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Sustainability Megatrends Guiding the Emergence of a Low-Carbon, Circular Pulp and Paper Industry

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Abstract: *The pulp and paper industry is undergoing a structural transformation as sustainability, decarbonization, and circularity move from peripheral concerns to core strategic imperatives. Escalating climate commitments, tightening environmental regulation, resource-security pressures, and rising expectations from customers and investors are reshaping how pulp and paper assets are designed, operated, and positioned. This paper identifies and examines six sustainability megatrends guiding the emergence of a low-carbon, circular pulp and paper industry: (1) decarbonization and energy efficiency, (2) circular fiber economy, (3) the rise of the sustainability-conscious customer, (4) biorefineries and bio-products, (5) fiber-based packaging and (6) AI-driven digital optimization. For each megatrend, the paper discusses its strategic rationale, current state of adoption, technology evolution, and long-term implications, with particular attention to the Indian context. Together, these megatrends reposition the pulp and paper sector as a foundational pillar of the renewable bioeconomy, enabling long-term competitiveness, resilience, and environmental performance.*

Keywords: *Sustainability; pulp and paper industry; decarbonization; circular fiber economy; biorefineries; fiber-based packaging; artificial intelligence; digital optimization*

Introduction

The pulp and paper industry is undergoing a paradigm shift as it embraces renewable bioresources for both raw materials and energy. This transition is driven by environmental imperatives, stricter regulations, and a global move toward a circular bioeconomy. Pulp and paper companies worldwide face rising pressures to improve fiber security, enhance resource efficiency, and reduce carbon emissions. In response, the industry is innovating across multiple fronts: from decarbonization, exploring alternate fiber, to adopting AI and advanced biorefineries etc. We have identified and examined six sustainability megatrends guiding the emergence of a low-carbon, circular pulp and paper industry, mentioned in Fig 1.

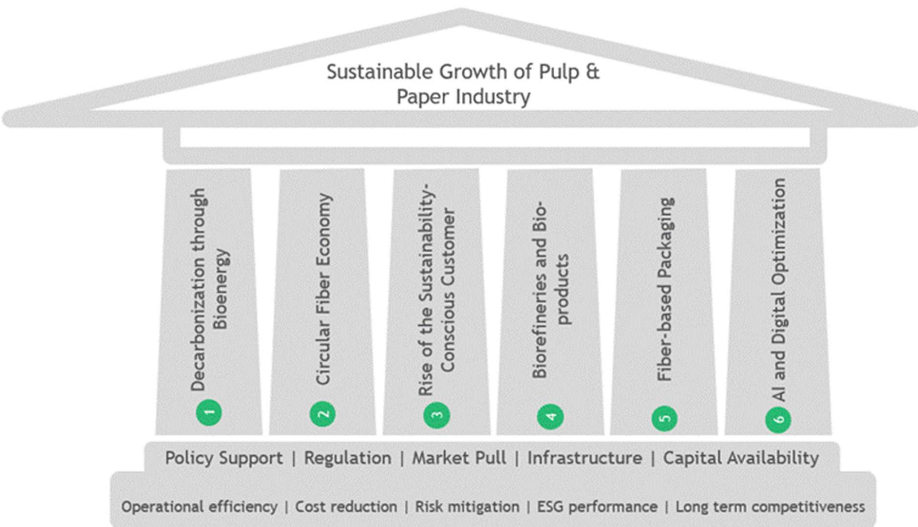

Fig. 1: 6 sustainability megatrends emerging in industry

Each of these trends is examined below in terms of its definition, current state and strategic implications for the industry. Together, they position the pulp and paper sector for a more sustainable and resilient future.

Megatrend I: Decarbonization through Bioenergy

What it is & why it matters

Decarbonization in the pulp and paper industry refers to the systematic reduction of greenhouse-gas (GHG) emissions across energy generation, process operations, and the broader value chain. This megatrend is driven by a combination of regulatory pressure, carbon-cost exposure, investor scrutiny, and customer expectations for low-carbon materials.

The sector is uniquely positioned among heavy industries. Pulp and paper mills operate with high thermal energy demand but also generate substantial quantities of biomass-based by-products, such as black liquor, bark, and other residues. These streams enable partial or near-total substitution of fossil fuels with renewable bioenergy, reducing Scope 1 emissions while improving energy security.

Decarbonization matters not only as a compliance obligation but as a determinant of long-term asset viability. Mills unable to reduce emissions intensity face rising operating costs under carbon pricing regimes, increasing difficulty in accessing capital, and potential exclusion from sustainability-driven supply chains [1].

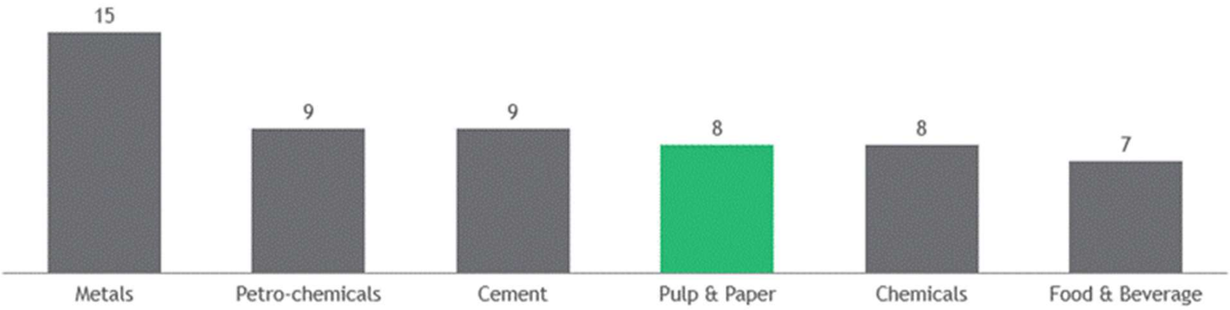

Fig. 2. Global energy consumption (Ejoule per year) comparison across major industries

Where the industry is today

The pulp and paper industry has already achieved meaningful decarbonization progress relative to other industrial sectors. According to CEPI, biomass accounts for approximately 60% of total primary energy consumption in the European pulp and paper sector, making it one of the most bioenergy-intensive manufacturing industries [2]. This transition has contributed to an estimated ~28% reduction in CO_2 emissions between 2005 and the early 2020s, despite broadly stable production volumes [2].

At the mill level, integrated kraft pulp operations often approach energy self-sufficiency. Black liquor typically supplies 40–60% of total mill energy demand, while additional biomass residues cover a significant share of remaining needs [3]. As a result, fossil fuels are increasingly confined to start-up operations, peak loads, or legacy assets.

Nevertheless, energy use remains concentrated in a few highly intensive processes. Pulping, evaporation, and paper drying dominate thermal demand and emissions profiles. According to the International Energy Agency (IEA), further progress toward net-zero pathways will require not only fuel switching but also deep reductions in underlying energy intensity [4].

India provides a practical illustration of policy-driven industrial decarbonization through bioenergy. According to the Ministry of Power and the Central Electricity Authority, biomass and bagasse-based cogeneration capacity in India exceeded 10 GW by 2023, with the pulp and paper sector representing a significant industrial user of captive biomass energy. According to IPMA, integrated paper mills in India now generate over 40% of their power on-site by utilizing biomass from the pulping process. Industry-wide energy efficiency drives (e.g. the PAT scheme under India's National Mission for Enhanced Energy Efficiency) have helped cut specific energy consumption by ~20% in the last five years [5]. Tamil Nadu Newsprint and Papers Ltd. (TNPL) has implemented an anaerobic digester to produce biogas from mill effluents like bagasse wash water, replacing fossil fuels in its lime kiln and boilers.

Technology and solution evolution

Decarbonization pathways in pulp and paper are evolving from conventional biomass combustion toward more integrated, system-level solutions:

(a) Energy efficiency and process integration

Incremental efficiency improvements—such as advanced evaporation, optimized heat recovery, and improved drying technologies—remain central. Mills are increasingly pursuing deeper heat integration to reduce steam demand and recover low-grade waste heat that was previously rejected.

(b) Selective electrification

Electrification of specific thermal loads is emerging where technically feasible. High-temperature industrial heat pumps are attracting interest as a means to upgrade waste heat from drying and other processes, particularly in regions with access to low-carbon electricity [4]. While full electrification of paper drying remains challenging, selective deployment can materially reduce fossil fuel use.

(c) Bioenergy with carbon capture and storage (BECCS)

The pulp and paper industry is widely regarded as one of the most promising industrial candidates for BECCS. CO_2 streams from recovery boilers and biomass boilers are biogenic and relatively concentrated, making capture technically attractive. Where storage infrastructure and policy support exist, BECCS can enable mills to achieve net-negative emissions, positioning them as carbon-removal hubs rather than merely low-emissions producers.

(d) Diversification of biomass pathways

Beyond direct combustion, mills are exploring biomass gasification, improved black-liquor utilization, and renewable gaseous fuels (biogas, renewable natural gas). These pathways offer cleaner combustion, improved controllability, and greater flexibility in matching energy vectors to process needs [6].

(e) Long-term process innovation

At the research and pilot level, more radical concepts are being explored. Studies suggest that innovations such as non-thermal water removal, dry-laying, superheated steam drying, or water-lean papermaking could reduce sectoral energy demand substantially in the long term, fundamentally altering emissions profiles if commercialized [7]. While such technologies remain pre-commercial, they signal the scale of potential transformation.

Table 1. Low-carbon energy and fuel pathways in the pulp and paper industry

Energy / Fuel Type	Typical Calorific Value (MJ/kg)	Key Benefits	Key Challenges	Maturity
Black liquor	13–15 (dry solids)	In-process fuel, chemical recovery	High capex, kraft-only	Fully commercial
Biomass briquettes / pellets	14–18	Coal substitution, agri-waste use	Supply variability, slagging	Commercial, growing
Agro-residues (e.g., rice straw)	10–14	Low cost, open-burning reduction	High ash/silica, seasonality	Regional
Biomass gasification	—	Cleaner combustion, flexibility	Capex, complexity	Early commercial
Electrification / heat pumps	—	Zero on-site emissions	Power cost, temperature limits	Pilot
Renewable gaseous fuels	20–25 (methane basis)	Dispatchable, low emissions	Feedstock availability, cost	Niche

Gap to ambition

While emissions intensity has declined by roughly 3% per year over the past decade, this pace is insufficient to align with a Net Zero by 2050 pathway. Achieving climate targets will require intensity reductions closer to 5% per year through 2030. Closing this gap will depend on accelerated deployment of bioenergy, electrification, and carbon capture technologies, supported by policy incentives and capital investment.

Strategic implications

Decarbonization is increasingly a strategic differentiator. Mills that achieve high levels of energy self-sufficiency reduce exposure to fossil-fuel volatility and carbon costs while strengthening their value proposition to sustainability-driven customers.

In India, policy actions—such as restrictions on coal, pet coke, and furnace oil in NCR regions—are accelerating interest in biomass-based fuels [8,9]. However, outcomes depend heavily on feedstock quality, boiler design, emission controls, and supply-chain management. Seasonal availability, ash characteristics, and storage risks make fuel quality assurance and operational discipline critical.

Over the long term, mills that combine bioenergy, efficiency, digital optimization, and emerging carbon capture solutions will be best positioned to remain competitive in a carbon-constrained world.

Megatrend II: Circular Fiber Economy

What it is & why it matters

The circular fiber economy seeks to maximize the recovery, reuse, and recycling of paper fibers, replacing the traditional linear "take–make–dispose" model with closed-loop material systems. This megatrend is central to sustainability in pulp and paper because fiber is both the primary raw material and a key lever for reducing environmental impact.

Recycling paper fibers conserves forest resources, reduces energy and water consumption relative to virgin pulp, and minimizes landfill and incineration. From a commercial perspective, recovered paper has evolved from a secondary input into a strategic raw material, influencing cost competitiveness, supply security, and customer sustainability claims [10].

Current state of adoption

Circularity outcomes vary widely by region. Europe leads globally, with a paper recycling rate of approximately 71% in 2021, supported by extended producer responsibility schemes, landfill restrictions, standardized sorting systems, and strong collaboration across the value chain [11]. The United States reported a ~68% recycling rate in 2022, including ~93% for corrugated boxes, reflecting mature collection and recovery infrastructure for packaging grades [12].

India presents a structural paradox. While ~75–76% of paper production relies on recycled fiber, recovery rates remain only ~25–30%, due to fragmented and informal collection systems, inconsistent quality, and diversion into secondary uses [13]. This mismatch forces reliance on imported waste paper, exposing mills to global price volatility and logistics risk.

Several Indian mills and industry bodies have initiated structured collection and sorting pilots in urban clusters, demonstrating that improved segregation and baling can reduce contamination and improve yield. For instance, ITC Limited's "Well-being Out of Waste (WOW)" program has established source-segregation and collection systems across multiple cities, covering 25 million citizens and collecting over 67,000 tonnes of dry waste (paper, plastic, etc.) as of 2025. These initiatives highlight that India's circularity challenge is less about end-use demand and more about collection system modernization and channelization.

System constraints and solution evolution

Circularity is constrained by fundamental material limits. Wood fibers can typically be recycled only 4–7 times before becoming too short for papermaking, and certain products (e.g., tissue) permanently remove fiber from the system [10]. Virgin fiber therefore remains structurally necessary.

To extend circularity, the industry is focusing on:

- Design for recyclability, reducing plastic laminates and non-separable barriers
- Improved sorting and cleaning technologies, enabling higher-quality recycled pulp
- Collaborative platforms, such as Europe's 4evergreen alliance, which develops guidelines and standards for circular packaging design and recycling infrastructure [14]

Momentum vs. circularity ambition

Ambition is rising faster than infrastructure in many regions. Mature markets are pushing toward higher recycling rates and closed-loop packaging systems, while emerging markets face the harder challenge of building collection, sorting, and processing capacity at scale.

In India, the Centre for Science and Environment (CSE) highlights that large volumes of recovered paper are diverted into secondary applications (hawkers, eateries, record-keeping), limiting industrial recycling despite strong demand [13]. Addressing this diversion is critical to improving circularity outcomes.

Strategic implications

Circularity has become a source of competitive advantage. Mills that secure recovered fiber through investments in collection, sorting, and quality management reduce exposure to virgin pulp price cycles and strengthen alignment with packaging and consumer goods customers seeking recycled content and circularity claims.

For India, the strategic opportunity lies in strengthening domestic recovery systems, improving channelization into mills, and reducing dependence on imports—enhancing both sustainability and resilience.

Megatrend III: Rise of the Sustainability-Conscious Customer

What it is & why it matters

One of the most powerful megatrends reshaping the pulp and paper industry is the rise of the sustainability-conscious customer. This shift goes beyond general environmental awareness toward demand for verified, auditable sustainability performance across materials, processes, and supply chains. For pulp and paper producers, this fundamentally changes what wins business.

Customers, particularly multinational brand owners, retailers, and converters, are increasingly embedding sustainability criteria into procurement, including certified sourcing, traceable recycled content, substantiated environmental claims, and compliance with recyclability and packaging regulations. Sustainability is therefore no longer a marketing differentiator but a baseline expectation for participation in many value chains.

For India, this megatrend is especially relevant because incremental growth is increasingly export-linked, either directly or through global brand supply chains. Even domestic demand is being influenced by global norms as Indian consumers interact more with international brands and packaging standards.

Current state of adoption

Consumer research confirms that sustainability remains a material purchasing factor even under inflationary pressure. PwC's 2024 Voice of the Consumer Survey reports that consumers are willing to pay an average ~9.7% premium for sustainably produced or sourced goods, indicating resilience of sustainability preferences despite cost-of-living concerns [15].

Packaging-specific research shows a more nuanced picture. McKinsey's global packaging studies indicate that while sustainability influences preferences, price and functionality remain dominant—reinforcing that sustainable paper solutions must deliver cost-justified performance to scale [16]. In India, Mintel's packaging insights similarly note openness to eco-friendly packaging, but with affordability and convenience prioritized, suggesting that adoption accelerates when sustainability aligns with functional value.

Large buyers are translating these signals into procurement mandates. IKEA reported that 97% of the wood it used in FY2024—including indirect materials such as packaging—was FSC-certified or recycled, clearly signaling that certified and traceable fiber is becoming a baseline requirement rather than a premium option [17].

Regulatory reinforcement

In the EU, sustainability is becoming enforceable compliance. The EUDR mandates due diligence and traceability for deforestation-free pulp and paper [18], while the PPWR introduces recyclability-by-design and labeling requirements from August 2026 [19]. Strengthened EPR frameworks further tighten accountability for packaging waste.

India is moving in a similar direction. The Ministry of Corporate Affairs has introduced Business Responsibility and Sustainability Reporting (BRSR) and BRSR Core, requiring large listed companies to disclose detailed sustainability and supply-chain metrics. This is increasing downstream pressure on Indian pulp and paper suppliers to provide auditable data on fiber sourcing, recycled content, and environmental performance.

Strategic implications

This megatrend shifts competition from "being sustainable" to proving sustainability. For pulp and paper producers, especially in India, competitive advantage increasingly depends on certification readiness, data integrity, and traceability systems that can withstand regulatory and customer scrutiny.

Strategically, the largest opportunities lie in solutions that combine verified sustainability with performance and cost—such as recyclable barrier papers, optimized recycled-content packaging, and fiber-based alternatives that meet functional requirements without undermining circularity. Mills that institutionalize credible sustainability proof points will be better positioned to win global brand business, reduce regulatory risk, and sustain long-term growth.

Megatrend IV: Biorefineries and Bio-products

What it is & why it matters

In the pulp and paper context, a biorefinery refers to an integrated facility—often centered on a pulp mill—that converts biomass into a portfolio of products beyond pulp, paper, and energy. These include bio-based chemicals, materials, and fuels derived from wood components such as lignin, hemicelluloses, and extractives.

This megatrend matters because it enables the industry to move up the value chain and diversify revenue streams, particularly as demand for graphic papers declines. By valorizing streams historically burned for energy, biorefineries improve overall resource efficiency and reposition pulp mills as multi-product renewable materials platforms rather than single-product assets [20].

Current state of adoption

Many global pulp mills already operate as partial biorefineries, producing tall oil, turpentine, and lignosulfonates. What is changing is the scale and formalization of these activities.

In Europe, approximately 139 forest-based biorefineries have been identified, with ~84% integrated into chemical pulping mills. Bio-based products beyond pulp and paper generate an estimated ~€2.7 billion annually, representing roughly ~3% of sector revenue, with activity concentrated in Sweden, Finland, Germany, France, and Austria [21].

India follows a structurally different pathway. With only ~18–20% wood-based paper, ~74–76% recycled fiber, and ~6–8% agro-residues, classic Nordic biorefinery models are constrained. Opportunities instead center on agro-residue and waste-stream valorization, particularly at large bagasse-based mills.

Some Indian mills have embraced "waste-to-product" approaches in line with biorefinery principles. For instance, TNPL operates a small cement plant that uses lime sludge, fly ash, and other by-products from the pulping process to produce cement, turning solid waste into a revenue-generating construction material.

Beyond the mill gate, India's push for biofuels has led to standalone biorefineries that illustrate what's possible with lignocellulosic feedstocks: in August 2022, Indian Oil Corporation (IOCL) commissioned the country's first 2G ethanol plant in Panipat, designed to convert ~200,000 tonnes of agricultural residue (rice straw) into about 30 million liters of ethanol per year.

While not integrated with a pulp mill, this facility demonstrates at scale the kind of biomass valorization (from farm waste to fuels) that could, in the future, be synergistic with agro-residue based pulp mills.

Table 2. Examples of biorefinery products in the pulp and paper industry

Product	Biomass Source	Key Applications	Commercial Status
Tall oil	Kraft pulping	Renewable fuels, chemicals	Commercial
Kraft lignin	Black liquor	Resins, binders, carbon materials	Commercial
Lignosulfonates	Sulphite pulping	Construction additives, dispersants	Commercial
Bioethanol	Hemicellulose streams	Fuels, chemicals	Pilot / early
Bio-based chemicals	Wood sugars	Polymers, intermediates	Pilot / early
Bio-char	Residues	Soil, energy, materials	Emerging

Technology and solution evolution

Technological advances are enabling deeper valorization of biomass components. Lignin extraction technologies now allow production of high-purity lignin for resins, carbon materials, and specialty applications. Hemicellulose streams can be converted into sugars, ethanol, or specialty chemicals.

At industrial scale, leading Nordic producers operate tall-oil-based biorefineries producing on the order of ~100,000 t/year of renewable fuels, while new biochemicals projects target ~200,000 t/year of bio-based chemicals—approaching the scale of small petrochemical plants [22]. Commercial lignin extraction units producing tens of thousands of tonnes per year further demonstrate maturation of these pathways.

Momentum vs structural constraints

Despite progress, biorefineries remain capital-intensive and complex. Not all mills have sufficient scale, feedstock quality, or integration potential, and returns depend heavily on product selection, market access, and policy support. In India, dispersed agro-residue supply, smaller mill size, and limited chemical-market integration further constrain adoption, concentrating activity among large, well-capitalized players or those with strong partnerships.

Strategic implications

Biorefineries provide a powerful diversification lever. By expanding into bio-based chemicals, materials, and fuels, pulp and paper companies reduce exposure to cyclical paper markets while improving asset utilization and ESG positioning. In India, near-term opportunities lie in incremental valorization of bagasse, sludge, or recycled-fiber residues rather than full-scale chemical biorefineries.

Large bagasse-based mills in India already operate integrated energy systems and have begun exploring incremental valorization pathways, including bio-chemicals from spent liquors and residue-derived fuels. While full-scale chemical biorefineries remain constrained by scale and market integration, these incremental pathways demonstrate a pragmatic Indian approach: stepwise diversification rather than full refinery transformation.

This reinforces that India's biorefinery future is likely to be selective, feedstock-driven, and partnership-led rather than a replication of European models.

Megatrend V: Fiber-based Packaging

What it is & why it matters

Fiber-based packaging encompasses paperboard, corrugated boxes, molded fiber, and emerging fiber-based formats that substitute plastic packaging. This megatrend reflects a structural shift toward "paperization," driven by regulation on single-use plastics, sustainability expectations, and rapid growth in e-commerce.

In India, restrictions on identified single-use plastic items effective 1 July 2022 have accelerated substitution opportunities for paper-based alternatives in specific formats [23].

Current state of adoption

Packaging grades dominate global paper production. In Europe, packaging paper and board accounted for ~59% of total paper output in 2021, with production growth outpacing other segments [2]. Recycling underpins the sustainability case, with European paper packaging recycling rates exceeding 80% [11].

In India, adoption is driven by regulatory pressure and demand growth. Plastic EPR requirements under the Plastic Waste Management (Amendment) Rules, 2022 raise compliance costs for plastics, strengthening the economic case for fiber-based alternatives where functional requirements permit. For example, major e-commerce and retail companies have voluntarily overhauled their packaging to reduce plastic use. Amazon India announced that it eliminated single-use plastic in its own fulfillment packaging by 2020, replacing plastic air pillows and bubble wrap with 100% paper-based dunnage and mailers.

Technology and solution evolution

Innovation is expanding the performance envelope of fiber-based packaging. New barrier coatings, structural designs, and forming technologies enable protection of food, replacement of protective foams, and entry into applications historically dominated by plastics. R&D efforts increasingly target recyclability-by-design, aiming to balance performance with circularity.

For instance, one of India's largest paper mills has successfully conducted trials using a biodegradable polylactic acid (PLA) coating on paperboard to replace traditional PE laminates, achieving a functional moisture/grease barrier that is fully compostable

Momentum vs structural constraints

Despite strong momentum, constraints remain. Performance trade-offs in moisture/grease barriers can require coatings that complicate recyclability. Rapid capacity additions can also create regional oversupply risk. In India specifically, a practical constraint is enforcement and transition readiness: while restrictions are in force nationally, effectiveness depends on coordinated action across stakeholders and enforcement against illegal manufacture/sale. This means adoption can be uneven by state/city and by product category, affecting demand certainty for fiber substitutes.

Strategic implications

For pulp and paper companies, fiber-based packaging is the core growth and repositioning lever, often supported by machine conversions from declining graphic grades to packaging. In India, strategy must explicitly account for policy-driven demand shifts: restrictions create near-term substitution pockets, while plastic EPR requirements increase the "total cost of plastics" for brand owners, strengthening the commercial case for fiber where it meets functionality. Winners will differentiate via performance (lightweighting, strength, barrier solutions), system readiness (recyclability-by-design), and customer collaboration, positioning as solution partners helping brands navigate compliance and sustainability expectations, not just material suppliers.

Megatrend VI: AI and Digital Optimization

What it is & why it matters

AI and digital optimization in the pulp and paper industry refers to the use of advanced digital technologies, AI and machine learning, IoT sensors, advanced process control (APC/MPC), analytics, computer vision, and digital twins, to improve manufacturing efficiency, reliability, quality, and decision-making.

In a continuous, asset-intensive industry, small improvements in uptime, yield, or variability translate into significant economic value. Digital tools also help address structural challenges such as raw-material variability, tightening sustainability targets, and the loss of experienced operators by embedding process knowledge into data-driven systems. As margins remain tight and operational excellence is a key differentiator, AI-enabled optimization is becoming central to competitiveness.

Current state of adoption

Adoption has accelerated in recent years, broadly tracking digitalization trends across manufacturing. Public market estimates indicate rapid growth in industrial AI spending globally, with manufacturing among the fastest-growing adopters. Within pulp and paper, the most common deployments today include predictive maintenance, quality prediction and control, advanced process control overlays, and energy optimization. While fully autonomous mills are still aspirational, many mills already capture tangible benefits from partial automation and analytics-driven decision support.

Technology and solution evolution

The focus is shifting from basic monitoring to more autonomous optimization. Model Predictive Control (MPC) and other advanced control techniques are increasingly applied to difficult process loops, enabling mills to operate closer to optimal limits while maintaining quality. Digital twins and dynamic simulators are used to test "what-if" scenarios, validate control strategies, and train operators without disrupting production. Computer vision is expanding defect detection and quality inspection capabilities, while AI-based forecasting and planning tools are improving coordination across production, inventory, and logistics. Together, these tools move the industry toward semi-autonomous operations.

Momentum vs structural constraints

Despite growing momentum, scaling AI across mills remains uneven. Structural constraints include legacy equipment, inconsistent instrumentation and data quality, cybersecurity concerns, and shortages of digital and analytics talent. In India, these challenges are often more pronounced, particularly in older mills, making large-scale rollouts harder than pilot deployments.

In practice, mills adopting AI-driven optimization have reported significant gains. An AI implementor in India for example claimed that its AI-based process control and analytics have achieved up to 15% higher output and 10% lower raw material usage by minimizing process variability and tightening controls

Strategic implications

AI and digital optimization are shifting from pilots to a structural competitiveness lever. Mills achieving higher uptime, lower variability, and more efficient use of energy, water, and fiber gain durable cost and reliability advantages. Success requires scalable digital capabilities, OT–IT integration, strong data governance, and alignment between process engineering and analytics. Digitalization also supports sustainability and ESG transparency.

For Indian producers, phased adoption focused on high-impact use cases can deliver near-term value while enabling the transition toward the self-optimizing mill and long-term competitiveness.

Conclusion

This traditionally resource-intensive sector is reinventing itself as a linchpin of the renewable bioeconomy, demonstrating agility and innovation in the face of global challenges. Mills are cutting carbon emissions by embracing bioenergy and carbon capture; recycling systems are closing the loop on fiber use at record rates; non-wood fibers like straw and bagasse are being integrated through new technologies; pulp mills are diversifying into biochemical and biomaterial production; fiber-based packaging is expanding as an alternative to plastic; and AI-driven smart manufacturing is boosting efficiency and precision on the factory floor.

For industry players, these trends are interconnected. Success in fiber-based packaging depends on circular fiber systems and innovation in bio-based barriers; decarbonization benefits from digital optimization and biorefinery approaches that convert residues to energy and higher-value products. Strategically, businesses that holistically integrate these trends into operations and corporate strategy are positioning themselves for long-term competitiveness. They will operate with lower carbon footprints, more diversified product lines, and higher resource efficiency, appealing to sustainability-driven customers and investors and building resilience against regulatory, resource, and technology disruptions.

Abbreviations

APC – Advanced Process Control

AI – Artificial Intelligence

BECCS – Bioenergy with Carbon Capture and Storage

BRSR – Business Responsibility and Sustainability Reporting

CAQM – Commission for Air Quality Management

CEPI – Confederation of European Paper Industries

CPCB – Central Pollution Control Board (India)

CSE – Centre for Science and Environment (India)

EPR – Extended Producer Responsibility

EUDR – European Union Deforestation Regulation

FAO – Food and Agriculture Organization of the United Nations

FSC – Forest Stewardship Council

GHG – Greenhouse Gas

IEA – International Energy Agency

IRENA – International Renewable Energy Agency

IPMA – Indian Paper Manufacturers Association

MPC – Model Predictive Control

MoEFCC – Ministry of Environment, Forest and Climate Change (India)

PPWR – Packaging and Packaging Waste Regulation (EU)

RNG – Renewable Natural Gas

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