Bundle | 14 November 2024

Greening aluminium: Its less than shiny net-zero reputation

Aluminium - that versatile metal used across countless industries - has a net-zero problem. While it may be a key component in much clean-energy equipment, its production is highly energy intensive and accounts for around 3% of global emissions. So, what can be done to cut emissions, and how committed are producers to greening their industry?

The urgent need to combat climate change has brought our attention to the global aluminium industry. In this bundle of articles, we examine the current state of play, examine various decarbonisation pathways, and examine producers' sustainability efforts.

And do join us for our live webinar on the aluminium industry on 21 November, 2024. Click on this link for more details.

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Greening aluminium: Ambitious goals on decarbonisation, but little progress

The aluminium sector's initial steps towards net-zero emissions

By Egor Fedorov, Ewa Manthey and Coco Zhang

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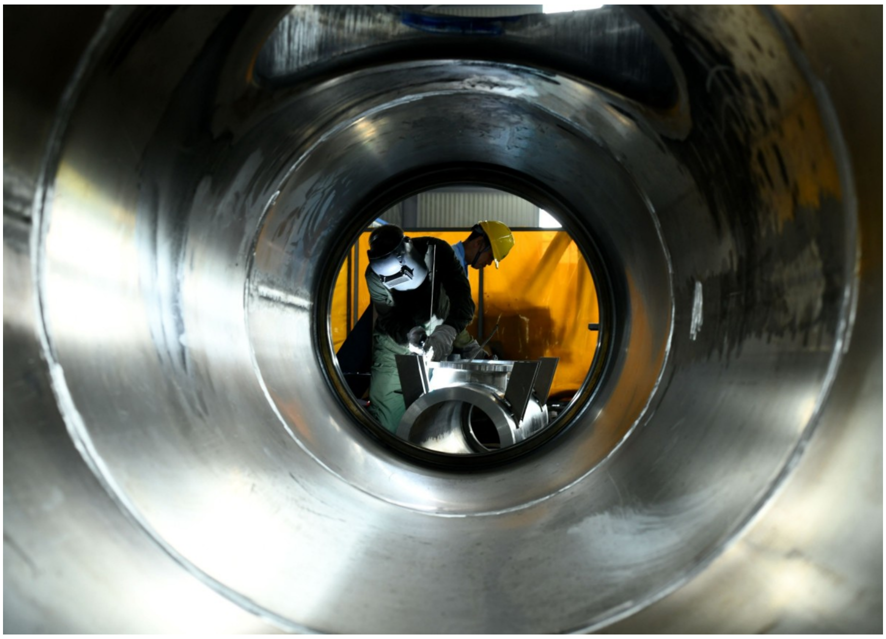
Greening aluminium: The urgent need to reduce emissions

Aluminium producers are under mounting pressure to slash emissions



A Chinese factory worker producing aluminium housings used in power networks

Aluminium is a key material for industries aiming to reduce their carbon footprints - and demand is soaring. However, its production is highly energy-intensive; it emits around 3% of the world's direct industrial CO_2 emissions. Producers are under mounting pressure to slash those emissions. True, they are decreasing, but they need to fall much faster if we're to reach net zero by 2050 and greener methods of production are increasingly needed.

Aluminium is used just about everywhere, from transport to buildings, aerospace to defence. It also plays a key role in energy generation, transmission, and storage technologies, notably those delivering the energy transition, such as wind and solar power, alternative fuel cells, hydrogen production, high-voltage cables, and batteries.

What causes aluminium's emissions?

The world consumes around 70 million tonnes of aluminium each year, and due to its role in decarbonisation, that number is expected to increase by almost 40% by 2030.

In addition to direct emissions resulting from the aluminium smelting (Scope 1 emissions), aluminium production also results in indirect emissions from the electricity or heat purchased for the aluminium production process (Scope 2 emissions).

Aluminium production from raw materials – primary aluminium production – requires more energy than any other industrial manufacturing method and releases large amounts of carbon dioxide into the atmosphere. Recycled, or secondary aluminium, produces around 5% of emissions compared to primary aluminium.

In primary aluminium production, the energy-intensive series of processes that turn raw bauxite ore into a pure metal emit, on average, 15 tonnes of CO_2 for every metric tonne of primary aluminium produced on a cradle-to-gate basis. This includes both direct and indirect emissions for the production process and inputs from raw material extraction until the product leaves the factory, according to data from the International Aluminium Institute (IAI).

Smelting is the most energy and carbon-intensive step in aluminium production

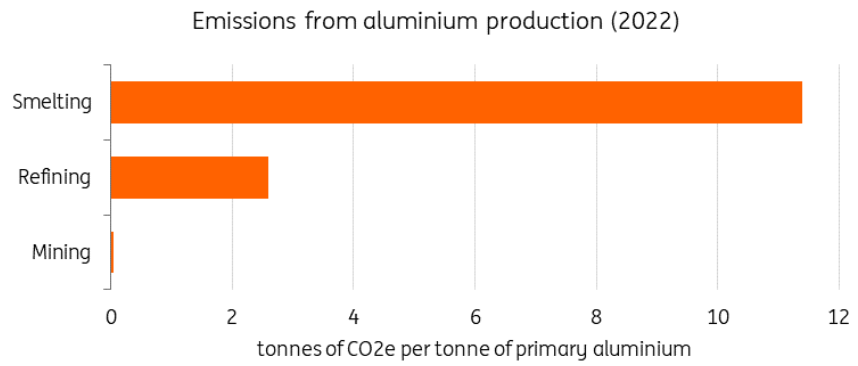
To achieve the goal of limiting global warming to within the threshold of 1.5° by 2030, as envisioned by the Paris Agreement, the aluminium industry needs to reduce its emissions to less than 0.5 tonnes of CO_2 per tonne of aluminium by 2050. That's according to data from the International Aluminium Institute.

Aluminium production involves three main stages: the mining of bauxite, refining into alumina and smelting into aluminium.

Mining bauxite is not particularly carbon-intensive – bauxite mining contributes just 0.04 tonnes of CO_2e/tonne of primary aluminium. Refining is a more carbon-intensive process, contributing 2.6 tonnes of CO_2 per tonne of aluminium. Those emissions are largely from the burning of fuels to produce heat.

The most energy- and carbon-intensive step in aluminium production is the smelting of alumina into aluminium.

Smelting is the most significant source of aluminium's emissions

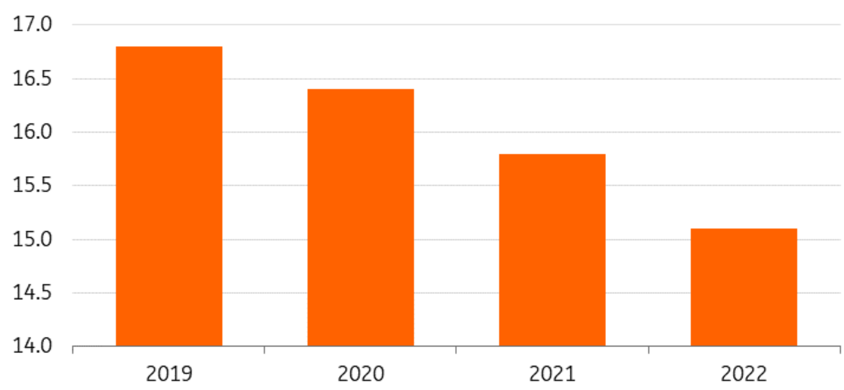


Source: IAI, ING Research

Aluminium emissions vary hugely depending on the power source used in the smelting process. This varies by geography. In North America, Europe and Russia, aluminium is typically made using hydro power, which has a relatively low emission intensity. In China and India, aluminium is made predominantly using coal power, resulting in high carbon intensity.

Greenhouse gas emissions intensity in primary aluminium

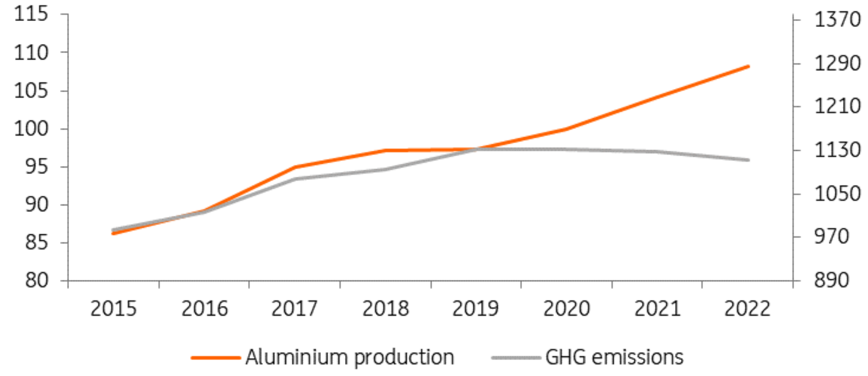
Cradle to grate (tonnes of CO_2e per tonne of primary aluminium)



Source: IAI, ING Research

The latest data from the IAI showed that, for the first time, total greenhouse gas emissions from the global aluminium sector were stable in 2022, even though aluminium production grew.

Production vs GHG emissions (million tonnes)



Source: IAI, ING Research

In 2022, aluminium production grew by 3.9%, from 104.1 million tonnes to 108.2 million. However, greenhouse gas emissions from the industry showed a slight decline from 1.13 giga-tonnes CO_2e to 1.11 giga-tonnes CO_2e, and the GHG emissions intensity of primary aluminium production (the average quantity of emissions from the production of a tonne of primary aluminium) has been declining since 2019. In 2022, intensity declined by 4.4% from 15.8 tonnes CO_2e per tonne to 15.1 tonnes CO_2e per tonne.

A shift towards more hydropower in China

The last time we saw a similar picture in the aluminium industry's GHG emissions was in 2009. The IAI data shows there was a production decline coinciding with the global financial crisis.

So, what's going on with this decoupling of production and the emissions trend? It is largely due to a shift towards more hydropower in China, the world's largest aluminium producer. The increasing use of renewable electricity in other producing regions, including the Middle East and Australia, as well as investments in other emission reduction technologies, including fuel switching in alumina refining and increased aluminium recycling rates and efficiency, are also playing important parts.

How is China decarbonising its aluminium production?

China is the world's largest producer of primary aluminium, accounting for nearly 60% of the global market. Like many others, its government is accelerating its efforts to decarbonise.

China's aluminium industry contributes significantly to the country's carbon footprint, making up around 5% of its total emissions. Its primary aluminium production comes directly from mined ore rather than using recycled or alloy materials.

Primary aluminium production in China is overwhelmingly reliant on coal-fired electricity, over 70% of all energy used in 2022 (according to IAI data), which is why decarbonising the power supply for Chinese primary aluminium production is critical.

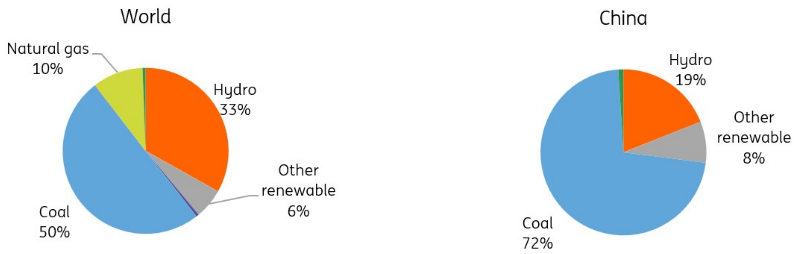
Due to the high proportion of coal-fired energy used, 12.7 tonnes of carbon is emitted per tonne of aluminium produced in China compared to a global average of 10.3 tonnes (according to IAI data covering the 2005 to 2019 period).

In 2018, China set a national capacity cap of 45 million tonnes for aluminium as part of its efforts to control power consumption in the sector.

Also, a trend that has become very clear in China is the moving of smelters from coal-fired electricity-dependent regions to hydropower-rich provinces, like Yunnan, as Beijing has set a goal of achieving carbon neutrality by 2060.

By 2027, 29% of China's aluminium output is expected to be powered by green energy. If this trend continues, the average carbon intensity for Chinese aluminium producers will reduce significantly.

Primary aluminium smelting power consumption (2023)



Source: IAI, ING Research

The challenges in China's energy transition path

In 2023, China's share of coal-fired aluminium capacity was 72%, and that of hydro was about 19%. In Asia, excluding China, coal-fired capacity accounted for 86%, with only 2% using hydropower. In comparison, North America's hydro share was 96% and Europe's 94%.

China Hongqiao, the world's largest private operator, has been increasingly relying on hydropower and solar energy. Its goal is to achieve peak emissions by 2025 and net zero by 2055. The producer is looking to move four million tonnes of capacity from the northern province of Shandong to China's southwestern Yunnan province by the end of 2025 to take advantage of low-carbon energy. The company has an annual production capacity of more than 6 million tonnes per year.

However, China's energy transition path is not without its challenges. Droughts over the past few summers forced cities in southwest China to curb power supply to heavy industries, disrupting aluminium production in the country. As China continues to decarbonise its aluminium industry, and as more smelters move from coal-dominated Shandong to hydropower-dominated Yunnan province, it's left more vulnerable to further disruptions, with green energy being heavily reliant on weather conditions and patterns.

Chinese producers will soon face extra costs for emitting carbon

Meanwhile, China plans to expand its national carbon trading market by including steel, aluminium and cement producers next year. A carbon tax is also being contemplated.

China's current carbon trading system, launched in 2021, only covers the coal-fired power generation sector. The inclusion of these additional industries would extend the market's coverage to about 60% of China's total carbon emissions. Beijing aims to cover 70% of its total emissions by 2030.

The move means Chinese aluminium producers will soon face extra costs for emitting carbon, which could incentivise significant emissions reductions.

Chinese authorities hope lower emissions will help soften the blow to domestic producers from a new carbon tariff – CBAM (Carbon Border Adjustment Mechanism) – to be imposed by the EU from 2026.

What does CBAM mean for aluminium flows?

Under the Carbon Border Adjustment Mechanism agreement – the first of its kind globally – goods imported into the EU will face a levy at the border based on their emissions footprint. This will be phased in from 2026 until 2034.

The CBAM will initially apply to six carbon-intensive industries: cement, iron and steel, aluminium, fertilisers, electricity, and hydrogen. These industries are at higher risk of carbon leakage. Eventually, the aim is for the carbon tax to cover all imports.

The CBAM entered its transitional phase on 1 October 2023, with the first reporting period for importers ending 31 January 2024.

During the trial period, importers of goods only have to report greenhouse gas emissions (GHG) embedded in their imports (direct and indirect emissions) without making any financial payments or adjustments. After the transitional period, indirect emissions will be in scope for some sectors, notably cement and fertilisers.

CBAM will come into force on 1 January 2026, and importers will need to declare each year the quantity of goods brought into the EU in the preceding year and their embedded GHG. They will then surrender the corresponding number of CBAM certificates. The price of the certificates will be calculated depending on the weekly average auction price of EU ETS allowances expressed in EUR per tonne of CO_2 emitted. The phasing out of free allocation under the EU ETS will take place in parallel with the phasing in of CBAM in the period 2026-34.

CBAM timeline

Source: European Commission, ING Research

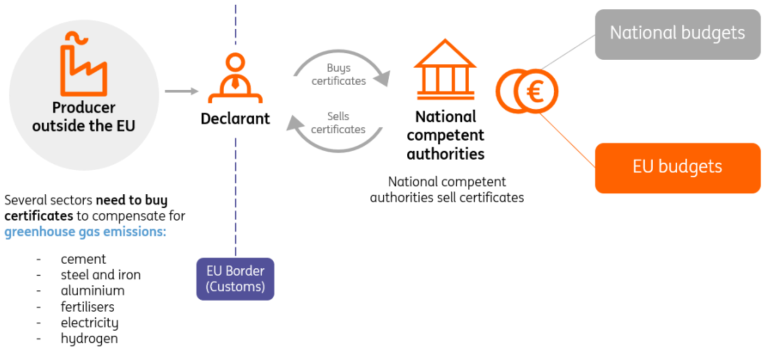
CBAM will not apply to Iceland, Liechtenstein, Norway and Switzerland, given they already participate in the EU ETS or their domestic ETS is linked to it, as is the case for Switzerland. Additionally, goods imported from countries that have a carbon price can offset the amount paid under CBAM by an amount equivalent to their domestic carbon price.

The first and most obvious impact of the implementation of CBAM is that European consumers will face higher prices. This is not only because imports will be more expensive but also because the allocation of free allowances to a number of these domestic sectors will be gradually reduced as the CBAM is phased in, which will drive costs higher for EU producers. However, given the phase-out period for free allowances will run from 2026 to 2034, the impact will be felt gradually. Reporting obligations related to CBAM will also push up costs, which will likely also be passed on to consumers.

Trade flows will also likely be affected. This will be felt both with imports and exports. For exports, the eventual removal of free allowances will impact the export competitiveness of European downstream sectors.

For imports, there will also be large shifts. However, the degree of impact will really depend on how carbon-intensive some of these third-country producers are and whether these countries have a meaningful carbon price already in place to drive the decarbonisation of domestic industries in the coming years. Suppliers who have a carbon intensity similar to that of EU suppliers will likely not be significantly impacted in terms of competitiveness. Low-emission producers are likely to increase their share of exports to the EU, given the lower CBAM burden they would face, while higher carbon emitters will likely look for markets where their high emission intensity will not be penalised.

CBAM process



Source: European Commission, ING Research

To meet global climate targets, the aluminium industry must accelerate its transition to greener production methods. By increasing recycling, adopting renewable energy and deploying emerging technologies such as hydrogen, carbon capture and inert anodes, the sector can significantly reduce its carbon footprint.

And we'll be discussing the different ways we can decarbonise aluminium production in our next article in this special Greening Aluminium series.

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Greening aluminium: How to cut emissions

Choosing the most suitable sustainability pathway is crucial for aluminium producers

Around 3% of global emissions are produced by the aluminium industry.

The aluminium industry contributes around 3% of global emissions, and with the demand for the metal set to soar, it's now crucial to decarbonise the production processes.

Several decarbonisation pathways have emerged, and this is what we're going to focus on here:

- recycling
- clean electricity
- inert anodes, hydrogen, and
- carbon capture and storage (CCS)

While recycling is a highly cost-effective approach, supplying aluminium production with clean electricity paints a more mixed picture depending on sources of generation and location. Meanwhile, inert anodes, hydrogen, and CCS are emerging technologies for a greener aluminium industry, but they differ in application outlook, cost, the timeline of application, and so on.

Your cheat sheet to aluminium decarbonisation pathways

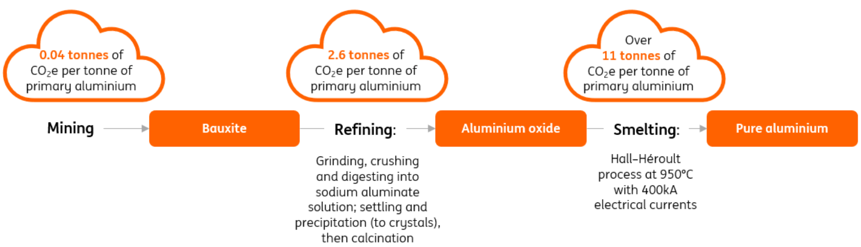
	How is it reducing emissions?	Emissions reduction potential	Technology readiness for the aluminium industry	Cost	Advantages	Challenges
Recycling	Direct and indirect emissions from mining, refining and smelting	High	High	$	• Already widely applied by producers • Uses 95% less energy	• Need better used-aluminium collecting, transporting and sorting mechanisms to further boost post-consumer recycling rate
Clean electricity	Indirect emissions from power usage	High[1]	High: Hydropower Medium: Renewables and CCS Low: Novel nuclear technologies	$$- $$$[4]	• High indirect emissions reduction potential • Many technologies are commercially available with decreasing cost	• Power price fluctuations • Potential need to switch location/grid • Cost can be high to install new technology instead of retrofitting
Inert anode	Direct emissions from smelting	Medium	Medium	$$: Greenfield $$$: Retrofitting	• Can mostly eliminate emissions from carbon anodes during smelting	• Still in small-scale testing phase • Retrofitting possible but requires significant cost • Uncertainty in total cost due still-developing technology
Hydrogen	Directing emissions from the thermal processes during refining	Medium	Low[2]	$$: Blue hydrogen $$$: Green hydrogen	• Can replace natural gas in thermal processes • Suitable for geographies with low costs of fossil fuels and CCS	• High cost • Insufficient infrastructure for transportation
CCS	Direct and indirect emissions from refining and smelting	Medium	Medium[3]	$$ Refining $$$ Smelting	• Good potential in reducing emissions from refining • Suitable for geographies with low fossil fuels and CCS costs	• High cost • Infrastructure needed for CO_2 transportation and/or storage

Source: ING Research, Mission Possible Partnership, European Commission

1. As indirect emissions from indirect power usage account for 62% of total emissions 2. Hydrogen technology readiness is higher on a broader level across all industries 3. CCS technology readiness is high a broader level across all industries 4. Cost depends on clean power sources (renewables, fossil fuels with CCS, hydro, and nuclear) and location. Cost also depends on whether aluminium producers choose to switch to a cleaner grid, develop standalone clean power, and/or purchase PPAs.

How is aluminium produced?

As we discussed in our previous article, aluminium production can be divided into three main steps: mining and filtering out the bauxite, refining it into aluminium oxide, and smelting it into aluminium.



Source: ING Research

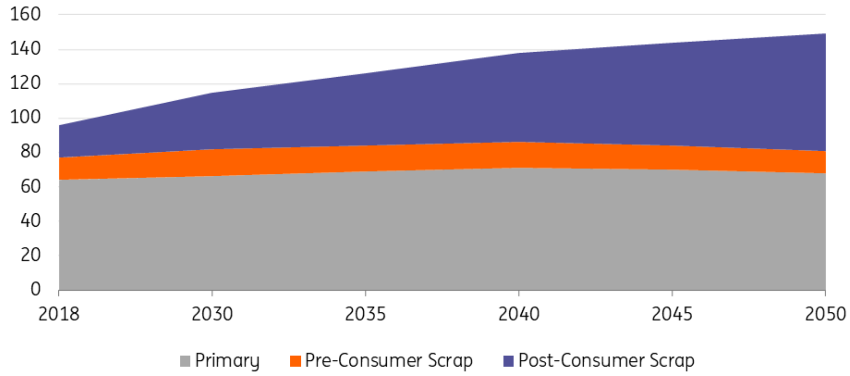
Recycling

One of the most effective ways to reduce emissions from the aluminium industry is recycling. Recycling consumes up to 95% less energy than producing it, making the cost largely manageable when energy savings are taken into account. The characteristics of the metal allow it to be recycled again and again without losing quality. Because of this, aluminium cans are the most recycled container on earth, and 75% of all aluminium ever produced is still being used today.

Yet, despite significant environmental benefits, only about 34% of the aluminium produced in 2018 came from recycled materials. According to forecasts by Rocky Mountain Institute (RMI), that figure needs to increase to 54% for the industry to reach net-zero emissions by 2050. The share of aluminium production from primary (i.e. new) materials would drop from 67% to 46%.

Forecast of aluminium production inputs in the 'net-zero by 2050' scenario

Million metric tons



Source: Rocky Mountain Institute

More attention needs to be paid to post-consumer recycling than to pre-consumer recycling. Pre-consumer recycling refers to reusing the leftover materials from aluminium production, whereas post-consumer recycling means collecting finished aluminium products (e.g., beverage cans), processing them, and reusing them as input for production.

It is increasingly acknowledged that although both processes recycle aluminium, post-consumer recycling is the desired method because the aluminium produced will have already completed its life cycle and can register emissions reductions if it is used again. In contrast, pre-consumer recycled aluminium will not have 'served its purpose' and still needs to book the carbon emissions from the original production process.

Tackling the impurity challenge

Admittedly, recycling aluminium from used products means producers need to tackle the impurity challenge, as the used aluminium is often mixed with plastic labels, dirt, and so on. But impurity is not a deal-breaking problem, and solutions are being developed and improved. Meanwhile, the environmental benefits of emissions reduction and waste management can more than offset the efforts needed to purify used aluminium.

As such, under RMI's net zero by 2050 scenario, the share of post-consumer recycling in aluminium production will increase from the current 20% to 46% by the middle of the century, and the share of pre-consumer recycling will drop from 14% to 9%.

Now, with a higher corporate focus on circularity, more aluminium producers are ramping up production from post-consumer recycling. Hydro, an aluminium and renewable energy company, is offering a product called Hydro CIRCAL that has at least 75% of post-consumer scrap. Alcoa, another aluminium producer, is advancing its ASTRAEATM recycling process to convert low-quality post-consumer aluminium scrap to high-purity aluminium.

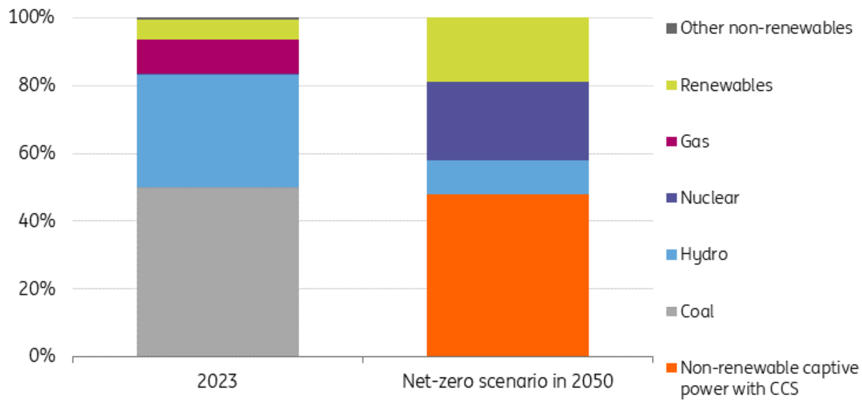
From a societal perspective, increasing the supply of post-consumer scrap can boost the rate of post-consumer recycling. This can be done not only by having more defined recycling signs and trash cans but also by enhancing a city/municipality's trash sorting facilities (many consumers believe that whatever gets separated at trash cans gets mixed again at processing facilities).

Clean electricity

Greening the mix of electricity an aluminium producer uses can also substantially change its emissions profile (reduce Scope 2 emissions). Aluminium production is a highly electricity-consuming process because the smelting process alone requires electric currents constantly running at 400 thousand amperes (A). In 2021, half of the electricity used to power the smelting process came from coal, and that is largely because China is the world's largest aluminium producer, and the country's aluminium production is predominantly coal-powered.

To reach net zero emissions by 2050, about half of the electricity used to power the smelting process needs to come from renewable energy, nuclear, and hydropower, according to an analysis by the Mission Possible Partnership (MPP), an alliance focused on facilitating the decarbonisation of high-emitting sectors. The remaining half will need to be powered by fossil fuel-based captive power equipped with CCS technologies.

Power mix of primary smelting processes



Source: International Aluminium Institute, Mission Possible Partnership, ING Research

Reducing Scope 2 emissions from power usage involves being connected to a cleaner grid, developing standalone clean power to be directly used for aluminium production, or buying renewable power purchase agreements (PPAs). The best solution depends on both a company's general strategy and the location of production. As we've previously mentioned, China has been transitioning a lot of its aluminium production from coal-rich areas to hydro-rich areas.

Many companies are also relying on Power Purchasing Agreements or PPAs. Rio Tinto, for instance, signed a renewable PPA for its aluminium operations in Australia, a region where coal accounts for 45% of the aluminium smelter electricity usage. Alcoa is selling EcoLum aluminium, which is produced predominantly at hydro-produced smelters. Reducing Scope 2 emissions from hydro and renewable sources can be a cost-effective means of green production for these actions that do not involve moving production locations or building completely new plants.

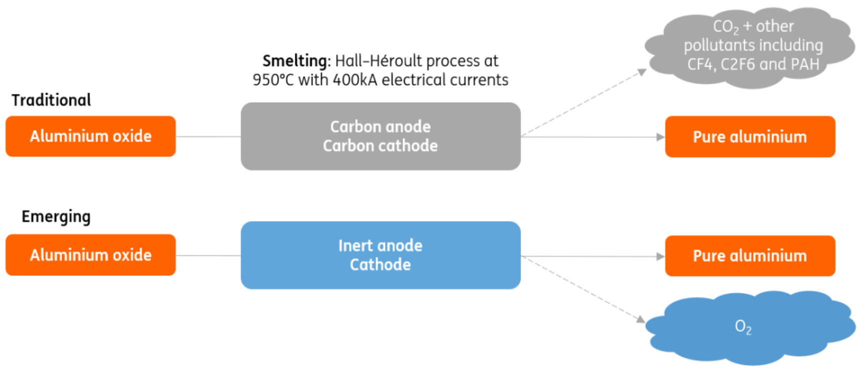
Nuclear is expected to account for more than 20% of the smelting electricity source by the MPP, and we agree that nuclear plays a role in decarbonising the grid and especially energy-intensive activities in the long term. The novel nuclear technology, Small Modular Reactors (SMRs), can be a powerful standalone electricity source capable of powering one or more aluminium sites without having to be connected to the grid. However, SMRs are still in the Research & Development phase. So, in the short to medium term, because of caution on traditional nuclear plants and the nascent stage of SMR technologies, nuclear's contribution to decarbonising the grid will be limited.

Inert anodes

Since smelting accounts for most of the emissions from aluminium production, emerging technologies are being developed to decarbonise that process. One that is gaining popularity is inert anodes, which replace carbon anodes in smelters. Traditionally, aluminium oxide runs through a smelter with carbon anodes, where oxygen is removed from the oxide and reacted with the carbon anodes.

As a result, high-purity aluminium is produced, but so is carbon dioxide (CO_2). An inert anode, however, does not contain the carbon element and is instead made of cermet, metal alloys, or other suitable materials. With inert anodes, the products of the smelting process are high-purity aluminium and oxygen.

Aluminium smelting process - traditional vs. inert anodes



Source: ING Research

This means that inert anodes have the potential to eliminate almost all the direct emissions (non-electricity and heating related) from the smelting process, bringing huge environmental benefits. The technology is still under development and not commercially available, but the outlook looks promising. In 2019, Elysis, a joint venture between Alcoa and Rio Tinto, succeeded in producing aluminium using inert anodes and started constructing the first commercial-scale prototype cells of the inert anode technology at a Rio Tinto smelter in Quebec, Canada.

Inert anodes are not yet commercially available, but because of the successful pilots mentioned above, the technology has the potential to be applied more widely in a shorter timeframe. The fact that inert anodes remain in the testing and development phase also makes it hard to estimate the cost, especially when it comes to the broader market. Now, some research groups believe that the cost of installing greenfield inert anodes would likely be 'medium' compared to green hydrogen and CCS for aluminium smelting ('high'). A report published by MPP suggests that retrofitting smelters to include inert anodes is possible but would require significant costs, which can make retrofitted inert anodes a less attractive option than CCS in smelters.

Hydrogen

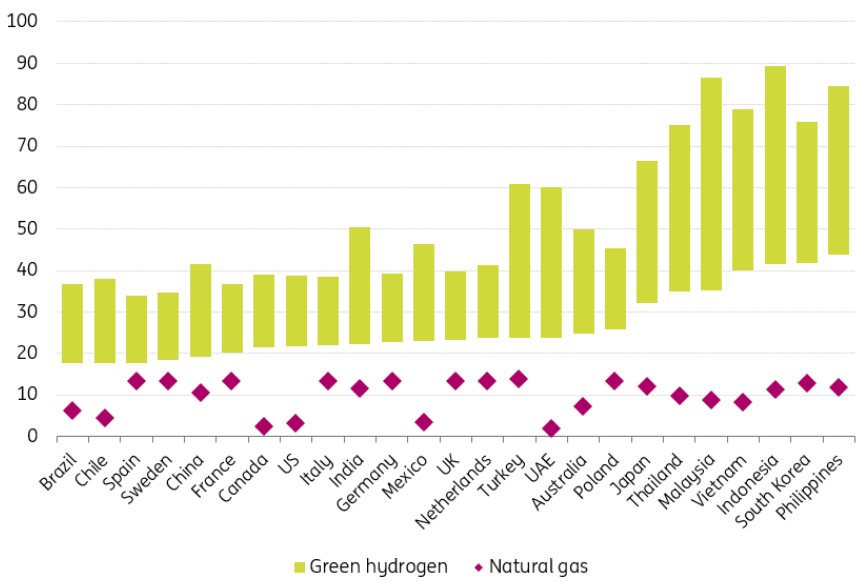
Hydrogen has been explored as an alternative to natural gas to be combusted during the industrial heating processes for producing steel, petrochemicals, and so on. The same technique is also being developed in aluminium production. Natural gas or coal is typically burned during the refining process to provide a heated environment of roughly 300 degrees Celsius for digestion and 950 degrees Celsius for calcination. With hydrogen as an alternative, only water, instead of CO_2, would be produced from the combustion. Such a method can substantially reduce the indirect emissions associated with refining.

Yet, the cost is hindering a faster application of hydrogen in the aluminium industry. Today, both green hydrogen (produced from electrolysing water using renewable power) and blue hydrogen (produced from fossil fuel sources with CCS) are still visibly more expensive than grey hydrogen (produced from fossil fuels without abatement). For blue hydrogen, CCS technologies are expensive to adopt; for green hydrogen, not only are electrolysers pricey to install but the availability and cost of renewable power are also a challenge.

In 2023, green hydrogen was more expensive than natural gas in all the countries listed below, according to Bloomberg New Energy Finance. And the gap is considerable in areas with low natural gas prices and/or high renewable power and electrolyser costs.

Levelised green hydrogen costs compared to natural gas prices in selected countries

2023, $/MMBtu

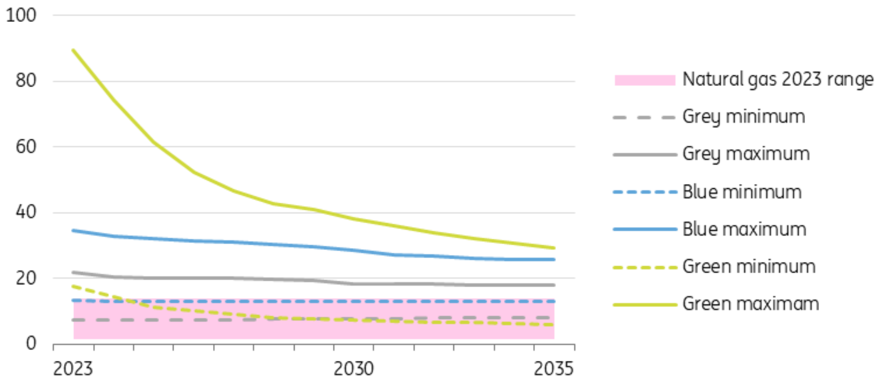


Source: Bloomberg New Energy Finance

The cost outlook of green hydrogen may significantly improve in the medium to long term, with the lowest possible cost of green hydrogen maybe trending below the lowest cost of grey hydrogen by around 2030. Policy incentives, which are being rolled out by many governments, can also boost cost competitiveness.

Levelised cost of different shades of hydrogen compared with natural gas prices

$/MMBtu, based on data from over 20 countries



Source: Bloomberg New Energy Finance, ING Research

For hydrogen to take off even faster, its transportation infrastructure—pipelines, suitable trucks, ships, or a combination of all of them—needs to be significantly strengthened.

Today, the use of hydrogen to decarbonise production is seen less often in aluminium than in other energy-intensive industries. Hydro produced the world's first batch of aluminium in a test with renewable hydrogen in 2023, and since the aluminium was produced from post-consumer scrap, the production process was essentially carbon-free. One can hope that such applications will become more widespread as the hydrogen industry matures.

Alternatives to hydrogen: biofuels and electrification

It is worth mentioning that competing technologies can potentially replace hydrogen as an alternative to natural gas. These include biofuels, which can be used for combustion, and electrification, which essentially eliminates the combustion process.

Among biofuels, renewable natural gas (RNG or biomethane) can be used to replace fossil natural gas. And because RNG has the same chemical composition as natural gas, it can serve as a 'drop-in' fuel that involves minimal infrastructure retrofitting. But just like many other clean energy options, RNG prices are visibly higher than natural gas, especially in areas where natural gas prices are low. RNG adoption in the aluminium industry is, therefore, low and will rely on policy support to scale up.

As for electrification, some research shows that replacing traditional furnaces with electrical ones can be more cost-effective than burning hydrogen in the low to medium-heat processes of refining in aluminium production. For the high-heat processes during refining, clean fuels like hydrogen would be a more suitable option, given the level of temperature and energy needed.

Carbon Capture and Storage

Finally, CCS is an emerging technology that can help the aluminium industry decarbonise. CCS can reduce carbon emissions from two parts of aluminium production:

1. CO_2 generated from industrial heating and processing
2. CO_2 generated during the smelting process when aluminium oxide reacts with carbon anodes

Although CCS technologies have existed for a long time and have reached commercial viability, their application in the aluminium industry is a lot more nascent with sector-specific challenges. In 2022, Aluminum Bahrain (Alba) and Mitsubishi Heavy Industries signed a memorandum of understanding to evaluate how to use CCS technologies to reduce emissions from Alba's plants, but no concrete result has been communicated since then. More recently, Fives, an industrial engineering group, set up a consortium with Aluminum Dunkerque, Trimet, and Rio Tinto to develop CCS solutions. Hydro also announced it's set to explore CCS in aluminium production but expects to develop an industrial-scale pilot only by 2030.

The high cost of applying the technology to smelting

The biggest challenge to adopting CCS in aluminium production is the high cost of applying the technology to smelting. To begin with, for any industry, deploying CCS already requires high upfront costs that can be hard to recover without policy incentives or other revenue streams, such as selling captured carbon. For aluminium smelting, specifically, capturing costs can be even higher. A main factor determining the cost of capturing is the CO2 partial pressure of a flue gas stream at the point source of emissions, which is directly related to CO_2 concentration: the higher the CO_2 concentration is, the higher its partial pressure is, and the lower the per-ton capturing cost is.

Aluminium smelters have one of the lowest carbon partial pressures among most sectors. This makes the cost of capture in aluminium smelters high, likely two to four times the cost of CCS in iron and steel production and approximately 25 times the cost in natural gas processing, fertiliser, and bioethanol production. Such a high cost of capturing CO_2 from smelters makes inert anodes a promising alternative, as it aims to achieve the same effect.

Cost of CCS in various types of power and industrial processes

Excluding downstream CO_2 compression

2020 dollars per tonne of CO_2

Source: ING Research estimates based on Global CCS Institute

However, the high per-unit cost of CCS only applies to capturing CO_2 from smelters. The cost for refining and heating in the rest of the production process is much lower, at a level comparable to applications in many other industries. This suggests that CCS can still have good potential in decarbonising aluminium production, just not for the smelting part in the short to medium term.

The challenges ahead

Reducing emissions is challenging for an energy-intensive industry such as aluminium, but efforts are underway. It is worth emphasising that simply switching to clean electricity sources such as hydro, solar, wind, and nuclear power can already lead to a roughly 75% reduction in emissions from the industry globally.

Reducing direct emissions from the production process is also important, though many possible technologies, such as hydrogen and CCS, remain costly to deploy. Although aluminium consumers are now keener to manage Scope 3 emissions, the high price tag for green aluminium is hindering faster demand growth. This means that significant investment is needed to fuel the R&D and infrastructure improvement.

Government policy is crucial to making this happen, be it financial incentives for clean aluminium production, carbon pricing, initiatives for clean aluminium production hubs, or other means. In future articles, we will explore the business case of these technologies and policies.

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Greening aluminium: Ambitious goals on decarbonisation, but little progress

The aluminium sector's initial steps towards net-zero emissions

Aluminium producers have been slow to decarbonise their industry

Decarbonisation has been slow and unimpressive

We have taken a closer look at the top 8 global aluminium producers* (accounting for 40% of global aluminium production) for the period between 2018 and 2023. We looked through their annual sustainability and climate progress reports to gauge production performance, climate targets and strategy and progress on decarbonisation over the last six years.

So, below, we're giving you a brief review of those selected companies' climate goals and statistics obtained from their annual reports. And we can confidently state that decarbonisation so far has been slow and unimpressive. In fact, some companies state they'll emit more tonnes of greenhouse gasses (GHG) up to 2030 and only then will they start the long-distance marathon towards ambitious net-zero targets.

Here are our key findings.:
Climate goals and carbon emission disclosure practices have improved since regulators worldwide implemented requirements for carbon emission disclosure reports as part of wider Sustainability initiatives.

Sustainability reporting requires improved disclosure of environmental expenditures. Environmental investment might be spread between operational and capital expenditure or cannot be disclosed properly under existing regulations. We cannot state with any certainty how much the sector is investing in decarbonisation now and how much this amount has changed over recent years. We believe that further development of sustainable reporting disclosures is an important topic, especially for corporates in non-EU jurisdictions.

Consolidated aluminium production of the top-8 producers reached 150.6mt in the six years between 2018 and 2023; Annual production from the top-8 reached 27.7mt in 2023 (+13.5% vs 2018), with total 2023 global aluminium production at 70.5mt.

Global aluminium supply & demand, sector GHG emissions

		2018	2019	2020	2021	2022	2023	% 2023 vs. 2018
ALCOA	smelting	5.60	5.98	5.08	4.43	4.36	4.15	-25.9
CHALCO	electrolytic	13.11	13.30	12.71	12.67	11.43	11.25	-14.2
HONGQIAO	Aluminium products	13.04	10.58	11.78	12.19	12.19	11.42	-12.4
Norsk Hydro	Electrolysis, based on ownership equity	1.60	1.60	1.59	1.64	1.57	1.54	-3.8
Rio Tinto	anodes	#N/A	#N/A	#N/A	1.65	1.66	2.08	#N/A
UC RUSAL	GHG (Scope 1) electrolysis HKEX KPI A1.2	2.11	2.04	2.04	2.02	2.00	1.99	-5.7
Vedanta (aluminium)	Carbon emissions (Scope 1 + Scope 2)	21.39	18.11	21.26	16.59	16.58	17.76	-16.9
South32	Carbon emissions (Scope 1 + Scope 2)	14.44	14.20	13.54	13.90	12.86	12.83	-5.7
Top-8 carbon intensity	**tonne of CO2e/ tonne of product**	**11.04**	**10.59**	**11.03**	**11.86**	**12.17**	**11.77**	**6.6**

Source: Corporates reports, ING

Aluminium production by the 8 largest producers

(mt)

	2018	2019	2020	2021	2022	2023	% 2023 vs. 2018
ALCOA	2.3	2.1	2.3	2.2	2.0	2.1	-6.4
CHALCO	4.2	3.8	3.7	3.9	6.9	6.8	62.8
HONGQIAO	6.4	5.6	5.6	5.6	6.0	6.3	-1.6
Norsk Hydro	2.0	2.0	2.1	2.2	2.1	2.0	1.9
Rio Tinto	3.2	3.2	3.2	3.2	3.0	3.3	1.3
UC RUSAL	3.8	3.8	3.8	3.8	3.8	3.8	2.5
Vedanta (aluminium)	1.7	2.0	2.0	2.3	2.3	2.4	41.5
South32	1.0	1.0	1.0	1.0	1.1	1.0	
Top-8	**24.4**	**23.5**	**23.6**	**24.1**	**27.3**	**27.7**	**18.1**
% of global total	38.1	36.7	36.1	35.7	39.6	39.3	

Source: Corporates reports, ING

Accumulated (Scope 1 and Scope 2) GHG emissions by the top-8 producers **reached 1,772 million tonnes** of CO_2e between 2018 and 2023. 2023 Scope 1 and Scope 2 GHG emissions increased by 21% vs 2018, to 326mt of CO_2e.

Scope 1 GHG Emissions by the 8 largest aluminium producers

(mt CO2e)

	2018	2019	2020	2021	2022	2023	% 2023 vs. 2018
ALCOA	17.5	17.7	18.5	17.4	16.8	16.5	-5.5
CHALCO	28.0	25.4	21.2	48.9	78.6	76.4	172.7
HONGQIAO	66.6	55.0	50.0	51.4	53.5	56.2	-15.6
Norsk Hydro	6.0	6.5	6.9	7.6	7.2	6.8	12.2
Rio Tinto	24.4	23.1	23.0	22.9	22.7	23.3	-4.5
UC RUSAL	8.7	8.8	8.9	8.9	8.9	9.0	2.8
Vedanta (aluminium)	33.2	34.7	41.4	35.5	32.0	39.2	18.2
South32	6.5	6.4	6.2	6.2	6.3	6.1	-5.8
Top-8 total	**190.9**	**177.6**	**176.1**	**198.8**	**226.0**	**233.5**	**22.3**

Source: Corporates reports, ING

Scope 2 GHG Emissions by the 8 largest aluminium producers

(mt CO2e)

	2018	2019	2020	2021	2022	2023	% 2023 vs. 2018
ALCOA	6.7	6.6	5.4	4.4	4.0	3.8	-43.1
CHALCO	28.0	27.0	28.0	29.6	48.4	47.3	69.3
HONGQIAO	17.7	13.3	26.1	27.3	25.2	17.6	-0.6
Norsk Hydro	1.5	1.5	1.4	1.8	1.2	1.2	-21.1
Rio Tinto	9.3	9.9	10.4	10.1	9.6	9.3	0.0
UC RUSAL	0.88	0.75	0.82	0.60	0.49	0.42	-51.9
Vedanta (aluminium)	2.7	0.8	0.5	2.1	6.0	2.9	8.8
South32	11.4	11.3	10.9	11.3	10.9	10.3	-9.9
Top-8	**78.0**	**71.1**	**83.5**	**87.2**	**105.8**	**92.7**	**18.9**

Source: Company reports, ING

Signs of hope

In 2023, annual consolidated GHG emissions (Scope 1 and Scope 2) from the top-8 aluminium producers dropped to 326mt from 332mt in 2022. Annual aluminium production remained flat at about 39mt.

Scope 1 and Scope 2 GHG Emissions by the 8 largest aluminium producers

(mt CO2e)

	2018	2019	2020	2021	2022	2023	% 2023 vs. 2018
ALCOA	24.2	24.3	23.9	21.8	20.8	20.3	-16.0
CHALCO	56.0	52.3	49.2	78.5	127.1	123.7	121.0
HONGQIAO	84.2	68.3	76.1	78.7	78.8	73.8	-12.4
Norsk Hydro	7.5	8.1	8.3	9.4	8.4	8.0	5.7
Rio Tinto	34.5	33.0	33.4	33.0	32.3	32.6	-5.5
UC RUSAL	9.6	9.6	9.7	9.5	9.4	9.4	-2.2
Vedanta (aluminium)	35.8	35.5	41.9	37.6	38.0	42.1	17.5
South32	17.9	17.7	17.1	17.5	17.2	16.4	-8.4
Top-8	**269.8**	**248.7**	**259.7**	**286.0**	**331.9**	**326.3**	**20.9**

Source: Company reports, ING

The sector's blended carbon emissions intensity** in 2023 dropped from 12.17 tonnes of CO_2e per tonne of aluminium produced to 11.77 tonnes of CO_2e per tonne of aluminium produced. Compared to 2018, carbon emission intensity grew by 6.6%.

Reported carbon emissions' intensity at the 8 largest aluminium producers

		2018	2019	2020	2021	2022	2023	% 2023 vs. 2018
ALCOA	smelting	5.60	5.98	5.08	4.43	4.36	4.15	-25.9
CHALCO	electrolytic	13.11	13.30	12.71	12.67	11.43	11.25	-14.2
HONGQIAO	Aluminium products	13.04	10.58	11.78	12.19	12.19	11.42	-12.4
Norsk Hydro	Electrolysis, based on ownership equity	1.60	1.60	1.59	1.64	1.57	1.54	-3.8
Rio Tinto	anodes	#N/A	#N/A	#N/A	1.65	1.66	2.08	#N/A
UC RUSAL	GHG (Scope 1) electrolysis HKEX KPI A1.2	2.11	2.04	2.04	2.02	2.00	1.99	-5.7
Vedanta (aluminium)	Carbon emissions (Scope 1 + Scope 2)	21.39	18.11	21.26	16.59	16.58	17.76	-16.9
South32	Carbon emissions (Scope 1 + Scope 2)	14.44	14.20	13.54	13.90	12.86	12.83	-5.7
Top-8 carbon intensity	**tonne of CO2e/ tonne of product**	**11.04**	**10.59**	**11.03**	**11.86**	**12.17**	**11.77**	**6.6**

Source: Corporates reports, ING

Calculated carbon emission intensity at the 8 largest aluminium producers

(tonne of CO2e/tonne of aluminium)

	2018	2019	2020	2021	2022	2023	% 2023 vs. 2018
ALCOA	10.71	11.38	10.56	9.94	10.35	9.62	-10.2
CHALCO	13.42	13.80	13.34	20.34	18.47	18.22	35.8
HONGQIAO	13.22	12.10	13.54	13.97	13.04	11.77	-11.0
Norsk Hydro	3.77	3.95	3.99	4.21	3.92	3.91	3.7
Rio Tinto	10.68	10.41	10.50	10.47	10.73	9.96	-6.7
UC RUSAL	2.56	2.55	2.59	2.51	2.45	2.44	-4.6
Vedanta (aluminium)	21.39	18.11	21.26	16.59	16.58	17.76	-16.9
South32	18.26	17.95	17.41	17.61	16.15	15.88	-13.0
Top-8 carbon intensity	**11.04**	**10.59**	**11.03**	**11.86**	**12.17**	**11.77**	**6.6**

Source: Company reports, ING

Key questions on decarbonisation

Has any company made progress towards decarbonisation?

Yes, almost all of them, but not enough to achieve a visible slowdown in emissions. The level of emissions from primary aluminium production depends on the type of raw material (bauxite, alumina or aluminium scrap), the technology for processing it into primary aluminium or aluminium products, the energy efficiency of such technology, and the structure of energy sources (including the percentage from renewable sources). As seen in company reports, the most visible progress on overall emission cuts has been through switching from coal to hydropower by corporates in China, although these producers remained the largest carbon emitters globally. Almost all major corporates have launched special low-carbon aluminium brands (with up to 4.0 tonnes of CO_2e per tonne of aluminium), utilising a combination of energy-efficient technology and a high share of renewable energy sources. That said, sales volumes of low-carbon aluminium remain insignificant.

Do the companies invest in decarbonisation?

Yes, but published reports reveal concrete levels for only a few of them. Of the corporations we looked at, relevant data was published by Norway-based Norsk Hydro thanks to EU Taxonomy regulation; its environmental expenditures comprised around 29% of overall Capex (c.$719m). The companies studied tend not to disclose detailed environmental investment amounts and offer only limited data.

Do producers have sufficient resources to invest in decarbonisation?

Aluminium corporates appear to be at low leverage and profit making, while the groups controlling aluminium businesses usually pay dividends. In 2023, we calculate that average Net Debt/ EBITDA of the top-8 producers was 0.8x. Consolidated net income reached US$13.9bn, operating cash flow US$32bn, Capex US$7.0bn, free cash flow from operations before dividends US$12.bn and total dividend payments US$11bn.

Is it only aluminium producers responsible for carbon emissions in the aluminium sector?

Not at all. While changing energy sources and developing technologies might significantly reduce emissions as we move towards net-zero emissions, customers of aluminium producers also need to pay more. According to Norsk Hydro, the current potential demand for low-carbon aluminium is estimated at 16mt of more than 70mt of global aluminium demand. A major portion of aluminium sector customers still prefer to buy cheap, carbon-intensive aluminium. The source of energy is also important when aluminium companies cannot swiftly switch from one energy supplier to another - Hillside Aluminium of South32 purchases coal–generated energy from Eskom (a key customer in the region with a long-term energy supply contract).

Corporate strategy and effectiveness also depend on the smelter's location, jurisdiction, national environmental strategy, the host country's environmental commitments, and the strategies and power sources that aluminium companies use. For example, Vedanta is increasing its GHG input while India is adding thermal power generation. China is making efforts on transition but stipulates that its carbon emissions should peak only by 2030. South32 is restricted in emission reductions due to its contract with coal power energy supplier Eskom.

You may be able to view more detailed corporate analysis on our investment research website at https://research.ing.com.

Footnotes:

***** We look at the eight largest aluminium producers which release publicly available sustainability and/or climate progress reports and carbon emission statistics. These are Rio Tinto, Aluminium Corporation of China Limited (CHALCO), China Hongqiao Group Limited (Hongqiao), Norsk Hydro (Hydro), ALCOA, Vedanta, South32 and UC RUSAL (US RUSAL remains under various sanctions)
****** The sector's blended carbon emission intensity for the eight companies we looked at is the ratio of consolidated emissions to aluminium production.

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