Shaping the Value Chain: Collaboration and Innovation in the Secondary Aluminum Industry

2025.11

About RMI

Rocky Mountain Institute (RMI) is a market-based, independent organization of experts established in 1982. RMI is committed to advancing the global energy transition through economically viable, market-oriented solutions for a prosperous, resilient, and clean low-carbon future. RMI has been working closely with organizations, policy makers. research institutions, entrepreneurs and cross-sector partners to drive strategic investments that scale deployment of clean energy solutions, reduce energy waste, and expand accessibility to affordable clean energy. While ensuring energy security and economic benefits, RMl partners with stakeholders to create a sustainable, brighter vision. RMl's research and practices have spanned over 50 countries and regions worldwide.

About CMRA

The China Nonferrous Metals Industry Association Recycling Metal Branch (CMRA) was established in May 2002 and is affiliated with the China Nonferrous Metals Industry Association. It is a national social organization voluntarily formed by enterprises, research institutions, industry bodies, and other organizations engaged in production, research, design, application, equipment manufacturing, and trade within China's recycled nonferrous metals industry. CMRA was approved by the former State Economic and Trade Commission and the Ministry of Civil Affairs. The organization currently has more than 500 member companies and maintains close ties with over 200 key overseas enterprises. CMRA is committed to serving government, industry, and enterprises, placing strong emphasis on member engagement and industry development. It promotes industrial progress as well as standardized and scaled development, advances international cooperation and resource security, and actively participates in national industrial strategy planning and policy formulation. CMRA organizes the International Forum and Exhibition on Recycled Metals on an annual basis, which has become one of the most influential global events in the recycled nonferrous metals industry.

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Citations

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Introduction

Global climate governance and the low-carbon transition are accelerating. China is entering a critical window for climate action. As the 15th Five-Year Plan approaches, its policy direction and industrial planning will profoundly shape the country's low-carbon development pathway over the next decade. The Plan explicitly calls for accelerating the comprehensive green transformation of economic and social development—covering not only the energy mix, but also production methods, consumption patterns, and other dimensions—signaling a broad and systemic transformation. Within this process, waste circularity has become a key driver of green transition. At the same time, China has submitted its 2035 Nationally Determined Contribution (NDC) targets to the United Nations, for the first time committing to absolute emission reductions across all economic sectors and all greenhouse gases (GHGs). This marks a major shift in China's emissions governance—from intensity-based targets to total emissions control—and places higher demands on industrial decarbonization pathways.

Against this backdrop, the secondary aluminum industry is entering an unprecedented window of strategic opportunity. It is not only a key pathway for deep emissions reductions in the aluminum sector—directly supporting China's total emissions control targets—but also a representative example of the circular economy and efficient resource utilization. As such, it has become an important driver of the green transformation of the economy and society and is poised to unlock greater growth potential in this process. In recent years, China's secondary aluminum industry has developed rapidly, with policy targets steadily increasing. The 14th Five-Year Plan for Circular Economy Development sets a target of 11.5 million tons of secondary aluminum production by the end of the Plan period. By 2024, output had already approached this target, reaching 10.55 million tons. In March this year, the Ministry of Industry and Information Technology issued the Implementation Plan for the High-Quality Development of the Aluminum Industry (2025–2027), further raising the target to over 15 million tons by 2027. Going forward, policy is expected to continue strengthening the high-quality development of the secondary aluminum industry, driving scale expansion, technological innovation, and green low-carbon transition, and laying the foundation for sustainable industry development. Looking ahead, rising demand for low-carbon materials from downstream sectors—including automotive, construction, and computers, communications, and consumer electronics (3C)—will serve as a strong driver of growth in the secondary aluminum industry.

The technical and economic viability of the Secondary Aluminum industry has been demonstrated through its long-term market practice. The industrial model for this industry has undergone continuous optimization, leading to a steady expansion of industry capacity, accelerated extension of the industrial chain, and continuous progress in technological equipment and product innovation. The industry has reached a critical juncture in its development. On one hand, demand for aluminum continues to grow. Given the constrained electrolytic aluminum capacity, there has been a significant increase in demand for Secondary Aluminum to replace primary aluminum, and this demand is shifting toward high-end applications. On the other hand, China is poised to enter a phase of concentrated release of scrap aluminum, presenting enormous potential for raw material supply. This creates both the conditions and necessity for the industry to break away from traditional paths and explore new models, particularly in areas where technological implementation is challenging and economic viability is uncertain. For enterprises, this facilitates the achievement of low-carbon product value and the seizure of market opportunities; furthermore, it represents a crucial opportunity to drive overall emissions reduction and enhance the industry's image.

However, to achieve this goal, the secondary aluminum industry still faces three core challenges. First, insufficient coordination among raw material supply, capacity layout, and downstream demand places midstream producers under dual pressure from both supply and demand, squeezing profit margins and constraining technological upgrading. Second, further progress is needed in technology, equipment, and product structure, including improvements in sorting and smelting equipment, pre-treatment and process integration capabilities, and the development of high-performance products. Third, the standards framework and certification mechanisms urgently need to be improved, requiring faster updates and implementation of domestic standards, as well as promoting alignment and mutual recognition with international standards.

Notably, new approaches and practices have begun to emerge within the industry. These include: (1) achieving end-to-end coordination across material processing, design and production, and recycling through upstream–downstream collaboration, thereby building a green, closed-loop supply chain that addresses raw material and technological constraints; (2) increasing the share of direct molten aluminum supply and promoting deeper end-user participation in alloy research and development; and (3) advancing front-end refined recycling with grade retention. These models not only provide valuable insights for industry innovation, but also help address the three key challenges to some extent, offering practical support for the secondary aluminum industry to move beyond traditional development paths and achieve high-quality development.

This report begins by reviewing the importance and development achievements of the secondary aluminum industry, in order to provide readers with an overall understanding of the sector. On this basis, it analyzes the key challenges to achieving breakthrough development, and summarizes and evaluates leading collaborative models and best practices. It further explores how these models can support enterprise growth while enhancing the industry's decarbonization impact. The report aims to inform policymaking, industry planning, and business practice, and to support the transition of the secondary aluminum industry toward high-quality, low-carbon, and sustainable development.

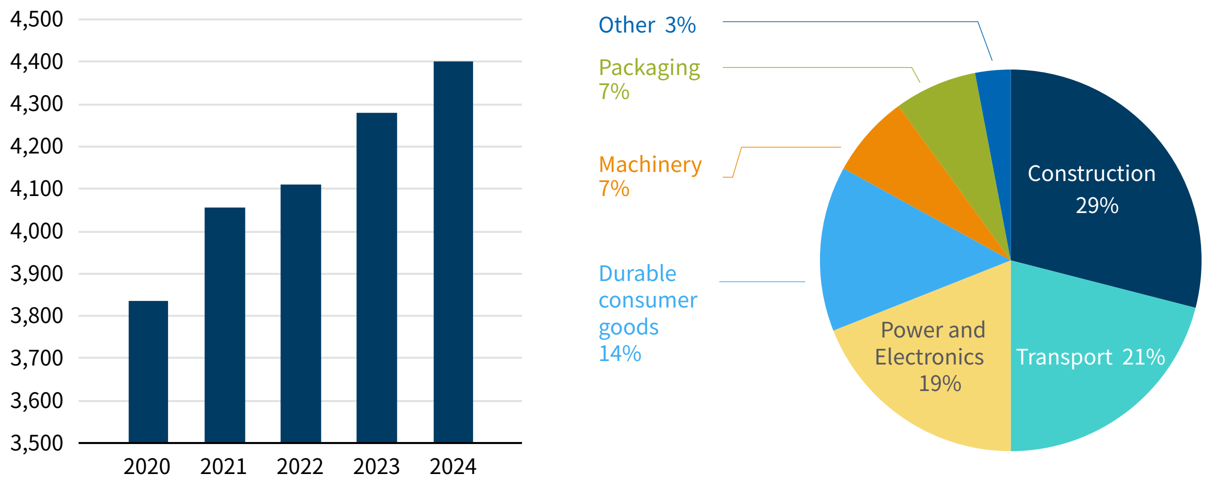
1. Large-Scale Application of Secondary Aluminum: A Key Pathway to Decarbonization in the Aluminum Industry

1.1 Application Expansion and the Low-Carbon Transition Drive Sustained Growth in Aluminum Demand

Aluminum is a strategically important metal widely used across key sectors, including structural materials in construction, lightweight components in the automotive industry, durable alloys in aerospace, conductive materials in telecommunications, and food and beverage packaging in daily life. It plays an indispensable role in economic transformation and industrial upgrading. At the same time, aluminum is one of the most promising metals for future applications. As lightweighting and green, low-carbon transition trends gain momentum globally, aluminum materials are expected to support the high-quality development of related manufacturing sectors.

From 2020 to 2024, China's primary aluminum consumption increased steadily from 38.35 million tons to 45.18 million tons, representing a compound annual growth rate (CAGR) of 4.18%. By 2030, total aluminum consumption is expected to remain at around 53 million tons, with primary aluminum consumption reaching nearly 45 million tons—about 5% higher than in 2023. By sector, construction accounts for the largest share of aluminum consumption, reaching 23% in 2024 (12.05 million tons). In terms of growth, demand from the transportation sector is expanding rapidly and continues to rise, with a CAGR of 11.3% from 2022 to 2024. For example, in the automotive sector, average aluminum use per new energy vehicle (NEV) in China was about 230 kg in 2024. According to the Energy-Saving and New Energy Vehicle Technology Roadmap, this figure is expected to reach 250 kg by 2025 and 350 kg by 2030. As China's urbanization slows, aluminum demand is expected to gradually shift toward the transportation sector. Meanwhile, the packaging sector is also growing at over 4%. Strong demand growth from new energy vehicles, solar PV, 3C electronics, and the power sector is further driving expanded use of aluminum.

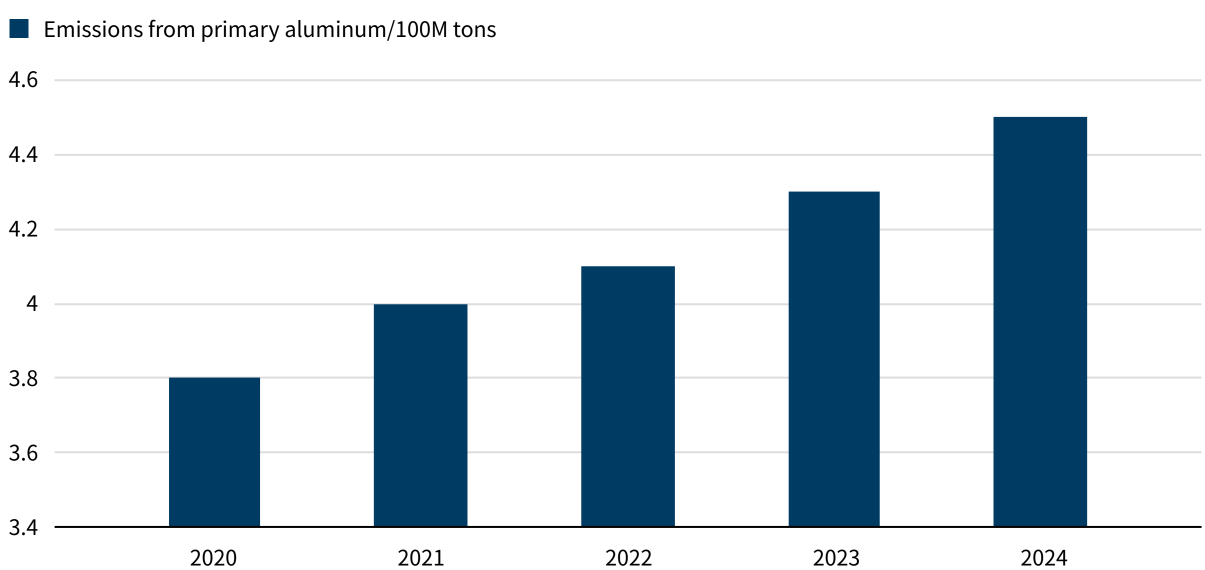
Exhibit 1 **Primary Aluminum Consumption in China (2020–2024) and Aluminum Consumption by Sector (2024)**



Source: CNIA

As aluminum applications continue to expand and demand rises, and as downstream manufacturing accelerates its green and low-carbon transition, the aluminum industry faces new and more stringent requirements for emissions reduction. In 2024, thermal power accounted for 73.8% of the energy mix in China's primary aluminum smelting sector. As output increases, carbon emissions from the production process have continued to rise, growing from 380 million tons in 2020 to 450 million tons in 2024. It is projected that China's primary aluminum output may approach the production cap of around 45 million tons before 2030. As a result, decarbonization of the aluminum industry is critical to the green development of emerging sectors such as new energy and electric vehicles. Expanding the rapid adoption and wider use of secondary aluminum is therefore essential.

Exhibit 2 **CO_2 Emissions from Primary Aluminum (2020–2024)**

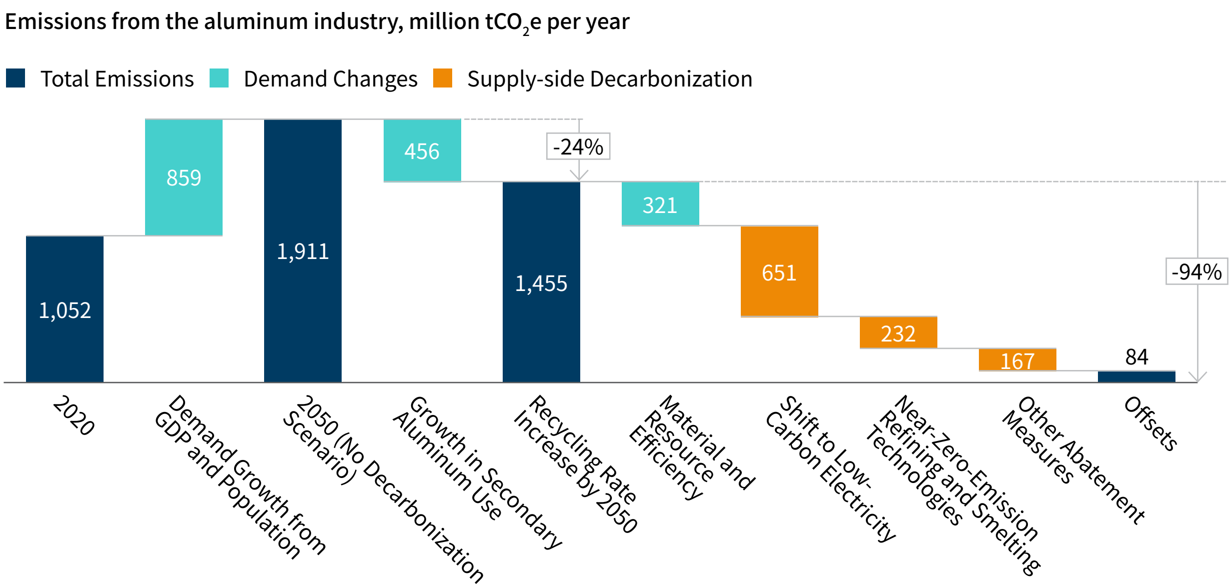


Source: CNIA

1.2 Secondary Aluminum: A Key Pathway for the Green Transition of the Aluminum

A broad consensus has emerged globally on how the aluminum industry can achieve carbon neutrality. The core strategies focus on three areas: decarbonizing the power supply, reducing direct greenhouse gas emissions (through the use of green hydrogen, carbon capture, utilization and storage (CCUS), and inert anodes), and scaling up recycling. To achieve net-zero emissions by 2050, it is estimated that approximately 456 million tons of emissions reductions (24%) will come from increased use of secondary aluminum. In addition, the use of low-carbon electricity and the deployment of near-zero-emission refining and smelting technologies could contribute approximately 651 million tons and 232 million tons of emissions reductions, respectively. In China, advancing the green transition of the aluminum industry is of strategic importance for achieving substantial emissions reductions. This requires a comprehensive three-pronged approach encompassing a deep transformation of the power mix, breakthroughs in anode technologies, and significant improvements in recycling levels.

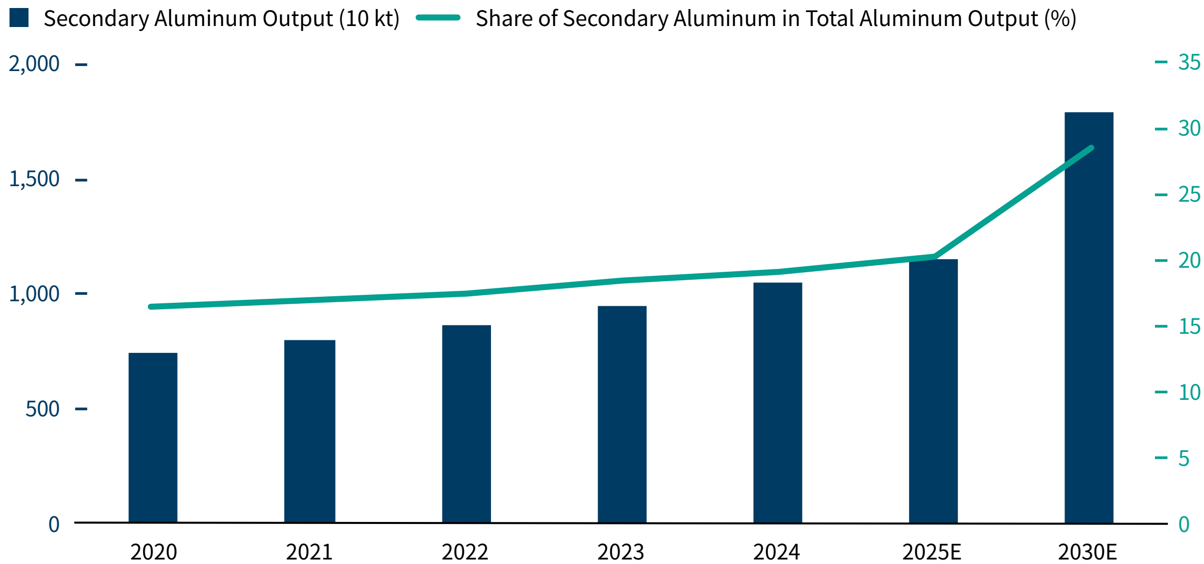
Exhibit 3 **Pathways to Achieving Net-Zero Emissions in the Global Aluminum Industry by 2050**



Source: Mission Possible Partnership (MPP)

Secondary aluminum has a relatively short production process, with natural gas as the main energy source and scrap aluminum as the primary feedstock. Its products are widely used in key sectors of the national economy, including automotive, construction, and electrical and electronics. From 2020 to 2024, China's secondary aluminum production reduced carbon dioxide emissions by 570 million tons compared with primary aluminum production based on coal-fired power. The share of secondary aluminum in total aluminum production has continued to rise, increasing from 16.8% to 19.34%. By 2030, this share is expected to reach 28.6%, a record high. Primary aluminum producers and aluminum processors are expanding their recycling operations, while downstream manufacturing sectors are placing increasing emphasis on low-carbon and green product attributes. In key sectors, secondary aluminum accounts for over 60% of total aluminum use in internal combustion engine vehicles, around 20% in new energy vehicles, more than 40% in aluminum beverage cans, and nearly 15% in architectural and decorative panels.

Exhibit 4 **Secondary Aluminum Output and Share of Total Aluminum Output (2020–2024, with Projections for 2025 and 2030)**



Source: CMRA

2. From Resources to Markets: Structure and Key Challenges of the Secondary Aluminum Value Chain

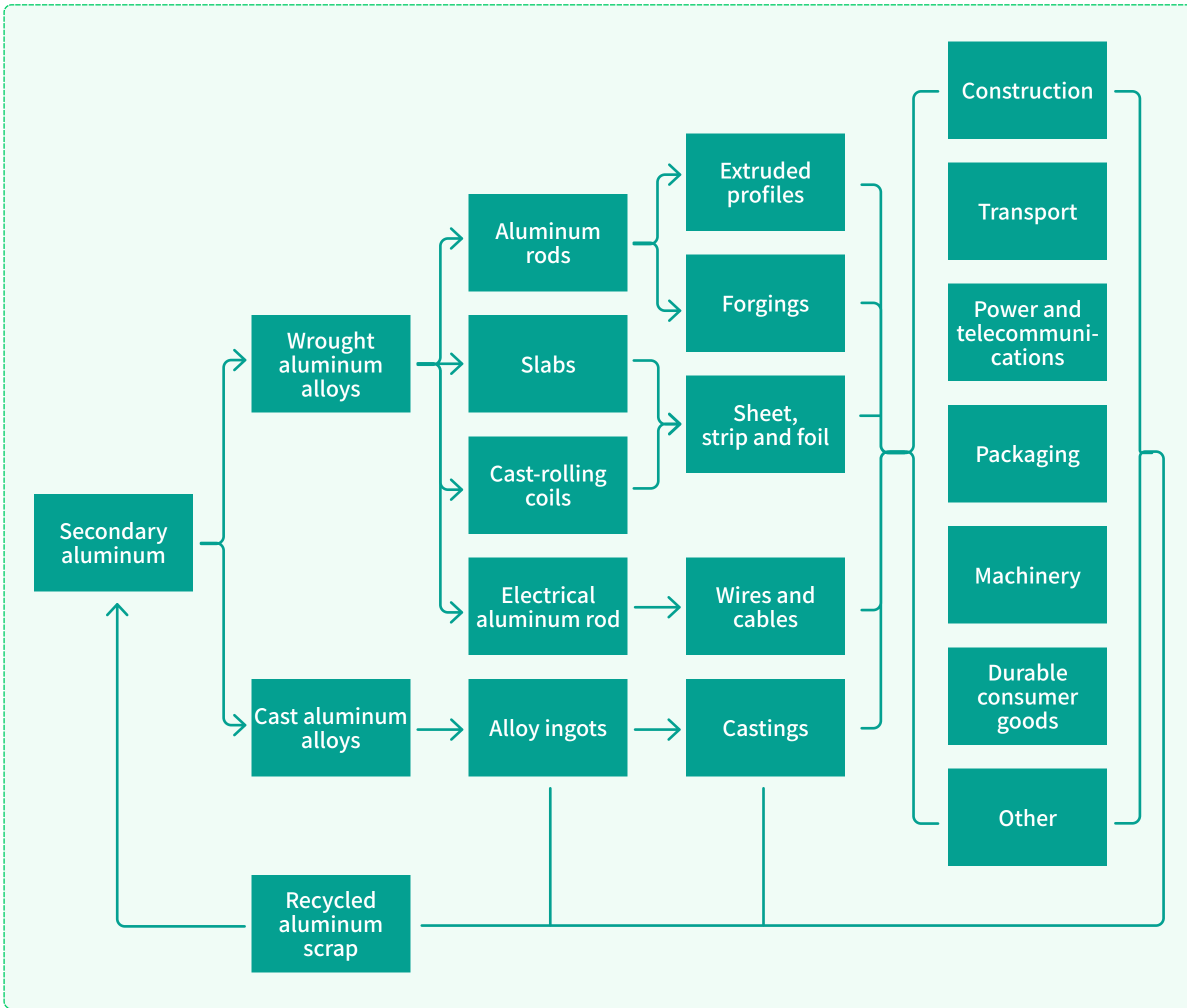
As noted above, as a key enabler of the aluminum sector's green transition, the secondary aluminum industry has become an important pathway for advancing resource recycling and achieving carbon neutrality. It demonstrates clear advantages in alleviating pressure on primary mineral resources and reducing carbon emissions across the entire value chain.

The first part of this chapter examines the upstream, midstream, and downstream segments of the secondary aluminum value chain, outlining their key characteristics and features. In the context of the aluminum sector's decarbonization pathways, it identifies the critical issues that require urgent attention in each segment during the green transition, providing a comprehensive view of the industry. The second part focuses on the key bottlenecks and challenges currently facing the secondary aluminum industry, laying the foundation for subsequent case studies and further discussion.

2.1 Structure and Operational Dynamics of the Secondary Aluminum Value Chain

The secondary aluminum value chain consists of three main segments. The upstream segment is supported by a diversified recycling system for scrap aluminum, covering areas such as building demolition, end-of-life vehicles, power infrastructure upgrades, packaging recycling, and durable goods recovery. The midstream segment centers on the resource utilization of recycled aluminum, where scrap is converted into standardized products such as aluminum alloy ingots, molten aluminum, and aluminum rods through processes including pretreatment, advanced sorting, smelting, and alloying. Downstream, secondary aluminum alloys are used across a wide range of sectors, including automotive, construction, packaging, and consumer goods, with a particular focus on transportation and construction. In the transportation sector, they are widely used in key components such as engine blocks, wheel hubs, and chassis structures. In construction, the focus is on developing green building materials such as prefabricated components.

Exhibit 5 **Composition of the Secondary Aluminum Value Chian**

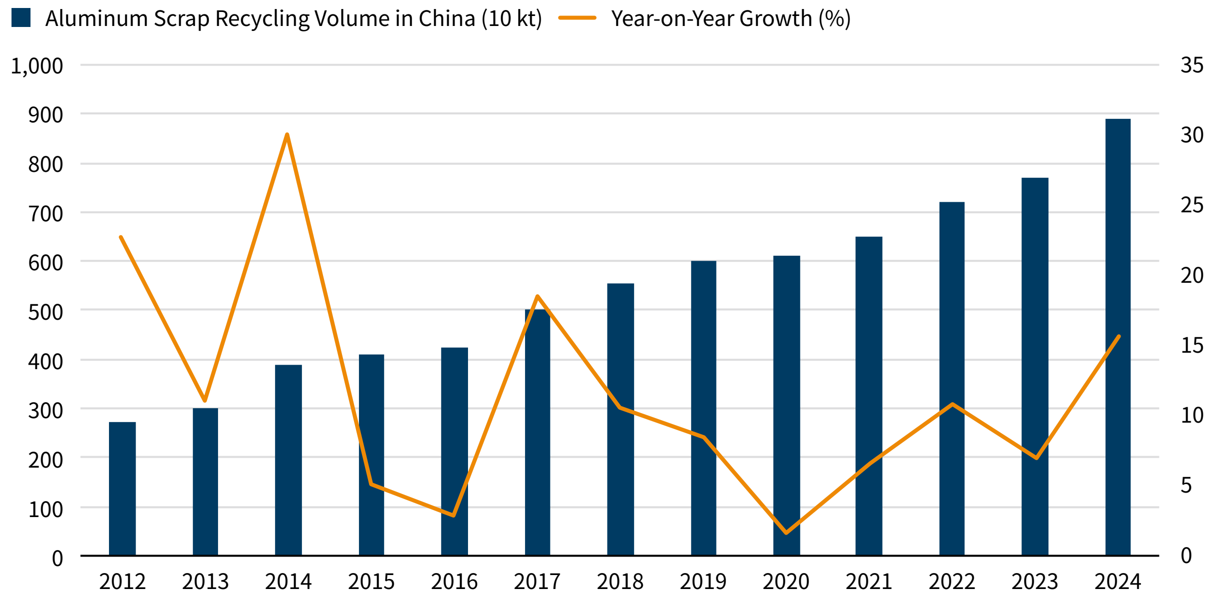


Source: CMRA

(1) Upstream: Aluminum Scrap Recycling System

China's aluminum scrap supply is characterized by a structure dominated by domestic sources, with imports as an important supplement. Both new scrap and old scrap are developing in parallel. New scrap refers to process scrap generated during the production of aluminum and aluminum alloy products, accounting for about 17% of the total. Old scrap refers to aluminum scrap from end-of-life products such as buildings, vehicles, and packaging, accounting for around 83%. To further strengthen the role of the secondary aluminum industry in decarbonizing the overall aluminum sector, efforts are needed in two key areas. First, improving the grade-preserving utilization of aluminum scrap. Second, accelerating the development of a comprehensive recycling network covering the full lifecycle of end-use products, in order to expand the collection and use of post-consumer scrap and support the central role of secondary aluminum in achieving deep emissions reductions.

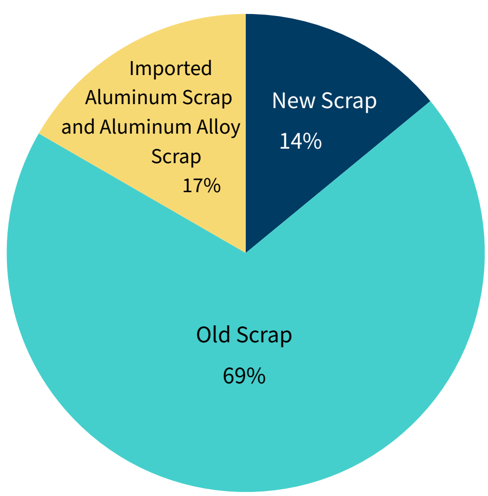
Exhibit 6 China's Aluminum Scrap Recycling Volume and Growth (2012–2024)



Source: CMRA

From 2012 to 2024, China's aluminum scrap recycling volume grew rapidly, with a compound annual growth rate (CAGR) of 10.38% and cumulative recycling reaching 71.57 million tons. In 2024, recycling volume reached 8.9 million tons, up 14.1% year-on-year, including about 1.5 million tons of new scrap and 7.4 million tons of old scrap. Aluminum scrap accounts for 83% of total supply. By 2030, domestic recycling volume is projected to reach 15.13 million tons, 70% higher than in 2024.

Exhibit 7 Share of Aluminum Scrap by Type (2024)



Source: CMRA

- **Domestic New Scrap**

New scrap is mainly generated during aluminum processing and precision die casting processes, including machining scrap, casting scrap, and other process scrap, as well as materials discarded due to composition deviations or substandard performance. It is primarily sourced from aluminum sheet, strip and foil producers, profile extrusion plants, aluminum rod processors, and precision die casting workshops. Given the large scale of China's aluminum processing industry, annual new scrap generation can reach tens of millions of tons. Approximately 80% of this new scrap is recycled internally through in-house smelting facilities[i], while the remaining 20% enters the market through specialized recycling companies. Due to its traceable sources and well-controlled supply chains, this type of scrap is generally of high quality, with well-defined composition and high purity. In addition, some processing enterprises recover scrap from downstream users through reverse collection, forming a closed-loop recycling system.

Globally, there is growing debate within the aluminum industry over whether emissions responsibility should be allocated to pre-consumer scrap, and no broad consensus has yet been reached. Common methods for calculating the embedded carbon emissions of pre-consumer scrap in product carbon footprint accounting include the cut-off method and the co-product allocation method. Under the cut-off method, aluminum producers generating pre-consumer scrap are required to allocate all emissions to their main products, meaning that scrap generated during the production process is assigned zero embedded emissions. When the scrap is subsequently recycled, users likewise treat it as having zero embedded emissions in their product carbon footprint calculations. By contrast, the allocation method assigns a share of emissions from primary aluminum production to pre-consumer scrap based on mass. This approach involves more complex accounting procedures and requires traceability of the scrap. It should be noted that, regardless of the method used, the risk of carbon leakage can be avoided as long as consistent accounting is applied between the generation and use of scrap.[ii]

Within the broader framework of low-carbon development in the aluminum industry, the utilization of new scrap should focus on both at-source utilization and downstream recycling. On the one hand, this can be achieved by enhancing production efficiency and process capabilities to maximize in-plant utilization of new scrap. On the other hand, efforts should be made to further optimize existing recycling systems and improve advanced sorting capabilities, in order to ensure that high-quality new scrap is utilized in a grade-preserving manner.

- **Domestic Old Scrap**

Old scrap is mainly sourced from end-of-life products such as vehicles, buildings, and packaging. After being processed at specialized recycling and distribution centers, the scrap then enters the secondary aluminum production system. Compared with new scrap, the recycling network for old scrap has a more decentralized and market-driven structure, and its resource utilization is highly dependent on the maturity

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i Different methodologies and standards use different approaches to distinguish between internal scrap and new scrap. In its *Aluminum Product Carbon Footprint Accounting and Reporting Methodology - Based on International Practices*, RMI recommends defining new scrap as scrap generated during post-casting processing, while classifying scrap generated during the casting stage as internal scrap. This approach helps ensure the comparability of scrap shares across aluminum producers with different levels of vertical integration.

ii RMI's *Aluminum Product Carbon Footprint Accounting and Reporting Methodology - Based on International Practices* recommends a dual reporting approach for the embedded carbon emissions of pre-consumer scrap. Reporting entities should calculate and report carbon footprint data using the cut-off method, and, where feasible, also report results based on the allocation method. Alternatively, entities may use background data provided by the International Aluminum Institute (IAI) in place of direct calculation, to accommodate different levels of traceability and disclosure requirements.

of waste collection systems. Ongoing policy support and technological innovation are gradually promoting large-scale and high-value recycling of old scrap.

In terms of market structure, the old scrap recycling system consists of three tiers: informal collection networks (primary market), regional distribution hubs (secondary market), and specialized sorting facilities (tertiary market). Each tier has distinct roles, with some internal specialization and overlap, forming an integrated recycling network. In practice, however, overly complex circulation chains can reduce the efficiency of information flows, increase material losses, and raise recycling costs.

- Informal collection networks (primary market): This segment relies primarily on mobile collection, using community-based service models to collect dispersed scrap materials. Typical examples include the recycling of aluminum products from residential settings, such as discarded doors, windows, and household appliances. Pricing is based on a combination of unit-based and weight-based methods, and is typically 10%–15% lower than prices in centralized scrap markets.

- Regional distribution hubs (secondary market): Individual collectors transport dispersed aluminum scrap to regional collection centers, where it undergoes preliminary sorting and sorting by category. For example, thermal break aluminum profiles—a typical type of construction scrap—when unsorted, typically trade at around 78%–78.5% of the prevailing aluminum ingot spot price. This price includes basic material sorting costs.

- Specialized sorting facilities (tertiary market): Certain types of scrap are transferred from regional hubs to specialized dismantling centers, where material purity is improved through physical sorting and chemical composition analysis. Experimental data show that thermal break aluminum profiles processed through the tertiary market achieve premium pricing due to enhanced material purity. End-market prices can exceed 80% of the aluminum ingot benchmark price, representing an increase of 1.5–2 percentage points compared with secondary market prices. Together, these tiers form a multi-tiered network in the old scrap market.

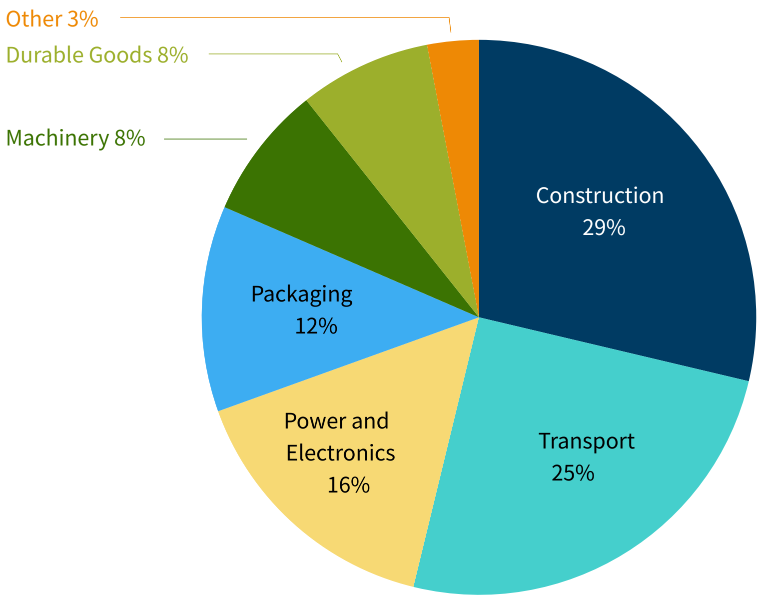
Old scrap is mainly sourced from the construction, transport, and consumer sectors. In the near to medium term, the renovation and replacement of building materials, along with a wave of vehicle and equipment retirements, are expected to be the primary drivers of growth in old scrap supply. On the one hand, recyclers should make strategic investments in these sectors to innovate and improve recycling systems for old scrap, in order to prepare for future increases in scrap supply and enhance recycling efficiency. On the other hand, attention should also be paid to the risks of price volatility arising from over-reliance on a single industry.

Construction: Aluminum alloy doors and windows, as well as curtain wall systems from the renovation and upgrading of existing buildings, together with aluminum components such as overhead conductors and substation busbars from power infrastructure upgrades, form a stable strategic resource base within urban mining systems.

Transportation: This segment mainly comes from vehicles and rail transit equipment that have reached end-of-life under mandatory scrappage regulations. Their aluminum body components, engine parts, and wheel hub units have high recycling value, making them a key resource for mobile source emissions reduction strategies. As policies promoting equipment renewal and consumer goods replacement are further implemented, and technical standards for the dismantling of scrapped vehicles continue to improve, this segment is generating over 300,000 tons of additional scrap aluminum annually.

Post-consumer aluminum from the consumer sector: Includes casings of discarded household appliances, cookware and tableware, and packaging such as aluminum beverage cans, forming a diversified, multi-source supply of recycled feedstock.

Exhibit 8 **Primary Sources of Old Scrap (2024)**



Source: CMRA

Improving the recycling rate of old scrap is critical for enabling deep emissions reductions in the aluminum sector and ultimately achieving climate targets. According to the International Aluminum Institute (IAI), to meet the aluminum industry's 2050 climate goals—assuming continued growth in total aluminum production and a stable share of pre-consumer scrap—global use of post-consumer scrap would need to reach 68 million tons, more than three times the 2018 level. From a carbon accounting perspective, there is broad consensus within the industry that old scrap is considered to have zero embedded carbon emissions, as it has already completed its life cycle. Low-carbon aluminum brands developed by Hydro, such as CIRCAL and REDUXA, also explicitly disclose the share of post-consumer scrap in their products.

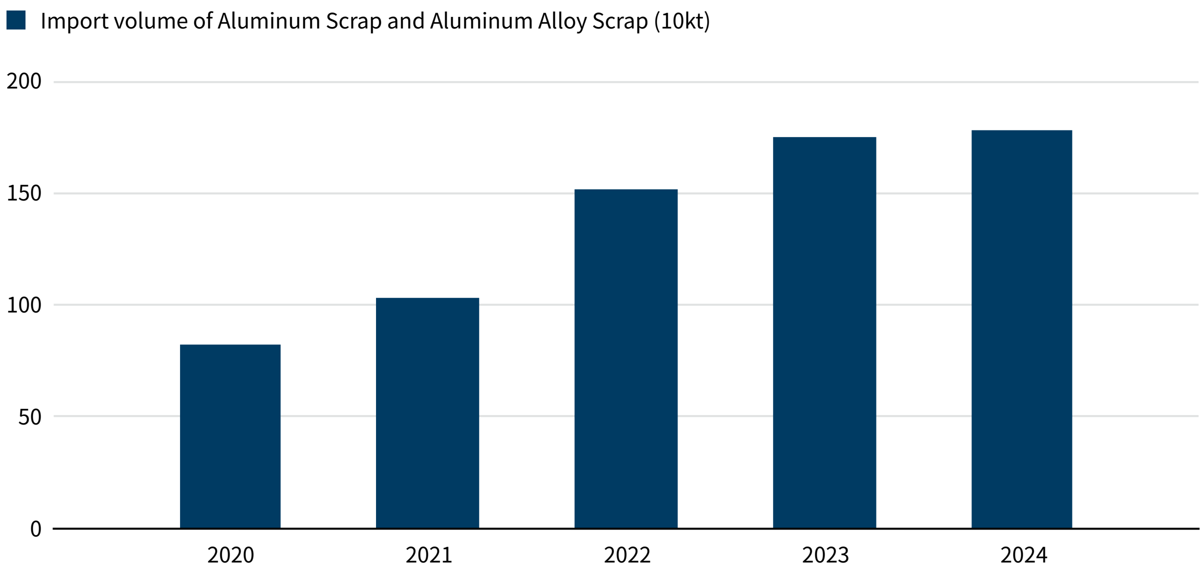
• Imported Aluminum Scrap and Aluminum Alloy Scrap

Following the issuance and subsequent revisions of import regulations for aluminum scrap and aluminum alloy scrap, along with the implementation of national standards for different categories of recycled aluminum scrap, China's imports increased from 820,000 tons in 2020 to 1.78 million tons in 2024, representing a compound annual growth rate (CAGR) of 21.38%. This reflects the full resumption of cross-border circular resource flows.

China's import sources for aluminum scrap and aluminum alloy scrap are relatively diversified, with no significant dependence on any single country. However, imports are concentrated in a few provinces. Driven by changes in overseas policies, Thailand surpassed Malaysia in 2024 to become China's largest source country, with imports reaching 298,200 tons and accounting for 16.74% of the total. Malaysia and Japan followed, accounting for 11.8% and 10.9%, respectively. Among importing provinces, Guangdong accounted for the largest share, with imports reaching 1.268 million tons in 2024, representing 71% of the national total, followed by Zhejiang Province at 18%.

As global attention to resource recycling and carbon emissions control continues to grow, and amid evolving trade policies, major regions are considering adjustments to their raw material export policies. The United States is promoting higher domestic recycling rates through legislation and tax incentives to reduce reliance on overseas processing. Europe's aluminum industry has proposed that the European Union impose tariffs of around 30% on scrap aluminum exports. Against this backdrop, the importance of strategies such as diversifying aluminum scrap import channels, expanding global sourcing strategies, and managing geopolitical risks will continue to increase.

Exhibit 9 **China's Imports of Aluminum Scrap and Aluminum Alloy Scrap (2020–2024)**



Source: China Customs

(2) Midstream: Secondary Aluminum Production and Primary Processing

China's secondary aluminum industry is characterized by strong regional clustering, with production capacity highly concentrated in East China, South China, and Central China. The combined capacity of these regions exceeds 20 million tons, accounting for more than 80% of the national total. Five provinces—Jiangsu, Guangdong, Henan, Shandong, and Anhui—have each formed capacity clusters of around 2 million tons, creating a multi-hub industrial structure. Meanwhile, western regions such as Xinjiang, Inner Mongolia, and Gansu are accelerating the development of secondary aluminum production bases, further optimizing the industry's geographic distribution. Building on existing industrial clusters, further efforts are needed to strengthen planning and policy guidance to develop efficient and coordinated regional recycling systems. This would help leverage economies of scale and shared infrastructure, while maximizing the low-carbon benefits of secondary aluminum and further improving the overall industry layout.

In terms of spatial distribution, the industry has shifted from coastal concentration to inland expansion. In the early stages, development was constrained by raw material supply distances, leading to a concentration of enterprises in coastal port areas. In recent years, however, the rise of inland manufacturing sectors such as automotive and electronics has led to the formation of new industrial clusters around cities like Chongqing and Wuhan, creating regional networks integrating raw material supply, processing, and application. Despite continued growth in the number of enterprises, industry concentration remains low, with capacity CR10 below 35%. As carbon constraints tighten and environmental standards continue to rise, combined with economies of scale, the competitive landscape is expected to improve gradually. Capacity is likely to concentrate more rapidly in enterprises with technological, managerial, and resource advantages, supporting the aluminum industry's low-carbon transition.

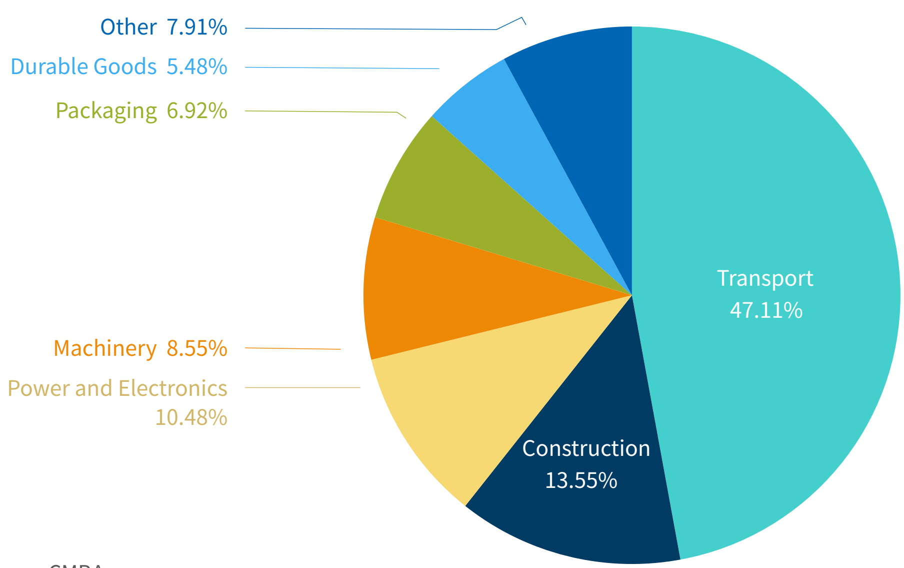
Semi-finished aluminum products are the main outputs of the midstream stage of secondary aluminum production. By form, they include aluminum alloy ingots, molten aluminum, and aluminum rods; by product type, they are categorized into casting aluminum alloys and wrought aluminum alloys. The product structure is dominated by die casting, with casting alloys accounting for about 60% of total output, while downstream processing plays a secondary role. Growth is mainly driven by increasing aluminum use in new energy vehicles (NEVs), where average aluminum content per vehicle is estimated to be about 40% higher than that of conventional fuel vehicles. In the aluminum processing sector, the share of secondary aluminum is also increasing. Driven by continued growth in aluminum demand and the policy-imposed cap on primary aluminum capacity, downstream processing enterprises—such as those producing aluminum rods, sheets, strips, and foil—are increasing the share of secondary aluminum in their feedstock.

However, the industry is facing intensifying intra-industry competition, as reflected in high product homogeneity, rising compliance costs, narrowing profit margins, and weak innovation momentum. In addition, on-site management still requires significant improvement, and average utilization rates remain well below the global level.

(3) Downstream: Key Application Sectors

Cast aluminum alloys account for more than 60% of secondary aluminum and are mainly used in transport, machinery, home appliances, and metal products. The automotive sector accounts for over 60% of demand for cast aluminum alloys and is expected to be a key growth driver, driven by lightweighting and low-carbon requirements. Wrought aluminum alloys are mainly used in construction, electrical and electronics, and home appliances, with solar PV frames emerging as a new growth area. The applications of secondary aluminum closely align with the main growth drivers of future aluminum demand. Data show that in downstream applications of secondary aluminum, the transport sector accounts for the largest share (47%), followed by machinery (8%), construction (14%), and electrical and electronics (11%).

Exhibit 10 **Downstream Applications of Secondary Aluminum**



Source: CMRA

- **Lightweight Applications in Transportation Equipment**

Secondary aluminum is widely used in both conventional fuel vehicles and new energy vehicles. In conventional vehicles, recycled aluminum alloys are extensively used in key components such as engine blocks, radiator supports, and wheel hubs, with average aluminum content per passenger vehicle reaching 140–160 kg. In new energy vehicles, despite the stringent material requirements of integrated die casting, the share of recycled aluminum is increasing from around 20% to as high as 70%. Its applications are expanding from wheel hubs and closure panels (doors, hoods, and tailgates) to structural body components. For example, a leading supplier has developed recycled aluminum wheels for BMW containing up to 70% recycled material.

In addition, secondary aluminum is widely used in motorcycles, where aluminum castings play a central role. Key applications include cylinder heads, engine blocks, shock absorbers, brakes, handlebar housings, and side covers.

- **Green Transition Applications in Construction**

The construction sector remains the largest consumer of aluminum, with structural applications accounting for over one-third of aluminum use in the sector. Secondary aluminum is mainly used in architectural aluminum profiles and aluminum sheets and strips used in construction. Aluminum profiles are primarily applied in curtain wall systems and door and window components, with recycled aluminum content in aluminum alloy doors and windows exceeding 15% per square meter in 2024. Aluminum sheets and strips are mainly used in building formwork, curtain walls, and aluminum panels. Among these, aluminum formwork systems—with over 300 reuse cycles—are increasingly replacing wooden formwork in prefabricated construction. Output of aluminum sheets and strips for architectural decoration reached 1.9 million tons, with the share of secondary aluminum rising to 14%.

Despite slower growth in demand for conventional curtain wall systems, aluminum profiles used in Building-Integrated Photovoltaics (BIPV) are opening up new applications for secondary aluminum, with demand growing at over 30% annually.

- **Material Upgrade Bottlenecks in Packaging**

Grade-preserving technologies are key to advancing the use of secondary aluminum in packaging. Due to the complex composition of aluminum scrap, high-quality recycled wrought aluminum scrap in the packaging sector is often downgraded into casting applications, resulting in value losses of over 30%. For example, China's beverage can market is large and growing rapidly, with recycling rates exceeding 98%. However, there remains a gap with international best practices in closed-loop recycling.

To improve closed-loop recycling, it is necessary to establish advanced sorting networks for aluminum scrap covering major cities, while also developing dedicated grade-preserving smelting lines.

- **Low-Carbon Transition in the Photovoltaic Industry**

The use of secondary aluminum in the photovoltaic industry effectively meets performance requirements such as mechanical strength and resistance to salt spray corrosion, enabling it to satisfy the 25-year lifespan requirements of coastal PV power plants while supporting deep decarbonization across the value chain. Leading companies have already established million-ton-scale secondary aluminum capacity. For example, Anhui Xinbo Aluminum's 200,000-ton secondary aluminum rod project has achieved a stable supply of solar panel frame materials, marking significant progress in closed-loop recycling within the photovoltaic value chain.

At present, the photovoltaic industry consumes a total of 5.04 million tons of aluminum, including 2.1 million tons used for aluminum alloy frames, 840,000 tons for cables, and 2.1 million tons for mounting structures. Integrating secondary aluminum into these key components offers significant potential for achieving deep emissions reductions.

Leading Global Practices in Downstream Applications of Secondary Aluminum

- **Non-Heat-Treatable Recycled Aluminum Alloys for Integrated Die Casting**

  In high-end manufacturing, non-heat-treatable aluminum alloy technology is emerging as a key advancement in materials science. Through precise composition design—such as optimizing the ratios of Si, Mg, and Cu—this material overcomes the performance limitations of conventional Al-Si-Mg alloys, achieving T6-level mechanical properties without solution treatment and aging. The main industrial bottleneck lies in the stringent requirements for trace impurities (Fe < 0.12%) in large, thin-walled die-cast components (wall thickness < 3 mm), which continue to drive reliance on primary aluminum.

  Lizhong Group has made a major breakthrough with its low-carbon recycled non-heat-treatable alloys. Its proprietary LDHM-02 series achieves tensile strength above 250 MPa and elongation above 10%, while increasing recycled aluminum content to over 50%. Notably, in Chery Automobile's full-size integrated chassis project, the alloy achieved 100% recycled aluminum content, overcoming key limitations of conventional non-heat-treatable alloys—such as narrow tolerance ranges for impurities (e.g., Fe and Zn), constraints on scrap selection during alloy preparation, and difficulties in incorporating higher recycled aluminum content.

- **Continued Expansion of Secondary Aluminum in Automotive Applications**

  The use of secondary aluminum in automotive applications is expanding rapidly, driven by both performance requirements and carbon reduction goals. Compared with traditional steel, aluminum has clear advantages in density, enabling weight reduction and improved energy efficiency. For fuel vehicles, every 100 kg reduction in body weight can lower fuel consumption by 0.5 liters per 100 km. For new energy vehicles (NEVs), the same reduction can increase driving range by 10–11% while reducing battery and operating costs by about 20%. The use of secondary aluminum in automotive components is increasing as it enables both lightweighting and carbon reduction.

  The rear body of Tesla's Cybertruck adopts an integrated die-cast recycled aluminum (AA6061-T6) structure, reducing weight by 40% compared with conventional steel structures and cutting carbon emissions by 2.3 tons per vehicle. LK Technology has developed a 12,000-ton die-casting machine capable of producing large-scale recycled aluminum components (1.8 m × 1.5 m, tolerance ±0.3 mm), used in the integrated battery chassis structure of the NIO ET9. CATL's Kirin 5.0 battery tray adopts a recycled aluminum honeycomb structure with a density of 1.8 g/cm^3. BYD's Blade battery casing uses 100% recycled aluminum, reducing primary aluminum consumption by 48 kg per system and lowering carbon footprint by 420 kg CO_2.

- **Innovative Secondary Aluminum Cable Technology**

In power transmission, the use of secondary aluminum is reshaping the industry landscape. Germany's Trimet and Nexans have jointly developed the RecAl® cable rod, which contains 90% recycled aluminum. According to life cycle assessment (LCA) results, its carbon footprint is reduced by 4.2 tons of CO_2e per ton of aluminum compared with primary aluminum. In 500 kV ultra-high-voltage cable applications, the material achieves conductivity of 61.5% IACS, with a bending radius exceeding 10D (where D is the cable diameter), with performance exceeding IEC 60287 standards.

This technological breakthrough offers three key strategic benefits. First, it improves energy efficiency, with secondary aluminum cables reducing transmission losses by 18% compared with copper cables. Second, it supports resource recycling, as each kilometer of cable consumes 4.2 tons of recycled aluminum, equivalent to recycling 120,000 aluminum cans. Third, it drives standard development, with Nexans initiating revisions to the EN 50182 standard for secondary aluminum cables. The material also maintains stable performance across a temperature range of −40°C to 90°C, making it particularly suitable for extreme environments such as offshore wind farms (95% RH humidity) and desert photovoltaic installations (70°C diurnal temperature variation), providing key material support for the global energy transition.

2.2 Barriers and Challenges in the Secondary Aluminum Industry

The secondary aluminum industry in China has grown rapidly in recent years, with expanding capacity, extended value chains, and continued progress in equipment application and product innovation. This growth has been driven by China's carbon peaking and carbon neutrality goals, resource recycling policies, and sustained market demand. However, as the industry enters a new stage of development, achieving low-carbon development and strengthening its role in supporting decarbonization of the broader aluminum sector still faces three key challenges: imbalances among raw materials, capacity, and demand; an urgent need for breakthroughs in technology, equipment, and products; and the need to unify and implement accounting methods, standards, and certification systems.

- **Imbalance among Raw Materials, Capacity and Demand**

First, the pace of capacity expansion is not fully aligned with aluminum scrap supply or the capabilities of the recycling system. From 2022 to 2024, China's secondary aluminum capacity increased by 4.6 million tons, with a CAGR of 11.8%, while scrap supply grew by only 1.95 million tons, lagging behind capacity expansion. On the one hand, scrap supply is constrained by structural factors such as scrap generation rates. On the other hand, the current recycling system lacks advanced sorting capabilities, further limiting the availability of scrap. As a result, domestic scrap collection has struggled to keep pace with capacity expansion, leading to a supply-demand imbalance. Scrap prices have shown a rigid upward trend, with raw material costs rising to 93% of total costs. Meanwhile, the supply structure is highly dependent on imported scrap and scrap from specific sectors. China imports over 15% of its aluminum scrap and aluminum alloy scrap, with more than 50% sourced from the construction and transport sectors. This results in frequent price volatility and increases uncertainty in raw material procurement.

Second, downstream demand growth remains relatively slow and is unable to absorb capacity expansion in the short term. Although applications of secondary aluminum continue to expand in sectors such as automotive, home appliances, and machinery, overall demand growth remains modest and lags behind capacity expansion. Data show that major downstream industries are growing at an average annual rate of about 8.2%, which remains below the 15.6% CAGR of upstream capacity. As a result, enterprises are forced into intensified intra-industry competition to secure limited orders.

Imbalances along the raw material–capacity–demand chain place dual pressure on secondary aluminum production from both the supply and demand sides. Industry profit margins have long hovered around cost levels, with some enterprises seeing profits fall as low as RMB 10–20 per ton, while operating rates remain around 50%. Against this backdrop, innovation capacity and willingness to invest have been weakened. With limited profit margins, resources are mainly used to maintain day-to-day operations rather than long-term R&D or technological upgrades. In 2024, the industry's R&D intensity was only 1.2%, below the manufacturing sector average, and progress in key areas such as grade-preserving recycling technologies and non-heat-treatable alloys remains slow.

- **Urgent Need for Breakthroughs in Technology, Equipment and Products**

As a result of the structural imbalance among raw materials, capacity, and demand, China's secondary aluminum industry also faces challenges related to insufficient coordination across technology, equipment, and product development. There is still significant room for improvement in areas such as advanced sorting and efficient smelting technologies, integrated equipment systems, and product structure optimization. In some segments, the technological foundation remains weak, limiting improvements in resource utilization efficiency and product value added, and constraining the industry's ability to substitute for primary aluminum products and further support decarbonization of the aluminum sector.

In terms of equipment, the technical level of sorting and smelting equipment still needs to be improved. More than 60% of small and medium-sized enterprises still rely on manual sorting, making it difficult to achieve precise alloy grade identification and separation. Product composition varies significantly, limiting the supply of raw materials for high-specification, high-value-added secondary aluminum products. At present, the domestic availability of intelligent sorting equipment is below 40%, and laser-induced breakdown spectroscopy (LIBS) technology remains dependent on imports, limiting improvements in sorting efficiency and cost control. In the smelting stage, there is still considerable room for improvement in impurity removal technologies and energy efficiency, while aluminum dross generation remains higher than that of European peers.

Technical capabilities remain insufficient in areas such as pre-treatment, composition control, and process integration. The oil removal rate in the pre-treatment stage of aluminum scrap still lags behind international best practices. In addition, a digital control system covering the full "sorting–smelting–refining" process has yet to be established.

Due to constraints in both equipment and technology, the grade-preserving utilization rate of recycled wrought aluminum scrap remains below 35%. As a result, China's secondary aluminum production is still dominated by mid- and low-end casting alloys, with wrought alloys accounting for only about 40% (roughly a 6:4 ratio). Enterprises with both grade-preserving capabilities and advanced processing capacity remain limited. Despite China's global leadership in secondary aluminum capacity and output, significant gaps remain compared with international best practices in areas such as grade-preserving utilization, advanced processing, and high-end applications. Leading companies are focusing on improving product structure and expanding into mid- to high-end segments, but the overall technological foundation still needs to be strengthened.

- **Gaps in Accounting, Standards, and Certification**

The secondary aluminum industry in China urgently needs updated standards and their effective implementation. In some areas, standards lag behind technological innovation, and national standard systems have yet to be established in fields such as product standards, testing, technologies, accounting methods, and traceability systems. This lack of standards limits R&D direction for enterprises. Meanwhile, alignment and mutual recognition with international standards remain limited, constraining the competitiveness of China's recycled aluminum products in global markets.

Amid industry-wide operational pressures and constrained corporate investment capacity, establishing a robust and practical carbon footprint accounting methodology, clarifying the definition of low-carbon products, and promoting alignment and mutual recognition with international standards are essential to converting the emissions reduction benefits of secondary aluminum into tangible economic value. For enterprises, the adoption of standardized accounting methods and certification standards can reduce reporting burdens, support production decision-making, and improve product recognition and bargaining power in international markets; at the industry level, well-designed accounting methodologies and certification mechanisms can ensure that products and practices with real emissions reduction benefits are recognized and incentivized. These mechanisms help direct resources toward higher environmental value and support the green transition of the aluminum industry as a whole.

Exhibit 11 **Standards Related to the Secondary Aluminum Industry**

SN	Standard Name	Standard No.
1	Methodology for Calculating Carbon Emissions of Recycled Casting Aluminium Alloy Products	T/ZGZS0108-202
2	Recycled Cast Aluminium Alloy Raw Materials	GB/T38472-2023
3	Recycling Materials for Wrought Aluminium Alloys	GB/T40382-2021
4	Recycling Materials for Pure Aluminium Scrap	GB/T40386-2021
5	Secondary Aluminum	GB/T8005.4-2022
6	Process Design Standard for Secondary Aluminum Plants	T/CNIA0067-2020
7	Guidelines for Green Low-Carbon Aluminum Evaluation and Traceability	T/CNIA0245-2024
8	Casting Aluminum Alloys	GB/T1173-2013
9	Casting Aluminum Alloy Ingots	GB/T8733-2016

Source: Industry standard statistics

3. Scaling Up: Typical Models for Secondary Aluminum Application

For a long time, the production and application of secondary aluminum have largely followed two traditional pathways. The first is to remelt secondary aluminum into casting alloy ingots for use by downstream die-casting manufacturers. The second involves aluminum processing enterprises using process scrap or machining swarf generated in their own operations, remelting and processing them into semi-finished products. These traditional pathways have been continuously optimized through long-term market practice and have proven to be technically and economically viable. However, some market participants still hold misconceptions about secondary aluminum, perceiving it as low-cost, lower quality, and more polluting. Even when quality and performance are comparable, secondary aluminum products are often priced lower than primary aluminum products.

The Green Supply Chain Partnership Program for Recycled Metals was launched in November 2024 to address key challenges, including variability in raw material quality, unstable supply, inconsistent standards and carbon accounting practices that hinder coordination, and low profit margins that weaken incentives for transformation. The program aims to break down industry barriers, promote efficient resource integration, enable end-to-end coordination across material processing, design, production, and recycling, and establish a closed-loop green supply chain system. It seeks to build six key value chains—product, technology, digitalization, standards and certification, recycling, and finance—covering areas such as R&D, production, sales, services, innovation, and sustainability, and has attracted more than 50 leading enterprises. In terms of industry–finance integration, China's first recycled metal futures and options product—casting aluminum alloy—was listed on the Shanghai Futures Exchange on June 10, 2025. By October 31, total trading value had reached RMB 98.734 billion. Some enterprises have begun using futures prices for basis trading, while others are actively adopting hedging strategies. This is of great significance for building a comprehensive industry risk management system, meeting diversified risk management needs, expanding the application of secondary aluminum, and supporting high-quality industry development.

Novel initiatives and practices have emerged in the market, driven by leading secondary aluminum enterprises and strong, evolving downstream demand. Key developments include increased direct supply of molten aluminum, greater participation of end users in alloy R&D, and improved front-end grade-preserving recycling. By summarizing and analyzing these emerging models, this chapter aims to provide insights for policymaking, industry development, and business practices, while supporting further discussion and innovation.

3.1 Direct Molten Aluminum Supply: Production Chain Integration and Efficiency Enhancement

Direct molten aluminum supply is an emerging production and supply model for secondary aluminum that closely links producers with downstream aluminum processing enterprises, forming an integrated production chain. In this model, molten aluminum, after smelting, refining, and composition adjustment, is transported using specialized equipment (e.g., molten aluminum ladles) directly to downstream production facilities. Once received, downstream enterprises feed the molten aluminum into die-casting machines or other casting equipment for component production. This model eliminates the need for remelting aluminum ingots, reducing energy consumption and material losses. By streamlining production processes and minimizing intermediate steps, it improves efficiency, reduces costs, and enhances product quality.

Direct molten aluminum supply offers several advantages over conventional secondary aluminum production and supply models:

Lower Costs: The main advantage of supplying molten aluminum directly to downstream manufacturers is cost savings. Exhibit 12 compares the cost of molten aluminum delivery within a 30 km radius. Producing 1 ton of aluminum ingots requires 70–90 cubic meters of natural gas and 90–100 kWh of electricity. In contrast, using molten aluminum can save about RMB 300 per ton in energy costs. In addition, secondary smelting results in about 2% burn loss, while direct production using molten aluminum reduces burn loss to about 0.9%, significantly lower than the 2–2.5% loss associated with remelting aluminum ingots. Based on an ADC12 price of RMB 20,000 per ton, this translates into cost savings of about RMB 200 per ton. Eliminating the operation of in-house melting furnaces at die-casting plants (RMB 80–100 per ton) further reduces costs. The cost of using molten aluminum includes transportation (RMB 150 per ton), insulation, miscellaneous processing costs, and equipment depreciation, totaling about RMB 600 per ton. Overall, this results in a cost reduction of about RMB 300 per ton.

High Efficiency: Direct molten aluminum supply involves placing molten aluminum at temperatures above 700°C into specialized transfer ladles, which are then used to transport it via dedicated vehicles to metered holding furnaces at downstream plants. This process eliminates the step of molten aluminum solidifying into ingots and being remelted, reducing production time while significantly lowering energy costs. Orders for molten aluminum only need to be placed about 4 hours in advance, while ingot procurement requires advance inventory planning.

High Quality: The use of large-capacity melting furnaces, combined with modification and grain refinement treatment of molten aluminum in alloy furnaces and advanced process control systems, improves uniformity and consistency across batches, ensuring stable product quality.

Exhibit 12 **Cost Comparison — Aluminum Ingots vs. Molten Aluminum**

Aluminum Ingots	Cost (RMB)	Molten Aluminum	Cost (RMB)
Energy consumption (natural gas 70–90 m3, electricity 90 kWh)	400	Molten aluminum insulation cost	70
Depreciation of melting equipment	50	Depreciation of molten alu-minum handling equipment	50
Ingot burn loss (2–2.5%)	400	Molten aluminum loss and transportation (30 km)	350
Labor	50	Special transport vehicle costs	100
Miscellaneous expenses	30	Miscellaneous expenses	30
Total	930	Total	600

Source: CMRA

Technical Requirements and Equipment for Molten Aluminum Direct Supply

The direct molten aluminum supply model places high requirements on production equipment, primarily encompassing the following aspects:

Melting furnaces: High-efficiency melting capacity is required to rapidly convert scrap aluminum into molten aluminum. Furnaces should be equipped with advanced temperature control and flue gas treatment systems to ensure stable operation and environmental compliance.

Refining equipment: Used to remove impurities and dissolved gases from molten aluminum, improving its purity. Common equipment includes rotary degassing units and electromagnetic stirrers, which effectively enhance molten aluminum quality.

Molten aluminum ladles: As key equipment for transporting molten aluminum, ladles must have good insulation performance and sufficient capacity to maintain temperature and fluidity during transport. They must also ensure reliable sealing and safety to prevent leakage and accidents.

Transport vehicles: Specialized vehicles should be equipped with dedicated ladle supports and insulation systems to ensure safe and stable transport. Vehicle speed and routes should be carefully planned to minimize transit time and reduce heat loss.

Transport distance: In practice, molten aluminum direct supply is typically only feasible when supported by nearby downstream enterprises. Optimal transport distances are generally 30–50 km, with maximum distances reaching 120–160 km.

China's output of recycled molten aluminum is about 3 million tons, accounting for about 30% of total secondary aluminum production. With continued technological progress and growing market demand, the molten aluminum direct supply market is expected to expand further in the coming years.

Regionally, molten aluminum direct supply companies are mainly concentrated in economically developed areas with well-developed aluminum processing industries, such as the Yangtze River Delta, the Pearl River Delta, and the Bohai Rim region. These regions not only have a strong concentration of aluminum processing enterprises but also benefit from convenient transportation, facilitating molten aluminum transport. With increasing national support for industrial park development, more companies are co-locating with downstream enterprises within industrial parks, promoting industrial clustering and coordination and further supporting the development of the molten aluminum direct supply model.

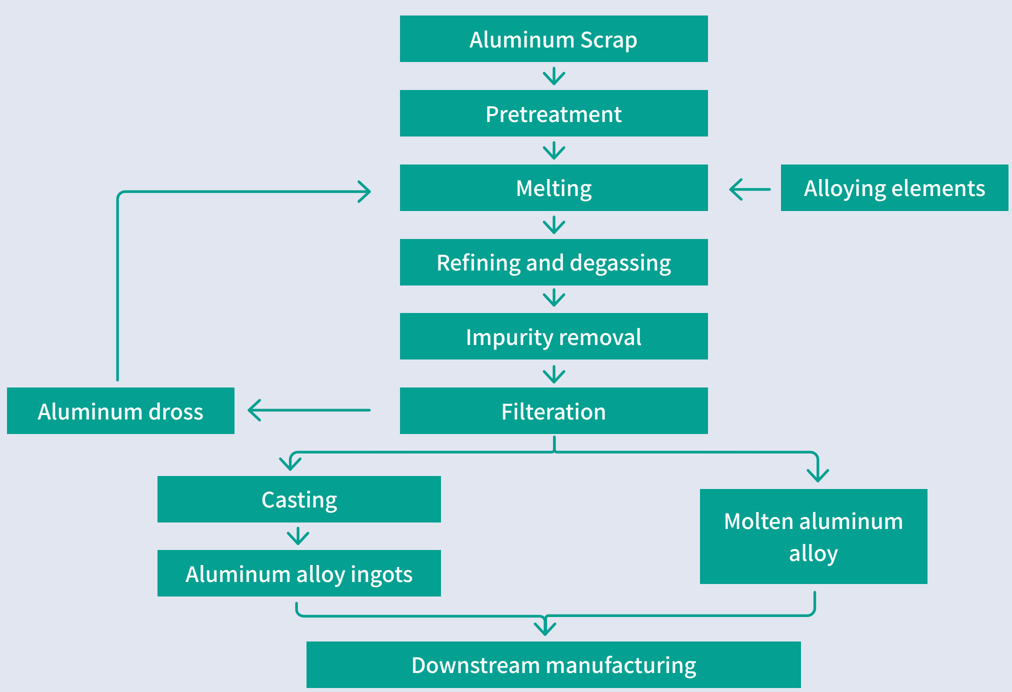
Case Study: Direct Molten Aluminum Supply of Hongjin New Materials

Guangdong Hongjin New Materials Group Co., Ltd. ("Hongjin New Materials") was founded in 1996. It is a specialized group engaged in the R&D of aluminum-based materials, direct molten aluminum supply, and the recycling and processing of aluminum scrap, including grade-preserving recovery. After nearly 30 years of development, Hongjin New Materials has become a leading enterprise in the industry, ranking among the top three in recycled molten aluminum distribution in China.

In August 2023, Guangdong Hongtu used its own funds to participate in the capital increase and share expansion of Guangdong Hongjin Aluminum Industry Investment Co., Ltd. Through this investment, Guangdong Hongtu forms a strategic partnership with Hongjin Aluminum and upstream partners to build a competitive industrial cluster. The initiative aims to establish a leading position in the aluminum alloy forming value chain, strengthen its leadership in the automotive components sector, and expand applications into NEV sensors and other die-cast components, while exploring new market segments and extending its value chain. On August 5, 2024, Guangdong Huajin, a subsidiary of Hongjin, began direct molten aluminum supply of ZL114A cylinder heads to Honda's new Dinghu plant in Zhaoqing.

In 2024, Hongjin New Materials reached an output of 650,000 tons, with molten aluminum accounting for about 70% of total production and delivery volume exceeding 450,000 tons. The company is actively expanding molten aluminum transportation and sales to reduce carbon emissions. Compared with conventional aluminum ingots, direct molten aluminum supply eliminates multiple energy-intensive steps such as remelting and casting, significantly reducing natural gas and electricity consumption. It also eliminates the generation of hazardous waste such as aluminum dross and reduces alloy variability by about 20%, thereby lowering additional carbon emissions. In addition, it reduces transport volume and weight, lowering transport energy consumption and associated carbon emissions.

Exhibit 13 **Production Flow of Molten Aluminum / Aluminum Ingot**

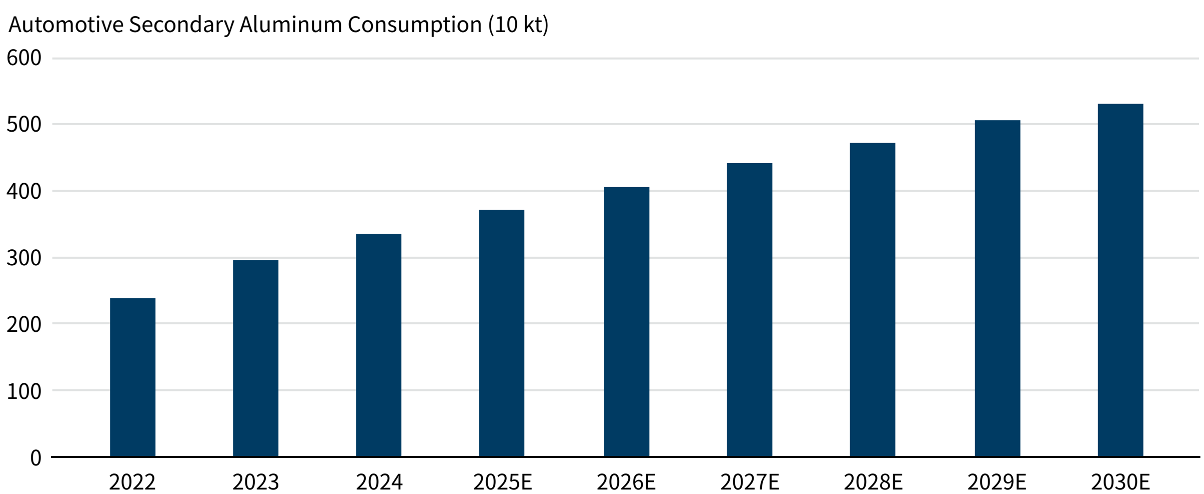


3.2 Joint R&D: Addressing Technical Challenges in High-Performance Secondary Aluminum Applications

The rapid growth of the NEV industry, together with the widespread adoption of integrated die-casting technology, has raised performance requirements for aluminum alloys in automotive manufacturing. These materials must support lightweighting to enhance vehicle range, while also providing high strength and toughness to meet the demands of integrated die casting. Aluminum alloys must enable heat-treatment-free forming in large, thin-walled structural components while ensuring consistent mechanical properties. At present, non-heat-treatable aluminum alloys still rely mainly on primary aluminum, and the use of secondary aluminum remains constrained by technical challenges such as purity control, impurity tolerance, and mechanical property stability.

In this context, close collaboration and joint R&D among multiple stakeholders—including secondary aluminum producers, automakers, and research institutions—have become essential. In this model, secondary aluminum companies use their expertise in production, material development, and impurity control to provide materials and process support. Automakers contribute their experience in design and manufacturing to define application requirements and performance targets, while research institutions provide technical support in advanced materials, process innovation, and validation. Through resource sharing and long-term collaboration, these three parties form a complete value chain from material R&D to product application, jointly addressing key challenges in high-performance material development, technology application, and value chain integration. This joint R&D model helps improve material performance, gradually increases the share of secondary aluminum, and promotes its application in high-end products, while providing important support for the green and low-carbon transition of the automotive industry.

Exhibit 14 **Automotive Secondary Aluminum Consumption Forecast (2022–2030)**



Source: IAI, CMRA

Key Focus Areas and Technical Breakthroughs in Joint R&D

Purity control: Improve the purity of secondary aluminum to minimize the impact of impurities on material performance.

mpurity tolerance: Develop alloy formulations with higher tolerance to impurities (e.g., Fe) to reduce production costs.

Mechanical property stability: Ensure consistent performance across batches and production processes.

Non-heat-treatable aluminum alloys: Develop alloys suitable for integrated die-cast body structural components, with a focus on improving mechanical properties and increasing recycled aluminum content.

Under the joint R&D model, automakers, secondary aluminum enterprises, and research institutions collaborate from the early stages of material development, allowing recyclability to be considered upfront and avoiding design choices that increase recycling complexity. Efforts are made across multiple areas, including optimizing product design, increasing the share of recycled metal, and developing higher-performance recycled materials. This approach improves material compatibility with end-product manufacturing while helping address technical and application barriers at the source, providing a foundation for greater use of recycled metals in end products.

Collaborative innovation: Close collaboration among automakers, secondary aluminum enterprises, and research institutions combines complementary expertise to form strong innovation capability. This collaborative mechanism accelerates material R&D and helps drive technological progress. Secondary aluminum enterprises leverage their expertise in material production and impurity control, while automakers contribute their deep understanding of component performance requirements, enabling more precise development of high-performance aluminum alloys that meet market needs. At the same time, research institutions provide advanced technical support and theoretical foundations, helping address key technical challenges such as purity control, impurity tolerance, and mechanical property stability, and supporting continuous improvement in secondary aluminum material performance.

Resource Optimization: The joint R&D model promotes efficient resource integration and allocation. Stakeholders share R&D resources—including funding, equipment, and technical talent—reducing redundant investment and resource waste. For example, secondary aluminum enterprises and research institutions can share advanced material testing and analysis equipment, lowering equipment investment costs for individual companies. In addition, a clear division of roles allows each party to leverage its core strengths and focus on specific R&D areas, improving efficiency and accelerating results. This model of resource sharing and collaboration also enhances flexibility and adaptability across the R&D chain, enabling faster responses to market changes and technological developments.

Market-Driven R&D: The joint R&D model is closely aligned with market demand, ensuring strong applicability and competitiveness of outcomes. Automakers, as end-product manufacturers, are highly sensitive to changes in market demand and can provide timely feedback to secondary aluminum enterprises and research institutions. This ensures R&D is aligned with market needs from the outset.

For example, the growing adoption of integrated die-casting in NEVs has driven increasing demand for non-heat-treatable aluminum alloys for large, thin-walled components. Through joint R&D, all parties can quickly focus their efforts on this area and jointly develop high-performance aluminum alloys that meet market needs. This helps increase the use of secondary aluminum in automotive manufacturing, generating tangible economic benefits and market returns for all stakeholders.

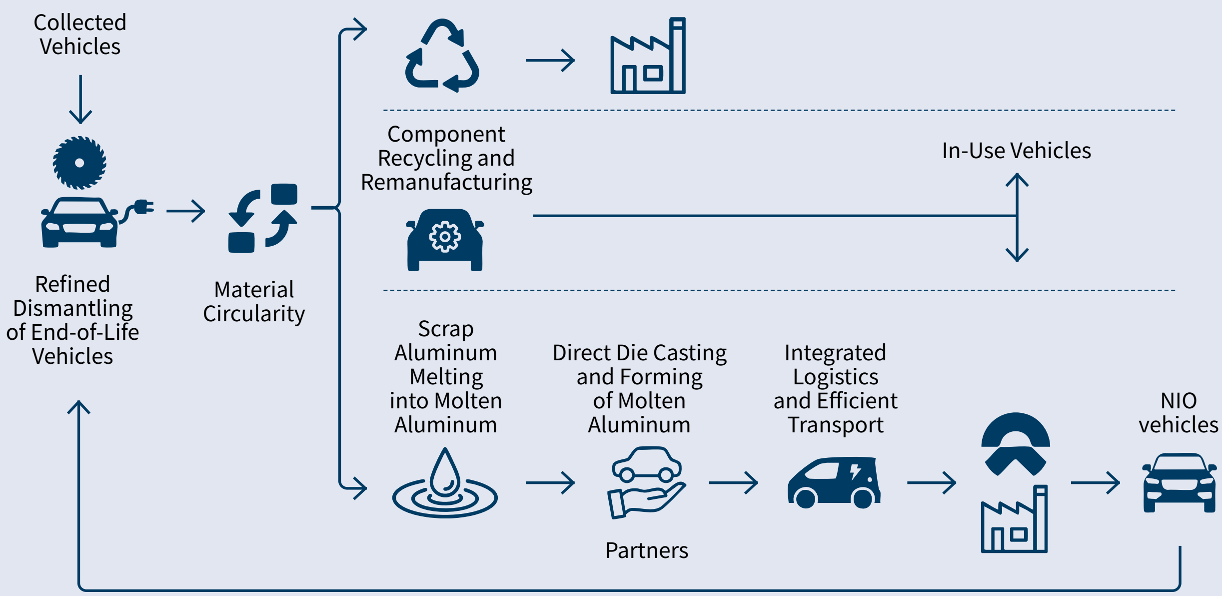
Value Chain Collaboration: The joint R&D model promotes close collaboration among upstream and downstream enterprises across the secondary aluminum value chain. From scrap recycling and secondary aluminum production to end-product applications, companies build stronger partnerships through joint R&D, enabling information sharing, technical exchange, and operational coordination. These collaborative efforts help optimize value chain structure while enhancing overall efficiency and competitiveness. For example, through joint R&D, secondary aluminum enterprises can better understand automakers' requirements for material performance, enabling them to optimize production processes and improve product quality and stability. At the same time, automakers can become more deeply involved in the development of secondary aluminum materials, supporting the development of customized solutions to meet specific performance requirements. In addition, value chain collaboration also drives the development of related supporting industries, such as scrap preprocessing, material testing, and certification. This helps build a more robust industrial ecosystem, providing a foundation for the sustainable development of the secondary aluminum industry.

Case Study: NIO's Collaborative R&D for Vehicle Recycling

On January 2, 2024, Lizhong Group announced a strategic cooperation agreement with Shuaiyichi New Materials Group Co., Ltd. (CSMET). The two parties plan to strengthen strategic collaboration through cross-shareholding between their subsidiaries, Wuhan Longda and Chongqing Shuaiyichi, expanding business cooperation and technical exchange in the field of recycled casting aluminum alloys. The cooperation covers business, technology, and equity integration. In April 2024, NIO signed a memorandum of understanding (MOU) with Lizhong Group and CSMET. The parties will strengthen cooperation in vehicle dismantling and recycling, low-carbon materials and components, and sustainability. NIO's supply chain and vehicle engineering teams have worked with aluminum smelting companies, including Lizhong Group and CSMET, to develop a viable closed-loop recycling pathway covering the full vehicle dismantling and aluminum recycling chain.

Exhibit 15 **NIO's "car-to-car" Aluminum Recycling System Flowchart**

Coordination with Surrounding Supply Chain Parks



Source: NIO

The three parties launched a vehicle dismantling and recycling project in 2023, with initial implementation of a closed-loop aluminum recycling system achieved in early 2024. Lizhong Group has realized the recycling of dismantled NIO vehicle parts into aluminum wheels and motor housings. CSMET has made significant progress in the development and application of non-heat-treatable aluminum alloys, with its C611 material successfully applied in integrated die-cast rear floor structures and front-end structures of NEVs, achieving mass production. NIO has incorporated the full vehicle lifecycle—covering design, production, use, and end-of-life recycling—into a circular system. By working with partners across the value chain, the company has verified the technical and industrial feasibility of "car-to-car" recycling using end-of-life test vehicles.

3.3 Closed-Loop Recycling: Fostering Deep Value Chain Collaboration

Closed-loop recycling is an advanced model for aluminum scrap utilization, enabling circular use of resources by converting manufacturing scrap and post-consumer scrap into aluminum alloys of the same grade. In this model, recycling enterprises and secondary aluminum producers work closely to form a complete “recycling – processing – reuse” value chain. In this model, recyclers and downstream enterprises play a key role by sorting, preparing, and pretreating scrap aluminum in accordance with the quality requirements of secondary aluminum producers, before supplying it directly to them. This collaborative approach minimizes losses and mitigates quality risks associated with intermediate steps. Producers can then optimize production schedules based on scrap availability, improving production efficiency and product quality.

Through advanced sorting and impurity control technologies, closed-loop recycling can maximize retention of original material properties and significantly improve resource utilization efficiency. This reduces downstream reliance on high-cost primary aluminum, lowers raw material and energy costs, and generates clear environmental benefits. Furthermore, enterprises adopting closed-loop recycling are better positioned to respond to market demand for green and sustainable products, strengthening their market competitiveness.

Reverse collection partnerships are key to achieving closed-loop recycling. They ensure stable scrap supply for secondary aluminum producers while helping end users reduce environmental compliance pressure and costs, creating mutual benefits. Reverse collection mainly takes two forms: end-product reverse collection and defective product reverse collection. The former applies to products such as aluminum formwork and vehicles that are well suited to circular systems. After reaching end-of-life, these products undergo sorting, pretreatment, and advanced sorting, and are then returned to secondary aluminum producers for impurity removal and reprocessing into new products. The latter involves direct collaboration between secondary aluminum producers and downstream factories. Downstream factories send defective products back to upstream smelters, either by paying processing fees or through material exchange arrangements. These materials are then reprocessed and supplied back for reuse, enabling efficient closed-loop resource flows.

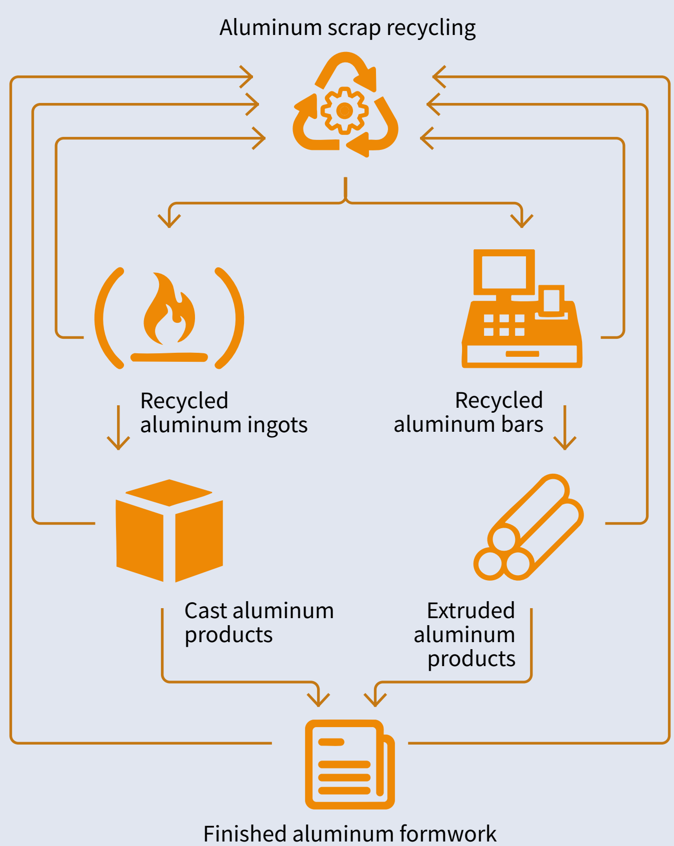
Closed-loop recycling has been widely implemented internationally. Leading companies work closely with downstream partners to build integrated value chains covering scrap collection, refining, and recycled alloy production. Through advanced sorting and impurity control technologies, they ensure that recycled aluminum meets performance requirements and can be directly reused in downstream manufacturing. In 2024, BMW successfully implemented closed-loop recycling of aluminum ingot scrap, increasing the share of recycled aluminum ingots in its casting operations to 65%. Mercedes-Benz has been working with suppliers to develop high-value recycled aluminum components such as wheel rims, and is also planning a “rim-to-rim” closed-loop recycling initiative to reduce reliance on primary resources. Novelis is collaborating with automakers such as Ford and Volvo to establish a closed-loop system for “automotive sheet → stamping scrap → automotive sheet.” By processing stamping scrap and recycled end-of-life automotive sheet into new automotive sheet products, this approach significantly reduces demand for primary aluminum and alloying elements. Through closed-loop recycling systems, Novelis enables recycling and reuse of up to 90% of metal scrap from Ford pickup truck bodies.

Case Study: Closed-Loop Recycling of Aluminum Formwork at Huajian Aluminum

Shandong Huajian Aluminum Group Co., Ltd. is a leading domestic producer and R&D company in aluminum alloy architectural and industrial profiles. As a large enterprise group focused on aluminum profiles, with coordinated development in related industries, it has an annual aluminum profile production capacity exceeding 800,000 tons and a secondary aluminum capacity of 300,000 tons.

Aluminum formwork is widely used in construction due to its high strength, low weight, and reusability. However, large volumes of discarded aluminum formwork pose significant recycling challenges. In response, Huajian Aluminum has developed a closed-loop recycling system. The company works with construction firms to collect discarded aluminum formwork, which is then sorted and pretreated to remove surface contaminants. The pretreated formwork is transported to secondary aluminum plants, where advanced smelting and refining technologies are used to melt it into high-quality recycled molten aluminum, which is then cast into new aluminum formwork and tailored to customer requirements. These new formwork products perform comparably to primary aluminum formwork, meeting the high standards of construction projects. They are then returned to the construction market, enabling efficient resource circulation.

Exhibit 16 **Aluminum Formwork Recycling Flowchart at Huajian Aluminum**



Source: Huajian Aluminum

Case Study: Grade-Preserving Recycling at Innovation New Material Technology Co., Ltd.

Innovation New Material Technology Co., Ltd. ("Innovation New Material") is a large integrated industrial enterprise engaged in the production of aluminum profiles for 3C electronics, automotive lightweight aluminum profiles, sheet, strip and foil, aluminum rods and cables, aluminum alloy bars, and structural components.

A leading communications electronics company is committed to achieving lifecycle carbon neutrality for its products and plans to fully transition to using recycled or renewable materials. To support this goal, the company has established a long-term partnership with Innovation New Material to develop high-performance recycled aluminum materials for product enclosures. The project collects end-of-life products from consumer recycling programs, as well as scrap generated during manufacturing. The collected scrap is sorted and pretreated to meet the quality requirements for recycled aluminum production. Innovation New Material then uses advanced grade-preserving recycling technologies and refining processes to convert the scrap into high-performance molten aluminum, which is further processed into aluminum alloy casings and other components meeting product specifications. By controlling impurities and improving corrosion resistance, the material achieves performance that matches or exceeds primary aluminum. This significantly reduces carbon footprint, supporting the company's sustainability goals.

Through this collaboration, Innovation New Material has become a key supplier to the company across recycled aluminum supply, technical solutions, and component manufacturing. The company has increased its use of recycled aluminum, leading to significant improvements in performance and durability while significantly reducing product carbon footprint. With its technical strengths and long-term partnership, Innovation New Material benefits directly from increased order volumes and supports the company's 2030 carbon neutrality goal.

4. Conclusion

Secondary aluminum, as a key enabler of emissions reduction across the aluminum industry and broader economic sectors, faces both significant challenges and important opportunities. On the one hand, low-carbon performance has become an inherent attribute of secondary aluminum. The industry's technical and economic viability has been proven through long-term market practice, with relatively mature and stable business models already in place. At the same time, the industry faces growing operational pressure as downstream markets impose increasingly stringent emissions reduction requirements. Traditional approaches face significant technical and economic challenges, requiring further efforts to unlock new potential and translate emissions reduction value into commercial value.

On this basis, to achieve breakthroughs and establish a new balance, the industry still faces several critical challenges, including structural imbalances among raw materials, capacity, and demand, insufficient coordination among technology, equipment, and products, and the need to establish unified and actionable standards and certification systems. These challenges cannot be addressed by individual companies or sectors alone, but require coordinated efforts across the entire value chain, as well as the development of innovative collaboration models across industries and segments.

The models presented in this report—including direct molten aluminum supply, joint R&D, and closed-loop recycling—have demonstrated strong results. The exploration and practices of leading enterprises are helping drive the industry to move beyond traditional pathways and advance toward higher levels of low-carbon development. Looking ahead, these practices, alongside improved policy frameworks and continued collaboration across the value chain, will enable deeper integration of green value and economic value within the secondary aluminum industry. This will position the industry as a key driver of high-quality development in China's aluminum sector, while providing stronger support for global industrial decarbonization and the achievement of climate goals.

References

1. Implementation Plan for High-Quality Development of the Aluminum Industry (2025–2027), Ministry of Industry and Information Technology, National Development and Reform Commission, Ministry of Natural Resources, Ministry of Ecology and Environment, Ministry of Commerce, Ministry of Emergency Management, State-owned Assets Supervision and Administration Commission of the State Council, General Administration of Customs, State Administration for Market Regulation, National Mine Safety Administration, March 11, 2025, **https://www.gov.cn/zhengce/zhengceku/202503/content_7016126.htm**
2. Energy-Saving and New Energy Vehicle Technology Roadmap, China Society of Automotive Engineers, December 1, 2016
3. Lizhong Group Annual Report 2024, Lizhong Group, April 21, 2025, **https://www.cninfo.com.cn/new/fulltextSearc h?notautosubmit=&keyWord=%E7%AB%8B%E4%B8%AD%E9%9B%86%E5%9B%A2**
4. Shunbo Alloy Co., Ltd. Annual Report 2024, Shunbo Aluminium, April 25, 2025, **https://www.cninfo.com.cn/new/disclosure/detail?orgId=gfbj0833081&announcementId=1223268966&announcementTime=2025-04-25**
5. Yongmaotai Co., Ltd. Annual Report 2024, Yongmaotai, April 19, 2025, **https://www.cninfo.com.cn/new/disclosure/stock? stockCode=605208&orgId=9900039946#latestAnnouncement**
6. Circular Economy Development Plan for the 14th Five-Year Plan, National Development and Reform Commission, July 7, 2021, **https://www.gov.cn/zhengce/ zhengceku/2021-07/07/content_5623077.htm**
7. Action Plan for Energy Conservation and Carbon Reduction (2024–2025), State Council, May 23, 2024, **https://www.mee.gov.cn/zcwj/ gwywj/202405/t20240530_1074495.shtml**
8. Action Plan for Promoting Large-Scale Equipment Renewal and Consumer Goods Replacement, State Council, March 7, 2024, **https://www.gov.cn/zhengce/ content/202403/content_6939232.htm**
9. Notice on Improving the Recycling System for End-of-Life Appliances, Furniture, and Other Recyclable Resources, Ministry of Commerce, National Development and Reform Commission, Ministry of Industry and Information Technology, Ministry of Finance, Ministry of Ecology and Environment, Ministry of Housing and Urban-Rural Development, State Administration for Market Regulation, General Administration of State Assets, All-China Federation of Supply and Marketing Cooperatives, January 23, 2024, **https://www. mofcom.gov.cn/zcfb/gnmygl/art/2024/art_598cb2396316419fba6b7fb1f87b91e8.html**
10. Guiding Opinions on Accelerating the Construction of a Recycling System for Waste Materials, National Development and Reform Commission, Ministry of Commerce, Ministry of Industry and Information Technology, Ministry of Finance, Ministry of Natural Resources, Ministry of Ecology and Environment, Ministry of Housing and Urban-Rural Development, January 17, 2022, **https://zfxxgk.ndrc.gov.cn/web/iteminfo. jsp?id=18632**
11. China Nonferrous Metal Recycling Industry Development Report 2024, China Nonferrous Metals Industry Association (CMRA), June 2025
12. China Nonferrous Metals Development Report 2024, China Nonferrous Metals Industry Association (CNIA), June 2024
13. China Nonferrous Metals Development Insights, China Nonferrous Metals News, 2024
14. Promoting the Integrated Development of “Recycling + Recycled Materials + Green Manufacturing,” Resource Regeneration, September 15, 2025

15. Recycled Nonferrous Metals: Injecting New Momentum into Green Development, Resource Regeneration, August 7, 2025
16. Recycled Metals Drive Industry Green Transition and Development, China Nonferrous Metals News, July 15, 2025
17. econdary Aluminum Supports Resource Security for Aluminum Industry: Driving Green Transition, Resource Regeneration, April 15, 2025
18. Current Status and Development Prospects of Waste Aluminum Alloy Recycling in China, Nonferrous Metal Processing, December 13, 2024
19. Optimizing Customs Supervision to Promote High-Quality Development of Recycled Metal Raw Material Imports, Resource Regeneration, September 15, 2024
20. Current Status of Recycling and Regeneration of Aluminum Alloy Automotive Wheels in China, Aluminum Processing, June 20, 2024
21. Analysis of Development Trends in Extraction and Recycling Technologies for Key Non-Ferrous Metals in New Energy Vehicles, Modern Transportation and Metallurgical Materials, January 15, 2024
22. 1.5 Degrees Scenario: A Model To Drive Emissions Reduction, International Aluminium Institute, 2021, **https://international-aluminium.org/resources/1-5-degrees-scenario-a-model-to-drive-emissions-reduction/**
23. Making Net-Zero Aluminium Possible, Mission Possible Partnership, 2023, **https://3stepsolutions. s3-accelerate.amazonaws.com/assets/custom/010856/downloads/Making-1.5-Aligned-Aluminium-possible.pdf**
24. Aluminum Product Carbon Footprint Accounting and Reporting Methodology — Based on International Practice, Liu Wenjuan, Sravan Chalasani et al., 2024, **https://rmi. org.cn/insights/aluminum_guidance/**

RMI, *Co-Shaping the Value Chain: Collaboration and Breakthroughs in the Secondary Aluminum Industry*, 2025,
https://rmi.org.cn/insights/collaboration-and-breakthroughs-in-the-recycled-aluminum-industry/

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