Alliance for Industry Decarbonization

Aluminium circularity
Industry insights and future directions

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About AFID

The mission of the Alliance for Industry Decarbonization (AFID) is to foster action for decarbonisation of industrial value chains, and to promote understanding of renewables-based solutions and their adoption by industry with a view to contributing to country-specific net-zero goals.

Joining AFID as a member or ecosystem knowledge partner is open to any legal entity engaged in decarbonising industry with renewable energy solutions. This includes, but is not limited to, public and private sector industrial firms, industry associations, the financial community and inter-governmental organisations.

The International Renewable Energy Agency (IRENA) co-ordinates and facilitates the activities of AFID.

About this paper

This report was developed jointly by members of the AFID Circularity Working Group. It builds on exchanges and discussions among the working group members that took place during a series of meetings to realise joint initiatives. The report is informed by the experience of AFID members and ecosystem knowledge partners from different regions across the world.

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This report is available for download: www.allianceforindustrydecarbonization.org/

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Abbreviations

°C	degrees Celsius
AFID	Alliance for Industry Decarbonization
AI	artificial intelligence
CBAM	Carbon Border Adjustment Mechanism
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
DRS	deposit return system
EGA	Emirates Global Aluminium
EPR	extended producer responsibility
FMC	First Movers Coalition
UAE	United Arab Emirates
USD	United States dollar

Executive summary

The aluminium sector faces an immense challenge of decarbonising at a pace and scale to meet both demand growth and targets for net-zero greenhouse gas emissions. Aluminium production was responsible for more than 1.1 billion tonnes of carbon dioxide equivalent in 2022. The sector is expected to grow 40% between 2020 and 2030 (in tonnes of aluminium per year) and must therefore cut emissions more than 95% by 2050 to align with a decarbonisation pathway to keep global temperature rise within 1.5 degrees Celsius.

Circularity – through recycling, material efficiency and closed-loop systems – is one of the most powerful levers for decarbonising the sector, reducing material losses, and building a resilient, resource-efficient economy. Thanks to its physical properties, aluminium is an ideal material for the circular and low-carbon economy as its composition makes it exceptionally easy to recycle repeatedly, achieving already very high yields and without degradation of its properties. Beyond emissions reduction, the value proposition of aluminium also includes employment creation. A study by the Global Alliance for Incinerator Alternatives estimated that recycling 10 000 tonnes of aluminium waste creates 115 jobs, or around 50 times as many as landfills and incinerators.

Nearly three-quarters of all aluminium ever produced is still in use today, demonstrating the material's durability and circular potential. Innovation in recycling technologies is improving the efficiency of recycling operations. Worldwide initiatives are starting to create and signal a demand for sustainable aluminium from both the public and private sectors; efforts include the Aluminium Stewardship Initiative, the Aluminium Industry Greenhouse Gas Initiative, Alliance for Industry Decarbonization and the First Movers Coalition. Additionally, the World Economic Forum and the International Aluminium Institute have launched the Net-Zero Aluminium Initiative under the Mission Possible Platform, which aims at mobilising industry to support policies for low-emission aluminium. The international demand for sustwainable aluminium is rising as countries and industries strive for carbon neutrality. Despite clear economic and environmental benefits, however, progress towards aluminium circularity remains uneven.

Challenges preventing the advancement of circularity concepts in the aluminium sector include the fragmentation of scrap collection and the need for improved sorting technologies (which could boost scrap collection rates and increase efficiency in managing them); the absence of universal carbon and circularity standards (which could ensure transparency and consistent metrics for assessing the environmental performance of aluminium products); the lack of clear roadmaps (which could provide long-term vision and mobilise investments); the limited access to finance for circular innovation (which is crucial to deploy projects); and weak collaboration across value chains (which could support the sector in all aspects).

To address these challenges, three strategic areas of action are being proposed: material efficiency, scrap recycling and process efficiency (Figure ES1).

FIGURE ES1 Key strategies to improve the circularity of the aluminium sector

Pilar 1

Material Efficiency

Reduce aluminium demand through increased material efficiency thanks to smarter design, alloy simplification and extended product lifespans.

Pilar 2

Scrap Recycling

Maximise scrap recovery via closed-loop systems, advanced sorting technologies (e.g. XRT, LIBS, AI-powered robotics) and policy mechanisms like deposit return systems (DRS).

Pilar 3

Process Efficiency

Improve the process efficiency of aluminium production through electrification of key production stages (especially alumina calcination) and invest in next-generation furnaces and purification technologies such as ASTRAEA.

To accelerate progress, the report presents five main recommendations:

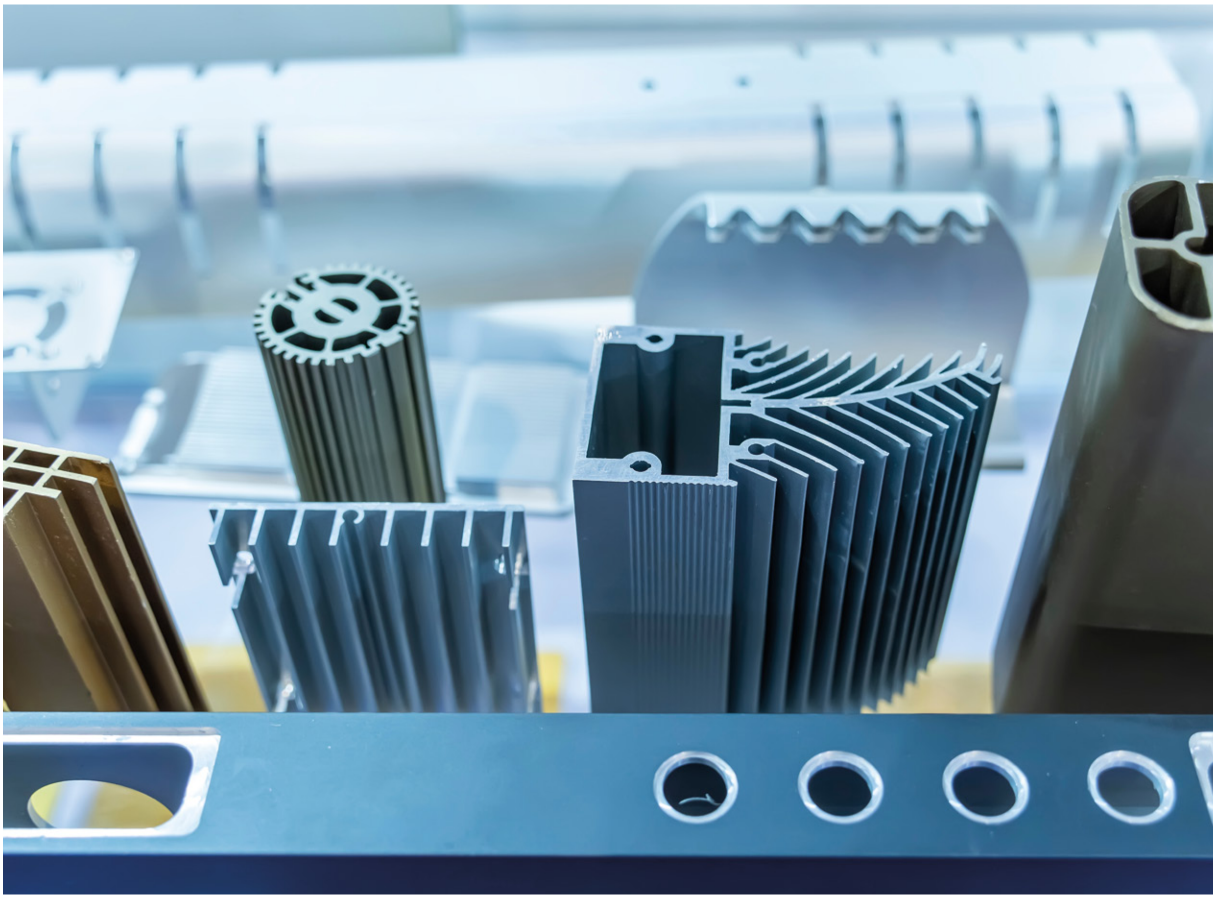
Improve scrap collection. This includes investing in advanced sorting and separation technologies and systems that enable high-value recovery and re-use of post-consumer aluminium.

Enforce product standardisation and certification. A key step is to develop global benchmarks for carbon intensity, circularity metrics, and product certification schemes to ensure transparency and comparability along the value chain.

Develop strategy and increase uptake of circular aluminium. Governments could establish clear decarbonisation roadmaps and long-term targets to be integrated into national industrial policies; phase out fossil fuel subsidies and implement carbon prices to internalise carbon costs; and stimulate demand for low-carbon aluminium through public procurement and market quotas.

Mobilise green funds. Dedicated green finance instruments and innovation funds can support decarbonisation efforts through investments in research and development and the deployment of advanced technologies.

Strengthen partnerships and collaboration across the value chain. Producers could collaborate closely with downstream partners and establish long-term partnerships with original equipment manufacturers. Governments could de-risk through public-private partnership and fiscal incentives.



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1 Overview of the aluminium industry

This section offers an overview of current aluminium production emissions, observed trends, and the upcoming opportunities and challenges to decarbonise at a pace and scale to meet both demand growth and net-zero targets.

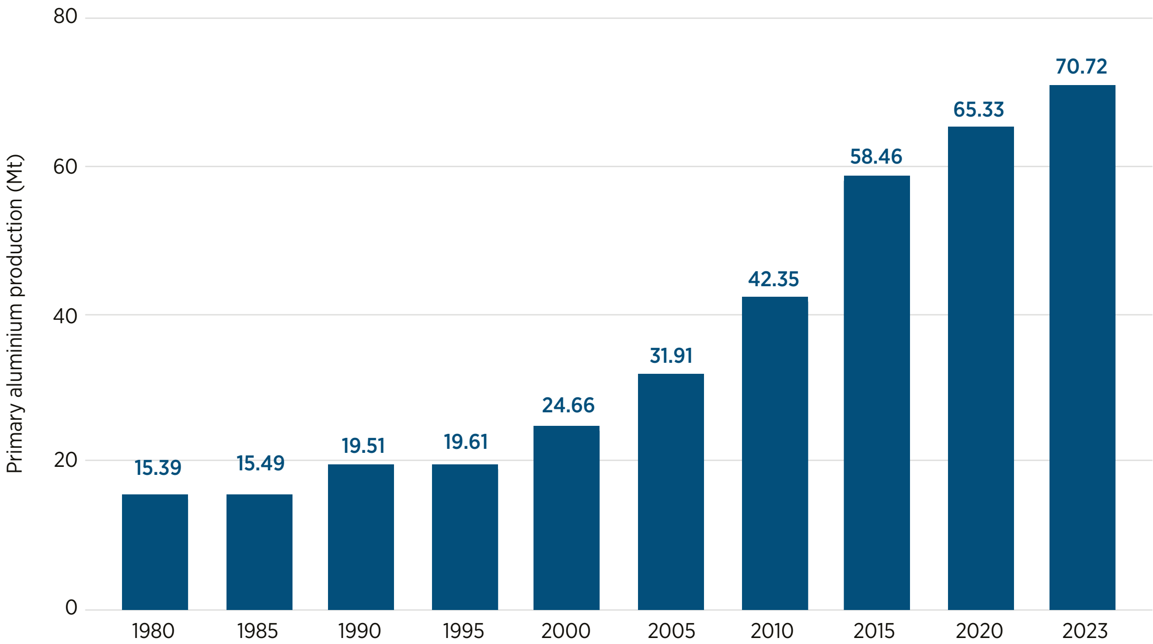
1.1 Global aluminium production

The aluminium sector is a crucial contributor to the global economy and is pivotal to the green energy transition. Aluminium is found in a wide array of applications due to its versatility, lightweight nature, high strength, recyclability and good conductivity. The major sectors consuming aluminium are transport (23%), construction (25%) and electrical applications (12%) (IRENA, 2025). Aluminium is also widely applied across nearly all energy generation, transmission, and storage technologies, ranging from wind and solar power to alternative fuel cells, hydrogen production, high-voltage cables and batteries.

As economies grow and evolve, the demand for aluminium continues to rise, particularly in sectors that prioritise sustainability and energy efficiency (Hindalco, 2024). For example, aluminium is increasingly used to enhance fuel efficiency and reduce emissions in the automotive industry, in addition to its diverse applications in renewable energy technologies (Fast Markets, 2024).

Global aluminium production has grown remarkably over the years (Figure 1). This is attributed mainly to rising demand from emerging economies in Asia, particularly China, in which production resulted in nearly 43.4 million tonnes (Mt) of primary aluminium production in 2024 to meet the increase in demand (Figure 2) (IAI, 2024a). The expansion of primary aluminium production capacities in Gulf Cooperation Council countries and in Asia (excluding China) also contributes to the industry's growth trajectory. Figure 3 shows the top three countries in each stage of the aluminium production process: bauxite mining, alumina production and aluminium production (Bhutada and Fortin, 2022).

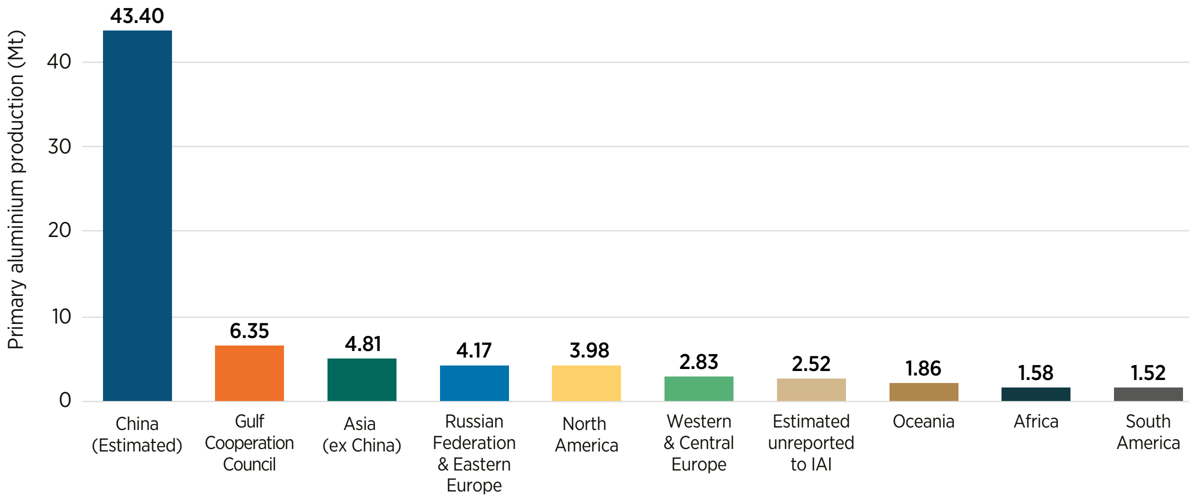
FIGURE 1 Growth in primary aluminium production, 1980 to 2023



Source: (IAI, 2023a).

Note: Mt = million tonnes.

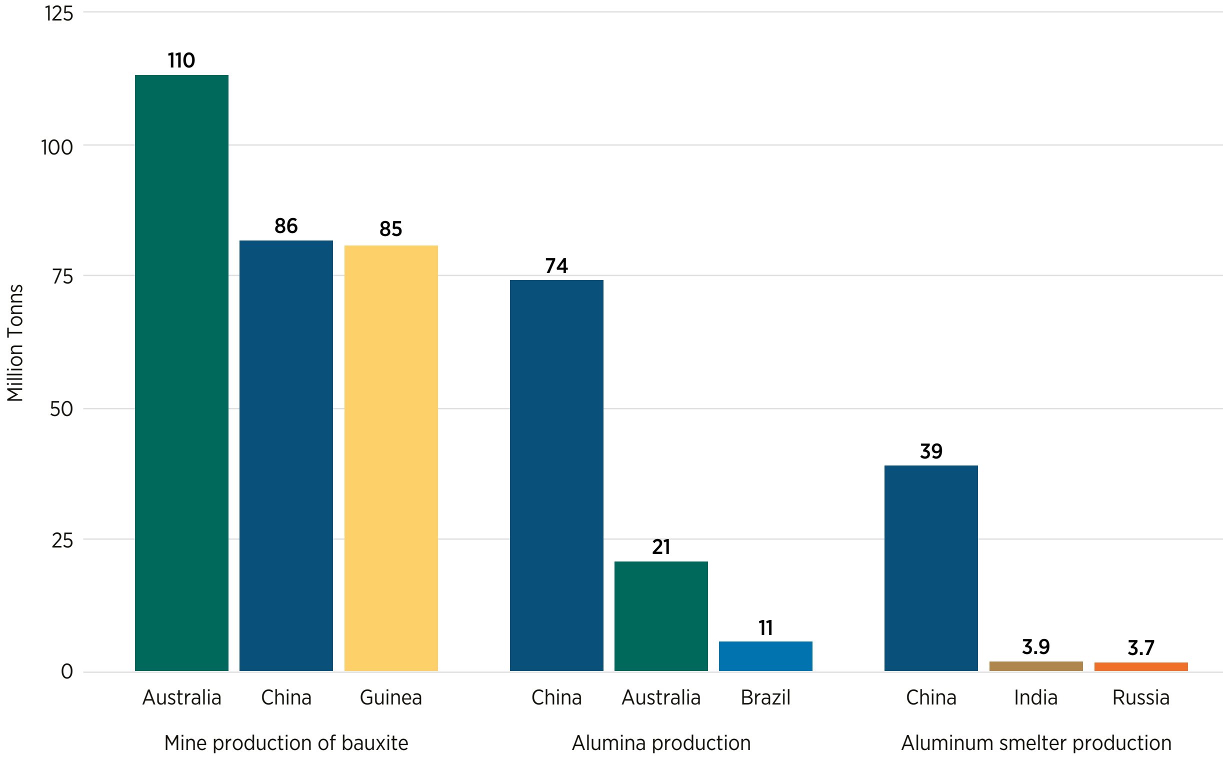
FIGURE 2 Primary aluminium production by region in 2024



Source: (IAI, 2024a).

Note: Mt = million tonnes.

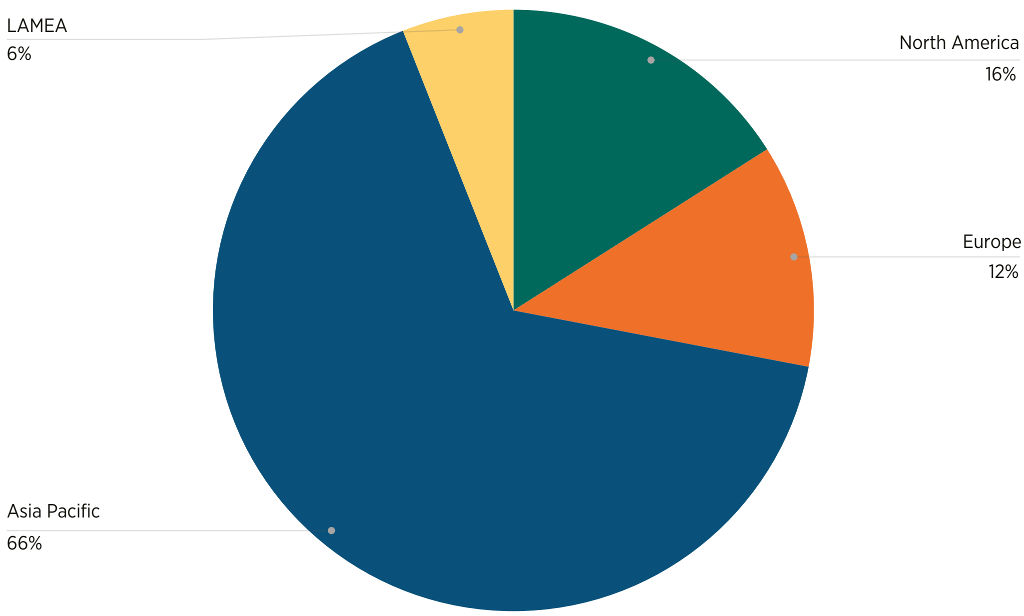
FIGURE 3 Top three countries in each stage of primary aluminium production in 2021: bauxite mining, alumina production and aluminium production



Source: (Bhutada *et al.*, 2022).

With these production capacities, the global aluminium market was valued at around USD 169.0 billion in 2023 and is projected to reach around USD 311.4 billion by 2033, with a compound annual growth rate of around 6.3% during the period 2024 to 2033 (AMR, 2024). The Asia-Pacific region accounted for around two-thirds of the global aluminium market in 2024, driven mainly by significant industrial activity and urbanisation in China and India (Figure 4). Europe represented around 12% of the global aluminium market, supported by strong investments in construction and sustainable practices.

FIGURE 4 Aluminium's market share by region in 2024



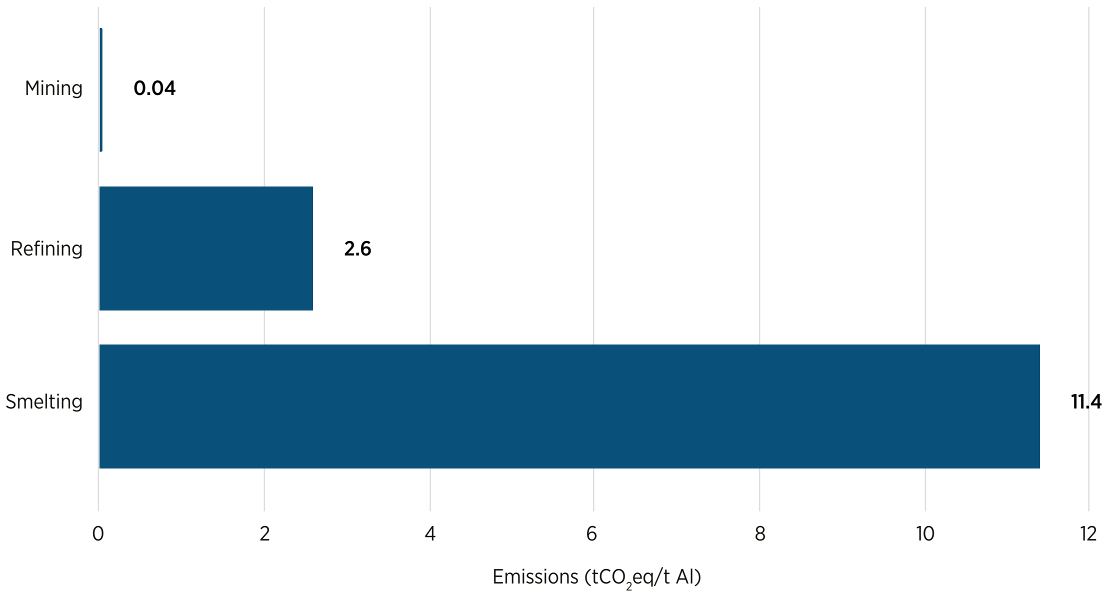
Source: (Precedence Research, 2025).

Note: LAMEA = Latin America, Middle East and Africa.

1.2 Greenhouse gas emissions

The production of primary aluminium is characterised by three key stages: 1) mining of bauxite, 2) refining bauxite into alumina, and 3) smelting alumina into metallic aluminium. Smelting is by far the most carbon-intensive stage of aluminium production on a cradle-to-gate basis (Figure 5), as the process requires electric currents as high as 400 000 amperes (A). Emissions from aluminium production are thus mostly dependent on the electricity mix. If fossil fuels (mainly coal) are used for electricity production, the smelting process emits more than 11 tonnes of carbon dioxide (CO_2) per tonne of primary aluminium produced.

FIGURE 5 Emissions intensity in each stage of primary aluminium production on a cradle-to-gate basis in 2022



Source: (IAI, 2023b; I.N.G. Bank, 2024).

Notes: Al = aluminium; CO_2eq = carbon dioxide equivalent; t = tonne.

The second most carbon-intensive process in aluminium production, after smelting, is alumina refining. The use of the Bayer process to convert bauxite into alumina (through calcination) typically emits around 2.6 tCO_2/t Al (primary) produced. Bauxite mining, in contrast, emits only 0.04 tonnes of CO_2/t of Al produced, since there is minimal processing at this stage.

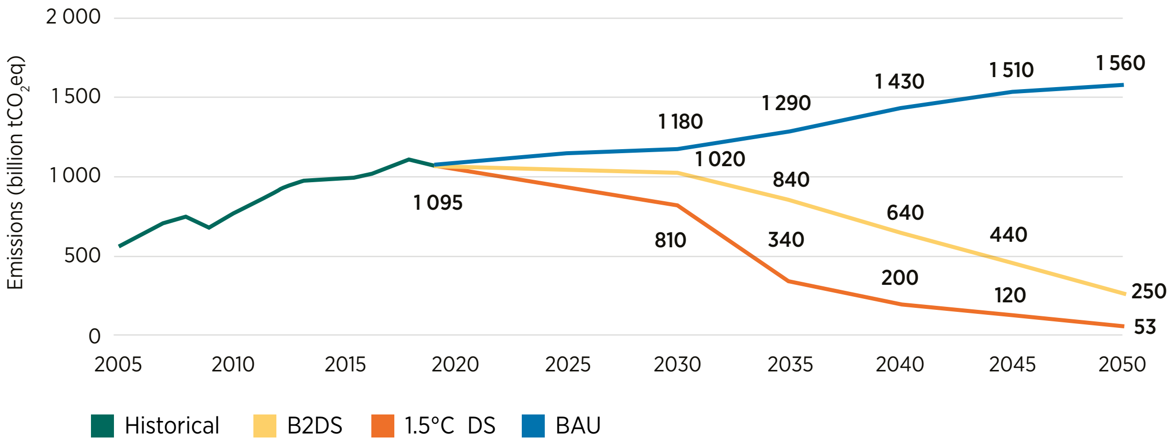
For the overall aluminium production process, the current emissions average is around 15 CO_2/t of Al produced. To achieve the Paris Agreement goal of attaining net-zero emissions by 2050, the average emissions from aluminium production should fall to 0.5 CO_2/t of Al (primary) (I.N.G. Bank, 2024).

As economies continue to develop, global aluminium demand is set to increase nearly 40% between 2020 and 2030. To meet this projected growth, the sector will need to produce an additional 33.3 Mt, rising from 86.2 Mt in 2020 to 119.5 Mt in 2030 (IAI, 2022).

Despite its significant contributions to modern society and the global economy, the aluminium production sector was responsible for around 1.1 billion CO_2eq emissions in 2022 (IAI, 2023b). This includes around 270 Mt of direct emissions, with the rest being mainly indirect emissions from electricity generation (IEA, 2023). The energy intensity for producing primary aluminium is around 70 gigajoules (GJ)/t, making it more energy-intensive than steel and cement (IAI, 2024b).

To align with a scenario to keep global temperature rise within 1.5 degrees Celsius (°C), emissions from the sector must be reduced more than 95%, from 1.1 billion CO_2eq in 2022 to 53 Mt by 2050 (see orange line in Figure 6) (IAI, 2021a). To achieve this goal, all aluminium producers will need to reduce their emissions, including producers of recycled aluminium and producers of primary aluminium made with 100% low-carbon power for smelting (IAI, 2021b).

FIGURE 6 Emissions reduction trajectories for the aluminium sector to 2050



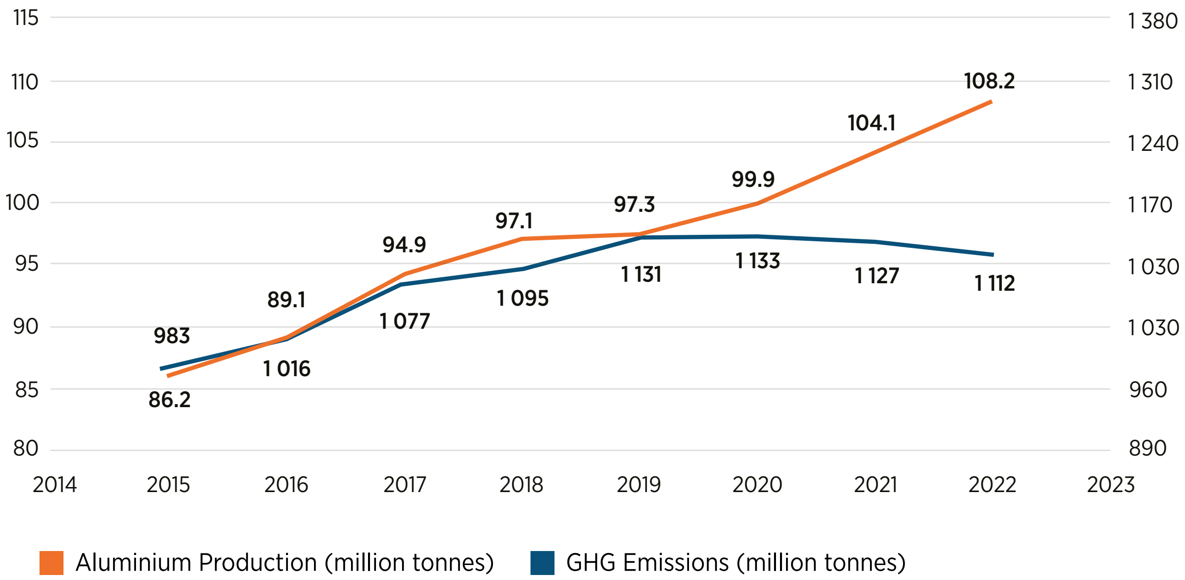
Source: (IAI, 2021b).

Notes: B2DS = Below 2 Degrees Scenario; 1.5DS = 1.5°C Degrees Scenario; BAU = Business As Usual.

Fortunately, bringing the sector on a path to net-zero emissions by 2050 is technically and economically possible (WEF, 2024a). In recent years, strides have been made in this direction based on three key drivers. The first is China's shift from coal to hydropower for smelting, which is relevant given that China is the world's largest producer of aluminium and consumes around 13 200 to 16 000 kilowatt hours (kWh) of electricity per tonne of aluminium produced. The other two drivers of emissions reduction are higher aluminium recycling rates, and the adoption of wind and solar power for power generation.

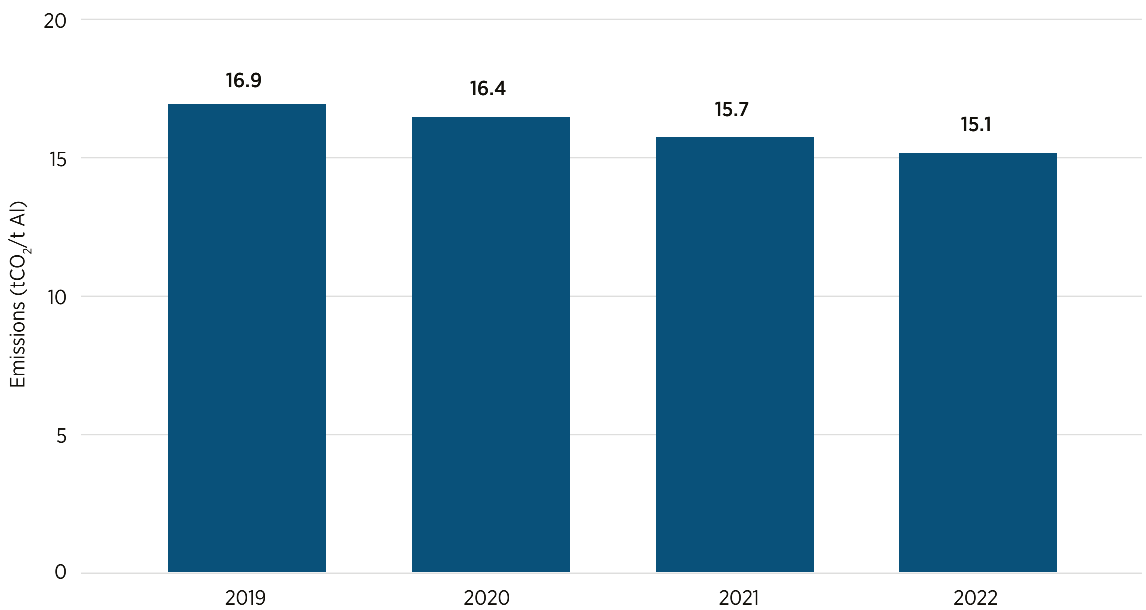
In 2022, for the first time on record, total greenhouse gas emissions from the global aluminium sector remained stable despite an increase in aluminium production (Figure 7). In parallel, the emissions intensity of primary aluminium production decreased between 2019 and 2022, reaching an average of 15.1 CO_2eq/t of primary aluminium produced (Figure 8) (I.N.G. Bank, 2024). While these trends hint at a potential decoupling of aluminium production and emissions, more needs to be done at pace and scale to meet both demand growth and net-zero targets (IRENA, 2025). Addressing this formidable challenge requires engaging in sector-wide as well as inter-sector partnerships, as in the case of AFID.

FIGURE 7 Aluminium production capacity and greenhouse gas emissions (both in million tonnes), 2015 to 2022



Source: (Amanor-Wilks, 2024).

FIGURE 8 Greenhouse gas emissions intensity of primary aluminium 2019 to 2022



Source: (I.N.G. Bank, 2024).

Note: tCO_2/t Al = tonnes of CO_2 per tonne of aluminium.

As described by the International Aluminium Institute (IAI, 2021b), the industry's future growth is poised to be shaped by ongoing innovations and regulatory frameworks that focus on the following levers:

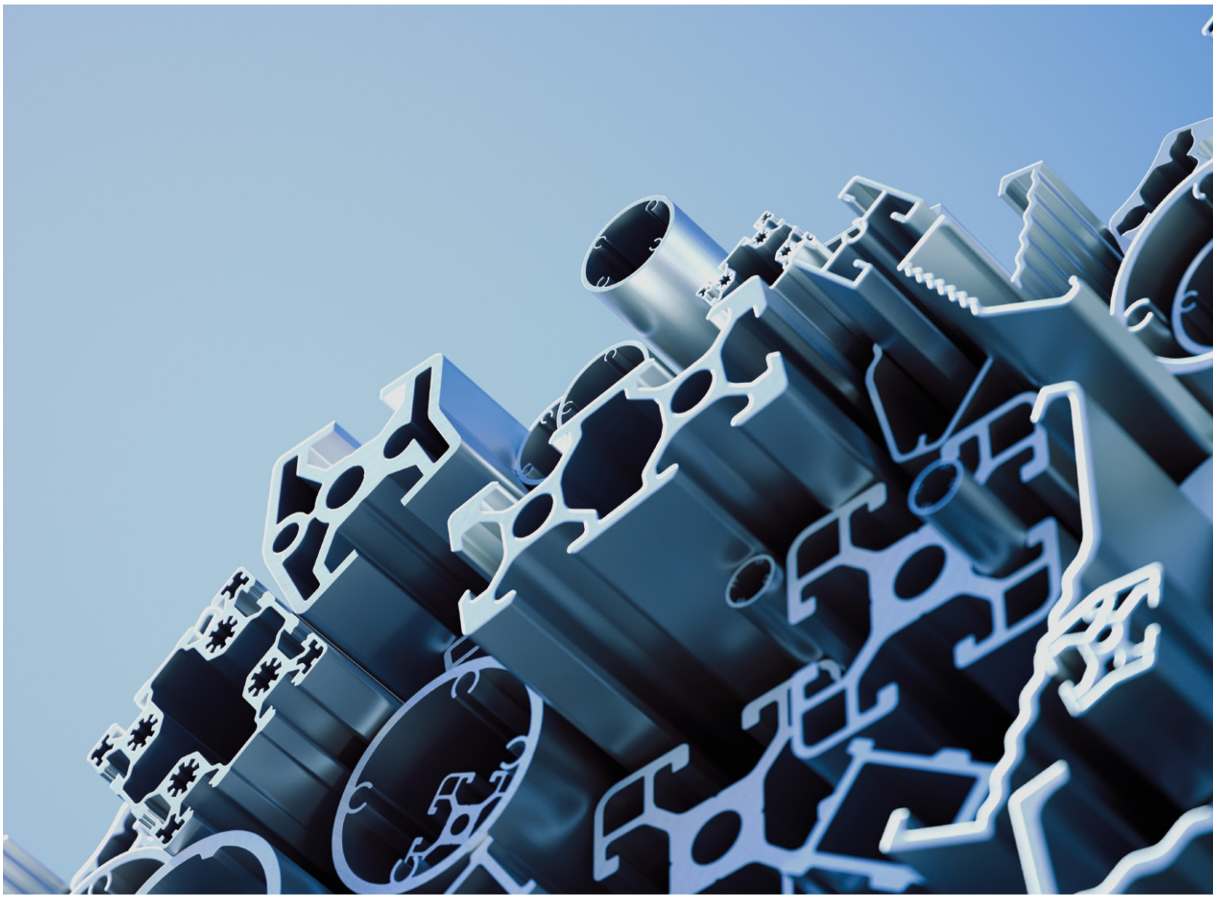
Electricity decarbonisation: Around 65% of the energy required in the aluminium sector comes from electricity generation. This is used mostly in the smelting process, the emissions of which vary greatly depending on the electricity mix. Smelters that use renewable energy sources such as hydropower have lower emissions than those dependent on fossil fuels. Thus, integrating increasing amounts of renewables such as wind and solar instead of fossil fuels is key to reducing the sector's carbon footprint.

Several smelters already plan to integrate solar photovoltaic and wind power capacity through long-term power purchase agreements (PPAs). However, most smelters continue to find it challenging to secure attractive renewable energy PPAs due to a combination of factors. These include regulatory and market barriers that prevent rapid deployment of renewables, as well as high demand for low-carbon electricity, which can drive up prices beyond the level that aluminium producers are able to pay, given the industry's tight margins. Also, the variability of solar and wind is a challenge for smelters, which traditionally require a constant power supply (IRENA, 2025).

Direct emissions reduction: The sector's other two major sources of CO_2 emissions are from refining alumina and the use carbon anodes (applied in the aluminium electrolysis process). These sources contribute almost a fifth of the total CO_2 emissions from primary production and are a significant share of emissions in regions where low-carbon electricity is already used for smelting. Deep decarbonisation of the aluminium sector would involve wide-scale adoption of efficient, low-carbon refining processes and technologies such as inert anodes and chlorine electrolysis. However, the costs for low-carbon refining processes are still high in many cases, and inert anodes and chlorine electrolysis are not yet commercially available.

Circularity (recycling and resource efficiency): Recyclability without loss of properties is one of aluminium's key advantages. Currently, the recycling of post-consumer scrap offsets the need for nearly 20 Mt Al (primary) each year, avoiding around 300 Mt CO_2eq emissions (IAI, 2021b). When recycled metal is lost from the system, it must be replaced with primary aluminium, which requires 95% more energy to produce. Today's primary production has a greenhouse gas emissions profile on average 25 times higher than the recovery of metal from post-consumer scrap. Achieving close to 100% recycling rates, improving scrap sorting and reducing metal losses could cut the demand for primary aluminium 20% by 2050 – resulting in an additional emissions reduction of 300 Mt CO_2eq (IAI, 2021b).

Section 2 explores how aluminium, due to its intrinsic properties, is particularly well suited for a circular and low-carbon economy, and identifies trends, innovations and needs to fully realise its potential.



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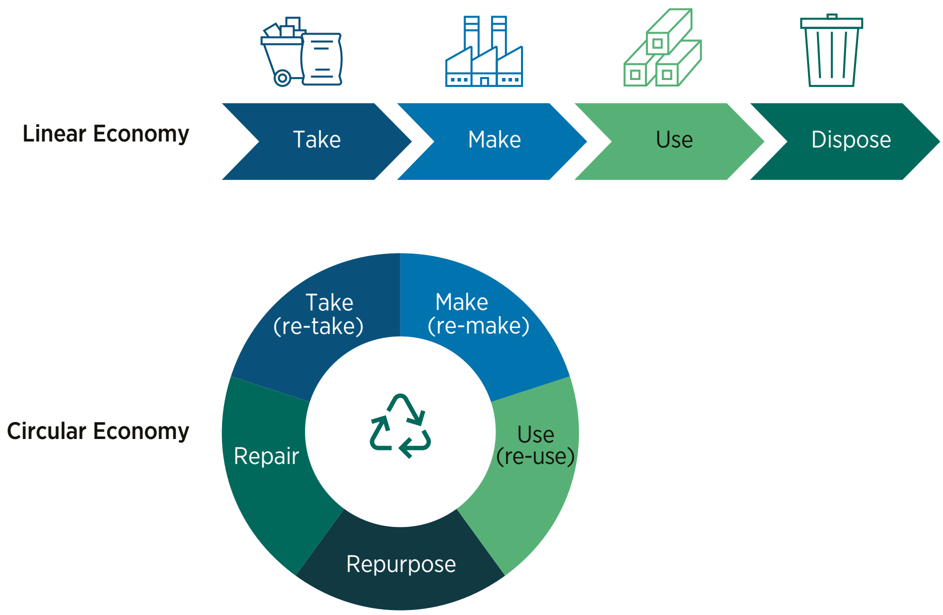
2 Aluminium circularity

With growing global attention to environmental challenges, the need to adopt sustainable practices is becoming increasingly clear. One such solution is the circular economy – a systemic solution aimed at closing the loop on materials, reducing waste, maximising the use of resources, and ensuring the continued re-use, repair and recycling of products throughout their life cycle. Unlike the traditional linear economy, which follows a "take, make, use, dispose" approach, the circular economy promotes systems that keep products and materials in circulation (Figure 9), thereby reducing environmental impact and promoting sustainability (ASI, 2023).

FIGURE 9 Linear economy and circular economy approaches



Circularity is a strong trend due to its multi-faceted potential and impacts. It not only facilitates a substantial and accelerated reduction in the greenhouse gas emissions associated with materials and products, but also offers considerably lower decarbonisation costs compared to traditional approaches that rely on the extraction of raw materials. In many cases, the degree to which circularity can be implemented greatly influences whether the decarbonisation cost structure of a material or product is favourable or unfavourable. Adopting circular practices helps maintain the value of resources, diminishes reliance on virgin materials and finite resources, enhances cost management, boosts energy efficiency throughout the value chain, increases predictability in supply and demand, and fortifies the resilience of supply chains. Ultimately, circularity can act as a safeguard against fluctuations in both raw material and decarbonisation costs.

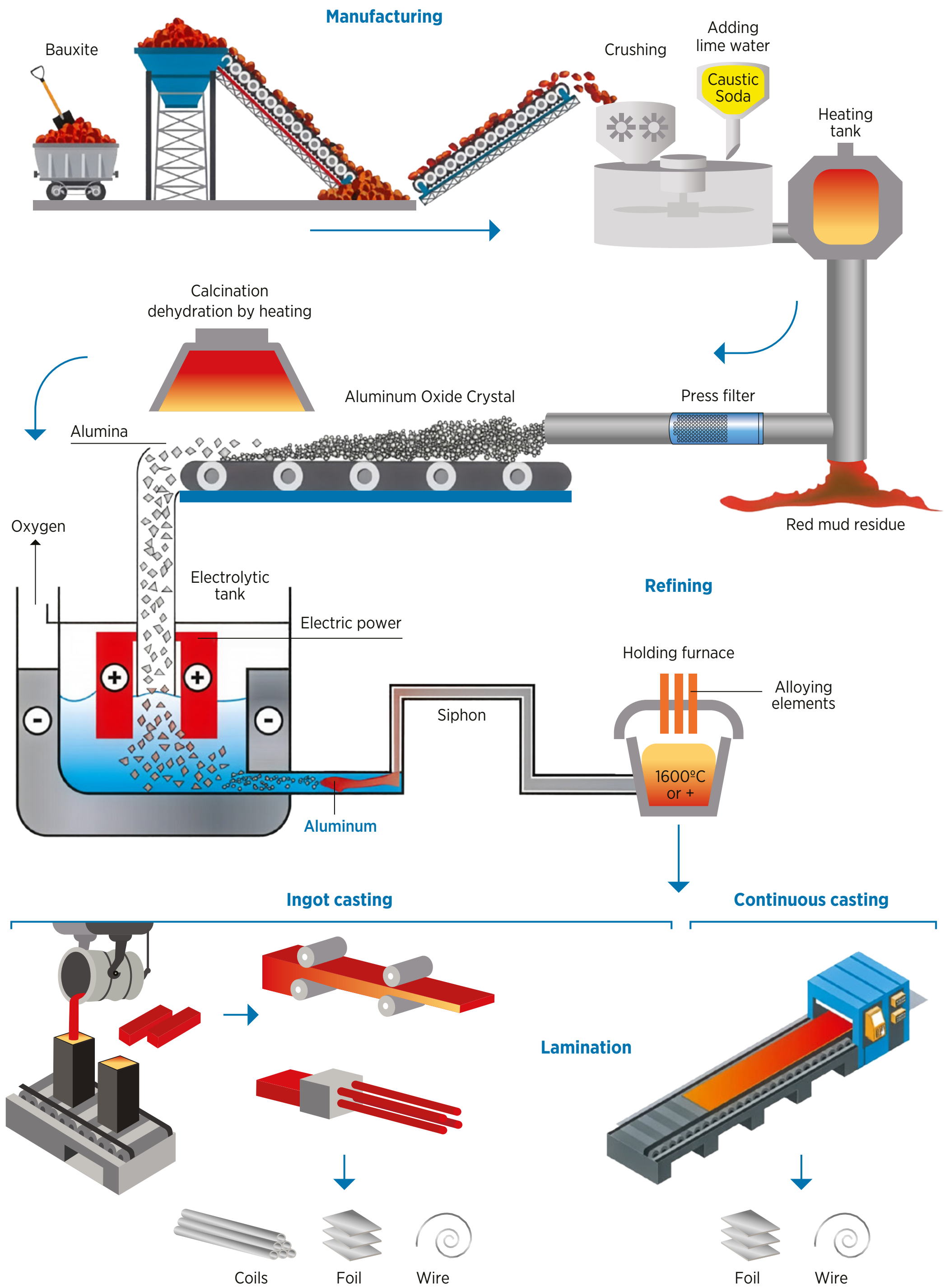
Aluminium circularity plays a critical role in reducing the sector's raw material consumption, energy use, and carbon footprint, all while meeting growing global demand. To understand how aluminium circularity is crucial for a more sustainable global economy, it is important to understand the two distinct routes of aluminium production.

2.1 The aluminium production process

Aluminium is the most widely used metal globally and is also the most abundant metal (in raw form) in the Earth's crust. However, it does not occur in its pure form naturally, and the production of primary aluminium (*i.e.* from bauxite) entails a complex process that demands vast amounts of electricity and fuel. The raw material for producing primary aluminium is bauxite, a rock composed of aluminium oxides and other minerals. Around 390 Mt of bauxite are produced annually, and 85% of this amount is processed to produce alumina (Bhutada *et al.*, 2022). This conversion process is resource intensive, as 4 tonnes of bauxite are needed to produce just 2 tonnes of alumina, and then upon smelting, only 1 tonne of aluminium is produced (Bhutada *et al.*, 2022).

The two production routes for aluminium are the primary route and the secondary route, with the distinction between them being the starting point of the production. In the primary route, the starting point is aluminium ore, whereas in the secondary route the starting point is recycled aluminium. The primary route involves three critical stages: 1) mining bauxite, 2) extracting alumina from bauxite and 3) smelting alumina into metallic aluminium (Figure 10). The secondary route can be grouped in five main stages: 1) collection and sorting, 2) pre-treatment, 3) melting, 4) refining and 5) casting.

FIGURE 10 Primary aluminium manufacturing process starting from bauxite mining to aluminium production



Source: (PRESI, 2024).

Primary route

Stage one: Bauxite mining

The production of aluminium starts with mining bauxite, which generally contains more than 40% aluminium oxide (European Commission, 2020). This mineral is primarily found in tropical and sub-tropical regions, including Australia. With its abundant resources, the country produced around 100 Mt of bauxite in 2023 (World Population Review, 2024).

Stage two: Extracting alumina

The second primary step in producing aluminium involves extracting alumina from bauxite. This includes several stages of the Bayer process:

1) **Crushing** – crushing the bauxite to increase the surface area for the extraction process.
2) **Grinding** – mixing the crushed bauxite with caustic soda (sodium hydroxide).
3) **Digestion** – heating the slurry in a digester to around 220°C under pressure, enabling the caustic soda to react with aluminium compounds in the bauxite, resulting in a sodium aluminate solution (LearnMetallurgy, 2024).
4) **Settling** – letting the slurry rest in a tank where impurities that do not dissolve settle to the bottom.
5) **Filtration** – pumping the remaining liquid through cloth filters to trap any fine particles of impurities in the solution.
6) **Precipitation** – pumping the sodium aluminate solution into large precipitators, where aluminium hydroxide seed crystals are introduced to start the precipitation process, forming large aluminium hydroxide crystals.
7) **Kiln heating** – heating the aluminium hydroxide crystals in rotary kilns at temperatures of 1 400°C (LearnMetallurgy, 2024) to remove water molecules, producing a white alumina or aluminium oxide powder.

Stage three: Smelting alumina into metallic aluminium

The final stage in this process involves smelting the alumina into metallic aluminium using the Hall-Héroult process (the dominant process in the industry, known for its high energy consumption), following three steps (The Aluminum Association, 2024a: 101):

1) **Preparation** – dissolving the alumina in molten cryolite within a carbon-lined pot.
2) **Electrolysis** – applying electric current to the mixture to separate oxygen from the alumina and combining it with the carbon anodes, resulting in molten aluminium collecting at the bottom of the smelting pots.
3) **Collection and casting** – casting the molten aluminium from the smelting pots into different shapes (ingots, billets, slabs) in a cast house.
4) The aluminium can also be transferred to another furnace, where different alloying elements can be added to the melt. These processes lead to the production of semi-finished aluminium products, which are subsequently turned into finished goods.

Secondary route

The secondary route of aluminium production is a highly energy-efficient process that recycles aluminium scrap into reusable aluminium while maintaining material performance standards and integrity.

The aluminium recycling process has five main steps, including:

1) **Collection and sorting** – collecting the scrap materials and categorising them into manufactured waste and end-of-life products, such as used beverage cans (manufactured waste is generally purer than end-of-life products). This is followed by sorting the scrap according to impurity levels and alloy types, then using advanced technologies, such as eddy current separators and colour sorting systems, to improve the quality of the recycled materials.

2) **Pre-treatment** – shredding, crushing and thermally treating the aluminium to remove contaminants such as paint or plastic, which improves scrap density and ensures cleaner metal during melting.

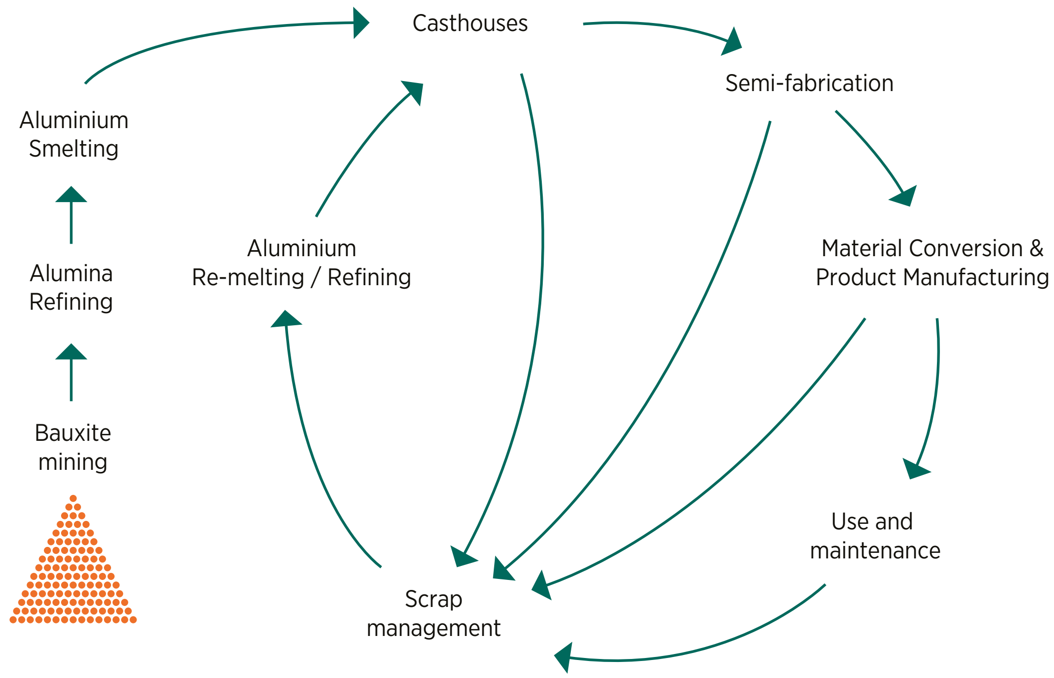
3) **Melting** – heating the prepared aluminium scrap in a furnace to 704°C to 760°C, which remelts clean or lightly contaminated processing scrap from semi-production and manufacturing as well as clean and separated end-of-life scrap. Then, alloying elements and fluxes are added to achieve desired properties and remove impurities. During this process, dross is generated and recycled in the refiner to recover the contained aluminium.

4) **Refining** – melting and recycling all other scrap into casting alloys in the refiner, often by using fluxing salt. The generated dross is recycled internally to recover the contained aluminium, whereby some aluminium is lost and remains in non-metallic residues that are used by the cement industry or for mine filling.

5) **Casting** – casting the refined molten aluminium (casting alloys and wrought alloys) into solid forms (ingots, billets, or slabs, depending on the size and purpose) using methods such as direct-chill casting for large billets and continuous casting for sheets.

6) Circularity requires that the entire life cycle of aluminium products is considered, from design and responsible sourcing to production and end-of-life management. This entails integrating the primary and secondary routes (Figure 11) to enhance resource efficiency and sustainability.

FIGURE 11 The life cycle of aluminium circularity



Source: (ASI, 2023).

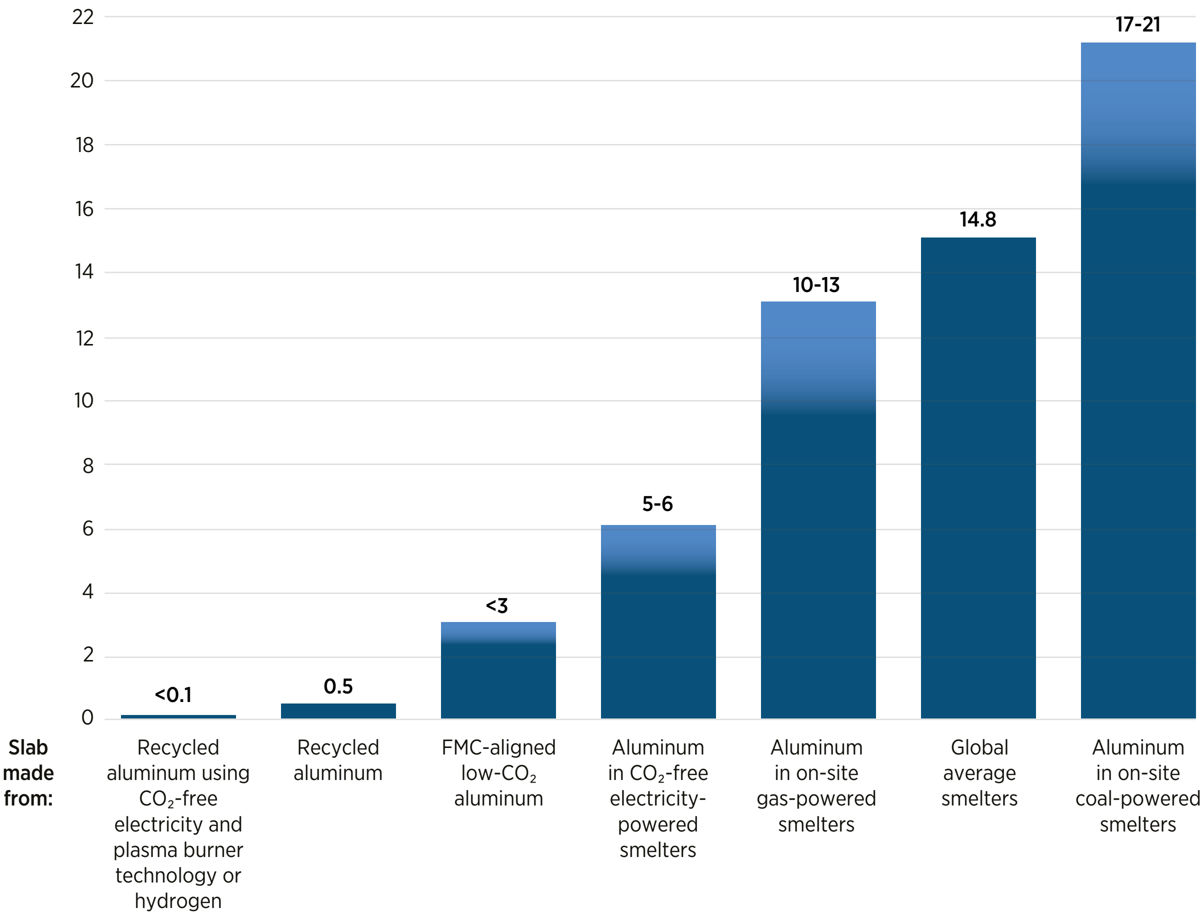
2.2 The value proposition of aluminium circularity

Carbon intensity of recycled aluminium

Recycling aluminium not only conserves resources but also greatly reduces the environmental impact associated with primary production, which involves resource-intensive mining and energy-intensive processes. According to the International Aluminium Institute, in 2019 the primary energy consumption for global primary aluminium production, from mine to cast house, was 186 gigajoules per tonne. In contrast, the primary energy demand for recycled aluminium was 8.3 gigajoules per tonne, saving 95% of the energy needed for primary aluminium production and achieving lower carbon emissions and higher energy efficiency (IAI, n.d.).

Along these lines, the global average carbon intensity for primary aluminium, encompassing all scopes, was 14.8 tonnes of CO_2-equivalent per tonne of aluminium produced in 2023 (IAI, 2024c). The main factor defining the carbon intensity of primary aluminium production is the source of electricity for aluminium smelters (Figure 12). The carbon intensity of primary aluminium ranges between 17 and 21 tonnes of CO_2 equivalent per tonne of aluminium if produced by on-site coal-powered smelters, and between 10 and 13 tonnes of CO_2 equivalent per tonne of aluminium if produced by on-site gas-powered smelters (Ball Corporation, 2025). When smelters are powered by carbon-free electricity, the carbon intensity ranges between 5 and 6 tonnes of CO_2 equivalent per tonne of aluminium produced (Ball Corporation, 2025).

FIGURE 12 Cradle-to-gate carbon footprint of rolling slab aluminium products



Note: A rolling slab is a semi-finished aluminium material used in mills to produce sheets or coils.

Source: (Ball Corporation, 2025).

The First Movers Coalition (FMC) is an initiative that advances the most critical, emerging climate technologies by leveraging the collective purchasing power of members. The companies in the FMC for aluminium have pledged that by 2030 at least 10% of the primary aluminium they procure will be low carbon, produced using breakthrough technologies and emitting less than 3 tonnes of CO_2 equivalent per tonne of aluminium produced. This goal will likely be accomplished not only by powering smelters with carbon-free sources but also by using new and innovative technologies – such as inert anodes; carbon capture, use and storage (CCUS); green hydrogen and mechanical vapour recompression (WEF, 2022a).

Figure 12 shows the dramatic drop in carbon intensity when aluminium is recycled: 0.5 tonnes of CO_2 equivalent per tonne of aluminium produced. This value could be even lower if remelting furnaces are run using carbon-free electricity and plasma burners, a technology that offers a transformative approach to the electrification and decarbonisation of aluminium and the reduction of dross, a waste by-product of aluminium smelting and melting processes.

Aluminium recyclability

Aside from the high resource and energy efficiency of aluminium circularity, the intrinsic physical properties of aluminium render it highly amenable to recycling through a remelting process that occurs at relatively low temperatures and yields remarkably high recovery rates (Box 1). Although a small fraction of metal may be lost, aluminium can be recycled again and again without compromising its quality and properties: lightness, conductivity, formability, durability, impermeability and multiple recyclability. Aluminium's light weight reduces energy consumption in transport, while its durability ensures long product lifespans, further promoting sustainability (Elka Mehr Kimiya, n.d.).

BOX 1 Why aluminium circularity?

- Recycling aluminium requires 95% less energy than producing primary aluminium.
- Fully recyclable again and again without quality losses, despite color, size or format.
- Aluminium scrap has a low melting temperature compared to other metals.
- High yields achieved in recycling.
- No degradation of properties cycle after cycle.
- High cubic efficiency: aluminium products pack into a given volume with minimal wasted space.
- High compaction rate (12:1): 12 units of loose volume are reduced to 1 unit of compacted volume.
- Lightweight, easy and safe to transport.
- Recycle value is higher than processing and transport costs.
- Nearly 75% of all aluminium ever produced is estimated to be still in use today.

Aluminium recyclability is further enhanced by the fact that aluminium can be readily separated from waste streams, and technological advancements in sorting and melting technologies have improved the quality and efficiency of recycled aluminium. Moreover, closed-loop recycling systems enable aluminium recycling within the same alloy family, which helps maintain material quality and reduces the need for new raw materials (Fast Markets, 2024). This efficiency is crucial for industries aiming to decarbonise and maintain material integrity.

The value proposition of aluminium circularity beyond emissions

Along with environmental impact, aluminium circularity brings important economic and societal benefits. The value chain for circular aluminium is strategic to cultivate domestic job markets, stimulate investment in local suppliers and manufacturers, advance community development, and support the growth, competitiveness and contribution to gross domestic product of a key manufacturing industry. Increased collection and recycling of scrap means keeping aluminium out of landfills and more local jobs in waste management and aluminium remelting and rolling. This is on top of bringing production and consumption closer to each other and strengthening resource security and supply chain resilience (Ball Corporation, 2025).

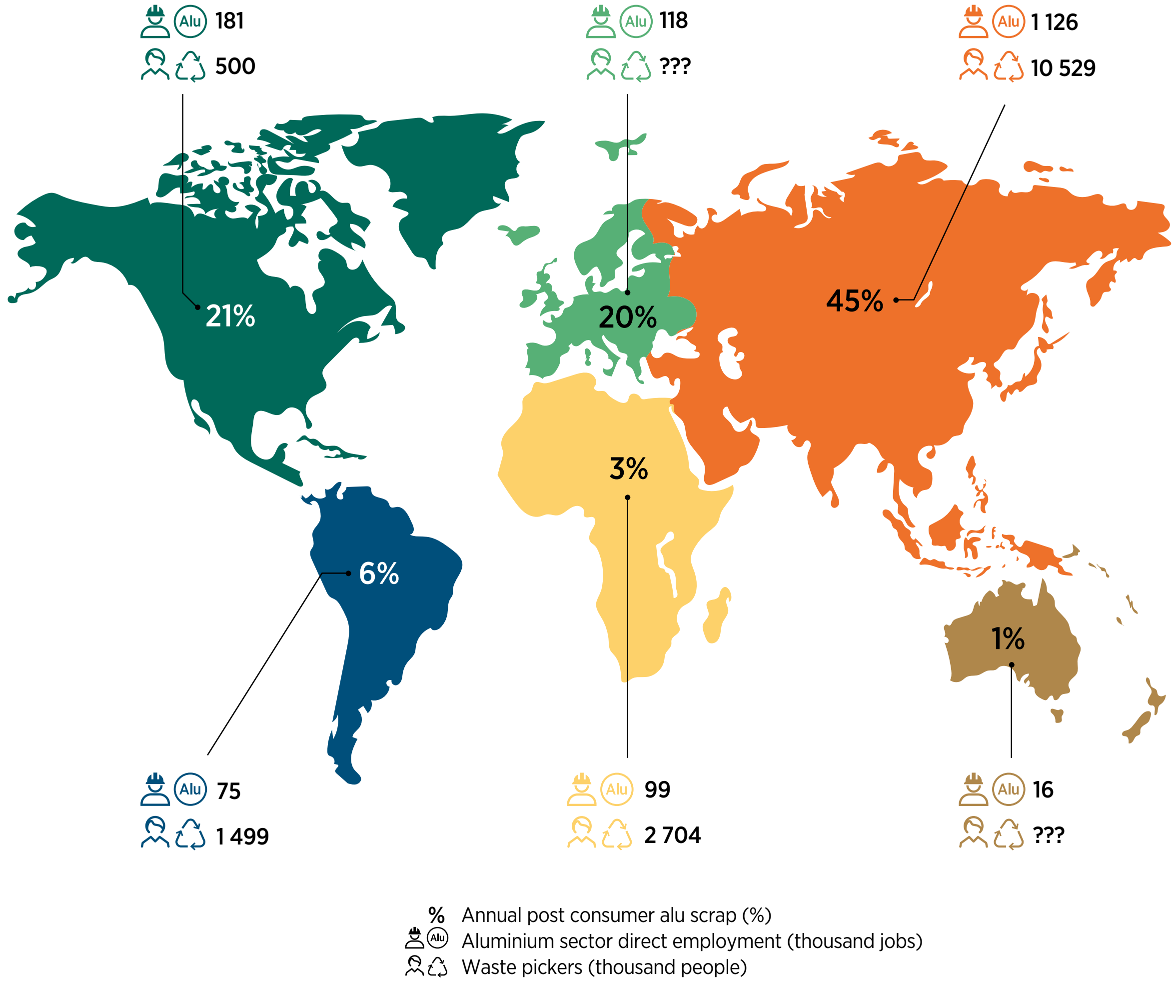
Employment

In 2024, the aluminium sector in the United States directly employed more than 164 000 workers and indirectly supported an additional 535 000 workers (a multiplier effect of 3.16) (The Aluminum Association, 2024b). Recycling of aluminium accounted for 10 109 direct jobs. Between 2022 and 2024, US jobs in aluminium recycling grew 12.5%, hitting a national record.

The European aluminium industry represents 1 million jobs directly and indirectly, with alumina refineries accounting for 3% of the total, primary production for 8% and downstream activities for 89%, which includes rolling, extrusions and recycling.

Globally, the aluminium sector employs 1.6 million people directly, while 15 to 20 million waste pickers play a critical role in collecting post-consumer scrap, greatly boosting recycling, decarbonisation and circularity (IAI, 2020). Figure 13 shows the geographical distribution of people employed directly in the sector and waste pickers.

FIGURE 13 Aluminium scrap shares, sectoral employment, and waste pickers, by region, 2019



Source: (ASI, 2025).

Disclaimer: *This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.*

A study of 16 countries by the Global Alliance for Incinerator Alternatives found that recycling 10 000 tonnes of aluminium waste creates 115 jobs and around 50 times as many jobs as landfills and incinerators (GAIA, 2021). The data showed that semi-mechanised operations, which depend less heavily on machinery for the collection and processing of recyclables, tend to be more job intensive than operations that depend less heavily on manual labour. Thus, the aluminium recycling industry is a significant contributor to job creation and economic activity due to the higher labour intensity of collection and recycling.

Advancing aluminium circularity depends greatly on the critical role of waste pickers, who collect, sort and re-integrate valuable materials into the supply chain, saving substantial costs (both economic and emission-related) in waste management. Efforts to promote circularity therefore must prioritise the social and economic well-being of waste pickers, with a focus on fair wages, good working conditions, safety and access to resources. Promoting responsible sourcing practices and fostering collaboration among workers, governments and industries can help create a fair recycling ecosystem that not only builds a world free from waste but also uplifts communities, leading the way to a circular future that works for all. Figure 14 outlines inclusive recycling practices as defined by the Aluminium Stewardship Initiative.

FIGURE 14 Inclusive recycling practices

- Develop standards for safe working conditions for waste pickers and vulnerable groups.
- Provide benefit programs (healthcare, education, housing) tied to employment.
- Partner with NGOs to boost economic benefits for recycling communities.
- Ensure fair wages meeting or exceeding national standards.
- Offer job training programs tailored for waste pickers and vulnerable workers.
- Implement community development programs for sustainable economic, educational, and health benefits.

Source: (ASI, 2025).

Material value

Aluminium's inherent circularity, through its recyclability without losing properties, greatly increases its material value in a circular economy.

Aluminium is by far the most valuable item in the recycling bin, on a per tonne basis. For example, although aluminium beverage cans were only 3% by weight of all recyclable materials generated at US single-family homes in 2020, they represented nearly half of the revenue of those recyclable materials (The Recycling Partnership, 2020). Without the revenue from aluminium beverage cans, many municipal recycling programmes would not be viable, and recycling sortation facilities in the United States would not be able to operate (Can Manufacturers Institute, 2020; The Aluminum Association and CMI, 2024).

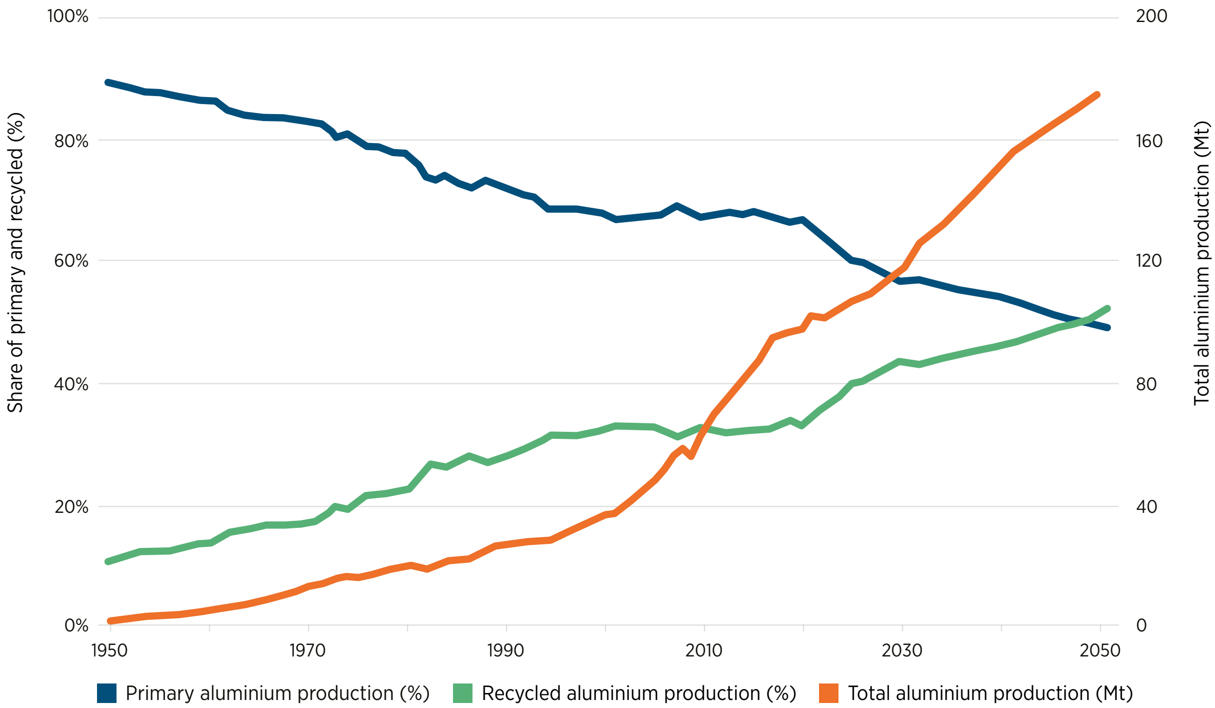
The Aluminium Association estimates that recycling all the aluminium beverage cans that end up in US landfills each year would result in around USD 1.2 billion in economic savings and would save enough energy to power more than 2 million homes for a full year (The Aluminum Association, 2022). Data based on 2024 recycling rates suggest that the US economic loss from not recycling could be closer to USD 2.1 billion and that, globally, around USD 2.7 billion in savings is lost to landfills every year (Eunomia, 2024).

2.3 Aluminium circularity to 2050

As a result of the robust value proposition of aluminium circularity, the role of scrap recycling has increased significantly since the early 2000s. The global market totalled 38 Mt in 2024 and is projected to reach 57 Mt by 2030, rising at a compound annual growth rate of 7% (Research and Markets, 2025).

Under the International Aluminium Institute's 1.5°C scenario, by 2050 a projected 81 Mt of recycled (secondary) aluminium will be produced from recycled scrap. Of this, 68 Mt will be derived from post-consumer sources and only 13 Mt from new or manufacturing scrap, indicating that improved collection systems will ensure that minimal aluminium is lost to landfills or incineration. Under the same scenario, 68 Mt of primary aluminium will be produced in 2050, with recycled aluminium overtaking primary aluminium production in 2030 (Figure 15). The scenario assumes that the carbon intensity of primary aluminium will fall to 0.5t CO_2eq/t Al and that the carbon intensity of recycled aluminium will fall to 0.1 t (IAI, 2021b).

FIGURE 15 Share of primary and recycled aluminium along with global production rate, 1950 to 2050



Source: (Raabe *et al.*, 2022).

Achieving these volumes and rates is not without challenges. Inter-related technical obstacles include the need to advance post-consumer collection methods, efficient sorting techniques and the quality of scrap aluminium; these are combined with economic challenges and the need for significant upfront investments. The design and implementation of adequate policies and incentives are critical. Moreover, recycling should be enhanced and complemented by strategies, new business models, and practices to reduce waste and keep aluminium in circulation (ASI, 2023). Industry alignment, value chain collaboration, cross-sectoral partnerships, and joint work with governments and communities must be further developed and strategically scaled to realise the full potential of aluminium.

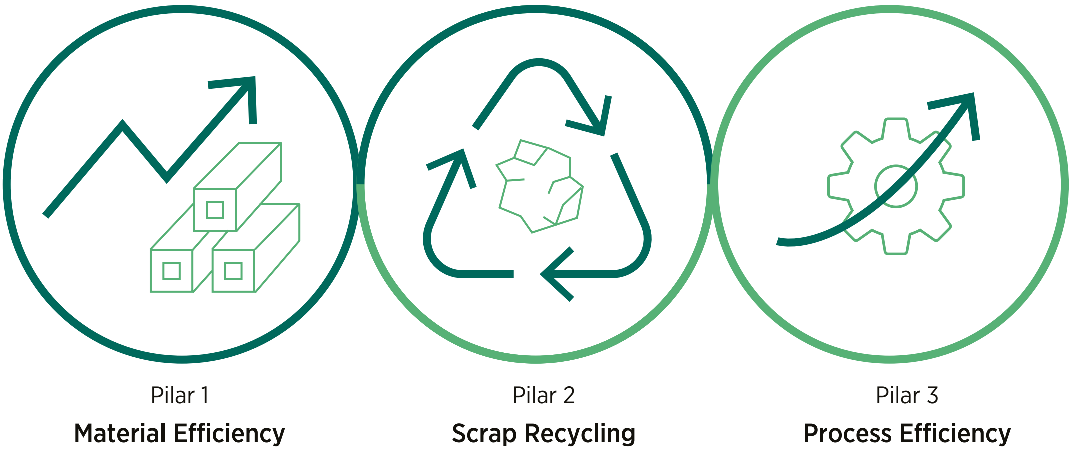
The next section addresses these topics by exploring strategies and innovations aimed at further improving the circularity of the sector, including material efficiency, maximising the potential of recycled aluminium, and improving process efficiency in aluminium production.

2.4 Leveraging aluminium's properties for circularity

Circular economy pillars in the aluminium sector

Within the aluminium industry, three pillars of circularity play a central role in enhancing sustainability, combined with strategies to further improve the way aluminium is used and recycled. These pillars are: 1) reducing aluminium demand through increased material efficiency, 2) maximising the potential of scrap recycling of aluminium, and 3) improving process efficiency in aluminium production (Figure 16).

FIGURE 16 Circular economy pillars in the aluminium sector



Pillar 1: Material efficiency

Material efficiency plays a key role in advancing the circularity of the aluminium sector by optimising aluminium use, extending the life cycle of the material and reducing demand for primary aluminium. Measures include producing lighter aluminium products and structures, refurbishment and re-use, and product design for disassembly and recycling (IEA, 2019).

There is a push to reduce alloy complexity, in terms of both the processing required and the chemical composition. Simpler alloys are not only more energy efficient to produce but also easier to recycle, as fewer elements are involved, leading to reduced contamination risks. In addition, the design of alloys with minimal processing steps and fewer chemical ingredients contributes to energy savings and streamlines production. This aligns with the goal of achieving desired material properties more through microstructural adjustments rather than relying heavily on composition changes.

Pillar 2: Aluminium scrap recycling

Leveraging the extraordinary properties of aluminium, and recycling it in closed loops, is critical for improving circularity by maximising resource use, reducing waste, and preserving the value of the material, keeping it in use for as long as possible at its highest value. To make the most of aluminium scrap recyclability, several key factors must be in place: product design that allows for higher levels of recycled content, including innovative alloys; investments in remelting capacity; and enhancements in collection quantities, supported by effective policies and advancements in collection and sorting technologies (Raabe *et al.*, 2022).

Techniques such as spectroscopy and artificial intelligence (AI)-assisted alloy detection are being employed to better classify and sort scrap based on alloy type. These innovations not only enhance sorting accuracy but also increase the efficiency of the recycling process by ensuring that the correct alloys are recycled together. Another important focus is the efficient recovery and recycling of critical alloying elements, which are essential for maintaining the properties of high-performance aluminium products. By ensuring that these elements are recovered during recycling, the sector can reduce the need for primary material extraction and further close the loop in the aluminium life cycle.

Pillar 3: Process efficiency

Enhancing process efficiency in aluminium production is essential to minimise resource consumption, reduce the environmental impact of production and improve sustainability. Moreover, optimising the production processes can lower costs, making aluminium more competitive while simultaneously supporting the transition to a circular economy.

One approach to improve process efficiency in the aluminium industry is to develop process workflows that streamline production by minimising the number of process steps, reducing the need for auxiliary materials and cutting down on energy requirements. Moreover, low-temperature production methods are being explored, such as low-temperature warm rolling protocols and low-temperature annealing treatments, which require less energy compared to traditional high-temperature methods (Raabe *et al.*, 2022).

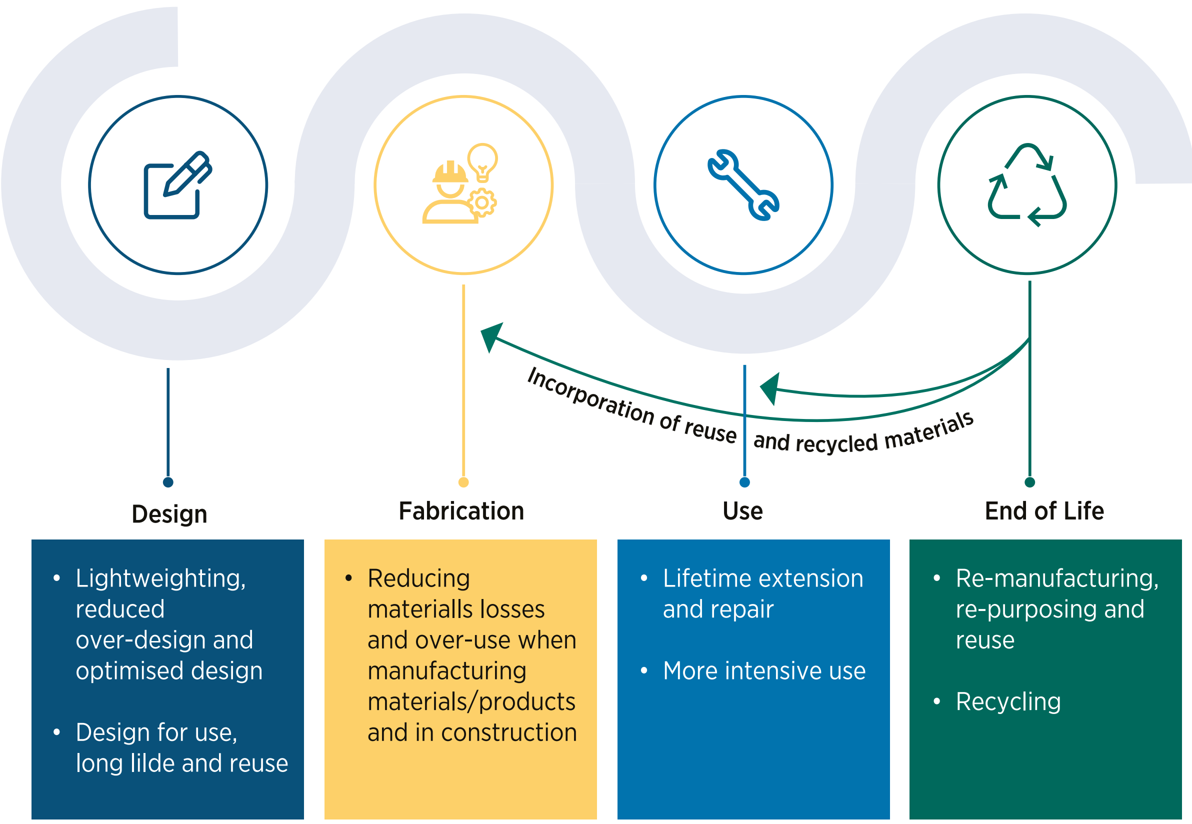
Options to improve the circularity of the sector

Strategy 1: Reduce aluminium demand through increased material efficiency

Aluminium demand is projected to increase 40% between 2020 and 2030, from 86.2 Mt to 119.5 Mt (IAI, 2022). This could lead to significantly higher greenhouse gas emissions, waste generation and environmental penalties in the aluminium sector. There is an urgent need to adapt material efficiency measures to decrease demand, without compromising the aluminium market.

Strategies should be explored that reduce aluminium demand while promoting sustainable aluminium use and potentially offering larger-scale environmental and economic benefits. For example, adapting lightweight aluminium cans for food and beverage packaging will directly reduce material, production, and transport costs, thereby reducing the product selling cost. Figure 17 summarises the material efficiency strategies that may be applicable in the aluminium value chain.

FIGURE 17 Material efficiency strategies across an industry value chain



Source: (OECD, 2024).

TABLE 1 Potential strategies to reduce material loss in aluminium production

Production stage	Material loss	Reduction strategy
Bauxite mining and alumina refining	During the Bayer process, a large portion of bauxite (c. 30-50%) is left as red mud waste, containing iron oxides, silica and unextracted alumina. Some alumina remains in the residue due to incomplete extraction.	Pursue red mud valorisation (recovering residual alumina, extracting rare metals, etc.) Use process optimisation to increase alumina extraction efficiency.
Aluminium smelting	Oxidation of molten aluminium leads to dross formation, where some aluminium is lost.	Further develop and scale dross recycling technologies to recover aluminium content; explore the applications of non-metallic residues.
Casting and rolling	Poor-quality casting can lead to defects, requiring remelting and reprocessing. Cutting and shaping aluminium sheets can leave excess material as scrap.	Use high-efficiency casting techniques to minimise defects. Maximise material use in sheet cutting.
Fabrication and machining	Metal shavings and offcuts can remain from machining. Over-engineering of components may lead to unnecessary aluminium use.	Adapt near-net-shape manufacturing techniques to minimise post-processing. Implement circular design strategies.
Remelting	Contamination of aluminium streams through alloy mixing or the accumulation of foreign elements, combined with limited melt purification options during remelting, restricts recycling and leads to permanent downcycling or quality losses (Paraskevas *et al.*, 2019).	Improve collection and sorting. Aim for closed-loop recycling for the material to come back into the market to serve the original purpose for multiple uses, without quality losses or material degradation.

Design

To achieve material efficiency, circular design must be adapted for aluminium products. Thoughtful design and engineering can help achieve the same or improved functionality while greatly reducing the amount of material required. Efficient design principles such as lightweighting, structural optimisation and precise manufacturing may minimise material use while maintaining performance standards. For example, reducing aluminium thickness and weight in non-structural applications such as single-use packaging (i.e. beverage cans and kitchen foils) will effectively reduce aluminium consumption. Meanwhile, in structural applications such as in the automotive and construction industries, aluminium components can be designed to be both stronger and lighter, allowing for the same structural integrity with less material. The use of recycled aluminium must be considered in designing new products, which should be conceived to be easily recycled and potentially repurposed, ideally turning them into higher-value products.

Special consideration should be given to alloy design, as standardisation (when feasible) would avoid using multiple alloy compositions and would simplify material recovery. There are hundreds of registered aluminium alloy types. Although only a limited number of these are widely used, the broad range of compositions and alloying elements complicates segregation and sorting processes. The 1000 series, with over 99% aluminium content, is relatively pure and most ready to recycle. In contrast, the 7000 series includes higher levels of alloying elements such as zinc, which limits their recyclability. In the near term, aligning alloy compositions with those present in recovered material streams can help increase recycled content without compromising material properties or performance.

Over time, the number of alloy variants should be reviewed to determine whether their proliferation poses a challenge to effective and efficient recycling. Using multiple alloy types within a single product often results in contamination, leading to downcycling. Rationalising alloy selection during the design stage could support easier recovery and open opportunities for more circular approaches such as re-use or remanufacturing (Pilgrim and Runton, 2023). This design shift may be encouraged if designers and producers are more invested in material recovery – whether through regulatory measures or new business models.

Lastly, designing products with greater durability would encourage re-use and result in longer lifespans and greater efficiency.

A circular economy approach that combines smart design, material efficiency, and enhanced recycling can reduce primary aluminium demand, cut emissions and improve cost efficiency for various aluminium applications.

Fabrication

Material losses occur at various stages of the aluminium production process, which leads to waste generation and unused resources. Strategies to reduce loss and optimise material efficiency during aluminium manufacturing must be explored, as shown in Table 1. Some losses may be inevitable, such as when creating material-efficient lightweight components that require intricate processes to be formed according to their application, but there could be areas in the process where material loss can be potentially reduced.

Use

To reduce aluminium consumption, one of the most effective approaches is to extend the service life of aluminium products. This includes increasing the longevity of existing products and repurposing aluminium materials for different uses. This is also the stage in the value chain where consumer engagement is crucial. While the aluminium manufacturing industry is responsible for the design of durable aluminium products that can withstand longer service, lifetime extension through repair and re-use relies on the consumers. Promoting re-use and repair, rather than relying on disposal, would help decrease the need for fresh material production. For example, aluminium components in buildings or infrastructure can be re-used in other applications that do not require further processing, reducing the need to produce new aluminium supply.

Consumer products made from aluminium, such as packaging or electronics, often have shorter service life, especially single-use products. In this case, policies and systems that focus on convenience and that incentivise the return and efficient disposal of aluminium products are fundamental for circularity. When possible, repair of products and regular maintenance of structural aluminium-based products such as those used in aerospace and automotive applications can extend their useful life, further decreasing the frequency of replacements and minimising the overall demand for new aluminium materials.

End of life

Prior to disposal at the end of an aluminium product's service life, re-use must first be considered. Re-using a product or material reduces the demand for aluminium production. Re-use can take various forms, including relocating, refurbishing, cascading and re-forming (Table 2) (IEA, 2019). In cases where re-use is no longer possible, recycling must then be considered.

TABLE 2 Types of re-use and potential examples for the aluminium sector

Type of re-use	Definition	Example
Relocating	Component is used in another product of the same type for the same purpose, with little refurbishment.	An aluminium engine block from a decommissioned car is re-used in another vehicle of the same model, with minimal cleaning and inspection.
Refurbishing	Component is used in another product of the same type for the same purpose, after undergoing significant repair and reconditioning.	Used aluminium window frames are repaired, repainted and reconditioned before being installed in another building.
Cascading	Component is used in a different type of product, with little reconditioning.	Discarded aluminium aircraft panels are repurposed as durable roofing sheets for shelters, with minimal processing.
Re-fill	Aluminium product is re-filled to serve the same application, with some reconditioning.	Aluminium bottles for personal and home care products are returned, professionally washed and disinfected, refilled and distributed back to consumers.

Source: (IEA, 2019)

While decreasing overall aluminium demand is important, in some cases aluminium use is the preferred option. Aluminium possesses good strength-to-weight ratio and is a good lightweight alternative to steel and other metals (particularly for the design of lightweight vehicles). When choosing among different energy- and emission-intensive metals or products, the overall benefit of increasing production must be weighed. Even so, aluminium demand must be reduced whenever possible and must be utilised responsibly.

Strategy 2: Maximise the potential of recycled aluminium

The environmental benefits of creating a strong circular system come from displacing primary resource production – ensuring that recycled materials, rather than primary resources, are used to create new, high-quality products.

Aluminium scrap, the raw material that feeds the aluminium recycling process, has a high intrinsic value because most of the energy required to produce primary aluminium is embodied in the metal itself – and, consequently, in the scrap. Therefore, the energy needed to melt aluminium scrap is only a small fraction of that required for primary aluminium production.

Recycled content is the ultimate circularity metric for accelerating aluminium decarbonisation. Achieving high levels depends on several critical factors: product design that allows for higher levels of recycled content, including innovative alloys; enhancements in scrap availability and closed-loop recycling, supported by effective policies and advancements in collection and sorting technologies; and investments in remelting capacity.

Product design

An aluminium alloy is a metal mixture where aluminium is the primary metal, combined with other elements (such as copper, magnesium, manganese, silicon or zinc) to enhance its strength, corrosion resistance, workability and other properties for various applications. Mixing different aluminium alloys during recycling creates cross-contamination, which is usually "corrected" by adding pure primary aluminium in the remelting process, hence limiting the potential for higher recycled content.

The development of recycling-friendly alloys and the design of products that can accommodate them, combined with purification technologies able to remove impurities such as iron and silicon from molten aluminium in the remelting process, should enable the production of high-quality recycled aluminium with performance comparable to primary alloys, allowing greater use of recycled content in markets traditionally reliant on primary aluminium.

High-quality scrap availability and closed-loop recycling

The ability of the aluminium industry to realise its full circularity potential depends on the sufficient supply of high-quality scrap to recycle, which is generally scarce. Scrap availability and, in turn, recycled content can only increase if adequate infrastructure, technologies, and policy mechanisms and incentives are in place to collect, dismantle and sort end-of-life aluminium. For example, a key policy mechanism for increasing the recycling rates of beverage containers is deposit return systems, or DRS (Box 2).

Where collection systems are not efficient, end-of-life aluminium products are co-mingled. The resulting mixed alloys often cannot be recycled into the same product and are converted into lower-quality products such as cast aluminium, which is used for applications like car engine blocks in a process known as open-loop recycling.

A real circular economy requires a shift from conventional recycling towards material preservation, ensuring that resources remain in use at their highest functional value for as long as possible. Closed-loop recycling, unlike open-loop systems, allows materials to re-enter the market for the same application, maintaining quality across multiple cycles and greatly reducing waste. This model fosters a positive feedback loop: high recycling rates and a greater share of recycled content in new products. The overall effectiveness depends on the performance of each stage in the recycling value chain, including collection, sorting, remelting and the making of a new product.

BOX 2 Deposit return systems for aluminium beverage cans

A deposit return system (DRS) is a policy mechanism that has successfully increased the recycling rates of beverage containers in certain geographies. DRS schemes have been adopted in over 50 markets worldwide, covering a global population of nearly 357 million, according to Reloop. In this approach, consumers pay an upfront deposit that is returned when the empty aluminium, PET (polyethylene terephthalate) plastic, and in some cases glass containers are taken back to specific collection points, either manually operated or automated with a reverse vending machine.

The implementation of modern and well-designed DRS schemes has been shown to achieve collection rates of 90% within a few years. As a result, the proliferation of such systems has recently accelerated, evidenced by an increase in Europe from 9 DRS programmes for beverage cans in 2016 to 17 programmes in 2025. The recently adopted robust Packaging and Packaging Waste Regulation in the European Union mandates that Member States meet high separate collection targets for both single-use plastic bottles and metal beverage containers by 2029.

Consequently, the number of countries adopting DRS schemes is anticipated to rise further. Greece, Poland, Portugal, Spain, Türkiye and the United Kingdom are all poised to implement DRS programmes in the coming years. Already, DRS schemes have been effectively adopted in various jurisdictions, including most provinces in Canada, some of which have had such systems in place since the 1970s. In Quebec, where a DRS was introduced in 1984, a modernisation initiative is under way that entails increasing the deposit value, expanding the programme to encompass additional beverage types, and incorporating a wider array of container sizes.

A similar modernisation effort has been enacted in the US state of Connecticut, enhancing the deposit value and extending the range of eligible containers to include more beverage types, alongside improvements to the redemption network to offer greater convenience to consumers. These enhancements have already led to a reported 30% increase in container returns, with projections indicating a recycling rate of around 2 billion containers annually, according to Tomra.

In Australia, the states of Victoria and Tasmania are set to join the remainder of the country in implementing a comprehensive DRS scheme.

Technologies that improve the economics of deposit return systems

In the last few years, significant advancements have occurred that can potentially change the economics, social acceptance and industry interest in DRS schemes. These include advances in reverse vending machines, counting centres, logistics and other technologies. Decreasing the collection cost per container, reflected in lower producer fees, could make the systems more appealing to brands. Innovations in return-to-depot models make recycling refund systems more appealing to retailers. Bulk and bag drop make the process more convenient to consumers. Table 3 describes several innovations and concepts that can change the acceptability of DRS programmes and policies, especially in regions where new legislation has struggled to pass.

TABLE 3 Technologies that improve the economics of deposit return systems

Technology	Description
Return-to-depot models enabled by high-volume counting and sorting technologies	Traditional DRS schemes, particularly in Europe, have largely adopted a "return-to-retail" model. In this set-up, stores that sell beverages are legally obligated to accept used containers for recycling, typically using reverse vending machines located on their premises. In contrast, regions like the United States have preferred a "return-to-depot" approach that centralises collection away from retail locations. This method allows for convenient options such as "bag drops" or "bulk returns", where beverage containers can be returned mixed together. Modern technology now enables effective sorting and separation of different container types before transporting them to reprocessing facilities. The introduction of next-generation, highly automated counting and sorting equipment is enhancing cost efficiency by managing a larger volume of containers.
Bag drop and cash-in-hand reverse vending machines	Bulk-feed reverse vending machines allow consumers to effortlessly empty large bags of empty containers directly into the machine, enhancing convenience. With high-capacity storage, super-fast container processing, and minimal handling, these machines are capable of processing over 100 used beverage cans in one go, making recycling easier for consumers.
Compact reverse vending machines	Compact reverse vending machines provide a cost-effective solution for locations with limited space and lower processing capacity. These machines are designed for convenience stores, service stations and behind-the-counter use in bars. Some models come with wheels for added portability.
Mobile reverse vending machines	Mobile reverse vending machines are an innovative solution designed for events like music festivals. These machines are equipped with point-of-sale counting, a storage capacity of 14 000 containers and a heavy-duty compression unit that offers a 10:1 compression ratio for metal cans. This design not only enhances convenience and efficiency but also requires a lower investment and provides immediate payment.
Serialisation	While still an emerging concept that lacks a clear definition and is not yet commercially available, the idea of serialised DRS schemes is gaining momentum, particularly as a complement to traditional DRS. In this approach, each container is labelled with a unique serialised code, often represented as a two-dimensional code, making it possible to trace individual aluminium cans along with detailed information on their production, sale, consumption and disposal. This enhanced data collection could greatly improve the economic viability of DRS, creating stronger incentives for wider adoption in various regions. A serialised DRS system could reduce reliance on reverse vending machines, enabling the establishment of alternative collection points and enhancing accessibility.

Sorting technologies that enable recovery from materials recovery facilities, landfills and incinerators

A variety of improved sorting technologies exist that would enable greater recovery of aluminium from materials recovery facilities, landfills and incinerators. These are described below and summarised in Table 4.

- **Eddy current separators.** Eddy current separators are belt systems that exploit the physical principle whereby non-ferrous metals, when subjected to a variable magnetic field, experience repulsion forces that cause them to jump away from the source of that magnetic field. This technology has been used in materials recovery facilities for many years and typically offers a good return on investment due to the high value of aluminium. Adding eddy current separators to sorting centres leads to significant improvement in the separation of aluminium from other materials. These systems also effectively target smaller aluminium fractions, such as coffee capsules or crushed cans that may fall into the smaller segments of the trommel. Heavy-duty eddy current separators are commonly installed at mixed municipal solid waste plants to recover aluminium from general waste, either prior to landfilling or before the waste is incinerated.
- **XRT, XRF, ISS, LIBS for alloy sorting.** Advanced sorting techniques – including X-ray transmission (XRT), X-ray fluorescence (XRF), inductive sensor sorting (ISS) and laser-induced breakdown spectroscopy (LIBS) – enable precise alloy sorting in the recycling process. These technologies facilitate the accurate identification of aluminium alloys, improving the quality of recycled aluminium and expanding the range of scrap materials that can be processed and kept in high-circularity applications.

- **Robots + AI.** The integration of robotics and AI into sorting processes enhances efficiency and accuracy and can have a decisive role in fostering new end-of-life strategies and practices. AI algorithms can optimise sorting operations in real time, allowing for rapid adjustments based on material composition, shape, size and other visual characteristics. This leads to:
  - Innovative technologies for alloy identification and material identification combined with robotics and digitalisation for smart sorting processes.
  - Better sorting of end-of-life products.
  - Higher recovery rates and improved operational efficiency.
  - Higher quality of scrap flow, when combined with targeted dismantling operations.
  - When paired with better collection processes and technologies, limited need to treat incinerator bottom ash (to the minimum necessary) and potential phase-out of landfilling completely.
- **Recovery from mixed waste sorting before landfills and incinerators.** Currently, more than 2 billion tonnes of municipal solid waste are generated each year worldwide, with volumes continuing to rise (Valavanidis, 2023). Mixed waste sorting serves as a final-stage solution to recover recyclable materials – such as plastics, metals and paper – prior to incineration or landfilling. Adopting mixed waste sorting as a standard practice could prevent greenhouse gas emissions of up to 730 Mt of CO_2eq globally by 2030. Countries that use mixed waste sorting typically increase their recycling rates by two to five times (TOMRA, 2025). Even though recovering metals before landfill or incineration is a wise, resource-efficient practice, it is not broadly implemented.

  Whether it is installing eddy current separators or sensor-based technologies, the paybacks for incinerators are often very good, and more aluminium recovery before incineration can be expected. Recovering aluminium from incinerator bottom ash is also possible but comes with some oxidation.

TABLE 4 Technologies for aluminium sorting and separation

	XRT technology	LIBS technology	AI-based technology
Function	Sorting aluminium by density	Sorting aluminium by alloy class	Sorting by specific visual material properties
Typical applications	Sorting of low- and high-density alloyed aluminium fractions	Sorting of specific aluminium alloys, e.g. 5xxx or 6xxx classes	Additional cleaning of wrought or cast aluminium
Detection method	X-ray transmission	Laser-induced breakdown spectroscopy	Neural networks
Sorting criteria	Atomic density	Chemical composition	Shape, texture, form
Benefits	• Allrounder in aluminium sorting • High-volume and high-quality processing • Long-proven technology	• Most advanced sorting step in the aluminium market • Sorting at the finest possible level of detail • Tapping into new market opportunities	• Low operating costs • Allows upgrading of aluminium • Flexibility to adapt to new applications with future updates
Synergies with other technologies	Core step in aluminium sorting, enhanced by other technologies	Next-level sorting after XRT pre-treatment	Complementary to XRT and/or LIBS technologies for specific sorting tasks
Technology maturity	>20 years	<5 years	<5 years

Source: (TOMRA, 2024)

Remelting capacity

Remelting and rolling capacity have to grow steeply to meet the projected growth by 2030 to deliver the volumes needed in a scenario that is compliant with keeping global temperature rise within 1.5°C by 2050.

Rolling mills are making several investments in remelting and rolling processes that will enhance their remelting capacity, thereby increasing the potential for incorporating more recycled content in their products. While no data are available on existing global remelting and rolling capacity, Table 5 compiles recent remelting and rolling capacity announcements and is derived from publicly available sources; it may not be exhaustive or comprehensive.

TABLE 5 Remelting and rolling capacity announcements

Investment	Capacity (kilotonnes)	Description	Location	Status
Novelis Bay Minette	600	Integrated remelting and rolling mill	Alabama, US	Due to be finished in second half of 2026
Aluminum Dynamics Columbus	600	Rolling mill with two satellite remelt casthouses	Mississippi, US (rolling mill); Nevada, US and Mexico (remelt casthouses)	Due to open in 2025
Constellium Neuf Brisach	130	Remelt casthouse and recycling centre adjacent to existing rolling mill	Neuf-Brisach, France	Opened in 2024
Novelis Latchford	85	Expansion of existing satellite remelt casthouse	Manchester, UK	To begin commissioning in 2026
Ma'aden Ras Al Khair	400	Remelt casthouse adjacent to existing rolling mill	Ras Al Khair, Saudi Arabia	Announced in 2024
Novelis Pindamonhangaba	70	Rolling capacity expansion	Pindamonhangaba, Brazil	Planned for 2026
Hindalco	170	Cold mill capacity	Hirakud, India	Scheduled for commercial production in 2026
Speira Rheinwerk	Not available	Additional recycling furnace	Rheinwerk, Germany	Production scheduled to start in early 2026
Hydro Spain	70	Greenfield aluminium recycling plant to produce extrusion ingots	Torija, Spain	Final build decision was expected in second half of 2024; production expected to start in 2026

Source: (Ball Corporation, 2025)

Next generation of more efficient furnaces

The advancement of next-generation furnaces is increasingly characterised by enhanced operational efficiency, which, paired with the availability of higher quality of certain aluminium scrap, translates into a shift in recycling paradigms. Brands that have secured first rights of refusal are now channelling larger volumes of end-of-life aluminium towards major rolling mills for closed-loop recycling. Consequently, there is a strong incentive to establish product-specific recycling furnaces. These are equipped with special features such as dedicated, specifically designed loading points, minimising dross generation and reducing temperature loss during the recycling process.

Conversely, emerging furnace designs are increasingly accommodating lower-quality scrap materials. In addition, improvements to reverberatory melting furnaces are enhancing their efficiency in handling scrap materials with a higher concentration of volatile organic compounds (VOCs), leading to reduced raw material costs and improved energy consumption.

The integration of automated control systems at remelting and casting facilities – featuring sophisticated technologies such as AI for image analysis and various sensor technologies – combined with predictive analytics and smart automation frameworks, has resulted in notable operational improvements, including: reduction of cycle times, decrease in gas consumption, optimisation and homogenisation of production efficiency across all shifts, and increase in metal yields and reduction in dross losses.

Electric holding and pusher furnaces

Electric holding and pusher furnaces operate at relatively low temperatures, typically below 600°C, and can be electrified as the required technology is already established. Numerous examples of electrified heat treatment furnaces are in operation worldwide.

Aluminium scrap purification technologies

Alcoa is developing a process called ASTRAEA that converts low-quality aluminium scrap to purity quality levels far exceeding commercial smelters, potentially tapping vast supplies of unused aluminium scrap (Alcoa, 2021). The ASTRAEA process could take any post-consumer aluminium scrap, regardless of alloy combination, and beneficiate it up to P0101 (a high-purity alloy). This super-pure metal could then be blended with less-pure scrap to produce a metal that meets purity thresholds, vastly improving the supply of post-consumer scrap that can be used as a raw material. The purity would be high enough for most rolling mill and extrusion applications, including in aerospace. No pilot has been announced yet.

Dross recovery improvements

Dross recovery technology plays a vital role in minimising waste and recovering valuable aluminium from dross, a hazardous solid waste by-product of aluminium smelting that contains aluminium, salts and oxides. Rotary furnaces can process dross and add value to an otherwise discarded residue from the furnaces and smelters. The typical recovery rate of dross is around 40% to 60%; however, it depends on the aluminium content of the source, as the aluminium contained can be extracted or recovered during the dross generation or by good practices to minimise dross formation in the furnaces. The overall global trend among aluminium smelters and remelters is to incorporate this equipment into their facilities to ensure maximum profitability of the scrap purchased and generated within the plant.

Strategy 3: Improve process efficiency in aluminium production

The carbon footprint of aluminium varies widely across different regions and production facilities, indicating substantial potential for efficiency improvements through the adoption of best practices. Several options presented in this report can greatly enhance the efficiency of aluminium production, addressing both energy consumption and carbon emissions.

This section explores another fundamental element in aluminium decarbonisation: process electrification, with a focus on alumina calcination, the last key step in alumina refining. It also outlines the technological, economic, and regulatory and policy challenges hindering the effective deployment and maximisation of process and energy efficiency measures.

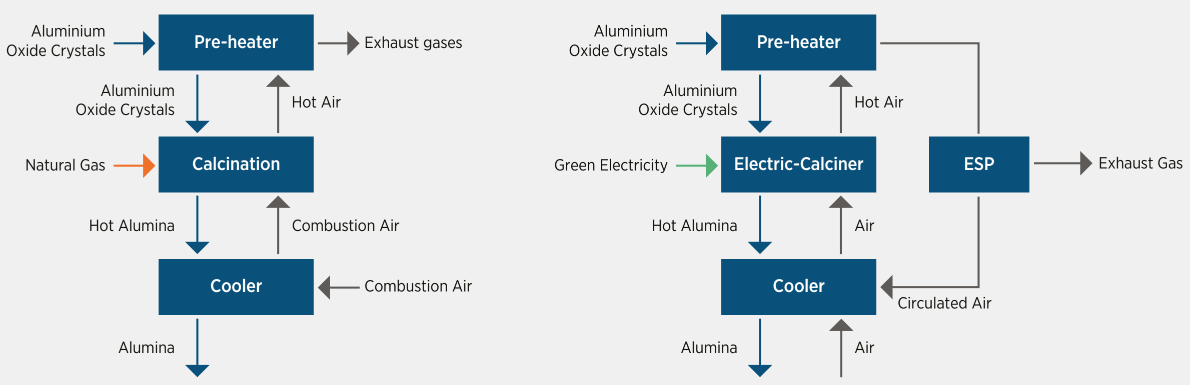
Process electrification

Zero-carbon electrification is increasingly within reach in industrial decarbonisation, representing a key opportunity to reduce emissions. Aluminium has long been one of the most electrified industry verticals, and further steps should be taken across the aluminium value chain. Electrification is a viable option to decarbonise most low- and medium-temperature heat needs, such as aluminium remelting or alumina digestion, the first main step in the alumina refining process.

The last main step, the calcination process, poses significant challenges for decarbonisation due to the high temperatures involved, which exceed 900°C. However, electric calcination technologies offer a promising alternative for alumina refining by using renewable electricity to operate the calciner. These technologies also incorporate mechanical vapour recompression to recover waste energy that would otherwise be expelled through the calciner's stack. When combined with thermal storage systems, electric calcination has the potential to provide grid stabilisation support, functioning similar to a battery. Currently, electric calcination remains in the research and development phase (Ball Corporation, 2025).

The blueprint in Table 6 provides an example of how process electrification can be implemented in the aluminium industry to reduce CO_2 emissions from the calcination process, lower costs and optimise production.

TABLE 6 Blueprint solutions of how process electrification can be implemented in the aluminium industry



How it works	The existing process relies on a combustion system that burns fuel with air to produce hot gases, which are then channelled into the calcination unit for the conversion of bauxite into alumina. However, transitioning to an electric heating system enhances temperature control and eliminates the reliance on fossil fuels, greatly reducing direct CO2 emissions associated with combustion. In this method, heated air circulates to transfer heat to the materials, providing greater flexibility in temperature adjustments. This can result in more uniform heating, potentially improving the quality and consistency of the final product while further decreasing CO2 emissions.
Economics	The economics of electrifying the calciner in aluminium plants depend on CO2 taxation, the efficiency of electric heaters (up to 99% compared to 60-70% for gas or coal furnaces) and green production incentives. These factors influence capital expenditure / operating expense (CAPEX/OPEX) and require evaluation for specific use cases to determine economic viability.
Decarbonisation potential	60-80% potential reduction depending on the level of electrification.
Strengths, weaknesses, opportunities, and threats (SWOT)	Strengths: • Can greatly reduce CO2 emissions by eliminating the need for fossil fuels. • Can achieve high efficiency with fewer energy conversions. • Supports the transition to more sustainable industrial processes and aligns with global climate goals. Weaknesses: • The upfront investment for electrifying existing systems can be substantial. • The levelised cost of heat for electric heaters can exceed that of conventional fossil fuel heaters, primarily because electricity tends to be more expensive than fossil fuels. • Dependence on a stable and sufficient supply of low-cost, low-carbon electricity. Opportunities: • Potential for technological advancements and innovations in electric heating methods. • Increasing regulatory pressure and incentives for reducing carbon emissions can drive adoption. • Companies adopting electrification can position themselves as leaders in sustainability. Threats: • Potential issues with grid capacity and reliability, especially in regions with less developed infrastructure. • Fluctuations in electricity prices and availability of renewable energy sources can impact cost-effectiveness. • Other decarbonisation technologies, such as carbon capture and storage, may compete for investment and adoption.

Policy and society	Headwinds: • Inconsistent carbon pricing across regions. • Absence of defined CO_2 intensity and renewable energy targets. • Significant disparities in the advancement of electrification policy discussions among regions. • Existing policy frameworks lack a clear roadmap to sufficient renewable power capacity. • Economic differences make it hard for developing countries to implement carbon pricing. • Political resistance in some areas makes it hard to adopt and enforce carbon pricing. Tailwinds: • Strong government policies and incentives for low-carbon/green aluminium technologies. • Financial support, tax incentives, grants and subsidies to reduce initial costs and encourage investment. • Growing societal and political support for green aluminium, with policies such as the EU's Decarbonisation Innovation Fund and Carbon Border Adjustment Mechanism (CBAM) motivating companies to decarbonise. • International collaboration through agreements like the Paris Agreement. • Technological advancements making electrification more feasible and cost-effective.
Ease to implement in brownfield (AFID, 2024)	Calciner's inside battery limit: Modification of duct between secondary air cyclone and the furnace, including the installation of dampers to allow for a bypass configuration when the electric heater is offline. **Disruption: Medium** Calciner's outside battery limit: Significant power infrastructure required, including modifications to the electrical network to deliver high-voltage supply for electric heaters. Additional area will be needed to accommodate the heaters and their auxiliary systems. In cases where the available plot plan is limited, the unit may be placed at a distance, which would increase the extent of inter-connecting ductwork and lead to higher capital expenditure. In case of lack of power capacity, transmission lines will need to be added. **Disruption: High**
Technology readiness level (TRL) / example projects	Several studies have been carried out for electrifying the calciner in aluminium plants. The pilots are yet to be carried out. However, megawatt-scale electric heater technologies pilots are under development and are at TRL 3 to 4, with further advancements expected in the coming years.

Barriers preventing further efficiency improvements in the aluminium industry

Enhancing efficiency through the use of advanced technologies in the aluminium industry offers several economic and environmental benefits. These improvements lead to significant cost savings by reducing energy consumption. Furthermore, optimising the production process increases aluminium productivity, enabling higher output with the same or fewer resources, reducing waste and emissions. However, the aluminium industry faces several technological, economic, and regulatory and policy challenges that hinder the implementation of efficiency maximisation measures.

Technological barriers

The aluminium production process is highly complex, and improving its efficiency necessitates significant changes that carry inherent risks. As a result, many companies are hesitant to implement these changes, fearing potential disruptions to production. Additionally, existing reduction cells face technological limitations that hinder improvements in energy and production efficiencies. Overcoming these challenges requires substantial technological advancements, making it difficult for companies to adopt new solutions. Furthermore, there is a lack of commercially viable alternatives to the Bayer and Hall-Héroult processes, which means that primary aluminium producers must invest in and adopt new technologies to achieve higher efficiencies. While inert anode technology shows promise for substantial energy savings and emissions reductions, it also requires funding for research and development (Zore, 2024).

Economic challenges

Several economic challenges hinder the implementation of efficiency maximisation. A significant challenge is the high upfront costs associated with adopting new technologies or upgrading processes, which often deter companies from making these investments. Additionally, substantial capital investments can be difficult for companies to justify, especially in an industry characterised by thin profit margins. Competing investment priorities within the company can also lead to a lack of financial resources being allocated to efficiency initiatives, resulting in these projects being postponed or abandoned. Furthermore, modifying processes typically requires production disruptions, which pose a risk of short-term losses. As a result, companies may be hesitant to take on this risk, even when long-term gains are possible (Zore, 2024).

Regulatory and policy barriers

Several regulatory and policy barriers can greatly impact the implementation of efficiency improvements in the aluminium industry. Companies hesitate to invest in long-term efficiency projects due to uncertainty surrounding environmental regulations. These uncertainties prevent companies from investing in new technologies and processes that could enhance efficiency (Box 3). Another barrier is energy pricing policies, which influence fluctuations in energy prices. These fluctuations can greatly affect production costs, making it difficult to justify long-term investments in efficiency measures. Additionally, the lack of standardisation for energy efficiency complicates benchmarking performance and identifying areas for improvement. Finally, financial resources allocated to efficiency projects are limited, as capital investments are often prioritised for regulatory mandates in other areas (Sajwani, A. and Nielsen, 2019).

BOX 3 Emirates Global Aluminium: Advancing aluminium decarbonisation through global recycling, innovation and renewable power

EGA is the world's largest producer of "premium aluminium" and is the leading industrial company in the United Arab Emirates (UAE) outside of oil and gas. EGA is at the forefront of sustainable aluminium production, leveraging global recycling business expansion and the integration of renewable energy with recycled content.

CelestiAL-R: the world's first blend of solar aluminium and recycled metal

EGA made history by becoming the first company to commercially produce aluminium using solar power, branded as CelestiAL. Building on this achievement, EGA subsequently introduced CelestiAL-R, a blend of solar energy and recycled metal, which has a carbon footprint of below 4 tonnes per tonne of aluminium produced, depending on the alloy composition. This innovation addresses the significant environmental challenge posed by the aluminium industry, where electricity generation for smelting and production contributes to around 60% of its greenhouse gas emissions. Recycling aluminium reduces energy consumption by 95% compared to primary production and substantially lowers greenhouse gas emissions.

CelestiAL-R meets the stringent performance requirements of the automotive sector, making it suitable for drivetrain housings and structural components. The scrap metal used in CelestiAL-R is sourced domestically within the UAE, comprising pre-consumer industrial scrap and post-consumer scrap, such as engine blocks. EGA rigorously tests all incoming scrap against 40 different chemical and property requirements to ensure quality.

In 2025, EGA expanded its product range by introducing CelestiAL-R billets to meet the growing demand for low-carbon aluminium in extrusion and forging applications. Previously, EGA produced CelestiAL-R foundry alloys, ideal for remelting applications. BMW, the pioneering client for CelestiAL solar aluminium, now exclusively sources CelestiAL-R from EGA.

Scaling a global aluminium recycling business

EGA is constructing the UAE's largest aluminium recycling plant, a 170 000 tonnes per year facility adjacent to its Al Taweelah smelter. This new plant will process both post-consumer and pre-consumer aluminium scrap into low-carbon, high-quality "premium aluminium" billets marketed under the product name RevivAL.

In 2024, EGA expanded its global recycling footprint by acquiring two recycling businesses: Leichtmetall in Europe and Spectro Alloys in the United States. Leichtmetall, a European specialty foundry, produces up to 30 000 tonnes per year of aluminium billets using renewable energy, with secondary aluminium as 80% of the input material. Spectro Alloys, based in Rosemount, Minnesota, is a leading secondary foundry alloy producer with a production capacity of around 165 000 tonnes per year of aluminium ingots and billets.

Promoting recycling and public engagement

EGA co-founded the Aluminium Recycling Coalition, collaborating with leading UAE beverage producers, can-makers and waste management companies to support government efforts on aluminium recycling regulation and policies. The coalition aims to develop the aluminium recycling infrastructure further.

Through the Every Can Counts UAE chapter, EGA encourages the recycling of aluminium cans. The UAE recycles just one-third of its 660 million cans annually, well below the greater than 95% rates in some countries. Achieving universal recycling could avoid up to 60 Mt of global CO_2 emissions annually. EGA drives recycling awareness in schools and neighbouring communities through digital platforms and door-to-door collections in partnership with Veolia RECAPP. The "Yalla Return" programme reaches over 4 000 households, using smart bins and app-based rewards to incentivise recycling behaviour.

In conclusion, EGA's initiatives in producing low-carbon aluminium and promoting recycling contribute greatly to a more sustainable and circular economy. The company's leadership in integrating renewable energy with recycled content sets a benchmark for the aluminium industry globally.

EGA is demonstrating how aluminium can be reimagined to power a net-zero future. By integrating renewable energy and recycling, EGA is setting new benchmarks for industrial decarbonisation and circularity.

Source: (EGA, n.d.)

3 Accelerating progress towards a more circular aluminium sector

As the world moves towards a more sustainable and environmentally conscious future, the aluminium industry stands at the forefront of this transition through its commitment to circularity. With its exceptional recyclability and versatility, aluminium is set to be a crucial element in the journey towards a climate-neutral and circular economy.

This section explores the elements required to expedite progress in creating a more circular aluminium sector and aims to provide a detailed roadmap for stakeholders to enhance aluminium circularity, contributing to a more sustainable future. It reviews the advancements achieved so far, showcasing improvements in recycling rates, energy efficiency and policy implementation. It also addresses the necessary frameworks to further this progress, including policy recommendations, technological innovations and market incentives. Additionally, it identifies opportunities for international co-operation to boost circularity in the aluminium industry, promoting global best practices and collaborative solutions to meet the ambitious targets set for 2030 and beyond.

3.1 Progress to date

Aluminium has made significant progress in circularity due to the considerable energy savings it provides compared to primary production. Nearly 75% of all aluminium ever produced is still in use today, highlighting its durability and circular potential. The aluminium industry is transitioning towards a circular economy by emphasising recycling systems that enable aluminium products to be collected, recycled and converted into new products without degradation (Novelis, 2025). Innovations in recycling technologies, including advanced sorting and processing techniques, have enhanced the efficiency of aluminium recovery from post-consumer products.

Stakeholders in the aluminium industry are actively working on initiatives and sustainable practices aimed at lowering greenhouse gas emissions. Certain aluminium manufacturers have demonstrated their commitment to reducing emissions by adopting net-zero goals. In 2023, the International Aluminium Institute introduced an initiative to assess and publicly monitor emissions from all its members. The International Renewable Energy Agency's Alliance for Industry Decarbonisation promotes discussion and encourages collaboration to assist companies in their decarbonisation efforts (IRENA, 2025). The Aluminium Stewardship Initiative has established standards for responsible sourcing and recycling practices, promoting a circular economy within the industry ('ASI', n.d.). Initiatives such as the Circular Aluminium Action Plan aim to maximise recycling rates and keep aluminium in active use, contributing to a climate-neutral economy (Pilgrim *et al.*, 2023).

Governments play a vital role in promoting aluminium circularity by enacting policies and regulations that enhance recycling infrastructure and promote sustainable practices, ensuring the availability of scrap materials and carbon pricing. For example, Aluminium Deutschland urges government measures to guarantee a consistent supply of scrap, which is crucial for a robust circular economy (Packaging Europe, 2025). Governments can also implement measures such as deposit return systems (DRS), also known as recycling refund programmes, and extended producer responsibility (EPR) to increase domestic recycling rates (Taylor, 2024). Additionally, policies that shield local producers from unfair competition can support a competitive and sustainable aluminium industry (Packaging Europe, 2025).

Many countries have implemented EPR laws that require manufacturers to take responsibility for the entire life cycle of their products, including end-of-life recycling. In addition, government incentives for recycling facilities and investments in green technologies have bolstered the aluminium sector's transition to a circular economy. For example, the European Union's Circular Economy Action Plan aims to enhance resource efficiency and reduce waste, which has a direct impact on the aluminium industry (Pilgrim *et al.*, 2023).

The private sector is instrumental in advancing aluminium circularity through investments in recycling infrastructure and technological innovations. Companies such as Hydro and Novelis have greatly increased their recycled content over the past decade, aiming for even higher targets and to reduce their carbon footprint (Hydro, n.d.; Novelis, 2025). Private initiatives such as the RecAL Project in Europe are revolutionising the aluminium ecosystem by developing more efficient recycling processes (European Commission, 2024). These efforts not only reduce waste and emissions but also create economic value and support sustainable growth (Novelis, 2025). Collaborations among manufacturers, recyclers and technology providers are also fostering new solutions for efficient aluminium recovery and re-use.

Worldwide initiatives are starting to create and signal a demand for sustainable aluminium from both the public and private sectors, including AFID, the Aluminium Stewardship Initiative ('ASI', n.d.), the Aluminium Industry Greenhouse Gas Initiative (IAI, 2024d) and the First Movers Coalition (Light Metal Age, 2022). Additionally, the World Economic Forum and the International Aluminium Institute have launched the Net-Zero Aluminium Initiative under the Mission Possible Platform. It aims to mobilise industry to support policies for low-emission aluminium (WEF, 2022b, 2024b). This demand creation tool encourages the adoption of environmentally responsible practices in the aluminium industry.

Financial institutions are increasingly engaged in facilitating the transition to a circular aluminium economy by offering financing options for sustainable projects. The Sustainable Aluminium Finance Framework exemplifies how financial mechanisms can align with decarbonisation goals, providing a structured method for financing sustainable aluminium production. This involvement helps to bridge the estimated USD 1 trillion gap in funding required over the next 25 years to decarbonise the aluminium sector (WEF, 2024c).

The international demand for sustainable aluminium is rising as countries and industries strive for carbon neutrality. Industries such as automotive, construction, and packaging are pursuing aluminium with lower carbon footprints, resulting in a surge in demand for recycled aluminium. A global call to action for 100% recycling of aluminium beverage cans by 2050 could save over 60 Mt of CO_2eq emissions annually. This growing demand is driving innovation and investment in aluminium recycling technologies, making sustainable aluminium a key material in the transition to a low-carbon economy (RECYCLING magazine, 2024; WEF, 2024c). A report from the World Economic Forum highlights that the move towards sustainable materials is set to transform supply chains and generate new market opportunities for aluminium producers dedicated to circular practices.

As both consumers and businesses emphasise sustainability, the aluminium industry must evolve to meet these changing demands. With an increasing number of countries establishing ambitious recycling targets, the demand for sustainable aluminium is expected to keep rising, prompting the industry to adopt even more circular practices (WEF, 2020a, 2025a).

3.2 Enabling framework to accelerate progress

Despite clear economic and environmental benefits, progress towards aluminium circularity remains uneven due to persistent systemic barriers – technological, economic and regulatory. Challenges include fragmented recycling systems, inconsistent scrap quality, lack of standardised carbon and circularity metrics, limited access to finance (especially in emerging markets and small and medium-sized enterprises) and weak public-private co-ordination.

A coherent enabling framework – harmonising policies, fiscal tools, standards and roadmaps – is essential to unlock investment, drive collaboration, and create demand for high-quality, low-carbon, circular aluminium. Moreover, mechanisms such as the EU's Carbon Border Adjustment Mechanism are reshaping international trade dynamics and reinforcing the urgency for globally aligned policies and standards. This section outlines the pillars of an effective enabling environment and explores the tools available to accelerate aluminium circularity at scale.

A coherent enabling framework can address the following systematic challenges:

- fragmented scrap collection and poor sorting technologies
- absence of universal carbon and circularity standards
- lack of clear roadmaps
- limited finance access for circular innovation
- weak value chain collaboration.

Table 7 maps these challenges to strategic enablers and real-world solutions that can scale aluminium circularity.

TABLE 7 Challenges and related solutions that can scale aluminium circularity

Challenges/ Gaps	Pillar/Levers	Examples	Impact on circularity
Limited availability of high-quality scrap	• **Boost collection rates** –Collaborate across the aluminium value chain and with policy makers and expand deposit return schemes to maximise scrap recovery. • **Advance separation and storage technologies** – Invest in improved methods for extracting and storing and managing scrap efficiently.	• The Aluminium Recycling Coalition (ARC), founded by the EGA and key partners, enhances collaboration to address recycling challenges and support national sustainability goals (EGA, 2025). • The Critical Materials Circularity Accelerator aims to boost access to high-quality secondary materials, starting with aluminium, by fostering collaboration across the critical materials value chain (WBCSD, 2025).	Enhances collection capacity, increases recycling rates and strengthens national circular economy targets. Improves availability of quality recycled aluminium and encourages scalable partnerships for circularity.
Lack of standardised scrap quality and carbon accounting	• **Develop emissions tracking framework** – Create a standardised system to calculate, monitor, and report carbon emissions and reduction progress. • **Enforce industry standards** – Implement and uphold consistent, industry-wide standards.	• The Aluminium Stewardship Initiative provides standards guidance to the sector, promoting investments and progress towards a 1.5°C scenario (Mission Possible Partnership, 2022). • The EU's CBAM may effectively prevent carbon leakage by redirecting EU imports from less carbon-efficient countries to more carbon-efficient countries. • Recycled Content Calculation Harmonisation promotes a standardised method to measure recycled content in aluminium can sheet, enhancing traceability, data reliability and comparability across companies (CMI, 2025).	Ensures transparency, standardisation, and consistent metrics for assessing the environmental performance of aluminium products, enabling clear market signals and comparability.
Absence of decarbonisation roadmaps	• **Develop national sector transition roadmap** – Create a comprehensive strategy with clear timelines, costs and scalable actions.	• Germany's Circular Economy Strategy (IEA, 2024). • The EU Circular Economy Action Plan aims to achieve a fully circular economy for aluminium by 2030 (WEF, 2020b).	Provides long-term vision, mobilises investment and aligns public-private actions.

Challenges/ Gaps	Pillar/Levers	Examples	Impact on circularity
Financing barriers for circular innovation	• **Mobilise capital for circular innovations** – Secure funding for research and development in new purification technologies and product-to-product recycling. • Promote circular business models.	• Recycling technologies for circular Aluminium Fund Programme (European Commission, 2024). • The First Movers Coalition's Aluminium Group is an initiative by the World Economic Forum aimed at leveraging companies' purchasing power to unlock and scale emerging technologies essential for global decarbonisation by 2050 (WEF, 2022a).	Expands secondary aluminium potential. Incentivises companies to invest in low-carbon and recycled aluminium technologies.
Fragmented collaboration across value chains	• **Foster strategic partnerships** – Establish long-term collaborations with off-takers and original equipment manufacturers to provide investor confidence, secure demand and mitigate investment risks. • **Promote circular business models** – Collaborate with downstream partners to implement circular business models and closed-loop recycling systems.	• Alliance for Industry Decarbonization launched the Enterprise Twinning Platform: Connecting Businesses for Industrial Decarbonization. • A partnership between Novelis and Volvo launched a closed-loop recycling system for Volvo cars (WEF, 2020b). • FMC members Ball Corporation and Novelis collaborated with Alcoa to pilot an aluminium cup made of 90% recycled and 10% primary aluminium produced using a carbon-free smelting technology (WEF, 2025b). In 2023, Novelis entered a long-term agreement to supply high-recycled-content aluminium beverage can sheet to Ball Corporation. This was instrumental to enable construction of what would be the first US fully integrated aluminium manufacturing plant in nearly four decades, with an initial capacity of 600 000 tonnes of finished goods primarily for the North American beverage can and automotive markets (Novelis, 2023). • At the 2023 United Nations Climate Change Conference (COP 28), companies in the aluminium beverage can value chain issued a call to action for the Global Beverage Can Circularity Alliance, urging national governments to adopt policies aimed at reaching global recycling targets of at least 80% by 2030 and close to 100% by 2050 (IAI, 2024e).	Secure demand for secondary aluminium and mitigate risks from high investments. Raises collection and recycling rates globally, supports policy development, and drives strategic investment and alignment across the value chain.

3.3 Recommended areas for alignment and collaboration

Pro-active and collaborative efforts involving policy makers, producers, consumers, researchers and investors are essential to accelerate progress. The transition to a circular aluminium economy requires a multi-faceted strategy that addresses market, technological, regulatory and financial challenges. This section summarises key areas of action, recommended interventions and relevant stakeholders (IRENA, 2025).

TABLE 8 The five key areas to transform to aluminium circularity

Improve scrap collection • Governments can enhance collection systems through deposit return schemes and digital tracking. • Aluminium producers can explore the potential to strengthen partnerships among scrap suppliers, recyclers and municipalities to maximise recovery rates. • Research institutions can work to improve storing technology, develop advanced separation techniques to decrease alloy mixing, and design digitised collection systems that track scrap throughout its life cycle and direct it to the correct channel.
Develop strategy and Increase uptake of circular aluminium • Governments can establish clear decarbonisation roadmaps and long-term targets for the aluminium sector and integrate circularity and sustainability objectives into national industrial policies. • Governments can phase out fossil fuel subsidies and implement robust carbon pricing to internalise environmental costs. • Governments can stimulate demand for low-carbon aluminium through green public procurement and market quotas.
Enhance product standards • Governments can develop and enforce standardised carbon and circularity metrics. • Governments can introduce robust certification and labelling schemes for low-carbon aluminium.
Mobilise green funds • Financial institutions and development banks can establish dedicated green financing instruments and innovation funds to support efforts. • Stakeholders across the aluminium value chain can actively invest in research and development and the deployment of advanced technologies.
Strengthen partnerships and collaboration across the value chain • Aluminium producers can collaborate closely with downstream partners to develop circular business models. • Aluminium producers can establish long-term partnerships (spanning 20 to 30 years) with original equipment manufacturers. • Governments can de-risk investments in new technologies through public-private partnerships and fiscal incentives. • Advance collaboration under the Alliance for Industry Decarbonization as a global platform for enhancing dialogue through exchange of insights, experiences and best practices.

These co-ordinated interventions can collectively unlock the full potential of circular aluminium and support the global decarbonisation agenda.

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