



Sustainable
Markets
Initiative

MASDAR 

 OliverWyman

The drive to decarbonise industry

A how-to guide for companies

November 2023

Acknowledgements

Sustainable Markets Initiative

Founded by His Majesty King Charles III in 2020, as Prince of Wales, the Sustainable Markets Initiative has become the world's "go-to" private sector organisation on transition. Launched in 2021, the Terra Carta serves as the Sustainable Markets Initiative's mandate with a focus on accelerating positive results for Nature, people and planet through real economy action.

Energy Transition Task Force

By invitation, executives from some of the world's largest and most influential industrial, energy, and financial companies have come together to form the Energy Transition Task Force. This task force is charged with determining how companies from across the energy value chain, individually and collectively, can play a leading role in driving and accelerating the transition to a sustainable future.

The Decarbonising Industry Working Group is one of multiple Energy Transition Task Force working groups that serve as a collaborative platform for member companies to identify and develop carbon emission abatement solutions.

The Decarbonising Industry Working Group is focused on three of the hardest-to-abate industries – steel, aluminium, and mining. Besides companies from these industries, the working group also includes selected energy and technology companies that are interested in supporting carbon emissions abatement efforts in these industries.

In total, there are 11 members in the working group: Mining companies Anglo American and Rio Tinto, aluminium producer Emirates Global Aluminium (EGA), steelmaker Tata Steel, metals producer and trader Glencore, renewable energy producers Masdar, Orsted, Octopus Energy, and ReNew, technology company Siemens Energy, and global energy corporation bp. Oliver Wyman supported Masdar in leading this working group.

Working group members



GLENCORE



octopusenergy



ReNew

RioTinto

SIEMENS
ENERGY

TATA STEEL

Masdar CEO Introduction



Mohamed Jameel Al Ramahi, Chief Executive Officer, Masdar

As the energy transition continues to gain traction, there still remains a number of obstacles preventing it from accelerating, something that we know is needed in order to contain global emissions to 1.5 degrees Celsius in line with the goals of the Paris Agreement.

One of those obstacles is the decarbonisation of critical hard-to-abate sectors such as steel, aluminium, and mining. Altogether, these sectors contribute approximately 12% of global carbon dioxide emissions, representing a tremendous opportunity to significantly drive down emissions.^{1,2}

With that goal in mind, Masdar, a global clean energy pioneer, is proud to be leading the Decarbonising Industry Working Group as part of the Sustainable Markets Initiative's Energy Transition Task Force. After bringing together leading companies from across the energy and hard-to-abate sectors, the Decarbonising Industry Working Group is now ready to launch our first deliverable "How-to Guide," focused on exploring tangible solutions for decarbonisation. I am thankful to colleagues from across the working group for sharing insights and seeking meaningful collaboration opportunities, the Sustainable Markets Initiative leadership for bringing us together, and Oliver Wyman for their support.

This work demonstrates the potential that renewable energy, energy efficiency, carbon capture, green hydrogen, and other solutions can offer in greening industries across their value chains. And it highlights the obstacles we still need to overcome to get there. One thing is clear: The decarbonisation journey can only be successful through partnership. This is what makes the role of the Sustainable Markets Initiative so important.

As we prepare for COP28 in the United Arab Emirates, where developing actionable solutions to ensure the world meets its climate commitments will be front and centre, this guide offers a timely and informative view from industry leaders on how we can overcome what is, in many ways, one of the "final frontiers" of climate change: Decarbonising hard-to-abate sectors.

Oliver Wyman CEO Introduction



Nick Studer, Chief Executive Officer, Oliver Wyman and **Interim Chair**, Sustainable Markets Initiative's Energy Transition Task Force

Steel, aluminium, and mining contribute directly to around 12% of global carbon dioxide emissions.³ Business leaders in these carbon-intensive industries are faced with a once-in-a-generation opportunity to innovate and collectively shape the transition to a more sustainable future.

The Decarbonising Industry Working Group within the Sustainable Markets Initiative brings together market leaders in the energy, steel, aluminium, mining, and technology sectors to work together to accelerate the transition to net zero across hard-to-abate industries. The premise of this group is that organisations will make greater and more efficient strides towards sustainability through collaborative efforts than by pursuing initiatives alone.

These hard-to-abate industries face numerous challenges to decarbonise, including securing access to renewable energy and green hydrogen at affordable scale, navigating an evolving global marketplace, and being able to rely on a sufficient and consistent regulatory framework to enact change.

During 2023, the working group has sought to overcome those challenges by identifying opportunities to decarbonise the steel, aluminium, and mining industries. Through open discourse and sharing expertise, several decarbonisation topics have been identified that have the potential to reduce carbon emissions materially in each of the three sectors. After further exploration and testing, the group intends to develop pilots that could transform their own operations and inspire their sectors towards swifter progress.

To succeed in a forum like the Sustainable Markets Initiative, all industry participants must ensure strategic alignment with counterparties, bring the full force of their organisation to the table, engage with trust and openness, avoid wasting energy on duplicative initiatives, and bring in other entities where partnerships provide a faster pace of execution.

At Oliver Wyman, we are proud to support this "How-to Guide" and the work of the Sustainable Markets Initiative, which we believe will be helpful in delivering decarbonisation across industrial sectors.

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1. Executive summary

As part of the Sustainable Markets Initiative's Energy Transition Task Force, its Decarbonising Industry Working Group was created to focus on the decarbonisation needs of three industries – aluminium, steel, and mining. Its membership includes 11 companies spanning the energy, steel, aluminium, mining, and technology sectors, with a collective mission to identify, develop, and undertake potential emissions abatement pilot projects and studies within the three designated hard-to-abate industries.

Together, the group developed a mutual understanding of priority regions, value chain steps, and activities for decarbonisation within the three sectors. The most promising and relevant abatement solutions were then reviewed in expert interviews and workshops and assessed based on their potential to produce significant reductions, given factors such as technological maturity and scalability.

The outcome was a series of collaboration topics that address critical sustainability challenges within the respective sectors. These topics, which are outlined in this document, have the potential to be further developed into pilot projects that accomplish key decarbonisation milestones.

Enabling and accelerating decarbonisation requires enhanced collaboration and action between multiple stakeholders: Governments, financial institutions, investors, the target industries and enterprises that support their operations, technology developers, and customers.

1. Global frameworks for regulation and policy on emissions abatement must be developed to ensure a level playing field across regions and industries. More alignment on carbon accounting practices across industries and countries is needed.
2. Demand for green products is picking up but needs to be supported with policies and incentives. Policymakers need to implement incentives and regulations that encourage sustainable procurement practices across industries and countries.

3. Energy infrastructure and capacities need to be scaled up rapidly. Policymakers need to ensure subsidies, incentives, and regulatory frameworks in place are supportive of such an ambition.
4. Transformational investments are needed to move towards low-carbon practices at scale. Policymakers must establish funding programs, grants, subsidies, and low-interest loans specifically targeted at supporting the adoption of low-carbon solutions across sectors.
5. More funding of research and development is needed. Governments can support the adoption and advancement of low-carbon technologies by further increasing the funding and incentives for green technology-related research, patents, and piloting.

The simple bottom line: The pace of transformation in hard-to-abate industries needs to accelerate to comply with the 2015 Paris Agreement's target of net zero by 2050 to keep the planet's temperature increase to around 1.5 degrees Celsius. Heavy industry faces a unique challenge as demand for its products – many fundamental to the global green transformation – continues to rise. Platforms like the Sustainable Markets Initiative are working to provide the strategies and technologies to accelerate industrial progress, even in hard-to-abate sectors.

The aim of this guide is to provide a roadmap for all industries and companies on how to step up to the decarbonisation challenge and provide sufficient resources to build towards a more sustainable future.



2. The Decarbonising Industry Working Group

Group objectives

As part of the Energy Transition Task Force, the Decarbonising Industry Working Group's objective is to accelerate emissions reduction efforts and provide strategic breakthroughs for hard-to-abate industries. Achieving net-zero targets in steel, aluminium, and mining requires significant process and business model transformations, and this working group aims to drive this effort by cultivating collaboration among key industrial, energy, finance, and technology players.

This working group set out to determine feasible alternative technologies, processes, and raw materials that would accelerate decarbonisation pathways and identify collaborative initiatives and studies that might foster faster decarbonisation through potential pilot projects.

The guide is intended to serve as a useful resource for stakeholders in hard-to-abate industries. It provides details on the emissions profiles, technical, and geographical challenges, key abatement pathways, and pressing topics for each of the three profiled industries. It also demonstrates an approach to cross-company collaboration for leaders with similar ambitions to follow and captures lessons learned from earlier efforts.

Additionally, the guide highlights the need for multiple stakeholders to get involved in decarbonisation discussions to accelerate innovation and partnerships. Collaboration is crucial for achieving the necessary transformation, and the guide emphasises that no single company can achieve this transformation alone.

The working group plans to continue this engagement after the release of this guide with the goal of developing the collaboration agreements further and conducting feasibility and pilot studies.

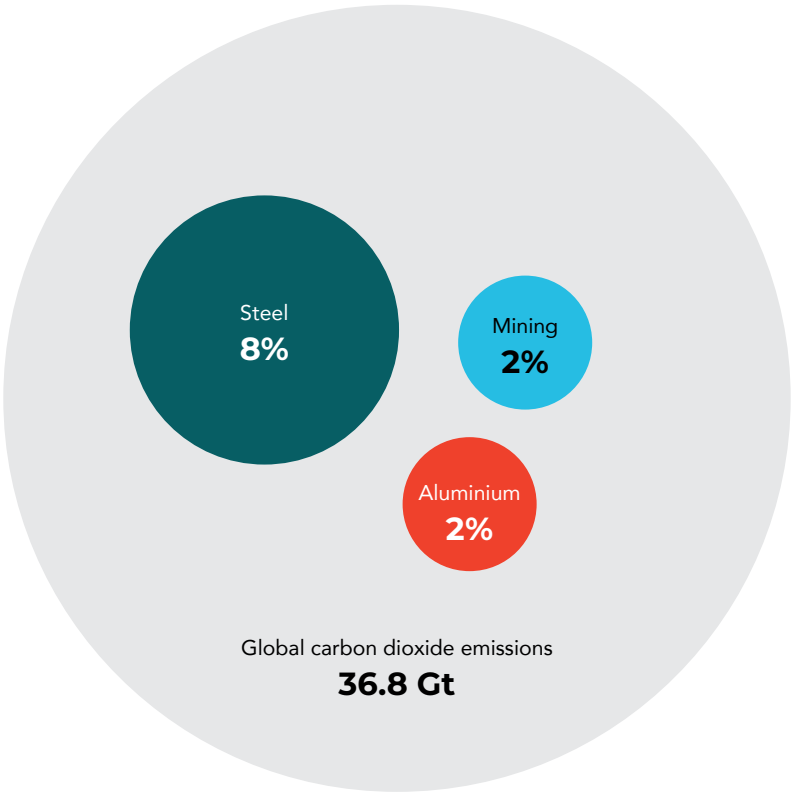


3. Carbon abatement challenges and opportunities

Steel, aluminium, and mining collectively contribute to around 12% of global carbon dioxide emissions.^{4,5} These industries were specifically prioritised by the Sustainable Markets Initiative because of their potential to significantly reduce global emissions, their importance to the global economy, and the relative difficulty of curbing the carbon intensity of their operations and processes. This section outlines the emission abatement challenges and opportunities in each industry and shows why they are considered hard to abate.

Exhibit 1: Direct global carbon dioxide emissions in 2022

In percentage of global carbon dioxide emissions



Note: Mined materials in scope include coal, copper ore, usable iron ore, nickel, zinc, and bauxite and figures exclude fugitive methane emissions.

Sources: IEA (2023), *Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach*, IEA, Paris License: CC BY 4.0, Oliver Wyman analysis

Deep Dive

The biggest emissions challenges

What makes the steel, aluminium, and mining industries hard to abate?

Seven prevalent economic, regulatory, and technical themes across the three sectors underscore the magnitude of the challenge in curtailing carbon emissions.

- **1 The inherent carbon intensity of the processes**

Key processes and activities in hard-to-abate industries often entail carbon dioxide generation through essential chemical reactions and high-temperature operations that demand substantial energy input, necessitating transformational technology to address them effectively.
- **2 Increasing production volumes along with economic growth**

The industries in scope are foundational for economic growth and development – whether it involves consumers such as construction, automotive, energy infrastructure, or consumer goods. With future economic growth and increased demand of these building-block components for the energy transition, production volumes and subsequent carbon emissions will only increase if nothing changes.
- **3 Lack of easy alternatives**

Although low-carbon alternatives may exist, these sustainable technologies may not have reached commercial scale or are not yet cost competitive in a global marketplace making swift decarbonisation across hard-to-abate industries difficult.
- **4 Reliance on other industries to decarbonise**

Hard-to-abate industries cannot decarbonise alone. To eliminate emissions from operations, they depend on the availability of reliable and scalable renewable power, supporting infrastructure such as the grid and energy storage, and access to critical input materials such as green hydrogen and high-quality iron ore.
- **5 Long investment cycles and high investment requirements**

The complexity, scale, and global interdependence of hard-to-abate industries leads to large upfront capital investment. Companies are reluctant to alter their technologies and infrastructure before they have realised returns on their past investments unless they are confident it will result in significant emissions reduction, cost savings, or higher prices for green products.
- **6 Competitive dynamics**

Hard-to-abate industries require clear market demand signals for green products to inform investment decisions. However, these industries today are lacking the necessary offtake agreements from customers for green products, especially those that come at a premium.
- **7 Regulatory uncertainty**

Hard-to-abate industries will rely on governments in the short- to medium-term to make their net zero transition possible. Negative sentiment around regulatory uncertainty puts existing or potential sustainable investments at risk, especially if companies are competing in a global marketplace with an uneven playing field.

3.1. Steel

Key figures

1.9 billion tonnes

of primary and secondary steel produced annually

~8%

of global carbon dioxide emissions attributable to steel production

>2 tonnes

of carbon dioxide produced per tonne of steel

Key technical challenges



Access to green hydrogen and renewable power for crude and secondary steel production



Reducing emissions from blast furnaces in the medium-term



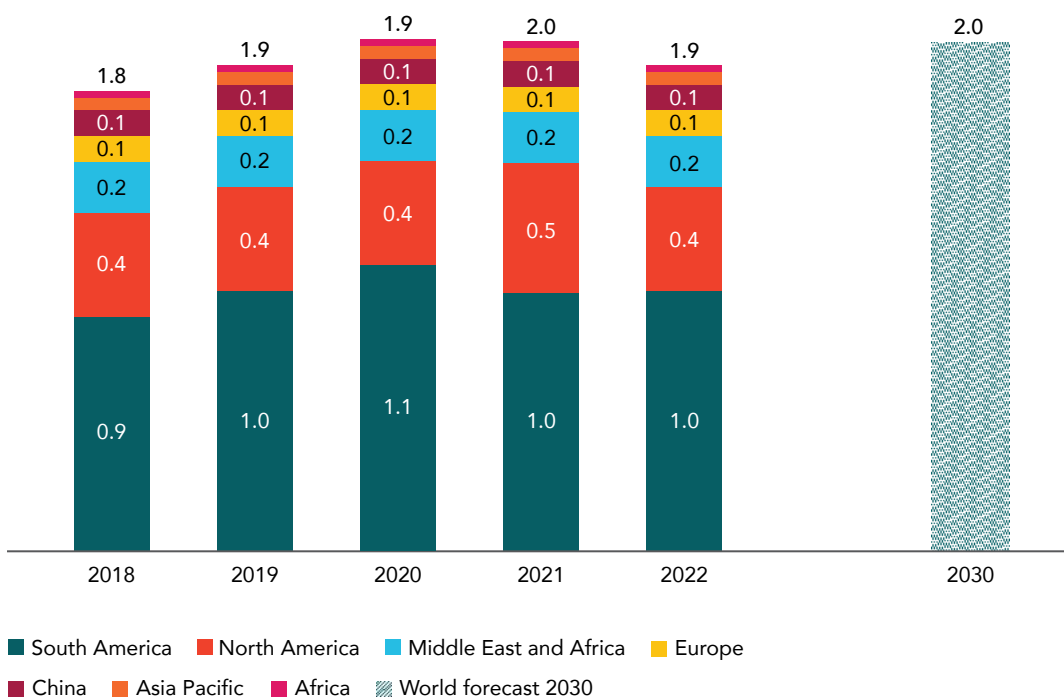
Improving scrap recycling, collecting, and sorting infrastructure

Steel's direct carbon footprint (Scope 1 and 2) comprises around 8% of global carbon dioxide emissions, and for each tonne of steel produced, nearly two tonnes of carbon dioxide (CO₂) are emitted on average.⁶

Over the last few years, just under two billion metric tonnes of steel have been produced annually – with emerging markets leading the growth in demand.⁷ These projections underscore the need for greater efforts by the industry to adopt sustainable practices and minimise steel's environmental impact, given its current emissions-intensive profile.

Exhibit 2: Global steel demand growth by region

In billion tonnes



Sources: World Steel Association (2022), *Total production of crude steel, World total 2022*, Oliver Wyman analysis

Carbon dioxide emissions profile

Blast furnace – basic oxygen furnace

The steel production industry primarily follows three steel production pathways, with the most prevalent being the blast furnace-basic oxygen furnace (BF-BOF) route, accounting for 63% of global steel production capacity and emitting 2.2 tonnes of carbon dioxide per tonne of steel produced on average.⁸

The primary energy input for the BF-BOF process is coking coal, which is used to generate the heat inside of the blast furnace and chemically react with the iron ore. Coking coal, as a pure form of carbon, is used rather than regular coal because of its strength which is needed in a blast furnace operation as well as its high carbon content which aids in the reduction of the iron ore.

The process of making coking coal, which involves baking coal in an oven for 12 to 36 hours at almost 1,100 degrees Celsius, also produces emissions. This process reduces impurities, but it also creates CO₂ and methane, another greenhouse gas with as much as 80 times the warming potential of CO₂ over 20 years. Additional CO₂ emissions are released when pure oxygen is injected into the basic oxygen furnace to convert the pig iron into steel by reducing its carbon content.

Scrap-based electric arc furnace

Scrap-based electric arc furnaces (EAF) are the second most prevalent steel production method. In an EAF where heat is generated from an electric arc between two graphite electrodes which melts the scrap steel and iron ore. The graphite also acts as a reducing agent, which liberates the oxygen atoms from the iron ore.

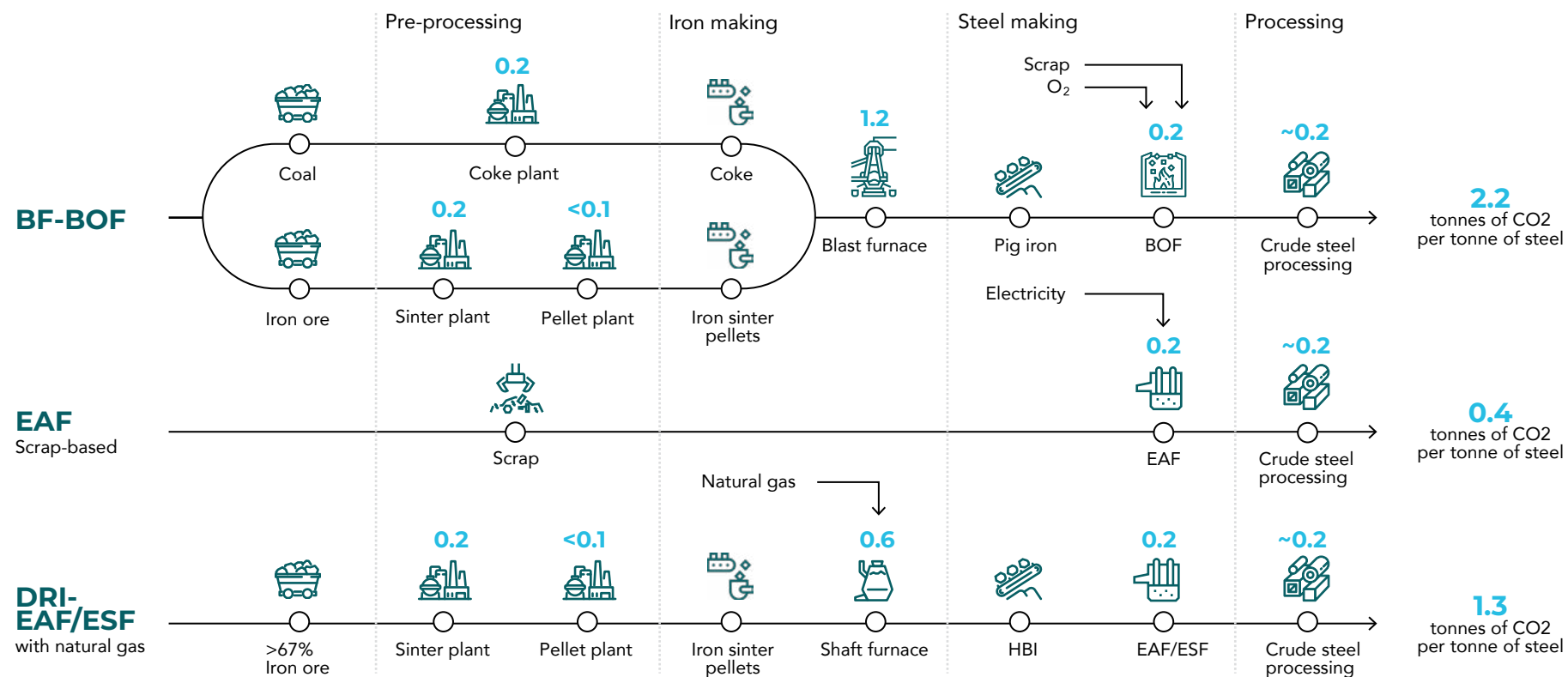
Average emissions from electric arc furnaces are considerably lower than the BF-BOF route at 0.4 tonnes of CO₂ per tonne of steel (tCO₂/t of steel) as seen in the chart below since the recycled scrap just needs to be remelted and purified.⁹ Per tonne emissions from electric arc furnaces can reach as low as 0.1 tCO₂/t of steel if powered by renewable energy; however, EAF's typically rely heavily on on-site power generation and local electricity grids. Depending on the energy mix of the power generation, carbon emissions from these sources can be significant.

Direct reduced iron – electric arc furnace and electric smelting furnace

Processes using direct reduced iron (DRI) account for seven per cent of global steel capacity.¹⁰ The DRI process reduces high quality iron ore pellets directly in solid form at lower temperatures to produce hot briquetted iron (HBI) without the need for blast furnaces and coking coal. Depending on the HBI quality, the material is transferred to an EAF or electric smelting furnace for melting and steel production.

If the DRI shaft utilises green hydrogen, emissions from the production of the iron can be near zero. However, most of DRI facilities in use today are powered by natural gas or coal, which emit CO₂ through the reduction of the DR iron ore grade in the shaft furnace. Total emissions from DRI-based processes can range from 1.3 tonnes of CO₂ per tonne of steel produced when using natural gas to over 2.5 tonnes of CO₂ in the case of coal-based DRI.¹¹

Exhibit 3: Principal steel production pathways



Notes: EAF, sintering, pelletising, and crude steel processing emissions depend on the energy mix of the electricity supply, estimates based on global averages, total emissions per production route may differ from sum shown because of rounding.

Sources: European Commission (2022), *Technologies to decarbonise the EU steel industry*, Oliver Wyman analysis

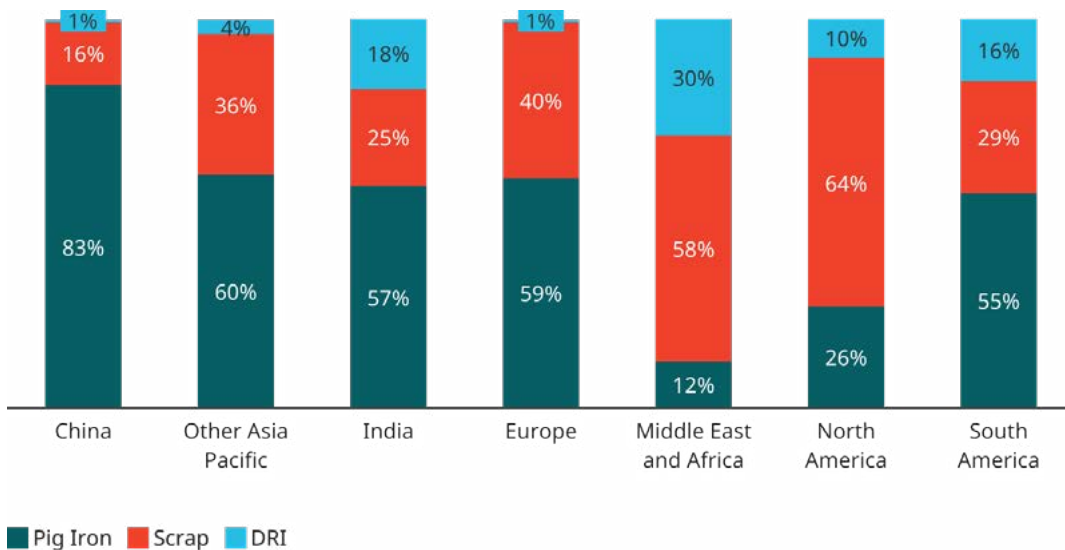
Geographic diversity

The conflicting challenges of fulfilling rising global demand and reducing emissions are further exacerbated by the diversity of steelmaking techniques and landscapes around the world. Each region's unique asset mix, energy inputs, production feedstocks, and regulatory environment necessitates a tailored steel decarbonisation pathway.

A region's share of secondary steelmaking through EAF and the age of existing BF-BOF assets set a baseline for emissions reduction targets and pathways. Given the significant decrease in emissions per tonne of steel produced via EAF, regions with higher shares of secondary production often fare far better in terms of average carbon intensity. However, EAFs depend on the availability and pricing of scrap steel to operate, and regions with historically low steel usage and/or production face a further decarbonisation challenge because of the low scrap supply and high import costs.

Exhibit 4: Regional overview of steel production mix 2023

In percentage of total production



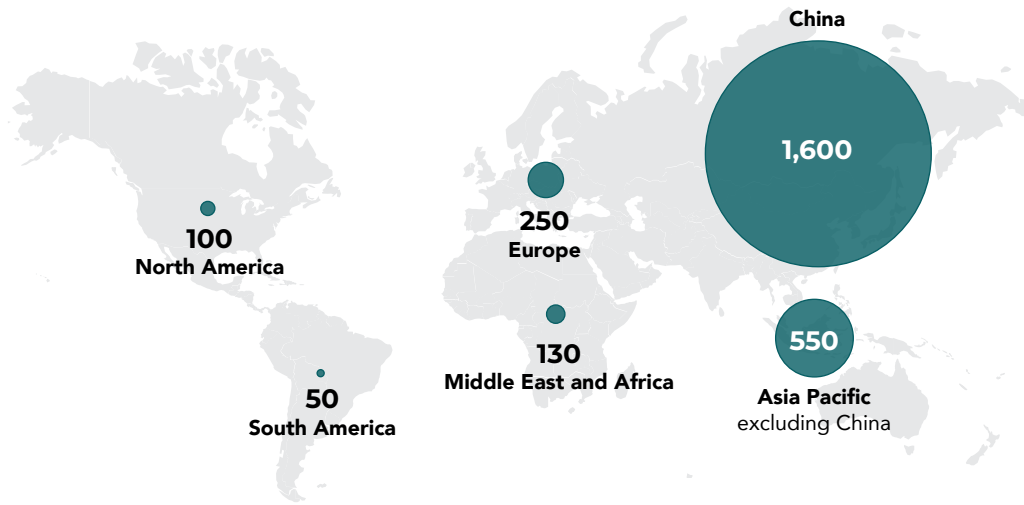
Sources: Global Energy Monitor (2023), *Count of Iron & Steel Plants by Production Method in Each Country*, Oliver Wyman analysis

The age of steel production assets also affects decarbonisation pathways and investments. Steel production assets typically have a lifespan over four decades, and younger steel markets are less likely to move towards low-carbon technologies because of the need to realise a return on the infrastructure investment. Strategies for decarbonising younger, emissions-heavy assets may include a combination of fuel switching, retrofitting existing steel plants, and decommissioning or incentivising the switch through foreign aid or investment to compensate for lost return on investment (ROI).

Achieving a decarbonised steel industry is key for a sustainable future and reaching net zero. It requires the diverse and unique constraints present in each region to be understood and addressed through industry commitment and government policies such as tax credits, or decarbonisation subsidies.

Exhibit 5: Primary emissions from steelmaking by region in 2022

In million tonnes of carbon dioxide



Note: Bubble sizes indicative.

Sources: IEA (2020), *Iron and Steel Technology Roadmap*, IEA, Paris License: CC BY 4.0, World Steel Association (2022), *Total production of crude steel*, Oliver Wyman analysis

Abatement pathways and challenges

The decarbonisation of steelmaking principally relies on two pathways: Decarbonising crude steel production and reducing carbon dioxide emissions from secondary steel production.

Decarbonising crude steel production

To address the demand for crude steel, hydrogen-powered DRI technology presents a decarbonisation opportunity. DRI processes have several inherent sustainability advantages over carbon-based blast furnaces. First, they can be retrofitted to utilise both natural gas and hydrogen as the iron ore reducing agent – both of which emit less carbon than the integrated steelmaking route and coal-based DRI. Second, the hot briquetted iron produced can be fed directly into existing downstream infrastructure reducing the need for further investment.

Using green hydrogen – produced through electrolysis with renewable energy – is the optimal solution because it releases almost no emissions.

Increasing demand signals for green steel producers

Through a detailed lifecycle emissions assessment of offshore wind farms, Orsted identified steel procurement as a major source of Scope 3 emissions.

Through a partnership with Dillinger, low-carbon steel produced via a DRI-EAF facility will be used for offshore wind turbine foundations, reducing emissions from steel procurement by over 50%.

Offtake agreements such as this provide the steel industry with the demand and price signals needed to justify the required investments in low-carbon steel production.⁸



There are challenges associated with the widespread adoption of hydrogen-powered DRI. Since the iron ore is reduced in its solid state, the iron ore input quality standards for DRI are typically higher than that of traditional blast furnaces; only 13% of iron ore exports today are suitable for feeding into DRI shaft furnaces.¹² Given the projected steel production originating from these processes, the industry will need to invest in upstream beneficiation technology for lower grade iron ores and subsequent downstream processes to allow the outputted hot briquetted iron to be utilised in an electric arc furnace.

For DRI technology to create a significant impact on steel emissions, the industry must address three key hydrogen-related issues: Building out the hydrogen supply chain (including generation, transport, and storage), growing the current inadequate supply of renewable energy required for green hydrogen production, and navigating the demand and price competition for hydrogen from other heavy industries (for example, chemicals).

Addressing the challenges of green hydrogen and iron ore supply will be crucial for the successful large-scale integration and global adoption of DRI and EAF technologies. It will require different industries working together to coordinate efforts and raise the capital investment required.

Steelmakers can also capture CO₂ from blast furnaces or their downstream operations and either store or utilise the gas to create value-added products, such as methanol, biogas, or sustainable aviation fuel. Such methods are critical for short- or medium-term solutions.

Reducing carbon dioxide emissions from secondary steel

The EAF share of steel production is expected to increase as the scrap market expands globally. In the European Union (EU), the EAF share is expected to grow from 40% today to 80% in 2040.¹³

If powered by renewable energy, the carbon dioxide emissions from the melting of scrap steel in an EAF are near zero and can be coupled with electrified upstream and downstream processes, such as scrap handling and steel processing, to produce near-zero green steel.

However, the expansion of EAF technology will be constrained by high scrap prices coupled with limited supply and by inadequate access to renewable energy and storage to reliably power a zero-emissions electric arc furnace. For example, by 2030, producing 32 million tonnes of flat green steel in Europe would consume 12% of the renewable energy available in the region, while still only satisfying about 30% of demand.

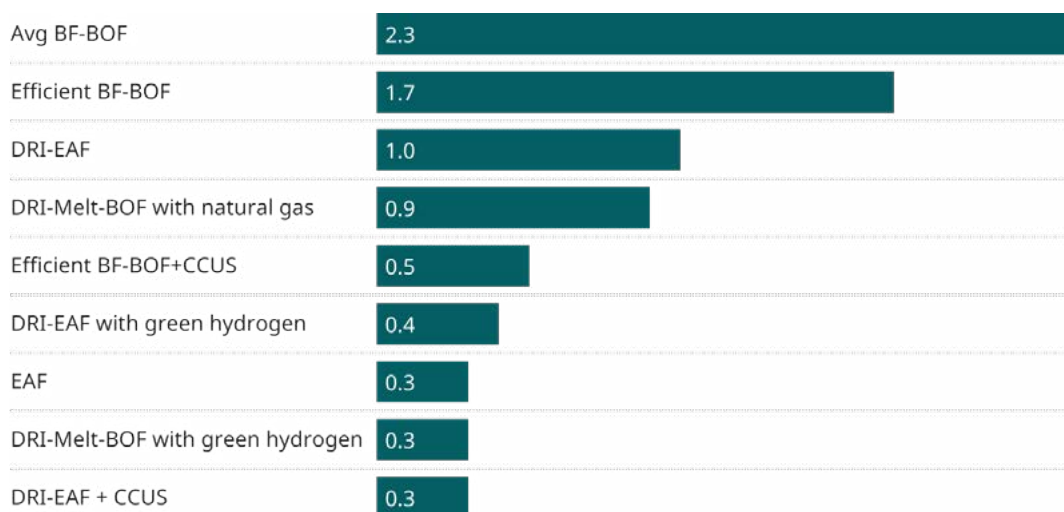
Additionally, the quality of steel produced from this process is also limited by the quality of the scrap feedstock. To support EAF production, the steel industry must increase their access to renewable energy and develop greater capabilities for scrap collecting, handling, and sorting.

Industries currently reliant on byproducts from primary and secondary steelmaking will also face the challenge of adapting their processes and supply chains to account for the reduced availability of raw materials. For instance, slag created in blast furnaces serves as a crucial raw material input for Portland Cement producers because of its cost-effectiveness and robust material properties, making it an ideal feedstock for large-scale construction projects.

To scale up green steel production, many steel producers are also planning to phase out their blast furnace fleet by combining scrap-based electric arc furnaces and DRI-based processes.

Exhibit 6: Carbon dioxide emissions from current and future low-carbon steel production

In tonnes of carbon dioxide per tonne of crude steel



Source: Mission Possible Partnership (2022), *Making Net-Zero Steel Possible*.

Key Takeaways

1. Decarbonisation of primary steelmaking will rely on the buildout of hydrogen infrastructure including the renewable electricity required for hydrogen generation.
2. In order for hydrogen-powered DRI to transform the industry, steelmakers and mining companies must innovate around the shortage of DR grade iron ore and invest in enhanced upstream beneficiation and downstream processing to make lower grade ores suitable for use.
3. Carbon capture will play a crucial role in decarbonising steelmaking since many traditional integrated steel mills around the globe still have long useful lifespans and residual emissions will exist for most low-carbon steelmaking routes.
4. Policymakers must work to even out the playing field for low-carbon steelmakers to compete in a global marketplace with different levels of support required by region.
5. Customers of the steel industry must grant long-term offtake agreements with clear demand and price signals to low-carbon steel producers to de-risk future infrastructure investments. In the absence of clear green premiums and volumes, stricter governmental regulation, and an increased carbon tax will have to fill in the gap.

3.2. Aluminium

Key figures

>65 million tonnes

of primary and secondary aluminium produced annually

~2%

of global carbon dioxide emissions attributable to aluminium production

>16 tonnes

of carbon dioxide produced per tonne of primary aluminium

Key technical challenges



Reliable, cost-effective renewable energy for locations without hydropower



Electrifying alumina refining processes in conjunction with renewable energy



Developing commercial scale inert anodes

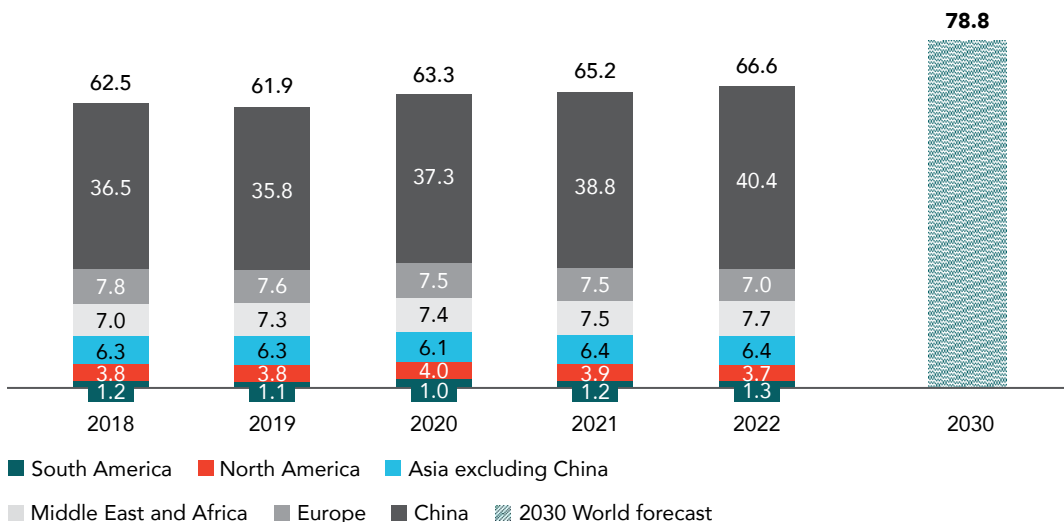
Aluminium production emits an average of over 16 tonnes of carbon dioxide emitted per tonne of primary aluminium. Thus, the aluminium industry's direct contribution to annual carbon dioxide emissions is about two per cent.¹⁴

By tonnage, aluminium is the second largest manufactured metal, with its primary consumers in the transport and construction industries which account for about half of total demand, and global demand is expected to increase further over the coming decades as standards of living rise around the world. A sizeable portion of the anticipated growth is expected to be driven by demand for the materials required for the industry transition, such as solar photovoltaic (PV) panels.

Furthermore, aluminium's lightweight and robust properties make it a crucial enabler for other sectors such as aviation to reduce their carbon footprints.

Exhibit 7: Global aluminium consumption

In million tonnes



Sources: International Aluminium (2022), *Primary Aluminium Production*, Oliver Wyman analysis

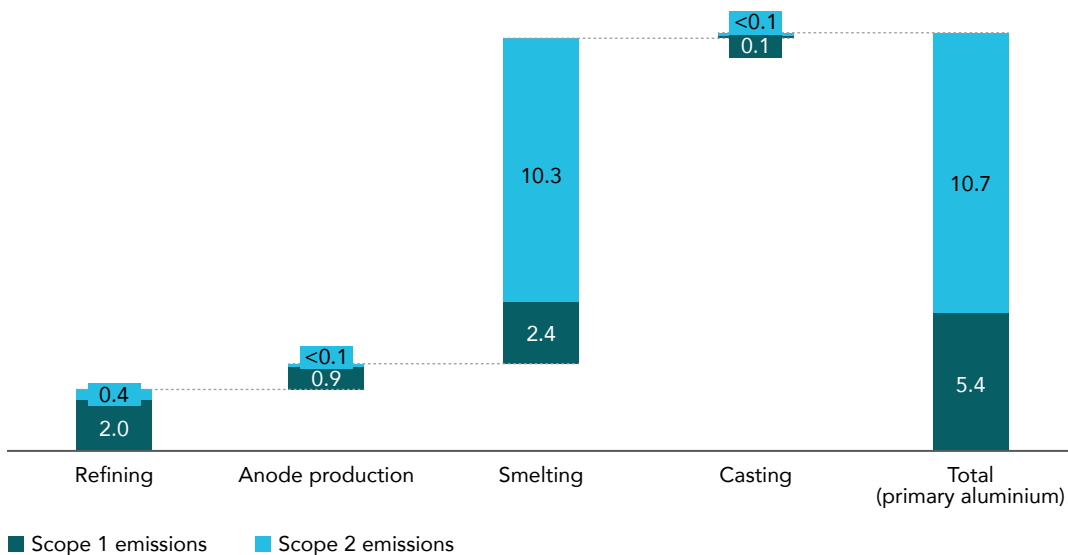
Carbon dioxide emissions profile

About 70% of all aluminium production involves the process of refining bauxite, aluminium's base raw material, into alumina and smelting the alumina into primary aluminium.¹⁵ Secondary aluminium production involves the recycling of scrap aluminium and remelting it to purify the material for re-processing.

As shown in Exhibit 8, approximately 85% of the Scope 1 and 2 emissions generated during the production of primary aluminium come from the refining and smelting phases (including anode production).¹⁶ Bauxite mining and aluminium casting combined account for a fraction of the Scope 1 and 2 emissions generated during the production of primary aluminium.

Exhibit 8: Direct and electricity-related greenhouse gas emissions of primary aluminium production

In tonnes of carbon dioxide equivalent per tonne of aluminium produced (tCO₂ Eq/tAl)



Note: Scope 1 emissions includes CO₂ and perfluorocarbon (PFC) emissions; emissions calculated as full lifecycle (cradle-to-gate) emissions.

Sources: International Aluminium (2021), *Greenhouse Gas Emissions Intensity- Primary Aluminium*, Oliver Wyman analysis

Smelting

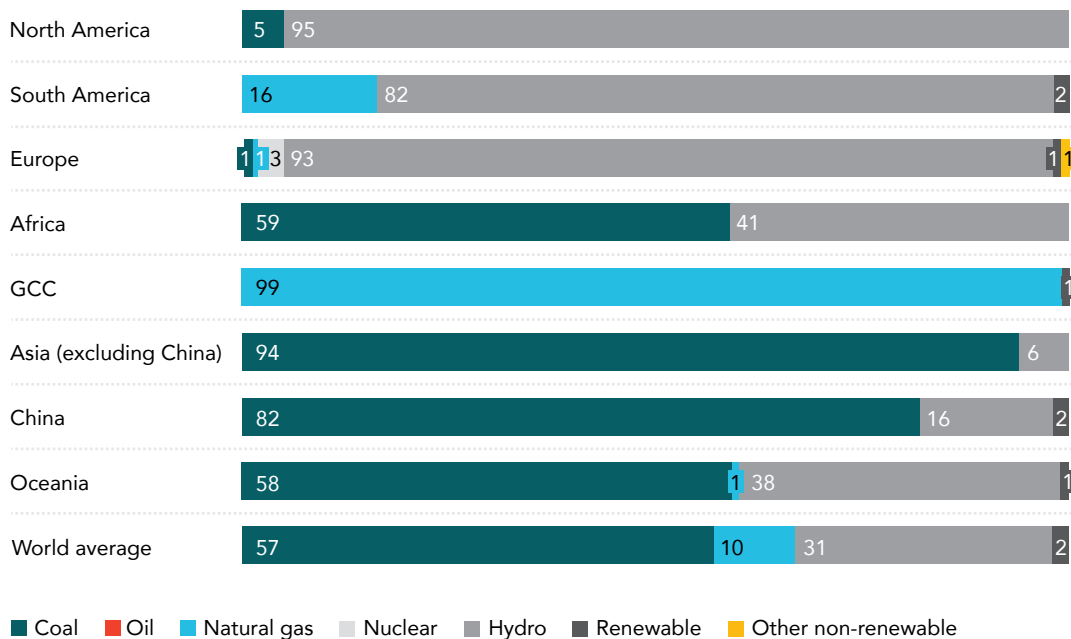
The high average carbon intensity of aluminium production primarily stems from the electricity demand of smelting alumina, generally by means of the Hall-Héroult process, accounting for over 80% of aluminium production's Scope 1 and 2 emissions.¹⁷ In fact, the combined electricity consumption from smelting globally is greater than the total electricity consumption of entire countries such as Brazil, or the United Kingdom.

Of the emissions from smelting, around 19% are direct emissions derived from the use of carbon-based anodes. The production of the carbon anodes needed for electrolysis alone generates 0.9 tonnes of CO₂ per tonne of aluminium (tCO₂/tAl) because of the energy required to refine coking coal into anodes. Moreover, during electrolysis, significant CO₂ and perfluorocarbon emissions are released as the anodes react with the oxygen atoms freed from the alumina. On average, the Scope 1 emissions from the smelting totals around 2.4 tCO₂/tAl.

The bulk of smelting emissions are electricity-related emissions derived from the energy generation needed to power the smelters – the global power mix supplying these smelters remains heavily reliant on fossil fuels. In 2022, 55% of the power supplied to smelters came from coal and 10% from natural gas.¹⁸ However, the dependence on fossil fuels is notably higher in China, Oceania, and the rest of Asia, while the Americas and Europe rely mostly on hydropower (see Exhibit 9).

Exhibit 9: Smelting power mix by power source

In percentage of total power



Sources: International Aluminium (2022), *Primary Aluminium Smelting Energy Intensity*, Oliver Wyman analysis

Refining

In addition to smelting, the refining process requires high temperatures during alumina hydrate calcination and large amounts of hot steam for the Bayer process and calcination where steam and heat are typically generated using fossil fuels. Refining bauxite into alumina ready for smelting is the second most emissions-intensive phase of aluminium production, accounting for approximately 15% of the industry's Scope 1 and 2 emissions.¹⁹

Of the 2.4 tCO₂/tAl emitted across the refining process, 83% are Scope 1 emissions made up of thermal energy, non-CO₂ emissions and ancillary materials. The remaining 17% of emissions from the refining processes are Scope 2, with the Bayer process and calcination typically powered by fossil fuels. In North America, Europe, and the Middle East, alumina refining relies on natural gas to generate 95% to 100% of the energy needed, while in Australia, around 60% is derived from gas with the remainder from coal.²⁰

Geographic diversity

The aluminium industry must contend with unique geographical constraints in each region. One shared concern is the emissions from electricity consumption used in primary aluminium production where access to renewable energy resources, effective storage, and energy management is vital. The location of aluminium production, and specifically the smelter's location, significantly influences the total greenhouse gas emissions. For instance, the emissions factor of the South African power grid, primarily coal-powered, is around 20 times higher than Norway where most power is generated from hydropower.²¹

Also, since secondary aluminium has a significantly lower energy and carbon intensity than primary aluminium, regions with access to robust recycling infrastructure, sorting facilities, and large scrap quantities fare far better in terms of average carbon intensity from aluminium production.

Expanding secondary aluminium in the Middle East

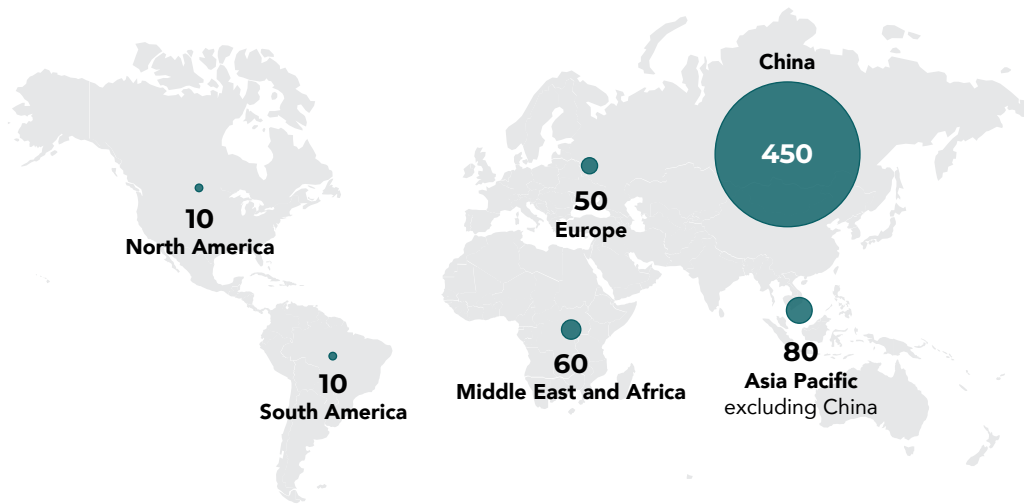
Secondary aluminium requires only five per cent of the energy needed for primary aluminium production. EGA, in partnership with leading waste management companies, formed the Aluminium Recycling Coalition to embed recycling practices and infrastructure in the Middle East economy.

EGA is also planning to build the largest recycling facility in the United Arab Emirates with a capacity of over 150,000 tonnes per annum.



Exhibit 10: Primary aluminium production carbon dioxide emissions by region in 2022

In million tonnes of carbon dioxide



Note: Bubble sizes indicative.

Sources: International Aluminium (2022), *Primary Aluminium Production*, Oliver Wyman analysis

Abatement pathways and challenges

Aluminium is considered a hard-to-abate industry because of the relative technological immaturity of the necessary solutions and substantial financial commitment of transitioning to decarbonised technology. The large and constant energy demand of smelters is at odds with the intermittency of renewable energy. Nonetheless, with accelerated and sustained efforts, decarbonisation is possible, and progress is being made as many of the necessary technologies approach commercial maturity.

Smelting

The greatest opportunity for reducing aluminium's carbon dioxide emissions rests with renewable power generation as more than 60% of the industry's carbon dioxide emissions is a consequence of electricity consumption. With one-third of the 200+ worldwide smelters reliant on grid power, the rate of decarbonisation will be mostly determined by the speed at which the grid transitions to a more renewable energy mix.²²

However, the increasing variable renewable energy in local power grids can cause transmission congestion, limiting the impact that renewables can have.

To limit grid congestion in networks, regulators must provide innovative frameworks to encourage the direct integration of variable renewable energy and heavy industry which can circumvent congestion at scale and at pace with lower societal cost from transmission infrastructure and reserve reimbursement.

Placing investments in renewables where they are needed the most

The scale of renewable expansion over the next two decades will be unprecedented. Vast amounts of new renewable generation capacity will need to come online to support heavy industry decarbonisation for hydrogen electrolyzers, aluminium smelters, electric arc furnaces, and newly electrified processes.

The Decarbonising Grids Working Group, also within Energy Transition Task Force, is seeking to increase grid capacity and flexibility in key African markets by combining public and private funding and bringing the right stakeholders together to create a regulatory and policy framework to support external investment.

The increased prevalence of renewable power purchase agreements offers some bargaining leverage for quicker adoption of renewable power through the grid, but the market remains immature in several key regions. In many countries, demand far outstrips supply. For the remaining two-thirds of the world's smelters that use producer-generated energy, two principal solutions are increased renewable power generation, including hydroelectric power, hydrogen, and other renewables, and/or increased use of carbon capture, utilisation, and storage (CCUS) technologies.

Alongside increasing renewable energy usage, the development of inert anode technology is critical to achieving carbon-free aluminium. Inert anodes eliminate the Scope 1 emissions by replacing the carbon anodes with another material that can remove the oxygen atoms from the alumina without releasing carbon dioxide.

Refining

Pathways to cut alumina refining's Scope 1 and 2 emissions require a transition to renewable power, and electrification of refining processes. Since most traditional calciners are fossil-powered, the industry requires an electric or hydrogen-powered calciner to take advantage of fossil-free energy. Also, there are opportunities for heat recapture and process efficiency in the Bayer process through various technologies. If previously wasted thermal energy in the form of uncontaminated steam can be reutilised from electric calcination, emissions from power generation and steam production can be reduced. However, the steam requirements for the Bayer process will require further energy input. To produce the additional steam, processes must be adapted to use renewable energy, such as condensed solar and photovoltaic.

Key Takeaways

1. Although a decarbonised power supply and increased secondary aluminium are critical to achieving net zero, the aluminium industry will require several other developing technologies to work in tandem with each other.
2. Customer and producers require a clearer regulatory framework for carbon accounting, carbon pricing, and subsidies to incentivise further investments in decarbonisation. Regional variations in access to renewable energy and technological development must be considered.
3. Access to renewable energy and secondary aluminium varies widely across the globe; regulators must strike a careful balance while incentivising green production.
4. Customers of the aluminium industry have a crucial role to play in giving long-term offtake agreements with clear demand and price signals to producers to incentivise future investments in low-carbon aluminium.

3.3. Mining

Key figures

15.6 billion tonnes

of key metals and minerals mined per year

<2%

of global carbon dioxide emissions attributable to mining activities

0.6 billion tonnes

of carbon dioxide produced by the mining industry (Scope 1, 2) annually

Key technical challenges



Further developing zero-carbon alternatives to haulage and transport



Transition to renewable energy and electrification for processing



Developing low-carbon shipping fuels for seaborne transport

The core mining activity – extracting and moving billions of metric tonnes of material and equipment – makes it easy to understand why the mining industry is one of the major contributors of emissions, accounting for less than two per cent of global carbon dioxide emissions (not including fugitive emissions). This figure only accounts for extraction and basic on-site processing of the six key mined commodities (coal, copper ore, iron ore, nickel, bauxite, and zinc), with production, manufacturing, and end use resulting in further Scope 3 emissions. These indirect emissions can be up to 10 times greater than those emitted at the mine site and must therefore be targeted during the decarbonisation process of the entire value chain.²³

Scope 1 and 2 carbon dioxide emissions across the industry are primarily driven by diesel-powered haulage, and on-site processing which usually relies on natural gas, diesel generators, or electricity either supplied from the grid or off-grid sources. Each power source represents an additional source of emissions, requiring tailored decarbonisation solutions.

Carbon dioxide emissions profile

A closer look at industry-wide emissions reveals significant heterogeneity in the carbon intensity of mining operations. The industry produces a broad range of minerals and metals, mostly extracted through either open pit or underground mining. The emissions intensity of any one operation is determined by product type, grade of ore, location, mining method, process efficiencies, as well as types and age of equipment and energy supply. For example, the average mining emissions intensity to produce one tonne of nickel is around five tCO₂ per tonne of nickel, while the same metric for iron ore is below 0.1 tCO₂ per tonne.²⁴ Significant differences in emissions can exist even for the same metal or mineral, depending on the factors mentioned above.

Role in the energy transition

Mining is a key industry needed to support the energy transition. However, the challenges are complex and require a rethinking of how the industry conducts business. First, there is expected to be an increase in demand for most mined commodities. Part of this demand is generated by the energy transition itself, and part is the product of global economic growth, especially in emerging markets.

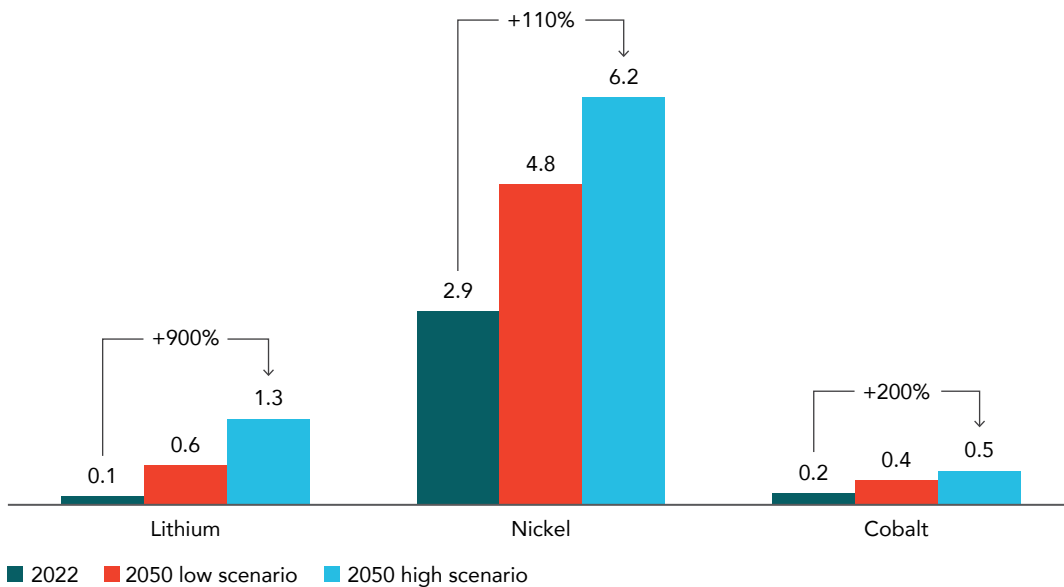
Demand for mined resources to support the energy transition is projected to surge because of their significant role in expanding renewable energy generation, infrastructure, and storage. By 2050, the global demand for nickel, lithium, cobalt, and graphite is forecasted to at least double, while demand for clean technologies is expected to quadruple, driven in part by the global expansion of electric vehicle (EV) production.²⁵

Nickel, lithium, cobalt, and graphite are key elements in EV batteries.²⁶ The intensifying demand for such resources, and the required increases in mining activities to satisfy it, makes the need to decarbonise mining operations even more urgent if we are to supply these critical commodities in a sustainable fashion.

This pressure to expand production must be balanced against the urgent need to cut emissions at a pace that will push the industry to net zero by 2050.

Exhibit 11: Global demand for lithium, nickel, and cobalt

In million tonnes



Sources: IEA (2023), *Critical Minerals Market Review 2023* IEA, Paris License: CC BY 4.0, Oliver Wyman analysis

Power supply

On-site mining operations, such as processing (for example, washing, crushing, grinding) of extracted metals or minerals, are mostly powered by electricity – either sourced from local grids (not always available in remote locations) or from on-site power generation.

If sourced from local grids, this exposes mining companies to the emission intensity of the respective power grid, which can vary by region. In Australia, for example, 22% of the mining sector's energy needs are met by a grid that is 71% is powered by fossil fuels.²⁷

"Off-grid" mines depend upon on-site power generation from diesel and natural gas. The key issue with a transition to renewable sources remains the intermittency of renewable power from solar and wind when mining operations need an around-the-clock reliable energy supply.

In-mine operations

Heavy haulage operations, a key driver of carbon dioxide emissions, are almost exclusively diesel-powered today. Three options to decarbonise this activity seem most viable in the long term: The transition to battery-powered electric haulage vehicles, hydrogen-powered haulage vehicles, or advanced biofuel-powered haulage vehicles. While all solutions are in development, there is limited proof that either option works effectively in a real-world mining context which requires high power density and long run times before refuelling.

Fugitive emissions

Fugitive methane emissions from coal mining are a significant contributor to greenhouse gas emissions. These emissions in mining pertain to the unintentional and frequently uncontrolled release of gases or particulate matter into the atmosphere during mining operations. Managing and containing these emissions, particularly methane, is a challenging task in underground and open pit coal mining. The challenge is primarily rooted in the absence of technologically advanced infrastructure capable of efficiently capturing and controlling these fugitive emissions during mining operations.

According to the International Energy Agency, around 40 million tonnes of fugitive methane were released from coal mines in 2022 which correlate to a carbon dioxide equivalent of 1.28 billion tonnes per year over 100 years – larger than direct emissions from all other mining activities combined.²⁸

Long-haul transport

Transporting mined products is another major driver of Scope 3 emissions, with the movement of extracted minerals and metals from often remote locations on fossil fuel-powered rail, trucks, and/or cargo ships. The feasibility of integrating low-carbon solutions into the transport process is being investigated but is so far proving challenging because of the scale of operations, the investment required to make the transition, the often-remote locations of mining operations, and the relative immaturity of some of the technologies for industrial applications.

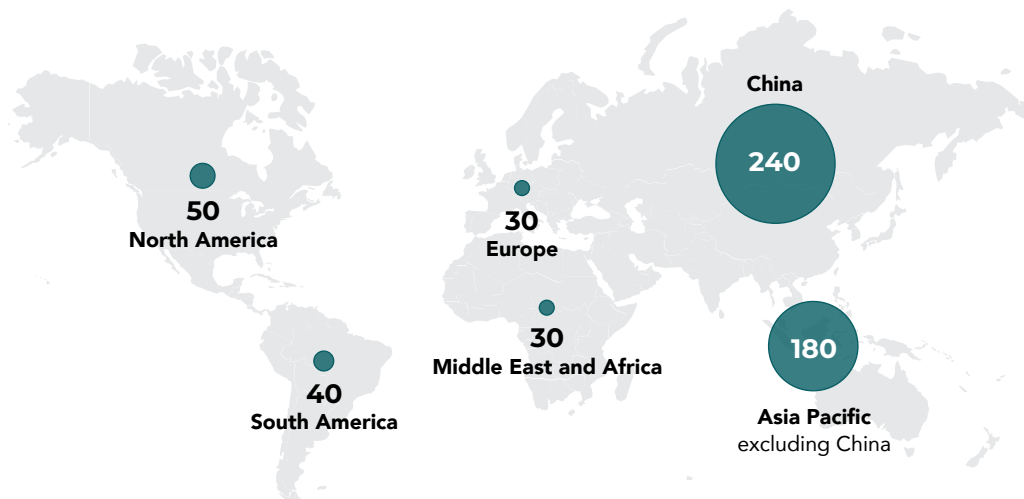
Geographic diversity

Mining's diverse geographical footprint creates both abatement challenges and opportunities, and any decarbonisation solution must be tailored to the unique requirements of each mine and location. Because of high production volumes and complex mining activities for key metals and minerals such as iron ore, coal, bauxite, lithium, copper, and zinc, Asia Pacific is accountable for approximately 70% of global Scope 1 and 2 emissions from mining. Of these, China alone is estimated to account for over 40%, with Australia also a key contributor given its significant mining operations.

In Australia, mines are often located in edge-of-grid or off-grid areas, resulting in operations being powered by on-site generators operated by independent vendors or the mining companies themselves.

Exhibit 12: Primary carbon dioxide emissions from mining activities by region in 2022

In million metric tonnes of carbon dioxide



Note: Bubble sizes indicative; emissions exclude fugitive methane emissions.

Sources: Oliver Wyman analysis

Abatement pathways and challenges

As mentioned, mining's existing emissions profile and corresponding decarbonisation pathways are unique for every individual mining operation because of factors like location, energy supply, and the materials being extracted.

Haulage

Haulage refers to the movement of extracted materials across mining sites. The exact haulage infrastructure and approach differs across mining operations: Haulage, almost exclusively, employs diesel-powered combustion engines, giving rise to significant Scope 1 emissions. As mentioned, there are a few examples of low-carbon solutions, such as renewable diesel, hydrogen, or fuel cells, but most are currently limited to pilot-scale feasibility studies.

Biofuels are widely seen as the chief intermediary pathway to decarbonisation, given its technological maturity and relative ease of integration into existing operations. For instance, many current vehicle engines can already operate on biofuel blends with little modification. Biofuels are in high demand across multiple industries and, today, are more expensive than traditionally used fossil fuels.

The second option is to electrify haulage vehicles and power them with renewable energy. In haulage today, there are few examples of commercially scalable, battery-powered EVs, with most such solutions remaining at the pilot scale. The key technological barriers are battery size, weight, and charging times as well as the significant investments required to install the necessary electric infrastructure.

Hydrogen fuel cell-powered vehicles represent another haulage decarbonisation option, but one which is far less advanced than either biofuels or battery-powered EVs. Such solutions are being explored at the pilot level across the industry, with the major constraint being the lack of hydrogen infrastructure and generation. Hydrogen may prove to be a key transition pathway in years to come, but for now its application to haulage solutions remains limited.

In general, except for the biofuels option, switching existing vehicle fleets to lower-carbon alternatives translates to high investment requirements and operational risks.

Processing

Processing, the next step after the extraction and movement of mined materials, is another emission-heavy step in the mining value chain. The processing profile varies significantly between commodities and operations, with crushing and grinding the most energy intensive activities. For example, in underground nickel mining, the major driver of carbon dioxide emissions is processing, while the emissions contribution of processing in open-pit hematite mining is insignificant.

Most processing can be electrified, and full decarbonisation would involve a transition to renewable electricity sources. For grid-powered operations, the first abatement option is increasing the use of virtual or green power purchase agreements (PPAs) with the national grid to secure renewable energy supplies for processing.

Alternatively, for such operations where sourcing large supplies of green energy through the grid is not viable – because of a lack of grid infrastructure in remote mining operations or a lack of green PPA availability, for example – an option for mining operations is the development of their own renewable power generation capabilities. The central technologies, wind and solar, are mature, but the intermittent nature of their supply can put the solutions in conflict with the 24/7 energy requirements of modern mining operations. Energy and power storage solutions to alleviate the issue and ensure a constant, reliable power supply have so far mainly focused on batteries, but their high cost and low scalability pose challenges for this abatement option.

For the processes where electrification is not possible, transitioning towards low-carbon fuel alternatives is key. As detailed above, one main challenge with biofuels is their limited abatement potential. Hydrogen-powered solutions are also a possibility, but hydrogen infrastructure and supply limitations render its feasibility low for now.

Integrating renewables into the mix

Rio Tinto operates five power generation facilities in the Pilbara area alone, with total capacity of 480 megawatts (MW) to develop further solar farms of up to 300 MW capacity in the coming years, in an ongoing effort to decarbonise operations.

RioTinto

Transport

Transport-related emissions are another lever along the mining value chain to decarbonise. However, if the mining companies do not run shipping and transport activities themselves, related emissions are considered Scope 3 emissions. Consequently, abatement efforts addressing these Scope 3 emissions are necessary, but those would not directly address the Scope 1 and 2 carbon dioxide emissions of mining companies discussed in this guide.

Often the transport of mined material from pit to port is undertaken on private freight railways, with the majority still reliant on diesel combustion engines. Potential decarbonisation options include battery electric, hydrogen, and ammonia-powered solutions with studies and pilot projects ongoing across the industry.

Maritime shipping remains an emissions-intensive sector given its reliance on carbon-intensive bunker fuels. Regulatory pressure to decarbonise the marine segment is increasing, with short-term efforts focused on increased fuel efficiency. Mid- and long-term efforts are focused on alternative fuels, with various competing options present in pilots and feasibility studies, such as liquefied natural gas (LNG), biofuels, or methanol. The most pressing challenges with alternative fuels are the lack of adequate production capacity to meet the demand from multiple industries, the lack of required infrastructure, and the associated cost and investments of transitioning shipping fleets.

Two developments can currently be observed:

- First, shipping companies are using LNG-powered vessels as a transitional fuel, with the technology at high maturity. For example, Anglo American's new LNG-powered vessels offer approximately 35% carbon reductions relative to conventional bunker fuel.²⁹
- Second, among the competing low-carbon shipping fuels for the longer-term transition, the four frontrunners are advanced liquid biofuels, renewable methanol, green hydrogen, and green ammonia. All four remain relatively far from scale, with significant investment needed in production and distribution infrastructure.

Key Takeaways

1. Even as demand for coal is forecast to decrease mid- or long-term, demand for most other mined materials, especially those necessary for the energy transition such as nickel, lithium, cobalt, and graphite, will increase over the coming decades.
2. The replacement of fossil fuels, such as diesel, bunker fuels, or natural gas, for haulage, processing, and long-haul transport pose the largest opportunity for the mining sector to abate emissions.
3. Availability of cost-effective low-carbon fuels and provision of reliable renewable power are prerequisites for change to the industry.
4. Governments must continue working closely together with mining companies to define the right and most effective incentive schemes, policies, and actions to drive the sector's transformation.

4. Prioritising action



The Decarbonising Industry Working Group aimed to explore decarbonisation pilots for real-world application meeting three criteria: Address crucial emission challenges, leverage members' expertise, and be scalable across the industry.

A bottom-up assessment was conducted to establish a knowledge base which aimed to align participating companies' understanding of their emission challenges.

The working group then engaged a wider range of companies from various Sustainable Markets Initiative workstreams, such as hydrogen, finance, and CCUS, to leverage their expertise and discuss challenges, opportunities, and solutions. Concurrent interviews were held with subject matter experts and senior leaders overseeing sustainability initiatives to identify existing capabilities and potential gaps that could be filled through others' expertise.

After combining insights from both assessments, collaborative workshops were held to discuss priorities, and this collective effort resulted in the prioritisation of five emissions reduction areas that align with the selection criteria.

In the following part of this guide, the actionable emissions abatement topics identified by the working group are captured.

Key criteria for pilot topic selection

1



Focus on the critical emissions abatement challenges in steel, aluminium, and mining

2



Require the capabilities and expertise of the participating companies

3



Be scalable and beneficial to the wider industrial community

Expanding direct reduced iron ore grade feedstock

Rationale

The quantity of suitable direct reduced iron ore grade today is insufficient to meet future demands. DRI processes are projected to be a pivotal piece of steelmaking’s zero-carbon future, and the working group has identified this as a key topic of concern.

The current standard for DRI-EAF production requires high-quality iron ore (typically over 67% Fe content), but today, only 13% of seaborne iron ore is suitable for use in a DRI shaft.³⁰ Select working group members have collaborated on how to address this issue and transform processes in their existing plants to accept lower iron content ore. Workshops were held to brainstorm on challenges and potential solutions such as the additional infrastructure and technology required for hydrogen generation, transport, and storage.

In-depth knowledge on how different low-grade iron ore affects the DRI product quality is limited among steel companies. The objective of this collaborative initiative is to assess the impact of various lower-grade iron ores (for example, Indian iron ore, Australian iron ore) on the hot briquetted iron quality based on the tuning of the hydrogen injection in the DRI shaft furnace. Conducting this research is necessary to understand the various constraints around DRI feedstock.

The relevance to the global steel industry could be further enhanced by including additional low-grade iron ores to the testing scope.

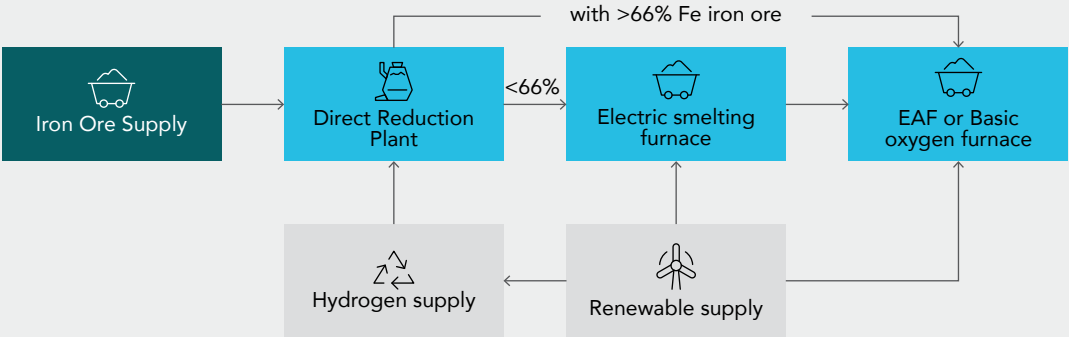
Only 13% of seaborne iron ore today is DR grade.³¹

Implications

This topic has the potential to expand DRI technology across the industry and reduce per tonne carbon dioxide emissions from steel production by over 65% for every new tonne of hydrogen-powered DRI that replaces existing BF production.

Understanding the iron ore requirements for DRI production allows steel producers around the world to accelerate DRI investments given reduced implementation risk and feedstock constraints. The potential to use less expensive, more abundant iron ore as feedstock can positively impact the overall cost of green steel and reduce the demand for high-quality iron ore.

Exhibit 13: Schematic overview of DRI production pathway



Strengthening the carbon capture and storage business case

Rationale

In the short- to medium-term, reducing carbon dioxide emissions from crude steel production will require carbon capture. However, the industry is challenged by both the technical and financial feasibility with the best available carbon capture technology today costing 40 to 100 USD per tonne of captured carbon.³²

To make carbon capture a viable solution, the optimum sequestration pathways need to be identified on a plant-by-plant basis to improve the investment outlook. Further research across the industry is needed to identify the optimum pathways by analysing the key levers and market outlook that impact these pathways.

Also, identifying indirect benefits in carbon value chain pathways such as end-product usage in other industries can improve both the investment and sustainability outlook of potential projects.

Finally, the potential to impact climate change as well as policy and regulatory enablers need to be assessed to determine the likelihood of recognition in various compliance and regulatory standards.

The topic was selected by the working group due to the criticality for the global steel industry and the outsized impact a solution like carbon capture and storage can have.

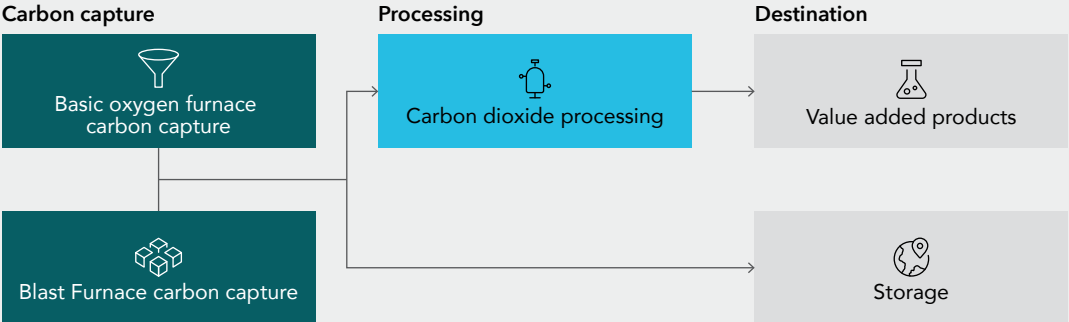
Implications

If successful, this study can provide the steel industry with key carbon capture knowledge, processes, and a proof of concept that can be widely adapted to reduce emissions from integrated steelmaking as well as strengthening the investment case for carbon capture projects.

The lessons learned from this potential study can also be expanded and applied to DRI-EAF/ ESF processes to produce and recycle methanol back into the steelmaking process to build a fully circular business model.

In addition, this study can also serve as a critical proof of concept for other hard-to-abate industries with the utilised carbon having potential application in the aviation and marine sector.

Exhibit 14: Schematic overview of carbon capture pathways for steelmaking usage



E-methanol to fuel the future of shipping

Rationale

Less than one per cent of bunker fuels today are low carbon with the other 99% coming from fuel oil and marine gas oil. Given the inter-connectedness of mining operations and vast quantities of material that must be shipped globally, mining companies are highly exposed to carbon emissions in this sector.

Accelerating innovation and the scaling up of low-carbon alternatives economically can significantly reduce emissions for the mining sector as well as all sectors that rely on seaborne trade.

Members of the Decarbonising Industry Working Group identified this area as a key focus point for their operations. Identifying the most cost-effective production pathway for e-methanol at select locations would be valuable for the industry.

Areas of a potential analysis should include a techno-economic evaluation of potential production pathways that depends on location, feedstock supply, product specifications, product demand (offtake), and available energy sources.

The produced e-methanol could then be supplied to shipping operations in the mining sector, supporting the abatement efforts to decarbonise parts of the mining value chain.

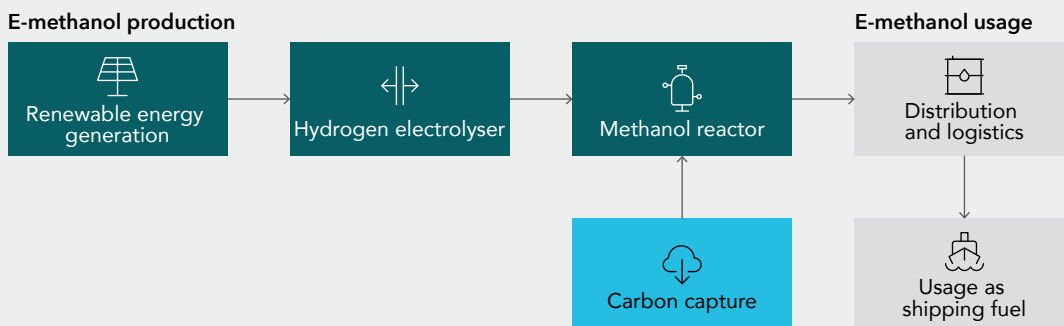
Improving the understanding of cost drivers and technological challenges when producing e-methanol will benefit multiple industries to reduce production cost and ramp up capacities.

Implications

E-methanol has the potential to significantly reduce carbon dioxide emissions of shipping operations by more than 90% as well as reducing pollutants such as sulphur oxides (SOx) and nitrogen oxides (NOx) in comparison to traditional shipping fuels.³³

Demonstrating economic feasibility at a defined locations can increase support and investments in e-methanol production for low-carbon bunker fuel.

Exhibit 15: Schematic overview of E-methanol production process



Replacing fossil fuels with electric calcination

Rationale

Eliminating emissions from the alumina refining process requires a transformation in the way traditional calcination is done. Over 60% of alumina refining emissions could be reduced through the application of electric calcination – on a global scale, total emissions abatement can be significant.

Given the potential impact, the working group prioritised and collaborated on the design and development of an electric calciner. This process is intended to replace existing calciners and could be expanded globally if the pilot proves successful.

In addition to the development of the core technology, working group members are potentially looking to integrate Mechanical Vapour Recompression to capture the uncontaminated steam from the electric calciner to feed back into the Bayer process, further reducing alumina refining emissions.

Implications

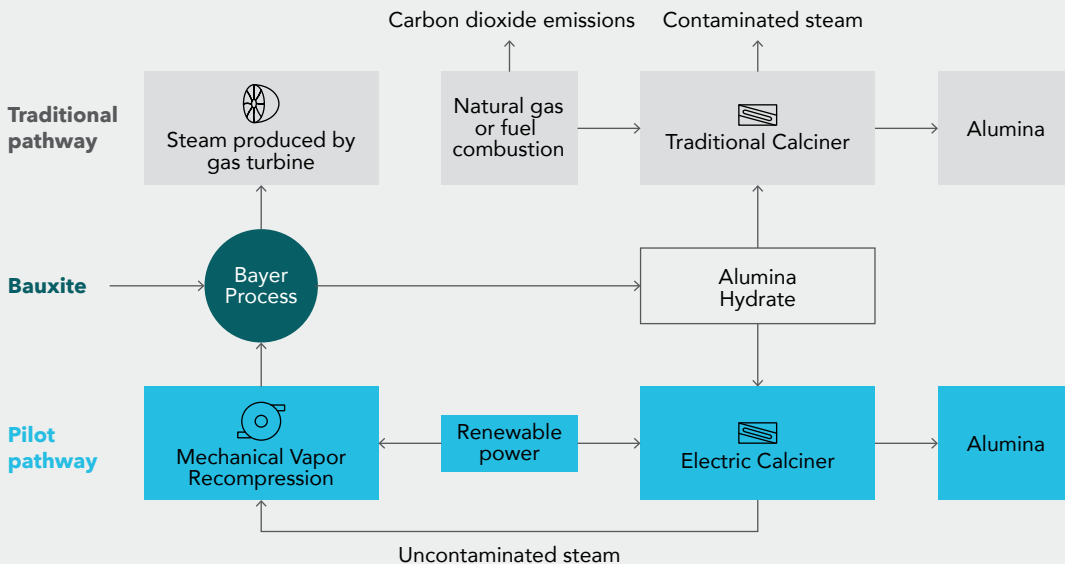
Eliminating emissions from calcination can potentially reduce Scope 1 and 2 emissions from aluminium production by over 10% if powered by renewable energy.

This technology has high scalability potential, and, once a proof of concept is successfully achieved and the technological maturity level increases, the entire alumina refining industry can benefit from this development.

In addition to the core technology, this study could expand to include Mechanical Vapour Recompression in conjunction with electric calcination to reduce emissions further.

Electric calcination can reduce primary aluminium emissions by 10%.

Exhibit 16: Schematic overview of electric calcination versus traditional pathway



ALUMINIUM

Producing zero-carbon steam

Rationale

This study suggests examining the feasibility and suitability of retrofitting zero-carbon steam processes in the Bayer process during alumina refining.

Zero-carbon steam is generated using a combination of renewable energy generation and thermal energy storage to produce steam at suitable pressures and temperatures to be used in industrial processes.

In this context, an existing refining plant could be leveraged to integrate and test potential zero-carbon steam processes.

The production of steam – mostly fossil fuel-powered – required for the Bayer process in alumina refining is a significant contributor to aluminium's greenhouse gas footprint due to the pressure and temperature requirements.

The technology in scope could be adapted to various locations if reliable renewable power can be supplied.

Implications

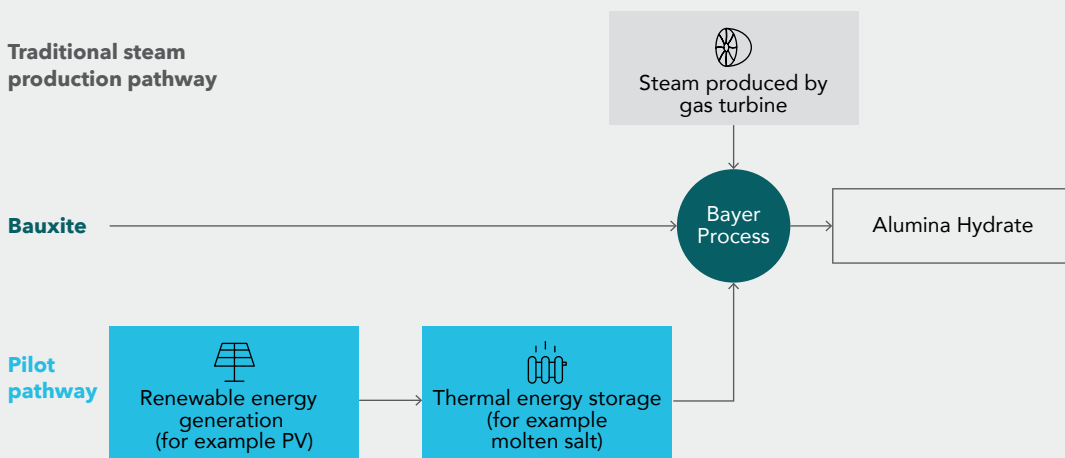
Emissions from aluminium production could decrease by more than five per cent due to this technology.

Decarbonising steam production is a key element of aluminium's decarbonisation pathway. A study could provide a valuable proof of concept for the entire aluminium industry.

The technology and concept being developed could potentially be utilised in other industries such as the chemicals industry or mining for zero-carbon steam generation.

Primary aluminium emissions could be reduced by 5% due to this technology.

Exhibit 17: Schematic overview of zero-carbon steam process





5. A call for action

Over the course of this initiative, it became clear that considerable progress on emissions abatement can be achieved in hard-to-abate industries when the right organisations and stakeholders collaborate in a mission-driven manner.

The three hard-to-abate industries profiled are responsible for approximately 12% of direct global carbon dioxide emissions and must therefore become a focus of global decarbonisation efforts.^{34, 35} However, it is critical for organisations to have confidence that positive actions taken today on behalf of the environment will not disadvantage them or harm their competitiveness disproportionately.

Throughout the work, a recurring challenge for the group was wrestling with the commercial uncertainty surrounding the rate of adoption of abatement technologies. Much of this uncertainty stems from the lack of a level playing field around regulatory practices and an absence of established “green premiums” that guarantee products with lower embedded greenhouse gas emissions will be rewarded with sustainable higher prices. Without assurances that competitors will face the same regulatory imperatives or a guarantee of higher prices for adopting greener processes, businesses struggle to evaluate the economic feasibility of emissions abatement initiatives.

Consequently, although transitioning to green production processes might offer competitive advantages over the long run, the current absence of well-established demand and price-points for green products within the three industries often hinders the viability of decarbonisation pathways.

Calls for action

Steel, aluminium, and mining face a broad range of commercial and technical challenges, with multiple overlapping barriers faced by all three. If decarbonisation efforts are to proceed on a larger scale, the following prerequisites must be met:

1. **Global frameworks for regulation and policy on emissions abatement must be developed to ensure a level playing field across regions and industries.** The industries need to advocate for the development of international agreements and frameworks that promote and support the adoption of low-carbon solutions. Industry players cannot move ahead at pace without the assurances that their global rivals will face the same or similar set of standards, regulations, and guidelines. Additionally, more alignment on carbon accounting practices across industries and countries is needed to provide companies guidance, but also to ensure differing practices will not hinder the rollout of effective abatement studies and pilots where organisations do not understand whether efforts would support their net-zero ambitions.

2. **Demand for green products is picking up but needs to be supported with policies and incentives.** Policymakers need to implement incentives and regulations that encourage sustainable procurement practices across industries (and countries). This can be achieved either through the introduction of new requirements to produce or use low-carbon products, or by introducing support schemes for bridging the cost gaps between low-carbon products and traditional products. Such schemes could give market demand and price clarity a much-needed push in the right direction. Increased demand for low-carbon products enhances the security and transparency for producers and reduces the risks associated with larger decarbonisation investments.
3. **Energy infrastructure and capacities need to be scaled up rapidly.** The accelerated scaling of renewable power generation, green hydrogen production, and grid capacities is mandatory to decarbonise the steel, aluminium, and mining industries. Policymakers need to ensure subsidies, incentives, and regulatory frameworks in place are supportive of such an ambition. “Fit-for-purpose” permitting processes for new capacities need to be ensured by policymakers, enabling organisations and investors to expand capacities rapidly. Additionally, policymakers should foster collaboration with relevant organisations and the financial community to resolve issues and to encourage capacity expansions.

Accelerating “olive” financing

The energy transition will require not only investment into green technologies, but also into the decarbonisation of existing hydrocarbon assets (referred to as “Olive” projects). However, there are fundamental limitations on funding Olive projects, both on regulated capital due to current risk and ESG frameworks as well as on private investors’ appetite.

A workstream within the Sustainable Markets Initiative is evaluating strategies to accelerate financial support, as well as ways to increase the allocation to countries, organisations, and projects that might otherwise face challenges getting sufficient and attractive funding for decarbonisation.

4. **Transformational investments are needed to move towards low-carbon practices at scale.** Tremendous investments will be needed to decarbonise steel, aluminium, and mining, starting with the necessary expansion of renewable energy. Policymakers must be prompted to establish funding programs, grants, subsidies, and low-interest loans specifically targeted at supporting the adoption of low-carbon solutions across sectors. Additionally, policymakers should consider providing tax incentives and fiscal benefits to companies in hard-to-abate industries that invest in low-carbon technologies, like those created in the 2022 Inflation Reduction Act in the United States and the European Union's Green Deal. Given the substantial amounts of financing required, companies could also consider adopting the issuance of green bonds to drive green investments.
5. **More funding of research and development is needed.** Governments can support the adoption and advancement of low-carbon technologies by further increasing the funding and incentives for green technology-related research, patents, and piloting. Additionally, international platforms and forums need to be expanded and supported to bolster progress and joint problem solving. Research-focused collaborative partnerships, whether among companies within the same industry or across different sectors, also play a pivotal role. These partnerships can enable organisations to harness their collective research and development capabilities, contributing to the advancement of technologies, accelerating learning, and successfully executing emissions abatement pilot projects. This collaboration can also help to build markets for the new low-carbon products.

The outcomes of the collaborations as part of this Sustainable Markets Initiative working group illustrate the collective commitment from hard-to-abate sectors to establish strategies for reducing emissions. However, the outcomes formed during this process are a double-edged sword: On one hand, they highlight the potential for significant progress, but on the other hand, they underscore the challenges of achieving widespread decarbonisation across industries.

The calls to action are an effort to emphasise some of the changes needed to expedite an effective transition across the three industries.

Steelmakers, aluminium producers, and miners cannot change their industries alone. While industry players know what key challenges need to be addressed and how this could potentially be done, we now must create the right incentive mechanisms, financial support, and technological development to accelerate decarbonisation.

Acronym table

APAC	Asia-Pacific region
BF-BOF	Blast Furnace-Basic Oxygen Furnace
CCU	Carbon Capture and Utilisation
CCUS	Carbon Capture, Utilisation and Storage
CO₂	Carbon Dioxide
DRI	Direction Reduction Iron-Ore
EAf	Electric Arc Furnace
EU	European Union
EUROFER	European Steel Association
EV	Electric Vehicle
GHG	Greenhouse Gases
GWh	Gigawatt hour
HBI	Hot Briquetted Iron
IAI	International Aluminium Institute
IEA	International Energy Agency
JSA	Joint Study Agreements
kWh	Kilowatt hour
LNG	Liquefied Natural Gas
MEA	Middle East and Africa
MW	Megawatt
p.a.	Per annum
PFC	Perfluorocarbon
PPA	Power Purchase Agreement
PSA	Pressure Swing Adsorber
PV	Photovoltaic
ROI	Return on Investment
SMR	Steam Methane Reformer
tCO₂e/t	Tonnes of carbon dioxide equivalent per tonne
tCO₂-Eq/tAl	Tonnes of carbon dioxide equivalent per tonne of aluminium

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Endnotes

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The decarbonisation of the mining sector and the value chains that our products feed into is a complex challenge. However, given the central role many metals and minerals play in providing the foundations and technologies for a low-carbon future, it is a vital task. It involves the efforts of individual companies to set and take ownership of their own decarbonisation ambitions, but crucially it also involves consistent as well as creative partnerships along and across value chains, including the steel value chain. Some of these partnerships build on existing relationships, but the Sustainable Markets Initiative provides a breadth and diversity of membership, which is unique. Working in multi-company partnerships is novel and complicated, but such creativity will surely play a vital role in delivering a low-carbon world.



Decarbonisation of hard-to-abate sectors requires collaboration at an unprecedented scale to innovate, accelerate, and help deliver a more sustainable future. Through its work, the Decarbonising Industry Working Group within the Sustainable Markets Initiative's Energy Transition Task Force has sought to stimulate that collaboration – bringing together companies across the energy, technology, and industry sectors to try to solve some of the toughest decarbonisation challenges in steel, aluminium, and mining.

bp is grateful for the openness and commitment of the members of this workstream. Energy transition challenges were shared transparently, and all involved made the effort to look for innovative and pragmatic solutions. We look forward to watching the progress of the collaboration topics that have been identified and playing our part to help advance the energy transition of hard-to-abate sectors.



Abdulnasser Bin Kalban, Chief Executive Officer of Emirates Global Aluminium, said: "Aluminium is an essential material for decarbonising other industries, from electricity generation to transport. Decarbonising aluminium production requires cooperation across industries. This is why EGA is participating in the Sustainable Markets Initiative's Energy Transition Task Force and the Decarbonising Industry Working Group. Our first goal with this cooperation is to find ways to decarbonise our alumina refining. Full electrification of calcination at the scale of EGA's operations has never been achieved before. We have already made progress. I am confident that by working with members of the group and others, we will solve this challenge in the coming years."



We need to build markets that work for our planet and its people. The Sustainable Markets Initiative brings businesses together and provides an opportunity for the private sector to deliver the necessary change. Industry needs to decarbonise quickly in line with net zero and this workstream is making progress towards meaningful change in this area. We support the work of the Decarbonising Industry Working Group and are committed to unleashing clean power for industrial uses.

Ørsted

As one of the world's leading renewable energy companies, Ørsted is committed to creating a world that runs entirely on green energy. Currently, around one-third of global carbon emissions come from industry and heavy transport, so the decarbonisation of these hard-to-abate sectors will be essential to delivering net-zero targets and meeting global climate goals. While we have the technology to produce green hydrogen and green fuels to decarbonise these sectors, there remains some key challenges including combining and scaling these solutions and making them cost-competitive. This guide provides insight into how we might meet these challenges and provides concrete solutions to successfully decarbonise our economy and enable a successful transition to net-zero emissions by 2050.

SIEMENS ENERGY

Energy is the foundation for social development, economic growth, and prosperity. Tackling the energy transition means tackling multiple sectors causing global greenhouse gas emissions in parallel to achieve the implementation of the Paris Climate Agreement in 2015 and its long-term goal.

The Sustainable Markets Initiative is an outstanding initiative for all affected industries not only for discussion, but rather to partner and act together as a community of leading companies across the value chain with a strong will to make a change: In concrete projects with defined actions, joint implementation and thus creating blueprints for energy-intensive industries considering the perspectives of the energy consumer, the energy provider, and the technology provider.

It is time to act. Only concrete and actionable measures will drive the desired change. In the words of Antonio Guterres, secretary-general of the United Nations, "leaders must lead, no more waiting for others to move first." As Siemens Energy we are delivering our share to shape and drive the energy transition – as an integrated energy technology company.

TATA STEEL

Tata Steel has been a part of the Energy Transition Task Force of the Sustainable Markets Initiative and primarily got engaged in the activities related to decarbonising the steel industry in this working group. Engaging consultant Oliver Wyman with contribution from Masdar and other members has been helpful to bring all partners in the discussion forums to exchange ideas regularly and easily. The How-To Guide for this Decarbonising Industry workstream is a well-made report which we believe will be very useful for industries engaged in the journey of reducing carbon emission.

The Sustainable Markets Initiative has provided a platform for Tata Steel to discuss novel decarbonisation initiatives for low-carbon steel production. We have plans to invest substantially in such technologies during this decade so that low-carbon steel can integrate into our commercial production beyond 2030. We have had ample opportunities to engage with diverse partners and understand their perspectives on green hydrogen, green energy, and carbon capture, utilisation and storage (CCUS). The Sustainable Markets Initiative's efforts to bring together energy and manufacturing companies with a focus on decarbonising industry will facilitate long-term collaboration and drive sustainable industrial growth in the future.

ReNew

Decarbonisation of the hard-to-abate sectors is perhaps the most difficult challenge facing the industrial net-zero plan. The lack of first movers for such decarbonisation initiatives is a big bottleneck. The Sustainable Markets Initiative, therefore, is playing a very important role by getting together companies to set up pilot programmes, that will eventually help create the right signals for both the demand and supply of low-carbon/near-zero solutions.

ReNew benefits by being part of this initiative both as an infrastructure-intensive company that is a user of these carbon-intensive products such as steel and cement. As well as a decarbonisation solutions provider that helps other companies achieve their net-zero agenda. It is encouraging to see the participation of the working group, which includes other leading global organisations. We look to engage meaningfully with the group and deliver outcomes and solutions that could be scalable in the future.

RioTinto

The mining industry produces materials essential to the energy transition: Copper, aluminium, critical minerals, and even steel all have a role to play. At Rio Tinto, we have put climate change and the low carbon transition at the heart of our strategy. We are working hard to decarbonise our operations, to reduce Scope 1 and 2 emissions by 50% by 2030, and achieve net zero by 2050. Meeting this challenge is not easy, and we cannot do this alone. We must work with our customers, communities, host governments and other external stakeholders to achieve our shared goals. The Sustainable Markets Initiative creates an opportunity to bring together others in hard-to-abate industries, to leverage their knowledge, to find innovative solutions for meaningful, positive, sustainable change at pace.



Sustainable Markets Initiative