In collaboration with Accenture

WORLD ECONOMIC FORUM

Aluminium for Climate: Exploring pathways to decarbonize the aluminium industry

COMMUNITY REPORT

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Executive summary

The aluminium sector is an integral part of the sustainable economy, but as a carbon-intensive industry it will need to proactively address its sectoral carbon footprint.

The aluminium industry generates more than 1.1 billion tonnes of CO_2e (carbon dioxide equivalent) emissions annually – around 2% of global anthropogenic emissions. In view of the projected growth in demand for aluminium, emissions need to be addressed to limit global warming to 1.5°C in order to curb climate change risks. In this report, the World Economic Forum and Accenture explore the case for change in the aluminium industry and aim to inspire the sector, its suppliers and customers to address this challenge proactively and collaboratively.

Focus on three priority areas would significantly reduce the emissions of the aluminium industry. First, the decarbonization of electricity consumption (accounting for more than 60% of the industry's carbon footprint). The aluminium industry's power supply can be fundamentally addressed through the transition to renewable energy sources and/or carbon capture, utilization and storage (CCUS) technologies. Second, the decarbonization of direct emissions from the processing of aluminium (accounting for 25–30% of sectoral emissions). The highest-impact pathways to decarbonize process emissions are transitioning to technologies that can provide heat and steam without the use of fossil fuels and the development of a non-carbon anode. Finally, the recycling of aluminium scrap, which requires just 5% of the energy needed to produce primary aluminium. Increased collection and recovery of post-consumer scrap can reduce the need for carbon-intensive primary aluminium by up to 15%.

Successful decarbonization of the aluminium industry relies on joint action across the value chain from suppliers, aluminium players and customers. Collaborative research and development will reduce the cost to individual companies that operate on slim profit margins and result in industry-wide benefits. Aluminium players, especially smelting operations, should work closely with power providers to support the transition to renewables and cost-effectively scale low-carbon electricity.

All industry players can start taking action to begin the path to decarbonization, such as:

- Working internally to understand current-state emissions and set targets to decarbonize
- Collaborating with value-chain partners on research and development opportunities, including inert anode development, CCUS applications and improved scrap collection and sorting methods
- Influencing global decarbonization policy to drive common standards

While the aluminium industry faces many challenges in its path towards decarbonization, a net-zero future is achievable. We call upon leaders in the aluminium industry to engage in the conversation about decarbonization, to set ambitious targets and to work together on a path to reach net zero by 2050.

1

Introduction

As a heavy emitter, the aluminium industry has a pivotal role to play in meeting global decarbonization goals.

The heavy industry sectors together emit more than 10 gigatonnes (Gt) of total greenhouse gas (GHG) emissions, of which the aluminium industry generates around 1.1 billion tonnes of CO_2e annually, predicted to increase by 50% by 2050 under a business-as-usual scenario.[1, 2]

The world relies on aluminium. As the second most-used metal in the world by mass, it is integral to several vital industries including construction, transport and power transmission. While aluminium is an essential material for a sustainable future, the industry is currently responsible for 2% of global anthropogenic GHG emissions.[3]

The United Nations calls upon all to ensure 2020 ushers in the decade of delivery. For every industry, including aluminium, now is the time to act.

The aluminium industry must play a key role in accelerating the transition to a low-carbon economy given its prominence in supporting global growth. The Aluminium for Climate Initiative was established in 2019 under the Mission Possible Platform, a World Economic Forum coalition committed to reducing heavy industry GHG emissions. The aim of the initiative is to support the sector's collective efforts in addressing its major challenges and to help capture opportunities to meet society's decarbonization needs.[4]

In this report, the World Economic Forum and Accenture explore the case for change in the aluminium sector, including industry-specific decarbonization challenges, examples both within and outside of the industry, and potential pathways for tangible impact to reduce the sector's carbon footprint. It aims not only to tell the story of why action is needed, but also to inspire the sector, its suppliers and customers to address this challenge proactively and collaboratively.

2 The case for change

Despite challenges, now is the time to act to sustainably meet increasing aluminium demand.

Global response to climate change

Scientists around the world agree that human activity has led to a sharp increase in greenhouse gas (GHG) concentrations, which is causing rapid climate change that threatens livelihoods around the world – affecting food security, weather patterns, sea levels and more.[5] In response, nearly every nation signed the Paris Climate Agreement in 2015. The Paris Agreement aims to "strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C".[6]

Since that initial commitment in 2015, countries and organizations around the world have developed even more ambitious decarbonization targets to combat climate change as additional information on projected pathways becomes available.

In 2018, the Intergovernmental Panel on Climate Change (IPCC) published a special report detailing what it would take to limit global warming to 1.5°C above pre-industrial levels.[7] Human activities have already caused a 1°C rise in global warming and at the current rate of emissions it is likely that we will reach 1.5°C warming between 2030 and 2052, accelerating climate-related events.

The IPCC states that to limit global warming to 1.5°C, it is necessary to reduce greenhouse gas emissions by 45% from 2010 levels by 2030 and to reach net zero by 2050.[8] Even under the 2°C scenario, rapid action is needed; the International Aluminium Institute (IAI) projects that the aluminium sector would need to eliminate emissions from electricity consumption (currently making up more than 50% of sector emissions) and reduce direct emissions by 50% by 2050 (on a 2018 baseline).[9]

Taking action now

At this point, there is no evidence that greenhouse gas emissions have peaked and begun to decline.[10] With every year the peak is delayed, more rapid action will be required to meet either a 1.5°C or 2°C scenario. As consumers, investors and governments expect action, companies face increasing pressure to limit the impact on the environment or risk facing the court of public opinion and legal repercussions.

Fortunately, 2020 seems to mark an inflection point of both interest and urgency in the global fight against climate change. Although the 26th UN Climate Change Conference (COP26) has been postponed to the autumn of 2021 due to the COVID-19 pandemic, it is often argued that "COVID-19 has already given us a glimpse … of what a full-fledged climate crisis and ecosystem collapse could entail".[11] COP26 will pay particular attention to the role of industrial decarbonization pathways and the progress of heavy industry sectors to reach their commitments.

Materials such as aluminium are critical to achieving a sustainable economy. Substantial progress has been made, but more is needed. As Climate Action Champions we support this journey towards a net-zero industry by working with our allies in all continents and by supporting the establishment of closer interlinkage points with key customer industries and policy-makers.

Nigel Topping, UK High-Level Climate Action Champion, COP26

Although the sense of urgency varies across the different heavy industries, the direction of sustainability performance across all sectors is consistent. Heavy industry players are facing real business risk; if aluminium is not seen as a low-carbon material, it is likely that future demand will be affected as consumer-facing industries pivot and search out low-carbon alternatives. We have already seen demand for materials responding to environmental, social and governance (ESG) concerns. For example, the construction industry has begun shifting towards mass-timber structures that early studies indicate have lower life-cycle GHG emissions than traditional steel and concrete structures.[12,13]

As a significant emitter, it is the aluminium sector's time to present an industry action plan on the pathway to decarbonization. While some aluminium players have set public targets to decarbonize, many have not (yet). The industry needs to raise the level of collective ambition in order to drive meaningful change.

TABLE 1 | Examples of aluminium players' public climate ambitions

Aluminium player	Ambition*
Alcoa[14]	Reduce GHG emission intensity (Scope 1 and 2) by 30% by 2025 and by 50% by 2030 from a 2015 baseline
EN+ Group/RUSAL[15]	Limit warming to 1.5°C via science-based emissions reduction (sign up to SBTi)
GFG Alliance/Alvance[16]	Achieve carbon neutrality by 2030
Norsk Hydro[17]	Reduce GHG emissions by 30% by 2030
Rio Tinto[18]	Reduce carbon intensity[19] by 30% and absolute emissions by 15% by 2030 and reach net-zero emissions by 2050

* Not exhaustive

Decarbonization ambitions across the aluminium value chain [20]
Apple

In July 2020, Apple announced its commitment to reach carbon neutrality across its supply chain and products by 2030 through reducing emissions by 75% by 2030 and supporting carbon removal solutions to address the remaining 25% of emissions (Scope 1, 2 and 3). The company has already reached carbon-neutral corporate operations worldwide and will continue its accelerated journey to net zero. Some of the actions Apple plans to take include: improving end-of-life recovery of materials used in its products, making products and operations more energy-efficient, moving its entire supply chain to 100% renewable power, investing in nature-based carbon removal solutions, and collaborating with aluminium suppliers to develop the first-ever direct (Scope 1) carbon-free aluminium smelting process. Apple is focused beyond its direct operations and is gaining commitments from suppliers to similarly transition to net zero.

Aluminium industry carbon footprint and material life cycle

As decarbonization efforts are accelerated across the world, the aluminium sector has a vital role to play in the path towards net zero. More than 90% of the aluminium industry's emissions are due to primary production processes, despite primary aluminium amounting to less than 70% of global supply.[21 22]

The aluminium value chain is responsible for several significant emissions sources, including:

– Combustion of fuel and use of electricity for mining

– Industrial heat and steam and the use of electricity for refining

– Production of ancillary materials used during refining and smelting (e.g. anodes)

– Fossil fuel-based electricity to power the electrolytic cell during smelting

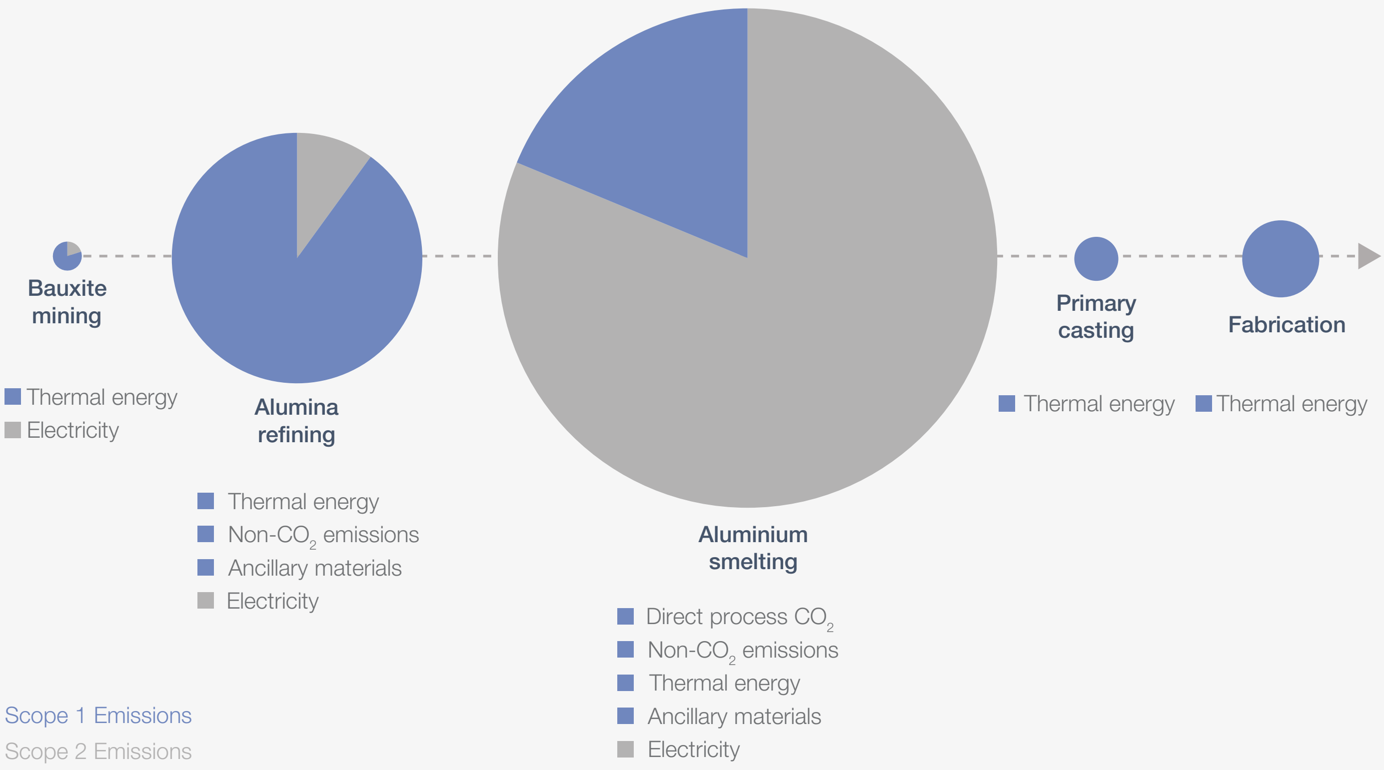
– Direct CO_2 emissions from carbon anode consumption during electrolysis

– Thermal energy to generate heat and steam for casting and fabricating aluminium

– Transportation to different sites for manufacturing or retail

– Waste processing and disposal

FIGURE 1 | CO_2e emissions in primary aluminium production[23]



Some 77% of aluminium sector CO_2e emissions are generated in the smelting process, of which more than half (and 64% of sector-wide emissions) are due to electricity usage.[24] Because of this high reliance on electricity, the sector's ability to decarbonize is heavily dependent on the type of power available to the 200-plus aluminium smelters worldwide.[25]

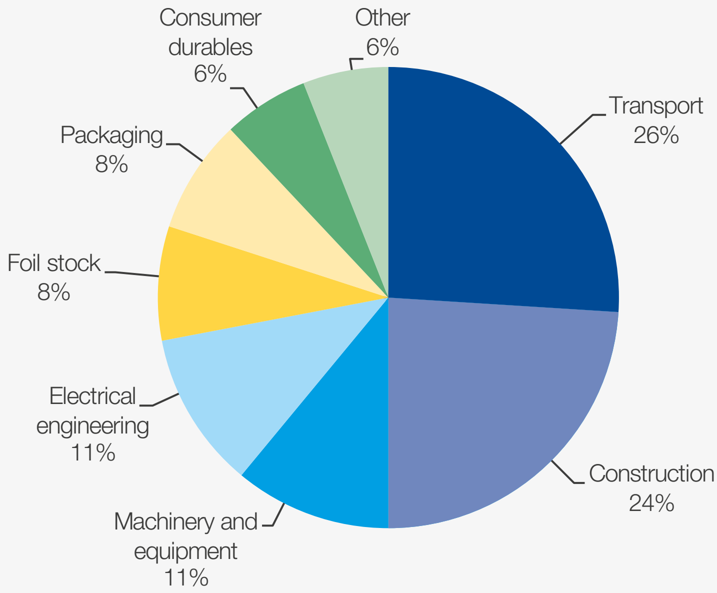
Aluminium production uses either grid power or captive power; each of these sources provides different benefits and challenges when it comes to decarbonization. Around one-third of the aluminium industry is reliant on grid power, while two-thirds use captive power sources. Grid-powered plants are dependent on the pace of change of national utilities and constrained by local regulations that may inhibit a competitive market for new renewables capacity. However, it is captive plants, most notably (but not solely) coal-fired power plants, that are driving increasing emissions across the sector.[26] The industry has in the past two decades built a greater reliance on coal power, primarily due to captive coal-fired power plants being built in China.[27]

While recycled aluminium production contributes less than 10% of industry carbon emissions, it currently makes up around 30% of demand. Recycled aluminium production uses just 5% of the energy needed for primary production. Replacing high-carbon primary aluminium with recycled aluminium (more than 25 times less carbon-intensive) will be key to reducing overall industry emissions.[28]

Demand projections

Aluminium plays an integral role in the modern world, supplying nations with the materials needed to build infrastructure and support further development.

FIGURE 2 **Global end use of aluminium (2019)**[29]



Aluminium demand is anticipated to grow by more than 50% by 2050 to 298 megatonnes (Mt).[30 31] The IAI anticipates that demand increase cannot be met solely by recycled post-consumer scrap and will require an additional 90 Mt of primary aluminium production by 2050, assuming no change in recycling rates, or 75 Mt with increased recycling (from a 2019 baseline of 65 Mt). Demand met from scrap is projected to increase from 33% today to 50–60% by 2050, under several scenarios.[32]

If no action is taken, this increase in primary production to meet growing demand will correspond to a rise in sectoral carbon emissions of around 30%.[33]

Several factors contribute to the anticipated growth of the aluminium sector:

- Global population growth
- Increased urbanization requiring new construction and expanded transportation
- Growth of the electric vehicle industry (offers lightweight vehicle material)
- Expansion of the electrical grid, especially in developing countries
- Greater use in consumer goods' packaging (to replace single-use plastics)

Another driver of the increasing demand for aluminium is the role it will play in the sustainable economy. Aluminium is necessary for the construction of both conventional (coal, natural gas, nuclear) and renewable (solar, wind, energy storage) technologies. This is particularly true for solar photovoltaics (PV) – aluminium accounts for more than 85% of most solar PV components.[34] According to analysis conducted by the World Bank Group, the aluminium demand for solar PV technologies under a 2°C scenario from 2020–2050 exceeds 90 Mt.[35] As this demand increases from the energy sector, it is crucial that aluminium makes an effort to decarbonize or risk displacing the carbon savings of renewables with the high-carbon footprint of the materials needed to produce those technologies.

Challenges to decarbonization

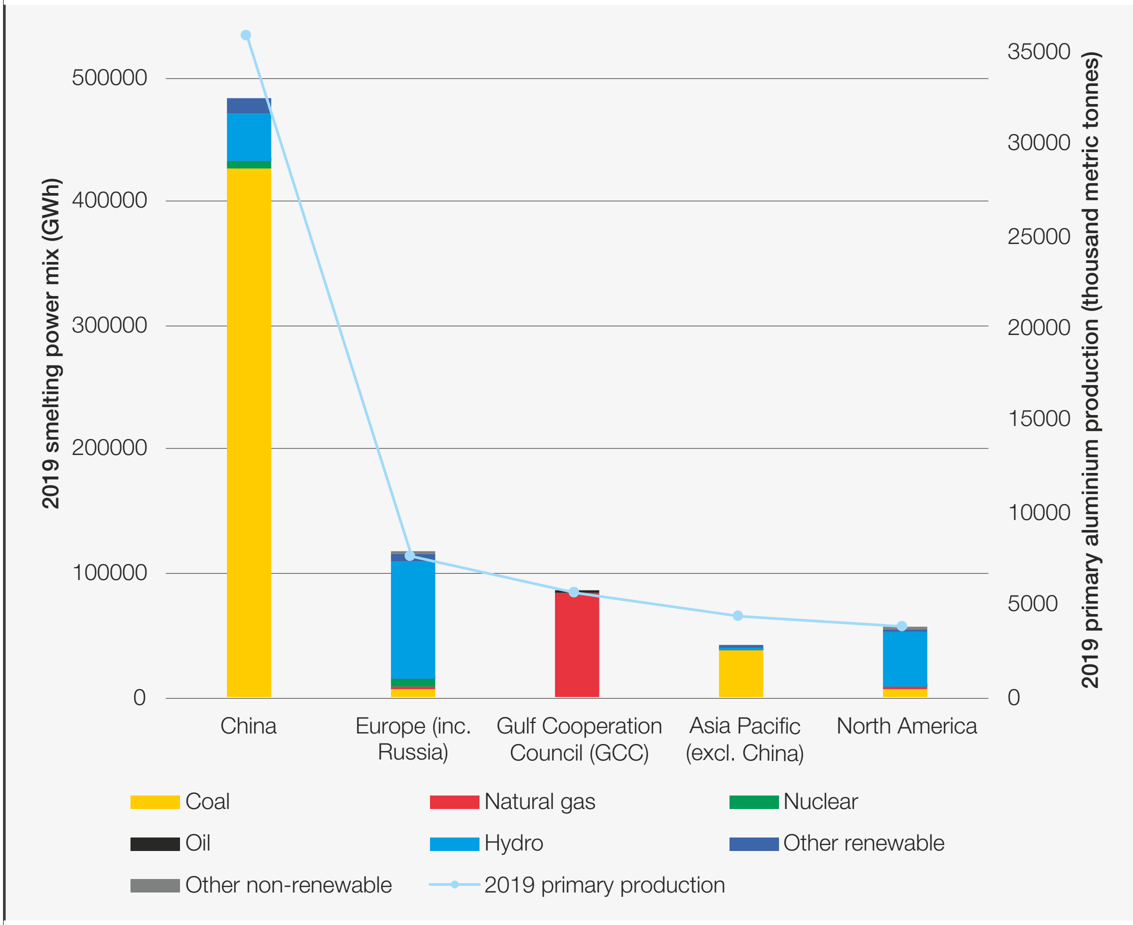
Such strong growth projections and a continuous need for primary material make decarbonization of the aluminium sector particularly urgent and challenging.

Industry-specific challenges

There are significant disparities in decarbonization starting points for aluminium players across the value chain, which inhibits a coordinated response.

The greatest disparity is the availability of cost-competitive renewable power. In an energy-intensive sector such as the aluminium industry, renewable power is one of the greatest opportunities to lower carbon emissions. Although all power supplies must reach net zero by 2050 to meet a 1.5°C or 2°C scenario, regional variations in generation mix make the transition to renewables more expensive and difficult for some companies.

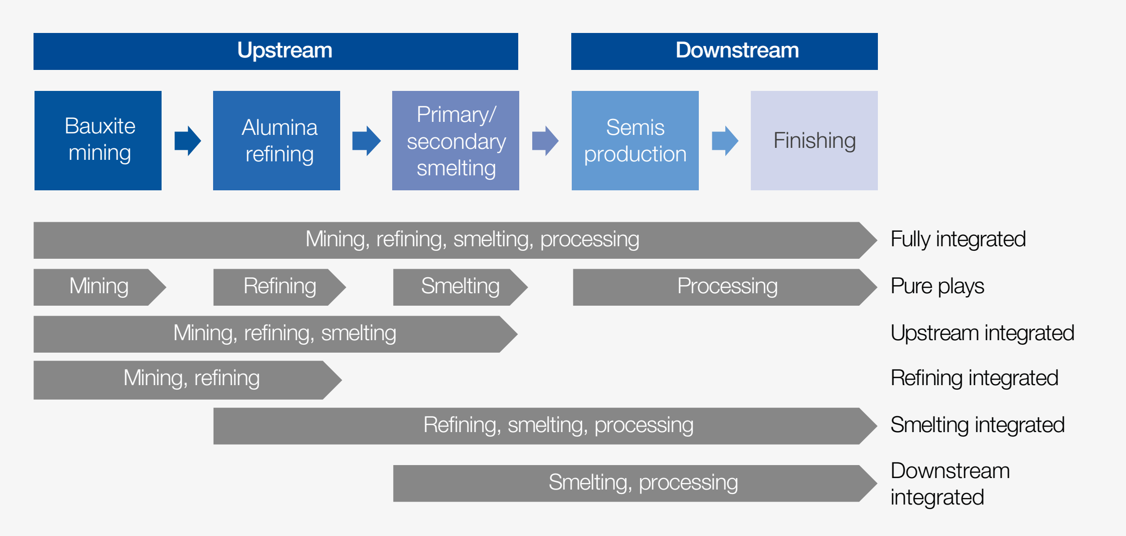
FIGURE 3 **Global power mix and primary aluminium production (2019)**[36]



As aluminium producers operate on relatively low margins, producers must use the most affordable and consistent power source.[37] Electricity accounts for around one-third of operating costs for aluminium smelters, with $/kWh varying based on fluctuating local power costs.[38] Low margins also make it difficult to fund any significant capital investment needed to transition to an alternative power source, the viability of which varies greatly depending on geography. Recently, China announced its commitment to reach peak carbon emissions by 2030 and achieve net zero by 2060.[39] This is a bold ambition set by a nation with the largest carbon footprint and has the potential to transform the way the sector, and the world, is addressing the climate crisis.

Aluminium industry players have different organizational boundaries, making it difficult to compare the decarbonization efforts of companies that participate in different components of the value chain. A company's boundaries determine how significantly the organization is able to affect the carbon intensity of the end product. In order to decarbonize the entire industry, value-chain partners need to work together to achieve net-zero emissions from mining to the finished product.

FIGURE 4 | **Examples of organizational boundaries in the aluminium industry**[40 41]



Demand signals

Shifting the aluminium production process to produce carbon-neutral aluminium will require significant investment. Although industry players are interested in investing in the journey to net-zero carbon, most companies highlight the need to better understand the fundamental business case of decarbonization efforts before moving forward. Others are realizing that waiting to act presents a greater financial risk.

Like most commodities, the aluminium industry operates on slim profit margins with an industry average EBITDA[42] margin of just 5–10% in 2019.[43] In such a highly competitive marketplace, clear market signals indicating a demand for low-carbon aluminium would provide a key input to the industry's decarbonization business case.

Signals from select consumer goods companies support increased demand for low-carbon aluminium. For example, both Apple and Nespresso have set ambitious decarbonization targets, with sustainable aluminium as a vital component.[44 45] However, these signals are not yet widespread enough across aluminium consumers to indicate the extent of the value potential.

Despite a lack of sufficient demand signals, major industry players have begun developing mechanisms to facilitate the buying and selling of low-carbon aluminium. In June 2020, the London Metals Exchange announced the anticipated creation of a spot trading platform for low-carbon aluminium.[46] This platform would allow aluminium producers to submit carbon-related details for their products and improve understanding of pricing and trading of sustainable metals. Similarly, in September 2020, Trafigura, a commodity trading company, established a low-carbon aluminium financing platform.[47] They will provide a preferential interest rate and premium to low-carbon producers with the goal of supporting the upstream transition to low-carbon technologies and helping downstream manufacturers meet the increasing demand for low-carbon aluminium.

Investors across the globe are following suit, increasingly prioritizing ESG-focused investments. Since 2013, companies with consistently high ratings for ESG performance have outperformed their peers, enjoying operating margins 4.7 times higher than low-ESG performers.[48] Furthermore, throughout the COVID-19 pandemic, high-ESG performers experienced greater resilience. Since the start of 2020, the top quintile of ESG performers within the mining and metals industry consistently outperformed the bottom ESG performers throughout the pandemic.[49]

If the industry waits until demand signals are fully transparent, it will be forced to react rather than lead. The aluminium industry has an opportunity to step forward, lead the conversation and take ownership of its path to decarbonization.

3

Pathways to decarbonization

Aluminium players need to address emissions sources across the value chain to reach net zero.

In order to meet global climate goals, the aluminium sector can begin by focusing on three major areas: 1) decarbonization of power generation; 2) decarbonization of process emissions; and 3) growth of scrap usage and recycling.

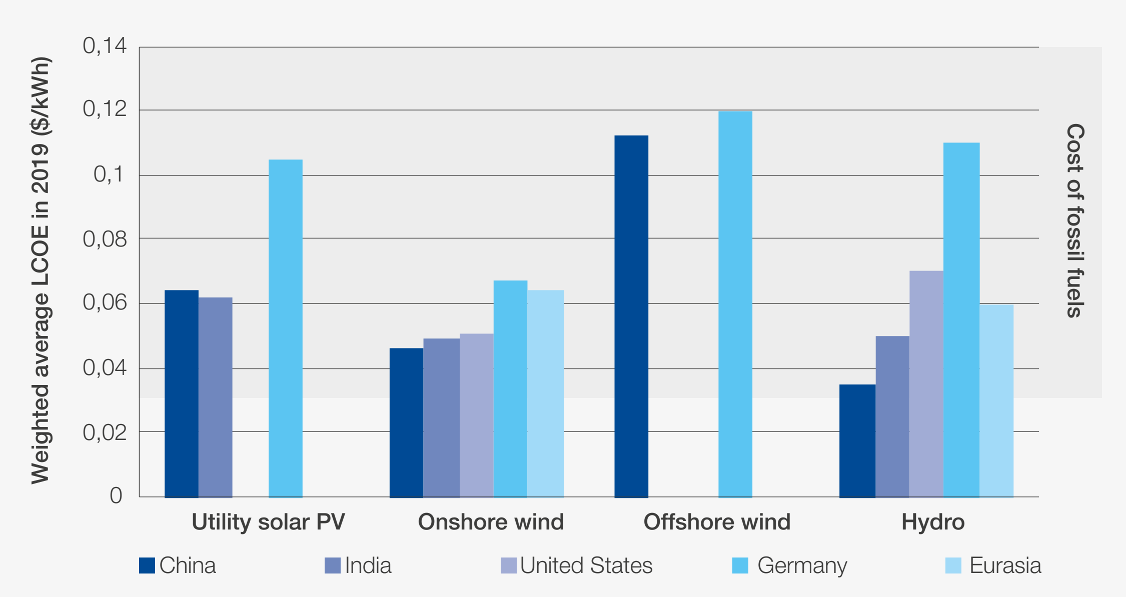
Decarbonizing the power supply

Accounting for more than 60% of the industry's carbon emissions, electricity is the greatest opportunity for decarbonization.[50]

The aluminium industry's power supply can be fundamentally addressed in two ways: 1) the transition to renewable energy; and/or 2) carbon capture, utilization and storage (CCUS) technologies to reduce emissions.

Global reliance on renewable energy has increased 3.4-fold from 2000 to 2019, primarily due to the increasing affordability of renewable power.[51] Renewables' levelized cost of energy (LCOE), the average net present cost of generating electricity from an asset over its lifetime ($/kWh), has become competitive with fossil fuel-based energy solutions.[52] This holds true in most parts of the world, even in an unsubsidized environment. Renewable generation costs are "entirely below the range of LCOE for new coal-fired power plants" and "in the same range" as the operating cost of existing coal plants in China and India.[53]

FIGURE 5 **Regional weighted average LCOE for renewables (2019)***[54]

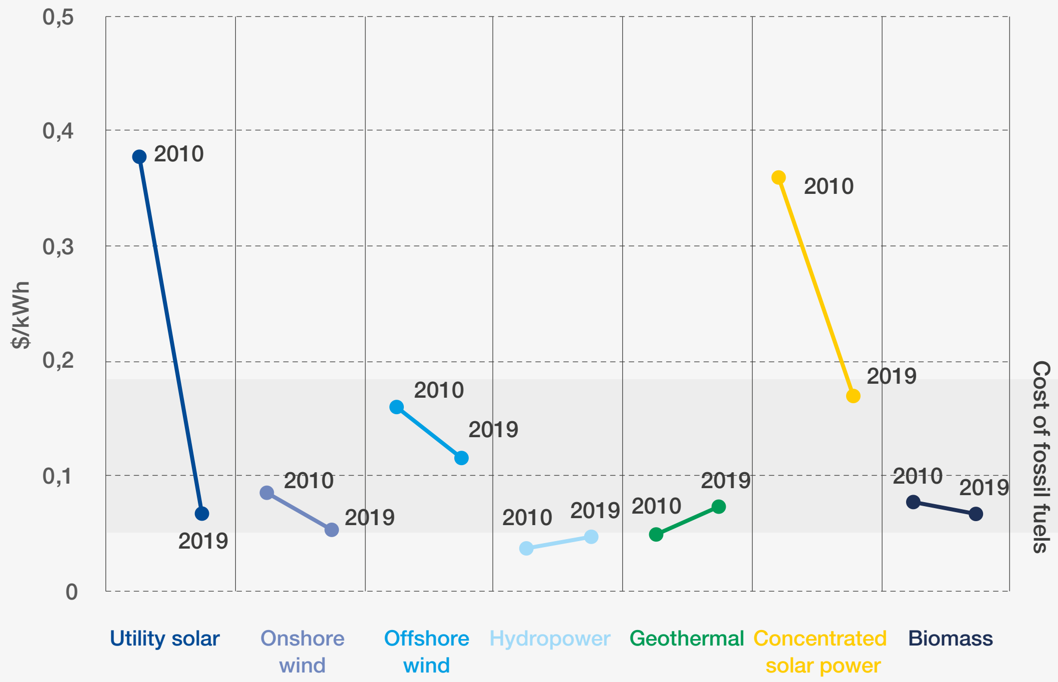


* Data not available for some regional renewables LCOE

Renewables can provide additional benefits in regions with policies that encourage a transition to more sustainable energy sources. Lazard reports that some renewable energy technologies, notably onshore wind and solar, are approaching the stage where it is competitive to invest in the construction of new renewable sources rather than continuing to operate conventional sources.[55]

Operators of captive power plants in areas that are suitable for solar and/or wind power could benefit from evaluating the impact of transitioning to renewables. Operators will also need to consider the intermittency of both solar and wind power and account for storage solutions and/or the availability of power purchase agreements to balance supply and demand.

FIGURE 6 | **Change in LCOE of renewable sources (2010–2019)**[56]



Hydro and geothermal power are the most-used renewable sources for aluminium production due to their ability to provide continuous 24/7 power. However, conventional hydro and geothermal power have limited growth potential as they are relatively mature and dependant on proximity to geological features. Expanding the renewable power mix in aluminium manufacturing will require the integration of alternative renewable sources into their power portfolio.

Utility-scale CCUS solutions also offer avenues for net-zero energy generation by capturing and sequestering emissions in durable products or depositing emissions into long-term storage sites such as underground geological formations. Scalable CCUS could potentially reduce emissions at a comparable rate as a transition to renewables. CCUS technologies are currently immature and not yet widely available at utility scale, but will likely play a major role in the degree of success in meeting a 1.5°C or 2°C scenario. It is likely that, at least in the short to mid term, a combination of transition to renewable sources and CCUS will be required to support the decarbonization of the aluminium industry.

Hydropower aluminium[57]
Hongqiao Group

In September 2020, Hongqiao began production at a new hydro-powered aluminium smelter in Yunnan. This is the first of several projects to relocate Chinese aluminium production close to hydropower sources in support of China's decarbonization targets. As state sanctions on coal use increase, industries will continue to be encouraged to find low- or zero-emission alternatives to conventional coal-fired power plants. Although the use of hydropower will significantly reduce GHG emissions, it is not without complications and can disrupt ecosystems and negatively affect regional biodiversity.

Industrial CCUS[58]
Net Zero Teesside

Net Zero Teesside in northern England is a CCUS project being driven by several oil and gas companies including BP, Eni, Equinor, Shell and Total to decarbonize carbon-intensive businesses by 2030. This initiative has been launched in partnership with local industry players to support the British government's commitment to reach net-zero emissions by 2050. The programme aims to prove the viability of CCUS applications in decarbonizing hard-to-abate emissions by capturing and storing up to 10 million tonnes of carbon dioxide.

Challenges to implementation

While decarbonization of the power supply is the greatest opportunity to reduce emissions in the aluminium industry, several challenges stand in the way of rapid action.

Although plants with captive power sources may have greater ownership over their energy transition options, many of the captive coal-fired power plants active today have been built in areas with limited, unreliable or more expensive grid-power alternatives. In order to transition to renewable sources, energy storage solutions will need to be implemented to ensure smelters have access to the power they need 24/7. In addition, it is likely that companies with newer infrastructure would impair returns on their initial investment if they were to transition prior to the plant's intended end of life, as long as 30–40 years, resulting in stranded assets and high costs to build additional infrastructure. In the short to mid term, it may be necessary to invest in CCUS technologies or purchase carbon offsets until decarbonization of these power sources becomes viable or other incentives are in place.

Partnership with the power industry is necessary to address the one-third of emissions associated with grid power. As other sectors, particularly heavy industries, make the transition to renewable energy, the aluminium industry may face competition for access to renewable grid power. As grids transition to renewables, it is possible that aluminium smelters can continue to support the power supply and provide demand-side flexibility to the grid, accommodating for the intermittent nature of renewables.

Aluminium production in China is a major driver of sectoral GHG emissions, with coal-powered electricity used during primary smelting accounting for around 58% of the sectoral carbon footprint in 2019.[59 60] As demand increases in the next 30 years, it is anticipated that it will be met primarily in China and South-East Asia. Without efforts to mitigate carbon emissions from electricity, the industry-wide reliance on fossil fuels could continue even if action is taken to reduce carbon emissions in other parts of the world. However, with China's recent commitment to reach carbon neutrality by 2060, it seems promising that momentum to decarbonize is building in high-emitting countries.

Decarbonizing process emissions

Secondary to addressing the carbon footprint of electricity demands, direct emissions related to the processing of aluminium are another high-impact opportunity area for decarbonization.

Primary aluminium production generates direct emissions from the electrolysis of alumina using a carbon anode during smelting and from fuel combustion during unit processes to produce heat and steam. In 2018, anode consumption accounted for around 10% of sectoral emissions and fuel combustion accounted for 15–20% of sectoral emissions.[61] Although direct emissions are a proportionally smaller decarbonization opportunity area than power consumption, they are easier to address collectively as aluminium refining and smelting techniques are shared across the industry (e.g. Bayer process, Hall-Heroult process).

The highest-impact pathways to decarbonize direct process emissions across the aluminium sector are: 1) the development of a non-carbon anode; and 2) transitioning to technologies that can provide heat and steam without the use of fossil fuels.

Carbon anodes are a critical component of electrolytic processing, which separates pure aluminium from alumina and generates CO_2 as a by-product of the reaction. Carbon-rich materials are used as anodes because they are good conductors of electricity, inexpensive and plentiful.[62] The replacement of a carbon anode with an inert material could eliminate direct emissions from electrolysis. Several aluminium producers are already working on the development of anodes that produce oxygen rather than CO_2. The capital costs of inert anodes are projected to be 10–30% less than carbon-based anodes.[63] Given the financial and environmental benefits of anode innovation and the global application in aluminium smelting processes, advances in anode technology could be quickly commercialized and offer wide-scale decarbonization for the industry. While inert anodes are the most mature avenue for decarbonization of electrolysis, additional technologies, including carbothermic reduction or multipolar electrolytic cells, can be used to further reduce energy demand and corresponding emissions.[64]

Inert anode technology[65]
Rio Tinto, Alcoa and Apple

Like many technology companies, Apple has made commitments to reduce its carbon footprint, and the ability to use low-carbon aluminium will help it on its journey. Elysis is a joint venture between Rio Tinto and Alcoa that aims to replace the carbon-based anode used in aluminium smelting, the largest source of direct process emissions. Rather than CO_2, the alternative material releases only oxygen. This inert anode will reduce both direct carbon emissions and the operating cost of aluminium smelting. However, as electrolysis with an inert anode is more energy-intensive, it is important to power it with renewable sources to produce a truly carbon-neutral product.[66] Apple, an investor in the venture, purchased the first batch of carbon-neutral aluminium to use in its products.

Along with the creation of an inert anode, aluminium processing requires large amounts of heat and steam during refining, currently primarily generated using fossil fuels. This heat transfer is necessary for the conversion of bauxite into alumina. Alternatives for heat production include solar water heaters, biomass, geothermal, green hydrogen or concentrated solar power (CSP). These technologies are being explored for industrial use worldwide, but, as with other renewable sources, they are largely dependent on geography.

Industrial concentrated solar power[67]
Heliogen

Industrial heat remains one of the most difficult challenges to the decarbonization of heavy industries. In 2019, Heliogen demonstrated at a concentrated solar facility that CSP technology can reach temperatures of more than 1,000ºC. Heliogen made this advance by conducting in-depth, real-time analysis to continually adjust the mirrors to optimize operating efficiency. After this proof of concept, the company received funding from three billionaires: Bill Gates, Steve Case and Patrick Soon-Shiong. Heliogen aims to make CSP competitive with fossil fuels even in an unsubsidized environment to decarbonize heavy industries.

Industrial geothermal[68]
Eavor Loop

Eavor Loop is a Canadian start-up looking to commercialize affordable baseload and dispatchable geothermal energy for less than $50/MWh by 2030 – in line with the current LCOE of other renewable sources. Unlike conventional geothermal methods, Eavor Loop uses a closed-loop system that allows water to be pumped 3–5 km into the ground and converted into steam to spin turbines; this new methodology uses horizontal drilling techniques from the oil and gas sector to allow the water to circulate without the need for a pump. This technology offers a self-contained, scalable solution at market-competitive prices that could play a vital role in the energy transition.

Small-scale CCUS could also support decarbonization of industrial heat and steam production, with the potential to deliver a 35% reduction in emissions across the aluminium sector.[69] CCUS presents a viable interim solution to reduce carbon emissions while other low-carbon technologies mature and become more efficient and affordable.

Challenges to implementation

Although alternatives to carbon-intensive direct emissions processes are currently being explored, there are still several challenges facing the development and adoption of these solutions.

It is currently difficult to create the high intensity of heat and steam required by many industrial processes through renewable sources. Several technologies have been proven at a small scale or in a pilot study, but it will be necessary to scale and accelerate the development and adoption of these technologies across the industry. For example, CCUS could eliminate direct emissions from existing fossil fuel-based industrial heating methods, but large-scale application of CCUS has not been widely developed or deployed. All industries that rely on fossil fuel combustion will need to invest in industrial net-zero solutions; this could provide an opportunity to collaborate across industries to accelerate change.

Increased scrap recovery

While aluminium is a widely recovered material, capturing the remaining end-of-life scrap (5% new and 30% old) that currently evades collection could decrease the requirement for primary aluminium and the corresponding carbon emissions.

Aluminium production from scrap requires just 5% of the energy needed to produce primary aluminium. Recycled aluminium accounts for around 33% of aluminium production, a relatively constant demand since 2000.[70] Aluminium is an almost infinitely recyclable material and collection rates are already high. In 2018, around 80% of scrap aluminium was collected and recycled.[71] The IAI calculates that around 15 million tonnes of aluminium will be lost each year by 2050 if no improvements are made to scrap collection and sorting. If 14.25 million tonnes were able to be recovered, it would reduce the need for primary aluminium by 15% and save an estimated 250 million tonnes of CO_2e per year (based on 2018 carbon intensity).[72]

It is unlikely that the aluminium industry can meet a net-zero target by 2050 without maximizing the collection of aluminium scrap.

Efforts to increase scrap recovery should focus on:[73]

– Advancing methods to divert aluminium from landfills

– Improving separation techniques to decrease the mixing of alloys

– Working with downstream partners for circular business models and closed-loop recycling

– Supporting more complex collection and separation processes with digitization to track scrap throughout its lifetime and direct it to the correct channel to retain its value

– Designing and creating products that are easily separated, collected and recycled

Closed-loop recycling[74]
Novelis and Volvo

In 2019, Novelis and Volvo partnered to develop and implement a closed-loop recycling system for the aluminium components of Volvo cars. This reduced Volvo's reliance on primary aluminium, decreasing the carbon intensity by 78%. Beyond emissions reduction, Novelis was able to ensure Volvo of the high-quality material being produced by eliminating scrap mixing. Novelis has formed similar partnerships with other automotive companies to decrease reliance on traditional manufacturing processes.

Recovery of non-ferrous metals[75]
Covanta

In 2017, Covanta constructed a new plant in Fairless Hills, Pennsylvania, with improved methods to separate non-ferrous metals, such as aluminium, from municipal solid waste. Traditionally, non-ferrous metals are separated using eddy current technology, which results in a commingled collection of non-ferrous metals. Covanta's new plant uses induction sorting to air-separate non-ferrous metals by alloy as they move across the conveyor belt. This sorting technology enables Covanta to sell single-alloy scrap, which commands a higher market price than commingled scrap.

Challenges to implementation

Aluminium scrap recovery methods are mature and the industry has a high collection rate, making capturing an additional 10–15% of total scrap a challenge – especially as collection often lies outside the industry's purview.

Because of aluminium's durability, it is often used as a long-lasting material for construction or transportation with a lifespan of 20-plus years. Although aluminium is highly recyclable, many aluminium products will not be able to be recaptured as scrap for decades after initial production. Scrap availability is the largest constraint to increasing the use of recycled aluminium.

The quality of scrap varies widely depending on how well it has been sorted. In the future, there will be increased demand for wrought alloys that require higher-quality, well-sorted materials.[76] This shift in demand will require improved sorting techniques to ensure that high-value aluminium alloys retain their value throughout recycling. Improving scrap collection and sorting will require government and value-chain support to develop recycling infrastructure, regulations and incentives for aluminium and other recyclable materials.

Corporate plastics recycling[77]
Japanese government

The Japanese government aims to make the recycling of plastics from corporate offices and factories mandatory by April 2022, a measure that will support the country's goal of cutting disposable plastic waste by 25% by 2030. In 2018, more than 50% of the plastic waste generated in Japan was from corporate sources and the majority was incinerated. This new policy aims to increase the low recycling rates from these sources and encourage large waste generators to separate plastics from municipal waste to send directly to a recycling company. Japan is also looking to reduce plastic waste by increasing the use of bioplastics, increasing the recycling rate of household waste and encouraging stores to ask customers before providing them with single-use plastics.

Full circularity action plan[78]
European Aluminium

In April 2020, European Aluminium published its Circular Aluminium Action Plan, which aims to achieve a fully circular economy for aluminium by 2030, with all scrap collected and recycled throughout Europe. This plan hopes to take advantage of aluminium's virtually infinite recyclability to increase the use of recycled aluminium, which uses just 5% of the energy required for primary aluminium production. European Aluminium believes as much as 50% of Europe's aluminium demand could be satisfied by recycled materials by mid-century and aims to support and guide policy that will enable full circularity.

4 The need for collaborative action

Players across the aluminium sector must act together to support a holistic and inclusive transformation.

Successful and rapid decarbonization of the aluminium industry relies on joint action across the value chain and the building of trusted relationships with ecosystem partners and competitors. This change needs to permeate all aspects of the industry, with sustainability a foundational tenet and guiding principle to operations.

In recent years, companies are going beyond making individual decarbonization commitments and forming industry coalitions to set targets and take action.

TABLE 2 **Summary of industry coalitions working towards decarbonization**

Industry	Coalition	Participants	Ambitions
Airline	oneworld[79]	13 member airlines	Achieve net-zero carbon emissions by 2050 by: – Improving fuel efficiency – Using sustainable fuel sources – Reducing waste and single-use plastics – Use of more sustainable materials
	CORSIA[80]	UN International Civil Aviation Organisation (192 countries)	Deploy a market-based mechanism to: – Make all growth in international flights post-2020 carbon neutral – Buy emissions reductions to compensate for increase in emissions – Use low-carbon fuels
Construction	Global Alliance for Business and Construction[81]	130+ members from government, the private sector, civil society and international organizations	Meet the Paris climate goals by: – Retrofitting existing buildings – Future-proofing new buildings – Mobilizing across the value chain – Encouraging policy that promotes the uptake of existing cost-effective solutions alongside continued innovation
Cement and concrete	Global Cement and Concrete Association[82]	40 of the world's leading cement and concrete companies	Deliver carbon-neutral concrete by 2050 by: – Reducing and eliminating energy emissions – Reducing process emissions through new technology and CCUS – More efficient use of concrete – Reuse and recycling of concrete – Enhancing concrete's ability to absorb and store atmospheric carbon
Transport	Decarbonising Transport Initiative[83]	Members from transport, oil and gas industries, research institutes, universities, professional organizations, NGOs and more	Provide tools for carbon emission mitigation efforts such as: – Building a catalogue of effective solutions – Aiding in data analytics – Sharing techniques to accelerate adoption – Building a global policy dialogue that incorporates a perspective on transport
Energy	Oil and Gas Climate Initiative[84]	12+ oil and gas majors	Support meeting the Paris climate goals by: – Investing $7 billion each year in low-carbon technologies and solutions – Reaching near-zero methane emissions by 2025 – Reducing yearly carbon intensity by 4%

Ambitions in the steel sector[85]
ArcelorMittal

ArcelorMittal, along with other major players in the steel industry, has set a target of net-zero emissions by 2050.[86] ArcelorMittal sees decarbonization as a necessary step if it is to remain competitive and address the climate crisis. The company is exploring several pathways to net zero via technologies such as hydrogen, bioenergy and CCUS. It is working collaboratively with other steel producers through the Energy Transitions Commission's Net-Zero Steel Initiative in partnership with the World Economic Forum. ArcelorMittal is also partnering with the Science-Based Targets Initiative (SBTi) to identify achievable science-based targets for the steel industry, and with governmental organizations to shape policy that will support the steel industry's journey to net zero.

Keys to success

Successful industry collaboration relies on several factors beyond a willingness to change.

Clear, transparent and consistent reporting is vital to tracking the aluminium industry's decarbonization journey. A common framework and methodology will need to be implemented across the industry to consistently baseline, monitor and report carbon emissions. Several organizations in the aluminium industry are already dedicated to the standardization, collection and interpretation of data. Most notably, the International Aluminium Institute (IAI) gathers and publishes cross-industry data and the Aluminium Stewardship Initiative (ASI) measures members' sustainability performance against a broader standard. Working in collaboration with these organizations would provide additional governance to decarbonization efforts.

Sector-wide decarbonization will take significant investment from players across the aluminium value chain. Collaborative financing of projects will reduce cost and risk to any one company. What seems like an insurmountable challenge independently can be much more achievable if the burden is shared across several organizations. Regional collaboration to invest in renewable energy, CCUS and/or storage solutions could allow cost-prohibitive technologies to become viable at scale.

Much of the conversation about decarbonization is tied to the necessary technological innovations, but as with any major change, foundational organizational capabilities are also important for success. In an industry that often struggles with data quality, availability and visualization, it is likely that companies will need stronger and more integrated data platforms for managing and optimizing the energy and carbon data required for consistent and transparent reporting. Companies will need to redefine business processes, ways of working and key performance indicators (KPIs) as their operations transform through new technologies. Although complex, this transformation will extend beyond enabling more sustainable operations; it will help companies achieve other corporate goals such as improved decision efficiency, production optimization, worker health and safety – and more.

Carbon transparency platform[87]
COMET

The Coalition on Materials Emissions Transparency (COMET) is a partnership between MIT's Sustainable Supply Chains Initiatives, the Columbia Center for Sustainable Investment, the Rocky Mountain Institute and the Colorado School of Mines to create a carbon transparency platform. COMET is collaborating with producers, buyers and investors to develop a universal GHG calculation framework specifically for mineral and industrial supply chains in order to address the discrepancies and variations in current industrial emissions reporting. The coalition aims to create a level of consistency across industries and to give companies insight into their emissions so that they can make meaningful change.

Reducing the carbon footprint of human and economic activities is a shared goal across most nations and industries. Only through collaborative action, rather than competition, will we be able to achieve these milestones globally.

Policy and regulated carbon markets

The scale and speed of emissions reduction needed across the aluminium industry cannot be accomplished without strong policy and supportive governments.

One approach many governments have used to accelerate decarbonization is the creation of regulated carbon markets. For example, the European Union's Emissions Trading Scheme (ETS) is a cap-and-trade system where companies receive emissions allowances, can trade among each other and are fined heavily if they emit more than their allowances account for.[88] The EU ETS has shown some impact, with 2020 emissions from the included sectors decreasing by 21% compared to 2005 levels; yet it still faces several challenges such as:

- Low prices for emissions allowances do not necessarily support long-term technological innovation

- Carbon leakage, or the offshoring of heavy industries to nations with fewer regulations

Individual countries often introduce their own measures to mitigate these impacts, such as setting a price floor for carbon, introducing a country-specific carbon tax or adjusting internal policies. Aluminium producers will face greater challenges in a fragmented and complex regulatory environment compared to the adoption of more globally consistent policies and carbon markets.

Although some regions have actively pursued robust policies, a sense of urgency and progress at a global level is lacking. The industry will need to work collaboratively with high-emitting countries to design policy for an effective transition; for example, a well-designed Chinese carbon trading scheme may be the most effective way to encourage decarbonization of heavy industries and the expansion of renewables.

There are several paths policy-makers can take to encourage decarbonization efforts, whether through the penalization of high-carbon producers or encouraging good practices. Some examples include:

- Establishing mandatory carbon reductions over a period of time

- Setting a maximum allowable carbon intensity for certain products and materials

- Applying border carbon adjustments, an emissions trading system, or tariffs

- Subsidizing or incentivizing investment in renewable energy, CCUS or other types of carbon-reduction technologies

As governments take more decisive action to support the energy transition and mitigate harmful environmental impacts, the aluminium industry has the opportunity to inform and shape the policy that will define how the industry evolves over the next 30 years.

TABLE 3 **Existing policies that support decarbonization**

Country	Example policy	Targets and implications*
China	13th Five Year Plan (2016)[89]	Reduce CO_2 emissions per GDP by 40–45% by 2020 compared to 2015 6–10 trillion RMB ($0.6–1.5 trillion) investment in environmental initiatives Increasing costs for pollution and tighter emissions standards
European Union	European Green Deal (2020)[90]	EU reaches net-zero GHG emissions by 2050 Decarbonization of the energy sector Ensure buildings are more energy-efficient Invest in environmentally friendly forms of private and public transport
United Arab Emirates	National Climate Change Plan of the United Arab Emirates (2017)[91]	Deploy a national GHG emissions management system to account for emissions and offsets across all sectors Enable private-sector-driven innovation through regulations and incentives Develop a comprehensive evidence-based plan for adaptation initiatives
United States	Renewable Portfolio Standards (state-based)[92]	Set requirements for a certain percentage of electricity sold by utilities to come from renewable sources California: 60% renewable by 2030, 100% clean energy by 2045

* Excerpts, not exhaustive

Nationwide climate policy[93]
India

In September 2019, India's Prime Minister Narendra Modi detailed several pathways the nation will take to lessen environmental impact and fight climate change. Since India is the world's third-largest emitter of GHG, these commitments can go a long way to reducing the global carbon footprint. Commitments include:

– Installing 175 GW of renewable energy capacity by 2022 and 450 GW by 2030
– Collaborating internationally to fight climate change
– Aiming to achieve net-zero emissions by 2050 in hard-to-abate sectors (e.g. steel, cement)

Many of India's states are developing policies that complement those set forth by Prime Minister Modi. For example, Rajasthan aims to build 50 GW solar capacity in five years, while Gujarat will not allow new coal plants to be built and aims to increase renewables to 30 GW by 2022.

Research, design and development

Current technologies are not yet mature enough for aluminium producers to reach net zero at a reasonable cost and at the speed required. Additional innovation is needed to develop new technologies, as well as to improve existing technologies and adjust them to suit the unique needs of the aluminium industry.

Some potential opportunities for the aluminium industry to collaborate on research, design and development (RD&D) solutions include:[94]

– The continued development of inert anode technology

– Methods for generation of heat and steam for industrial processes

– Improved scrap sorting and purification to retain the value of high-quality scrap

– Application of CCUS technologies to refining and smelting to capture process emissions

– Supporting the integration of renewables to meet the vast power demands of the aluminium industry, including storage solutions to manage intermittency

– Optimization and efficiency improvements for process technologies to reduce energy consumption

Collaborative RD&D could help accelerate decarbonization efforts across the aluminium industry. Success is probably dependent on establishing a robust governance structure overseen by a third party to protect the interests of all participants and, where needed, manage shared intellectual property. It will be important to build trustworthy relationships among competitive companies to encourage transparency within the scope of RD&D efforts. Although this seems complex, examples of collaborative RD&D already exist.

Collaborative innovation for low-carbon-emitting technologies in the chemical industry[95]
World Economic Forum and the chemical industry

In 2019, the World Economic Forum launched the Low-Carbon Emitting Technologies initiative together with its Chemicals and Advanced Materials industry community. This initiative aims to accelerate the development and upscaling of low-carbon-emitting technologies for chemical production towards a marked reduction in GHG emissions in the chemical industry and brings together 20 chemical companies across the globe. The initiative aims to support the formation of alliances for the collaborative implementation of the prioritized technologies, potentially structured as joint ventures, start-ups, hubs, consortia and others.

Oil and gas industry collaborative RD&D[96 97]
Oil and Gas Climate Initiative (OGCI)

OGCI is a group of leading companies in the oil and gas industry, representing 30% of global oil and gas production, that is committed to objectives consistent with the Paris Agreement to reach net-zero emissions. OGCI focuses on areas in which the collective can add greater value than the individual. The participants collaborate with industry, governments and investors to explore pathways for decarbonization. These companies support OGCI Investments, a $1 billion fund that invests in external decarbonization solutions. In July 2020, OGCI announced a new target to reduce the carbon intensity of its members from a baseline of 23 kg CO_2e per boe[98] in 2017 to 20–21 kg CO_2e per boe by 2025. This target is consistent with the pathway set out by the Paris Agreement and will result in a reduction of 36–54 million tonnes of CO_2e per year.

Voluntary carbon markets and offsets

Many organizations have begun to address decarbonization through the use of voluntary carbon markets or carbon offsets.

Although carbon markets have historically been driven and regulated by governments, we are now seeing renewed interest from private companies in developing their own offset and GHG removal projects. This reflects the pressure companies face from consumers to engage in more sustainable practices and shows how they will be vital players in driving and accelerating carbon-reduction practices across the world.

Rather than a cap-and-trade scheme, carbon offsets grant companies an opportunity to avoid emissions or to invest in carbon sequestration advancements to counteract their direct emissions. The cost of carbon offsets is likely to rise in the coming years as more industries set aggressive targets to decarbonize. With limited opportunities to reduce all sectoral emissions, the demand for offsets (whether generated by emissions avoidance or GHG removal projects) is likely to rise.

Corporate offsetting guidelines[99]
The Gold Standard

The Gold Standard was established in 2003 by the World Wildlife Fund and other NGOs to set standards for climate intervention initiatives. The Gold Standard aims to accelerate progress to achieve Paris Climate Agreement targets and the Sustainable Development Goals by reducing barriers to entry for individuals and corporations to decarbonize. It provides opportunities to invest in credible, high-impact projects and receive meaningful carbon credits. To date, 1,700 projects have been delivered, reducing 134 million tonnes of CO_2e.

Voluntary carbon markets and offsetting can support decarbonization and provide a short- or mid-term pathway to net zero for aluminium producers that face financial or technological constraints in making the transition (e.g. due to recently built coal-fired power plants). However, these approaches depend on other sectors of the economy reaching negative emissions through carbon removal, which creates risk around the permanence and additionality of savings.

5

Conclusion

While the aluminium industry faces many challenges in its path towards decarbonization, a net-zero future is achievable through collective action.

Aluminium remains an integral material for the future of a net-zero economy. Airlines and transport companies, particularly those producing electric vehicles, are major consumers of aluminium and are setting ambitious decarbonization targets. The aluminium industry needs to work alongside its ecosystem partners to reach net zero or risk being forced to respond to imposed requirements rather than shaping them. Encouraging steps have been taken by individual organizations, but these alone are unlikely to get the sector on track to meet a 1.5°C or 2°C scenario.

All players in the aluminium industry have the power to begin plotting their path towards decarbonization, both independently and collaboratively. The wide range of starting points will affect each company's priority focus areas and inform potential collaborative partnerships to address shared challenges.

FIGURE 7 **Recommended steps to begin aluminium industry decarbonization**

Independent actions

1. Work internally to understand the current state of operations and baseline emissions
2. Set internal targets to decarbonize
3. Work backwards from target dates to understand the key activities and initiatives required to reach decarbonization goals
4. Define the business case for renewables and develop a plan to transition captive or grid power sources
5. Work with local governments to support and define decarbonization policy

Collaborative actions

1. Collaborate alongside other aluminium producers to address electrolysis emissions through the development of inert anode technology
2. Collaborate alongside other aluminium producers to decarbonize captive power sources and industrial heat and steam generation through CCUS and/or renewables
3. Collaborate with value-chain partners to improve the circularity of aluminium through improved scrap collection and sorting methods
4. Work as an industry to influence global decarbonization policy to drive common standards and markets for low-carbon aluminium
5. Take an active role in supporting the energy transition by engaging energy partners and other heavy industries to address the need for renewables
6. Develop a standardized framework to calculate, monitor and report carbon emissions and the value/success of reduction efforts
7. Work alongside partners to address emissions across the value chain (e.g. transport, waste processing) to reach net zero

Sustainability performance is increasingly seen as a prerequisite for participation in the market, rather than just a competitive differentiator. Heavy industries will need to address sustainability issues at all levels of their organizations – just as they have had to respond to the revitalized safety culture seen today. Companies have a responsibility to their stakeholders to acknowledge and address the need for change in working towards a greener future.

Despite the headwinds all have faced due to the COVID-19 crisis, there is continued momentum in terms of proactively addressing heavy industries' carbon footprint. This is apparent in the collaborative action already undertaken by industry players, policy-makers and governments – from joint ventures to accelerate relevant technologies to increasingly supportive legislation to international conferences such as COP26. The industry is expected to evolve.

We call upon leaders in the aluminium industry across the globe to engage in the conversation about decarbonization, to set ambitious targets and to work together on a path to reach net zero by 2050. We invite all industry players not only to set ambitious goals and define their respective corporate pathways but also to act collectively to accelerate the aluminium sector's transition. The Forum's Aluminium for Climate platform has been established to support the sector's decarbonization efforts. The potential role of aluminium in the net-zero economy might be clear, but society's Race to Zero will require all to act.

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Sustainability Manager, Emirates Global Aluminium, United Arab Emirates

Amandine Chaillous
Senior Energy Advisor, Alvance Aluminium Dunkerque/GFG Alliance, France

Harald Friedl
Lead Aluminium, COP 26 – Global Climate Action Champion, United Kingdom

Alexandra Gundobina
Associations and Partnerships Manager, Sustainable Development, En+ Group, Russian Federation

Georgina Hallett
Chief Sustainability Officer, London Metal Exchange, United Kingdom

Sofia Hedevåg
Senior Vice-President Sustainability, Gränges, Sweden

Olga Krylova
Sustainability and Marketing Manager, RUSAL, Russian Federation

Anastasia Kuskova
Sustainability and Transformation Director, Eurasian Resources Group, Luxembourg

Jerome Lucaes
Marketing Director, Sustainability, RUSAL, Russian Federation

Jessica Sanderson
Director of Sustainability, Novelis, United States

Will Savage
Director of Business Development, Alvance Group/ GFG Alliance, France

Torbjörn Sternsjö
President Europe, Gränges, Sweden

Contributors

World Economic Forum

Jörgen Sandström
Head, Mining and Metals Industry, World Economic Forum

Renée van Heusden
Project Lead, Materials Cluster – Aluminium and Steel, World Economic Forum

Partnering Contributors

Harry Morrison
Managing Director, Sustainability Services, Accenture

Lucyann Murray
Manager, NA Natural Resources, Accenture

Mary Puleo
Consultant, NA Natural Resources, Accenture

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Editing and Design

Alison Moore
Editor

Timothée Scalici
Graphic Designer

Floris Landi
Design Lead, World Economic Forum

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World Economic Forum
91–93 route de la Capite
CH-1223 Cologny/Geneva
Switzerland

Tel.: +41 (0) 22 869 1212
Fax: +41 (0) 22 786 2744
contact@weforum.org
www.weforum.org