

The Green Supply Chain of Electronic Product Recycling: Taking Apple Company as an Example

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Abstract: Electronic waste has become an urgent global environmental issue, green supply chain management (GSCM) has become an important way to achieve sustainable development. This article explores the structure and practices of Apple's green supply chain, focusing on its electronics recycling program. The study first discusses the definition of recyclability in electronic products and its strategic importance, emphasizing the circular economy principles and environmental standards such as ISO 14001. Through a case study of Apple, this research explores the company's lifecycle-oriented green supply chain, including recyclable product design, the renewable materials use, energy-efficient manufacturing, sustainable logistics, and reverse logistics systems for the end-of-life products recycling. Additionally, this study also analyzes Apple's cooperation with suppliers through standard implementation, financial support, and performance incentives. Cost-benefit analysis shows that although green plans require significant investments in technology, infrastructure, and compliance, they can bring long-term benefits, such as reduced operating costs, brand enhancement, and improved regulatory adaptability. The study concludes that Apple's approach provides a effective model for other companies seeking to integrate environmental sustainability into their global supply chains.

1 INTRODUCTION

Driven by the digital economy's rapid development, electronic products have become indispensable in people's daily lives and work. At the same time, the global supply chain's rapid expansion has significantly enhanced electronic products production and distribution efficiency, enabling technology enterprises to integrate resources and optimize costs globally. However, this development is also accompanied by serious environmental challenges, especially the sharp increase in electronic waste (e-waste). From 2020 "Global E-Waste Monitoring Report", approximately 536 million tons electronic waste were generated in 2019 globally, but only 17.4% was properly recycled and processed (Forti et al., 2020).

Until now, the handling methods of electronic waste are still generally lacking in scientific norms. A large amount of electronic waste is simply buried or incinerated without proper treatment, releasing toxic and harmful substances such as lead, mercury, and

cadmium, directly threaten the ecological safety of soil, water bodies, and air. These practices not only cause serious environmental pollution but also mean the waste of precious resources. Therefore, the green supply chain concept emerged. It not only focuses on the production and circulation processes' efficiency but also emphasizes environmental friendliness throughout the entire process across the entire supply chain. Optimizing resource utilization, promoting material recycling, and reducing carbon emissions, can help green supply chain can reduce the generation of electronic waste at the source and improve the efficiency of electronic product recycling and reuse. Therefore, in the global background for sustainable development, establishing a scientific and efficient green supply chain system has become an important and unavoidable issue for the electronics industry.

With the strengthening of global environmental protection policies and the consumer's increasing environmental awareness, enterprises are increasingly required to be responsible for their

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product environmental impact throughout their life cycle.

Environmental-friendly products can not only stimulate consumers' purchasing willingness but also help enhance the company's social responsibility reputation, thereby increasing brand loyalty and customer satisfaction (Gu, 2024). Especially for electronic product manufacturers, the environmental impact after the product's disposal has become an important indicator for measuring their social responsibility and sustainable development.

Given that the company bears a significant responsibility for the product's sustainability, and the green supply chain is one of the important paths to achieving product sustainability, Apple was the first to recognize this and has continuously advanced green supply chain management in practice. By integrating environmental protection concepts in aspects such as raw material procurement, product design, manufacturing, logistics, and recycling, Apple not only improved resource utilization efficiency but also became a benchmarking enterprise in the global green manufacturing sector.

The main objective is to investigate how Apple integrates recyclability into its product design and supply chain operations, including material selection and recycling plans, to assess the application identification and analysis of Apple's green supply chain in the background of circular economy. The paper also aims to identify and analyze the environmental and industry standards that influence Apple's supply chain decisions and conduct a comprehensive assessment of Apple's environmental technology. By conducting an in-depth Apple case, this research can help emphasize the sustainability integration into core business model and stimulate feasible changes throughout the electronics industry's entire value chain.

2 LITERATURE REVIEW

2.1 Recyclability Definition and Importance

In the management of electronic product life cycles, recyclability is the core aspect for achieving green supply chains and circular economies. The product's recyclability includes its nature and the actual recycling pathways available after its use (Pomberger & Bezama, 2024). Recyclability not only refers to the fact that products can be recycled after use but also includes strategic and engineering considerations made during the product design stage to ensure the

material selection, structural design, assembly methods, etc., which can help to later disassembly, recycling, and reuse. Especially in the field of electronic products, recyclability covers multiple aspects such as the feasibility of material recycling, resource utilization efficiency, environmental friendliness, and the adaptability of product disposal after retirement.

From an operational level, recyclability includes two key parts: first, whether the product has sufficient physical and economic value for recycling after it becomes waste; second, whether the materials it uses are compatible with the existing recycling infrastructure. This means that whether an electronic product is "recyclable" not only depends on the potential for reusing the resources it contains but also on whether it can be efficiently and safely disassembled and classified under the current technological conditions. For example, using detachable screws instead of adhesives, adopting standardized interface designs, and using non-composite materials are all common ways to improve recyclability.

With the electronic waste rapid growth, improving electronic products' recyclability has become particularly crucial for achieving resource recycling and relieving environmental pollution. Electronic products contain a variety of complex materials, including precious metals, base metals, and harmful substances. If not properly recycled, these materials will bring toxic waste and resource depletion. This also leads to the loss of non-renewable resources such as metals and rare earths. In 2022, only approximately 22.3% of the recorded electronic waste was properly recycled. It is projected that by 2030, the amount will reach 82 million tons, posing a threat to human health and the environment (UNITAR, 2024).

For a company like Apple, enhancing recyclability can achieve two purposes simultaneously: improving environmental performance and ensuring compliance with global regulations. This can help the company gain a good reputation, attract more customers, and build customer loyalty. Apple devote itself to making new products by maximizing the recycled materials from recycled products. Up to now, the company has achieved using materials in the product, 24% of which are sourced from recyclable or renewable resources (Apple, 2019). Apple has enhanced disassembly and material recycling efficiency by fully considering recyclability in product design (such as modular design, reduce adhesive usage, and screw standardization). This can help reduces the

environmental impact and enables valuable materials, thereby promoting economic sustainability.

2.2 Circular Economy and Green Supply Chain Management

Circular Economy (CE) is a development model centered on the resource's sustainable utilization. It emphasizes the implementation of a "resource-product-renewable resource" closed-loop system through measures such as extending product life cycles, remanufacturing, reuse, and recycling. Compared to the traditional linear economy such as "production-consumption-waste", Circular Economy aims to "reduce resource usage, minimize waste, and achieve reuse", fundamentally addressing resource depletion and environmental pollution issues. It is possible to better facilitate the circular economy realization by designing products that can be utilized to the fullest extent within a longer life cycle, creating multi-functional products with different uses in different periods, and employing systematic supply chain management methods to assess the connections between the product's extracted energy, materials and environment (Arruda et al., 2021). There are various ways to achieve a circular economy. For instance, through multi-functional product design, the product's adaptability and lifespan can be enhanced, which helps reduce the frequency of updates and excessive consumption; a device with multiple functions can replace multiple single-purpose electronic products, thereby reducing the total material usage and the scrap rate. Adopting systematic supply chain management strategies can improve resource allocation efficiency, enabling enterprises to optimize environmental impact throughout the entire process to achieve material's "closed-loop circulation". Additionally, promoting modular and standardized product design also helps simplify the dismantling process, enhancing maintainability and recovery rate.

Green Supply Chain Management (GSCM) is a key operational framework that drives the circular economy. It integrates environmental protection concepts into the product's entire lifecycle management, covering process like raw material procurement, production, manufacturing and product usage and recycling. GSCM ensures that enterprises achieve economic benefits while also considering environmental performance through refined supplier management, green logistics, energy-saving manufacturing, and recycling mechanisms establishment.

The practices in circular economy and green supply chain management fully show these concepts. In its product design, it incorporates the principle of recyclability, such as adopting modular structures, reducing the composite materials use, and increasing the recycled materials proportion in products continuously. The company has shifted to using recycled materials— To promote recycled materials used in manufacturing products, Apple has expanded the recycled metals use. More than two-thirds aluminum in Apple products, nearly three-quarters rare earths, and over 95% tungsten are sourced from 100% recycled materials. Since 2019, Apple's disassembly robot Daisy recovered over 11,000 kilograms cobalt from dismantled batteries (Apple, 2023). These innovations show Apple's commitment to green recycling and building a restorative supply chain.

Apple's achievements in the green supply chain also confirm a key point put forward by the Ellen MacArthur Foundation: "Companies followed circular economy model will have greater adaptability and competitiveness in the future." Through product design innovation, material recycling technology, and global supply chain collaboration, Apple is building a resource-efficient and environmentally friendly industrial model, which not only enhances its own brand value and social reputation but also provides a replicable and scalable green transformation path for global technology enterprises.

2.3 Environmental and Industry Standards

In the background of global sustainable development, multiple international organizations and regional institutions have formulated environmental-related frameworks and standards, aiming to encourage enterprises to enhance their environmental management capabilities, reduce resource consumption, decrease pollution emissions, and strengthen their green competitiveness. For electronic product manufacturers, complying with these standards is not only a compliance requirement but also an important foundation for achieving green supply chain management.

To ensure accountability and standardization of environmental protection work, various global frameworks and industry-specific standards have been established. The most influential ones include: ISO 14001 (provides organizations a systematic framework to manage company's environmental responsibilities and encourages their continuous

improvement and compliance with legal and regulatory requirements), RoHS (Restriction of Hazardous Substances Directive) which restricts specific hazardous materials use in electronic and electrical equipment manufacture, WEEE (Waste Electrical and Electronic Equipment Directive)-directive originates from the European Union and stipulates the electronic waste collection, treatment and recycling, with Extended Producer Responsibility (EPR) as the core principle, and REACH (Registration, Evaluation, Authorization and Restriction of Chemicals) which key management the risks associated with chemical substances.

Although the above standards belong to different institutions or regions and their control point are slightly different, they share a high consistency degree in their goals to encourage enterprises to identify and reduce the product's negative environmental impacts and production processes, improve resource utilization efficiency, and achieve sustainable development. These standards constitute the green supply chain management institutional foundation and are important reference criteria for enterprises to carry out green design, procurement, manufacturing, and recycling.

Apple has always insisted its operations comply with these standards, and often even exceed them. For example, Apple releases the "Environmental Progress Report" every year, detailing its carbon footprint, the recycled materials used, and compliance with environmental policies. Apple devoted to reducing its carbon footprint to achieve carbon neutrality and has committed to transforming its value chain to achieve 100% clean electricity by 2030. It also collaborates with suppliers to eliminate the waste and facilities sent to landfills by the company. Moreover, Apple's suppliers are required to obey the "Apple Supplier Conduct Code", which incorporates environmental compliance and sustainable practices into the contractual obligations.

These international and industry standards not only serve as the minimum compliance requirements but also serve as crucial tools for driving enterprises' strategic environmental management and building green value chains. However, these standards not only serve as standards but also protect the company from reputational and regulatory risks. By integrating these frameworks into its operations, Apple demonstrated that compliance with environmental and industry standards is not only about legal compliance but also about leadership and innovation in the sustainable development field.

3 CASE ANALYSIS

3.1 Supply Chain Structure

Apple's supply chain is complex and globally integrated. Its notable features include a vertical integration strategy, a strict supplier accountability system, and an efficient logistics and distribution system. These features collectively form Apple's core competitiveness in maintaining product quality, market response speed, and supply continuity in the global competition. The following will be analyzed in detail according to the supply chain process sequence.

3.1.1 Vertical Integration and Core Control

Apple's vertical integration enables the company to maintain key link control in the supply chain, including the ability to design hardware and software independently, when part of business outsourcing, which ensures Apple's competitive advantage (Dixit, 2024). Apple adopts a highly vertically integrated strategy in the procurement stage of components at the very top of the supply chain, maintaining strong control over key components (chips, displays, batteries, body materials, etc.). Different from the traditional approach of relying on third-party designs, Apple insists on self-developing core hardware (M series chips) and operating systems (iOS, macOS), and deeply customizes key components in its supply chain. This high-level synergy between hardware and software not only enhances product performance but also brings advantages in the supply aspect: For instance, the independent design and core components control reduce the reliance on external critical technologies and resources, avoiding risks from supplier disruptions or technological limitations. By establishing independent standards to regulate the supply chain from upstream to downstream, Apple can ensure that the technical specifications, environmental protection indicators, and all product user experiences are highly consistent. The independent design capability shortens the period from product research to mass production and enhances the ability to respond quickly to market demands.

3.1.2 Supplier Accountability System Ensures the Implementation of the Standards

During the product manufacturing and assembly stage, Apple mainly collaborates with suppliers through the contract manufacturing model but

implements strict accountability systems for its partners. Its core manufacturers, such as Foxconn, Pegatron, and Wistron, are located in various countries and regions including China, India, Vietnam, and the United States. Apple requires its suppliers to obey behavioral guidelines, including demanding suppliers to offer safe working conditions, fair employee treatment, and environmentally friendly production processes (Apple, n.d.). This mechanism ensures: environmental compliance in the manufacturing process; the laborers' rights and interests have been guaranteed, and various green manufacturing standards have been effectively implemented, such as the full-scale promotion of the ISO 14001 environmental management system.

3.1.3 Digitalization and Global Layout Enable Efficient Response

At the supply chain's final stage, Apple has established global distribution network and an efficient logistics system. The company achieves high-efficiency global delivery through a data-driven forecasting system, regional distribution centers, automated warehousing systems, and a mixed distribution model that collaborates with third-party logistics service providers (DHL and UPS).

Apple has also continuously optimized its packaging design and transportation routes. For instance, by reducing the product packaging volume, increasing the packaging density to lower carbon emissions, and improving transportation efficiency. Additionally, the company has established local assembly plants in key markets (India and Vietnam) to cope with trade protection policies, reduce transportation distances, and enhance local supply capabilities and market response speed. Apple has communicated with suppliers effectively and conducts regular reviews, thereby enhancing the supply chain's overall efficiency. This also helped solve transportation problems and enabled Apple to maintain a leading position in the competition (W. Zhao, 2024).

3.1.4 Conclude

Apple's supply chain structure is characterized by "strong upstream control, strict accountability in the middle stage, and high efficiency in the downstream". Through vertical integration, strict management, and digital optimization, Apple has established a supply chain system with high flexibility, green characteristics, and global coordination capabilities, providing a solid foundation for its transformation in

green supply chain and its practice in the circular economy.

3.2 Apple's Electronic Product Recycling Current Situation

Apple has been committed to establishing a closed-loop material utilization system. Its electronic product recycling program covers multiple aspects, including consumer incentives, technical means, and material handling, building a relatively complete recycling closed loop.

First, Apple Trade-In Program: Apple encourages customers to return old equipment to get store credit or to recycle responsibly. The returned products will either be renovated and resold or disassembled for recycling. As a profit strategy to confront TPR, trade-in programs can often enhance consumers' willingness to pay for products and counteract the third-party remanufacturing's positive impact on consumer surplus (Zhao et al., 2021).

Second, Disassembly robot: Apple launched the "Liam" robot in 2016, which is equipped with 29 arms and can disassemble an iPhone 6 within 11 seconds. Soon afterward, Apple introduced the "Daisy" robot in 2018, which increased the disassembly speed. The company's newly developed robot helps separate magnets from audio modules to recycle more rare earth elements (Apple, 2022). Robots can precisely recover key metals such as rare elements to avoid material waste and pollution caused by manual disassembly. Moreover, the earlier version "Liam" also accumulated valuable experience for subsequent recycling technologies.

Third, Material Recycling Facility (MRF): By cooperating with recycling companies, Apple ensures that the collected products are processed in facilities that can handle electronic waste and recycle valuable resources safely which can help ensure high-value metals and rare resources can be safely and efficiently recycled and reused.

Although Apple has implemented several advanced measures in its recycling system and achieved certain results, its electronic product recycling practice still faces many challenges.

On one hand, the user recovery rate still needs to be improved. According to a survey by a third-party institution, the electronic products worldwide recovery rate is generally low, especially in developing countries, consumers' environmental awareness is relatively weak and the recycling channels are not well-established, which has become an obstacle to the closed-loop recycling system promotion. On the other hand, the product's

repairability and the third-party recycling difficulty also caused controversy. For example, some products still use proprietary screws, strong adhesives, etc., which limits the disassembly and repair of devices by non-official institutions, affecting recycling cooperation openness in the entire industry.

3.3 Apple's Sustainable Development Goals

Apple has formulated ambitious environmental and sustainable development goals that are in line with the United Nations Sustainable Development Goals (SDGs). These initiatives show Apple's promise to reducing its footprint to build a sustainable future.

Achieve carbon neutrality by 2030: Apple aims to achieve carbon neutrality throughout its entire value chain by 2030. This covers its operations all aspects, including manufacturing, supply chain, and product lifecycle. To achieve comprehensive carbon reduction across the value chain to reduce carbon footprint significantly, Apple has set a goal to reduce 75% emissions compared to 2015 by 2023 and to reduce them by 90% by 2050 (Apple, 2024a).

Renewable Energy Plan: Although traditional fossil fuels bring economic growth, they have brought great environmental pollution and climate change. Therefore, to achieve and obey the SDGs (The Sustainable Development Goals), renewable energy is regarded as a tool to reduce climate change, it is also considered as a means to achieve other goals (Agbakwuru et al., 2024). By adopting clear and strict measures for product decarbonization to reduce emissions, Apple has devote itself to achieve product's carbon neutrality by 2030. Take the Apple Watch as an example, its manufacturing and products are powered by 100% clean electricity, and it ensures that each product reduces at least 75% of its emissions (Apple, 2023).

Innovations in product design and materials:
Recycled cobalt and lithium- In terms of recycling rare earth elements, the report presented by Apple in 2022 shows that the rare earth materials' complete recycling rate reached 73%, which was higher than the previous year's 45% (Kate, 2023).
Recycled copper- Apple has used 100% recycled copper in key heat dissipation applications for products such as the iPhone 15 (Apple, 2024).
Carbon neutrality- Apple has launched products that achieve complete carbon neutrality, such as the Apple Watch Series 9. These products ensure a significant reduction in carbon emissions in terms of materials, electricity, and transportation (Reccessary, 2024).

Waste Reduction and Recycling Program: Apple has execute a comprehensive recycling program to minimize waste and promote a circular economy. Customers can recycle their devices to earn a discount or for free if they meet the requirements. This is to encourage responsible materials disposal and reuse. Apple supports product recycling and recycling collection programs promotion through online or offline channels, such as giving Apple Store gift cards, offering free recycling, or providing points (Apple, 2024b). Moreover, Apple has developed an advanced disassembly robot like Daisy, which can disassemble iPhones efficiently to recover valuable materials.

Transparency and reporting: Apple maintains its environmental protection efforts transparency by publishing its yearly environmental progress report. These reports provide detailed information on the company's various initiatives, progress towards goals, and improvement areas. It also focuses on Apple's strategies in clean energy, material innovation, recycling, and carbon removal.

3.4 Cost and Benefit Analysis

3.4.1 Cost

In the process of establishing a green supply chain and implementing an electronic product recycling program, enterprises must make a balance between environmental responsibility and commercial value. For Apple, the green transformation not only involves significant upfront investment but also brings long-term economic returns. Therefore, conducting systematic cost and green supply chain benefit analysis practices helps evaluate sustainable strategy commercial feasibility and provide a reference for other enterprises.

Cost Composition Analysis: During the process of promoting a green supply chain, Apple faces various cost expenditures, including research and development, supplier transformation, reverse logistics, and compliance systems establishment. Firstly, the company continuously invests funds in developing recyclable product designs and automatic disassembly robots to enhance recycling efficiency and reduce resource waste; secondly, to achieve the carbon neutrality goal by 2030, Apple invests a large amount of resources to assist suppliers in transitioning to renewable energy, including providing technical support and financial incentives. Additionally, building global material recycling laboratories, product recycling networks, and logistics systems is also an important expenditure,

aiming to improve the reverse circulation path of electronic products. Finally, to ensure compliance with global environmental standards such as ISO 14001, RoHS, and WEEE, Apple regularly conducts environmental compliance audits and third-party certifications, which increases compliance and management costs. These costs constitute the initial investment base required for the Apple Green strategy.

Investment Analysis Return: Despite the huge initial investment, Apple has achieved benefits in multiple aspects through its green supply chain reform. In terms of operations, clean energy use has reduced the risks brought about by fluctuations in energy costs and significantly saved long-term operating expenses; in terms of materials, the large-scale use of recycled aluminum, rare earths, cobalt, and other recycled resources has effectively avoided fluctuations in raw material prices which help improved supply stability. At the same time, the environmental protection strategy enhanced the brand image and consumer recognition attracted users with strong environmental awareness, and improved customer loyalty and market share. Moreover, Apple successfully published green bonds to raise funds for its sustainable projects, which also enhanced its appeal to ESG investors. By obey the global environmental protection regulations in advance, Apple has maintained a leading position in policy risk management and consolidated its long-term stable development capabilities in the global market.

3.4.2 Benefits

Cost savings from operations: Investments in renewable energy and energy efficiency have significantly reduced operational costs. For instance, integrating renewable energy into business operations has reduced reliance on fossil fuels to bring about considerable long-term cost savings.

Reduce material costs: By using recycled materials (99% cobalt in all Apple-designed batteries), Apple has reduced its reliance on raw materials, thereby saving costs and stabilizing the supply chain.

Enhancing brand value and customer loyalty: Apple's commitment to sustainability has enhanced its brand image, attracted consumers with environmental awareness, and cultivated customer loyalty. This positive perception can translate into growth in sales and market share.

Attracting investors through green financing: Apple's green bonds not only provide funds for its environmental protection initiatives but also attract

investors interested in sustainable development projects. These bonds usually come with favorable terms, which help to lower the company's capital costs.

Compliance with regulations and risk mitigation: By actively adopting sustainable practices, Apple has positioned itself in a beneficial term of current and future environmental regulations, which can help reduce the risks associated with non-compliance and potential penalties.

4 PRACTICAL ANALYSIS OF THE RECYCLABILITY

4.1 Product Recyclability Design

Apple has reduced the environmental impact by adopting recycling and composting systems and using separate containers to promote recycling efforts worldwide. Apple also offers product recycling programs in 95% of its sales regions and has made significant progress (Chen, 2023).

Apple has fully considered recyclability during the product design stage to ensure that its products can be recycled and reused after their lifecycle ends efficiently. Firstly, Apple adopts a modular design concept. For example, in products like MacBook and iPhone, key components can be easily disassembled, replaced, or upgraded. The company has reduced the use of adhesives and soldering, and use adopted connection methods such as screws and clips that are easier to disassemble. Furthermore, Apple gradually replaces raw materials. For instance, they use 100% recyclable aluminum casings, 100% recycled rare earth magnets, and cobalt batteries to reduce the primary materials consumption at the source. This design not only facilitates disassembly, and promotes the green recycling implementation but also reduces energy consumption and carbon emissions significantly.

As Apple delves deeper into the field of product recycling, the company has independently developed a disassembly robot. It precisely recovers high-value materials including rare metals, cobalt, and tungsten. This automated solution has significantly improved recycling efficiency and reduced the environmental and safety risks associated with manual operations. Through recyclable design, Apple not only achieves material reuse but also provides a global standard for electronic waste management.

4.2 Green Supply Chain Measures

Apple has established a green supply chain management system covering the entire product lifecycle, including key aspects such as raw material procurement, production and manufacturing, logistics transportation, recycling and reuse, aiming to minimize environmental impact through the entire supply chain.

4.2.1 Material Purchase

At the beginning, Apple has established green cooperation mechanisms with hundreds worldwide suppliers, encouraging them to use environmentally friendly materials and adopt sustainable processes during the raw material's extraction and components manufacturing.

To standardize the cooperation standards, Apple has established a strict "Supplier Code of Conduct", which sets out environmental protection requirements, labor rights, health and safety indicators. Apple also provides supplier training and support to enhance production efficiency and quality to achieve sustainable development goals and establish long-term and close partnerships with suppliers. This helps to better manage the production process and promotes resource recycling and reutilization actively (Xing, 2023).

Meanwhile, the company established a comprehensive supplier evaluation and auditing mechanism. It releases the "Responsible Supply Chain Report" every year, conducting third-party audits to monitor the supplier's compliance performance to ensure that the green procurement goals are effectively implemented. Apple also requires its major suppliers to obtain ISO 14001 environmental management system certification, and prefers to choose enterprises that use environmentally friendly materials such as recycled aluminum, recycled cobalt, and low-carbon steel.

4.2.2 Manufacturing

In the manufacturing process, Apple encourages its suppliers to adopt green production methods by reducing the use of high-carbon emission manufacturing processes and improving energy efficiency. Since 2018, Apple has achieved 100% use of renewable energy in all its offices, retail stores, and data centers worldwide. Apple also encouraged its suppliers to join the "Supplier Clean Energy Program", which help reduces the carbon footprint and decreases the reliance of the supply chain on fossil energy. Meanwhile, the company provides financial support to suppliers to help them implement clean energy projects. Apple also promoting energy-

saving technologies application in its own factories, for instance, by using automated equipment to reduce energy waste and employing water recycling systems during the assembly process to decrease water consumption. This help reduces the carbon footprint in manufacturing, and also enhances supply chain efficiency.

4.2.3 Logistics Transportation

In the logistics process, Apple has also reduced its overall carbon emissions by optimizing global transportation routes, increasing loading density, and encouraging the use of less carbon-intensive transportation methods such as sea freight to replace air freight. The company also carried out a lightweight and recyclable design for the product packaging structure, abolishing the traditional plastic film and replacing it with recycled cardboard and reducing the product size, thereby improving transportation efficiency. For instance, the iPhone 13 series removed the outer plastic film, which can reduce approximately 600 tons of plastic usage annually. These comprehensive measures indicate that Apple's green supply chain has evolved from improvements in a single link to systematic optimization throughout the entire chain. Furthermore, Apple trying to deploy electric delivery trucks and green warehousing systems in certain areas to promote green delivery for the "last mile" of logistics.

4.2.4 Recycling and Reuse

At the end of the product lifecycle, Apple has established a closed-loop recycling system to reuse and dispose of electronic waste in an environmentally friendly manner. Company launched "Apple Trade-In" program, where consumers can return their old devices for recycling and receive purchase discounts or environmental rewards. The recycled products will be sent to Apple's or partner's recycling centers for inspection, disassembly, or refurbishment. To improve the disassembly efficiency, Apple has independently developed intelligent robots such as "Daisy". Furthermore, Apple has a materials recycling laboratory (Material Recovery Lab) in the United States, continuing to explore efficient and safe new recycling technologies.

4.3 Suppliers Participation and Standards

In the process of building a green supply chain, Apple attaches great importance to the environmental performance and supplier's sustainable development capabilities, and gradually established a systematic supplier management system covering multiple aspects such as standard setting, capacity building and performance incentives.

Firstly, Apple has formulated the "Supplier Code of Conduct" to set out the basic requirements for suppliers clearly in areas such as environmental protection, occupational health and safety, labor rights, and ethical business practices. This refers to several international standards and regulations, such as ISO 14001 environmental management system, SA8000 social responsibility standard, and OHSAS 18001 occupational health and safety standard, which requires all partners to implement the relevant systems within their organizations and achieve compliance. In addition, Apple conducts regular on-site audits to assess suppliers' actual implementation in terms of environmental emissions, energy consumption, and waste management, includes these evaluations in the annual report to ensure that environmental protection, occupational health and safety, and social responsibility are properly implemented.

To help suppliers in achieve a green transformation and meet relevant standards, Apple not only sets requirements but also provides a number of support measures. On one hand, Apple has established green bonds worth over 4.5 billion US dollars, which are used to fund suppliers in arranging clean energy systems, upgrading energy-saving equipment and improving environmental facilities in their factories. On the other hand, Apple also offers specialized training courses to suppliers to help them understand environmental standards, carbon neutrality goals and green material alternatives. At the same time, the company regularly organizes technical exchanges and experience-sharing meetings to promote knowledge spread among supply chain enterprises to enhance the entire network's green collaboration capabilities.

During the implementation process, Apple also established an effective supplier performance evaluation and incentive mechanism. The company rates cooperative suppliers environmental performance and publicly releases the "Supplier Responsibility Progress Report" every year to outstanding enterprises are commended. For example, enterprises that have received the "Excellent Green Performance Supplier" title for consecutive times will be given priority for future project cooperation opportunities. Through such a mechanism, Apple

effectively promotes suppliers to form a positive competitive atmosphere and speed up the green development process in the entire supply chain.

In conclusion, Apple not only sets clear standards for its suppliers in the green supply chain, but also provides support through various ways such as funds, technology and training. Lastly, it achieves a closed-loop cooperation from management to incentives through the performance feedback mechanism. This model provides systematic and operational experience for other multinational enterprises to implement green supply chain management.

5 CONCLUSION

This article focuses on the green supply chain of electronic product recycling and conducts an analysis based on Apple. It deeply explores its green practices in product design, supply chain optimization, and supplier cooperation. The research shows that Apple has established a relatively complete green supply chain system. Starting from the product recyclability design, by adopting recycled materials, designing easily disassemblable structures, and using automated disassembly robots, Apple has significantly improved its recycling efficiency. At the same time, Apple has achieved a green transformation from the upstream to the downstream by promoting suppliers to join the clean energy program, optimizing logistics routes, and enhancing the recycling facilities' capacity. Apple's practices not only reduce environmental impacts but also create long-term economic benefits and brand value.

Although Apple has achieved remarkable results in green supply chain management, there is still room for improvement. Increasing global recycling participation rate: In developing countries and emerging markets, the recycling system is not fully established. Apple can increase its environmental protection publicity and investment in facilities in these markets to enhance user participation. Enhancing product maintainability: While improving recyclability, greater emphasis should be placed on product maintainability to extend their service life and reduce resource consumption at the source.

Promote industry collaborative standards: Apple can build on its existing practices to establish unified industry recycling standards to facilitate green collaboration among enterprises within the industry and achieve a win-win situation for the entire supply chain. Transparency of carbon footprint data: Further refine and disclose the carbon emissions and recycling ratios at each product's life cycle, enhancing external supervision and user trust.

Green supply chain management will play an important role in global sustainable development issues. For Apple, its green innovation is not only reflecting corporate social responsibility but also will become one of the enterprise's competitive advantages. With the strengthening of global environmental protection policies and consumers' environmental awareness improvement, a green supply chain will become the new standard for technology enterprises. In the future, with technological development such as artificial intelligence, big data, and blockchain, Apple can achieve supply chain traceability, intelligent management, and carbon emissions real-time monitoring to enhance response efficiency and supply chain sustainability. Apple can also expand its green practices to more product lines and services, such as enhancing the recycling and remanufacturing system of Mac, iPad, wearable devices, etc., and building a "closed-loop supply chain" model comprehensively.

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