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*Case Study*

# Sustainable Growth of the Paper Industry: Cases of Paperboard

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**Received:** 07 January 2025
**Revised:** 20 April 2025
**Accepted:** 30 November 2025
**Published:** 27 February 2026


**Abstract:** (1) Background/Purpose: Korea's white paperboard (folding boxboard) industry faces a compounding crisis: domestic and global supply surpluses driven by large-scale capacity additions in Southeast Asia (notably XSD International Paper's 350,000 t/y Malaysia facility in 2022), intensifying export-market competition, rising raw material costs, tightening environmental regulation including the EU Carbon Border Adjustment Mechanism (CBAM), and accelerating digital transformation. This study seeks to identify evidence-based strategic responses that can enable Korean paperboard firms to move from crisis management to sustainable competitive growth. (2) Methodology: The study combines systematic environmental analysis (PEST, Porter's Five Forces, market sizing), industry data from the Korea Paper Association and international sources (PMI, Fisher International, SCI Verkehr), and four in-depth innovation case studies: Company A's fly ash recycling and $CO_2$ carbonation technology; Company B's sterilized-pack circular economy model; Stora Enso's biomass-based Formed Fiber technology and intelligent manufacturing system; and Metsä Board's Excellence Centre 2030 digital-circular integration program. (3) Findings: Despite structural pressures, four transformative growth pathways are identified. First, waste-to-resource innovation: Company A's fly ash recycling reduced waste disposal costs by 50% and enabled domestic PCC production with $CO_2$ capture; Company B's sterilized-pack recycling achieved 100% circular valorization of pulp and polyAl layers, establishing a customer lock-in model. Second, renewable materials market creation: Stora Enso's Formed Fiber generated EUR 280M in Q3 2023 revenue (+35% YoY), secured by long-term contracts of EUR 400M/year to 2025. Third, AI-driven manufacturing intelligence: Stora Enso's IMS (2,000+ sensors, digital twin, AI quality prediction) reduced defect rates by 32%, improved energy efficiency by 24%, and saved EUR 12M/year; Metsä Board's predictive quality management reduced defects by 47% and raised customer satisfaction by 18%. Fourth, circular-by-design partnerships: Metsä Board's Circular Design program and water recycling system achieved 99% product recyclability and 15% water cost reduction. (4) Originality/Value: This study provides the first integrated strategic analysis linking Korean paperboard industry structural challenges to both domestic innovation cases and Nordic benchmark practices, producing a multi-horizon strategic framework covering technology innovation, new market entry, cost competitiveness, digital transformation, and human resource development.

**Keywords:** paperboard; white paperboard; sustainable growth; circular economy; fly ash recycling; digital twin; predictive maintenance; biomass materials; Stora Enso; Metsä Board; CBAM; ESG

## 1. Introduction

### 1.1. Research Background

The global paper industry has supported modern economic development for over a century, supplying essential materials for printing, publishing, packaging, and industrial applications. Following explosive demand growth in the second half of the twentieth century, the industry now faces a fundamentally transformed operating environment. The proliferation of digital media has eroded printing paper demand; environmental regulations have become substantially more stringent; and competitive intensity has been magnified by the globalization of production capacity.

Within this broader context, the white paperboard sector occupies a paradoxical position of simultaneous opportunity and crisis. On the demand side, the rapid expansion of e-commerce has driven sustained growth in packaging material consumption, and heightened consumer awareness of sustainability is creating new demand for paper-based alternatives to plastic packaging. On the supply side, large-scale capacity additions—particularly in Southeast Asia—are creating a structural supply surplus that threatens to trigger destructive price competition. In 2022, XSD International Paper commissioned a 350,000-tonne-per-year white paperboard facility in Malaysia, directly targeting the markets that absorb approximately 70% of Korea's white paperboard exports. Simultaneously, domestic capacity expanded when Hanchangje Paper acquired Shinpoong Paper's white paperboard equipment for KRW 13.5 billion, adding more than 300,000 tonnes/year of domestic production capacity against stagnant domestic demand.

The compounding of supply surplus with external cost pressures—pulp price volatility (BHKP reaching USD 900/tonne in 2022), logistics cost inflation from geopolitical disruption, and the approaching implementation of the EU Carbon Border Adjustment Mechanism (CBAM)—creates a multi-dimensional strategic challenge that cannot be resolved by operational optimization alone. Structural strategic reorientation is required.

This study proceeds from the recognition that the crisis facing Korean white paperboard producers contains within it the seeds of transformative opportunity. Companies and industries that respond to structural disruption with technological innovation, business model evolution, and collaborative ecosystem-building consistently outperform those that respond with cost-cutting and capacity rationalization alone. The experiences of domestic pioneers such as Company A and Company B, and of Nordic industry leaders Stora Enso and Metsä Board, provide a concrete evidence base for identifying what those transformative responses look like in practice.

### 1.2. Research Objectives

This study pursues three specific objectives:

1. To provide a comprehensive environmental analysis of the Korean white paperboard industry, integrating macro-environmental trends (PEST), structural competitive dynamics (Porter's Five Forces), and market sizing and trajectory data.
2. To conduct in-depth innovation case analyses of four companies—two domestic (Company A, Company B) and two international (Stora Enso, Metsä Board)—to extract transferable strategic lessons for Korean paperboard producers.
3. To derive a multi-horizon strategic framework covering technology innovation, new market entry, cost competitiveness, digital transformation, and human resource development, providing actionable implementation guidance for companies and policy recommendations for government.

### 1.3. Research Methodology

The study employs a mixed-method approach combining systematic literature review and quantitative market analysis with qualitative case-study methodology. Market sizing, structural analysis, and trend identification draw on data from the Korea Paper Association, Korea Trade Association, PMI, Fisher International, and SCI Verkehr. Industry structure analysis applies Porter's Five Forces framework. Case analyses draw on company annual reports, sustainability reports, patent registrations, and published academic literature. Industry expert consultation has been conducted to validate interpretations and enhance practical applicability.

## 2. Environmental Analysis

### 2.1. Macro-Environmental Analysis (PEST)

#### 2.1.1. Political and Regulatory Environment

The regulatory environment for paper and paperboard manufacturing is tightening substantially on multiple fronts. The EU's Carbon Border Adjustment Mechanism (CBAM), entering its transitional phase in 2024 and full implementation thereafter, will impose carbon costs on imports of carbon-intensive products into the EU. Korean paperboard exports to European markets—while currently modest relative to Southeast Asian volumes—will be directly subject to these costs. More significantly, CBAM creates a regulatory template likely to be adopted by other major markets, and signals the direction of global trade policy toward carbon pricing at borders.

Domestically, the 2022 revision of Korea's Framework Act on Resource Circulation strengthens manufacturer recycling obligations. The Greenhouse Gas Emissions Trading Scheme imposes increasingly rigorous carbon management requirements. The government's 2050 Carbon Neutrality Declaration creates a long-term regulatory trajectory that mandates fundamental decarbonization of energy-intensive manufacturing processes. However, the government's 'Materials, Parts, and Equipment 2.0 Strategy' simultaneously provides support for eco-friendly material development—representing both a compliance burden and an innovation opportunity for firms that move proactively.

#### 2.1.2. Economic Environment

The global economic deceleration since 2022, amplified by persistent inflation and elevated interest rates, has dampened demand growth across major export destinations. For Korean paperboard producers, whose exports are concentrated in Southeast Asia, the moderation of growth in those markets compounds the competitive pressure from new local capacity. Raw material cost volatility constitutes a structurally significant challenge: domestic producers rely on imports for over 90% of their pulp requirements, creating exposure to both international pulp price swings and currency

fluctuations. The 2022 surge in bleached hardwood kraft pulp to USD 900/tonne is illustrative of this vulnerability. Medium-to-long-term demand dynamics are more constructive: e-commerce market growth, increasing preference for sustainable packaging, and demographic trends (growth in small household formats; pharmaceutical packaging demand associated with population ageing) are positive demand drivers.

#### 2.1.3. Social and Consumer Environment

Consumer attitudes toward environmental sustainability have shifted substantially, particularly among younger demographics. Preference for paper-based packaging over plastic is now a measurable purchasing factor in consumer goods categories. The regulatory reinforcement of this preference through single-use plastics bans and extended producer responsibility schemes is accelerating the substitution of plastic packaging with paperboard across food, personal care, and pharmaceutical categories. Demographic transitions—the growth of single- and two-person households driving demand for smaller package formats; an ageing population driving pharmaceutical packaging growth—create differentiated sub-market opportunities within the broad paperboard category.

#### 2.1.4. Technological Environment

Fourth Industrial Revolution technologies are reshaping manufacturing across sectors, and paper and paperboard production is no exception. AI-enabled production optimization, IoT-based real-time process monitoring, digital twin simulations, and big data-driven predictive quality management are being deployed by leading global producers to achieve step-change improvements in efficiency, quality, and resource utilization. Eco-materials innovation—biomass-based specialty materials, advanced recycling process development, carbon capture and utilization integrated into production processes—is creating genuinely new market categories rather than merely improving existing products.

### 2.2. Industry Structure Analysis (Porter's Five Forces)

**Table 3. Porter's Five Forces analysis of the Korean white paperboard industry.**

| Force | Intensity | Key Factors |
|---|---|---|
| Threat of New Entrants | LOW | Capex requirements (>KRW 100B); minimum economic scale ~300K t/y; environmental compliance costs; established distribution relationships |
| Threat of Substitutes | LOW-MEDIUM | Bioplastics, biodegradable film, regenerated cellulose emerging; however plastic regulation accelerating shift toward paperboard |
| Supplier Power | HIGH | Global pulp market: top 5 firms >40% share; domestic dependency on imports >90%; bleached pulp reached USD 900/t in 2022 |
| Buyer Power | MEDIUM-HIGH | Major food/pharmaceutical/cosmetics customers demand ESG compliance; long-term supply contracts with strict quality and sustainability criteria |
| Industry Rivalry | MEDIUM (domestic) HIGH (export) | Domestic: duopoly (top 2 firms >70% share); export: intensifying price competition from SE Asian producers (XSD, 350K t/y, Malaysia 2022) |

The Five Forces analysis reveals that the Korean white paperboard industry's primary competitive threats come not from new domestic entrants or substitute materials, but from the structural power of upstream pulp suppliers and—most acutely—from intensifying competition in export markets driven by the entry of large-scale Southeast Asian producers. The domestic market's duopolistic structure provides relative stability, but this is insufficient to offset export market deterioration. The strategic implication is clear: competing on price in an oversupplied export market is a path to mutual destruction. Differentiation—through product innovation, sustainability credentials, service integration, and digital capability—is the only sustainable path forward.

### 2.3. White Paperboard Industry Overview and Outlook

#### 2.3.1. Product Classification

White paperboard is a category of paperboard manufactured primarily from bleached chemical pulp, characterized by high whiteness, excellent printability, and superior processability. Its physical properties make it the material of choice for pharmaceutical, cosmetic, food, and premium consumer goods packaging. Growing interest in sustainability is driving increasing demand for eco-friendly variants incorporating higher proportions of recycled pulp and certified sustainable virgin fiber.

**Table 1. White paperboard detailed classification. Source: Korea Paper Association.**

| Grade | Raw Materials | Key Characteristics | Typical Applications |
|---|---|---|---|
| White Paperboard Grade 1 (Premium White / FBB) | 100% bleached chemical pulp (virgin) | High whiteness; excellent printability; high bulk and stiffness | Pharmaceuticals, cosmetics, premium food packaging, luxury goods |
| White Paperboard Grade 2 (Ivory Board / GC2) | Bleached chemical pulp top ply; mechanical pulp middle ply | Good printability; lower cost than Grade 1 | Food service, beverage cartons, mid-range consumer goods |
| White-Lined Chipboard (WLC / GD) | Recycled pulp (bottom and middle); bleached pulp top ply | Cost-effective; good recycled content ratio; lower whiteness | Industrial packaging, general consumer goods, dry foods |
| Eco-Friendly White Paperboard | Increased recycled pulp ratio; certified sustainable fiber sources | High recycled content; FSC/PEFC certified | Sustainable packaging, retail brands with ESG commitments |

### 2.3.2. Market Size and Growth Trajectory

The global paper and paperboard packaging market reached approximately USD 215.3 billion in 2020 and is projected to grow at a CAGR of 3.3%, reaching approximately USD 287.4 billion by 2029 (PMI, 2021). Asia-Pacific is the largest and fastest-growing region, driven by China's continued economic development and the rapid expansion of e-commerce and consumer goods industries across ASEAN markets. North America and Western Europe are growing more slowly in volume terms but are generating new demand through plastic substitution and premium sustainable packaging adoption.

**Table 2. Global paper and paperboard packaging market size by region. Source: PMI (2021).**

| Region | 2020 Market Size (USD B) | 2029 Forecast (USD B) | CAGR 2020–2029 (%) | Key Growth Drivers |
|---|---|---|---|---|
| Asia-Pacific | ~85 | ~118 | ~3.8% | E-commerce expansion; urbanization; rising income in India and SE Asia |
| North America | ~45 | ~59 | ~3.0% | Plastic substitution; sustainable packaging regulation; e-commerce |
| Western Europe | ~42 | ~55 | ~3.1% | EU Green Deal; CBAM; plastic ban driving paper shift |
| Rest of World | ~43 | ~55 | ~2.9% | Infrastructure development; food & beverage growth |
| Global Total | ~215 | ~287 | ~3.3% | E-commerce, sustainability regulation, plastic substitution |

Korea's domestic white paperboard production reached approximately 1.47 million tonnes in 2020, declining slightly to approximately 1.42 million tonnes by 2023, reflecting the impact of intensified export competition on throughput utilization. Domestic consumption stands at approximately 800,000 tonnes, with exports accounting for more than 40% of production. The domestic market is heavily concentrated: Hansol Paper and Kkaekkeuthan Nara collectively hold more than 70% market share, with Hansol Paper maintaining an approximately 45% share in the premium white segment and Kkaekkeuthan Nara an approximately 32% share in the WLC segment.

Korea's export dependence on Southeast Asian markets—approximately 70% of export volume directed to Malaysia, Thailand, Indonesia, and Vietnam—creates acute vulnerability to new local production capacity. The XSD Malaysia facility represents the most immediate competitive threat, but the broader trajectory of Southeast Asian paperboard capacity expansion represents a structural shift in the competitive landscape that cannot be reversed by price responses alone.

## 3. Case Analysis

Four innovation cases are examined: two domestic (Company A, Company B) and two international (Stora Enso, Metsä Board). Table 4 provides a comparative overview; the following sections analyze each case in depth.

**Table 4. Comparative case analysis summary.**

| Dimension | Company A (Fly Ash) | Company B (Sterilized Pack) | Stora Enso (Finland) | Metsä Board (Finland) |
|---|---|---|---|---|
| Core Innovation | Fly ash recycling + $CO_2$ carbonation → PCC synthesis | Sterilized pack → pulp + polyAl pellets (100% circular) | Formed Fiber (100% renewable NE wood pulp); 16 patents | Digital twin + predictive quality management; smart water recycling |
| Investment Scale | Incremental R&D; government CCU project participation | Custom processing line + batch high-temp delamination system | EUR >1B over 2020–2022 (35% of capex) | EUR 1.5B through 2025 (Excellence Centre 2030) |
| Key Outcomes | Waste disposal cost -50%; PCC self-supply; $CO_2$ reduction | Polyal pellet valorization; customer lock-in; near-zero landfill | Product revenue +35% YoY (Q3 2023); defect rate -32%; energy efficiency +24% | Defect rate -47% (2020→2023); customer satisfaction +18%; water costs -15% |
| Technology Partnerships | Calcium carbonate manufacturer; government CCU program | Key customer (dairy firms); external data/certification bodies | Royal Institute of Technology (Sweden); VTT (Finland); Siemens | ABB (digital twin); IDE Technologies (water treatment) |
| Strategic Significance | Waste → resource; PCC import substitution; carbon capture | Circular economy model; new revenue stream; ESG leadership | Market creation through renewable materials; sustainability-as-growth | Digital-circular convergence; quality as competitive differentiator |

## 3.1. Company A: Fly Ash Recycling and $CO_2$ Carbonation Technology

### 3.1.1. Background and Innovation Context

Company A is a leading Korean paperboard manufacturer that has developed pioneering waste valorization technologies targeting fly ash generated from paper sludge incineration. Fly ash from paperboard production incineration processes had historically been classified as a disposal cost center, with annual disposal expenditures reaching tens of billions of KRW. Company A identified this waste stream as a potential resource and initiated systematic research in 2018 to characterize its properties and identify viable utilization pathways.

**Figure 1. Fly ash generation process in paperboard manufacturing. Source: Company A patent documentation.**

### 3.1.2. Fly Ash Recycling Technology (Patent No. 10-2020-013142)

In October 2020, Company A filed a patent for ‘A method for manufacturing paper raw materials using fly ash from paper incinerators’ (Application No. 10-2020-013142). The core of the technology is a multi-stage pre-treatment process designed to remove fiber-bonding inhibitors and quality-degrading elements from raw fly ash: magnetic substance and chloride ion removal; particle size classification; and unburned material separation. The pre-treated fly ash demonstrated substantially improved physical and optical characteristics relative to raw fly ash, enabling its use as a partial replacement for conventional fillers.

Practical benefits include: partial replacement of purchased fillers with zero-cost internally generated material; improvement in paper bulk and formation characteristics; contribution to drying efficiency with associated energy cost reduction; and no detrimental impact on final product properties. The most significant economic outcome was a reduction of approximately 50% in annual fly ash disposal costs. Environmental benefits include reduced landfill volumes and improved compliance with waste management obligations.

**Figure 2. White paperboard product structure illustrating the role of filler materials. Source: Company A.**

### 3.1.3. Fly Ash Carbonation Technology (Patent No. 10-2521806)

Building on the fly ash recycling foundation, Company A subsequently developed a fly ash carbonation technology registered in April 2022 (Registration No. 10-2521806): ‘A method for manufacturing paperboard core layer materials

using fly ash from paper incinerators.' This technology represents a qualitative advance over basic fly ash recycling: rather than mechanical valorization, it achieves chemical transformation of fly ash into precipitated calcium carbonate (PCC) through reaction with $CO_2$ from boiler flue gas.

The technical mechanism is elegant: chloride-ion-removed fly ash slurry is exposed directly to $CO_2$-containing boiler exhaust gas, triggering precipitation of calcium carbonate without requiring separate $CO_2$ capture equipment. The synthesized PCC exhibits near-spherical particle morphology that improves paper retention and drainage characteristics. Optical quality reaches over 90% of purchased PCC performance. The process simultaneously achieves carbon utilization (reducing flue gas $CO_2$) and PCC production, creating a dual environmental benefit.

Company A is actively scaling this technology with related equipment installation, and is participating in the government's 'Carbon Capture and Utilization Technology Development' project. The implications for the broader industry are significant: fly ash carbonation represents a model for converting a compliance cost (waste disposal) and a procurement cost (PCC purchase) into an integrated solution that also contributes to carbon management objectives.

## 3.2. Company B: Sterilized Pack Circular Economy Model

### 3.2.1. Background and Strategic Context

Company B has developed a pioneering recycling business for post-consumer sterilized beverage packs (aseptic cartons)—a material stream that presents significant technical challenges due to its composite structure (paperboard + polyethylene + aluminium foil). Korea's sterilized pack recycling rate stood at only 1.5% in 2023 (Korea Circular Resources Distribution Support Center), reflecting the difficulty of economically processing this multi-layer material. Company B identified this gap as both an ESG obligation and a strategic business opportunity.

### 3.2.2. Process Innovation and Technical Outcomes

Company B developed a dedicated processing line utilizing high-temperature batch delamination to separate sterilized pack composite materials. Steam injection into the pulper under optimized temperature and pressure conditions achieves separation of the paperboard pulp fiber from the polyethylene-aluminium (polyAl) layer at a significantly higher efficiency than general-purpose recycling systems. All stages of the process—from pack receipt through pulping, separation, production, and output—are monitored in real time and documented through integration with external certification bodies.

**Figure 3. Company B's sterilized pack circular resource model. Source: Company B.**

The key innovation that distinguishes Company B's model from earlier attempts at sterilized pack recycling is the full valorization of the polyAl layer. Previously, separated polyAl was typically re-classified as waste, requiring disposal at additional cost. Company B has developed a process of melting and molding the polyAl residue under controlled heat and pressure to produce high-purity polyAl pellets, which are then sold as raw material for plastic products. This transformation converts a liability into a revenue stream, simultaneously eliminating disposal costs and generating sales income from a previously wasted material.

### 3.2.3. Business Model and Strategic Value

Company B has structured its sterilized pack recycling business around strategic partnerships with major dairy and food companies whose products generate sterilized pack waste. Providing customized collection, processing, and recycling services tailored to each partner's requirements creates strong customer lock-in while enabling those customers to fulfil their own ESG commitments regarding packaging recyclability. This positions Company B as an essential sustainability partner rather than a commodity supplier, supporting premium pricing and long-term contract stability. The business model illustrates how circular economy engagement, when designed with commercial logic, creates sustainable competitive advantage rather than merely compliance cost.

## 3.3. International Benchmark: Stora Enso and Metsä Board

### 3.3.1. Stora Enso: From Paper Company to Renewable Materials Leader

Stora Enso's strategic transformation began in earnest with the board's 2019 approval of the 'Future Smart' program and the 2020 declaration of its identity as a 'Renewable Materials Company.' This reframing was operationalized through a Science Based Targets Initiative (SBTi)-validated Net-Zero roadmap: 50% reduction in direct Scope 1+2 emissions by 2030 (vs. 2019); 35% reduction in Scope 3 (supplier) emissions by 2030. CDP has awarded Stora Enso an A rating for four consecutive years.

Total sustainability-related investment from 2020 to 2022 exceeded EUR 1 billion, representing 35% of total capex. Sustainability investments demonstrated superior returns: average payback period of 4.2 years versus 5.8 years for conventional capex. The flagship technology, Formed Fiber, uses 100% renewable Nordic wood pulp and is protected by patents in 16 countries. Developed in collaboration with the Royal Institute of Technology (KTH, Sweden) and VTT Technical Research Centre (Finland), Formed Fiber generated EUR 280 million in Q3 2023 revenue, up 35% year-on-year, secured by long-term supply contracts worth EUR 400 million/year to 2025. Customer satisfaction surveys indicate 93% reporting 'very satisfied' or higher.

Production digitalization at Stora Enso's Skoghall mill, developed in partnership with Siemens with a EUR 68 million investment over 2021–2022, has deployed an Intelligent Manufacturing System (IMS) incorporating 2,000+ sensors, AI-based quality prediction, and digital twin simulation. Results: defect rate -32%; energy efficiency +24%; quality-related customer claims -45%; annual cost savings EUR 12 million. Forest management has been transformed through the 'Smart Forestry' program (drone and satellite monitoring, AI-based growth prediction), achieving 2.8% annual productivity improvement and 3.1 million tonnes of annual carbon sequestration across 2.2 million hectares of FSC/PEFC-certified forest.

#### 3.3.2. Metsä Board: Digital-Circular Convergence

Metsä Board's 'Excellence Centre 2030' project, launched in 2020 with EUR 1.5 billion in planned investment through 2025, is aligned with Finland's 'Green Transition' policy framework. The program exemplifies the convergence of digital transformation and circular economy principles.

The Äänekoski mill's circular water treatment system, completed in 2022 at a cost of EUR 41 million, raised process water reuse from 60% to 90% using a membrane bioreactor (MBR) combined with reverse osmosis (RO) technology developed with Israeli water treatment specialist IDE Technologies. Annual water-related costs declined 15%, and the improved water quality contributed to measurable product quality improvement. Metsä Board's 2030 target is a 30% reduction in process water consumption per tonne of product versus 2018 baseline.

The Äänekoski digital twin system, developed with ABB, incorporates 2,500+ sensors feeding an AI-driven 'Predictive Quality Management' system that continuously monitors process conditions and detects quality deviations before they manifest as defective product. Defect rate declined 47% from 2020 to 2023; customer satisfaction increased 18%. The 'Circular Design' program, launched in 2022, integrates customers' recyclability requirements from the earliest product design stage, achieving 99% recyclability across the product range by 2023.

#### 3.3.3. Cross-Case Strategic Insights

Three cross-cutting lessons emerge from the four case analyses:

4. Sustainability investment generates positive returns when approached with commercial discipline. Both Nordic companies demonstrate that sustainability-related capital allocation achieves shorter payback periods than conventional investment in the current regulatory and market environment. Domestic companies A and B illustrate the same principle at smaller scale: waste elimination and circular valorization simultaneously reduce costs and create new revenue streams.
5. Digital transformation must address the entire value chain, not only production efficiency. Stora Enso's IMS and Metsä Board's digital twin both extend beyond process automation to encompass quality prediction, customer relationship management, and supply chain visibility. The most valuable outcomes (customer claim reduction, satisfaction improvement) are relationship-level, not merely operational.
6. Open innovation and strategic partnerships are necessary accelerants. No single firm can develop all required capabilities internally. Stora Enso's academic partnerships (KTH, VTT) provided the technology foundation for Formed Fiber. Siemens and IDE Technologies provided the digital and environmental engineering capabilities that Stora Enso and Metsä Board deployed. Company B's customer partnerships provide both demand stability and ESG co-creation value. For Korean firms, partnership-building with international technology providers, domestic academic institutions, and customer organizations is a strategic imperative, not merely a tactical convenience.

## 4. Strategic Recommendations

Drawing on the environmental analysis and case study findings, five integrated strategic recommendations are presented for Korean white paperboard companies. These are organized across short-term (0–2 years), medium-term (2–5 years), and long-term (5+ years) implementation horizons, and are complemented by policy recommendations for government.

### 4.1. Technology Innovation Strategy

Short-term: Prioritize process optimization and energy efficiency improvement in existing facilities. Invest in IoT sensor retrofitting on critical production equipment as the foundation for subsequent AI-enabled quality management. Expand fly ash pre-treatment and recycling capacity based on Company A's proven model to reduce waste disposal costs and improve filler self-sufficiency.

Medium-term: Develop biomass-based specialty materials capability. Stora Enso's Formed Fiber illustrates that renewable material innovation can create genuinely new market categories rather than merely serving existing ones. Industry-academia research partnerships with KAIST, Seoul National University, and sector-relevant research institutes (KEIT-funded programs) should be structured around 3–5-year development timelines with clear commercialization milestones. Advance Company A's carbonation technology to full commercial scale, with participation in government CCU programs to access co-funding.

Long-term: Establish carbon-neutral production systems. Renewable energy transition (solar, biomass, waste heat recovery), carbon capture and utilization (building on the fly ash carbonation technology), and closed-loop water management (building on Metsä Board's water recycling model) collectively constitute the technical pathway to 2050 carbon neutrality alignment.

### 4.2. New Market Entry and Marketing Strategy

The structural supply surplus in Southeast Asian commodity paperboard markets makes continued competition in those markets on a cost basis economically untenable. Korean firms must pursue two complementary market repositioning strategies simultaneously.

First, product portfolio premiumization within existing markets: develop sector-specific differentiated products (pharmaceutical blister packaging; luxury cosmetic rigid boxes; food contact-compliant sustainable packaging; pharmaceutical anti-counterfeit features). Each sub-segment requires deep customer understanding and co-development capability. Metsä Board's Circular Design program—integrating customer recyclability requirements from earliest design stages—provides the collaborative product development model to emulate.

Second, geographic market diversification: the Middle East (growing pharmaceutical and food manufacturing; premium consumer goods growth), India (among the world's fastest-growing paperboard markets; 1.4B consumer population), and developed European markets (plastic substitution driving premium eco-paperboard demand; CBAM-compliant sourcing preferences) represent priority market development targets. Government-supported Korea Trade Promotion Agency (KOTRA) market entry programs should be actively leveraged.

### 4.3. Cost Competitiveness Enhancement

Three cost structure transformation levers are identified:

7. Raw material diversification and self-sufficiency: expanding domestic recycled fiber sourcing, scaling fly ash PCC self-production (Company A model), and diversifying pulp sourcing geographically to reduce BHKP price and exchange rate concentration risk.
8. Production efficiency through digitalization: AI-enabled quality management systems (Stora Enso IMS model) and digital twin process optimization (Metsä Board model) have demonstrated 20–47% defect rate reductions and 15–24% energy efficiency gains in comparable manufacturing environments. These are not speculative projections but documented outcomes from operational deployments.
9. Energy cost reduction through renewable transition: on-site solar generation, biomass boiler fuel switching, waste heat recovery system installation, and participation in government renewable energy purchase programs reduce both energy cost and carbon exposure simultaneously.

### 4.4. Digital Transformation Strategy

Digital transformation must be approached as a strategic investment program, not a series of isolated automation projects. A four-stage roadmap is recommended:

10. Foundation stage (Year 1–2): Standardize data collection infrastructure across production, quality, supply chain, and customer service functions. Deploy IoT sensors on critical equipment. Establish a centralized data platform.
11. Analytics stage (Year 2–3): Implement AI-based quality prediction and predictive maintenance systems. Develop digital twin simulations for key production processes. Begin customer-facing data integration (real-time order status, quality reporting).

12. Optimization stage (Year 3–4): Achieve closed-loop optimization—AI-driven continuous adjustment of process parameters based on real-time quality data. Extend digital twin to full supply chain simulation. Launch customer portal providing supply chain transparency.
13. Innovation stage (Year 4+): Use digital platform capabilities as a foundation for new service offerings: total packaging lifecycle management, carbon footprint reporting services, circular economy co-design services. Digital capability becomes a differentiating customer value proposition, not merely an internal efficiency tool.

### 4.5. Human Resource Development

The technology and digital transformation agenda outlined above cannot be executed without the human capital to design, deploy, and operate new systems. Priority capability investments are:

- Environmental engineering and eco-material development: recruiting PhD-level researchers with biomass chemistry, carbon capture, and advanced recycling expertise; establishing joint research positions with universities.
- Data science and AI engineering: recruiting ML engineers, data scientists, and industrial IoT specialists; establishing internal data science training programs for existing production engineers.
- Global market development: recruiting professionals with direct experience in target markets (India, Middle East, Europe); developing language capability and cultural competence for strategic export markets.
- Organizational culture: developing innovation-permissive internal governance that allows experimentation and accepts learning from failure; establishing open innovation programs that connect internal teams with external startups, research institutions, and customer innovators.

The Nordic benchmark is instructive: Stora Enso allocates more than 30% of its annual training budget to digital capability development. Korean firms must make comparable proportional commitments to build the human foundations for the strategic programs described above.

## 5. Conclusions and Implications

### 5.1. Research Conclusions

This study has diagnosed the structural crisis facing Korea's white paperboard industry and identified, through analysis of four innovation cases, concrete and transferable pathways to sustainable competitive growth. Four principal conclusions are drawn.

First, technology innovation transforms waste streams into growth drivers. Company A's fly ash recycling and $CO_2$ carbonation technology simultaneously eliminates a disposal cost, creates a PCC self-supply capability, and contributes to carbon management—converting a compliance cost center into a competitive asset. Company B's sterilized pack circular economy model demonstrates that packaging waste can be valorized into new revenue streams while building strategic customer partnerships. These domestic cases confirm that the resources for circular economy innovation already exist within the Korean paperboard industry; what is required is systematic R&D investment and commercialization commitment.

Second, AI-driven manufacturing intelligence delivers quantifiable competitive advantage. Stora Enso's IMS (defect rate -32%, energy efficiency +24%, annual savings EUR 12M) and Metsä Board's predictive quality management (defect rate -47%, customer satisfaction +18%) are not aspirational targets but documented operational outcomes. These performance levels are achievable by Korean firms with comparable manufacturing bases if equivalent digital infrastructure investment is made and the organizational capability to leverage it is developed.

Third, the circular economy is becoming a structural competitive requirement, not an optional ESG enhancement. Metsä Board's 99% recyclable product portfolio and Circular Design program are responses to customer demand—specifically, the demand from major branded goods companies for packaging that supports their own sustainability commitments. Korean paperboard producers who do not develop equivalent circularity credentials will progressively lose access to the premium customer segments where margins are defensible.

Fourth, open innovation and strategic partnerships are essential enablers. Stora Enso's academic collaborations produced 16-country patent protection for Formed Fiber. Company B's dairy industry partnerships created stable demand and ESG co-creation value. No single firm can build all required capabilities in-house; structured collaboration with universities, research institutes, technology companies, and customers is a strategic necessity.

### 5.2. Policy Implications

For government and regulatory bodies, three priority recommendations are offered. First, expand R&D and facility investment support for eco-friendly and digital transition through expanded tax incentives, policy finance programs, and grant funding—with particular attention to supporting medium-sized paperboard producers whose capital bases are insufficient to fund transformation at the required scale independently. Second, strengthen the institutional framework for circular economy development: rationalize regulations on recycled material use; establish circular resource certification standards; develop ESG management evaluation models for the paper sector; and accelerate green finance mechanisms that assign preferential lending terms to sustainability-linked investments. Third, deepen engagement with international standards and trade policy: proactive participation in CBAM compliance preparation; co-development of international paperboard sustainability standards; and government-to-government coordination to establish market access pathways in priority growth markets.

### 5.3. Research Limitations and Future Research

This study acknowledges several limitations. Access to detailed financial and operational data for domestic case companies was constrained by confidentiality; case analyses rely on patent documentation, public disclosures, and expert consultation rather than comprehensive internal data. International case data relies on published reports and may not capture most recent developments. Quantitative economic analysis of technology investment returns—return on investment, net present value, payback period—would strengthen the business case analysis but is beyond the scope of the current study.

Three priority areas for subsequent research are identified. First, quantitative economic analysis of eco-friendly technology investment returns, including comparative assessment of investment timing and scale decisions. Second, econometric analysis of the impact of digital transformation on production efficiency and profitability across a sample of Korean paperboard producers. Third, policy scenario analysis: modeling the differential impact on Korean paperboard industry competitiveness under alternative circular economy policy frameworks and carbon pricing trajectories.

## Acknowledgements

The authors gratefully acknowledge the companies and industry experts whose knowledge, data, and case study cooperation made this research possible. [Specific acknowledgements to be finalized prior to publication.]

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| ① **백판지 1급 :** 모든 층이 표백 화학펄프로 구성된 고급 판지. 고급화장품, 의약품, 담배 포갑지 등으로 사용<br>– 도공(Coated) : 백판지 1급 중 도공한 것<br>– 비도공(Uncoated) : 백판지 1급 중 도공하지 않은 것 |
| ② **백판지 2급 :** 표백 화학펄프와 폐지를 혼합하여 제조한 판지. 표면층은 표백화학펄프, 나머지 층은 폐지로 구성<br>– 도공(Coated) : 백판지 2급 중 도공한 것<br>– 비도공(Uncoated) : 백판지 2급 중 도공하지 않은 것 |
| ③ **아이보리판지 :** 표백화학펄프와 폐지를 혼합하여 제조한 판지. 표면과 이면층은 표백화학펄프, 중간층은 폐지로 구성 |

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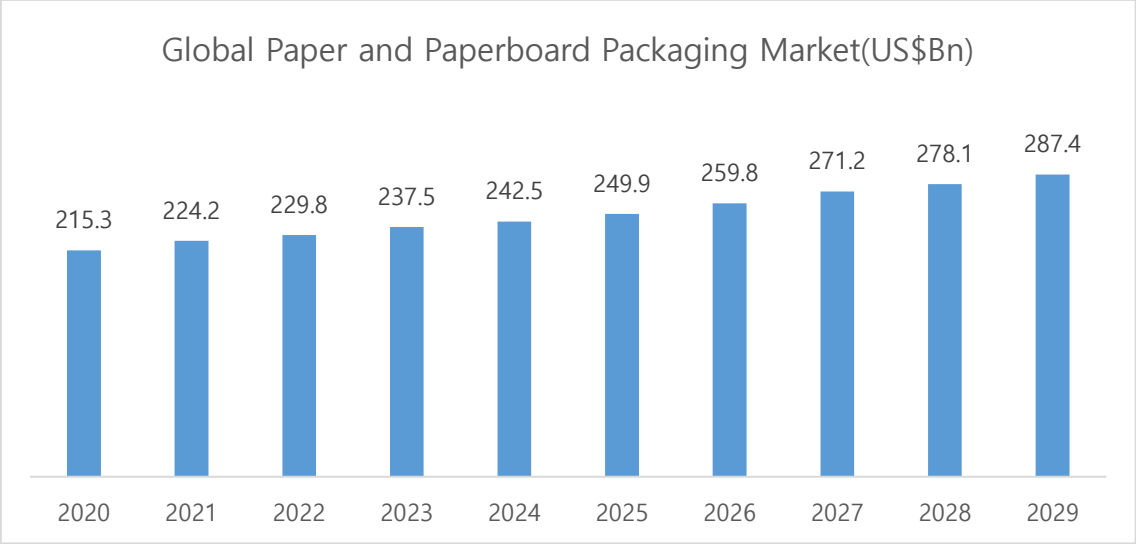
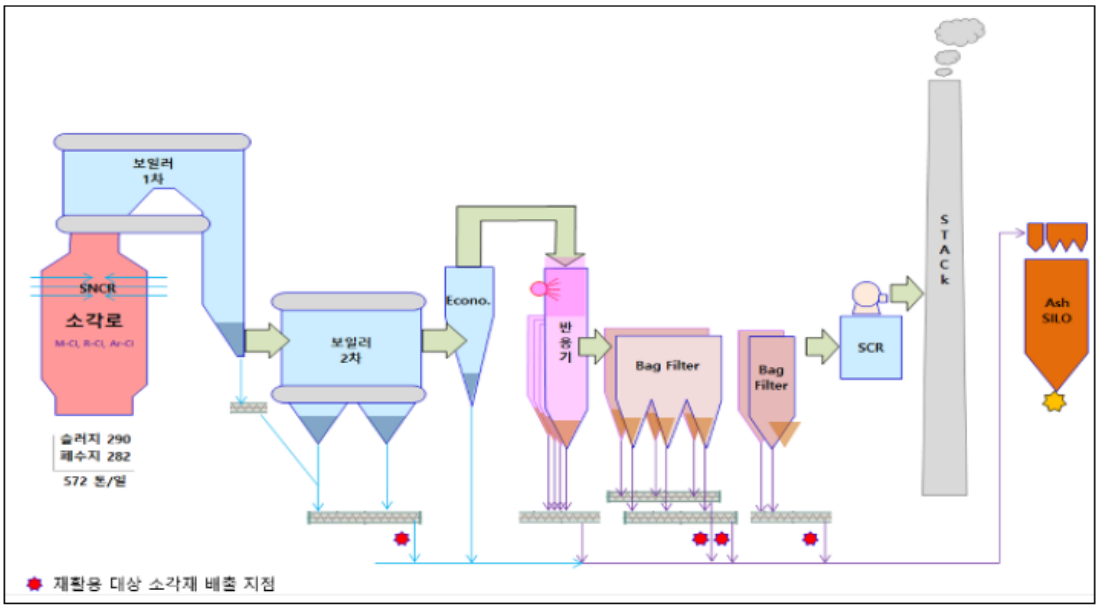



<표2. 세계 종이 및 판지 포장 시장 규모>

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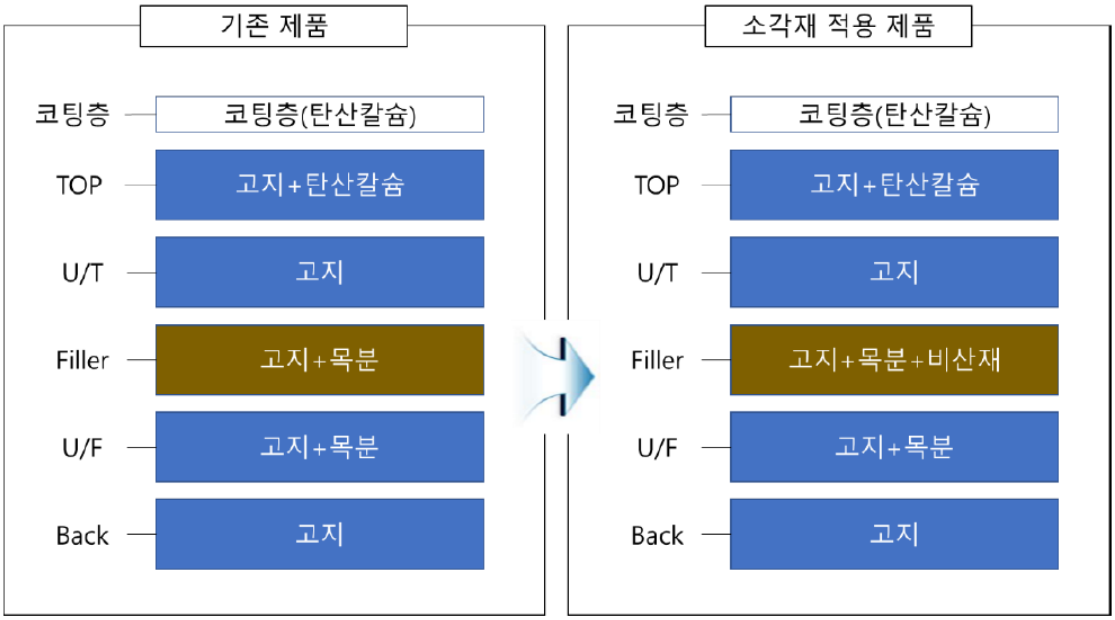


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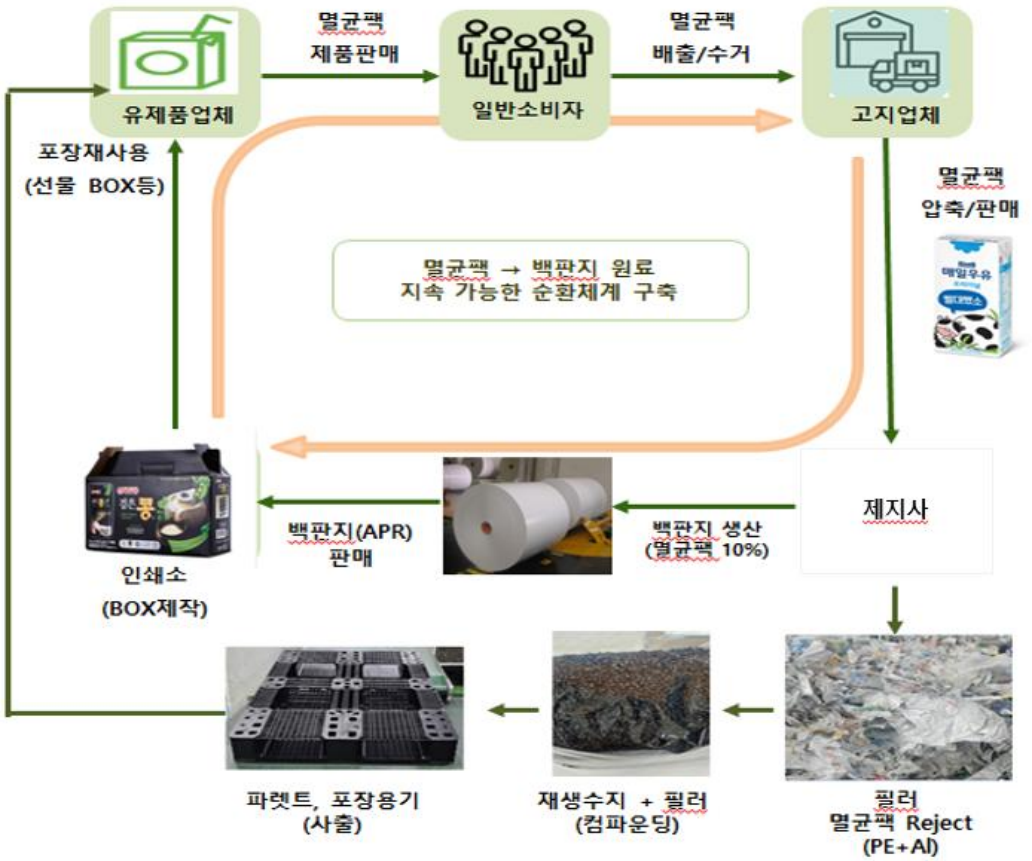


<그림> B사 멸균팩 순환자원 모델