Blue Book on Vehicle Circularity

From Zero To Infinity

—— Car-to-Car Loop Levers Circular Economy

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2025

Green, Low-Carbon, Circular, Intelligent: The New Pathway for Productivity Growth in the Automotive Industry

Amid growing challenges posed by global climate change, the automotive industry is undergoing profound transformation. Green, low-carbon, circular, and intelligent development of the automotive sector has become a global consensus and pressing demand, serving as a critical pathway to sustainable development.

The philosophical shift in human-nature relationships marks the starting point of this transformation. Humanity's attitude toward nature has evolved from "conquest and transformation" to "harmony and coexistence." In China, the concept of “Green mountains and clear waters are as valuable as mountains of gold and silver” has resonated deeply, becoming a key element of global governance. China's commitment to peak carbon emissions by 2030 and carbon neutrality by 2060 reflects its responsibilities as a major global power. For the automotive sector, this underscores the need to establish a mechanism of shared environmental responsibility, where producers, consumers, and governments work collaboratively to green the entire lifecycle of products.

However, the automotive industry faces numerous challenges during this transition. Green manufacturing necessitates cost-effective production models with low consumption, minimal emissions, and high efficiency. Although China has made substantial progress in curbing automotive carbon emissions, the relentless increase in vehicle ownership continues to exert pressure on carbon reduction goals. Meanwhile, the auto recycling industry, despite rapid growth in recent years with improving regulations and an increasing number of recycling companies, has room for improvement in its recycling volumes. On the intelligence front, the industry is evolving from vehicle-level intelligence to vehicle-road-network-cloud coordination. While intelligent manufacturing and logistics have achieved notable results, issues such as data security and privacy protection urgently need to be addressed.

To tackle these challenges, developing new quality productive forces has become the key. This concept emphasizes the integration of new technologies with skilled labor, modern finance, and data information. On the policy front, the Chinese government has launched various plans and roadmaps to clarify development targets, such as promoting new energy vehicles and driving breakthroughs in intelligent technologies. Regarding deep industrial transformation and upgrading, transitioning traditional energy systems towards low-carbon and zero-carbon energy is essential. Additionally, the electric vehicle market must be expanded, green supply chain management must be advanced, and manufacturing processes must be digitized and cleaned. Along the industrial chain, efforts must be made to ensure low-carbon transitions in automotive fuels and foster integration between new energy vehicles and the grid.

Artificial intelligence plays a pivotal role in enabling green manufacturing. For example, as the new energy vehicle market expands rapidly, the retirement volume of power batteries has surged, straining traditional disassembly methods. Intelligent disassembly can improve efficiency, lower costs, and reduce pollution. From Level 0 to Level 4 of disassembly intelligence, leveraging embodied intelligence technology, such as compound autonomous disassembly robots, demonstrates how AI can drive the sustainable development of the power battery recycling industry.

Taking NIO as an example, its practices in the circular economy within the automotive sector provide a vivid case for developing new-quality productive capacity. NIO employs one-piece die-casting technology to consolidate multiple components into single parts, which not only reduces production time and costs but also increases the recycling efficiency of materials. NIO's battery packs feature easy disassembly for replacement, upgrades, and recycling, enhancing both efficiency and resource reuse. Additionally, by adopting intelligent management systems for battery swap stations and using big data to establish battery health prediction models, NIO extends battery lifespan, optimizes resource allocation, and promotes intensive use of natural resources. Moreover, NIO has built circular economy industrial parks to promote local supply chains, fostering collaboration among disassembly, smelting, and die-casting companies, which effectively lowers logistics costs and supply chain risks.

In summary, the green and intelligent transformation of the automotive industry is an inevitable choice to address climate change and facilitate high-quality industrial development. It offers valuable insights for other traditional industries by empowering green manufacturing through artificial intelligence and advancing the shift toward high-end, intelligent, and green manufacturing. This further lays the foundation for achieving the goals of carbon peaking and carbon neutrality. The journey ahead involves seizing opportunities and tackling challenges to promote a comprehensive green transformation and intelligent upgrade of the automotive industry, which will provide valuable insights and references for global green and intelligent transitions in the sector.

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Content

Step by Step: From Zero to Infinity?

1.1 One, Zero, and Infinity

When discussing circulation, what exactly is being addressed?

1.1.1 Linear Economy and “Spaceship Theory”

Since the Industrial Revolution, linear economy has become the dominant economic model characterized by "resources-products-waste," relying heavily on the consumption of natural resources with a pursuit of rapid economic growth and scale expansion. However, high growth entails high consumption and high emissions, leading to strong dependence on resources. As the world population continues to rise, issues of resource scarcity and environmental pollution are becoming increasingly serious.

In 1966, American economist Kenneth Boulding published a paper titled "The Economics of the Coming Spaceship Earth," where he introduced the well-known "spaceship theory." In this paper, Boulding metaphorically likened Earth to a closed "spaceship," where resources are finite and cannot be infinitely sourced from external supplies, nor can waste be endlessly discharged. The paper indicated that humanity's previous economic model was characterized by predatory and exhaustive development, exploiting resources and discharging waste as if they were infinite. However, with population growth, technological advancement, and overconsumption of resources, we are beginning to face issues such as resource depletion and destruction of ecosystems. Therefore, humanity needs to shift its thinking and manage Earth as if it were a spaceship, cherishing limited resources to achieve sustainable development.

The United Nations Sustainable Development Goals (SDGs), launched globally in 2016, call on all countries to pursue economic prosperity while curbing climate change and protecting the environment. This aligns with the values of ecological civilization construction advocated by the

New Era Socialism with Chinese Characteristics. Sacrificing the environment and wasting resources in exchange for economic growth is unsustainable, whereas circulation is an important pathway to sustainability.

Figure 1.1 | The United Nations Sustainable Development Goals[1]

1.1.2 “Bending” the Linear Economy and Shaping the Circular Economy

The circular economy is a key solution to resource and environmental issues. It not only helps conserve resources and protect the environment, but also provides new momentum for economic development (see Table 1.1). Promoting the circular economy is not just an economic choice but also a responsible lifestyle for the future. Only through the circular economy can humanity achieve long-term survival and prosperity on this "spaceship".

Table 1.1 | Advantages of the Circular Economy [2][3]

Comparison Dimension	European Union	United States
Underlying Logic	• Regulation - driven: Prioritize legislation and set standards	• Market - driven + Emphasis on Flexibility: Combine federal and state legislation, focus on independent innovation of enterprises, and share responsibilities among all parties in the value chain
Formulation of Core Regulations and Standards	• EU New Circular Economy Action Plan (2020) • Policy Recommendations for the Circular Economy of Automobiles (2023) • EU Battery Regulation (2023) • Critical Raw Materials Act (2023)	• National Recycling Strategy (2021) • Inflation Reduction Act (2022) • Policy Framework for Recycling of Lithium - Ion Electric Vehicle Batteries (2022)
Coverage Scope	• Raw material level: Put forward recycling proportions for nickel, cobalt, lithium in power batteries, and material cycles of interior materials • Component level: The world's first region to propose life - cycle management of batteries	• Rely more on independent innovation of enterprises, such as the application of recycled plastics by Ford and the reuse of batteries by General Motors
Internal and External Regional Impacts	• Carbon Border Adjustment Mechanism (CBAM) to avoid carbon leakage, and influence the global supply chain through regulation output	• Less demand put forward for overseas markets in terms of the environmental dimension
Action Modes	• Emphasize cross - industry collaboration, such as battery passports • Emphasize upstream and downstream collaboration, such as the extension of producers' responsibility for batteries	• Promote the development of circular economy in enterprises through means like tax exemptions and investment incentives

1.1.3 Vehicle Circularity: A Key Driver of the Circular Economy

The automotive industry is a major pillar of China's economy. The value added by vehicles and their manufacturing and service industry chain accounts for about 6-7% of GDP, making it one of the country's most significant economic drivers.[4]. The automotive industry chain is long, highly interrelated, with strong multiplier effects, large trade volumes, and substantial employment. It also possesses a pronounced capacity for technological innovation and therefore exerts a significant influence on national and regional economic development. The entire life cycle of a vehicle almost connects all the key links of modern industry. Its circularity will systematically promote the coordinated changes in upstream raw material supply, midstream manufacturing processes, and downstream recycling systems. Therefore, the circularization of the automotive industry has become a key lever for the transformation toward a contemporary circular economy.

According to the hierarchy of the circular economy, it can be divided into several dimensions: the large cycle refers to the national and regional level, the medium cycle refers to the industry network and enterprise level, and the small cycle focuses on the product level, mainly concerning the circulation between companies and consumers. Vehicle circularity basically focuses on the medium and small cycles of the circular economy, exploring how partners across the automotive value chain put circular economy principles into practice [5].

If the linear economy is represented by "1", then every small cycle or medium cycle in vehicle circularity can be seen as a small "0". By perfecting these lower-level cycles, we can leverage the larger cycle of society, ultimately achieving the "∞" of the circular economy.

Figure 1.2 | Circular Economy Hierarchy [5]

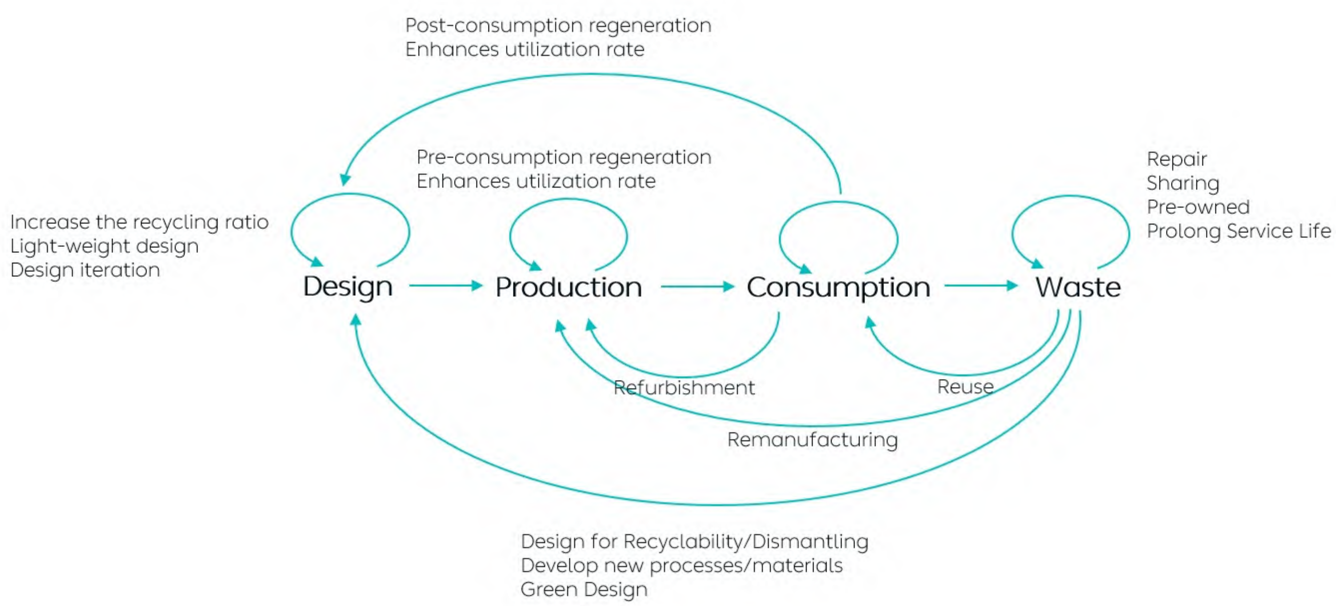
1.2 x→0 & $lim_{x \to 0} \frac{1}{x} = \infty$

The limit of each small cycle defines the limit of the large cycle.

1.2.1 Overview of the Circular Economy

The linear economy primarily follows the process of "design >production > consumption > disposal," whereas the circular economy seeks to close the loop at each stage, ultimately creating a large closed-loop of resource circulation.

Figure 1.3 | Infinite Cycle: Circular Economy

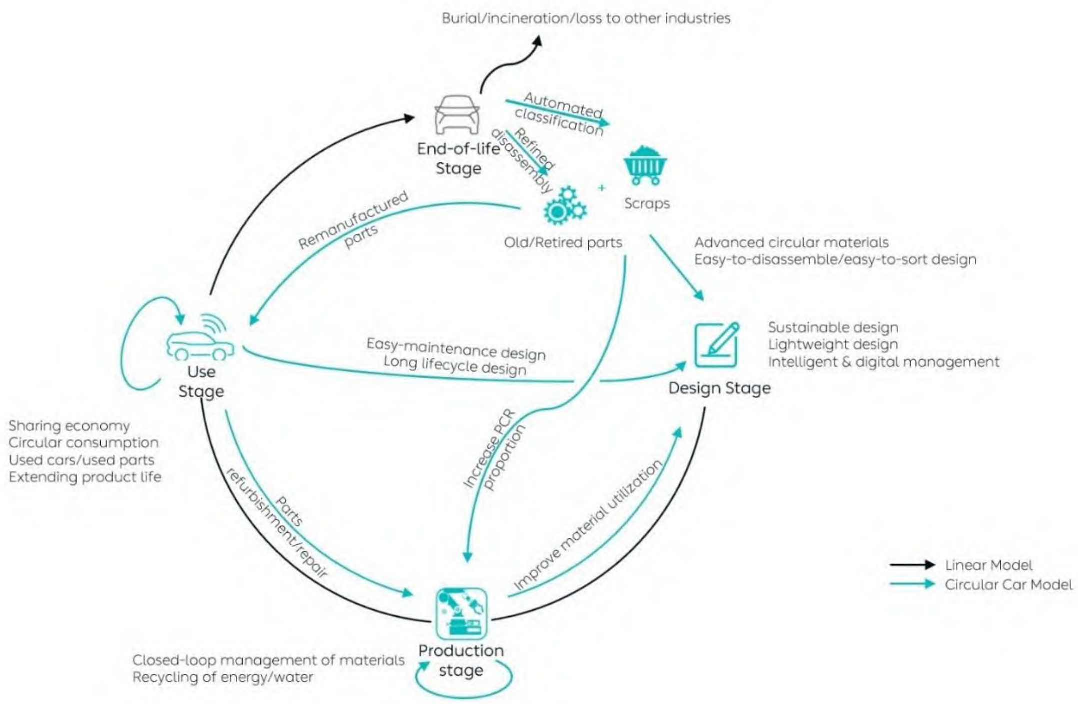


1.2.2 Overview of Vehicle Circularity

NIO aims to integrate the entire lifecycle of vehicle design, production, use, and decommissioning into a circular system, responding to the global trend of resource circulation. The following illustrates NIO's comprehensive thinking regarding vehicle circularity.

Guided by a holistic vision of vehicle circularity, NIO has established a project team to implement circular economy principles. In the design phase, NIO reduces the development and usage of minerals by employing sustainable design and using circular materials; in the production phase, the company aims to improve material utilization while recycling production waste; during the usage phase, through a "rechargeable, replaceable, and upgradable" battery service model, NIO optimizes resource allocation for enhancing product longevity; at the end of a vehicle's lifecycle, NIO utilizes decommissioned test vehicles in partnership with upstream and downstream collaborators to explore the technological and industrial feasibility of "car-to-car" recycling, having already completed a closed-loop cycle for over 1,000 vehicles. These experiments solidify the foundation for a circular model across the entire automotive industry chain and provide new impetus for initiating the infinite large cycles of the circular economy.

Figure 1.4 | Small and Medium Cycles: Vehicle Circularity



One Leaf Foretells Autumn

The Wind of Circularity Arrives

2.1 Guided by Policy: Driving Vehicle Circularity

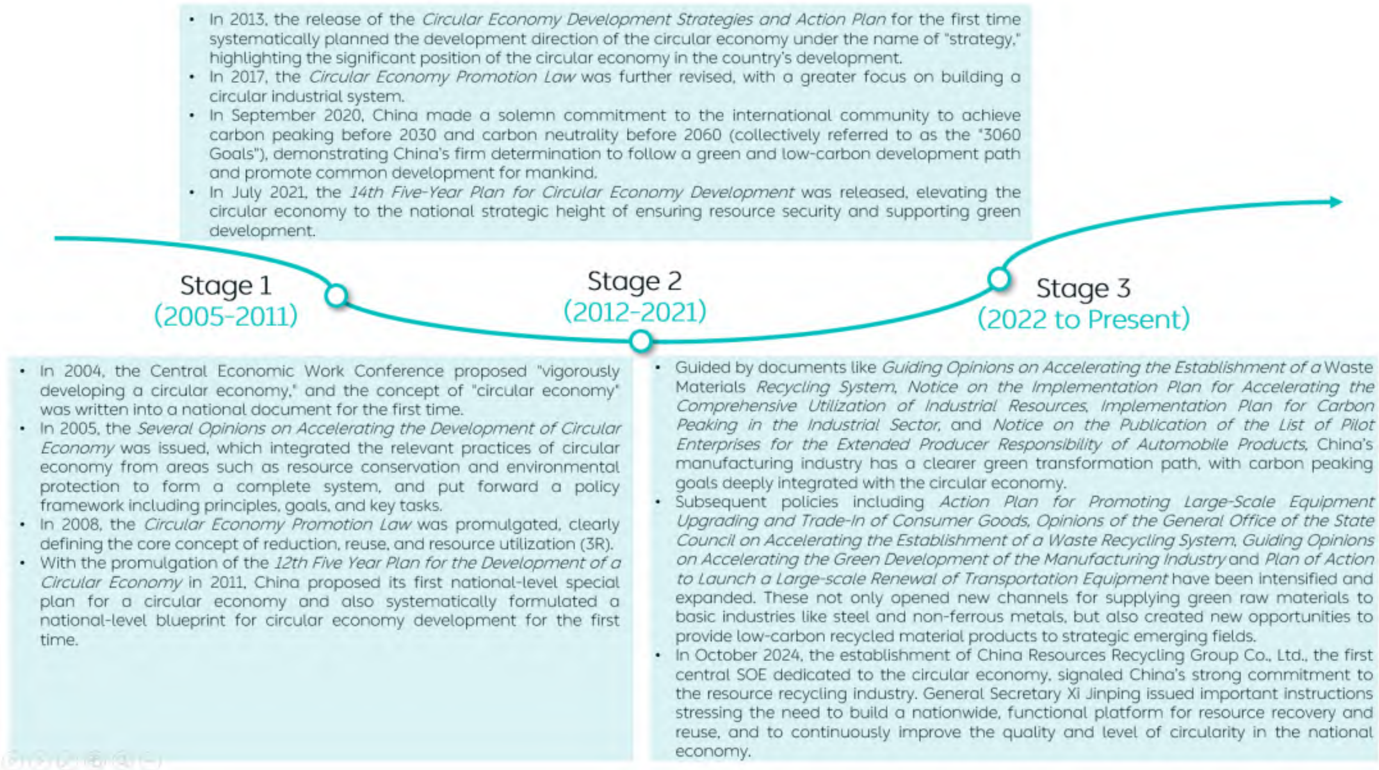
The world is undergoing profound political and economic changes. Major economies, represented by China and the EU, are stepping up circular economy policies and putting them into practice, with vehicle circularity emerging as a key direction for the green transformation of the automotive industry.

2.1.1 In China: Comprehensive Planning, Clearer Path

The circularity of the automotive industry is a crucial measure to implement the circular economy strategy, improve resource utilization efficiency, and reduce environmental pollution. As a pillar industry of the country, the automotive industry's circular model represents a key direction for its green transformation and will further become an excellent carrier for the implementation of domestic resource circulation. China's circular economy policies are systematic and coordinated, focusing on efficient resource use and recycling. Guided by the principles of "reduce, reuse, recover," they promote low consumption, low emissions, and high efficiency. The policies blend government guidance with market mechanisms, ensure oversight across the entire process, clarify the roles of all stakeholders, and apply both incentives and restrictions.

The development of China's circular economy policies and regulations can be divided into three stages (see Figure 2.1).

Figure 2.1 | China's Circular Economy Policies and Regulations: Development Stages



2.1.2 Overseas: Tailored to Local Conditions, Each With Its Strengths

When looking overseas, significant differences emerge in regional circular economy policies. For example, the EU and the U.S. take fundamentally different approaches to advancing the circular economy and circular automotive industry. The EU follows a regulation-driven path, focusing on legislation and "hard constraints." Its strategy has evolved from waste management to building a fully circular economy across industries, reflecting a strategic, systematic, comprehensive, and integrated framework. By contrast, the U.S. relies mainly on market forces, complemented by federal and state legislation. Its approach emphasizes enterprise-level flexibility and innovation, encouraging corporate initiative through incentives such as tax breaks and investment rewards to drive participation in the circular economy.

Table 2.1 | Comparison of Circular Economy Policies: EU vs. U.S.

Comparison Dimension	European Union	United States
Underlying Logic	• Regulation - driven: Prioritize legislation and set standards	• Market - driven + Emphasis on Flexibility: Combine federal and state legislation, focus on independent innovation of enterprises, and share responsibilities among all parties in the value chain
Formulation of Core Regulations and Standards	• EU New Circular Economy Action Plan (2020) • Policy Recommendations for the Circular Economy of Automobiles (2023) • EU Battery Regulation (2023) • Critical Raw Materials Act (2023)	• National Recycling Strategy (2021) • Inflation Reduction Act (2022) • Policy Framework for Recycling of Lithium - Ion Electric Vehicle Batteries (2022)
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Strict EU Regulations

In July 2023, the European Commission put forward the *Proposal for a Regulation on Circularity Requirements for Vehicle Design and on Management of End-of-Life Vehicles*. The proposal consolidates the *Directive 2000/53/EC on end-of-life vehicles* and the *Directive 2005/64/EC on reusability, recyclability and recoverability*, with the goal of improving resource efficiency across the sector by introducing new standards for circular design, collection, and recycling.

In addition to legislation, the EU emphasizes full life-cycle management, the setting of quantitative targets, and the establishment of standards and tools to ensure transparency across the industrial chain.

Full life-cycle management: Extended Producer Responsibility (EPR) is introduced, requiring manufacturers to fund the disposal of abandoned vehicles and ensure compliance with scrapping procedures. Manufacturers are encouraged to cooperate with recycling and processing institutions to enhance recycling efficiency and material quality.

Quantitative target setting: Under the EU's *Circularity Requirements for Vehicle Design and Management of End-of-Life Vehicles* proposal (July 2023 version), new vehicles must include at least 25% post-consumer recycled (PCR) materials, with 25% of that coming from vehicle-to-vehicle closed-loop recycling. The EU's new battery rules also set clear targets for the use of recycled cobalt, lithium, and nickel, with different requirements for different time periods.[6].

Standards and tools for industrial chain transparency: The EU promotes the Digital Product Passport to improve data transparency, tracking the carbon footprint and recycling routes of automotive batteries and components. Battery passports were first implemented in 2024 for automotive power batteries.

Figure 2.2 | EU Circular Economy Policy Timeline

Soft Incentives in the U.S.

Unlike the EU, the US mainly promotes resource recycling and reuse through a combination of market-driven strategies and federal and state government legislation. The approach emphasizes enterprise-level innovation and uses incentives such as tax breaks and investment rewards to encourage participation in the circular economy. It also focuses on managing plastic pollution, electronic waste, and construction waste.

Figure 2.3 | U.S. Circular Economy Policy Timeline

1976

Resource Conservation and Recovery Act (RCRA)

America's earliest circular economy law, establishing a management system for hazardous waste and solid waste.

1984

National Waste Minimization Plan

Encourages industrial enterprises to reduce waste emissions and improve resource recovery rates.

2020

Save Our Seas Act

Addresses marine plastic pollution issues, promoting plastic recycling and R & D of alternative materials.

2021

National Recycling Strategy

Proposes five major recycling goals, such as increasing waste recycling rates, improving recycling infrastructure, and encouraging product recyclable design.

2022

Inflation Reduction Act

Contains provisions to encourage domestic recycling of battery materials, aiming to reduce dependence on imported critical minerals and promote domestic production and recycling of electric vehicle battery materials.

Policy Framework for Recycling Lithium – Ion Electric Vehicle Batteries

The Auto Innovators alliance advocates for reuse, remanufacturing, and recycling of electric vehicle batteries to reduce dependence on imported minerals, enhance energy security, and create manufacturing jobs.

2.2 Vehicle Circularity: The Rising Star of the Industry

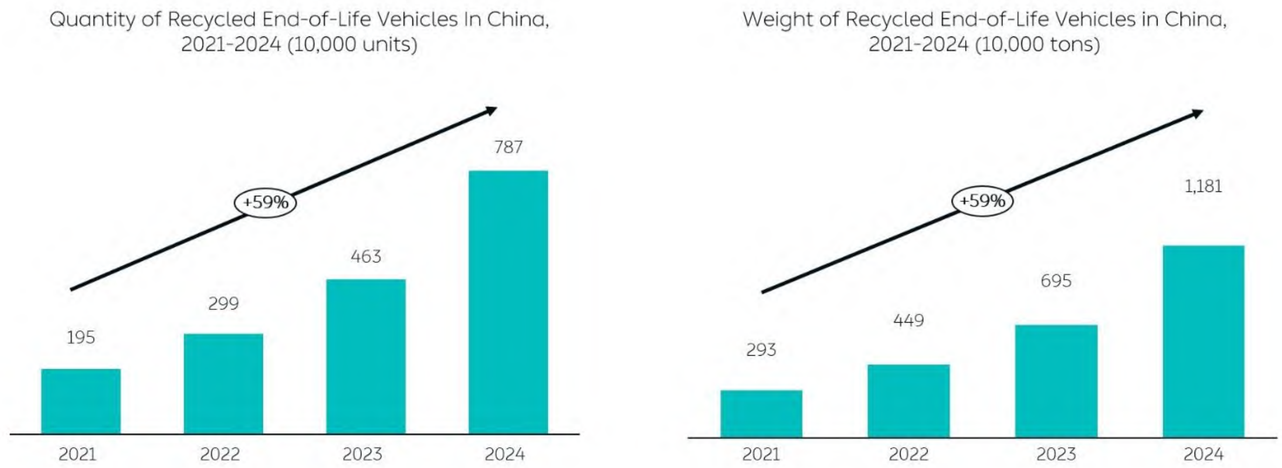
The circular automotive industry is emerging as a key growth path in a competitive market.

2.2.1 Supply Side: Unlocking Opportunities in Vehicle Scrapping

The circular automobile industry is a new driving force for the trillion-dollar market of the circular economy. The industry covers a broad spectrum and is significant in scale. According to Accenture's forecast, the market for the circular economy is expected to reach $4.5 trillion by 2030, with overall growth likely to remain over 10% CAGR [7].

As of the first half of 2025, the number of vehicles in operation in China reached 359 million, including 36.89 million new energy vehicles (NEVs), accounting for 10.27% of all vehicles. Of these, battery electric vehicles (BEVs) totaled 25.539 million, representing 69.23% of NEVs[8]. With the continuing rise in ownership, the implementation of regulations such as the phase-out of vehicles meeting China National III emission standards, and the strong boost from trade-in initiatives, the opportunity window for vehicle scrapping is approaching. In 2024, approximately 8.46 million vehicles were scrapped—a 64% year-on-year increase—setting a historical record, equivalent to about 10.6 million tons. According to the National Automobile Circulation Information Management System, the number of vehicles projected to be scrapped in China by 2025 will reach between 15 and 20 million[9].

Figure 2.4 | A Prime Window for Vehicle Scrapping in China [10]



China's automotive industry has now reached maturity. With the growing penetration of smart EVs, additional purchases and replacements already account for nearly 60% of new car sales. From 2025 to 2030, rising consumer acceptance and an expanding supply of smart EVs will accelerate the shift away from traditional ICE cars. As a result, retirements and scrapping will surge, driving a sharp increase in the overall volume of end-of-life vehicles.

Figure 2.5 | China's Auto Market Enters Replacement Cycle, Triggering a Surge in Scrapping [11]

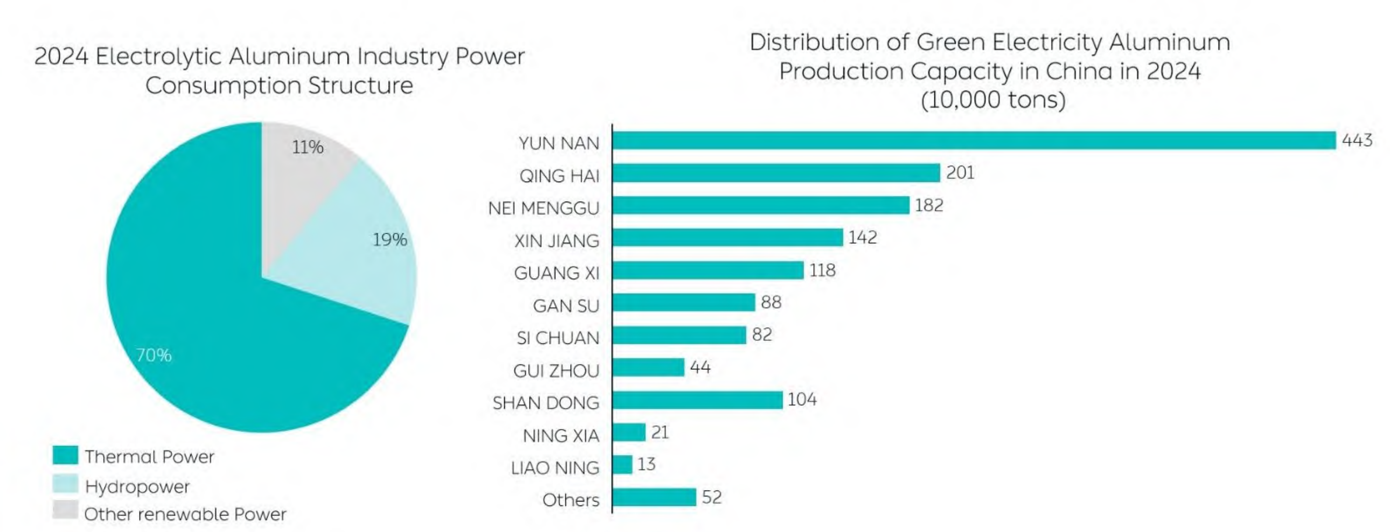
2.2.2 Demand Side: Increasing Demand for Material Recycling

From the supply-side analysis above, the approaching wave of vehicle scrapping is driving a significant increase in the supply of recycled automotive materials. The demand for these materials in vehicle applications will be a key determinant of whether the circular model can be implemented sustainably and at an industrial scale.

Smart EVs not only bring technological and user experience innovations but also set distinct material requirements compared with traditional ICE vehicles. The demand for lightweight yet strong structures is driving rapid growth in aluminum usage[12][13][14], while power batteries require substantial amounts of nickel, cobalt, and lithium. The introduction of the Global Plastics Treaty has promoted the recycling and use of recycled plastics in vehicles. Meanwhile, improving vehicle sustainability highlights the challenge of securing a stable supply of low-carbon raw materials while keeping costs under control.

Aluminum materials are one of the main contributors to the life-cycle carbon footprint of automotive products. The shift toward low-carbon vehicles has significantly increased the cost of automotive aluminum, with hydropower and other low-carbon aluminum commanding a 2–4% market premium[15], due to limited supply in China. In 2024, non-thermal power aluminum accounts for 30% of China's primary aluminum output, of which hydropower aluminum represents 63%. Regionally, the supply of low-carbon aluminum is concentrated in the southwest, where local production exceeds 40% of the national total. This geographic concentration underpins the relative scarcity and premium of low-carbon aluminum[14].

Figure 2.6 | Electrolytic Aluminum Industry: Energy Mix and Green Energy Capacity, 2024 [16]



Recycled aluminum is one of the key pathways for the new energy vehicle supply chain to achieve carbon reduction efficiently and support the circular economy. Aluminum's core production processes account for approximately 85% of its direct carbon emissions, while recycled aluminum consumes only 5% of the energy required for primary aluminum (0.6 tons of CO_2)[17]. This gives recycled aluminum materials an unparalleled advantage in component carbon emissions compared with thermal power aluminum.

Beyond aluminum, smart EVs have also greatly boosted the growth of the power battery industry. As the first batch of EVs reaches the end of its service life, a large number of retired power batteries are now facing the challenges of both recycling and cascade utilization. China's recycling and repurposing technologies for power batteries are at a world-leading level and are steadily improving.

Compared with the cost and carbon-reduction benefits of recycled aluminum, the recycling of battery materials plays an even more crucial role in easing resource supply pressures. According to the International Energy Agency, by 2040, the global demand for copper, lithium, nickel, and cobalt is expected to increase by one to seven times compared to 2024 (see Figure 2.7). Recovering these minerals from retired batteries could reduce the total demand for primary supply by about 12%—a tenfold increase over the share in 2030. This has the potential to substantially ease resource supply constraints[18] .

Figure 2.7 | Key Mineral Demand Growth in the 1.5 °C Warming Scenario [18]

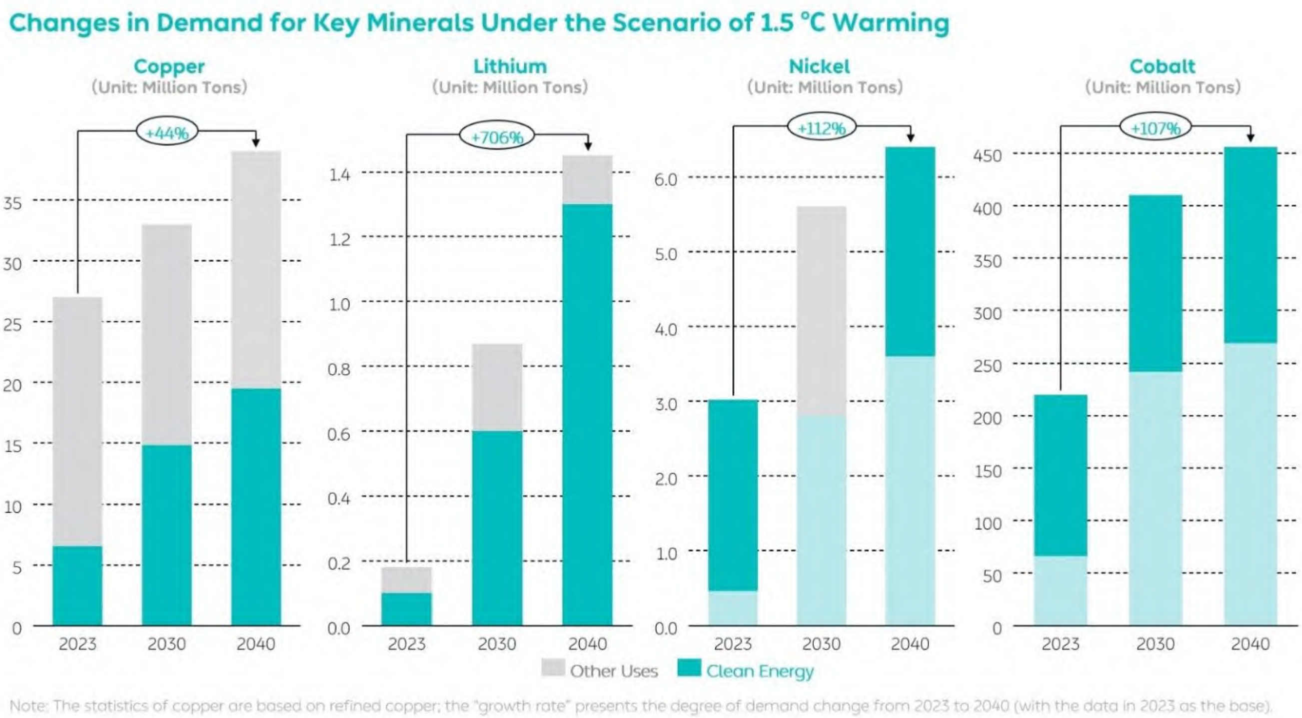
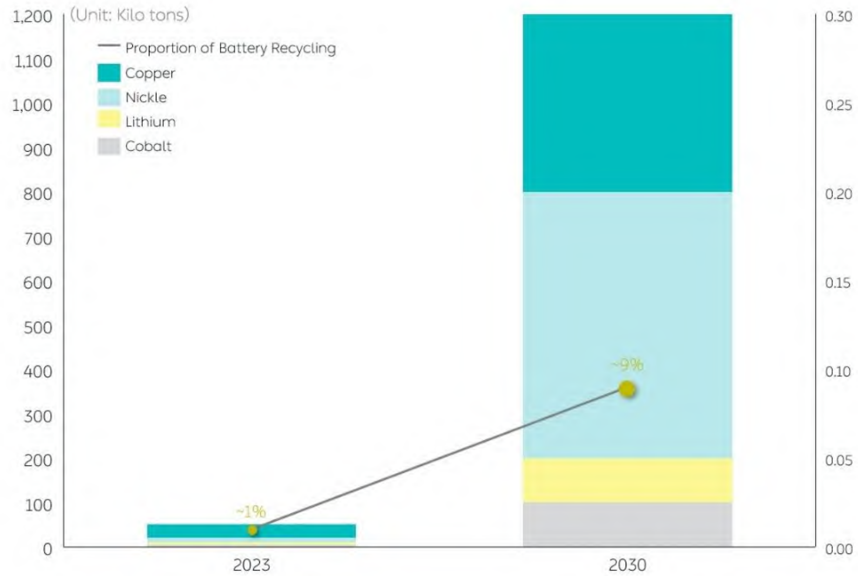


Figure 2.8 | Contribution of Battery Recycling and Reuse to Reducing Primary Mineral Demand[18]



2.2.3 Remanufacturing: The Secret to Increasing Profits From Parts

Compared to material recycling, the remanufacturing of automotive parts is more mature. For the traditional automotive industry, remanufactured parts offer higher profit margins, significantly increasing company profitability. This is one of the sources of profit for traditional vehicle manufacturers.

For example, LKQ Corporation's main businesses include the recycling and dismantling of end-of-life cars, remanufactured parts, distribution of replacement parts, and scrap metal recycling. According to LKQ's 2024 financial statements, its North American division, which runs remanufacturing operations (such as engines and transmissions), reported an EBITDA margin of 16.6%. The profit margin of LKQ's remanufacturing operations substantially exceeds that of traditional OEMs, highlighting the competitive advantages of the circular economy model (recycling, refurbishing, remanufacturing), which includes lower raw material costs, strong supply chain integration, and stable market demand. This underscores the high profitability potential of the remanufacturing business in the automotive aftermarket[20].

Figure 2.9 | Revenue Analysis of North American Division, LKQ Corporation (2024) (in millions of USD)[20]

As of Dec 31, 2024

North American Wholesale Business	Unit	2024	2023
Total Revenue by Segment	M USD	5,763	5,282
- Parts and Service	*M USD*	*$5,465*	*$4974*
- Others	*M USD*	*297*	*307*
- Inter-Department	*M USD*	*1*	*1*
Cost of Goods Sold	M USD	3,252	2,796
Gross Profit	M USD	2,511	2,486
Gross Margin	*%*	*43.60%*	*47.00%*
Sales, General and Administrative Expenses	M USD	1,567	1,535
Less: Other Segment Items	M USD	(15)	(24)
Segment Earnings Before Interest, Taxes, Depreciation and Amortization (EBITDA)	M USD	$959	$975
EBITDA Margin	*%*	*16.60%*	*18.50%*

2.2.4 Industrial Parks: An Excellent Platform for Circular Models

Circular industrial parks are designed based on the circular economy theory, transforming industrial systems through the simulation of the natural ecological system of "producers-consumers-decomposers." This creates an "ecological chain" of industrial systems to facilitate the exchange of by-products and wastes among park members, the cascade utilization of energy and wastewater, and the sharing of infrastructure, information, and park management systems, thereby establishing a sustainable system that balances economic benefits with environmental protection [19].

According to research by the industrial research institutes, there are already more than 10,000 circular parks of various sizes established across China. Among these, there are over 100 national-level circular parks and more than 300 provincial-level parks. Nationwide, circular economy industrial parks have the potential to generate a market scale exceeding one trillion yuan. Circular industrial parks provide an excellent platform for commercializing the circular chain. This is reflected in several aspects:

First, the organization structure of circular parks minimizes logistics costs throughout the circular chain, lowering value loss in material flows. A major feature of the circular economy is the need for a close interconnection and interaction between upstream and downstream participants from end to end. Vehicles must go through processes such as end-of-life vehicle collection, dismantling, smelting, and die-casting to fully close the loop. However, once a vehicle is dismantled, transporting different materials and components to distant downstream recycling or treatment facilities would result in excessive logistics costs without adding value to material recovery. By clustering key processes within the same industrial park, a “door-to-door” circulation model can be established, minimizing logistics expenses and improving overall recycling efficiency.

Second, the vehicle dismantling and recycling process is essentially the reverse of new vehicle manufacturing. While manufacturing reduces entropy, dismantling increases it. Extracting high-purity raw materials during dismantling is challenging, and the dismantled parts often contain impurities. Furthermore, compared to raw materials for new car production, dismantled scrap has lower consistency, creating additional process, cost, and quality control requirements for downstream metal recycling, smelting, and extraction. A circular industrial park enables downstream users to provide more direct and efficient feedback to upstream processes, improving information flow and enhancing quality control.

Third, the circular industrial park model also facilitates upstream and downstream traceability along the circular chain. Supply chain traceability has long been a challenge in the automotive industry. With Chinese automakers expanding aggressively into overseas markets, sustainability compliance and traceability across supply chains have become essential. Within a circular park, end-of-life material flow and processing can be monitored and traced at minimal cost, ensuring compliance and accuracy across the entire circular chain.

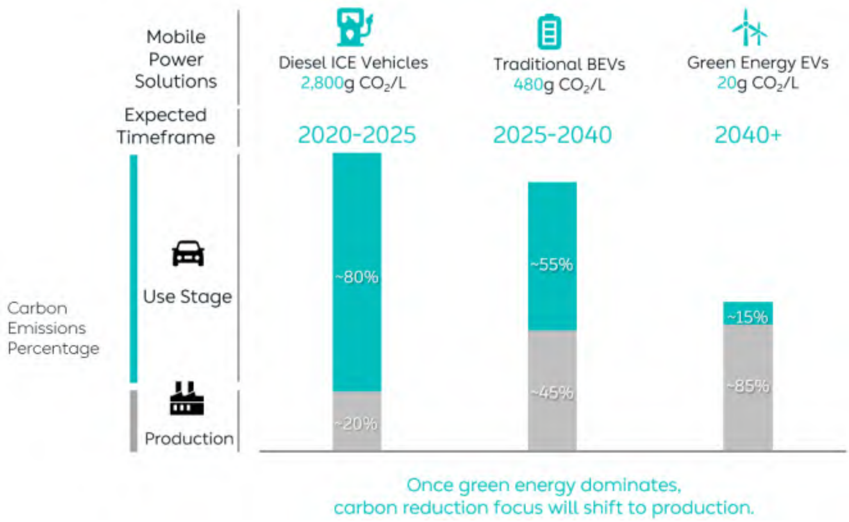
2.3 Environmental Benefits

The automotive industry faces increased pressure to reduce emissions under carbon neutrality targets. Circularity will become the forefront for green and low-carbon development in the automotive industry.

2.3.1 Circular Economy: A Stronghold for Automotive Carbon Reduction

According to McKinsey, in the present and next five to ten years, carbon emissions from the upstream supply chain will account for nearly 50% of the total carbon emissions of electric vehicles. The carbon emissions during the usage phase of battery electric vehicles primarily come from fossil fuels consumed in electricity generation. As the global energy structure continues to shift towards renewable energy, the consumption of fossil fuels required for power generation will decrease, lowering the carbon emissions in vehicle usage. By around 2040, it is expected that the upstream supply chain will contribute over 80% of the total carbon emissions of vehicles (see Figure 2.10).

Figure 2.10 | Vehicle Production vs. Vehicle Use Emissions (% of Total)



If the automotive industry is to achieve commercially sustainable low-carbon operations, circular economy practices may be the ultimate solution. Aluminum plays a significant role in decarbonizing the automotive sector, as the carbon emission factor (EF) for primary aluminum is high, while recycled aluminum is only 5% of that, resulting in only 0.6 tons of carbon dioxide generated[21]. According to the International Aluminum Institute, by 2050, through 100% recycling of aluminum, improved waste sorting, and the elimination of losses associated with pre-consumer waste metal, the demand for primary aluminum can be reduced by 20%, contributing an additional reduction of 300 million tons of absolute carbon dioxide equivalent emissions[22]. Given that inert anode technology has not yet achieved industrial-grade application, short-term carbon reduction in primary aluminum production during mass production remains challenging. Thus, recycled aluminum has emerged as a more practically feasible path for carbon reduction in aluminum materials.

In terms of market size, under the International Energy Agency's (IEA) 2050 net-zero emission scenario, secondary aluminum production will expand to over 40% of total aluminum output by 2030 [23]. For the Chinese market, recycled aluminum production exceeded 10.55 million tons in 2024, surpassing the 10-million-ton mark for the first time. The ratio of recycled aluminum to primary aluminum has approached 1:4 and is rapidly moving toward 1:2 [24]. With the evolution of the circular industry, it is projected that recycled aluminum production will exceed 15 million tons by 2027, accounting for 30% of the aluminum industry's total output [25].

2.3.2 Circularity: A Vanguard of Green Development

A key attribute of low-carbon and sustainable industries is "externality." Here, externality first refers to the fact that environmental impacts such as carbon emissions, are not limited to the microlevel of a single enterprise but on the entire society, meaning society bears the burden and impacts caused by enterprises on the environment. Externality also implies the need for cooperation of all enterprises along the entire industry chain to establish viable business and technical cooperation models to truly gain environmental benefits, transforming "negative externality" into "positive externality."

Against this background, the concepts and practices of circular vehicles naturally link all participants in the entire chain (dismantling, material recycling, alloy smelting, parts manufacturing, and vehicle manufacturing) in material and information flows. This will further facilitate the collection and verification of carbon emissions data, the allocation of carbon emissions targets, and the distribution of environmental benefits across the entire chain throughout the full lifecycle. At the same time, this information can serve as feedback to partners along the value chain, enhancing their ability to control carbon emissions effectively.

As a specific scenario of the circular economy, the circular automotive industry has the base for large-scale industrialization. From the perspective of laws and regulations, with the completion of the top-level framework for domestic regulations and detailed legislation, as well as the founding of China Resources Recycling Group, the circular automotive industry is expected to reach a pivotal stage for rapid development. From a business model standpoint, as the volume of scrapped vehicles enters a growth phase, paired with the highly certain demand for circular materials spurred by the wave of vehicle electrification and smart technology—the circular automotive industry is seeing a two-way street between supply and demand. As its scale continues to expand, over the long term, it will increasingly become a central driver for decarbonization in the automotive sector. It will also enhance the economic viability and traceability of decarbonization efforts across society, ultimately achieving "positive externality."

Exploring the Circularity Path:

How to Achieve Zero to Infinity?

3.1 A Thousand-Mile Journey Begins With a Single Step

Automotive value chain partners have recognized its great potential and have made many efforts to lay the groundwork for vehicle circularity.

3.1.1 Application of Advanced Sustainable Materials

Natural Materials

Ford has developed a variety of natural sustainable materials for automotive manufacturing through independent research and collaboration with companies such as Coca-Cola, Nike, Heinz, and Procter & Gamble. Ford is the world's first automaker to use wheat straw-reinforced plastic. Compared to traditional materials, wheat straw-reinforced plastic is lighter with better dimensional stability, and can effectively reduce production energy consumption due to the abundant supply of straw. Ford was the first in the industry to launch storage boxes made from wheat straw, terminal caps made from rice husks, and armrest frames and center console frames made from wood cellulose[26].

Yanfeng incorporates bamboo elements comprehensively into automotive interior design. Its BASSI® bamboo element door panels use bamboo skin as decorative pieces, and various bamboo fiber composite materials are used in door panels, armrests, map pockets, and door panel frames.

Bamboo is hard and flexible, grows quickly, and is abundant in southern China, making it very eco-friendly compared to slow-growing trees, allowing it to be widely used as vehicle interior trim. By adding 5% to 50% of bamboo fibers to different materials, weight can be reduced by up to 17%, with a corresponding 30% reduction in carbon emissions, while enhancing product texture and providing natural antibacterial properties[27].

Figure 3.1 | Ford Wheat Straw Fiber

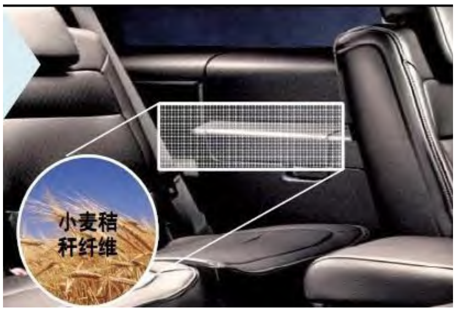


Figure 3.2 | Yanfeng Sustainable Material Interior

Figure 3.3 | Bamboo Fiber Composite Material

NIO Clean+ Materials

Clean+ materials are a collection of environmentally friendly materials developed by NIO and its partners, including renewable, recycled, and user health protection materials that produce fewer carbon emissions, aiming to provide users with a safer, healthier, and greener "second living room." The C-pillar lower trim of the NIO EC7 is made from recycled polycarbonate (PC) derived from post-consumer products like buckets and CDs, replacing traditional petroleum-based PC materials to achieve a 65% post-consumer recycled material ratio. This post-consumer recycled (PCR) material also has a third-party validated carbon footprint statement and has been certified for traceability under the Global Recycled Standard (GRS). The NIO ET5T uses Clean+ eco-friendly fabric as one of its main interior materials, 100% made from recycled PET bottles, thus reducing plastic pollution in the oceans and on land; The center console of the ET5T uses bio-based composite Poly Propylene (PP) plastic jointly developed by NIO and PRET. It incorporates wood fiber pulp from sustainable forests, with carbon emissions reduced by 72% compared to petroleum-based virgin PP materials. On top of material circularity, it is greener and lower in carbon emissions [28]. The instrument panel frame of the NIO ES8 uses recycled PP to replace 25% of virgin petroleum-based PP, which enhances material circulation and reduces carbon emissions at the material level by approximately 15%.

Recycled materials can also be found in many components in firefly. NIO's Firefly model also uses recycled materials in multiple parts.

Figure 3.4 | NIO Clean+ Interior

Figure 3.5 | NIO Clean+ Interior

Figure 3.6 | NIO firefly Clean+ Material

Figure 3.7 | NIO firefly Clean+ Material

Lightweight Composite Materials

High-strength steel, aluminum alloys, and magnesium alloys are used to replace traditional steel materials, achieving vehicle weight reduction with lowered density and quantity. The lightweight materials, structures, and processes are three key points for reducing vehicle weight. Among these, aluminum alloys have been widely applied in automotive manufacturing due to their lightweight and high-strength characteristics. With optimization of their micro-structure, the performance of aluminum alloys can be further enhanced. For example, by controlling the grain size and phase composition of aluminum alloys, their strength and corrosion resistance can be significantly improved. The use of aluminum alloy materials in vehicles can bring a weight reduction of 20-30%, reducing fuel consumption in conventional vehicles by 14-21% and increasing the range of new energy vehicles by approximately 12-18%. Currently, aluminum alloy components are widely applied in automotive components such as battery housings, liquid cooling plates, front and rear bumpers, shock-absorbing parts, electrical brackets, and CCB dashboard brackets[29].

High-strength steel and ultra-high-strength steel (UHSS) feature higher yield strength and tensile strength, allowing for smaller component sizes and reduced structural weight, thus saving on steel usage. The ONVO L60 employs a mixed-use of advanced lightweight materials including high-strength steel, UHHS, and aluminum alloys, combined with structural topological optimization and bionic design. This ensures leading safety performance with a lightweight steel-aluminum hybrid dual-compartment body. The NIO ET9 innovatively adopts lightweight technologies, such as integral die-casting (21% weight reduction from components), integral door-rings (10% weight reduction from components), and proprietary lightweight alloys and composite materials, resulting in an 18% improvement in overall torsional stiffness and a lightweight coefficient as low as 1.70, leading the industry.

Except for aluminum alloys, NIO's battery system adopts lightweight and recyclable materials. For non-primary load-bearing structural components such as the upper cover and internal brackets, lightweight plastics are used, reducing the weight and improving insulation performance of the battery system, which enhances the vehicle's range in low-temperature conditions. The coating for the underbody shield is low-density and high-wear-resistant, which can reduce weight by 25% compared to traditional PV coatings.

Figure 3.8 | ONVO L60 Body

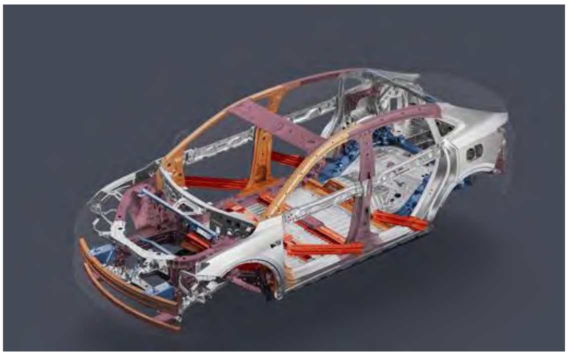


Figure 3.9 | NIO ET9 Body

Figure 3.10 | Lightweight Composite Material for 75kWh Battery Cover

Figure 3.11 | Lightweight Battery Pack

3.1.2 Green and Easily Recyclable Designs

Modular Design

Modular design is an innovative method that achieves product development and manufacturing through standardized designs and generic components. It breaks the vehicle down into multiple functional modules, each of which can be independently designed, produced, and flexibly combined. This design concept is also significant for environmental protection and sustainable development, because it champions optimizing resource use and reducing waste to reduce environmental impact. The body's modular design can be realized through integral die-casting[30].

NIO vehicles optimize structural design by integrating multiple parts, such as the longitudinal and cross beams of the rear floor, into a single cast piece. The integral die-casting technology combines stamping and welding from traditional vehicle manufacturing, shortening processing time while optimizing production costs. This modular structure design enables a higher level of hardware standardization and a shorter development cycle that matches the speed of software updates, adapting to the rapid iteration of vehicle models in the era of smart EVs[29].For example, the NIO ET5's integral die-cast rear floor consolidates 56 steel stamping parts into two components, reducing the number of self-piercing rivets by 30 and achieving a 25% weight reduction. Tesla has integrated over 70 components of the Model 3's rear underbody into two large parts for the Model Y through the same approach. This has resulted in approximately 20% savings in manufacturing costs, reduced welding time from two hours to 90 seconds, and also brought advantages such as improved precision, a higher raw material recycling rate, and a shorter vehicle development cycle.

Figure 3.12 | NIO ET5's Megacasting

Figure 3.13 | Tesla Megacast Part

Integration and modular design can also significantly reduce the types of materials, thus simplifying the car recycling process and lowering the costs of sorting and treatment. Unified materials contribute to not only efficient sorting and recycling, but also the disassembly process during end-of-life vehicle recycling. While recyclable materials can be efficiently treated, environmental pollution during the disassembly process is reduced. Such designs can significantly enhance the actual recycling rate of scrapped vehicles and promote the development of a circular economy.

Easy-to-Disassemble Design

Easy-to-disassemble design requires consideration about the disassembly and replacement of vehicle parts so that when a car reaches the end of its life cycle, it can be easily disassembled and recycled. Standardized design methods significantly improve disassembly efficiency and lower recycling costs.

NIO has launched an energy service system featuring "Chargeable, Swappable, and Upgradable" batteries, and has been continuously investing in the development of key technologies for safe and efficient battery swapping. For example, the easily detachable design of NIO's battery packs allows them to be flexibly swapped and upgraded independently of the vehicles, significantly improving battery usage efficiency; such a design also makes battery recycling and cascading utilization more convenient. Additionally, through NIO's in-house developed Battery Safety Evaluation Index (BSEI) system, the residual value of aged batteries can be accurately estimated and scored. Retired batteries can be screened, sorted, and treated in a centralized manner. Based on the scores given by the system, the batteries can be used in production scenarios such as energy storage and logistics, or directly disassembled for the recycling and reuse of the metallic elements within them.

The BMW i Vision Circular concept car carries forward the minimalism in the brand philosophy of BMW i, reducing the number of components, material types, and manufacturing processes. In its design, the use of adhesives and composite materials is minimized, making the entire vehicle easier to disassemble at the end of its life cycle for recycling and reuse[31].

Figure 3.14 | NIO's Swappable Battery Pack

Figure 3.15 | NIO's Swappable Battery Pack

3.1.3 Promoting Intelligence and Digitization

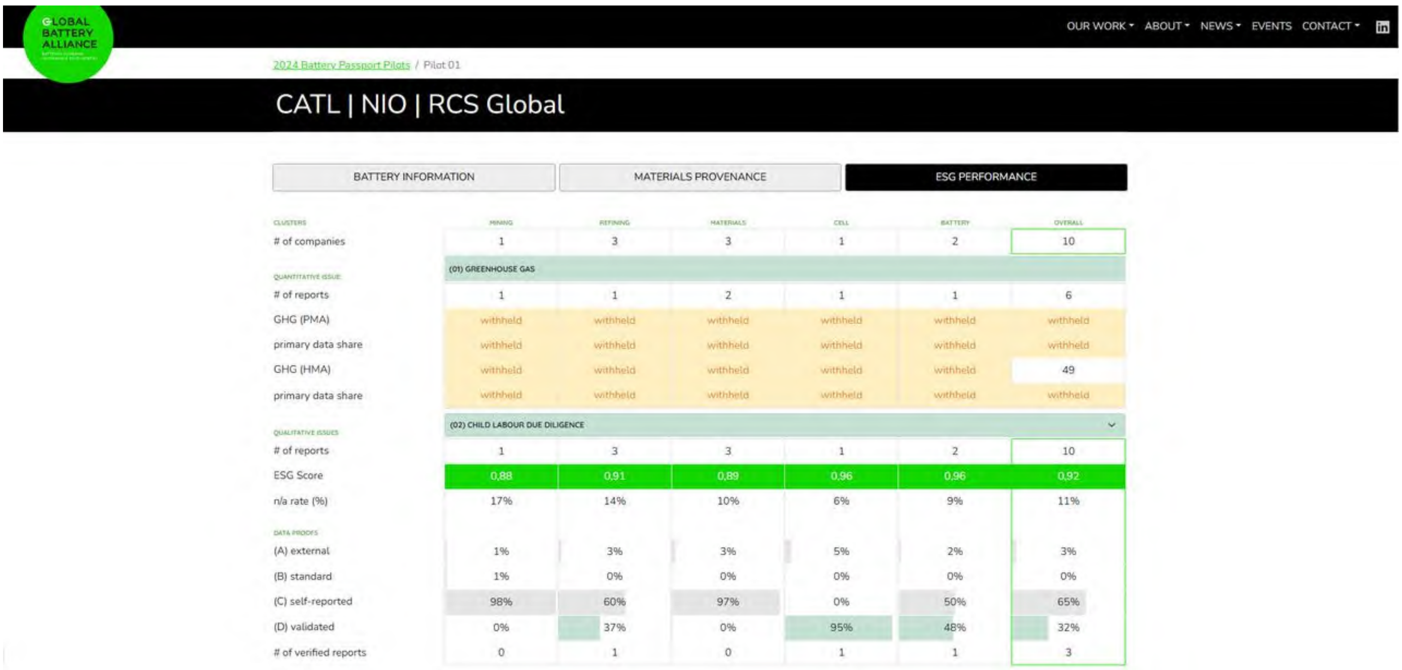
Big Data-Driven Lifecycle Management

The Battery Passport pilot project initiated by the Global Battery Alliance (GBA) marks an important milestone in promoting sustainable development across the global battery value chain. The project's data architecture integrates data on a battery's production, usage, and recycling, thereby enabling digital management throughout its entire life cycle. Battery passports enhanced transparency, sustainability, and circularity across the value chain. Furthermore, the platform is also capable of real-time monitoring and assessment of a battery's health status, which in turn provides data support for its cascading utilization and recycling [32].

NIO participates in the second wave of the project, conducting comprehensive digital tracking of the entire life cycle of the batteries and collaborating with partners in areas including carbon footprints, due diligence, environmental protection, and human rights.

Based on a vehicle lifecycle management system, Beiben Truck Group has integrated the business status from the entire process of production, delivery, sales, and service with and vehicle operation data for analysis, achieving comprehensive digital management from production to decommissioning. By collecting real-time data including vehicle operations, location information, and driving behavior through smart vehicles, the company can optimize logistics routes, predict maintenance needs, and improve the efficiency of vehicle use throughout its lifecycle. [33]。

Figure 3.16 | NIO Participates in the Second Wave of the GBA Battery Passport Pilot Project



CLUSTERS	MINING	REFINING	MATERIALS	CELL	BATTERY	OVERALL
# of companies	1	3	3	1	2	10
QUANTITATIVE ISSUE	(01) GREENHOUSE GAS					
# of reports	1	1	2	1	1	6
GHG (PMA)	withheld	withheld	withheld	withheld	withheld	withheld
primary data share	withheld	withheld	withheld	withheld	withheld	withheld
GHG (HMA)	withheld	withheld	withheld	withheld	withheld	49
primary data share	withheld	withheld	withheld	withheld	withheld	withheld
QUALITATIVE ISSUES	(02) CHILD LABOUR DUE DILIGENCE					
# of reports	1	3	3	1	2	10
ESG Score	0,88	0,91	0,89	0,96	0,96	0,92
n/a rate (%)	17%	14%	10%	6%	9%	11%
DATA PROOFS						
(A) external	1%	3%	3%	5%	2%	3%
(B) standard	1%	0%	0%	0%	0%	0%
(C) self-reported	98%	60%	97%	0%	50%	65%
(D) validated	0%	37%	0%	95%	48%	32%
# of verified reports	0	1	0	1	1	3

Building a Trustworthy Closed-Loop Traceability Network With Blockchain Technology

Volvo has established a cobalt tracking system using blockchain technology to ensure the transparency and traceability of the source and flow of the material[34]. Through smart contracts, the system enables automatic tracking and recording of cobalt, ensuring the transparency and reliability of the supply chain. Volvo also collaborates with Circulor, a traceability-as-a-service provider, to extend this new traceable supply chain solution to battery manufacturers. This end-to-end solution guarantees the transparency and reliability of shared data, thereby significantly improving the overall quality of the raw material supply.

Automobile manufacturers and component suppliers such as BMW, General Motors, Ford, Renault, Bosch, and ZF have formed the Mobility Open Blockchain Initiative (MOBI), aiming to explore the potential applications of blockchain technology and promote standardization and normalization in the automotive industry[35]. By formulating unified standards and norms, MOBI has facilitated the digitization and intelligentization in the automotive industry.

3.1.4 Revolutionizing Services and Business Models

Sharing Model—Optimizing Resource Allocation and Extending Product Lifespan

The sharing model has become an important mechanism for promoting the circular economy by optimizing resource use, extending product lifespan, and reducing idle capacity and waste. NIO Power is a recharging solution based on mobile Internet with an extensive network of charging and battery swapping facilities. Relying on NIO Power Cloud, it has built an energy service system featuring “Chargeable, Swappable, and Upgradable” batteries to provide users with comprehensive services, making recharging more convenient than refueling. NIO Power utilizes big data analytics to develop a battery health prediction model that can monitor a battery’s status in real-time, as well as predict its remaining life and performance changes, significantly enhancing battery lifespan and safety while offering users precise maintenance and swapping recommendations. With intelligent management, NIO’s battery swap stations conduct battery health checks and maintenance during each swap to extend the batteries’ service life. This model also allows battery packs to be swapped and upgraded independent of the vehicles. Users can select batteries of different capacities as needed without being restricted to high-capacity batteries for a long time. Users can opt for batteries of smaller capacities for daily use and rent larger ones for longer trips. Batteries can be swapped at stations across the country, which is as convenient as renting a power bank. By maintaining a limited pool of large-capacity packs and using NIO’s battery swap system to balance utilization across packs with different capacity, the model meets most users’ long trip needs, significantly improves battery utilization, and prevents premature retirement due to long mileage within the service life. This model is expected to save at least 17% of battery resources annually, achieving the economical and intensive use of natural resources.

At the end of the battery-swapping lifecycle for new energy vehicles, a new scrappage model separating the vehicle from the battery can be introduced, which allows batteries that haven't reached retirement conditions, once verified by authorized institutions, OEMs, or manufacturers, to recirculate in the market, thereby addressing the mismatch between the lifespans of batteries and vehicles and maximizing the efficient allocation of power batteries.

Figure 3.17 | Flexible Battery Upgrades

Figure 3.18 | NIO Power Swap Stations

3.1.5 Systematic Thinking of OEMs

BMW Group Recycling and Dismantling Center (RDZ)

The BMW Group established its own dismantling and recycling center (BMW Group Recycling and Dismantling Center, RDZ) in 1994, covering BMW, MINI, and Rolls-Royce. The RDZ is located in Unterschleißheim, a suburban area in Munich, Germany, and has a dual mission: to become a leading automotive recycler in the country and to lead advancements in the field. Since its inception, the RDZ has focused on the dismantling of pre-production vehicles, meticulously extracting valuable insights to improve the efficiency and sustainability of the recycling process in the future.

In BMW's circular strategy, it is explicitly stated that priority should be given to the circular consumption of wheels starting from aluminum recycling [36]. In 2023, BMW began collaborating with the federal government, research institutions, and enterprises to initiate the Car-to-Car project, planning to invest €6.4 million in the recycling and reuse of five major materials: aluminum, steel, copper, plastics, and glass, while exploring the potential improvements in vehicle dismantling and material identification with digital and AI technologies. At the same time, BMW has established over 3,000 recycling centers with global partners, facilitating the procurement of recycled materials and components. The BMW iX1 wheels are expected to contain 70% of recycled aluminum. Currently, the BMW Group uses nearly 30% of recycled and reused materials in its vehicle production on average, with a goal of progressively raising that number to 50% by 2030.

NIO Circular Car Lab — Building a Circular Business Model Fully Covering the Value Chain

NIO Circular Car Lab plans the recycling of scrapped vehicles with consideration of multiple aspects including design, dismantling, usage, and recycling, exploring "car-to-car" full value-chain recycling technologies to build a complete, closed-loop circular business model. NIO cooperates with vehicle dismantling enterprises including Yucheng Co. and Yuan Planet, utilizing technological and model innovations for precise dismantling and sorting. The sorted parts are then transferred downstream for remelting and manufacturing, ultimately re-entering the new car manufacturing process. NIO has also signed memorandums of cooperation with Lizhong Group and Shuai Yichi New Materials Group regarding vehicle dismantling, leveraging the capabilities and expertise of the partners in material recycling and downstream component casting to create a "car-to-car" material recycling system that closes the loop across the entire industry chain, maximizing the economic benefits from scrapped vehicles. This also improves the utilization efficiency of materials and realizes the re-introduction of end-of-life vehicles to the manufacturing process from an industrial perspective. Currently, over 900 vehicles have undergone the "car-to-car" closed-loop recycling in batch, demonstrating that the recycling of vehicles holds significant potential. This project was recognized as one of the "Top 10 Low Carbon Application Scenarios" in Anhui Province in 2023, paving the way for subsequent explorations into the high-value utilization of electric vehicles throughout their lifecycle, fostering deeper understanding and closer cooperation, thereby driving high-quality development across the value chain for vehicle recycling and utilization.

Circular Economy Industrial Park — Close Upstream-Downstream Collaboration to Support Circular Industry Development

Starting in 2022, NIO has fully promoted localized supply, providing a great opportunity window for building a circular supply chain. According to the most suitable model, suppliers are brought in directly to complete a circular system in one step. To this end, NIO signed agreements with the Lu'an Municipal Government and its partners to build a circular industrial park. The construction began in 2022, and the production gradually started in 2024. Currently, the dismantling factories, remelting plants, and die-casting plants in the Lu'an park and surrounding areas have all been completed and put into operation, fully fulfilling the plan.

Centering on aluminum remelting, NIO took the Lu'an park as a carrier and introduced upstream dismantling and downstream aluminum die-casting partners. Molten aluminum is supplied directly to nearby die-casting partners. This model also incorporates a unified and efficient logistics center, creating a transparent supply chain that responds in real-time to inbound and outbound demands. The advantages of the circular park model are as follows:

1. Dismantling, remelting, and die-casting enterprises are situated adjacently, minimizing logistics costs to the greatest extent. Calculations indicate that the industrial park model can achieve an annual reduction in logistics costs of approximately RMB 100 million.
2. An industrial park centralizes the key elements required by the value chain (land, quota, energy, materials, warehousing, etc.), enabling the control, optimization of these elements, as well as supply chain empowerment from the source. By reducing the number of processes, providing direct supply of molten aluminum, and minimizing processing losses, the overall cost of the processing chain is further lowered.
3. By consolidating the supply chain within the same region, the stability risks associated with a dispersed supply chain are reduced.
4. The design and implementation experience of a single park can be replicated to facilitate rapid expansion of parks in other regions. At the same time, the park model creates a sense of aspirational, attracting more capable partners to join.

Figure 3.19 | NIO Car-to-Car Circular Model

Figure 3.20| Lu'an Municipal Government Signs Framework Cooperation Agreement With NIO

3.2 Persevere & Prevail

The best time to plant a tree was ten years ago; the second-best time is now.

Early preparation and continuous innovation are key for companies transitioning to a circular economy.

3.2.1 Breaking Innovation Barriers and Addressing Technological Challenges

Key Technologies for Dismantling and Classifying End-of-Life Vehicles

Currently, the dismantling of end-of-life vehicles still primarily relies on manual labor, which is both labor-intensive and inefficient. The development of automated dismantling equipment has lagged behind and has not yet achieved large-scale application, severely limiting efficiency. Furthermore, there are significant structural and material differences between brands and models, resulting in a lack of unified technical standards, which makes it difficult to standardize and scale the dismantling process.

In addition, vehicles contain various materials such as metals, plastics, rubber, and glass, making precise identification and classification a major challenge during the dismantling process. Current identification technologies are not mature enough to achieve efficient and accurate sorting, often resulting in downgraded usage after recycling, leading to significant loss of material value.

The costs associated with the fine dismantling, classification, and recycling of end-of-life vehicles are high, requiring the development and adoption of advanced technologies such as AI-powered dismantling robots, recognition systems, and TOMRA's fully automated sorting equipment to improve efficiency and accuracy of the dismantling and classification processes.

Figure 3.21 | TOMRA Sorting Equipment

Material Recycling and Technology Standardization

Since recycling sources are diverse and vary widely in material types and classification methods, the standards for recycling materials are not uniform. For example, there are over 20 kinds of aluminum alloys, such as die-cast aluminum and deformed aluminum, adding complexity to material identification during vehicle recycling. Additionally, a large amount of non-separable impurities like steel and non-metals significantly increases the complexity of recycling. The consistency and stability of recycled materials cannot be guaranteed, making the application of these materials difficult. Establishing a stringent quality control system to ensure the reliability of recycled materials is therefore critical. Furthermore, recycled materials often suffer performance degradation compared with primary materials. Improving the performance of recycled materials to meet application demands remains an important technical challenge.

The German International Cooperation Organization (GIZ) has initiated a project in collaboration with Covestro, NIO, Volkswagen, GEM, and TÜV Rheinland Greater China to launch the *Closed-Loop Pathway for High-Value Plastics From End-of-Like Vehicle* in China, a project exploring processes for plastics from end-of-life vehicles, establishing a material tracking system for post-consumer recycled plastics, and creating transparent verification methods, so as to assist in the development of national and industry standards in China, such as guidelines for dismantling vehicles and quality certification standards for recycled plastics.

Figure 3.22 | Group Photo at the Launching Ceremony of the *Closed-Loop Pathway for High-Value Plastics From End-of-Life Vehicle in China*

Transparent Traceability Throughout the Product Lifecycle

The "Car-to-Car" closed-loop recycling model is long-term and involves complex processes. In addition to raw material procurement, parts production, vehicle manufacturing, and sales, it requires comprehensive data collection on vehicle usage, maintenance, and recycling. Each process contains a large amount of data, and effectively collecting, integrating, managing, and storing this data presents significant challenges.

Additionally, differences in data formats across stages and systems create difficulties in integrating and sharing data. Establishing unified data interface specifications and standardized data formats is essential to ensure interoperability and efficient data flow between systems.

3.2.2 Perfecting the Policy System and Strengthening Regional Coordination

In the process of promoting the circular economy, countries face numerous challenges regarding policy coordination and standardization, placing higher demands on the formulation of policies and standards.

Table 3.1 | Challenges and Solutions in Policy Coordination and Standardization

Challenges	路径
Reuse Product Application, Certification, and Tracking System Shortcomings	• Accelerating the establishment of standard systems: Deep governance, intelligentization, and precision management in the recycling process, defining clear technical standards for resource recycling and quality evaluation, improving market confidence. • Promoting full life cycle management: Using materials, production, manufacturing, recycling, and environmental designs based on a unified carbon footprint system. • Building data-sharing platforms: Protecting business confidentiality and personal privacy, while utilizing technologies such as blockchain to enable transparent and credible product application and certification data sharing.
Policy Diversification & Regional Cooperation Deficiencies	• Building circular economy policy frameworks: Implementing integrated policies across the full life cycle of products, and ensuring clear responsibility distribution to avoid policy overlaps. • Building cross-regional cooperation mechanisms: Promoting cooperation between rural and urban areas in waste management, setting up systems for waste resource sharing, and balancing resources and energy allocation. • International cooperation: Future development should continue to strengthen smart networking, carbon emission management, and technical standards, avoiding inconsistencies in international market structures.
Imperfect Circular Market Mechanism	• Perfecting economic stimulus mechanisms: Using tax benefits, green procurement, and green finance policies to reduce the cost of raw materials, and exploring the transformation of environmental benefits into economic returns. • Promoting industrial chain collaboration and innovation: Encouraging the establishment of industrial alliances for enterprises to explore new materials and applications, and the government providing specialized support in research and demonstration projects.

3.2.3 Popularizing Circular Economy Concepts and Establishing Consumer Recognition

Consumer Advocacy

In industries such as electronics, textiles, fast-moving consumer goods, and packaging, circular materials have been widely applied, with many luxury brands increasingly adopting sustainable practices and promoting circular concepts to enhance their premium image. However, in the automotive industry, which demands higher safety and reliability standards, circular materials are still gradually gaining consumer acceptance. Bridging the gap between consumers and circular vehicles can help them understand that the positive social impact of their choices is an important avenue for promoting circular consumption.

For example, promoting circular automotive products requires clear communication of their technical principles and environmental value, transforming consumers' perceptions of circular vehicles from merely "more eco-friendly" or "more energy-efficient" into tangible benefits. This could involve asking questions like "How much resource savings can a circular car's achieve over its lifecycle?" or "How does the closed-loop recycling system operate?" which can help turn circular vehicles from an abstract concept into practical, everyday choices.

Enhancing Consumer Recognition

Traditional vehicles, whether fuel-powered or electric, serve not only as transportation tools but also as a symbol of taste, identity, and status. However, circular vehicles currently lack this culture and emotional connection, leading to a natural distance from consumers. Breaking this barrier requires positioning circular vehicles as meaningful products, associating them with trends and social responsibility, thereby making circular vehicles both environmentally friendly and fashionable. Moreover, integrating automotive products with everyday consumer goods is also essential for enhancing consumer engagement. For circular vehicles, providing convenient and reliable after-sales support can further alleviate consumers' concerns and boost their confidence in choosing circular products.

Figure 3.23 | NIO Life's Original Fashion Brand With Sustainable Visions

Figure 3.24 | NIO Life Won Design Awards

Government-Enterprise Collaboration to Promote Circular Consumption

Promoting circular vehicles requires an ecosystem rather than just relying on individual enterprises. Under the sustainable development agenda, the government-enterprise collaborative model has become a key mechanism for fostering circular consumption. The government can lower barriers through policy incentives such as tax breaks and extended producer responsibility systems, while enterprises can enhance resource utilization efficiency through technological innovation and business model optimization. Research shows that government-enterprise cooperation can increase the recycling rate of urban waste by more than 50% and significantly enhance consumer acceptance of recycled materials[37]. Government measures such as purchase subsidies and tax incentives can reduce consumer costs and increase exposure to circular vehicles. A support system jointly built by government and enterprises can help establish consumer trust in circular vehicles, linking personal choices to social responsibility and promoting a transformative shift in consumption concepts.


From Zero to Infinity
The Journey Continues

From Zero to Infinity, the Journey Continues

As a vital driver of the green economy, circular vehicles not only demonstrate great potential in energy conservation, emissions reduction, and resource recycling, but also open up a new pathway for industrial upgrading, technological innovation, and the building of an ecological civilization. There is no doubt that this is the right direction. As with other business trends, the earlier a company plans for and participates in the development of circular vehicles, the greater their competitive advantage and the stronger their brand positioning in this new era of circularity.

This Blue book explores the imperative of automotive circularity from the perspectives of policy guidance, industrial development, and environmental benefits.

It provides numerous case studies highlighting the key technologies and innovative practices that enable circular vehicles to progress from zero to infinity, from adopting sustainable design and advanced materials in manufacturing, to leveraging intelligent and digital technologies for recycling and traceability, to integrating green manufacturing and green energy. These examples from industry pioneers are intended to inspire and inform.

However, at the current stage, enterprises will inevitably face various challenges such as navigating policies and regulations, advancing technological innovation, and cultivating consumer acceptance. To address these, we have also provided possible solutions and visions: harnessing digital and intelligent innovation, improving the circular policy system, and promoting sustainable consumption concepts. These forces can accelerate the realization of a genuine “vehicle-to-vehicle” cycle, which not only promises new growth for the future economy, but also offers a pathway for the decarbonization of the entire industrial chain.

At this critical juncture of economic transformation, we must move beyond the linear economic model of “exploit-use-discard” and create new possibilities for a circular “X.” When each “X” can achieve its own cycle of “0,” each tiny “0” can contribute to a larger cycle in the entire industry, converging into an infinite “∞.” Circular vehicles represent precisely such a super lever “X” that uses the micro-cycle of a single vehicle to unlock resource regeneration across society and to accelerate the global transition towards a “zero waste” economy.

From zero to infinity, the journey continues.

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