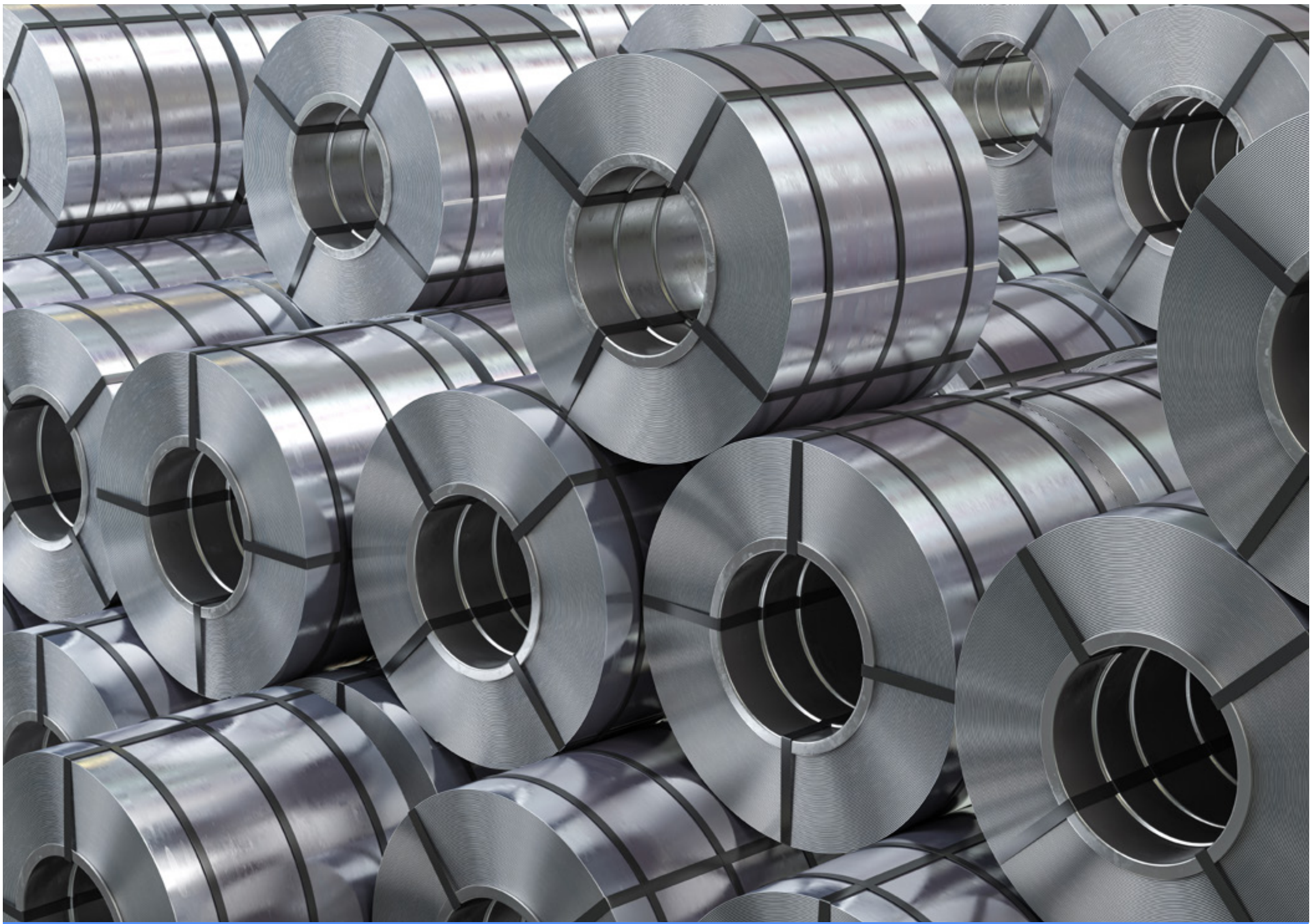
9

Aluminium industry net-zero tracker

The industry must prioritize low-carbon electricity, recycling and efficiency now, while advancing electrification, fuel switching, inert anodes and CCUS for aluminium emissions cuts.



- Emission intensity has decreased in the last five years due to reduced dependence on coal, enhanced energy efficiency and increased production of secondary aluminium.
- Renewable energy adoption in smelting has seen progress, but substantial infrastructure investments are still necessary to fully decarbonize the industry.

0.4%

Increase in absolute CO_2 emissions (2022-2023)

2.3%

Decrease in emission intensity (2022-2023)

2.7%

Increase in demand (2022-2023)

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Key performance data 2023[407,408,409,410]

2%	1.12 Gt CO_2e	1.3%
Contribution to global GHG emissions	Scope 1 and 2 emissions (2023)	Emissions decrease (2019-2023)
10.04 tCO_{2eq}	61%	1.8 times
Emissions intensity (per tonne of aluminium, 2023)	Fossil fuels in the smelting power mix (2022)	Demand increase in NZE scenario by 2050, compared to 2023

Performance summary

- The industry has reduced emission intensity by 13.6% from 2019 to 2023.[411] This is mainly driven by improvements in reduced reliance on coal, increased secondary production and energy efficiencies.
- The absolute emission for aluminium (primary and secondary combined) was 1.13 Gt of CO_2e in 2019, decreasing to 1.12 Gt of CO_2e in 2023.[412]
- Hydropower and renewable energy contribute to 39% of the electricity used in smelting.[413]
- Secondary aluminium, which requires significantly less energy, contributes to 36% of total production.

Future emissions trajectory

- The industry will need to reduce emissions intensity by 30% by 2030 and 97% by 2050, compared to 2022 levels, to be compatible with the IAI's 1.5 degrees scenario. The absolute CO_2 emissions for aluminium (primary and secondary combined) will need to be 810 Mt in 2030 and 53 Mt in 2050.[414]

Readiness key takeaways

Technology	3	– Electricity decarbonization for secondary aluminium smelting is available, with material and process efficiency at the demonstration stage (TRL 8).[415] – Inert anodes are at the demonstration stage (TRL 7) and CCUS is at the concept stage (TRL 3), both targeting commercial readiness by 2030.[416]
Infrastructure	3	– 9.5 MTPA of clean hydrogen and 86 MTPA of CCUS are required by 2050.[417] – 223 GW of clean power is required by 2050.[418] – Power purchase agreements (PPA) are increasing for use of clean power for production, with China harnessing hydropower.
Demand	3	– Approximately 30% of the total primary aluminium produced emitted less than 5 t of CO_2e/t of aluminium in 2021.[419] – The green premium for B2B is estimated at 40%.[420] – Momentum in offtake agreements and announced projects has slowed down over the last year.
Capital	1	– Currently, the aluminium sector has an annual CapEx of $23 billion. – Over $19 billion in additional annual investments are required by 2050 by the aluminium sector and by infrastructure buildout companies. – Significant additional investment requirement, low industry margins and ease of increasing capital are leading to the low capital readiness score.
Policy	2	– The EU has introduced CBAM, covering aluminium, with certificate purchases starting in January 2026.[421] – By 2025, 30% of China's aluminium capacity must meet efficiency benchmarks, 25% of energy must be renewable and recycled output should reach 11.5 million tons.

Sector priorities

Company-led solutions

Mid-term (by 2030)

- Source low-carbon grid power to reduce carbon intensity.
- Retrofit existing fossil-fuel-based captive power assets with CCUS, where access to clean power grids is not economical.
- Develop and deploy low-emission refining technologies like electric boilers, mechanical vapour recompression, etc.
- Accelerate market readiness for low-emission smelting technologies like inert anodes.
- Improve efficiencies and end-user scrap collection rate to maximize secondary production.
- Ensure product-level emissions reporting.

Long-term (by 2050)

- Scale up the use of electric boilers for low and mid-heat processes.
- Scale up the use of low-emission clean technologies (e.g. inert anodes).

Ecosystem-enabled solutions

Mid-term (by 2030)

- Invest in clean power infrastructure and grid capacity supported by energy storage systems to support the net-zero transition.
- Implement policies that further support the development and commercialization of low-emission clean technologies.
- Encourage scrap use and transparent declaration.
- Introduce and enforce industry-level standards (e.g. ASI's chain of custody[422]).

Long-term (by 2050)

- Reduce production cost premiums through an increased number of low-emission projects.
- Enable shared infrastructure and supply-chain stability through strategic partnerships.
- Develop infrastructure and market for green hydrogen to decarbonize boilers and calcination.

Performance

The sector currently accounts for 2% of global CO_2e emissions. As much as 60% of process emissions stem from electricity consumption, while 16% come from the fossil fuels used for thermal energy.[423] Thus, the electricity mix used, especially for smelting, is a critical driver for emission intensity.

TABLE 14 **Aluminium industry performance**

Performance metric	Change (2019-2023)
Industry output	+14.2%[424]
Emission intensity	-13.6%[425]
Total CO_2e emissions	-1.3%[426]

In the 2019-2023 period, demand increased by 14.2% while emission intensity decreased by 13.6%. The reduction in emission intensity is primarily due to:

1. **Reduced coal consumption**: Coal remains the largest contributor to the power mix used for aluminium, but the sector has seen a steady decrease in recent years, especially in China, where over half of global aluminium is produced. As major manufacturing countries reduce coal reliance and switch to renewable energy and less carbon-intense fuels, this will continue be a key driver in reducing emissions intensity.

2. **Higher rates of recycling**: Secondary aluminium production is steadily increasing in the industry, which uses less energy than primary aluminium. Scrap recycling rates are at an all-time high and are expected to continue to rise.

The smelting power mix still relies on fossil fuels for 61% of the power used and 39% from renewable sources (including hydropower). Coal represented 50% of the power mix in 2023, down from 57% in 2021, with the displaced coal primarily replaced by renewable energy.[427] The smelting power mix trajectory has been promising and is expected to eliminate the majority of Scope 2 emissions.

However, Scope 1 emissions are primarily in refining and process-related emissions, which have been relatively stable in recent years since the technologies required to decarbonize these processes remain nascent (e.g. hydrogen and CCUS).

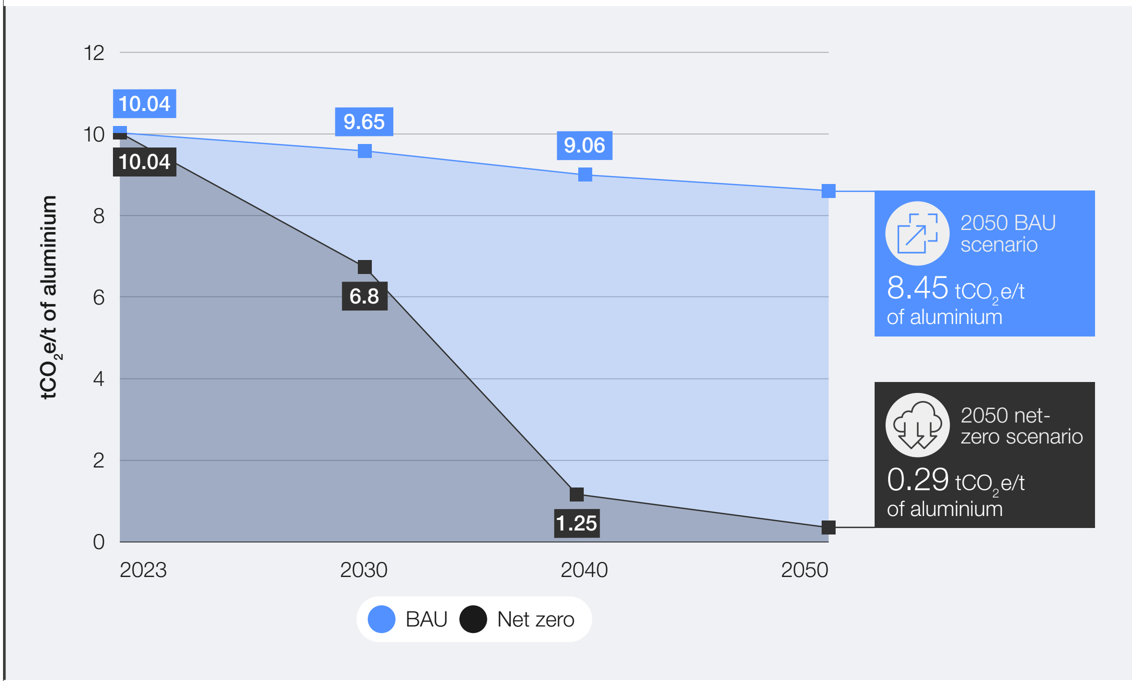
Several leading aluminium producers are testing breakthrough technologies, often in partnership. Examples include the Rio Tinto and Alcoa collaboration on inert anodes in Canada with support from Innovation, Science and Economic Development Canada (ISED); pilot tests on the use of hydrogen instead of fuels in alumina refining funded by the Australian Renewable Energy Agency (ARENA); and Norway-based company Hydro's attempts to use the carbochlorination process to produce zero-carbon aluminium, which is supported by the Norwegian government via state enterprise Enova.

Primary production has an energy intensity of 70 GJ per tonne, making it more energy-demanding than steel and cement. In contrast, secondary aluminium uses only 5% of the energy required in primary production.[428] Additionally, secondary aluminium is often cheaper from a process perspective – the challenge remains twofold: increasing scrap rate collection, which is currently at 70%, and removing impurities or alloying elements. Obvious limitations to growing secondary production are limited scrap availability, quality and segregation, and the fact that primary production is superior in technical specifications critical for certain industrial applications of aluminium.

Readiness

FIGURE 53

Emission intensity trajectory for the aluminium sector



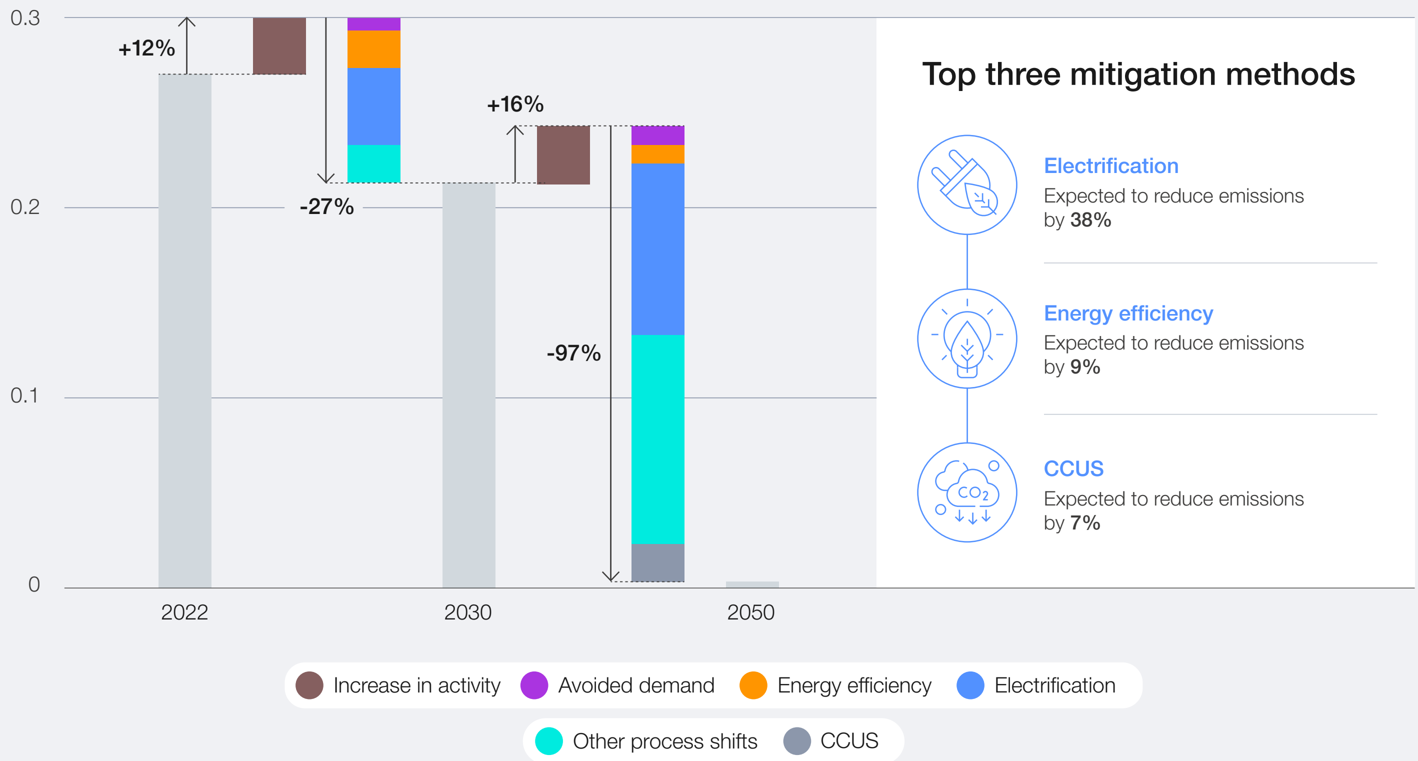
Source: IAI.

Overall aluminium demand is expected to grow by 80%[429] by 2050. The transport, construction, packaging and electrical sectors will account for most of the growth in aluminium demand. Increasing industrialization in emerging markets and global growth in transmission and distribution infrastructure are expected to be the main drivers for demand growth. Most of the demand growth is expected to be in the secondary aluminium market.

Thus, the industry needs to act fast on decarbonization to continue reduction in emission intensity and to offset the increase in demand.

FIGURE 54

Decarbonization levers and top mitigation methods (NZE Scenario)

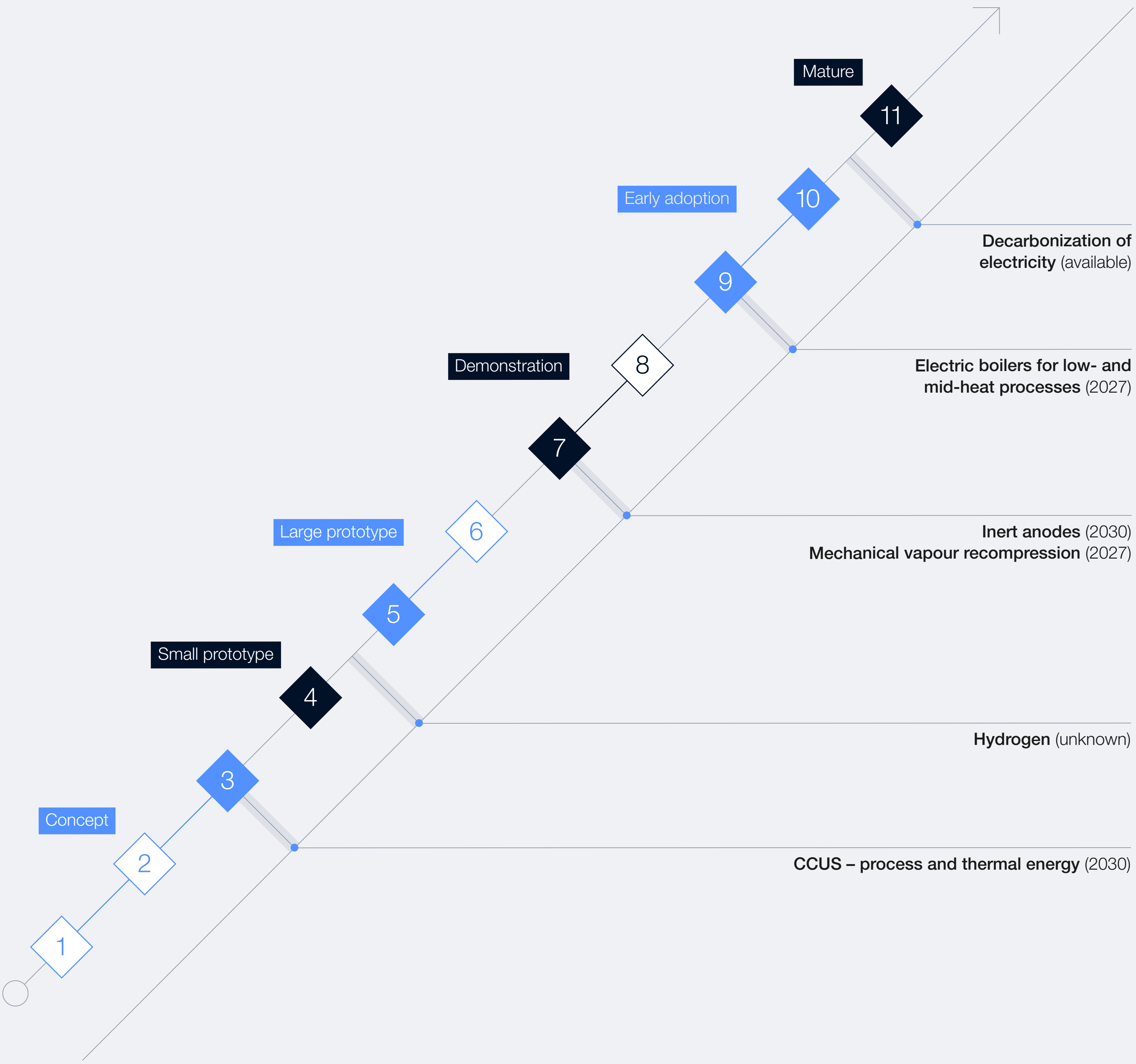


Source: Accenture analysis based on IEA data.

ALUMINIUM
3 Technology

Technologies to implement the decarbonization levers are at different readiness levels. Three key pathways are currently available: electricity decarbonization, reduction of direct emissions, and recycling and resource efficiency.

FIGURE 55 **Decarbonization TRLs and year of commercial availability**



Source: Accenture analysis based on data from IEA ETP Clean Energy Technology Guide and MPP.

Technology pathway 1: Electricity decarbonization

Renewable grids and electricity power agreements, combined with storage technologies to manage capacity volatility, offer a promising path for cleaner smelting and secondary production. However, these solutions are likely to incur additional costs in the short term. Another approach is the use of CCUS with captive power plants that rely on fossil fuels where renewable energy sources are not available. This method currently carries a cost premium of up to 30% in certain regions.[430] Additionally, nuclear-powered small modular reactors (SMRs) present an alternative, though this technology is still in the early stages of development.

Technology pathway 2: Reduction of direct emissions

Process emissions contribute around 15% of the industry's emissions. Inert anodes and CCUS are pivotal technologies for low-emission smelting. Inert anodes are projected to become commercially viable after 2030, although they may lead to a 9% increase in production costs. CCUS applications in smelting are still in the early stages, and due to the low CO_2 concentrations in smelting flue gas, this approach is expected to involve higher costs for carbon capture.

Emissions from fuel combustion contribute another 15% of the industry's emissions. Thus, implementing low-emission refining technologies is essential for reducing thermal energy emissions in the refining process. Technologies such as electric boilers and mechanical vapour recompression (MVR) are vital for this purpose. MVR technology, which addresses the digestion process responsible for 70% of refining energy consumption, is anticipated to become available after 2027.[431] For the remaining 30% of energy used in the calcination process, emerging technologies like hydrogen calciners and electrified calciners have the potential to lower emissions.

Technology pathway 3: Recycling and resource efficiency

Increased recycling can lead to a significant reduction in annual emissions, since secondary production emissions are much lower than primary production emissions. To achieve this, the availability of post-consumer scrap (which currently stands at 70%) needs to approach 100% by 2050.[432] The development and implementation of technologies that enhance scrap quality, such as advanced scrap sorting and purification methods, will be crucial in making this transition successful.

3

ALUMINIUM

Infrastructure

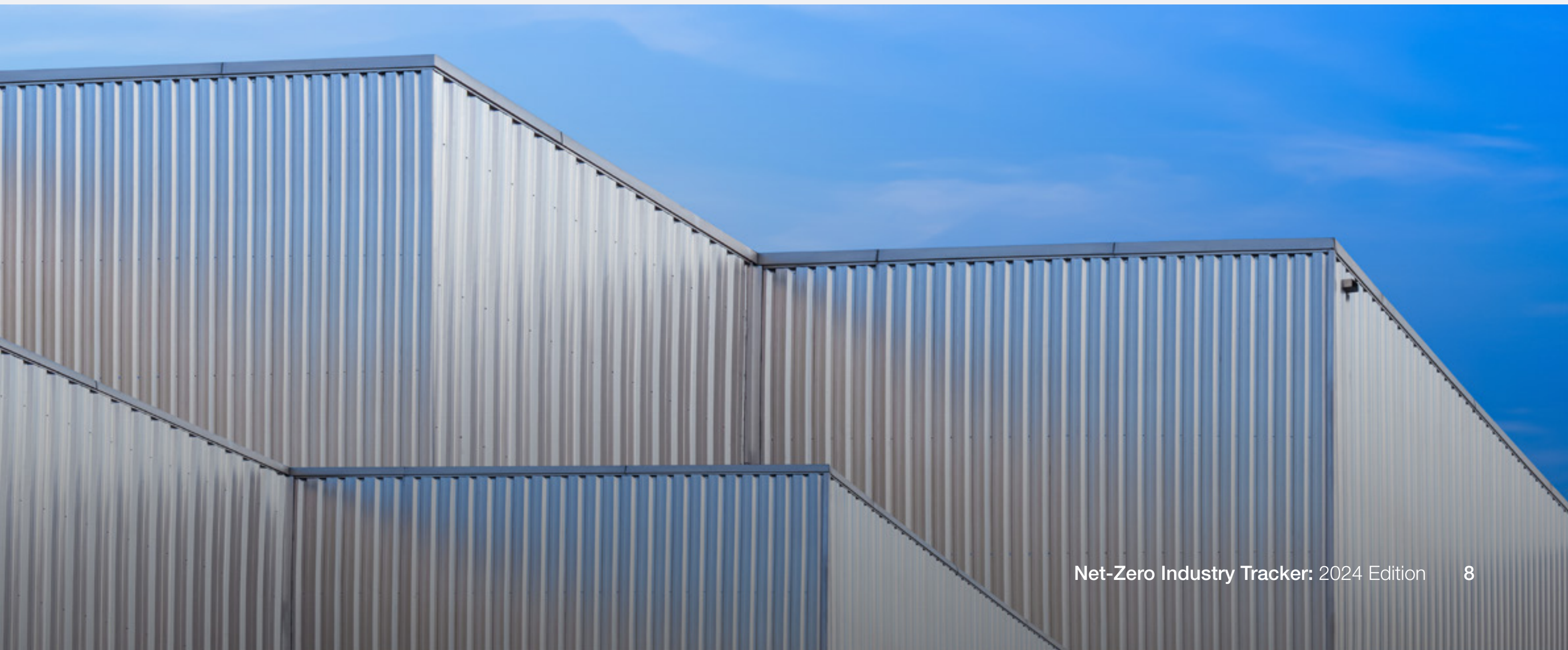
According to the MPP's Aluminium Transition Strategy, the aluminium sector currently has 14.3 GW of clean power available, primarily from hydropower. Low-carbon power capacity requirements are forecast to rise to 223 GW by 2050. The additional power demand is expected to be met through nuclear, renewables and captive power with CCUS.[433]

The aluminium sector needs to substantially expand its capacity for power from CCS or low-carbon grids to stay on a 1.5°C pathway. Currently, less than 1% of the CCUS capacity required by 2050 is operational. Progress in nuclear power has been slow due to the extensive R&D needed for SMRs, which are not anticipated to be commercially available to the aluminium industry until around 2035, with cost competitiveness potentially being achieved by 2040. Furthermore, the slow advancement of CCUS in smelting applications is attributed to its nascent stage and the challenge of capturing CO_2 from smelting flue gases, which are characterized by low CO_2 concentrations and higher capture costs.

FIGURE 56 **Infrastructure for decarbonization capacity**

	Current capacity used	Capacity required (2050)
Clean power generation	14.3 GW	223 GW
Clean hydrogen production	0 MTPA	9.5 MTPA
CO_2 transport and storage	0 MTPA	86 MTPA

Source: Accenture analysis based on MPP.



ALUMINIUM

3 Demand

In 2021, approximately 30% of the total primary aluminium produced emitted less than 5 tCO_2e/t of aluminium.[434] The main final uses for aluminium are for cost-sensitive industries such as aircraft, cars, construction and electric cables. This strains the ability of the ecosystem to absorb the B2B green premium for aluminium, which is estimated at 40%, with current technologies.[435] However, offtake agreements provide early signals for low-emissions aluminium demand growth. Additionally, major companies in consumer electronics, including Apple or Ball Corporation, already use low-carbon aluminium. It is important to note that a 40% B2B green premium translates to a 1% increase for end consumers of cars, which shows that the cost of decarbonization is primarily borne by aluminium producers and is not trickling down to end consumers.

For the industry to align with net-zero targets and strengthen demand signals, adherence to globally accepted definitions of low-emission and net-zero aluminium are necessary. Standards for carbon content remain opaque, regional and voluntary. Beginning in 2023, the China Green Metal Certification Centre began issuing certifications for green-power aluminium to qualifying smelters nationwide. This is a notable milestone, considering that China currently dominates aluminium production, with over 50% of the market share.[436] These certifications allow for clear differentiation between aluminium produced with green power and that made with thermal power, addressing the needs of downstream producers who require environmentally friendly raw materials.

Further commitment is evident as industry leaders ramp up their efforts to accelerate low-carbon product transparency and demand with a suite of new initiatives. Rio Tinto's "START" programme[437] intends to inform consumer choices, and the London Metal Exchange (LME) launched digital passports to store certificates of analysis and sustainability for listed metals.[438] Additionally, leading aluminium industry lenders (Citi, ING and Societe Generale) are working with the RMI, (formerly Rocky Mountain Institute) to develop a climate-aligned financing framework. For comparability reasons, the unified use of sector-specific carbon footprint methodology with cradle-to-gate boundaries that are inclusive of Scope 1, 2 and 3 upstream emissions would add to transparency and market creation.

Expanding the range of industrial customers beyond traditional uses is essential. Aluminium plays a crucial role in technologies that are anticipated to underpin a net-zero future, including EVs, wind turbines, photovoltaics and energy storage systems. Consequently, regions like China, which are projected to see increased demand for these technologies, will require more low-emission aluminium compared to other areas.

FIGURE 57 **Top countries/regions in aluminium production and demand**

Percentage of overall production	
1 China	59%
2 India	6%
3 Russia	5%
4 Canada	4%
5 United Arab Emirates	4%

Percentage of overall demand (2022)	
1 China	57.5%
2 Europe	14.2%
3 Asia (excluding China)	11.4%
4 North America	9.9%
5 Middle East	2.5%

Source: Nasdaq and Statista.

ALUMINIUM

1 Capital

The aluminium industry will need substantial capital investment to advance low-emission smelting and refining technologies beyond merely decarbonizing power sources, with an estimated requirement of $543 billion.[439] The majority of this investment must be invested by the ecosystem, and not only by aluminium companies, to build the enabling infrastructure. Aluminium decarbonization requires a scale-up of low-carbon power, hydrogen and CCUS. The aluminium sector must invest in retrofitting smelting and refining to enable electrification and reduce emissions.

It is projected that out of the total additional investment required, about 42% is expected to go towards electricity infrastructure (grid/PPAs), 24% towards captive power generation, 3% towards green hydrogen electrolyser capacity, less than 1% towards CCS infrastructure, 5% towards refineries and 27% towards smelters.[440] Overall, 32% of the total additional investment is expected to come from the sector companies, while the remaining 68% is expected to come from the ecosystem.

FIGURE 58 **Investments required by the sector and enabled by the ecosystem**

$543 billion

required in investment by 2050

Investments by the sector (around 25% of investments)

- Upgrade smelters for electrification (Clean power for smelting)
- Purchase power agreements (Clean power for smelting)
- Build more capacity for secondary production (Secondary production)
- Inert anodes for low-emission smelting (Low-emissions refining and smelting)
- CCUS (Low-emissions refining and smelting)
- Electric boilers and mechanical vapour compression (Low-emissions refining and smelting)
- Hydrogen calciners and electrified calciners (Low-emissions refining and smelting)

Enabled by the ecosystem (around 75% of total investments)

- Provide low-carbon power/renewable grid (Clean power for smelting)
- Develop nuclear-powered small modular reactors (Clean power for smelting)
- Collect post-consumer scrap (Secondary production)
- Enhance scrap quality (Secondary production)
- Supply low-carbon hydrogen (Low-emissions refining and smelting)

Clean power for smelting | Secondary production | Low-emissions refining and smelting

Source: Accenture analysis based on data from MPP.

With the aluminium industry's ROIC at 11%[441] and its WACC at 9.6%,[442] the industry's profits are just slightly higher than its costs of financing. This narrow margin means that without additional support from external factors (such as technological advancements, policy incentives and industry collaboration) the industry may struggle to afford and implement the significant changes needed for effective decarbonization. Nevertheless, the recent progress of the industry to reduce emissions intensity is promising and should encourage the ecosystem to help the sector progress.

2

ALUMINIUM

Policy

Global aluminium production is highly regionalized, with China contributing 60% of the total output. This underscores the importance of implementing effective and tangible policies to improve access to clean energy in key production regions. Domestic and international regulations aimed at encouraging low-emission aluminium production are still in development. To address this, priorities should include facilitating the adoption of clean power; supporting R&D alongside market-based approaches to advance early-stage low-emission smelting and refining technologies; and enhancing recycling rates through improved collection policies and infrastructure for sorting and purifying aluminium scrap. Given that policy measures to support decarbonization are still emerging, it is crucial to establish concrete policy actions in major producing regions.

Furthermore, policies and regulations to standardize carbon accounting frameworks, scope and system boundaries are pivotal to strengthening product-level reporting. Additional trust in decarbonized products, paired with stringent specifications and benchmarks, is likely to facilitate a market-based approach for decarbonized aluminium. Improved carbon accounting will conversely inform policy compliance and provide critical transparency to inform the consumer and hold producers accountable.

TABLE 15 **Aluminium industry policy summary**

Policy type	Policy instruments	Key examples	Impact
Market-based	**Carbon price**	EU-ETS[443]	Incentivizes aluminium producers to reduce emissions.
	Border adjustment tariff	CBAM[444]	Emission-intensive aluminium exporters to the EU face increased costs of compliance. Currently, 50% of aluminium consumed is imported from non-EU countries. This policy needs to be complemented by transparent and fair carbon accounting standards.
	Product standard	Aluminium Stewardship Initiative's Performance Standard 3, recognized by Green Building Council of Australia	Provides transparency and standardization to the environmental performance of aluminium products.[445]
Mandate-based	**Direct regulations**	Inclusion of aluminium in the EU's Critical Raw Material Act[446]	This act improves the circularity and sustainability of critical raw materials like aluminium but is still in the proposal stage.
	Government targets	China's renewable energy use targets for aluminium	Doubles the share of renewables in the aluminium energy mix by 2030.[447]
Incentive-based	**Subsidies**	China: provincial level subsidy	Public support to smelters to move to incentivize energy-efficiency technologies.[448]
	Direct R&D funds/grants	Canada's investment in ELYSIS' inert anode technology	A direct funding investment of $60 million positions ELYSIS to support further R&D and achieve commercial scale.[449] Additionally, funding support for R&D to accelerate innovative technologies should be reinforced by policies that enable technology access and transfer to developing countries.

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