOGY MATURITY, COMPLIANCE READINESS, RESOURCE EFFICIENCY, DIGITAL CAPABILITY, AND MANAGEMENT CAPACITY.

Some are still establishing the foundations required for regulatory compliance. Others are improving productivity and operational performance through technology upgrades. A smaller group is already positioned to evaluate and demonstrate next-generation technologies.

For this reason, a single technology pathway cannot be applied uniformly across the sector. The priorities, sequencing, financing requirements, and expected outcomes differ according to each facility's current position. What remains consistent is the direction of travel. Every facility must progressively strengthen its resource efficiency, manufacturing capability, digital maturity, and competitiveness over time.

Two starting conditions exist across India's manufacturing base. **Brownfield facilities**, which account for the overwhelming majority of textile capacity, must modernise while remaining operational, balancing legacy infrastructure with new technology investments. **Greenfield facilities**, particularly those developed through PM-MITRA and other planned industrial developments, can integrate next-generation technologies from the outset without the constraints of existing assets.

Because India's transformation will be driven primarily by the modernisation of its existing manufacturing base, this chapter begins with the brownfield reality. It then introduces three facility upgrade pathways, **Comply, Compete, and Transform**, which provide a practical framework for sequencing technology investments according to each facility's current position and long-term ambition.

The Brownfield Reality

01

AGE OF EQUIPMENT

A large share of installed capacity predates the digital and sustainability era.

02

COMPLIANCE STATUS

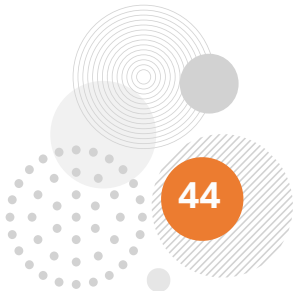
Many facilities have achieved minimum compliance, but few operate consistently above expectations.

03

TECHNOLOGY POSITION
RELATIVE TO GLOBAL BAT

Most facilities remain materially below global best available technology.

The implications of this reality are clear.



First, upgrade pathways must be designed around operational continuity, recognising that most facilities cannot suspend production while modernisation takes place.

Second, technology investment alone is insufficient. The capability to manage, operate, and extract value from upgraded systems is often as important as the technology itself.

THE PATHWAY THAT APPLIES TO A FACILITY IS DETERMINED NOT BY AMBITION, BUT BY ITS CURRENT LEVEL OF TECHNOLOGY MATURITY, COMPLIANCE READINESS, AND OPERATIONAL CAPABILITY.

Comply: Establishing the Foundation

For mills in the Comply pathway, transformation begins with meeting the minimum standards required for continued market participation. The objective at this stage is not differentiation or growth. It is establishing the environmental, operational, and data foundations upon which all future competitiveness depends. These facilities typically face gaps in regulatory compliance, environmental performance, chemical management, and operational data systems. As regulatory requirements tighten and buyer expectations become more stringent, addressing these gaps becomes increasingly important for maintaining market access and business continuity.

FOUNDATION	CAPABILITY	TRANSITION
- Assessment - Remediation - MRS� Readiness - Reporting Systems	- Wastewater Systems - Chemical Transition - Energy Metering - Data Infrastructure	- Stable Compliance - Resource Efficiency - Data-Driven Management - Productivity Investments
OUTCOME	OUTCOME	OUTCOME
Minimum legal and commercial operating position established.	Foundational compliance capabilities operational.	Compliance becomes a platform for competitiveness.

Transformation Focus: Resource-Intelligent Manufacturing
Enabling Capability: Digital Infrastructure & Traceability

The priority is to establish a credible baseline of compliance, resource management, and performance measurement. Without these foundations, progress on productivity, traceability, innovation, or market differentiation is unlikely to be sustainable.



Compete: Building Competitive Advantage

This is the largest segment of India's textile sector and the segment that will determine whether the 2030 targets are achieved. Facilities in the Compete pathway are compliant and commercially viable, but remain materially below global best practice on productivity, resource efficiency, digitalization, and operational excellence. They do not face a compliance challenge. They face a competitiveness challenge.

FOUNDATION	CAPABILITY	TRANSITION
- Energy & resource audits - VFDs & process optimisation - Operational baselines - Quick-win productivity gains	- MES deployment - Automation & process control - Data-driven management - Digital capability building	- Traceability systems - DPP-ready data - Carbon credits & sustainability credentials - Next-generation technology readiness
OUTCOME	OUTCOME	OUTCOME
Lower cost & higher efficiency	Greater visibility & control	Stronger competitiveness & market access

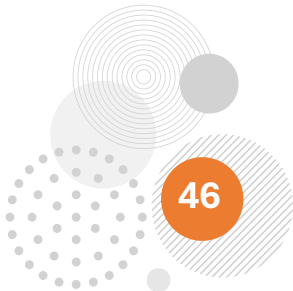
Transformation Focus: Resource-Intelligent Manufacturing and Manufacturing Capability at Scale
Enabling Capabilities: Digital Infrastructure & Traceability; Natural Fibre Leadership

These facilities typically have established buyer relationships, stable operations, and the capacity to invest. The opportunity lies in translating that foundation into higher productivity, lower resource intensity, improved quality consistency, and stronger market positioning. The challenge is not whether transformation is needed, but how it is financed, sequenced, and managed.

Industry consultations consistently highlighted two barriers: limited access to financing mechanisms aligned with technology-upgrade risk, and the underutilisation of operational data already being generated within facilities.

The financing architecture for this pathway must reward performance rather than procurement. Blended finance, viability-gap support, and outcome-linked disbursement can reduce the upfront risk of modernization while ensuring accountability for results. As facilities exceed resource-efficiency and emissions-intensity benchmarks, carbon credits, sustainability-linked finance, and buyer co-investment can further strengthen project economics.

AS MILLS EXCEED RESOURCE-EFFICIENCY AND EMISSIONS-INTENSITY BENCHMARKS, INSTRUMENTS SUCH AS CARBON CREDITS AND SUSTAINABILITY-LINKED BUYER PARTNERSHIPS CAN FURTHER IMPROVE PROJECT ECONOMICS.



INCREASINGLY, LEADING BRANDS ARE ALSO WILLING TO CO-INVEST IN SUPPLIER UPGRADES WHERE IMPROVEMENTS DIRECTLY SUPPORT THEIR OWN SUSTAINABILITY AND SOURCING COMMITMENTS.

The outcome of the Compete pathway is a facility that is more productive, resource-efficient, digitally enabled, and globally competitive, creating the platform from which it can transition into the Transform pathway.

Transform: Industry Leadership

Facilities in the Transform pathway operate at or near global best practice and represent the sector's innovation frontier. Their role extends beyond improving their own competitiveness. They validate emerging technologies, demonstrate commercially viable transformation pathways, and accelerate the diffusion of innovation across the wider industry.

INNOVATION	VALIDATION	LEADERSHIP
- Technology scouting - R&D and startup partnerships - Demonstration projects - Pre-commercial technology assessment	- Pilot deployment of next-generation technologies - Performance validation and business case development - Knowledge sharing and replication models - Climate and sustainability finance mobilisation	- Commercial-scale deployment - Industry demonstration facilities - Technology commercialisation - Technology export and industry diffusion
OUTCOME	OUTCOME	OUTCOME
Innovation pipeline established	Technologies proven and investment-ready	Industry leadership and technology origination

Transformation Focus: Innovation & Technology Origination; Technology Sovereignty
Enabling Capabilities: Resource-Intelligent Manufacturing; Digital Infrastructure & Traceability; Manufacturing Capability at Scale

THE OBJECTIVE AT THIS STAGE IS NOT TECHNOLOGY ADOPTION, BUT TECHNOLOGY LEADERSHIP. THESE FACILITIES VALIDATE EMERGING SOLUTIONS AND ACCELERATE THEIR TRANSITION FROM INNOVATION TO INDUSTRY-WIDE DEPLOYMENT.



The financing architecture must therefore reward innovation and first-mover risk. Priority instruments include the Textile Technology Transition Fund (TTTF) for pre-commercial technology deployment, climate and sustainability finance linked to verified environmental outcomes, strategic buyer co-investment, and performance-linked incentives that support technology demonstration at commercial scale.

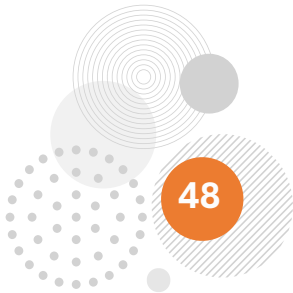
The outcome of the Transform pathway is a network of facilities that function not only as manufacturers, but as innovation platforms for the future of India's textile sector.

Upgrade Sequencing

The three pathways share one overriding principle: sequencing matters more than ambition. Investing in the wrong technology in the wrong order wastes capital and creates the conditions for adoption failure.

Sequencing Principles for Transformation: Four principles apply across all three pathways and should guide every technology and investment decision.

1 COMPLIANCE BEFORE COMPETITIVENESS Regulatory and buyer-compliance requirements establish the foundation upon which all subsequent improvements are built. Resource-efficiency, productivity, and sustainability gains create value only when they can be measured, verified, and demonstrated against a compliant baseline.	2 RESOURCE EFFICIENCY BEFORE TRACEABILITY Traceability systems are only as credible as the operational data behind them. Water, energy, chemistry, and process-performance information must be generated and verified at source before it can be translated into sustainability credentials, Digital Product Passports, or buyer-facing reporting.
3 DATA INFRASTRUCTURE BEFORE DIGITAL SYSTEMS Digital transformation begins with reliable data. The sequence is consistent across technologies: measure first, monitor second, optimise third, and report fourth. Digital platforms cannot compensate for the absence of accurate operational data	4 PILOT BEFORE SCALE New technologies should demonstrate technical performance, commercial viability, and operational suitability before large-scale deployment. Structured pilots reduce implementation risk, improve investment quality, and accelerate wider adoption across the sector.



*One finding from consultations deserves particular attention. The most common reason transformation initiatives underperform is not a lack of awareness about what needs to be done. It is a misalignment between **financing structures and transformation outcomes**. Too often, financing is linked to equipment installation rather than verified performance improvement, creating incentives to procure technology without ensuring that its full value is realised.*

This points to a significant opportunity for policy and financial innovation. Shifting from commissioning-based disbursement to outcome-based disbursement, linked to verified improvements in resource efficiency, productivity, emissions intensity, or operational performance, could substantially improve the effectiveness of modernisation investments. Few changes would have a greater impact on accelerating sector-wide transformation.

PM-MITRA: Building the Next-Generation Textile Ecosystem

The seven PM-MITRA parks represent a unique opportunity to build next-generation textile infrastructure from the ground up. Their strategic value lies not primarily in the capacity they add, but in the standards they establish. Unlike brownfield clusters, PM-MITRA parks can integrate advanced environmental, digital, testing, and innovation infrastructure into their design from day one.

INFRASTRUCTURE SUCH AS COMMON EFFLUENT TREATMENT SYSTEMS, DIGITAL TRACEABILITY PLATFORMS, TESTING FACILITIES, AND INNOVATION ZONES CAN BE INTEGRATED FAR MORE EFFICIENTLY AT THE DESIGN STAGE THAN RETROFITTED LATER IN THE PARK.

Advanced manufacturing zones should prioritise segments where future growth potential is highest and existing capacity is limited, including technical textiles, nonwovens, warp knitting, performance apparel, and advanced materials. Shared infrastructure can lower entry barriers for manufacturers while accelerating adoption of global best practices in sustainability, quality assurance, and digitalisation.

Perhaps the most consequential design element is the inclusion of dedicated innovation and demonstration zones. These spaces provide the critical link between research and commercial adoption, allowing emerging technologies to be tested under real production conditions before wider deployment. In doing so, they reduce adoption risk, accelerate industry learning, and create a pathway through which innovation can move from laboratory to market.



WHAT PM-MITRA MUST BUILD FROM DAY ONE

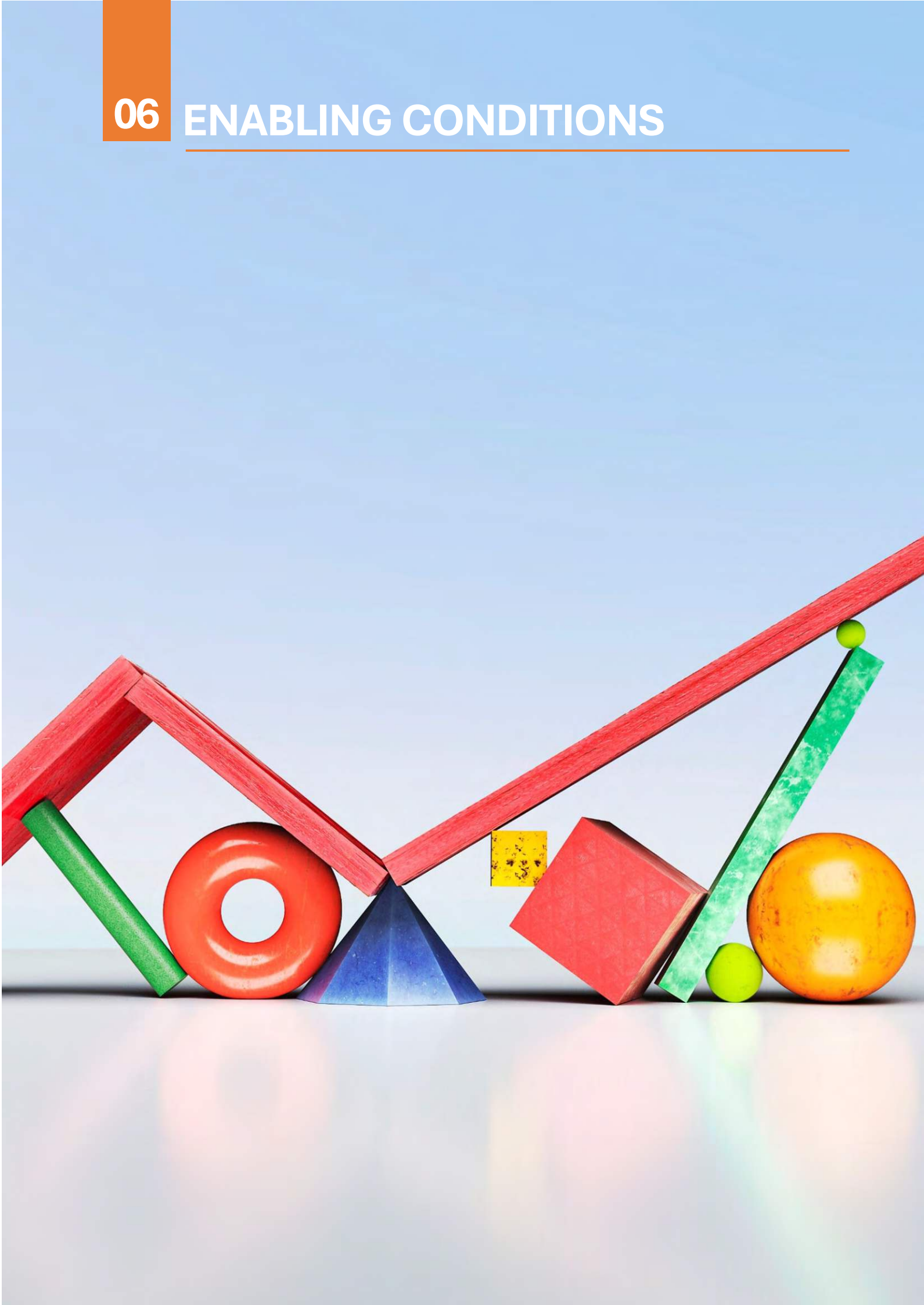
Six capabilities. One integrated system.

01 BAT-ALIGNED ENVIRONMENTAL INFRASTRUCTURE Integrated effluent and water-management systems designed to global best-practice standards.	02 SHARED DIGITAL INFRASTRUCTURE Common traceability, data, and DPP-ready platforms for all participating units.	03 ACCREDITED TESTING & CERTIFICATION Shared NABL-accredited facilities supporting quality, compliance, and export readiness.
04 ADVANCED MANUFACTURING ZONES Dedicated clusters for technical textiles, nonwovens, warp knitting, and performance materials.	05 INNOVATION & DEMONSTRATION CENTRES Facilities for validating and scaling emerging technologies under production conditions.	06 INTEGRATED SKILLS ECOSYSTEM Industry-linked training centres developed with ATDC, NIFT, and technical partners.

PM-MITRA succeeds when infrastructure is treated as a competitiveness platform, not a real-estate project.

PM-MITRA parks therefore serve a dual purpose. They are both industrial infrastructure and transformation infrastructure, demonstrating the systems, standards, and technologies that can progressively influence the wider textile ecosystem.

06 ENABLING CONDITIONS



The upgrade pathways in Section 5 define what individual facilities must do. This section defines the ecosystem conditions that must exist around those facilities for transformation to occur at scale. Technology is rarely the binding constraint. *More often, transformation stalls because the financing, skills, policy, data, and institutional conditions required to support adoption are either absent or misaligned.*

Financing Mechanisms

Financing is the most immediate of these enabling conditions. It touches every transformation direction and every upgrade pathway. Resource-Intelligent Manufacturing and Manufacturing Capability investments cannot scale without access to appropriate capital. Innovation & Technology Origination and Technology Sovereignty depend on financing mechanisms that can absorb first-mover risk and support technologies that have not yet reached commercial maturity.

Consultations produced a consistent conclusion. The technologies required for modernisation are largely known and, in many cases, already proven. The challenge is that financing structures remain poorly aligned to the investment reality of the sector. Three issues emerge repeatedly: financing instruments are linked to commissioning rather than performance; most products are designed for investment sizes above typical MSME requirements; and lending decisions frequently rely on historical financial performance rather than the demonstrated returns of the technology being financed.

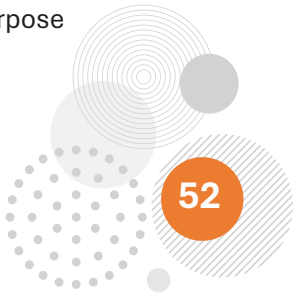
The most important redesign principle cuts across all pathways: public support should reward verified outcomes rather than equipment installation. Resource efficiency achieved, emissions reduced, productivity improved, and compliance demonstrated are the outcomes that matter. Financing structures should be designed accordingly.

ADDRESSING THIS GAP REQUIRES A FINANCING ARCHITECTURE ALIGNED TO THE THREE UPGRADE PATHWAYS: COMPLY, COMPETE, AND TRANSFORM. EACH PATHWAY FACES DIFFERENT RISKS, REQUIRES DIFFERENT INSTRUMENTS, AND DELIVERS DIFFERENT OUTCOMES. A ONE-SIZE-FITS-ALL APPROACH WILL NOT DELIVER TRANSFORMATION AT THE SCALE OR SPEED REQUIRED.

A dedicated technology-leasing mechanism for investments below ₹50 lakh could significantly accelerate MSME modernisation by reducing upfront capital barriers and making technology adoption more accessible.

Investment Framework

The investment requirement for a transformation of this scale is substantial, but the purpose



of this roadmap is to define the structure of the investment case rather than assign a headline capital figure. Quantifying investment requirements credibly will require dedicated financial modelling across segments, pathways, technologies, and capacity bands. Until that analysis is completed, the roadmap focuses on the architecture through which investment must flow.

THE INVESTMENT CASE DIFFERS BY PATHWAY. COMPLY REQUIRES FOUNDATIONAL SUPPORT, COMPETE OFFERS THE STRONGEST COMMERCIAL RETURNS, AND TRANSFORM REQUIRES RISK-SHARING CAPITAL TO ACCELERATE INNOVATION. EACH DEMANDS A FINANCING MODEL ALIGNED TO ITS RISK, RETURN, AND TECHNOLOGY PROFILE.

The investment case is particularly compelling in the Compete pathway. Resource-efficiency technologies such as variable frequency drives, automated dye kitchens, and low-liquor-ratio dyeing systems have already demonstrated commercially viable returns in the Indian context. When combined with capital subsidies, carbon market mechanisms, and sustainability-linked incentives, these investments can deliver both environmental and financial value.

The Transform pathway serves a different purpose. Its role is not to maximise short-term returns, but to accelerate the adoption of technologies that will define future competitiveness. Instruments such as the Textile Technology Transition Fund (TTTF) exist precisely to absorb the first-mover premium associated with these technologies until market adoption reduces cost and risk.

Accordingly, this roadmap recommends a dedicated financial modelling study as a priority next-phase activity. The study should assess investment requirements by pathway, segment, technology category, and facility size, while evaluating the impact of different financing instruments on adoption rates and commercial viability. Until such analysis is completed, the investment architecture presented here should be understood as structural rather than quantitative.

Regulatory Signals

Technology adoption is shaped as much by policy signals as by financing availability. India's experience with initiatives such as Zero Liquid Discharge (ZLD) in Tirupur and the BEE energy-efficiency programmes demonstrates a consistent lesson: clear, predictable regulation aligned with practical implementation pathways can accelerate transformation at scale. Conversely, mandates introduced without supporting infrastructure, financing, or transition timelines often deliver compliance on paper rather than meaningful change in practice.

THE PERIOD FROM 2026 TO 2030 REPRESENTS THE CRITICAL POLICY WINDOW FOR ENABLING THE TRANSFORMATION DESCRIBED IN THIS ROADMAP. EARLY ACTIONS ESTABLISH THE REGULATORY FOUNDATIONS FOR MEASUREMENT, REPORTING, AND COMPLIANCE. ACTIONS BUILD ON THOSE FOUNDATIONS TO STRENGTHEN COMPETITIVENESS, TRACEABILITY, CIRCULARITY, AND MARKET ACCESS.



Together, these measures create the policy environment within which investment, innovation, and technology adoption become commercially rational rather than purely voluntary.

Skills and Institutional Capacity

Technology adoption ultimately depends on people. Across consultations, one conclusion emerged consistently: workforce capability is becoming a greater constraint to transformation than technology availability. Modern equipment, digital systems, and advanced processes deliver value only when the workforce has the skills to operate, manage, and optimise them effectively.

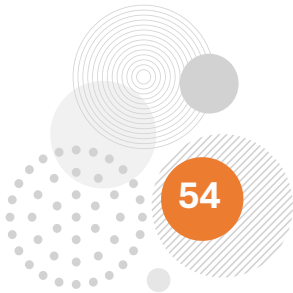
The challenge extends beyond shop-floor training. It includes supervisors managing data-driven operations, technical personnel integrating new systems, professionals preparing investment proposals, and financial institutions evaluating technology investments. This is not simply a training gap. It is a capability gap that spans the entire transformation ecosystem.

THE FUTURE TEXTILE WORKFORCE WILL BE DEFINED AS MUCH BY DIGITAL AND SUSTAINABILITY CAPABILITIES AS BY PRODUCTION SKILLS. INDUSTRY 4.0 SYSTEMS, TRACEABILITY PLATFORMS, LIFECYCLE ASSESSMENT, ADVANCED PROCESS MANAGEMENT, AND DATA-DRIVEN DECISION-MAKING ARE BECOMING ESSENTIAL COMPETENCIES. NATIONAL SKILLING PROGRAMMES MUST ADAPT ACCORDINGLY.

One capability area deserves particular attention: **middle-management digital capability**. Supervisors and production managers sit at the point where operational data is translated into operational decisions. Without this capability layer, investments in automation, monitoring systems, and digital platforms risk becoming reporting tools rather than performance-improvement tools. Technology Readiness Centres and Textile Research Associations can play an important role by combining technology access, digital readiness assessment, and in-factory coaching within a single support model.

Workforce transformation must also strengthen the attractiveness of employment within the sector. Career progression, safer working environments, income stability, and continuous upskilling are not only social objectives; they are essential to workforce retention and productivity. Technology adoption that improves job quality can strengthen the sector's ability to attract and retain talent while supporting higher-value manufacturing.

Gender inclusion must be embedded into this transition from the outset. As technical and supervisory roles become increasingly important, targeted recruitment, training, and advancement pathways can help ensure that women participate fully in the higher-skilled opportunities created by sector transformation. The outcome is a workforce ecosystem capable of supporting the six transformation directions, enabling technology investments to translate into measurable improvements in productivity, sustainability, competitiveness, and innovation.



Data Infrastructure

DATA INFRASTRUCTURE IS THE ENABLING CONDITION THAT CONNECTS ALL SIX TRANSFORMATION DIRECTIONS. WITHOUT TRUSTED, ACCESSIBLE, AND INTEROPERABLE DATA SYSTEMS, GAINS IN FIBRE QUALITY, RESOURCE EFFICIENCY, PRODUCTIVITY, AND SUSTAINABILITY CANNOT BE VERIFIED, MEASURED, OR TRANSLATED INTO MARKET ADVANTAGE.

Global competitors have already recognised this. China has developed LCAPlus platform to support supply-chain environmental assessment, while Vietnam has established EcoHub as a common sustainability data platform. India currently lacks an equivalent textile-specific digital infrastructure. As global requirements such as the EU Digital Product Passport (DPP) move from policy to implementation, this gap is becoming a competitiveness challenge rather than a technology challenge.

The solution is a shared national textile data platform, jointly developed by the Ministry of Textiles and MeitY, and anchored within India's Digital Public Infrastructure ecosystem. The platform should enable any textile enterprise, including MSMEs, to generate, verify, and access sustainability and traceability data through routine operations rather than through costly standalone assessments.

Three components are essential:

NATIONAL TEXTILE LCA DATABASE

A common repository of sector-specific environmental datasets that reduces the cost and complexity of product-level lifecycle assessment.

DPP AND TRACEABILITY LAYER

A standardised framework enabling exporters to generate interoperable, DPP-ready information aligned with emerging international requirements.

CARBON AND SUSTAINABILITY ACCOUNTING MODULE

A mechanism linking operational data, emissions reporting, and performance-based incentive systems, including future carbon market participation.

The objective is not to create another reporting platform. It is to establish the digital foundation through which sustainability, traceability, compliance, and competitiveness become scalable across the sector.



R&D and Innovation Ecosystem

The enabling conditions discussed so far support the transformation of existing capabilities. R&D infrastructure determines what capabilities India develops next.

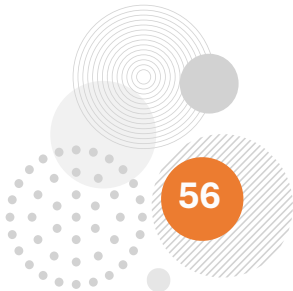
India possesses significant research strength across textiles, materials science, manufacturing systems, and machinery development. The challenge is not the absence of research. It is the absence of a consistent pathway through which research is translated into commercial products, industrial processes, and sector-wide adoption.

Addressing this gap requires an institutional architecture that connects research, validation, demonstration, and deployment. The proposed National Textile R&D Institution is the central element of that architecture. Industry co-governed and commercially oriented, its role would be to identify strategic technology priorities, coordinate research efforts, and accelerate the movement of innovations from laboratory to market. Its effectiveness depends on strong connections across four parts of the ecosystem:

- **IITs and Centres of Excellence** generating research and technology development.
- **Textile Research Associations (TRAs)** providing testing, validation, and industry engagement.
- **PM-MITRA Demonstration Zones** enabling production-scale technology validation.
- **Industry Partners** defining commercial challenges and supporting adoption.

The objective is not simply to increase research activity. It is to create a functioning innovation pipeline that consistently converts knowledge into competitive advantage.

Countries that lead textile manufacturing in 2047 will not be those that adopt technology fastest. They will be those that build the institutions capable of creating, validating, and commercialising technology continuously.

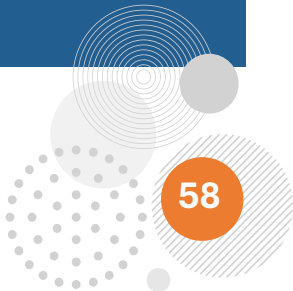
The background of the right page is a photograph of a road at night. A large, bright yellow arrow is painted on the dark asphalt, pointing towards the right. The road is illuminated by warm, orange-yellow streetlights, creating a glow on the pavement. To the right of the road, there is a red-painted curb or area. The overall mood is forward-looking and directional.

07 THE PATH FORWARD

THE ROADMAP IS DEFINED.
THE INSTITUTIONS EXIST.
THE TECHNOLOGIES ARE AVAILABLE.
THE NEXT STEP IS IMPLEMENTATION.

Transformation of the scale described in this roadmap will not begin everywhere at once. It begins with a small number of coordinated actions that establish the institutional, financial, and regulatory foundations for everything that follows. Together, these six actions create the conditions required for technology adoption at scale.

- 1. National Textile Data Platform** - Every downstream outcome in this roadmap, from Digital Product Passports and CCTS reporting to buyer-facing traceability and export verification, depends on operational data captured continuously rather than reconstructed at the point of export. Publishing the platform architecture, technical standards, governance model, and integration requirements provides manufacturers, technology providers, and financiers with a common framework for implementation.
- 2. National Textile R&D Institution** - India already possesses strong research capability across the IITs, Textile Research Associations, and Centres of Excellence. What is missing is an institution that connects research to commercial deployment. A nationally coordinated, industry-governed institution with a long-term commercialisation mandate will create the innovation pipeline required for the Accelerate horizon.
- 3. Blended Finance Facility for Technology Adoption** - The technologies needed to improve compliance, productivity, and resource efficiency already exist. The principal barrier is financing aligned to mill-level investment risk. A blended finance facility combining concessional credit, viability-gap funding, and performance-linked disbursement will accelerate adoption while rewarding verified outcomes rather than equipment procurement.
- 4. Progressive Regulatory Benchmark Calendar** - Manufacturers make investment decisions over ten to fifteen years, while regulatory requirements continue to evolve. Publishing a multi-year roadmap for resource-efficiency benchmarks, traceability requirements, and legacy technology phase-outs provides certainty, reduces investment risk, and enables proactive rather than reactive compliance.
- 5. Buyer Requirements with Technology Adoption** - Leading global brands already expect improvements in traceability, sustainability, and emissions performance. These expectations should be translated into structured cluster-level programmes that combine technology deployment, financing, technical assistance, and capability development, converting compliance requirements into coordinated investment.
- 6. Develop PM-MITRA Parks as Greenfield Technology Demonstrators** - PM-MITRA parks should demonstrate the technologies and systems that existing industrial clusters will progressively adopt. Embedding advanced manufacturing technologies, shared digital infrastructure,



common sustainability systems, and demonstration facilities from inception ensures that new capacity is built to future standards rather than retrofitted later.

The sector will not appear fundamentally different in 2027, transformation at this scale is measured in years rather than announcements.

By 2030, the foundations of a more productive, resource-efficient, digitally connected, and globally competitive textile sector should be firmly established.

By 2035, these foundations should have evolved into a mature ecosystem characterised by advanced manufacturing, innovation, indigenous technology capability, and trusted global market leadership.

By 2047, India should stand as a low-carbon, circular, globally competitive, and technology-originating textile economy, delivering the vision set out in this roadmap.





The United Nations Partnership for Action on Green Economy (PAGE) puts sustainability at the heart of global economic policymaking for a shift in finance and investment towards a just, circular, and green economic transformation.

The partnership brings together five United Nations agencies: UNEP, UNDP, ILO, UNIDO, and UNITAR, whose expertise and support assist and lead partner countries towards their transition to an Inclusive Green Economy (IGE) by providing policy advice, assessments, capacity building and analytical tools outputs.

PAGE was launched in 2013 as a response to the call at Rio+20 to support countries addressing one of the greatest challenges of our time: building economies that improve human well-being and social equity, while significantly reducing environmental risks and ecological scarcities

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