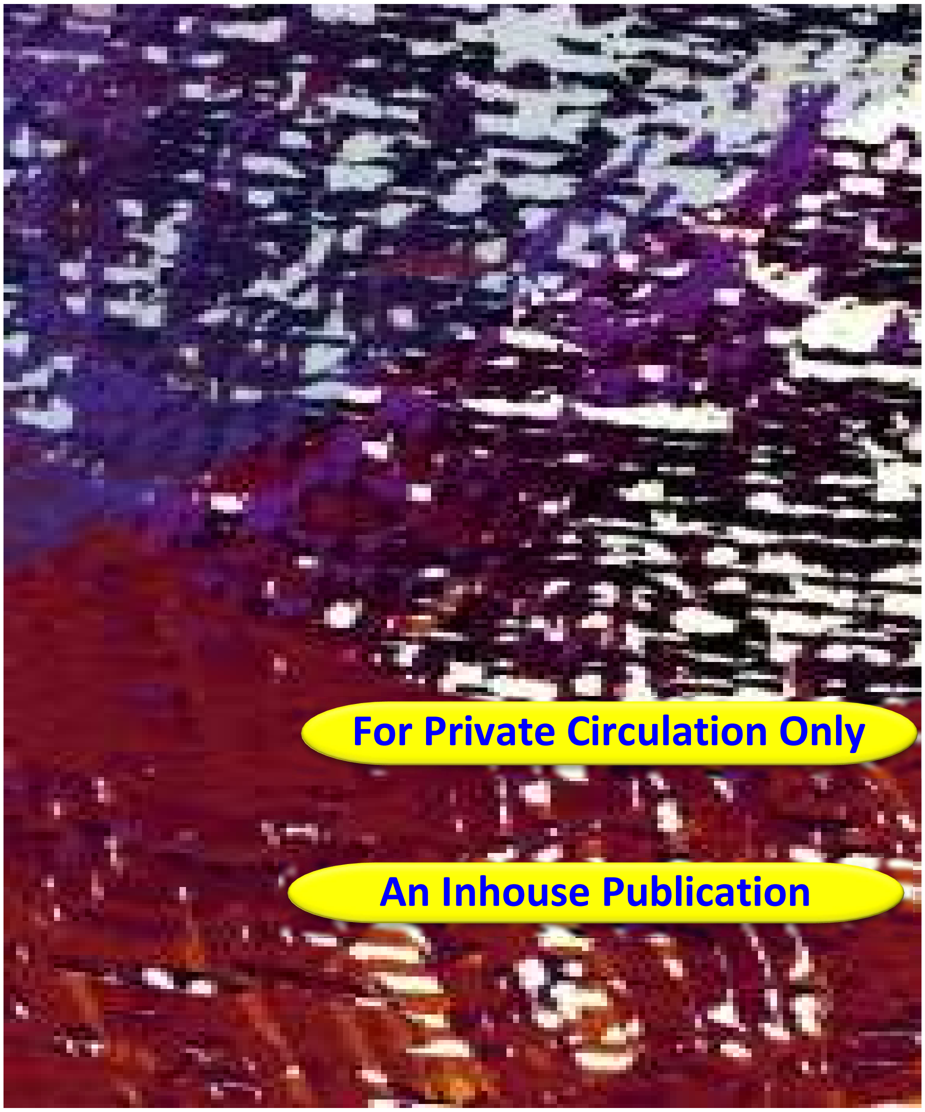
Met-Info



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Symposium on Artificial Intelligence/Machine Learning and Multiscale Modelling for Materials Discovery

IIT Delhi in collaboration with IIM Delhi Chapter is organising a symposium on Artificial Intelligence / Machine Learning and Multiscale Modelling for Materials Discovery on 26th & 27th April 2025 at Research & Innovation Park, IIT Delhi.

Members may like to participate in the Symposium.

Separately a mail has been sent to all the members in this regard.

Interaction with Dept. of Material Science & Engineering, IIT Delhi

Shri L Pugazhenthy, ED, India Lead Zinc Development Association and Past President of IIM, , Brig. Arun Ganguli (Retd.), Secretary General, IIM and Shri R K Vijayavergia, Chairman, IIM Delhi Chapter, along with some members of the Chapter visited Dept. of Materials Science & Engineering, IIT Delhi on 25th March 2025 for interaction with faculty members and students and to promote membership of IIM.

Shri L Pugazhenthy gave a talk on *ZINC & LEAD INDUSTRY IN INDIA - AN OVERVIEW*.

Brig. Arun Ganguli (Retd.) spoke about the importance of student membership of IIM and the incentives available to student members of IIM. It was also proposed to start a Student Chapter of IIM at IIT Delhi.


Circular Economy - Lead
NEW BATTERIES
NATURAL ORE
EXTRACTION
BATTERY MAKING
PRIMARY LEAD
APPLICATIONS
ALLOYING
ALLOYING
DISPOSAL
RECYCLED LEAD
BATTERY MAKING
RECYCLING
RECYCLING
NEW BATTERIES
OLD BATTERIES
DISPOSAL
APPLICATIONS
LEAD – Ideal Example for Circular Economy
LEAD – Most Recycled Material Globally
ILZDA
ORIGAMI

Shri R K Vijayavergia briefed about the activities of IIM Delhi Chapter undertaken in 2024-25 and plan for 2025-26. There was a lively interaction with IIT Delhi faculty members and students.


IIT-DELHI
DMSE


Departmental Seminar
IITD – IIM Delhi chapter student interaction session
IIM
DMSE Committee Room

How Copper Will Shape Our Future?

Copper has shaped human history and civilisation for millennia. In the 20th century, the story of copper was inextricably linked to the rise of electricity demand. As we harnessed electrical power, copper became an indispensable material, crucial to our energy systems and modern technology.

Through the 21st century, we expect copper to remain an essential building block to modern life as the world seeks to improve living standards for billions of people, transitions towards a net zero greenhouse gas (GHG) emissions economy, and further digitalises its industries and societies.

- *Global copper demand will grow by around 70% to over 50 million tonnes (Mt) a year by 2050. Copper's role in multiple applications will provide demand resilience.*
- *The looming global copper supply challenge as existing copper mines age, with the pipeline of potential projects less healthy than in previous cycles. Both brownfield and greenfield projects are expected to face cost and stakeholder challenges.*

Demand

Total global copper demand has grown at a 3.1% compound annual growth rate (CAGR) over the last 75 years – but this growth rate has been slowing. It was only 1.9% over the 15 years to 2021. Looking to 2035, however, the growth rate is expected to jump back to 2.6% annually.

This reversal will come from a combination of three key themes: *'Traditional' economic growth*, and the newer themes of the *'Energy Transition'* and *'Digital'* (primarily data centres).

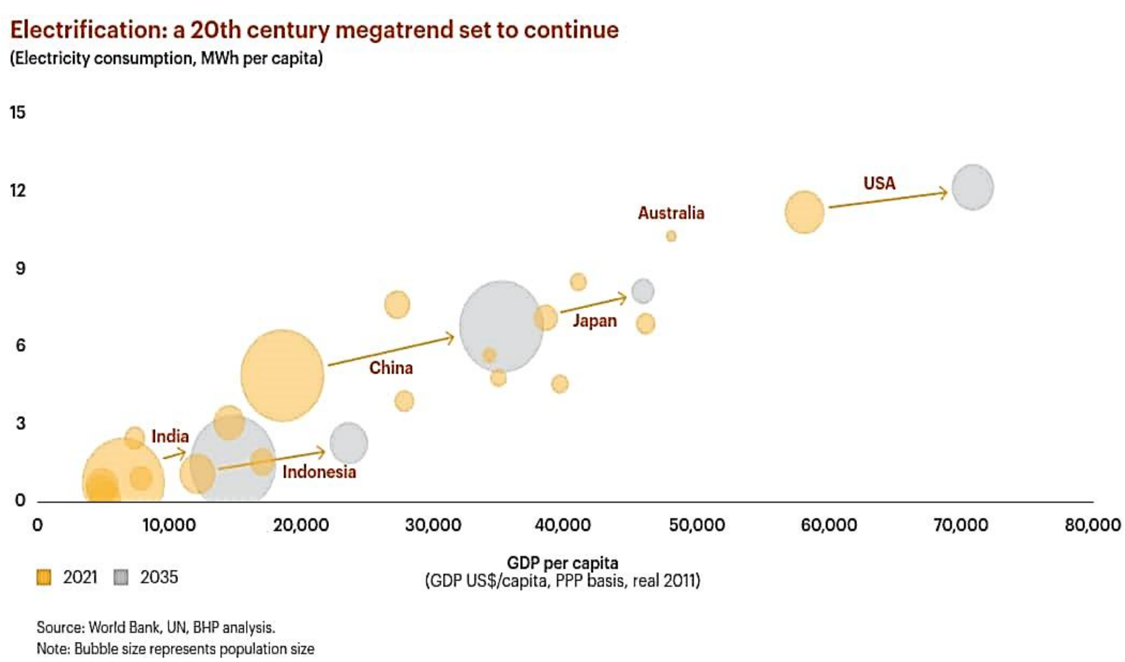
'Traditional' demand refers to the basic relationship between economic growth, electricity consumption and copper. Through the 20th century and into the 21st, as countries developed, electricity became accessible to industry and homes and led to the creation of products that lifted living standards: lighting, washing machines, refrigerators, air conditioners, radio and television, computers and smartphones. It is not only these products that need copper; so do the factories and supply chains that produce and deliver them, and the power infrastructure keeping them all

running. Copper's broad application across multiple end-uses has made it resilient and less-exposed to single point failures of demand.

Traditional demand in the developed world is expected to remain strong and as living standards rise globally, the demand for copper is expected to follow suit. Developing economies, which have nearly five times the population of high-income economies, will increasingly strive to achieve the same high standard of living. This transition will lead to a greater need for copper.

Take China for example, despite its enormous appetite for copper over the past two decades, it still only has half of the copper accumulated stock-in-use per capita (e.g. buildings, machinery, vehicles) compared to a developed economy, at around 100 kilograms per capita. India, the other major economy with over one billion people, also has a compelling copper story. India's electricity consumption per capita currently stands at around one-seventh of Japan's and one-fifth of China's, and it is expected that copper demand will grow five-fold over its pre-Covid volumes in the coming decades as electricity is made more accessible.

This *traditional* demand provides a solid foundation, but it does not account for the rapid acceleration of growth expected in the decades to come. That will be driven by the '*Energy Transition*' and '*Digital*' trends.

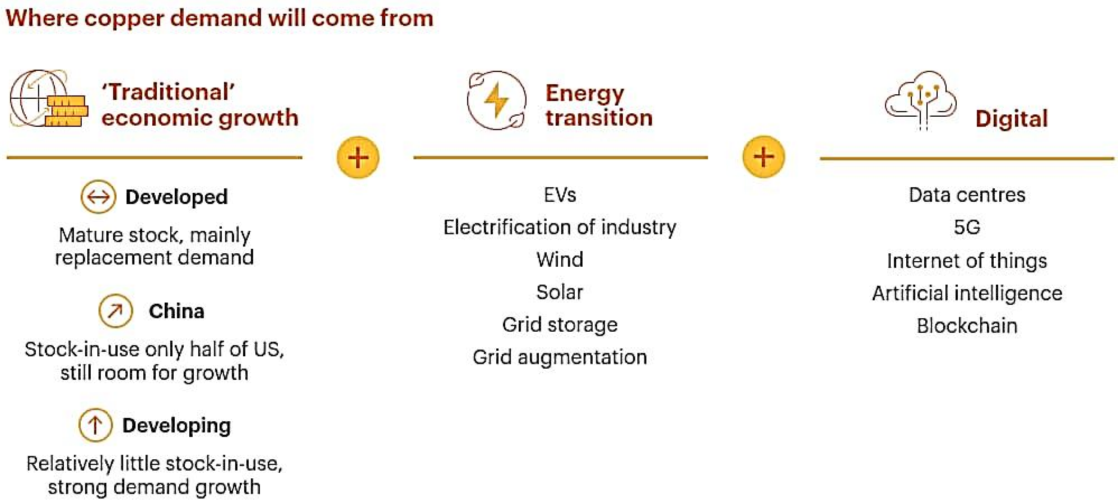


Since the Industrial Revolution, the use of fossil fuels has helped the world unlock greater levels of productivity. As the world seeks to rein in the use of these fuels (and their related carbon emissions), it will need more electricity (mainly from renewable sources) to keep everything running. Most energy modellers agree that electrification will be a major enabler of the decarbonisation of transport, buildings and large parts of industry. Under our base case, we see electricity demand roughly doubling from today to 2050, as electricity's share of total energy consumption also doubles to around 40% by 2050.[2]

'Energy Transition' copper demand refers to the additional copper required to achieve that level of electrification. As the most conductive industrial metal, copper is a key enabler of low GHG emissions energy sources, such as wind, solar, and hydro, as well as electric vehicles (EV) and batteries. An EV, for example, uses around three times more copper than typical internal combustion engines (ICE). As the energy transition unfolds, we anticipate the roll-out of EVs to lift the transport sector's share of total copper demand from around 11% in 2021, to over 20% by 2040.[3] Copper is also needed for energy efficiency and conservation measures, such as smart grids, LED lighting, and heat pumps. On top of this, the generation and transmission of low GHG emissions electricity is expected to require more copper than conventional fossil fuel power generation.[4]

'Digital' demand refers to the growth from the expected ramp-up in demand for digital infrastructure, as the world creates and consumes massive amounts of data, enabled by copper-hungry data centres. Artificial Intelligence (AI)-enabled technology requires vast amounts of data and processing capability, which in turn needs larger and faster computers consuming more electricity. We expect global electricity consumption for data centres to rise from around 2% of global demand today, to 9% by 2050, with copper demand in data centres increasing six-fold by 2050.[5]

Today, we estimate that the Traditional vs Energy Transition vs Digital split of global copper demand is around 92%/7%/1%. By 2050, we predict the split to have evolved to 71%/23%/6%.[6]



Towards 2050

What is unique about the next 25 years is the way copper demand from electrification, decarbonisation and digitisation will cut across high, middle and lower-income economies alike. Unlike the 20th century, where the adoption of cars, electricity, consumer electronics and white goods occurred at different times across various regions, we expect to see more-or-less concurrent adoption of the copper-intensive technologies of EVs, renewables and data centres around the world.

There will be some balancing factors for this significant growth in copper demand, such as from substitution and thrifting, which have been a feature of the copper industry throughout its history.

- Substitution refers to the replacement of copper by other materials, such as aluminium, plastics, or fibre optics, which can be cheaper, lighter, or more efficient for certain applications. (Or in some cases, the adoption of a different technology with a lower copper content.)
- Thrifting refers to the reduction of copper content or usage in products or processes, while maintaining functionality, through design improvements and technological innovations.

When it comes to copper-to-aluminium substitution, many have long held to the 'three to one' rule of thumb: when the copper price is more than three times the price of aluminium, you will start to get increased levels of substitution. More recently, some estimates have adjusted this ratio higher, to around 3.5 times.

However, the copper-to-aluminium ratio[7] has been in excess of 3.5 for much of the past five years, supporting the belief that the price ratio needs to be higher still, at around 3.5 to 4 times, before you see greater levels of substitution.

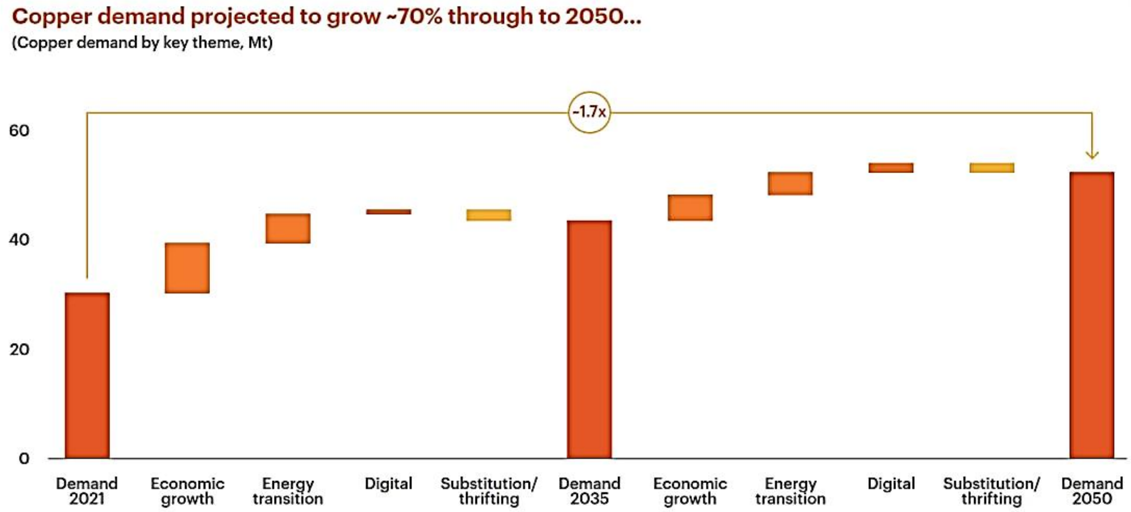
It is not just about cost either. Substitution and thrifting require design alteration, product line modification and investment in new equipment, and worker retraining. And uptake relies on customers believing the product works as well or better than what they can access today. None of these things happen quickly, especially in the well-established 'traditional' end-uses. The sectors that are most exposed to substitution and thrifting are those driving demand in the Energy Transition segment. These new technologies are still undergoing evolution and development, and each iteration presents a new opportunity to reduce copper use – up to a certain limit.

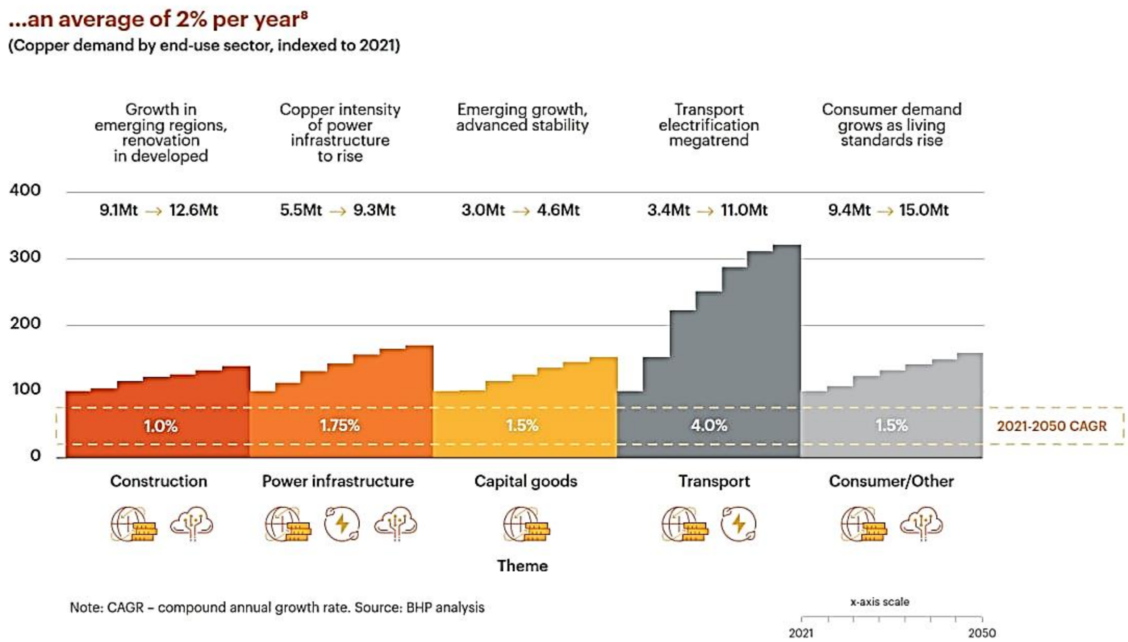
We also believe copper has some unique advantages that make it difficult to substitute or thrift in many end-uses, such as its conductivity, durability, recyclability and antimicrobial properties. This is why it remains widely used, despite potentially cheaper options being available. Copper also has a smaller GHG emissions intensity[8] footprint than aluminium, which may be a relevant factor when choosing materials in the future.

While we expect substitution and thrifting will rise from current levels, this should be a gradual process, as has been observed over the past century.

Putting all these levers together, we project global copper demand to grow by around 70% to over 50 Mt per annum by 2050 – an average growth rate of 2% per year.

Due to the concurrent adoption of new copper-intensive technologies, as well as support from the broad-based 'traditional' development across end-uses in emerging economies, we anticipate a re-acceleration of copper demand to 2035 of 2.6% CAGR, versus a 1.9% CAGR over the past 15 years. In absolute terms, this is roughly 1 Mt copper demand growth per year, every year, until 2035 – double the 0.5 Mt annual growth volume of the past 15 years.



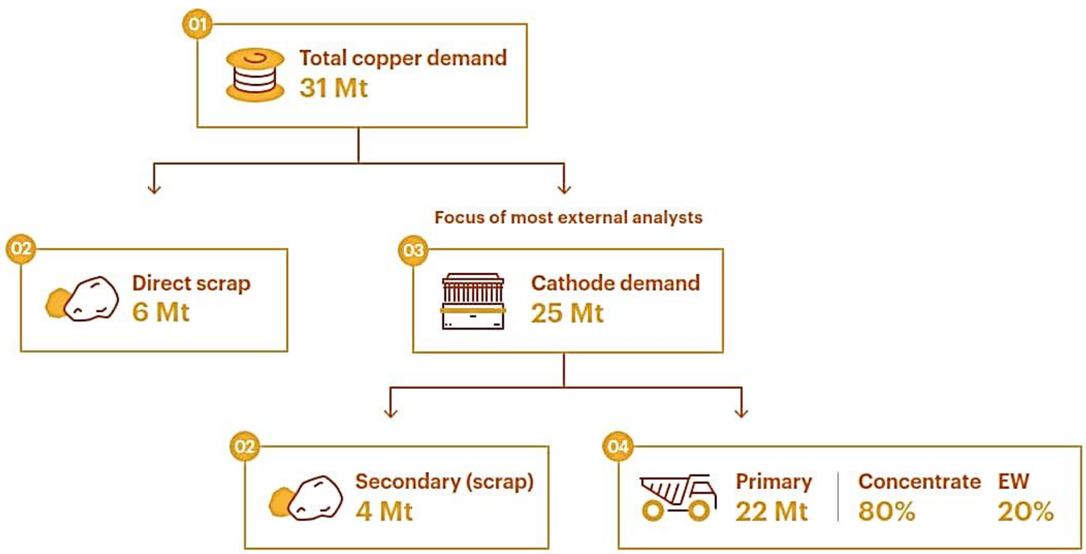


Supply

As with demand, there are different drivers of copper supply. First and foremost, primary supply comes from mines and processing facilities such as those that BHP operates.

But secondary, or scrap, copper is also an important source of supply. Copper can be recycled from end-of-life products ('old scrap') or from waste generated in the manufacturing process ('new scrap'), reducing the need for primary copper from mining.[9]

What do we mean by the copper market?



01. Total copper market

The total copper market refers to the copper units required to satisfy global semi-fabricated products (semis) demand, which is categorised as wire (rod), tubes, plates, sheets, strips and foils, bars and sections, powders and flakes.

02. Recycled sources

During the last decade, more than 30% of annual copper use came from recycled sources. The Fraunhofer Institute estimates that two thirds of the 550 Mt of copper produced since 1900 is still in productive use.

Scrap markets are quite opaque, resulting in most people focusing on the refined copper market.

03. Cathode

Copper cathode (refined copper) is produced by one of two process routes, pyrometallurgical (dry) or hydrometallurgical (wet).

Smelting (pyrometallurgical) is a process of heating and melting copper concentrate to remove impurities, resulting in product that is 98.5–99.5% copper.

Refining refers to any process that increases the grade or purity of the metal. After completing refining processes, copper cathode is generally 99.99% pure—this is the product that can be delivered into exchange warehouses, including the LME.

The **refined copper market** is often the focus most analysts, given its relatively higher level of transparency.

04. Primary copper production

Primary copper production starts with extraction of copper-bearing ores. These ores are processed into either concentrate (for smelting/refining) or directly to cathode.

Copper concentrate is produced using a froth flotation process, separating copper-bearing minerals from ore after grinding into small particles. This process is mainly used for sulphide ores.

Cathode is also produced at the mine from the hydrometallurgical processes known as leaching and solvent extraction/electrowinning.

Notes: CY23 volumes. Numbers may not tally due to rounding. EW means electrowon production (includes SxEw, and other leach production from DRC). The terms Direct and Secondary Scrap relate to where the copper scrap is used, while the terms New and Old Scrap relate to where the scrap is sourced. Refer to the Appendix for further information.
Source: ICA, IWCC, ICSG, BLC, CRU, Wood Mackenzie, BHP analysis.

Scrap and recycling

Recycled copper is expected to be an important source of supply to meet the large copper demand growth over the next 30 years. The main barrier to recycled copper supply is the availability of scrap.

The pool of 'old scrap'[10] is principally determined by the average lifetime of an end-use product. These lifetimes can range from weeks or months for some consumer products (e.g. from batteries, headphones, charging cables) up to several decades (e.g. from construction and infrastructure). We assess the average life of copper in-use to be around 20 years.

Much of this ‘old scrap’ is also not recovered. We estimate that in 2021 only 43% of available ‘old scrap’ was collected and recovered for re-use, falling to 40% in 2023 as lower prices, slowing economic activity and regulatory changes acted as headwinds. Rising ‘scrap nationalism’ to preserve the local use of secondary material and restrictions in cross-regional waste trade have also acted as a drag on growth for global scrap collection and recovery[11] (and may affect the availability of scrap in developing countries who have not yet built up their own substantial pool of copper in-use).

Nevertheless, we expect the increased focus on copper as a critical or strategic raw material will lift copper scrap collection and recovery rates from their current levels to 56% by 2035 and even higher longer term.[12]

With the growing scrap pool, we estimate that scrap supply will increase from around one third of global copper today to around 40% by 2035, and reach around a half of total copper consumption by 2050.

But even with this increasing use of copper scrap, we still expect more primary, or mined, copper will still be required when you add grade decline and mine depletions on top of this.

We estimate that the world will need about 10 Mtpa new mined copper supply[13] in the next 10 years.

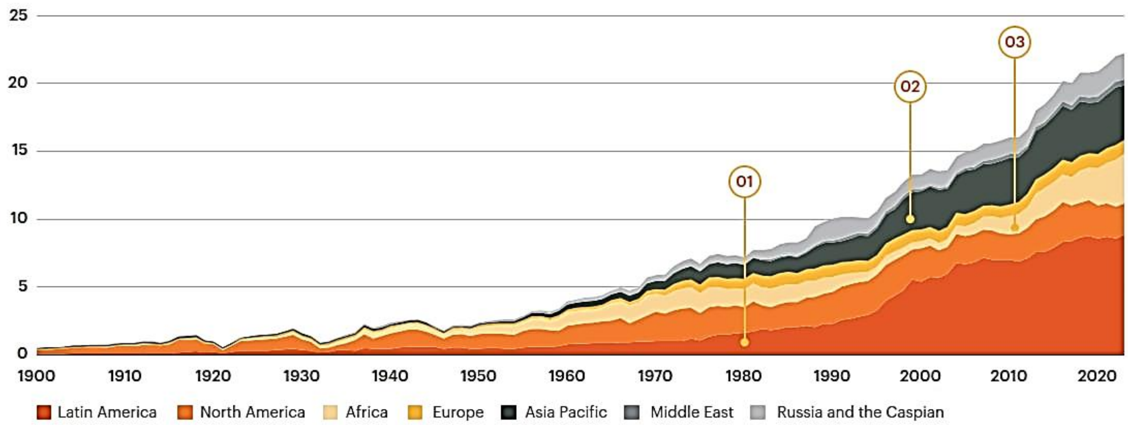
Where will it come from?

Mine supply

Copper reserves and production are concentrated in Latin America, Australia and Africa. The last 30 years has seen impressive supply growth globally, with production doubling to around 22 Mtpa today, primarily due to increases from Latin America (particularly Chile), the Asia Pacific region and Africa (over the last 10 years). This has been achieved through significant investment in greenfield projects and the wide-spread adoption of the leach-solvent extraction-electrowinning (SxEw) process from the mid-1980s, which unlocked previously uneconomic copper supply low grade oxide ores. This process now accounts for 20% of mine supply.

The industry’s current challenge is to repeat this substantial volume growth in less than half the time.

Mine supply has grown sharply in recent decades—primarily from Latin America, Africa and Asia Pacific
(Primary copper supply by region, Mt)



Source: Wood Mackenzie, BHP analysis.

01. Latin America

- After nationalising its copper industry in the 1970s, Chile reopened for international investment in the 1980s and adopted pro-mining policies.
- Wave of new copper mines developed in the 1990s.
- Rapid deployment of SxEw in 1990s.
- Incremental growth post 2010s, mainly from Peru.

02. Asia Pacific

- Growth from multiple projects across the region—Australia, Indonesia, PNG and Mongolia.
- Chinese domestic copper production included.

03. Africa

- Underinvestment and civil unrest led to collapse in production late 1990s to early 2000s.
- Production has recovered in the past decade, backed largely by Chinese investment.

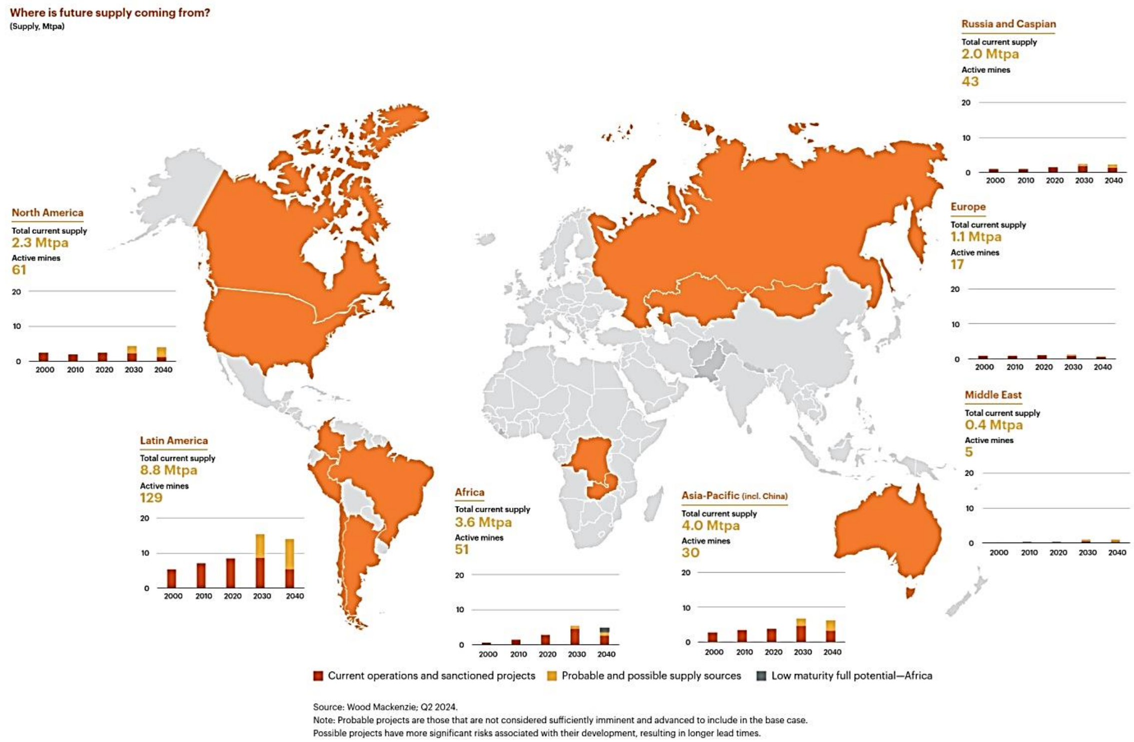
We expect supply growth over the next 10 years to be dominated by the same regions – Latin America Africa and Asia Pacific – with Africa having the highest growth rate (albeit off a much lower base than Latin America), and Latin America continuing to make the most significant contribution in absolute terms.

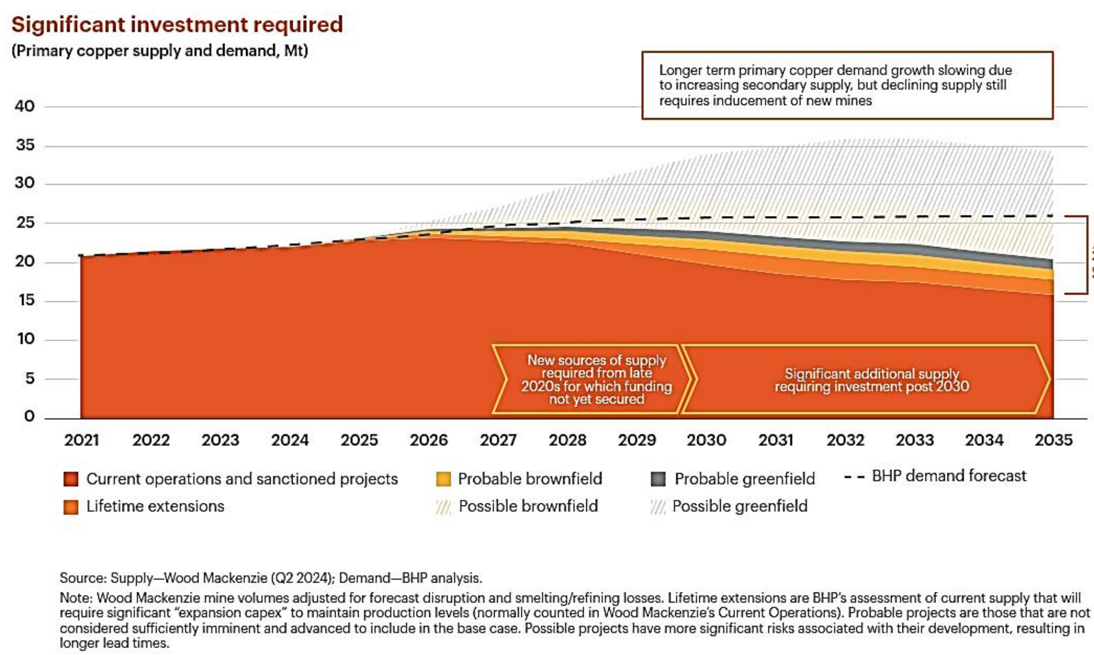
Against optimistic supply forecasts, which include the development of all probable copper projects, a significant gap to expected demand in 2035 is evident, even with our positive view on copper scrap supply.

Current mine supply

Currently operating copper mines are expected to provide more than half of the copper required to meet future global demand over the next decade. Even so, we estimate existing mines to be producing around 15% less copper in 2035 than they do today.[14]

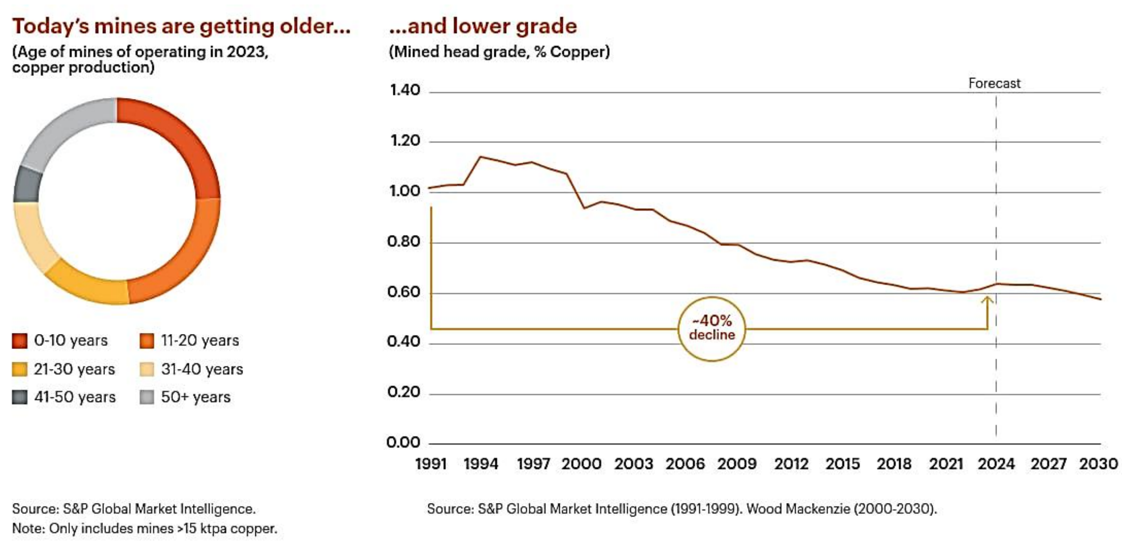
These mines are already mature and are likely to need additional capital investment to replace or upgrade aging infrastructure or processing facilities. Alternatively, they may take advantage of new technologies that can improve their efficiency or recovery (e.g. converting oxide leaching plants to sulphide leaching, or recovering copper from waste). They are also likely to need to comply with new and higher standards when renewing or extending permits and licences to meet the evolving expectations of communities, customers and regulators.





Existing copper mines also typically face declining grades, as higher grades are usually mined first, and lower grades are left for later. We estimate the average grade of copper mines has declined by around 40% since 1991. This is partly explained by processing advances, such as SxEw, which have improved the economics of lower-grade deposits and brought them into production. Declining grades also means that more ore needs to be mined, processed and transported to produce the same amount of copper. Without technological advancements, grade decline is likely to further increase production costs on a unit of output basis.

This trend may also increase potential environmental and social impacts, due to increased material movement if throughput is increased to maintain production levels.



It is expected that between one-third and one-half of global copper supply to face grade decline and ageing challenges over the next decade, which will drive increased unit costs and the requirement for capital reinvestment. While an incredible orebody can make a big difference, many older operations move up the cost curve as they progress through their life cycle. Given the strong demand signals, however, we expect the industry to vigorously pursue options to extend the life of these copper mines.

One way of overcoming these challenges is with technology. We see examples of incremental productivity improvements from AI-enabled insights in processing, the repurposing or reinvigorating of older facilities with latent capacity, and adoption of new technologies to improve leaching. But it will be difficult to see the impact of these technologies becoming widespread until at least the mid-2030s. Research and development of innovative sulphide leaching technologies is continuing and we expect to see test work and pilot projects improve understanding of their potential. This will allow the industry to evaluate their true capital requirements, and address permitting uncertainty. But in our view, adoption of any primary sulphide leaching technologies into existing operations will need to complement existing processing infrastructure in most life extension and brownfield options, and the economic trade-offs remain unclear at an industry level. For it to be a truly disruptive technology longer term (post 2035), we would also need to see significant advances in scalability, but adoption efforts to date suggest that leaching processes will need to be tailored to individual ore bodies.

Brownfield projects

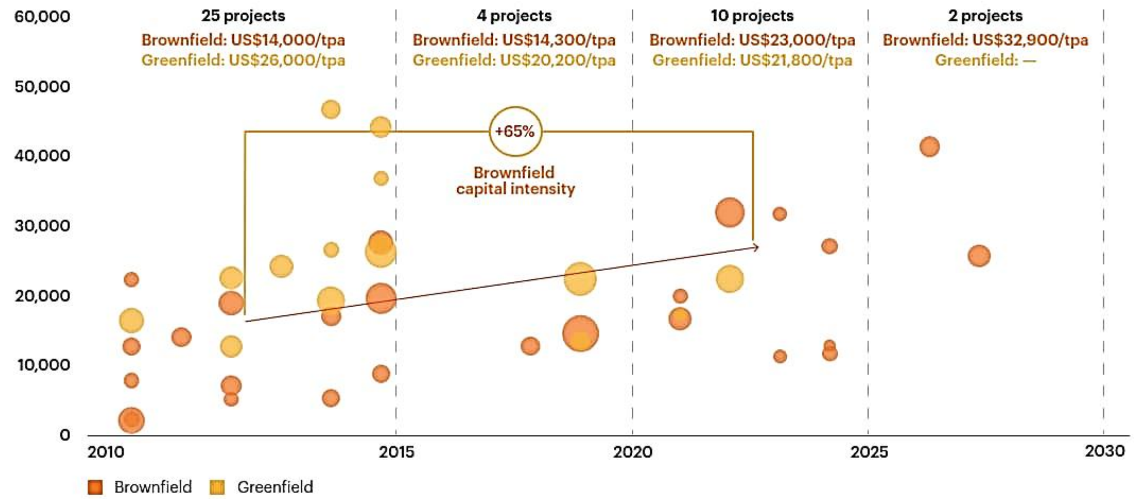
For current operations with significant resources remaining, brownfield developments will be an attractive response to the challenges outlined above. Based on our project-by-project global review, we expect new brownfield supply to contribute up to 30% of total copper supply by 2035. Today's pipeline of brownfield projects is healthy, and we see many high-quality options, particularly in Chile.

Brownfield life extensions and expansions benefit from existing infrastructure, facilities, workforce and knowledge, and usually face lower technical risk and uncertainty. However, they are not immune to changing regulatory and community expectations and standards. This can lead to increasing capital intensities, permitting delays and complexities where existing permits do not cover the full life of the project.

Our recent review of global project capital intensities shows a steady increase in brownfield capital intensity since 2010. When we look at the region with the strongest pipeline of brownfield projects – Latin America – average brownfield capital intensities for the projects sampled show a ~65% increase during that period (in 2024 real dollars), and since 2020, they have approached similar levels to greenfield projects.[15]

Steady increase in brownfield project capital intensity

(Latin American sanctioned project capital intensity, US$/tpa copper equivalent, real 2024)



Note: Sanctioned projects >50 ktpy copper equivalent. Year represents first production.
Source: Wood Mackenzie; Q2 2024. Data set adjusted by companies reports and SMI research.

While this increase has been driven by a number of factors, including higher costs for and availability of inputs (e.g. material and labour cost increases, supply chain constraints, skilled labour shortages, and Covid-19 effects), a major factor is that copper producers are, in general, simply building 'better' mines (e.g. incorporating newer technologies and addressing higher standards for health, safety and environmental performance).

Despite these cost challenges, it is expected that high-quality brownfield projects to be prized in the industry in the face of growing copper demand. While their historic cost advantages over greenfield projects are less guaranteed today than in the past, the experience, technical capability developed through years of production and detailed ore body knowledge remain as major advantages, particularly when it comes to more complex projects.

Greenfield projects

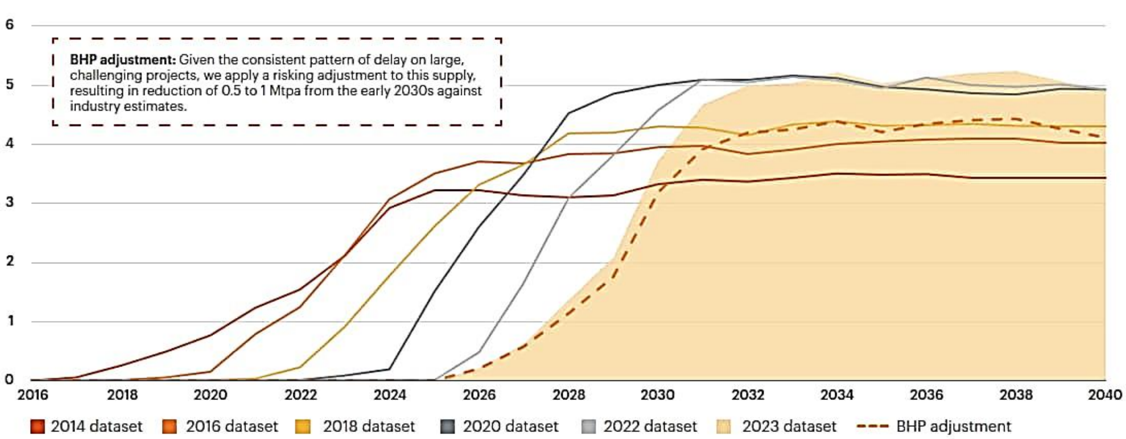
Greenfield projects continue to attract significant excitement and interest from developers and investors. They can avoid the challenges of aging facilities and grade decline and can unlock large and higher-grade copper deposits, develop new frontiers, and allow for the application of technology advances without the challenge of retrofitting.

But they also have potentially even greater challenges to brownfield developments, such as long lead times with environmental and social concerns needing to be navigated for the first time, and uncertainties associated with new jurisdictions or regions. And not all problems can be solved with money. For some projects, it is not a question of investability, but of executability.

The current pipeline of 'all possible' greenfield deposits are generally at the higher-difficulty end of the spectrum – and many are experiencing delays. When we investigated a selection of today's 30 largest (by expected production volume) undeveloped greenfield projects, we found that analysts (ourselves included) had continually moved the forecast supply stack out in time. We expect these projects to contribute around 5 Mtpa of copper by 2035, or 14% of total possible supply.

Start dates for more than 20 of these projects have shown a consistent pattern of delay since 2014, and all have been delayed in forecasts made from 2020 onwards. In 2014, the majority of these projects were forecast to be in operation by now. Given this trend, we now apply a risking adjustment to these projects, which removes between 0.5 to 1 Mtpa from our copper production forecast from 2030 onwards.

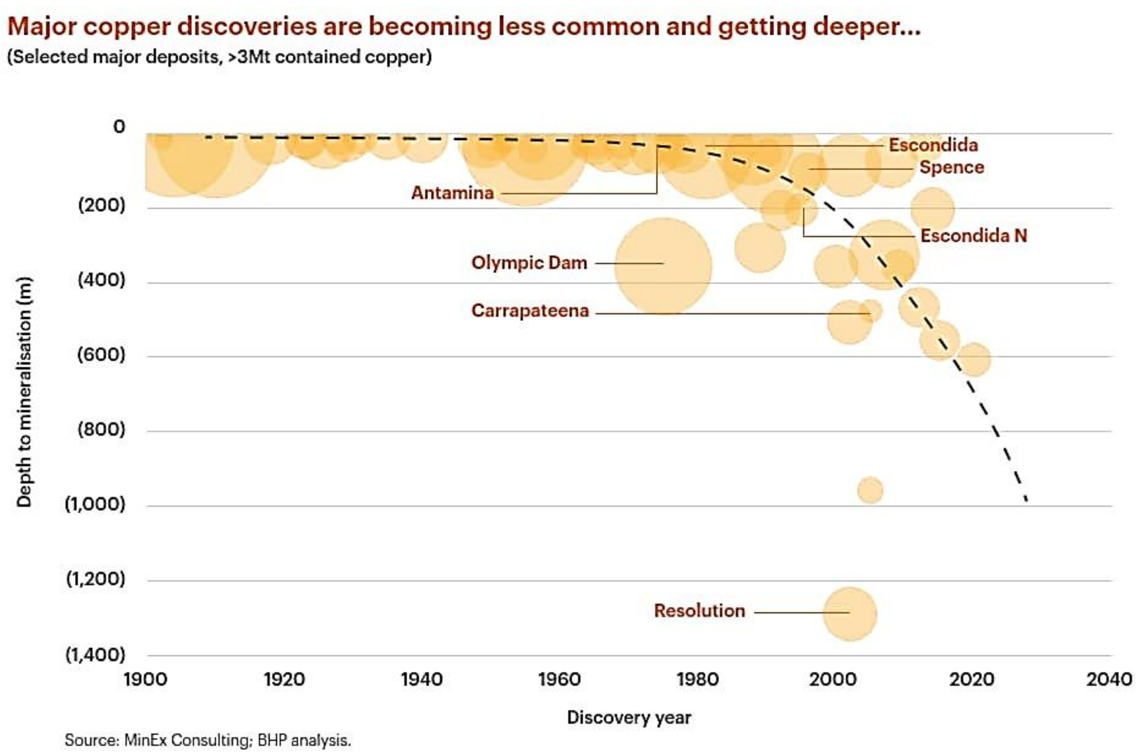
Large segment of greenfield volumes continue to be delayed
(Copper production capacity, Mtpa)



Source: Wood Mackenzie.
Note: Sample includes 30 largest (by expected production volume) undeveloped greenfield projects included in the 2023 database through time.

Those that have managed to eventually come online have still seen significant challenges on the journey. Copper mega projects (i.e. those with a capital cost more than US$5 billion) have experienced significant delays and cost overruns (e.g. QB2 and Oyu Tolgoi).

African greenfield projects, backed largely by Chinese investment, have been the exception to this global trend, delivering a 90% increase in copper production over the last decade at highly competitive capital intensities and execution rates. African deposits also make up eight out of the 10 highest grade deposits discovered since 1990. But in contrast to the porphyry-style deposits common in Latin America, in which mineralisation decreases gradually, African deposits tend to be ‘sediment hosted’, meaning mineralisation is more concentrated with sharp boundaries. This difference drives a more pronounced depletion in our African forecast. However, given recent trends in both discovery and development, we have revised upward our forecasts of expected volumes from the African region, including volumes related to projects or deposits that might, in other regions, be considered immature or insufficiently progressed to include in the forecast.



Despite the potential contribution from African copper, on balance, new greenfield supply globally will struggle to enter the market quickly and cheaply. This is exacerbated by a slowing rate of discoveries and the relatively long average time from discovery to production (17 years in 2023), which is making it less likely that greenfield developments will be able to respond to the strong demand signals.

According to S&P Global Market Intelligence's most recent annual copper discovery report, there were:

...239 copper deposits discovered between 1990 and 2023... we have recorded only four discoveries from the past five years (2019–2023), totalling 4.2 Mt of copper... Discoveries from the past decade account for just 14 of the 239 deposits included in the analysis.[16]

Capital availability

Capital availability is the other hurdle for copper developers. While challenging to model, given the project-specific nature, we estimate the total bill for all expansion capex from 2025-2034 to be around a quarter of a trillion US dollars (in 2024 real dollars). This represents a significant increase from the previous 10 years, where the total spend on copper projects was approximately US$150 billion.

In the 1990s and 2000s we saw the impact of Japanese and western investments into copper around the globe, and we have seen significant Chinese investment into African copper projects in the past decade. Political support has often accompanied such investments (in various forms), and sovereign interest in copper from other regions is growing, most notably from the Middle East and with renewed interest from the United States. Given copper's essential role in economic growth, the energy transition and digital transformation, we would expect sovereign interest and investment to continue to play a role in future copper projects.

Supply prospects are mixed

Taking all of these supply factors into account, we expect currently operating mines will need to work harder for longer, and both brownfield and greenfield projects will face cost and schedule headwinds, arising from skilled labour shortages, project complexity and higher ESG standards. Companies that can best navigate and adapt to these challenges, are experienced in managing more complex projects, and have solid social value credentials and a strong balance sheet will win.

Pricing

The copper price is driven by many factors, such as economic growth, investor sentiment, industrial activity, inventory levels, production costs, exchange rates, interest rates and geopolitical events. In the short term, the price is sensitive to changes in demand and supply, as well as to market sentiment and speculation, which can create price spikes or slumps.[17]

However, in the long term, the copper price is more determined by the fundamental supply and demand trends and drivers of the market, such as those we have set out in this blog. To narrow in on potential long-term pricing ranges, we prefer the long-run marginal cost (LRMC)-based inducement model, which seeks to identify the marginal unit of supply that will meet demand in the future, and what it will cost. It assumes new supply will be induced by a price signal that provides a sufficient return for the project. It uses a queue of projects that are ranked by their competitiveness and brings them on until future demand is met. It is the most reliable and consistent method for projecting the trend price of copper over long time periods, based on the fundamentals of demand and supply.[18]

The bullish drivers of demand (balanced by the forces of scrap, substitution and thrifting) present a huge task for copper miners. There is a shortage of 'easy' projects to replace existing supply and meet this growing copper demand. The projects that are available face new and increasing challenges that we believe will be reflected in their costs, and consequently, in the price required to incentivise their development. We think the price setting marginal tonne will come from either a lower-grade brownfield expansion in a mature jurisdiction, or a higher-grade greenfield in a higher risk and/or emerging jurisdiction. None of these sources of metal is likely to come cheaply, easily, or unfortunately— promptly.

Appendix

The chart below summarises the flow of copper units from mine through end-of-life capital stock.

References

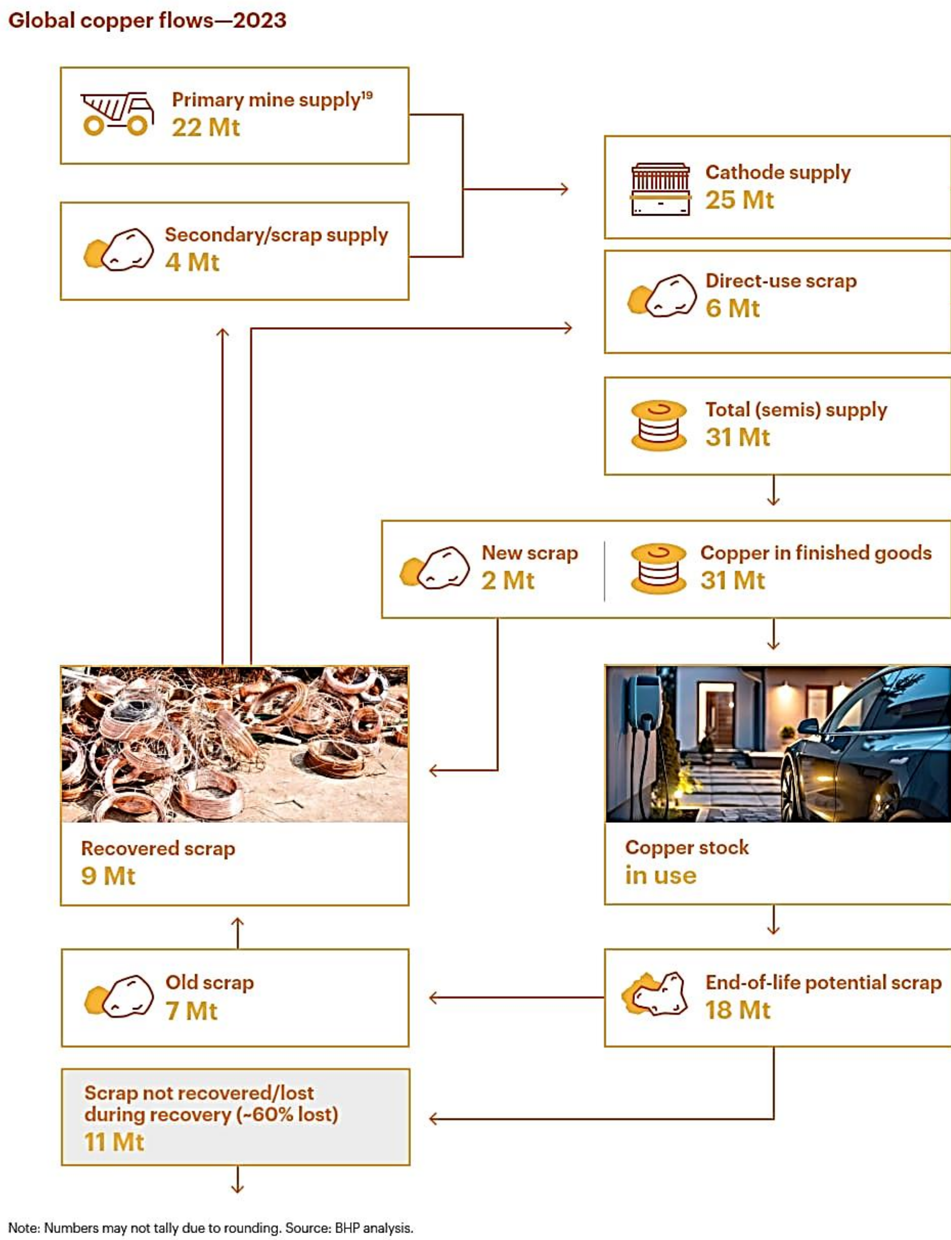
1 *Data and events referenced in this article are current as of September 2024.*

2 *Some aggressive decarbonisation scenarios come in 10 to 15 percentage points higher in terms of end-use electrification than we are assuming in the base case. For a full list of deep decarbonisation scenarios that we track, see BHP's Climate Transition Action Plan 2024 Additional information (page 62).*

3 *Forecast developed prior to the recent slowdown in EV adoption (ex-China). While the pace of adoption of EVs may underwhelm in the short term, the rationale for electrified transport remains compelling in the long run.*

4 *Offshore wind requires around 11 tonnes of copper per megawatt, or over 5 times as much as*

gas- fired power which uses around 2 tonnes per megawatt. Onshore wind and solar are also more copper-intensive, at around 1.7 and 1.4 times, respectively. In addition, the capacity factors of wind and solar power are generally lower than fossil power, which means you need to install more



renewable power capacity to generate the same amount of electricity.

5 *We estimate copper use in data centres (including those used for cryptocurrency and AI) to be around half a million tonnes of copper today, rising to around three million tonnes in 2050.*

6 *Note that Copper in power grids is counted under Traditional in the above splits.*

7 *Ratio of monthly average of LME Cash Settlement Price for Copper and Aluminium.*

8 *Global average CO2 footprint (CRU, 2021). Copper: ~4t CO2/t metal. Aluminium: ~13t CO2/t metal.*

9 *For more detail on the volumes of flows in the copper value chain, see the appendix*

10 *Please see the appendix for details of the copper cycle.*

11 Examples of policies that, while potentially positive in the long run, we believe have hindered/are hindering scrap use in the short term: China's Operation National Sword and recent review of tax and rebates ('Fair Competition Review'), EU's Regulation on Waste Shipments and Critical Raw Materials Act.

12 This assumption is underpinned by EV battery recycling targets, but also requires broader improvement in collection/recovery rates across end uses. This will necessitate changes in consumer behaviour (many consumer goods end up in landfill), as well as improvements in scrap processing and metal recovery. Recycling in many cases is labour and/or opex intensive. Current recycling rates are arguably a reflection of what is economic at current prices, so 'carrot and stick' policies will likely be required to alter behaviour and lift these rates.

13 The 10 Mtpa requirement considers: growth in primary copper demand, as well as reductions in current mine supply due to grade decline and resource depletion, and additional consideration for supply disruptions and metallurgical losses. The figure also includes mine life extensions for some currently operating mines.

14 This assumes mine life extensions and probable brownfield projects.

15 Wood Mackenzie; Q2 2024. Data set adjusted by companies reports and BHP analysis, inclusive of sanctioned projects >50 ktpa copper equivalent.

16 https://www.spglobal.com/marketintelligence/en/news-insights/research/new-major-copper-discoveries-sparse-amid-shift-away-from-early-stage-exploration

17 Refer to our 2024 Economic and Commodity Outlook for more details.

18 We recognise that LRMC has some limitations, such as being less helpful for the short and medium term, as it does not capture the cyclical and structural factors that can affect the price. This method is also sensitive to the exogenous assumptions that are imposed, such as the macroeconomic and financial variables, the return thresholds for projects, and the discrete decisions on project inducement. We also recognise that this method does not account for the possibility of price disconnecting from the cost curve, due to extreme tightness or scarcity in the market. Therefore, we also use other methods and models, such as cost-plus, historical average, substitution, probabilistic, and econometric, to complement and cross-check our price forecasts, and to generate alternative price scenarios and ranges to reflect the uncertainty and variability of the market.

Source: BHP Insights: https://www.bhp.com › news › bhp-insights › 2024/09

Tata Steel's H Blast Furnace Sets New Standards

Tata Steel's H blast furnace at Jamshedpur, marked a significant milestone in the history of steel production in India. As of January 8, 2025, this pioneering furnace has surpassed 50 million tonnes of hot metal production, becoming the first in India to do so without requiring mid-term repairs. Nearly two decades after its commissioning in 2008, the H Blast Furnace, surpassing its designed capacity by 20% every year, sets a new benchmark for operational excellence and sustainability in the Indian steel industry.

With an inner volume of 3814 m^3 and an annual production capacity of 2.5 mt of hot metal, this furnace was the largest ever built in India at the time of its construction, designed to elevate the annual production of Jamshedpur steelworks from 5.0 to 7.8 mt of hot metal. The project was completed in a record time of 25 months from the start of civil works, with successful blow-in achieved on May 31, 2008. Despite the challenge of constructing the new facility in a restricted area adjacent to the existing blast furnace, the project was executed with remarkable efficiency and optimized logistics.

The H blast furnace incorporated advanced technological solutions with a strong emphasis on energy efficiency and environmental sustainability. The design and layout were developed using a 3D design tool, ensuring reliable checks for potential interferences and detailed analyses for operational and maintenance accessibility. The blast furnace proper is equipped with a Bell Less Top® charging system, INBA® slag granulation plants to ensure efficient slag processing, an annular gap scrubber gas cleaning plant, a top gas recovery turbine (TRT), and a pulverized coal injection (PCI) plant contributing to improved energy efficiency, hot blast stoves including a heat recovery system. Finally, a flat cast house featuring TMT cast house equipment and probes addressed the operator's safety at the highest level. Top charging in ironmaking enhances the efficiency and environmental performance of blast furnaces.

The H blast furnace achieved the highest tuyere coal injection in India for nine consecutive years and has been recognized by the President of India for its energy-saving innovations. Furthermore, it has set industry benchmarks in hot metal quality, particularly in maintaining stringent control over silicon content. The World Steel Association has also highlighted the furnace's exemplary practices in process safety for two consecutive years.

Source: SMS group #Connect update - February 2025

Major Expansion Plan of Steelmaking Facility JSW Dolvi Works

Summary

- *JSW Steel's strategic expansion will increase the annual capacity of the existing steel mill by 3.7 million tons per year*
- *The expansion project involves the installation of one of India's largest BOF converters, boasting a 350-ton capacity, including twin ladle furnace and primary gas cleaning plant*
- *Comprehensive automation solutions guarantee consistent quality and production reliability*

JSW Steel Dolvi has commissioned SMS to supply a 350-ton BOF converter, including a twin ladle furnace, gas cleaning plant, and corresponding level 1 and level 2 automation. The project is part of JSW Steel's strategic expansion plans, which will increase the capacity of the existing steel mill by an impressive 3.7 million tons per annum (mtpa). Special highlights of the new BOF converter, one of the largest to be installed in India, include an advanced oxygen lance system capable of a maximum blowing capacity of 1,250 Nm^3/min, which will significantly enhance the production efficiency of the plant. The facility will also be equipped with a cutting-edge automation system, which provides users with a complete view of the plant without the need to switch between various automation levels. It will also have process optimization models that integrate process control, production strategies, and metallurgical models, thus providing consistent quality and production reliability.

In addition to the new steelmaking facilities, a new 4.5-mtpa blast furnace and a first-of-its-kind CSP® Nexus, an integrated casting and rolling mill that is capable of producing hot strip and plate with a maximum width of 2,600 milli-meters on a single plant, are also planned.

The new steel mill will go into operation in 2026.

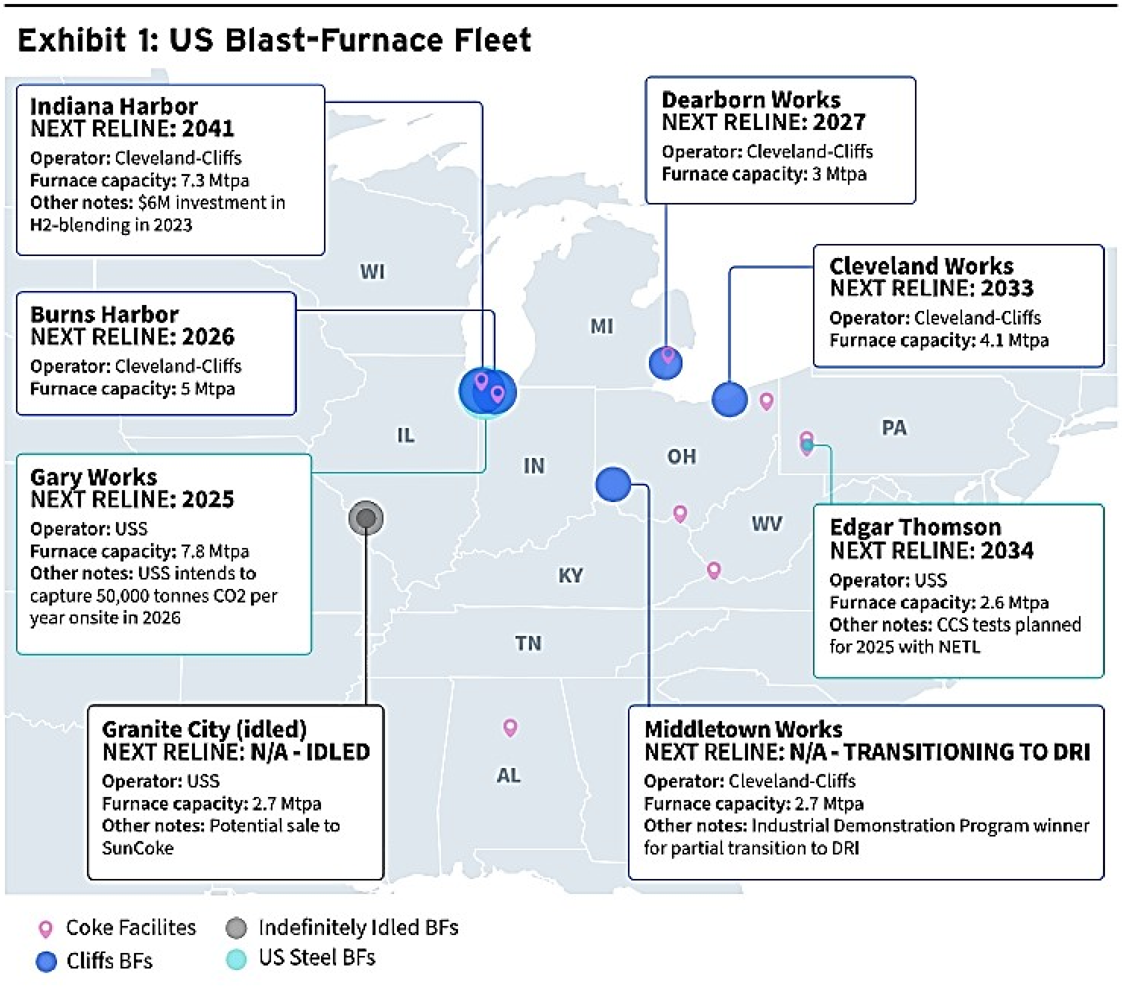
Source: SMS group #Connect update - February 2025

Reline or Revitalize: The Narrowing Window to Modernize the US Steel Industry

Investment in reviving or "relining" the seven aging blast furnaces in the Great Lakes region of US is a multi-billion dollar bet that risks continuing job decline at these assets, weakens the ability of the US steel industry to compete in the global market, and perpetuates serious health and climate emissions harm from coal-based steel production.

The remaining coal-based steelmaking assets, located in Indiana, Michigan, Ohio, and Pennsylvania, collectively account for 31% of domestic production and together employ 18,000 workers.

Although the seven remaining coal-based blast furnaces represent only about a quarter of US steel production, these plants generate approximately 75 percent of the industry's emissions. Continuing business-as-usual operations at these sites for the next few decades risks blowing past the domestic steel industry's carbon budget by nearly two-fold.



Blast furnaces nearing end-of-life typically require up to $400 million in reinvestment to extend their operations for another 20 years. Several — including Gary Works, Burns Harbor, and Dearborn Works — are facing this decision before the end of this decade. These reinvestment deadlines represent a window of opportunity to avoid stranded assets and pivot toward more modern, cleaner technologies that are more competitive in the long run. The accelerating US clean energy transition has led to a surge in market demand for low-emissions products, driving shifts in domestic production and manufacturing. These shifts, combined with existing federal incentives, create new pressures and tailwinds for legacy steelmakers and state policymakers.

With stable jobs, climate goals, and the health of neighbouring communities on the line, fast-approaching reline dates represent a critical decision point with major implications for the future of American primary steelmaking: *lock in coal and its consequences for decades to come, or invest in a modern, cleaner, and more competitive industry for the future.*

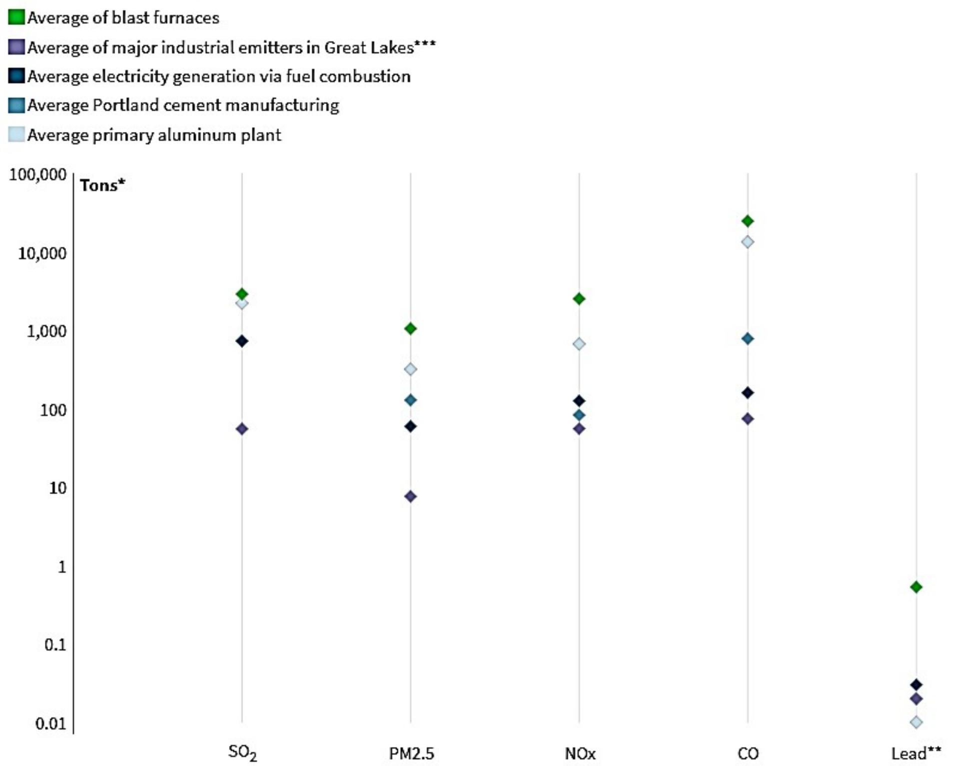
Relines place heightened pressures on steelworkers and local workforces downstream of the steel supply chain, whose jobs, families, and livelihoods rely on maintaining the historic competitiveness of the US primary steel industry. With the increase in scrap-based production and the shift of manufacturing jobs to the US South observed in recent decades, several blast furnaces have been forced to idle, leading to significant layoffs. Status quo operations and relines risk continuing these trends, as these assets would become increasingly uncompetitive in the market.

The remaining blast furnaces have been widely reported as dominant sources of industrial pollution in the states they operate in, many of which are considered the dirtiest industrial polluters across the Great Lakes region (see Exhibit 2) and chronically expose neighbouring communities to health-harming pollutants and chemicals. A subset of these chemicals (carbon monoxide, sulfur dioxide, nitrogen oxides, and fine particulate matter) are known as “criteria air pollutants” as human exposure limits have been established.

Even with proposed partial decarbonization investments, blast furnaces cannot meet clean steel thresholds, preventing the Great Lakes region from capturing the increasing demand for low-emissions steel in the United States, driven by federal procurement priorities and corporate purchasing targets. Based on recent announcements, they are inclined to extend the life of these assets, suggesting the use of “hydrogen (H_2) injection” or ”carbon capture, utilization and storage (CCUS)” at some future stage. However, neither of these technologies is planned or currently employed.

Blast furnace and basic oxygen furnace (BF-BOF) production has many concurrent operations on-site that each release large amounts of carbon dioxide independently, meaning that to significantly reduce onsite emissions via CCUS, producers would have to aggregate all these streams across the plant or install individual capture systems at each point source, both of which would be costly and logistically challenging. As such, no steel producer globally is trialing this pathway, and no blast furnaces in the United States have applied CCUS technology beyond the pilot scale. The recently announced CCUS project at USS's Gary Works intends to capture 50,000 tCO_2e per year, equivalent to less than 1 percent of total site-level process emissions.

Exhibit 2: Blast Furnace Steel Leads Against Major Sources of Industrial Emissions in Great Lakes Region

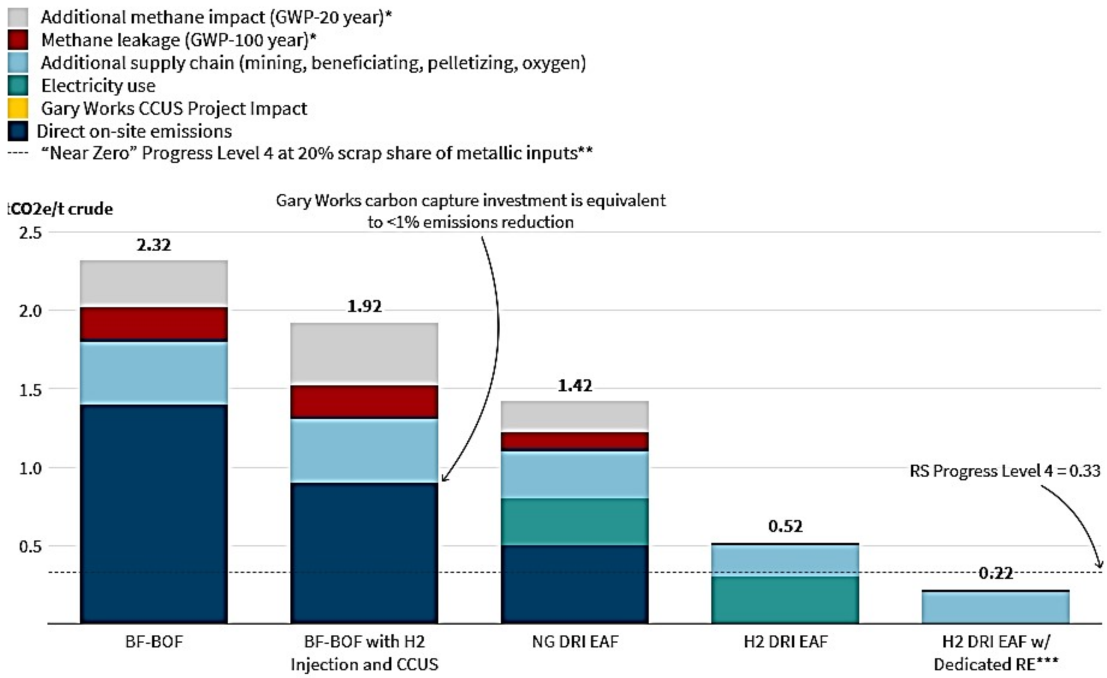


**Tons are shown on logarithmic axis due to wide range in values between lowest and highest emitters.*
***Airborne emissions of lead*
****Major Industrial Emitters include all "Large Facilities" classified by EPA's FLIGHT database located in Indiana (1,922), Pennsylvania (6,023), Ohio (4,610), and Michigan (5,913)*

Similarly, H_2 injection, which can offset some amount of coal (specifically, pulverized coal injection), is shown to reduce direct emissions by approximately 20 percent due to technical and physical limits. Nippon Steel's Super Course50 technology, which represents the highest level of BF emissions reduction achieved to date, estimates a 33 percent reduction in direct emissions from the combined use of CCUS and hydrogen injection (depicted in Exhibit 3). Nippon steel projects this technology may be able to reach a 50 percent reduction by 2040, which is not 1.5C aligned.

Instead, producers can redirect these investments toward a cleaner, more modern, and competitive production pathway. This moment presents a critical opportunity for primary steel suppliers to realize substantial emissions reductions for cleaner technology, positioning their portfolios to meet the clean market demands of the future.

Exhibit 3: Emissions Intensity by Steelmaking Archetype



Average intensities per archetype, 20% scrap level assumed.
Scope 2 grid factor = 0.46t CO2/ MWh; Upstream grid factor = 0.26t CO2 / MWh (MISO North); H2 is modeled to be 100% RE, behind-the-meter production
2.2% NG methane leakage rate, coal methane leakage derived from thermal/met-specific averages from operating US coal mines
The abated BF-BOF assumes a 33% reduction in direct emissions from the use of CCUS and hydrogen injection; Methane leakage from the abated BF-BOF represents net impact across H2 substitution and CCUS interventions.
H2 DRI EAF pathway assumes pyrolysis oil in the pellet plant and H2 use for ore heating in the DRI.
Ore-to-pellet feed rate to produce DR-grade pellet assumes crude ore with in-situ grade of 31.66%Fe (Cleveland Cliff's United Taconite mine); BF-grade pellet assumes crude ore with in-situ-grade of 24.88%Fe (avg of all US mines).
**Global Warming Potential measures the relative warming impact of one unit mass of a greenhouse gas relative to carbon dioxide, over a specific time horizon (20 years or 100 years).*
***Responsible Steel International Production Standard V 2.1*
****Dedicated RE is used for only on-site electricity use and does not apply to upstream power consumption.*

Direct Reduction (DRI) technology using renewably-produced hydrogen offers the most promising commercial-scale pathway to near-zero emission primary steelmaking today**.** Investment in H_2-Ready DRI technology at BF sites would avoid costly relines and, when properly planned, can offer significant benefits for the local, state, and regional communities and economies in both the near- and long term.

Today, only a 100 percent renewable-powered H2 DRI coupled with an electric arc furnace (H2-DRI-EAF) pathway is capable of reaching near-zero carbon emissions and is well-positioned to meet the highest emissions performance threshold set by leading market standards, which have already been linked to green premiums (Exhibit 3).

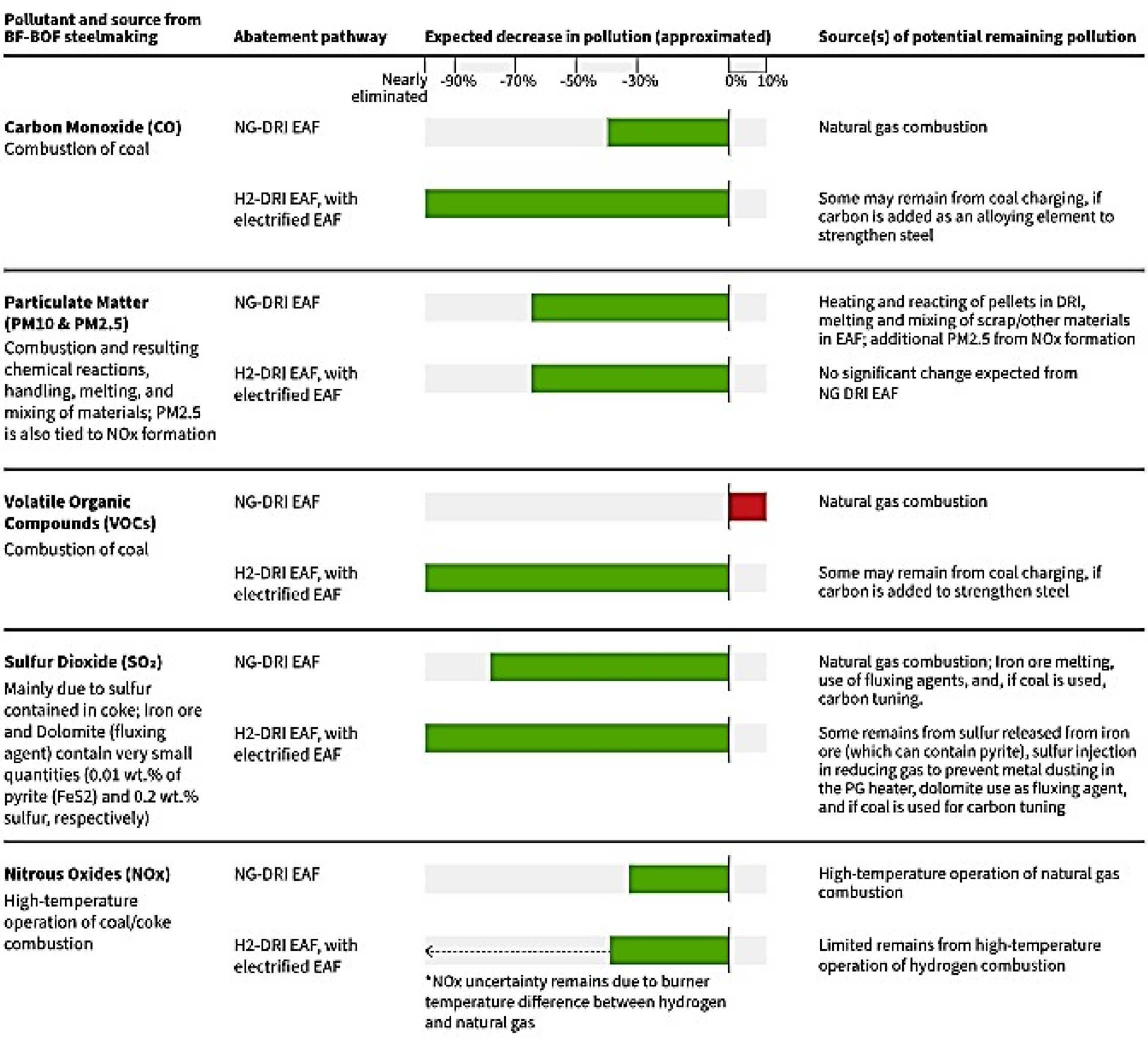
Beyond climate alignment, transitioning to DRI-EAF steelmaking (even when initially fueled by natural gas) can reduce health-harming criteria air pollutants compared to conventional coal-based production facilities (Exhibit 4). However, due to the nature of industrial facilities and processes, continued mitigation, monitoring, and reporting of these pollutants will be necessary regardless of production technology.

Ultimately, fully replacing natural gas and coal with renewable electricity and hydrogen in DRI-EAF production processes would further reduce pollutants, with some residual emissions of sulfur dioxide (SO_2) due to sulfur in ore and flux, and nitrous oxide (NOx) due to combustion in air. Based on limited reported data, it is estimated that ~15 percent – 30 percent of particulate matter may remain in a fossil-free pathway, due to the melting and mixing of materials in the furnace, and best-available dust capture systems should be required to mitigate harms.

Looking beyond emissions, making investments now will set up the local and regional steel economy for long-term competitiveness in the domestic and global markets. Early capital investment to transition to H_2-ready DRI effectively future-proofs facilities by allowing them to blend in increasing quantities of clean hydrogen as supply becomes available. The Department of Energy's Industrial Demonstration Program funding for Cleveland Cliffs is facilitating the transition of their BF in Middletown, Ohio to a DRI that can eventually run on hydrogen.

The capital investment required for relining can range from approx. $150M to $425M compared to the investment for a new DRI (the most emissions-intensive step of the process) which typically costs between $600M to $800M. Beyond that, however, the operational cost gap driven by energy costs remains. With existing federal incentives (renewable energy and hydrogen tax credits), an energy cost gap of approximately $2.50/kg H2 is estimated to remain in the near-term compared to coal-based production (Exhibit 5).

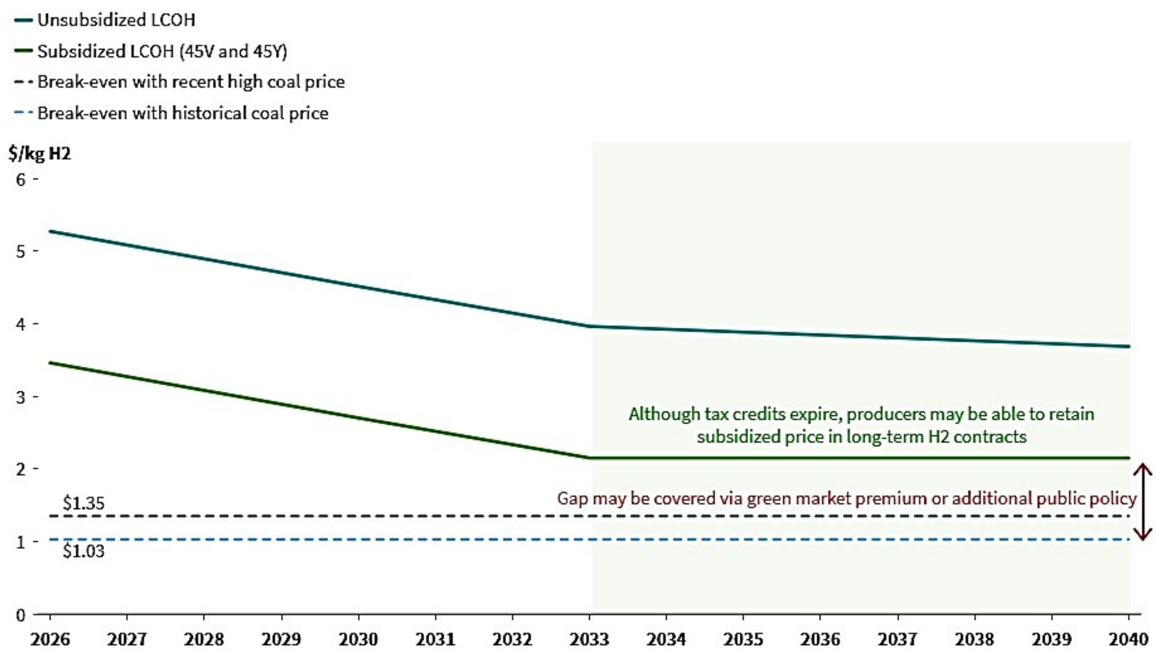
Exhibit 4: Decrease in Pollution Relative to BF-BOF



Pollution reduction potential relative to the BF-BOF pathway is estimated from a limited sample of self-reported facility data in EPA's National Emissions Inventory (NEI). Only the Louisiana DRI facility has reported to NEI, and steelmakers do not all report the same sets of compounds.

Modernizing and investing in the transition away from coal presents an avenue for blast furnace states to revitalize local communities by making use of existing infrastructure and protecting skilled workforces and union jobs. Compared to coal-based steelmaking, a hydrogen-based DRI-EAF is projected to require comparable levels of direct employment for mining, iron, and steelmaking (retaining more jobs than maintaining the status quo by the end of this decade) as well as an additional ~750 full-time jobs to produce the renewables and hydrogen upstream (per 2 Mpta steel production).

Exhibit 5: Levelized Cost of Hydrogen Decline Over Time vs Break-even H_2 Prices



If coal stays at $190/t, the breakeven H2 price is $1.03/kg. If coal increases to a recent high ($228/t), the breakeven H2 price is $1.35/kg.*

H2 Assumptions: Alkaline Electrolyzer CAPEX (uninstalled): $900/kW (2023), $594/kW (2026), $502/kW (2030)

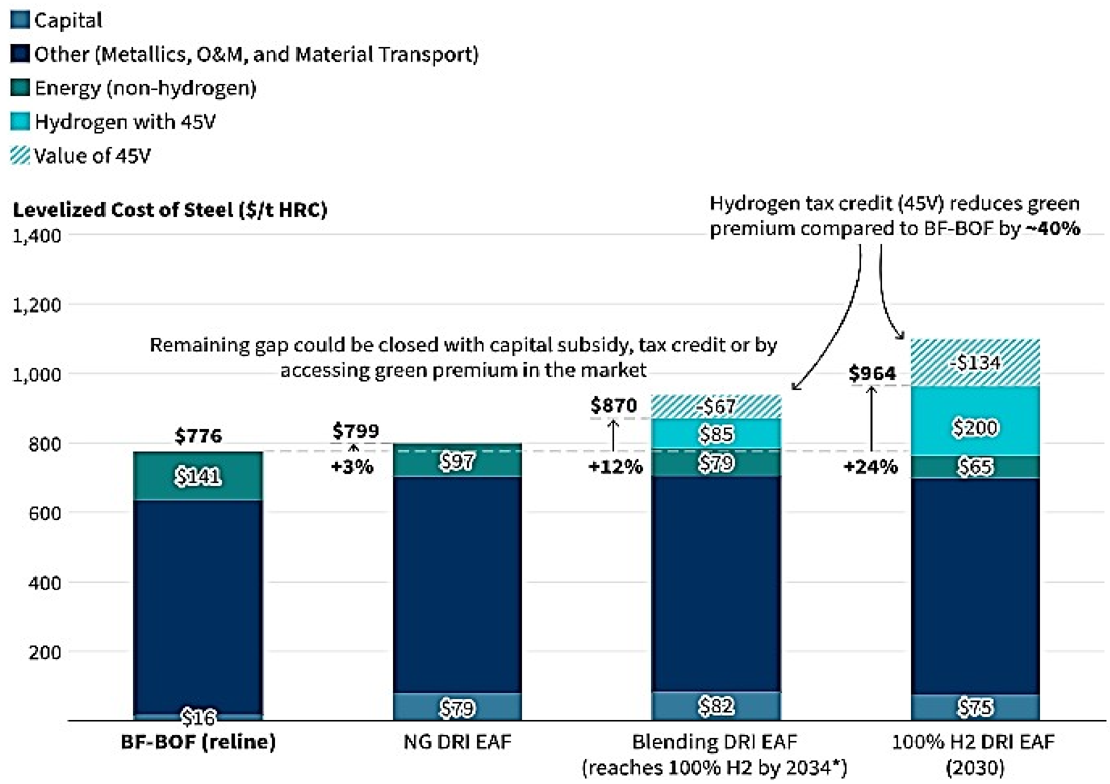
RE CAPEX: Solar: $1070/kW (2023), $930/kW (2026), $750/kW (2030); Wind: $1300/kW (2023), $1150/kW (2026), $1000/kW (2030)

**Breakeven values are based solely on levelized operating energy costs*

Remaining barriers to achieving this equitable and climate-aligned transition, and how can we overcome them to incentivize near-term investment?

Economic support is still needed to close the cost gap today, build upstream infrastructure, secure worker transition, and undertake meaningful community engagement to modernize the steel industry to shift away from blast furnace technology. A remaining cost gap for cleaner steel production exists compared to the incumbent process even beyond what federal incentives can cover (Exhibit 6).

Exhibit 6: Production Cost Gap



Subsidized H_2 Price: 5-year contract term at start (shifts to long-term contract prior to 45V expiration); H_2 in 2026: \$3.46/kg; H_2 in 2030: \$2.70/kg; H_2 in 2033: \$2.15/kg

**Blending: 30% in 2028, 55% in 2030 (coupled with investment capital), and 100% in 2034*

Coal Price: \$190/t (met), \$87/t (thermal); Gas Price: \$3/mmbtu; Average metallics: \$128 (BF-grade), \$134 (DR-grade)

Closing this gap can be achieved by a variety of means at the federal or state level:

1. Reducing the capital cost gap with an Investment Tax Credit or grant tied to emissions performance.
2. Reducing the operating cost gap via production tax credit or contract-for-difference mechanism for either the fuel (hydrogen) or product (iron/steel).
3. Support for renewable electrolysis-based hydrogen production and transmission, including siting and permitting renewable energy and hydrogen pipelines and storage.

Importantly, conditions and stipulations for workforce transition and meaningful community engagement are critical in ensuring that the transition of these facilities provides value to the community and workers. Demand for cleaner steel is only growing. We are approaching critical decision points: invest hundreds of millions of dollars in assets that will be outcompeted, or instead invest to modernize and transition assets for the future. If done right, this will offer competitive business advantages, slash emissions, improve community health outcomes, and secure jobs and economic development, continuing a proud legacy of industrial innovation and resilience of American steel.

Source: RMI Spark Newsletter, February 13, 2025

MENA's Opportunity to Lead the Green Iron and Steel Transition

The Middle East & North Africa (MENA) region has the potential to become the leader in global industry's transition to green iron and steel. The region is a leading hub for gas-based direct reduced iron (DRI) production, the ironmaking technology that has the flexibility to transition to using green hydrogen, enabling further emissions cuts. MENA enjoys significant advantages, including reliable access to feedstocks such as DR-grade pellet and fossil gas, as well as cheap renewable energy, that present a once-in-a-generation opportunity to capitalise on key markets for green iron and steel. As the global iron and steel industry races to decarbonise its production, MENA enjoys significant competitive advantages, bolstered by major projects announced in renewables, green hydrogen, and iron and steel. MENA has one of the world's fastest growing steel industries. Steelmaking from DRI using electric arc furnaces has lower emissions than traditional coal-based processes. It also offers the flexibility to transition from fossil gas to green hydrogen, enabling even greater emissions cuts. MENA's DRI capacity is growing; in 2023, it accounted for 45% of global DRI production, up 11% from 2021. In addition, MENA is one of the world's fastest-growing renewable energy markets and holds records for some of the cheapest renewable energy, supported by its unique solar and wind potential. As a result, the region is emerging as a leading green hydrogen hub, with deployment of green hydrogen in steelmaking already underway. MENA's established infrastructure, combined with growing investment in low-emissions technologies, will provide a significant competitive advantage in the evolving green steel market. By taking the right steps now, the region can seize this once-in-a-generation opportunity to supply green iron and steel to key markets such as Europe and Asia.

Source: IEEFA Friday Week in Review, Mar 8, 2025

Know Your Members

Rajesh Kumar Vijayavergia

Former Executive Director (Operations), SAIL, New Delhi
Former Advisor (SAIL), R&D Centre for Iron & Steel, SAIL, Ranchi
Former Advisor (R&D), NMDC Limited, Hyderabad
Former Consultant, Steel Research & Technology Mission of India

Mr. Vijayavergia graduated in Metallurgical Engineering, with Honours, in 1974, f*rom* Malaviya Regional Engineering College (now MNIT), Jaipur. He worked for few months with Jaipur Metals & Electricals Ltd. as Trainee Engineer and then with Dept. of Metallurgical Engineering at Malaviya Regional Engineering College as Associate Lecturer, before joining R&D Centre (RDCIS) of Steel Authority of India Ltd. (SAIL) in May 1975, where he spent 35 years carrying out various R&D assignments in BOF Steel Making, Stainless Steel, Coking Coal & Coke and Energy areas in SAIL Plants. He was shifted to SAIL Corporate Office in April 2010, as Executive Director (Operations), from where he superannuated in Aug. 2013. As a nominee of SAIL, he was a Member of the Board of NTPC-SAIL Power Company Pvt. Ltd. (NSPCL), and Chairman of SAIL Jagdishpur Power Plant Limited (SJPPL). He visited Sheffield City Polytechnique and University of Strathclyde, Glasgow, UK under UNDP program. He attended *Specialized Management Program* on "Leadership for Excellence" at ASCI, Hyderabad. He also visited Netherlands, France, Belgium, Luxembourg, Italy, China and Japan on various official assignments.

Subsequent to superannuation from SAIL in August 2013, he was Advisor at SAIL, Ranchi, Advisor (R&D), at NMDC Limited Hyderabad, and then Additional Executive Director of Steel Re-rolling Mills' Association at Delhi Office. Mr Vijayavergia was Consultant with Steel Research & Technology Mission of India (SRTMI), New Delhi from June 2018 to Sept. 2024.

Mr. Vijayavergia is a Life Member of **The Indian Institute of Metals** (IIM). He has been Executive Committee Member of Rourkela Chapter, Executive Committee Member, Jt. Secretary and Hon. Secretary of Ranchi Chapter, Executive Committee Member (2016-2023) and Chairman, IIM Delhi Chapter (2023-25). He is a Life Member of **Computer Society of India** and also **Indian Institute of Mineral Engineers.** He was Chairman, Computer Society of India, Ranchi Chapter, Vice Chairman, Delhi Public School, Ranchi and Member of Regional Advisory Committee of Central Board of Workers' Education (Min. of Labour), Ranchi.

He is recipient of Dr. M. Visveswaraya Medal (1989 and 2003) and SAIL Gold Medal (1991) awarded by The Institution of Engineers (India).

He edited pre-prints of 10 conferences held at RDCIS, Ranchi, and was in Editorial Board of '**Steel India',** bi-annual technical journal published by R&D Centre for Iron & Steel, SAIL, Ranchi (1999-2006). He was also a member of Editorial Broad IIM *Abstract Booklets* of *Annual Technical Meetings,* held in November 1988 at New Delhi; Nov. 1991 at Ranchi; Nov. 1994 at Visakhapatnam; Nov. 1997 at Jamshedpur; Nov. 2003 at Kolkata; and Nov. 2006 at Jamshedpur.

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