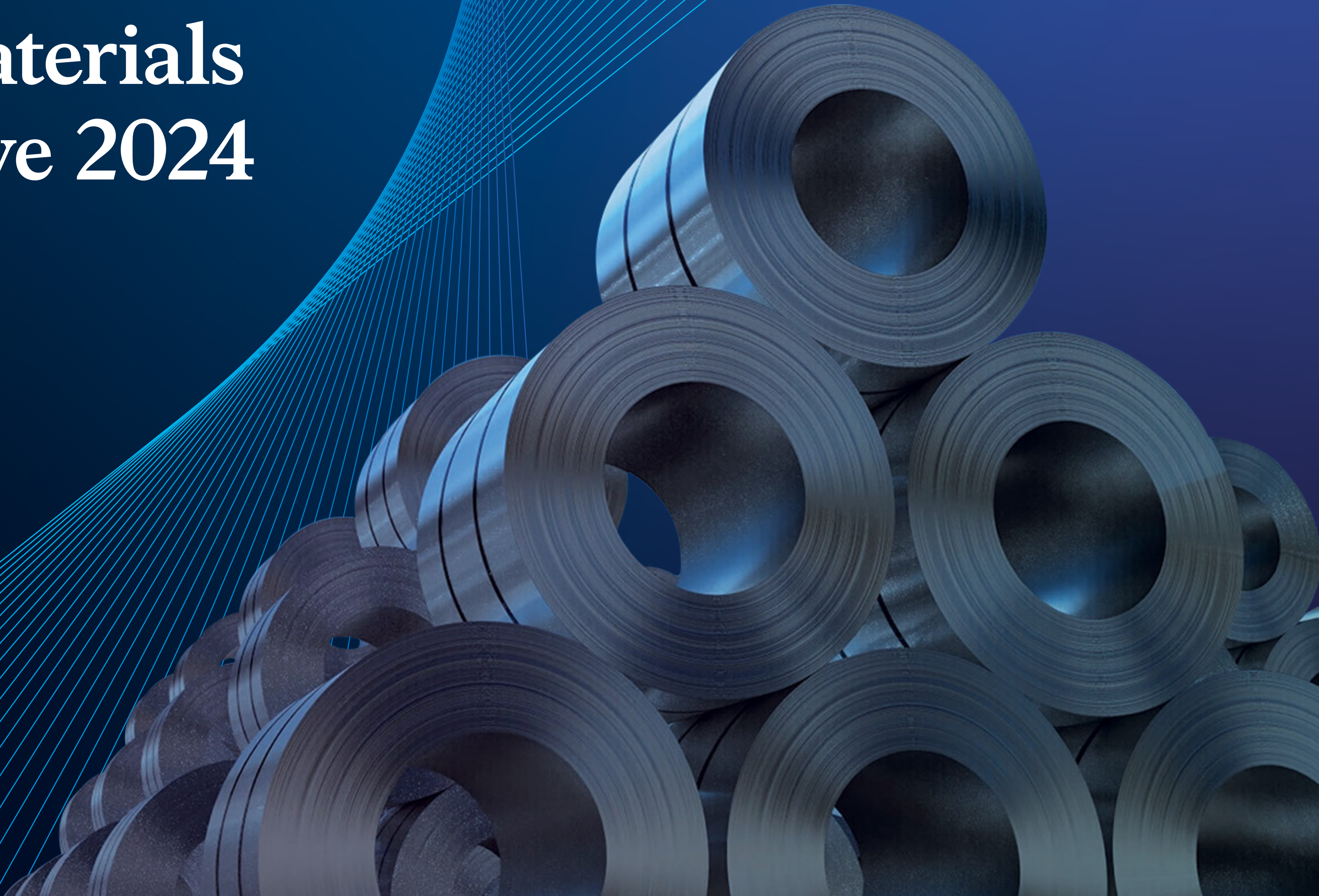
McKinsey & Company

Global Materials Perspective 2024

September 2024



About this report

The *Global Materials Perspective 2024* is produced by McKinsey's Global Energy & Materials Practice. Building on McKinsey's 2023 report on the materials transition, *The net-zero materials transition: Implications for global supply chains*, this report explores materials demand across three energy transition scenarios (differentiated by the speed of the transition) as well as two supply scenarios (based on asset level insights) modeled by McKinsey Metal&MineSpans, and aims to provide insights into the changing availability, affordability, and sustainability of materials critical to the energy transition.

While the materials industry spans a broad range of subindustries—including metals and mining, building materials (concrete and cement, glass, and others), plastics, and pulp and paper—this report primarily focuses on metals and mining, a subindustry that can be categorized loosely along the following long-term demand trends driven by the energy transition:

1. Materials for which demand is only to a small extent driven by the speed of the energy transition and which are consequently trending more or less in line with the growth of global GDP and the middle class (for example, steel and aluminum)
2. Materials for which demand is largely and positively impacted by the energy transition because they are embedded to a greater extent in one or several low-carbon technologies compared with conventional technologies, and are therefore frequently growing faster than in the previous decade (for example, copper, lithium, and rare earth elements [REEs])
3. Materials for which demand is largely and negatively impacted by the energy transition because they are fundamental to conventional technologies, which are gradually being phased out (the prime example here is thermal coal)

The *Global Materials Perspective 2024* encompasses all these categories but primarily illustrates trends for those materials, such as battery materials, that are critical for the at-scale deployment of low-carbon technologies, and that are collectively referred to as "energy transition materials" throughout this report.

About Metal&MineSpans: Metal&MineSpans is the Metals & Mining market intelligence solution of McKinsey, combining expertise with proprietary data. Metal&MineSpans provides information on mining and metals production costs and cost curves, CO_2 emissions, and supply and demand for 15 materials, based on a bottom-up analytical approach that focuses on asset level data and analytics. The solution aggregates detailed data for more than 11,000 assets from the mine or asset level up to the global market level to provide insights on the fundamental market drivers. Our insights are based on a comprehensive database built bottom up from referenced public data, proprietary information, and advanced analytics models, backed by McKinsey's more than 85 years of global Metals & Mining expertise.

About the Global Energy & Materials Practice: McKinsey's Global Energy & Materials Practice deploys its deep insights, functional capabilities, and proprietary benchmark and data solutions across the converging energy, materials, and natural resources supply chains to help create substantial and long-lasting value for stakeholders. Guided by advanced analytics and the power of a global team, it brings distinctive industry perspectives across sectors that support today's critical infrastructure ecosystems. The practice is proud to have partnered with hundreds of major industry players as the leading and most integrated advisor on strategic and functional transformations, enabling clients to accelerate decarbonization and realize the energy, materials, and food transitions.

About McKinsey & Company: McKinsey is a global management consulting firm committed to helping organizations accelerate sustainable and inclusive growth. We work with clients across the private, public, and social sectors to solve complex problems and create positive change for all their stakeholders. We combine bold strategies and transformative technologies to help organizations innovate more sustainably, achieve lasting gains in performance, and build workforces that will thrive for this generation and the next.

About the supply scenarios

Research components

11,000+
assets

130+
countries

13
cost and CO_2 factors

10+
year outlook

1.5 million+
data points

Supply scenarios

Included in scenario / Not included

Project status	Status description	Base case	High case	Full pipeline
In operation	Projects currently operating, corrected for depleting assets	Included	Included	Included
Certain	Projects currently under construction or with feasibility study completed and financing secured	Included	Included	Included
Probable	Projects with feasibility study under development; start-up date adjusted for likelihood of execution	Included	Included	Included
Possible[1]	Projects with prefeasibility study completed; start-up date adjusted for likelihood of execution	Not included	Included	Included
Unlikely	Projects with prefeasibility study completed, yet clear roadblocks identified	Not included	Not included	Included
Unrealistic/ in exploration	Any project that has been announced	Not included	Not included	Included

Scenario used throughout publication unless explicitly stated (Base case)

[1]Some prefeasibility study projects may also be included in "Probable" category in case the project's characteristics and expectations are robust.
Source: McKinsey Metal&MineSpans

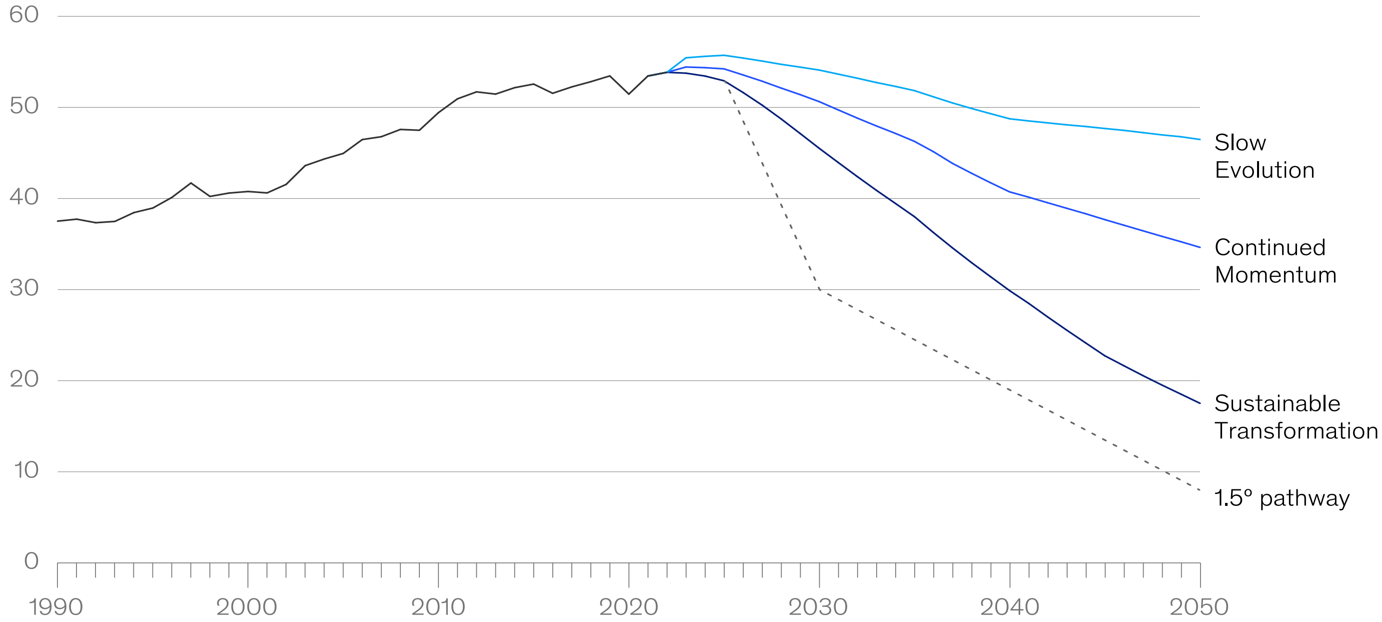
The supply scenarios explored in this publication are based on our research on the maturity and likelihood of individual projects in the metals and mining industry. The research is anchored in our Metal&MineSpans database, which contains more than 11,000 assets across more than 130 countries. Recycled materials are included in the supply scenarios, based on assumptions about average end product lifetimes and collection and recovery rates. Concretely, the findings in this report are based on the following two scenarios:

- *The base-case scenario* includes all operating assets (corrected for depletion where relevant) and projects currently under construction. It also includes projects for which a feasibility study has been conducted and financing secured as well as projects for which a feasibility study is currently being conducted.
- *The high-case scenario* includes the previous cases as well as projects for which a prefeasibility study has been initiated. Projects that have been announced but have not yet initiated a prefeasibility study are not included in the forecasts.

Supply scenarios are based only on announced projects to the extent they are available in the public domain, and do not include theoretical capacity increases.

About the demand scenarios

Global greenhouse gas emissions,[1] $GtCO_2$ equivalent per annum



Projected global temperature increase by 2050, °C

<1.5	**~1.8**	**~2.2**	**~2.6**
1.5° pathway	Sustainable Transformation	Continued Momentum	Slow Evolution

Faster **Speed of energy transition** *Slower*

Note: 1.5° pathway modeled as part of McKinsey's Climate Math effort; other scenarios modeled bottom-up as part of McKinsey's *Global Energy Perspective 2024.*
[1]Includes process emissions from cement production, chemicals production and refining, and negative emissions from applying carbon capture, utilization, and storage (CCUS).
Source: McKinsey, September, 2024

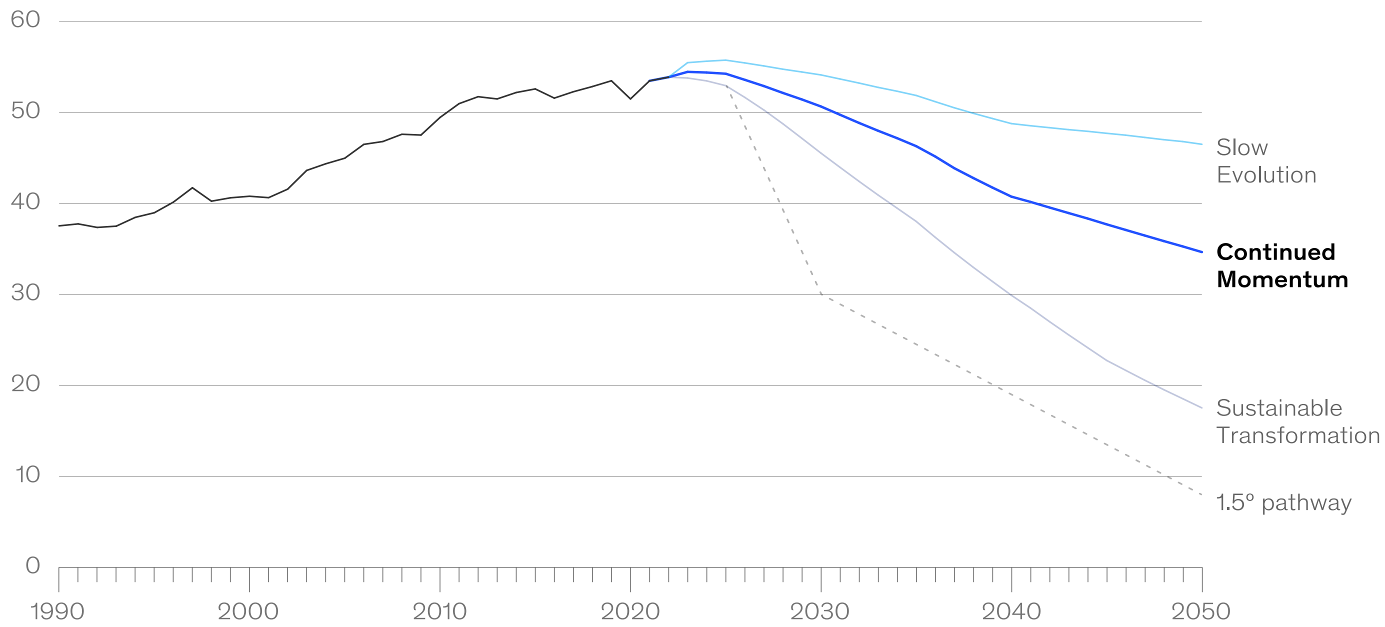
McKinsey's *Global Energy Perspective 2024*, which was released alongside this report, offers a detailed demand outlook for 68 sectors and 78 fuels across a 1.5° pathway, as set out in the Paris Agreement, as well as three bottom-up energy transition scenarios.

The scenarios have been redesigned this year to better reflect changing global conditions, including geopolitical challenges, increasingly complex supply chains, and higher inflation. Together they explore potential outcomes, ranging from a sustainable transformation—a plausible scenario in which sustainability becomes a global priority and nations coordinate toward decarbonization, despite the challenges—through a continuation of the current energy transition momentum, to slower evolution characterized by a fragmented response to decarbonization. Data for these scenarios come from a variety of sources, including the International Energy Agency (IEA), the Energy Institute, Eurostat, the Intergovernmental Panel on Climate Change (IPCC), Oxford Economics, the United Nations, the US Department of Agriculture (USDA), and the US Energy Information Administration, among others.

These bottom-up energy transition scenarios, and the underlying assumptions for the deployment of low-carbon technologies and broader economic development, have been employed along with McKinsey's latest perspective on technology choices (for example, battery chemistry in electric vehicles) to determine the associated materials demand.

Continued Momentum is the reference case for our Global Materials Perspective 2024

Global greenhouse gas emissions,[1] $GtCO_2$ equivalent per annum



Projected global temperature increase by 2050, °C

Scenario used throughout publication unless explicitly stated

<1.5	~1.8	~2.2	~2.6
1.5° pathway	Sustainable Transformation	Continued Momentum	Slow Evolution

Faster — **Speed of energy transition** — *Slower*

Note: 1.5° pathway modeled as part of McKinsey's Climate Math effort; other scenarios modeled bottom-up as part of McKinsey's *Global Energy Perspective 2024*.
[1]Includes process emissions from cement production, chemicals production and refining, and negative emissions from applying carbon capture, utilization, and storage (CCUS).
Source: McKinsey, September, 2024

In the Continued Momentum scenario, nations' focus on sustainability is balanced by other factors, including affordability and security of energy supply, with some emerging economies mostly prioritizing affordability and security of supply over sustainability.

Technology and efficiency improvements largely follow current trends, driven by economics where practical constraints persist in the widespread adoption of low-carbon technologies. This scenario largely mirrors current trends and assumes they will continue, resulting in uneven deployment of low-carbon technologies across technology type and regions.

This scenario would fail to meet key goals of the Paris Agreement, creating a range of negative social, environmental, and economic effects.

Global Materials Perspective 2024: Foreword

The global metals and mining industry is entering a new era. Historically, the industry has been driven by economic growth and the development of the middle class, resulting in major demand for materials such as steel, aluminum, and coal. While 80 percent of the industry today primarily consists of five materials—steel, coal, gold, copper, and aluminum—the landscape is rapidly changing as a result of the energy transition.

Indeed, the energy transition is first and foremost a physical transformation and the key challenges are therefore primarily physical, including the timely availability of materials embedded in low-carbon technologies (as detailed in McKinsey Global Institute's 2024 report, *The hard stuff: Navigating the physical realities of the energy transition*). The energy transition is changing the materials landscape in three main ways:

- It accelerates demand growth for materials that are embedded in low-carbon technologies as these technologies typically require more embedded materials than their conventional counterparts. For example, battery electric vehicles (BEVs) are typically 15 to 20 percent heavier than comparable internal combustion engine (ICE) vehicles.
- It triggers a long-term shift of the materials demand profile as low-carbon technologies require a different set of energy transition materials, which is gradually increasing the relative importance of these materials in the overall metals and mining portfolio.
- It drives a long-term reduction of thermal coal in the energy system, currently the second largest material in metals and mining measured by revenue (2023).

Key materials for the energy transition are crucial to achieve decarbonization in the global energy system—and a lack of sufficient and affordable supply would therefore risk hindering the at-speed deployment of crucial low-carbon technologies. This report aims to provide a fact base and perspective on the need to scale these materials sustainably and affordably. We present a view of the possible road ahead, based on data from approved, publicly available sources, checking this view against three energy transition scenarios differentiated by the speed of the transition as well as two supply scenarios modeled by McKinsey Metal&MineSpans and based on asset level insights.

The road ahead will inevitably bring challenges, including how to accelerate the scaling of supply to meet new demand patterns, how to keep materials affordable so they can continue to support the energy transition and fuel economic growth, and how to improve the sustainability of the industry. This is not simple, especially in the context of an evolving global policy landscape that further increases uncertainty for investors.

However, we are hopeful that the industry's response to the energy transition also presents substantial business opportunities for incumbents and new entrants alike, whether from conscious portfolio shifts, disruptive innovation, new business models, or the next wave of operational and capital expenditure (capex) advances, in some cases enabled by AI.

Key insights from our analysis

Ten important insights flow from our analysis in the Global Materials Perspective 2024

State of the industry

1

Despite continued turbulence, finances were healthy in 2023, although the outlook for 2024 is gloomier

The materials industry has experienced strong growth since the beginning of the millennium, reaching approximately $8 trillion in revenue in 2023. EBITDA has been strong too, growing to $1.7 trillion in 2023—of which $900 billion is from the metals and mining industry. Furthermore, balance sheets were healthy in 2023, with net debt over EBITDA ratios of 1.3 times—well below the through cycle average of 1.8 times—providing companies with more investment capacity. However, 2024 has already proven to be a more challenging year for the industry as overall economic growth slows down and the shift toward low-carbon technologies unfolds more slowly than expected, both of which are putting downward pressure on price levels, especially for battery materials, such as nickel and lithium.

2

Supply is scaling faster than expected, while accelerated technological innovation is creating increasing uncertainty for demand outlooks

Supply is scaling faster than expected for several energy transition materials. Comparing Metal&MineSpans' 2020 projections of announced supply with actual production in 2023 shows that production for lithium and nickel was underestimated by nearly 20 percent. At the same time, demand patterns are rapidly adjusting in response to anticipated supply shortages. The market has seen increased changes from technological innovation—for instance, the battery chemistry mix is shifting toward lithium-iron-phosphate (LFP), which has grown its market share from 25 percent in 2021 to 40 percent in 2023. In addition, an increasing number of automotive OEMs (40 percent of the top 25 globally)[1] are announcing a move toward electric motors less reliant on, or entirely free of, rare earth elements (REEs). These fast-paced technological developments and shifts are creating uncertainty for long-term demand outlooks, especially for those materials that are strongly dependent on the development of a small number of sectors, such as battery and magnet materials.

3

Concentration of supply is increasingly resulting in disruptive policies to protect local industries

The supply of ore is commonly concentrated in a handful of countries and largely driven by natural endowments. Next to that, China has built a global leadership position over the last few decades in the refining of a broad series of materials, often with a volume share of more than 50 percent. This regional concentration creates both risks in terms of supply chain disruptions and changes in competitive landscapes, as well as opportunities, as many countries enact a range of incentives to promote domestic supply and safeguard industry competitiveness. For example, Europe set absolute targets on self-sufficiency and single-country dependency on a list of more than 15 strategic raw materials as part of its Critical Raw Materials Act, while China put in place export controls on gallium, germanium, antimony, and rare earth separation and processing technologies, which resulted in a significant decrease in export volumes.[2]

4

Chinese investors have actively ramped up their ownership of global mining assets

China has long been the global leader in refining and is now stepping up its ownership in mining through investments in other countries. By capacity, Chinese investors increased their ownership in copper mines from approximately 10 percent in 2012 to 20 percent in 2023, in part driven by expansion in the Democratic Republic of the Congo; from 10 to 30 percent in lithium, in part driven by build-out of domestic lepidolite projects; and from 5 to 20 percent in nickel, largely driven by expansion in Indonesia.

[1] By number of electric vehicles sold in 2023.
[2] "Germanium and gallium: US trade and Chinese export controls," US International Trade Commission, March 2024; "Critical raw materials," European Commission.

Key insights from our analysis

Ten important insights flow from our analysis in the Global Materials Perspective 2024

Looking ahead

5

Although expected supply deficits remain for several key materials, the gaps are closing

Fast supply scale-up and shifting demand patterns resulted in smaller than expected supply shortages for several materials compared to our 2023 perspective.[3] However, our analysis shows that supply shortages are still expected for several materials by 2035—or even earlier—most notably for copper, uranium, lithium, REEs, iridium, and sulfur. For materials with shorter project development timelines and abundant known resources (such as uranium and lithium), this gap is likely to be closed by scaling supply once the demand signal is sufficiently strong. For those with longer development timelines (such as copper and iridium), the gap may need to be closed by demand reduction or continued substitution toward other materials. And while there are increasingly strong financial and regulatory incentives for supply chains to increase materials circularity, increased circularity alone will not close the gap for energy transition materials.

6

Price increases would be required to incentivize sufficient supply to come online

Theoretically, there would be sufficient financing capacity in the industry to scale up production to meet demand, with an estimated $5.9 trillion in financing capacity until 2035 versus an expected investment need of $5.4 trillion. However, the business case is not always attractive enough to incentivize investment. As an example, based on the current project pipeline, copper prices would have to increase to approximately $12,000 per ton (an increase of 20 percent from May 2024), lithium to $19,000 per ton (30 percent increase), and nickel to $21,000 per ton (5 percent increase) to incentivize sufficient supply to come online by 2035 (assuming a minimum internal rate of return [IRR] threshold of 15 percent, no disruptions to demand patterns, a stable project pipeline, and timely scaling of all projects). Scaling supply to meet demand would also require the build-out of around 250 to 300 gigawatts (GW) of renewable energy to power new refineries and mines, filling approximately 340,000 new jobs in the industry (albeit largely offset by an expected loss of roughly 1.25 million jobs in thermal coal), as well as building out logistics and freshwater infrastructure and scaling up equipment supply chains.

7

The pace of decarbonization is unfolding slower than required to support the goals of the Paris Agreement, given a disconnect between decarbonization costs and willingness-to-pay for low-carbon materials

The materials sector is a significant contributor to global greenhouse gas (GHG) emissions, accounting for around 15 percent of global emissions (equivalent to 7 gigatons of CO_2 [$GtCO_2$]). Assuming business as usual, and accounting for large-scale decarbonization announcements (especially in the steel industry in Europe where it is incentivized by increasing carbon tax), total emissions are projected to decrease by close to 15 percent, reaching 6 $GtCO_2$ by 2035. This modest reduction is partially explained by the fact that the cost of "deep decarbonization" remains high—often entailing an increase of more than 30 percent in operational costs for some materials, especially for brown-to-green transitions. Our analysis suggests this cost is fundamentally disconnected from consumer willingness-to-pay. In fact, fewer than 15 percent of surveyed decision makers indicate a willingness to pay a premium of around 10 percent if there is a scarcity of green materials by 2030.[4]

[3] *The net-zero materials transition: Implications for global supply chains*, McKinsey, July 5, 2023.
[4] Includes 36 respondents in steel, 27 in aluminum, and 15 in copper.

Key insights from our analysis

Ten important insights flow from our analysis in the Global Materials Perspective 2024

The way forward

8

Accelerating scale-up of supply in a sustainable manner requires increased collaboration and efforts to derisk investments

In an environment of increasing uncertainty on long-term demand patterns and policy shifts, various forms of collaboration and derisking efforts are needed to support long-term project competitiveness. Such efforts could include offtake agreements and supply contracts between customers and producers, increased infrastructure support and collaboration between peers scaling production in the same region, more efficient administrative processes from policymakers, and increased exploration programs to secure high-quality projects, thereby enabling continued supply growth toward 2050 as demand continues to grow.

9

Cost and capital expenditure efficiency will become increasingly pivotal in securing long-term affordability and competitiveness

The increasing level of competitiveness and worsening quality of ore deposits, combined with uncertainty around long-term demand patterns (and therefore price levels), will require strong and continued focus on cost and capex efficiency, for projects to be economically viable in the long run. For example, the average project cost overshoot during the past decade was more than 30 percent, which means getting closer to initial budget estimates could already create significant value and strengthen the business case for investors, as such, incentivizing continued supply scale-up.

10

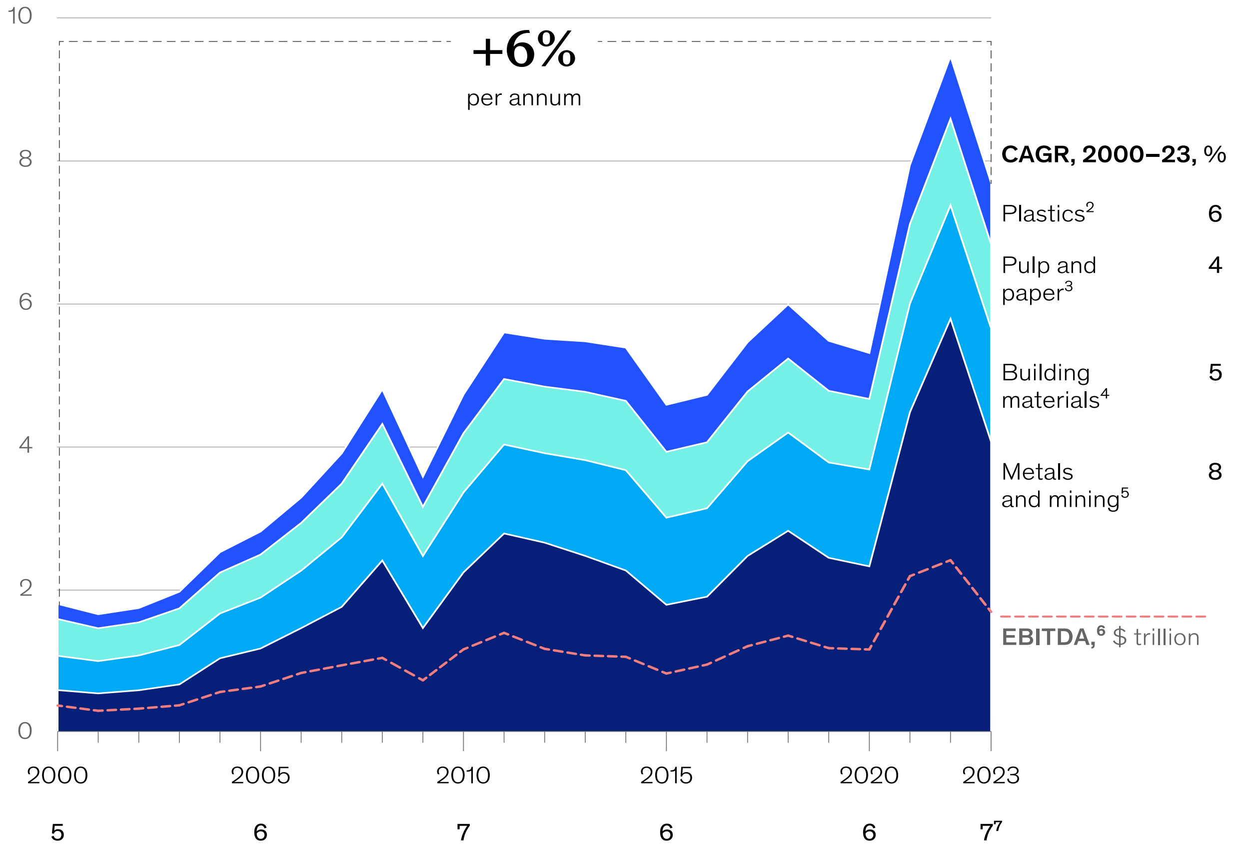
Incremental decarbonization, wholescale innovation, and regulatory clarity will all be critical for accelerating emissions reduction

For brown-to-green transitions, stakeholders can consider stepwise, focusing on cost-effective levers, possibly combined with mass balancing of products focusing on those subsectors with the highest willingness-to-pay, and dedicating part of the receipts to larger-scale decarbonization programs. For greenfield investments, stakeholders can increase innovation efforts, often with support from public innovation funding such as the EU Innovation Fund under the EU Emissions Trading System (ETS), and build partnerships to derisk the business case such as coinvestment with customers and equipment providers. Finally, regulators can define clear definitions for the emissions threshold of low-carbon materials—given there is currently no standardized framework and customers have different expectations—while harmonizing carbon tax regulations to create a level playing field, such as the EU's Carbon Border Adjustment Mechanism.

Despite a turbulent environment, finances were healthy until 2023—yet 2024 has a gloomier outlook

The materials industry has grown revenue by 6 percent per annum since 2000

Revenues of the materials industry,[1] nominal $ trillion



[1]Sum of revenues per material, using average yearly refined material market prices and demand volumes. [2]Material plastics, engineering plastics, and high-performance thermoplastics. [3]Pulp, paper, cartonboard. [4]Wood, cement, glass, sand, and gravel. [5]Steel, thermal coal, base metals (aluminum, copper, lead, tin, zinc), battery metals (cobalt, nickel, lithium, graphite, manganese), precious metals (gold, silver, diamonds, platinum group metals), and others (industrial minerals, rare earth elements, minor metals, fertilizers, uranium). [6]Revenue-weighted EBITDA based on metals and mining (including coal companies, excluding Glencore), construction materials and chemicals (material, diversified, specialty) companies out of top global 3,000. [7]Forecast 2023 GDP of $104.8 trillion.
Source: American Chemistry Council; Eurostat; Fastmarkets; IHS Markit; ITC Trade Map; Statista; World Bank; McKinsey Metal&MineSpans

The past two to three years have posed some challenges for the materials industry, with high price volatility driven by increased supply chain disruptions and volatility in energy prices, among other factors. While the industry has experienced cycles of boom and bust before, these recent fluctuations are unprecedented in scale.

Despite the challenges, the materials industry shows strong financial results over the past few years when compared with historical averages. Revenues grew by approximately $2.4 trillion (more than 40 percent) from 2020 to 2023, primarily driven by metals and mining, which grew by $1.7 trillion (an increase of approximately 75 percent). During the same period, EBITDA in metals and mining nearly doubled, increasing from $500 billion to $900 billion.

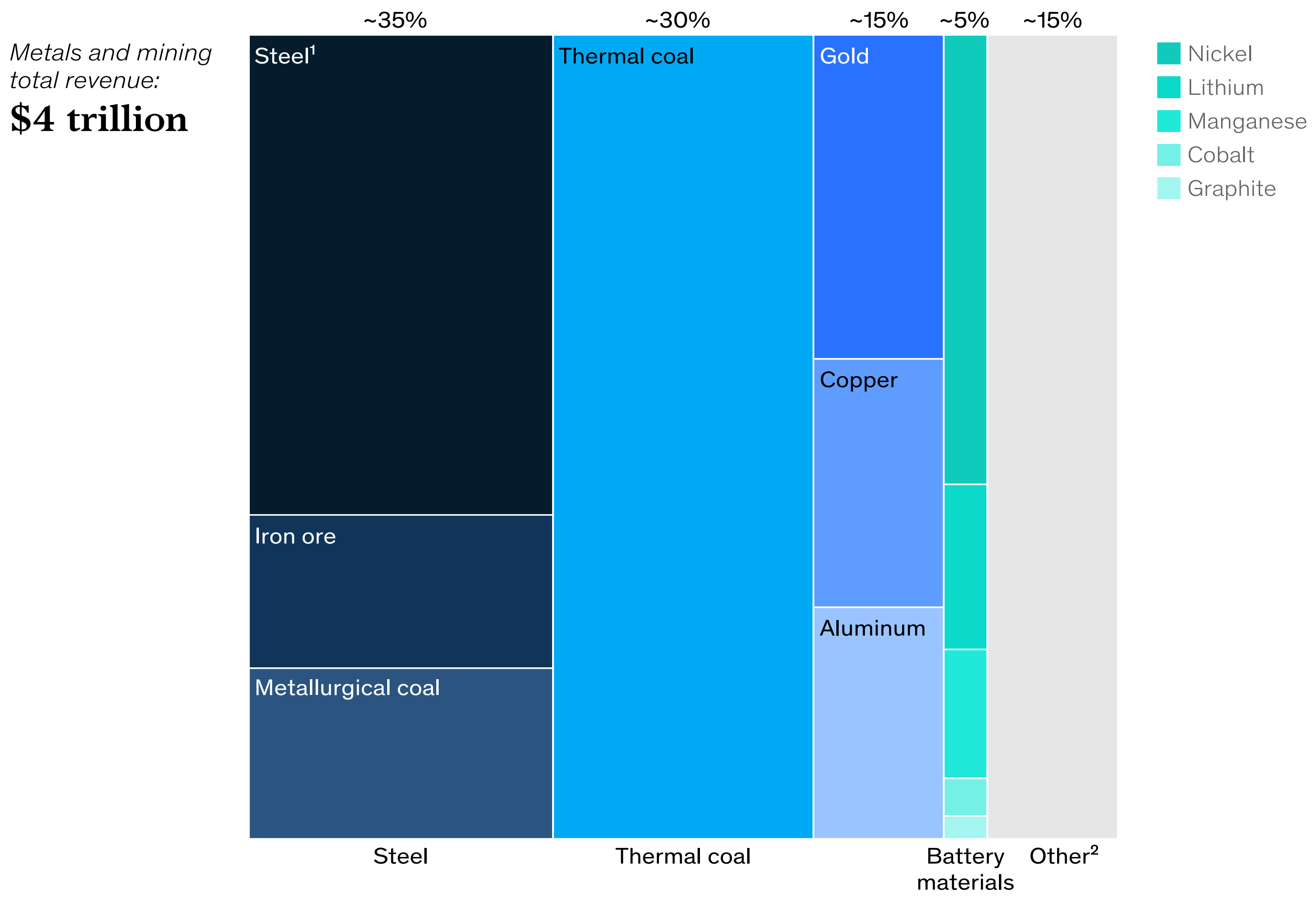
Overall, balance sheets are healthy, with net debt over EBITDA ratios of 1.3 times—well below the through-cycle average of 1.8 times—providing companies with more investment capacity.

However, 2024 has already proven to be a more challenging year for the industry as overall economic growth slows down and the shift toward low-carbon technologies unfolds more slowly than expected, both of which are putting downward pressure on price levels, especially for battery materials, such as nickel and lithium.

In metals and mining, around 80 percent of revenues stem from just five materials

Steel, thermal coal, gold, copper, and aluminum dominate the sector

Metals and mining revenue by material, 2023, % of total revenue



[1]Total value of steel excluding iron ore and metallurgical coal.
[2]Largest materials in the group include ferrochrome and potash; includes all other metals and mining materials, eg, rare earth elements (REEs), minor metals, etc.
Source: American Chemistry Council; Eurostat; Fastmarkets; IHS Markit; ITC Trade Map; World Bank; McKinsey Metal&MineSpans

The $4 trillion metals and mining industry is largely composed of just five materials: steel (including iron ore and metallurgical coal), thermal coal, gold, copper, and aluminum. Of these, thermal coal and steel account for approximately 60 to 70 percent of revenues, with production volumes more than 30 times higher than all other materials combined.[5] Gold, copper, and aluminum make up another 15 to 20 percent.

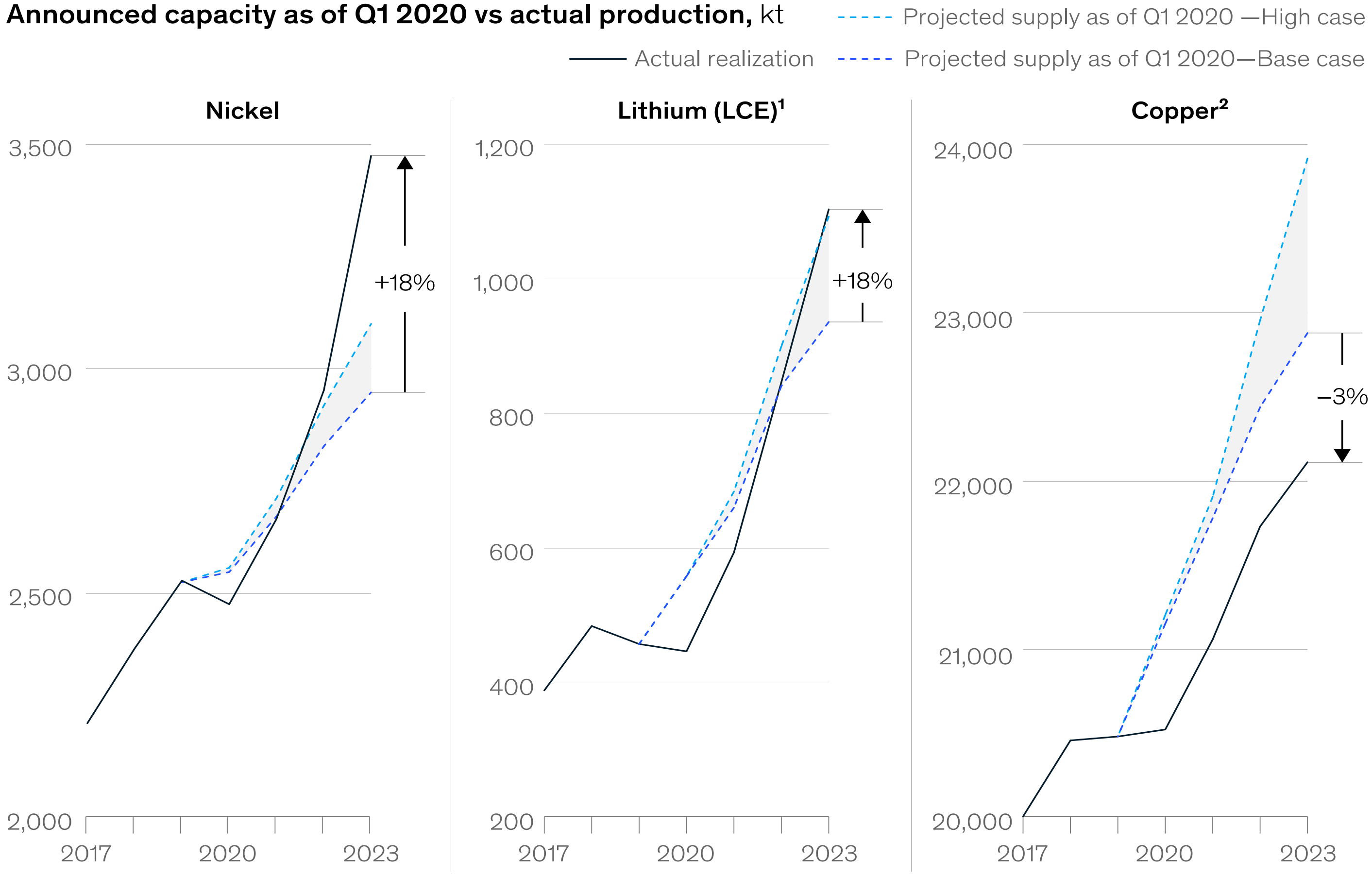
Other materials often associated with the energy transition, such as battery and magnet materials, remain small in terms of revenue but are growing in sync with the shift toward low-carbon technologies.

[5] Thermal coal (approximately 7,000 megatons [Mt]) and steel (apprimixately 2,000 Mt) and remaining materials are in the order of magnitude of 200 to 300 Mt, with aluminum being the third largest by volume at around 100 Mt.

Supply is scaling faster than expected for several materials key to the transition

Lithium and nickel are ramping up faster, while copper lags behind

Announced capacity as of Q1 2020 vs actual production, kt



Note: Projections are as per McKinsey Metal&MineSpans.
[1]Lithium measured in lithium carbonate equivalent (LCE).
[2]Copper measured as refined metal.
Source: McKinsey Metal&MineSpans

Comparing the Metal&MineSpans' first quarter 2020 projection for announced supply with actual production in 2023 shows that production for lithium and nickel was underestimated by nearly 20 percent.

For lithium, the difference is driven by assets funded by Australian and US investors coming online faster than expected, as well as an unanticipated scale-up of lepidolite assets in China in response to elevated lithium prices. And for nickel, the ramp-up stems almost solely from integrated high-pressure acid leach (HPAL) laterite assets in Indonesia. This accelerated supply buildup—in combination with a slowdown in electric vehicle (EV) sales—partly explains recent downward price corrections and why some projects have been called back.

By contrast, copper supply lags projections not only because of expected projects not coming online but also because several assets decreased production faster than anticipated.

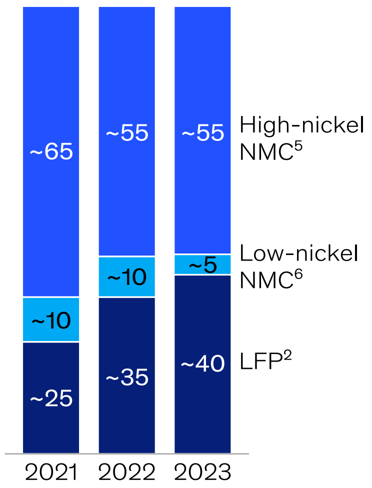
Accelerated technological innovation is creating increasing uncertainty for demand outlooks

OEMs in automotive are rapidly shifting toward alternative technologies

Selected case examples

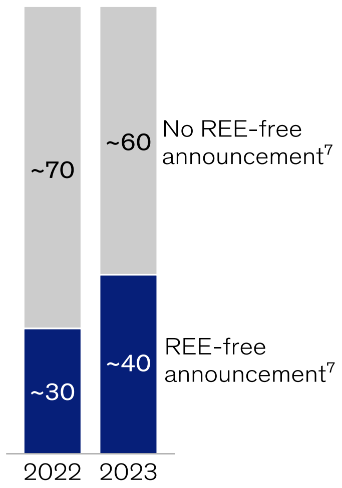
EV battery chemistries shifting from NMC[1] to LFP[2]

Share of cathode production by chemistry, % of total kWh battery capacity



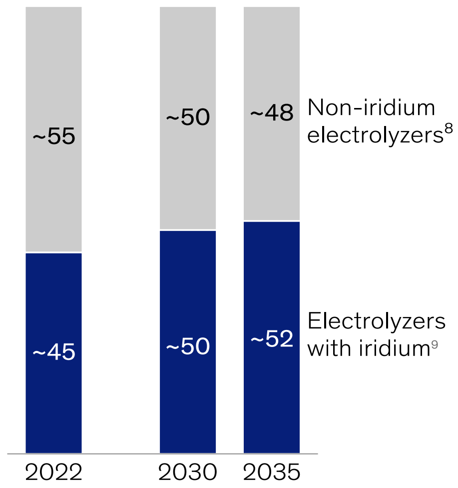
EV electric motors shifting away from REE[3]

Leading OEMs[4] stating they will build REE-free motors, % of cars sold by brand

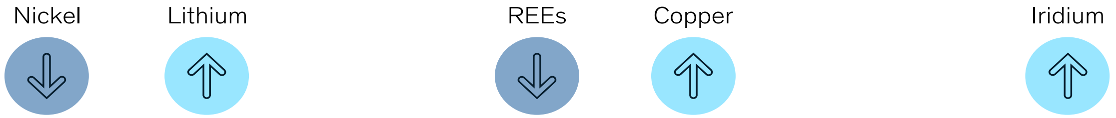


Iridium electrolyzers expected to continue to increase

Projected electrolyzer production by type, % of announced capacity (GW)



Summary, change in demand



[1]Nickel manganese cobalt. [2]Lithium iron phosphate, also includes lithium manganese iron phosphate (LMFP). [3]Rare earth elements. [4]Considering 23 largest OEMs by current EV market share. [5]Includes NMC622, NMC721, NMC811, NCA, and NMCA. [6]Includes NMC333, NMC532. [7]Announcements mentioning efforts (eg, partnerships, scientific innovations, etc) to move away from REE in motors. [8]AWE and SOEC electrolyzers. [9]PEM electrolyzers.
Source: Hydrogen Insights; IEA

As supply has scaled up faster than expected for some materials, demand patterns have adjusted in response to anticipated supply shortages.

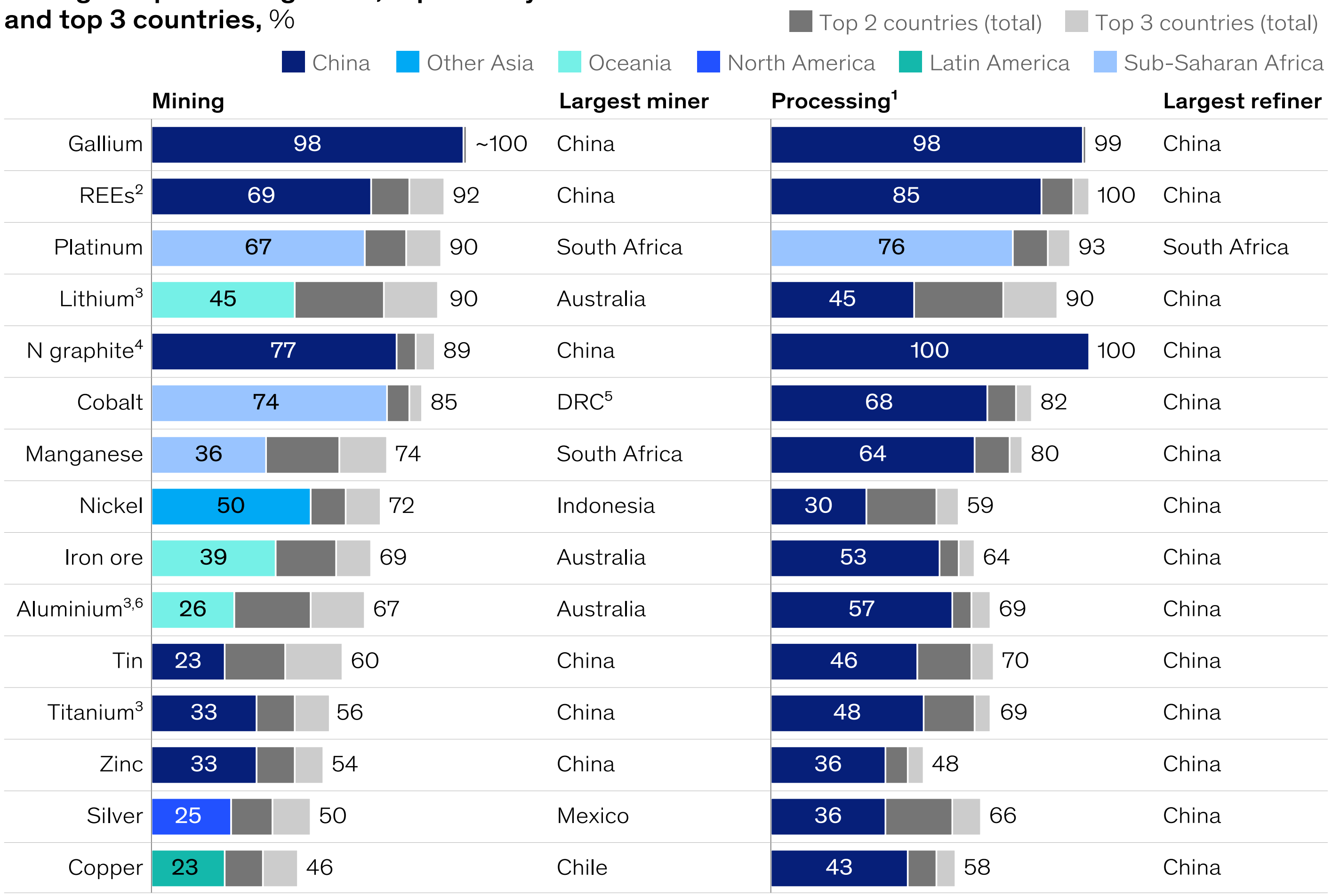
For example, the chemistry mix for batteries used in EVs is increasingly moving away from nickel-manganese-cobalt (NMC) to lithium-iron-phosphate (LFP). As another example, the share of leading OEMs stating they would shift toward electric motors that are less reliant on REEs increased from 30 percent in 2022 to 40 percent in 2023.

These trends, however, are not consistent across materials. For example, the move from iridium-intensive electrolyzers in anticipation of a potential iridium shortage is not yet apparent. This could be partially explained by the fact that hydrogen developers may still have flexibility to change electrolyzer designs at a later stage in the project development cycle.

Supply chains continue to be geographically concentrated

A handful of regions dominate mining, while China is the leader in refining

Mining and processing share, top country and top 3 countries, %



[1]Based on 2021 data excluding manganese, nickel, iron ore, aluminum, tin, zinc, and copper, which are from 2023. [2]Rare earth elements. [3]2021 figures. [4]Natural graphite. [5]Democratic Republic of the Congo. [6]For mining, based on bauxite mining; for processing, based on primary aluminium smelting.
Source: UN Comtrade; US Geological Survey; Worldsteel; McKinsey Metal&MineSpans

Supply of ore is commonly concentrated in a handful of countries, largely driven by natural endowment. In fact, the volume share of the top one to three producers for several materials is well above 60 percent of supply. In some cases, the largest country has an even higher volume share: approximately 75 percent of cobalt is mined in the Democratic Republic of the Congo and close to 70 percent of REEs are extracted in China.

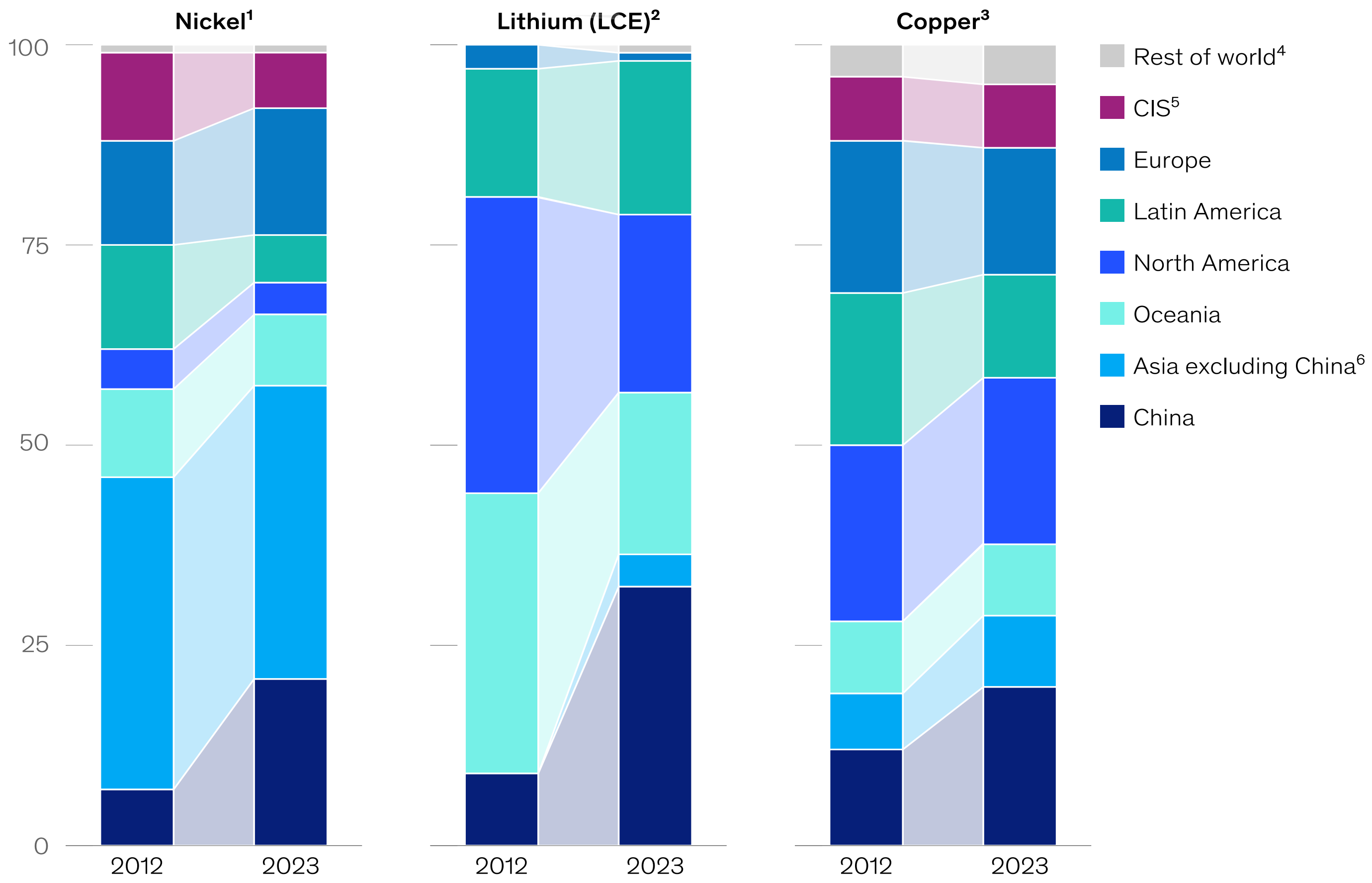
For both refined supply and refining capacity, China has built a global leadership position over the past few decades and is the main refiner for almost all materials considered in this report.[6]

[6] Not limited to the materials mentioned on this page.

Mine ownership has drastically changed in the past decade, with Chinese investors increasing their market share

Copper, lithium, and nickel have all seen increased Chinese ownership

Share of ownership of mine production by origin region of owner, %



[1]~20% of ownership of Indonesian production is unknown; this is allocated based on the same share of ownership as the other 80%. [2]Lithium measured in lithium carbonate equivalent (LCE). [3]Copper measured as metal contained. [4]Includes MENA and Sub-Saharan Africa. [5]Commonwealth of Independent States. [5]Includes developed Asia, India, and Southeast Asia.
Source: McKinsey Metal&MineSpans

Alongside the geographical concentration of supply, there is also a trend of shifting ownership across materials. Our research shows that Chinese investors increased their asset ownership in mining of copper, lithium, and nickel over the past decade. No other region has consistently increased its share of ownership across these materials over the same period.

From 2012 to 2023, Chinese ownership in copper nearly doubled, driven in part by expansion in the Democratic Republic of the Congo, while European and Latin American investors saw a decrease in market share. In lithium, Chinese investors increased their market share in part by the development of domestic lepidolite projects. Finally, in nickel, the majority of Chinese investors' ownership was gained over Latin America and the Commonwealth of Independent States (CIS), with expansion mainly seen in Indonesia.

Countries are putting policies in place to promote domestic supply and safeguard industry competitiveness

Policies will impact the global materials landscape

Highly concentrated supply has caused supply disruptions over the past few years. For example, nickel prices soared when Indonesia restricted exports of nickel ore in 2020, partially explaining why the market has started shifting away from nickel-intense batteries.[7]

Due to the criticality of these materials in strategically important applications, many regions and countries are enacting new policies—not only to increase self-sufficiency and improve the robustness of supply chains but also to help safeguard the competitiveness of their domestic industries in the years to come.

The following examples represent a small number of such policies. Many other countries are taking similar actions, and while smaller in scale, these initiatives collectively will have an impact on the global materials landscape.

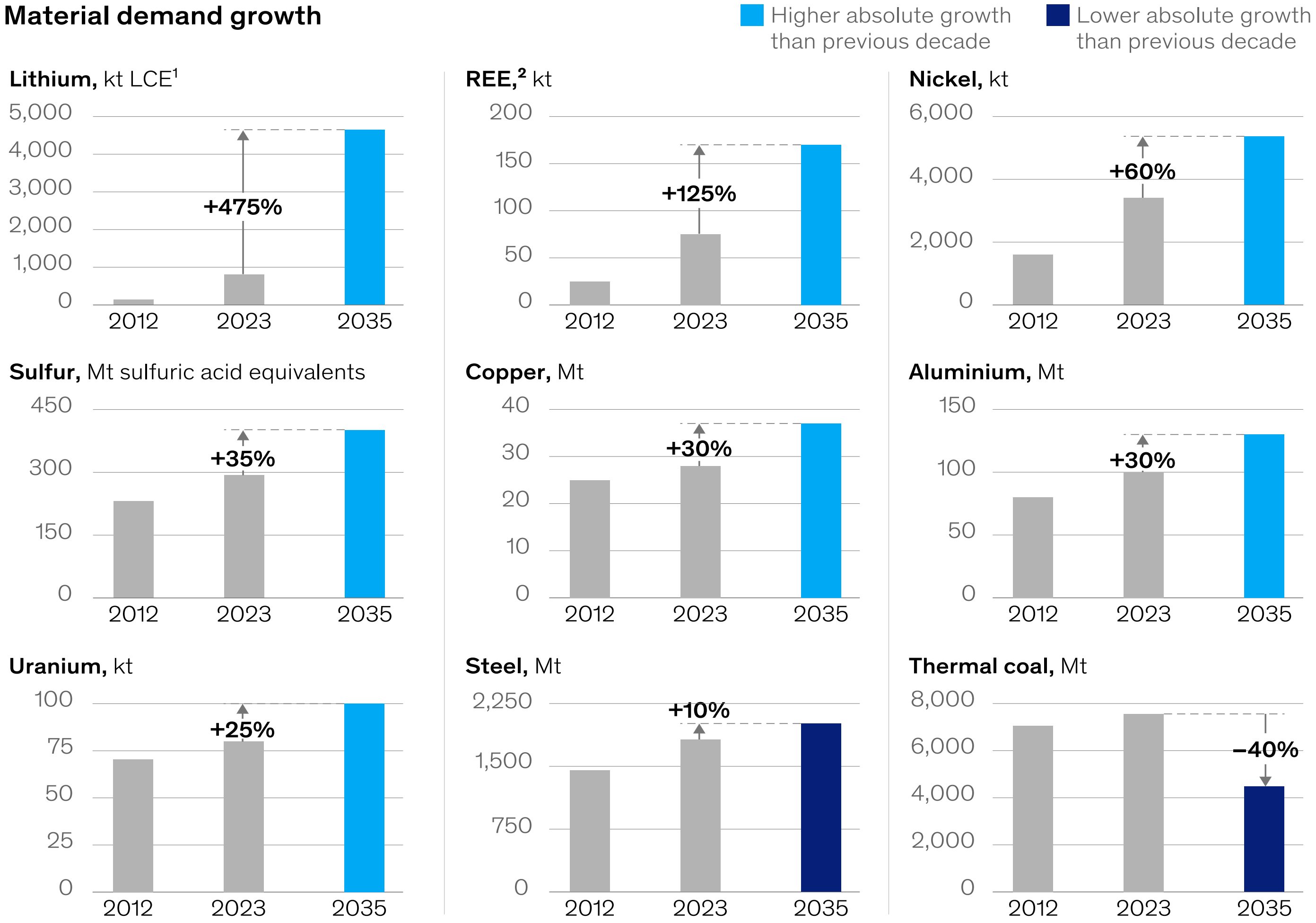
The US Inflation Reduction Act	Critical minerals strategy for Canada	The EU Critical Raw Materials Act	Export restrictions in China	Critical minerals strategy for Australia
The Inflation Reduction Act (IRA) includes subsidies for EVs if a certain share of battery raw materials is sourced in the United States or a country with which the United States has a free trade agreement. In addition, the IRA includes a potential 10 percent production cost credit and a potential 30 percent capex tax credit for novel materials projects.[8]	Canada's strategy targets 31 critical minerals and supports them with a 30 percent Critical Mineral Exploration Tax Credit as well as $1.5 billion to support the supply chain infrastructure build-out and $1.5 billion to support recycling and advanced manufacturing.	The EU Critical Raw Materials Act (CRMA) aims to regionalize extraction, processing, and recycling for more than 15 strategic raw materials by setting targets on local production and limiting single-country dependency to 65 percent for imports of each strategic raw material.	In the past year alone, export controls and restrictions in China were applied to gallium, germanium, graphite, antimony, and rare earth separation and processing technologies, all of which are critical materials for low-carbon technologies.	Australia's strategy targets more than 30 materials, supporting them with loans, guarantees, and equity for strategically important projects.[9] For example, the country has committed more than AU $1 billion (US $670 million) to a first-of-its-kind rare earth refinery in Eneabba.

7 David Guberman, "Nickel in Indonesia: A story of restraints and emerging technologies," US International Trade Commission, May 2021.
8 The details regarding precise qualification criteria for materials and mining projects are still under discussion at the time of this report's writing.
9 Funds committed via Clean Energy Finance Corporation, Export Finance Australia, and Northern Australia Infrastructure Facility. As of June 2023, loans approved of AU $2.3 billion, with another AU $4.0 billion earmarked via the National Reconstruction Fund.

Demand projections remain strong, with the majority of materials outpacing absolute historical growth

The highest relative growth will come from copper and lithium

Material demand growth



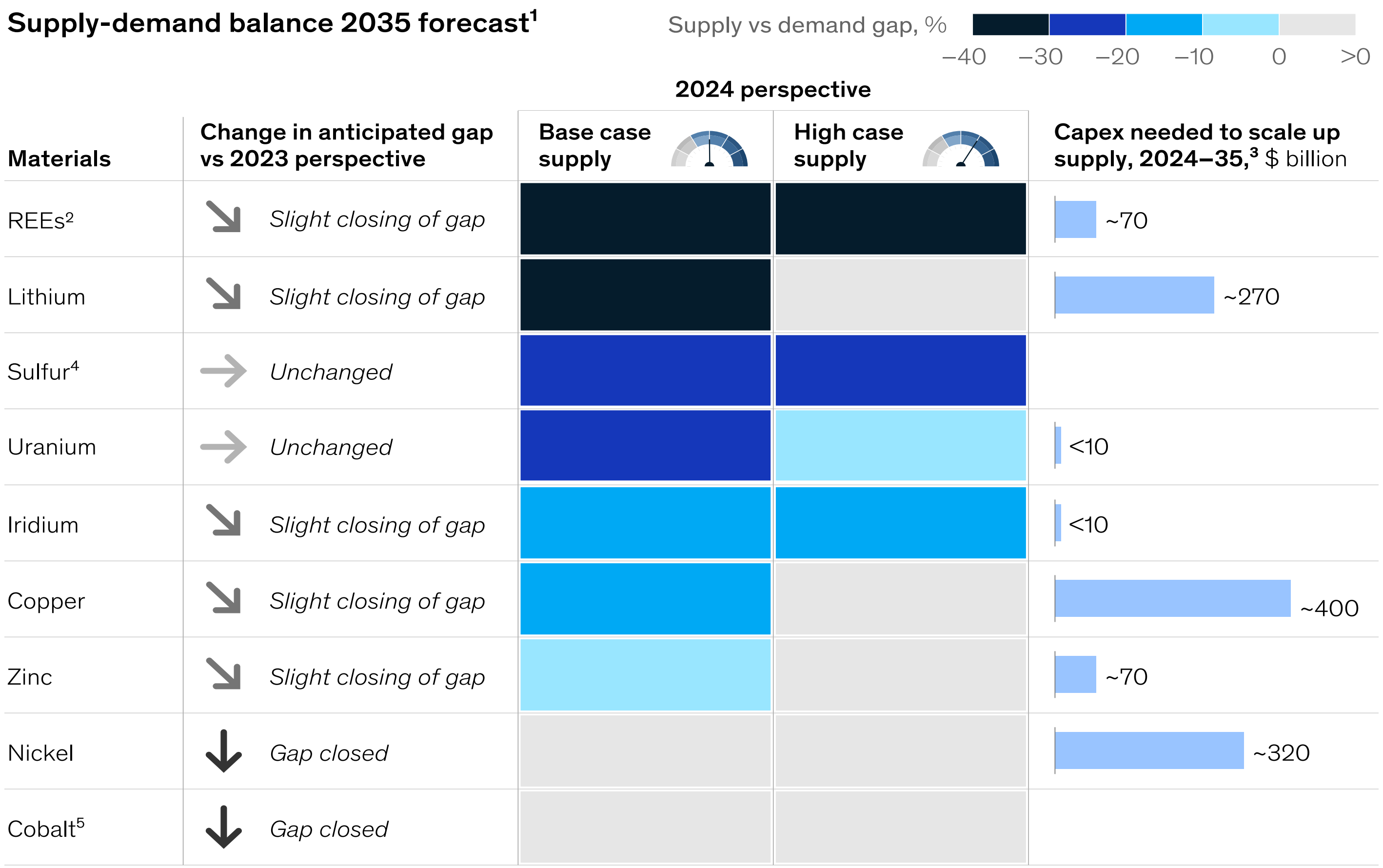
[1]Lithium carbonate equivalent.
[2]Rare earth elements; includes dysprosium, neodymium, praseodymium, and terbium.
Source: McKinsey Global Materials Insights; McKinsey Metal&MineSpans

Demand projections remain strong from now until 2035. In fact, except for steel and thermal coal, demand is expected to outpace absolute historical growth in the coming decade compared with the previous decade for all materials considered in this report, with lithium and copper in particular standing out.

Nickel and REEs are also projected to grow faster than in the previous decade, yet outlooks for both have been adjusted downward compared to estimates from our 2023 publication as demand from the automotive sector is shifting away from high-nickel batteries and REE-intensive EV motors.

Expected supply–demand in 2035 is more balanced compared with our 2023 perspective, but shortages are still anticipated for several materials

REEs, lithium, sulfur, uranium, iridium, and copper may face shortages



[1]Considering mined supply in final product equivalents. Only depicting select metals and minerals that are critical to the energy transition. [2]Rare earth elements. [3]Total mining and processing project capex need. [4]Capex not assessed due to uncertainties in supply development, as sulfur production is primarily a byproduct from oil and gas production rather than a mined product. [5]Cobalt mining and processing capex included in copper and nickel deposits as it is mined and refined as a secondary material.
Source: Bloomberg; CNBC; McKinsey Global Materials Insights; McKinsey Metal&MineSpans; MITMcKinsey

Recent changes in supply and demand have altered the projected supply–demand gap, especially after 2030. In the past 24 months, both nickel and cobalt have moved from expected undersupply to oversupply, as an example.

That said, shortages are still anticipated for several materials key to the energy transition, in particular REEs, lithium, sulfur, uranium, iridium, and copper.

For materials where timelines for project development are fairly limited (in some cases less than five years), the supply–demand gap is likely to be closed by further scaling up supply once demand signals become strong enough. This is the case for uranium, for which scaling challenges depend mainly on the uncertain future of nuclear power as opposed to the scarcity of reserves or a sufficient number of potential projects. A similar example is seen in lithium, where reserves are abundant and mines have relatively short development timelines.

For other materials, the supply–demand gap is less likely to close through the accelerated scale-up of supply because of long project timelines or limited high-quality reserves and projects. In such cases, given that supply and demand must match, demand adaptation or reduction is expected to take place to balance the market. The most notable example in this category is copper.

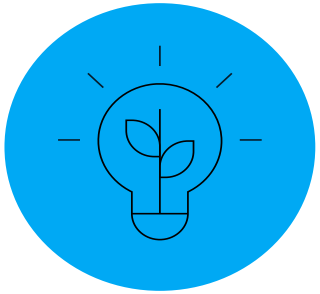
As much as $5.4 trillion in capex and 270 GW of power is needed by 2035 to scale up supply to meet expected demand

A third of a million new jobs may also be needed, as well as infrastructure build-out

Investment, power, and people needed to meet projected 2035 demand

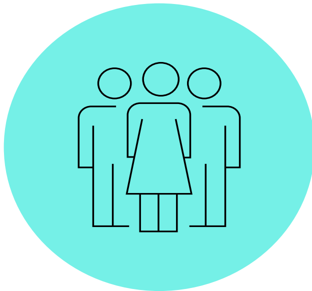
~$5.4 trillion
capex

including exploration, sustaining, and project capex, for both mining and processing,[4] a ***~10% increase*** *compared to previous decade[5]*



~270 GW[1]
power

in addition to the ***1,100[3] GW*** *that would be needed to decarbonize current industry power supply*



~340,000
new jobs[2]

globally in the metals and mining industry—excluding coal, where employment risks ***decreasing by 1,250,000 jobs***

Other enablers

- Timely build-out of infrastructure (logistics, freshwater supply, etc)
- Timely supply of rolling and fixed equipment
- Streamlined permitting procedures while retaining highest ESG standards

[1]Gigawatts; assuming renewable power at 90% utilization and 25% capacity factor. [2]Measured as full-time equivalents (FTEs). [3]Assuming renewable energy to fuel operations, requiring higher capacity than fossil due to lower capacity factor. [4]Includes both refinery and smelting in steel and aluminum, as well as blast furnaces in steel. Considers smelters, refinery plants, chemicals plants, and recycling plants for other materials. [5]Comparing 2012–23 with 2024–35, adjusting for inflation.
Source: McKinsey Metal&MineSpans

Scaling up will be challenging. Meeting projected demand will require an efficient and timely deployment of investments, energy, and logistics infrastructure and equipment, as well as the proper capabilities and steady freshwater availability.

- *Capex:* On a global level, $5.4 trillion is needed for supply to match current demand outlooks by 2035, an approximate 10 percent increase compared with the previous decade.[10]
- *Energy:* As much as 270 GW power is needed (with another 1,100 GW needed to decarbonize) by 2035. That said, the power required, although significant, does not constitute more than 3 percent of projected demand for renewables in 2035.
- *Labor:* 340,000 new jobs globally could be needed in the industry to scale supply, while 1.25 million jobs are at risk in the thermal coal industry.

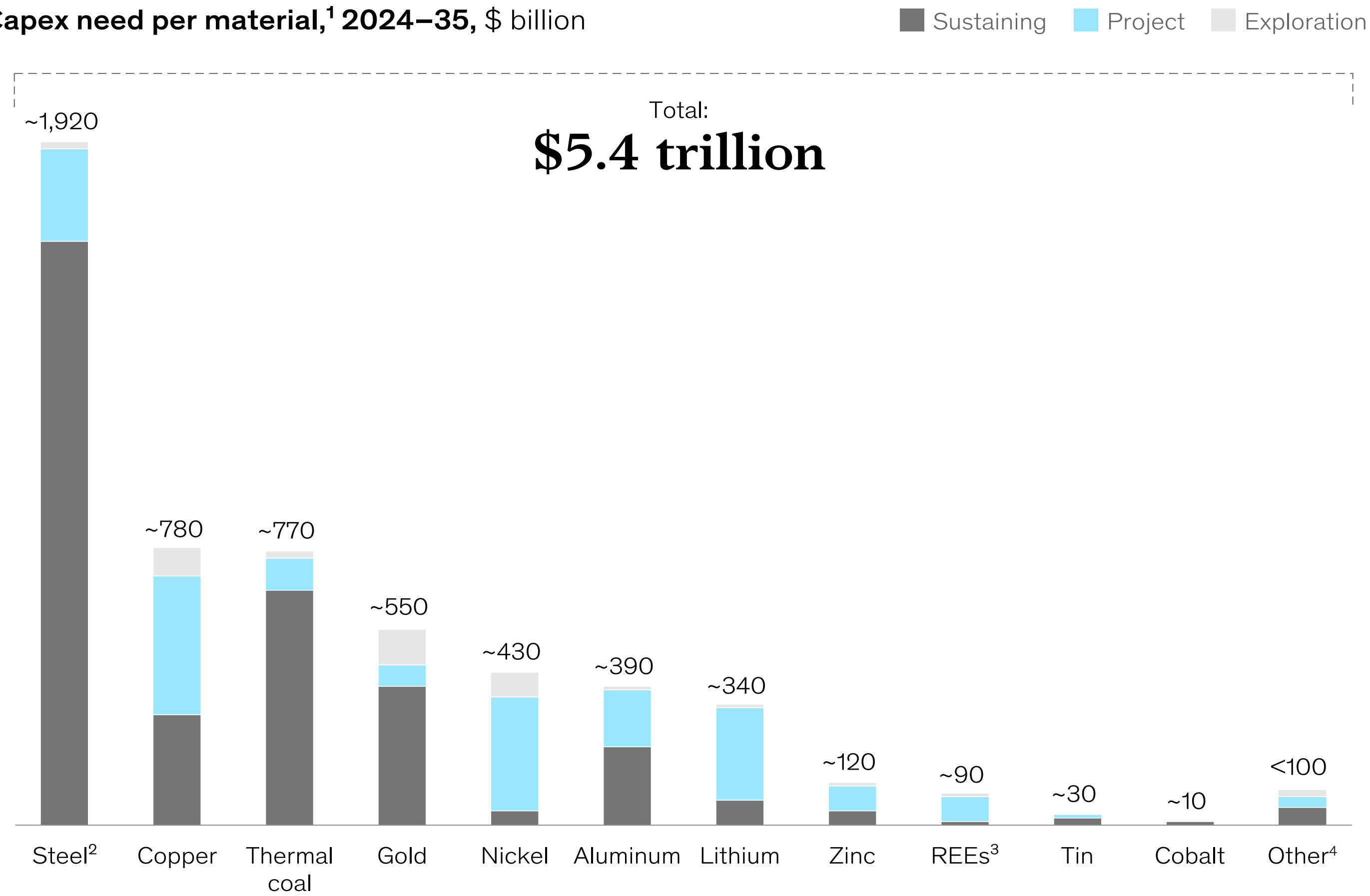
Local challenges regarding skilled labor, steady energy supply, water availability, logistics infrastructure, and equipment supply may hinder deployment, alongside project affordability.

[10] Capex covers exploration, sustaining existing projects, and new projects for both mining and refining.

The majority of investments will still be deployed to sustain existing assets

The top five materials account for 80 percent of investment need

Capex need per material,[1] 2024–35, $ billion



[1]Only sustaining capex for cobalt. Cobalt mining and processing capex included in copper and nickel deposits as it is mined and refined as a secondary material. Inflation adjusted with historical 2015–23 average global PPI, HCPI, and CCPI, with additional +1.5 per annum accounting for additional cost increases in sector for project and exploration capex; considering last 5-year average exploration capex intensity for gold, inflation adjusted for 2023. [2]Including capex need for iron ore, metallurgical coal, and H-DRI expansion. [3]Rare earth elements. [4]Considering other materials such as uranium, platinum group metals (PGMs), graphite, silicon, and manganese.
Source: S&P Global Market Intelligence; McKinsey Metal&MineSpans; McKinsey Value Intelligence Platform

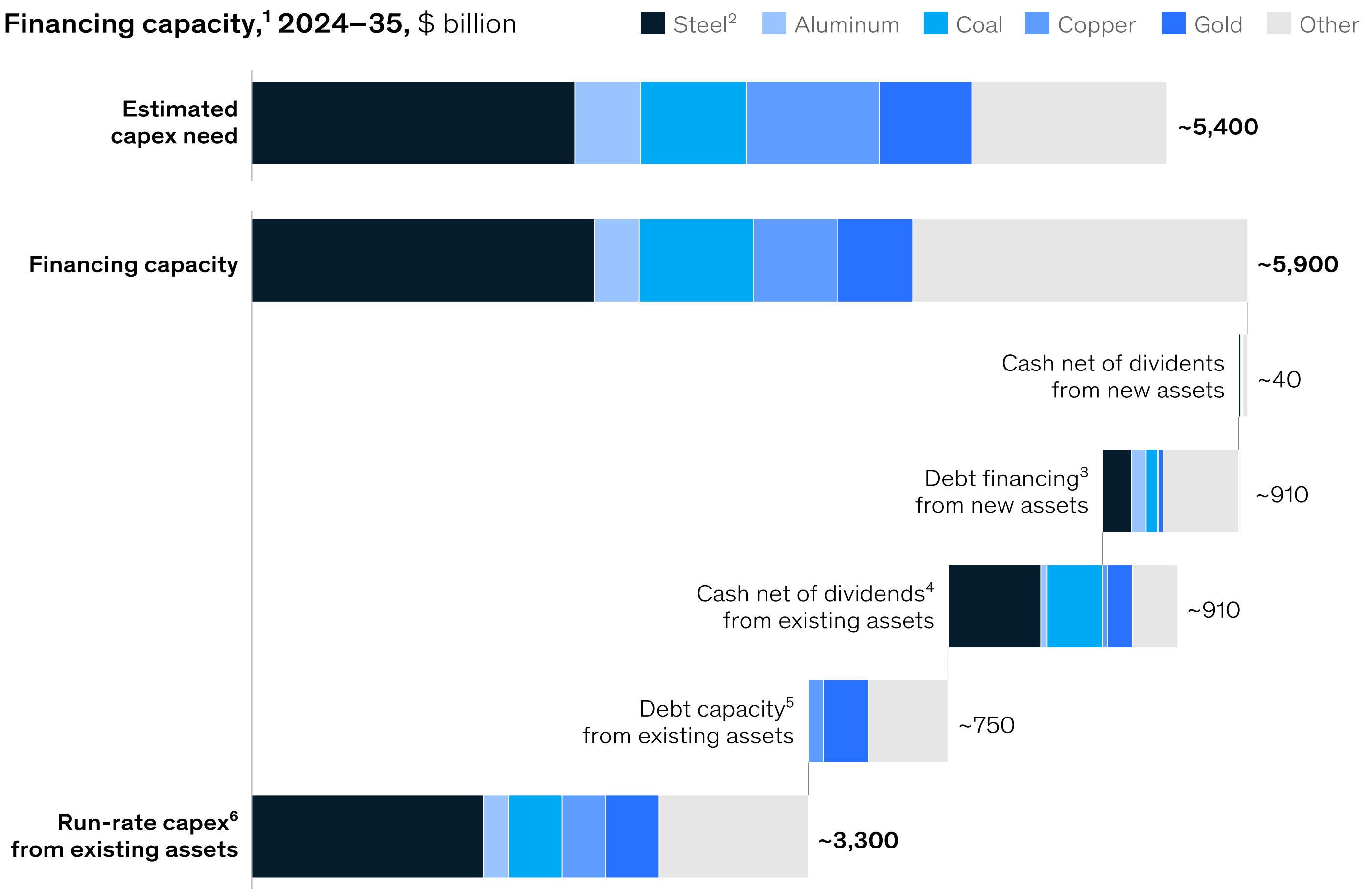
The scale-up will require investments in refineries and mines, though the majority of capex will be deployed in sustaining existing assets, particularly for the five primary materials: steel, thermal coal, gold, copper, and aluminum. The total investment need is estimated at a $5.4 trillion split between sustaining current projects (around 60 percent), new project development (35 percent), and exploration (5 percent). Out of that, the five largest materials account for 80 percent.

Capex requirements for projects will likely be most dominant in copper, nickel, and lithium (notably Indonesian nickel assets), which will trigger a ramp-up of capex deployment across Asia, Latin America, and Sub-Saharan Africa.[11]

[11] Asia, excluding India, Japan, Korea, Mainland China, or Taiwan.

The metals and mining industry's financing capacity could theoretically finance the scale-up

Strong financial performance in 2023 puts the industry in a solid position to invest



Note: Base-case scenario. Assuming long-term supply equaling demand.
[1]Based on 2012–23 uses of cash and performances of metals and mining companies out of the top 3,000 largest global companies (n = 120), subsequently applying forecasted demand and forward-looking inflation. [2]Including financing capacity of iron ore and metallurgical coal. [3]Project capex. [4]Net dividends and buybacks; copper and gold have negative values. [5]Increase from historical net debt/EBITDA to 2.0× when possible, excluding increased debt leverage to coal and steel assets. [6]Represents total historical capex levels including sustaining, exploration, and project capex, industry average excluding coal and steel for "Other."
Source: S&P Global Market Intelligence; McKinsey Metal&MineSpans; McKinsey Value Intelligence Platform

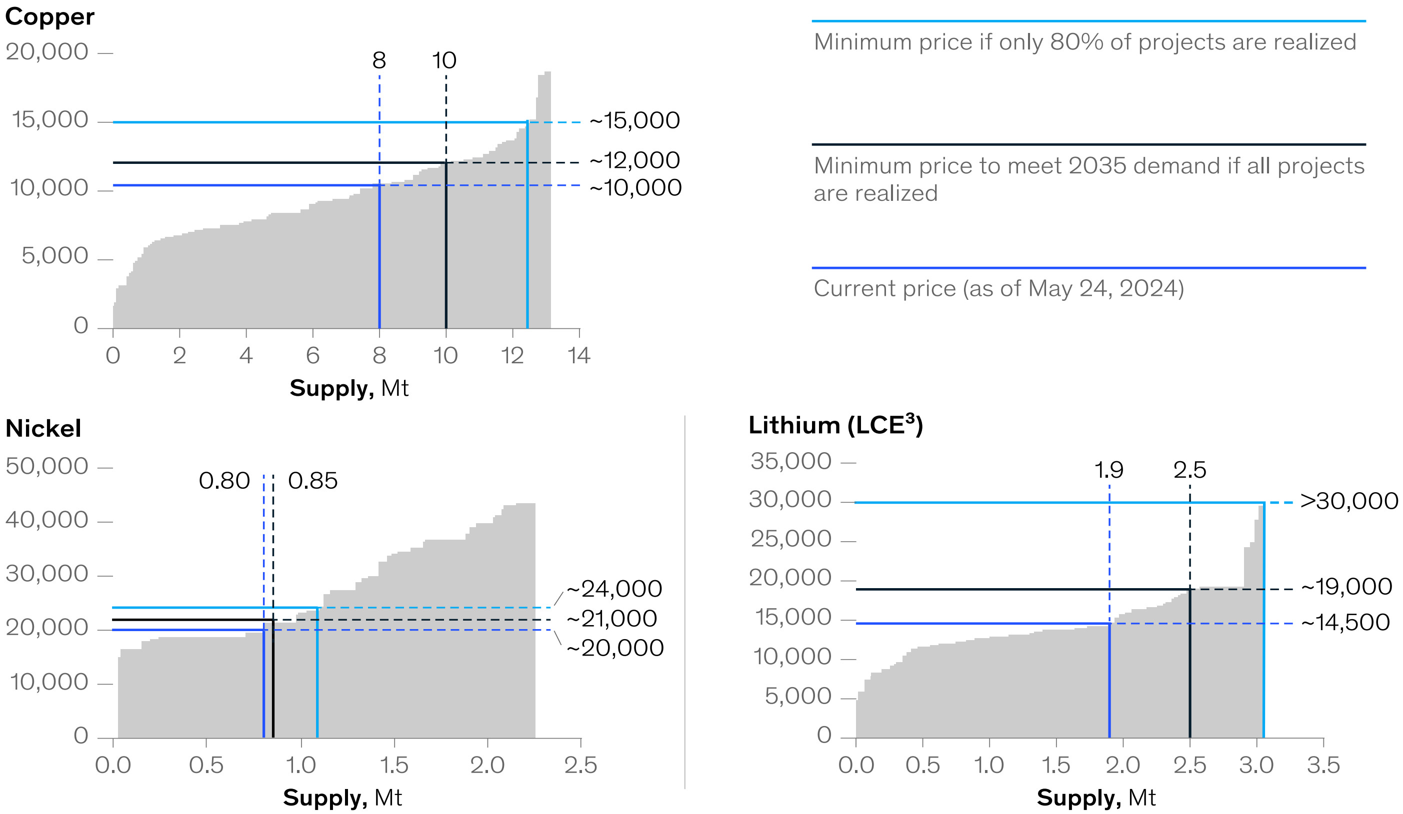
Given the strong financial performance of the mining sector in 2023, the materials industry's overall financing capacity (net of dividends), estimated at $5.9 trillion, should theoretically be sufficient to meet future projected demand.

The financing capacity considers cash generation in the coming decade net of dividends (approximately $900 billion), debt financing on existing assets up to an investment grade threshold of 2.0 times net debt over EBITDA—from the current 1.3 times (approximately $750 billion)—and debt financing of new assets up to 2.0 times (an additional $900 billion).

Price increases will likely be required to incentivize sufficient supply to come online

Current copper prices would need to increase by 20 percent to drive sufficient supply

Incentive price of announced copper, nickel, and lithium projects with 15% IRR,[1] High-case scenario, $/ton[2]



Note: Each project's incentive price is an estimate of the average benchmark price, throughout the life of the mine, that sets the net-present value of the investment to zero using a discount rate of 15%.
[1]Internal rate of return. Projects with an incentive price above $20,000/ton copper, $45,000/ton lithium, and $35,000/ton nickel are removed from the charts.
[2]Metal contained.
[3]Lithium carbonate equivalent.
Source: McKinsey Metal&MineSpans

Since 2022, prices for lithium have dropped by approximately 80 percent to $14,500 per ton lithium carbonate equivalent (LCE) and prices for nickel have dropped by approximately 20 percent to $20,000 per ton.[12] These decreases represent a "normalization" rather than a drastic shift in industry dynamics, as prices moved closer to typical production costs.

To incentivize sufficient supply, nickel prices would need to increase by around $1,000 per ton, a 5 percent increase from current levels, assuming that the most economical projects would be prioritized and delivered on time. For lithium and copper, the pipeline of announced projects is smaller and the demand increase is higher. Therefore, a higher price increase would be needed to incentivize sufficient supply to meet demand. For copper, an approximate 20 percent increase from current prices would be needed, and for lithium, the approximate required price increase is 30 percent, provided all announced projects come online.

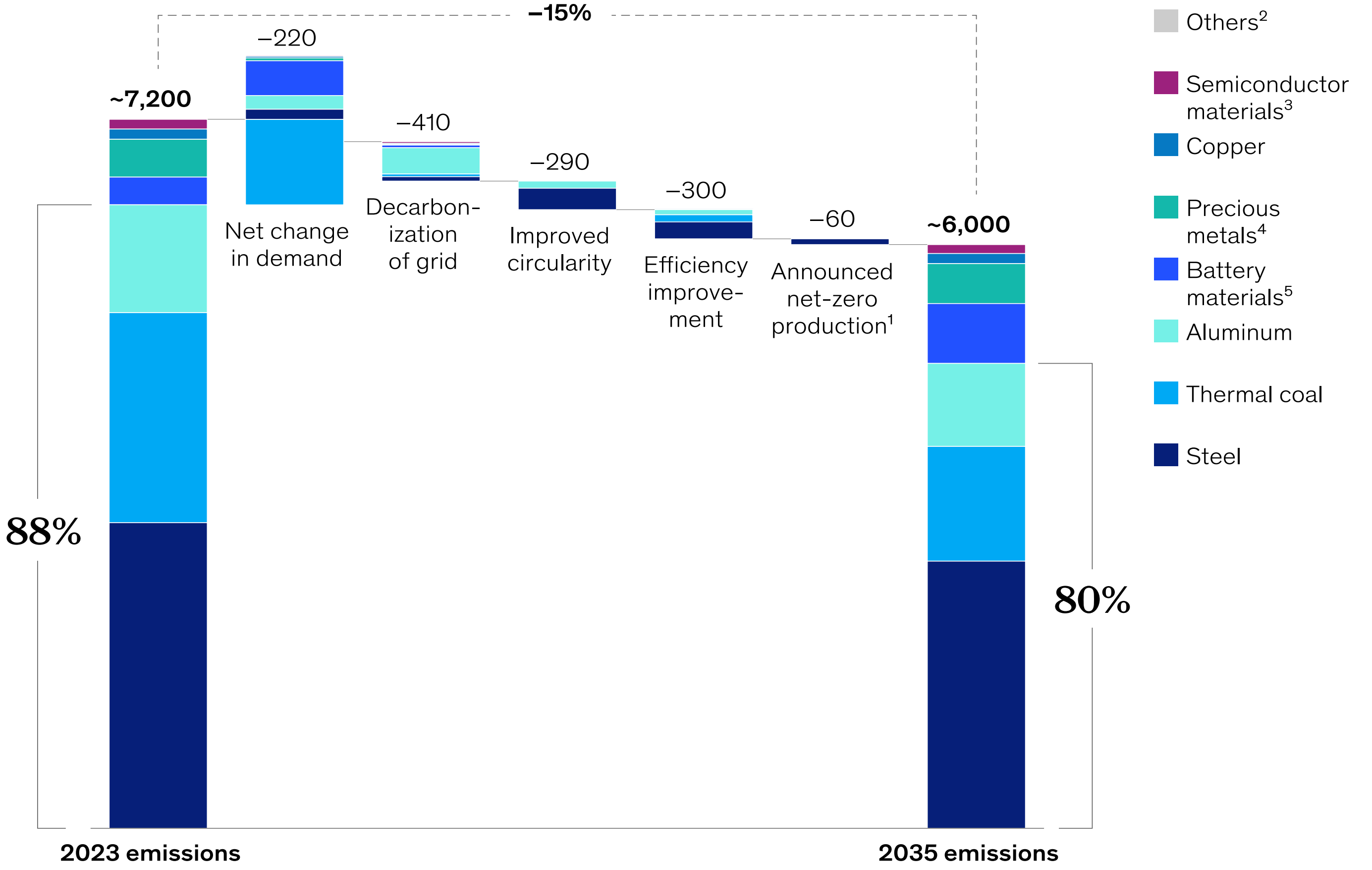
However, history has shown that the most economical projects are not always the first to be realized, given the range of barriers aside from profitability that can impact project execution, such as permitting delays. Moreover, individual projects may also have different required rates of return to be approved by owners and investors, which would in turn mean different levels of required incentive prices. All in all, if some of the more profitable projects were not to advance—whether due to barriers or higher return rates required—a further price increase would be needed to bring new supply online.

[12] LCE is a measurement used to convert lithium quantities into a standard unit for comparison; comparing annual average price of 2022 with year-to-date prices in May 2024.

Over the next decade, total metals and mining emissions are estimated to decrease by a modest 15 percent

The metals and mining industry could contribute 13 percent of global emissions in 2035

Emissions from metals and minerals production, $MtCO_2$ equivalents per annum



[1]Could significantly increase with uptake in projects. [2]Zinc, sulfur, uranium. [3]Tin and silicon. [4]Gold and platinum group metals (PGMs). [5]Lithium, nickel, cobalt, manganese, graphite.
Source: IEA; International Aluminum Institute; International Copper association; *Industrial Transformation 2050* (Material Economics, 2019); Statista; Transition Pathway Initiative; World Steel Association; McKinsey Metal&MineSpans

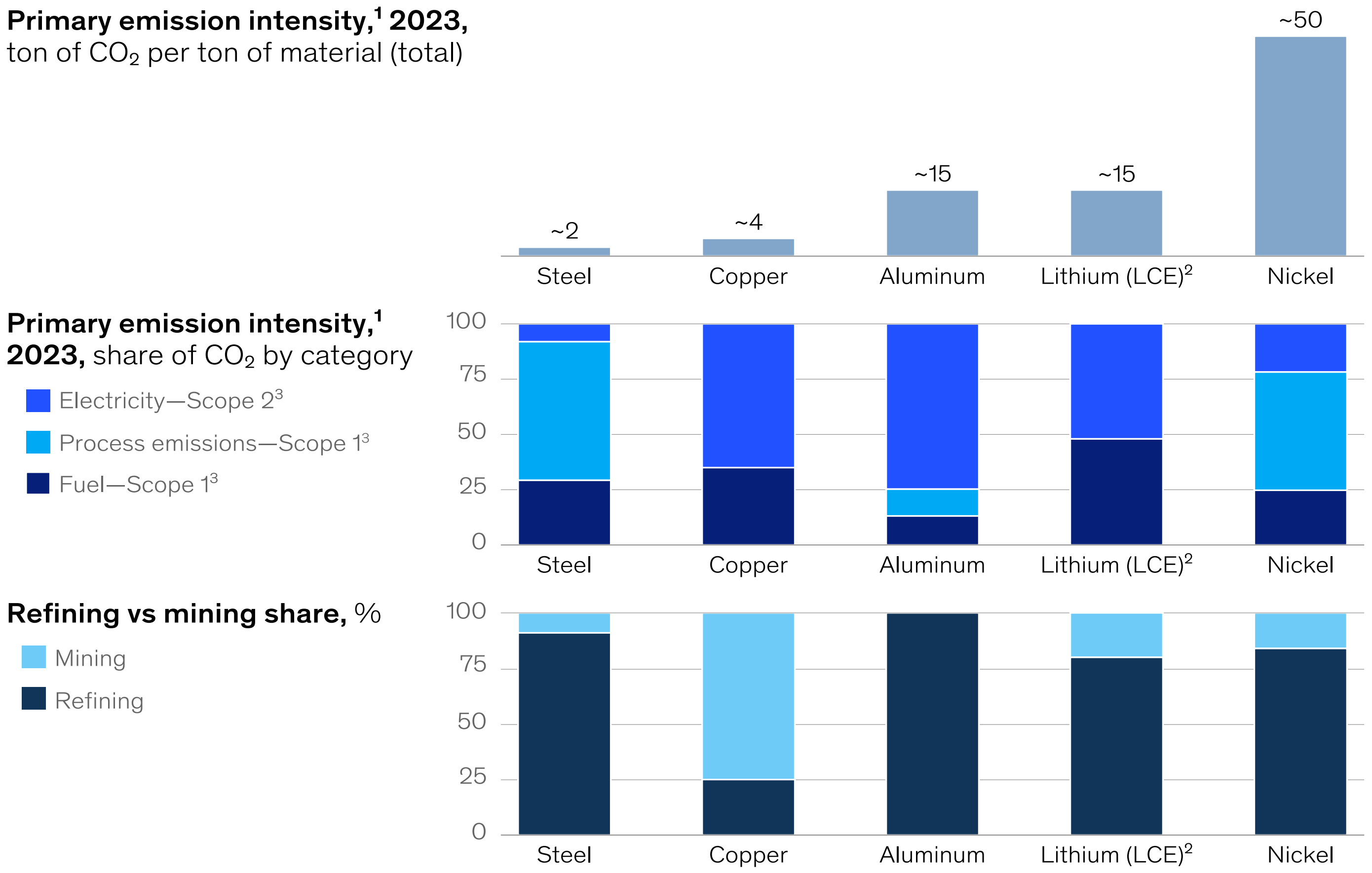
In 2023, total production emissions from the metals and mining industry accounted for approximately 15 percent of global emissions. Assuming no external shifts, the share is estimated to decrease to approximately 13 percent by 2035—a 15 percent decline. This decrease in emissions is driven by five factors:

- **Changes in demand:** Net impact from decreasing emissions from thermal coal production, offset by increasing emissions from other materials that will see demand growth.
- **Grid decarbonization:** The global grid is projected to decarbonize by close to 50 percent as the share of renewable energy increases, reducing emissions for those assets that are reliant on grid power for their operations.[13]
- **Improved circularity:** The share of recycled materials, which have a lower carbon footprint, will increase, driven by higher availability of scrap and improved collection and recovery rates.
- **Efficiency improvements:** Continued efficiency improvements estimated at 0.5 percentage point per annum.
- **Announced net-zero production:** In addition to incremental decarbonization, there have been several announcements of asset-level transitions toward new technologies. In steel alone, approximately 40 Mt capacity of such transitions have already been announced by 2035, which would lower global emissions by as much as 60 $MtCO_2$.

[13] *Global Energy Perspective 2024*, McKinsey, September 17, 2024.

Electricity-related emissions are the largest contributor of emissions for most materials in the metals and mining industry

Renewable energy could abate a significant proportion of emissions



Note: Based on reported performance of operational assets.
[1]Considering 2023 weighted average emissions intensity with production volumes. [2]Lithium measured in lithium carbonate equivalent (LCE). [3]The Scopes 1 and 2 here denote the accounting scope for a player that is producing the emissions, ie, for the player performing the mining or processing. While fuel and process emissions are always accounted as Scope 1, electricity that is generated by the player itself would be accounted for as Scope 1, while purchased electricity is Scope 2.
Source: IEA, International Aluminum Institute; International Copper association, *Industrial Transformation 2050* (Material Economics, 2019); Statista; Transition Pathway Initiative; World Steel Association; McKinsey Metal&MineSpans

Steel contributes approximately 45 percent of the industry's overall CO_2 emissions. However, there are several materials that report higher CO_2 intensities (the CO_2 generated per ton of material produced).

Electricity is often the primary contributor to emissions intensity, meaning that renewable energy could already abate a significant portion of emissions at reasonable cost. Although fuel-related emissions can also in principle be abated, costs for low-carbon heating fuels, such as biofuels or green hydrogen, are significantly higher than natural gas.

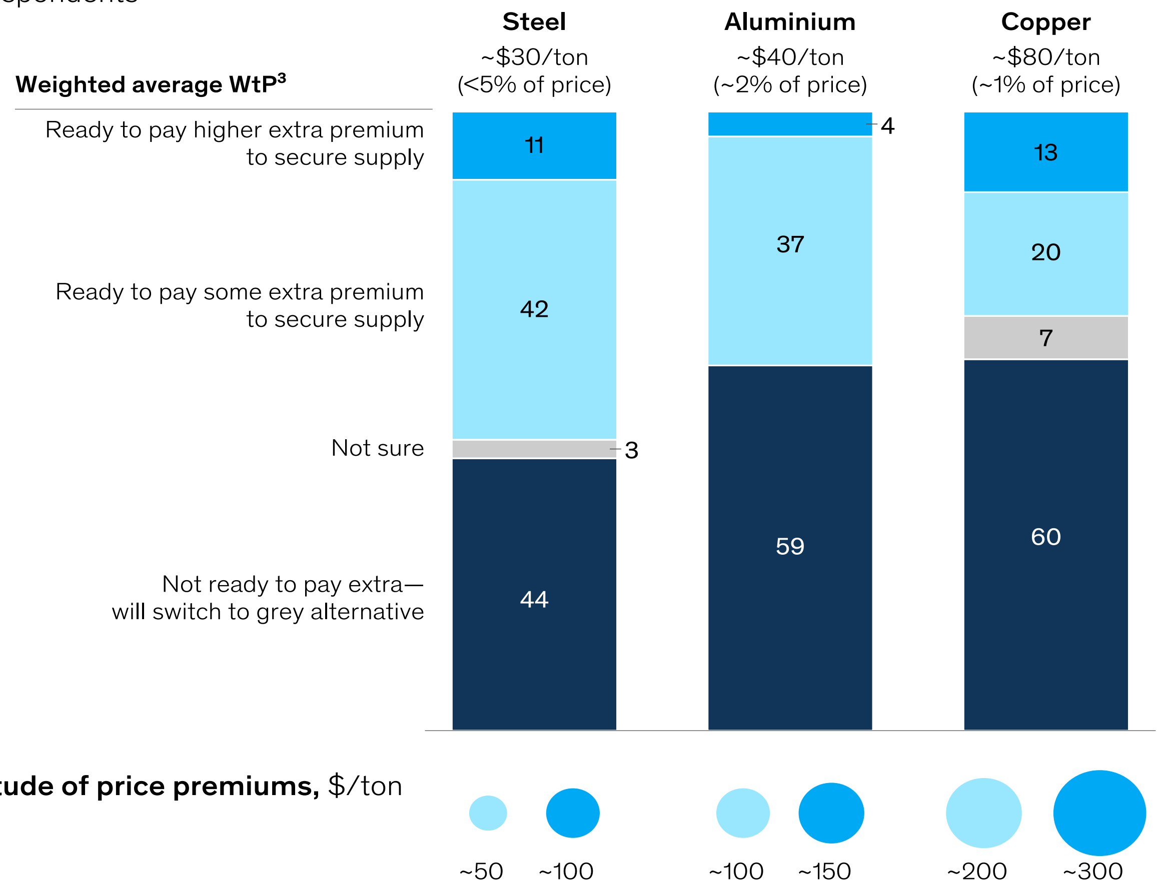
The chemical processes for producing steel, aluminum, and nickel yield CO_2 as a by-product. These emissions cannot be abated with green electricity or alternative fuels but instead require alternative production technologies or carbon capture.

Although technologies for "deep decarbonization" are available for several materials, production costs are expected to increase with the implementation of these technologies, making the implementation economically challenging in many cases. For example, to reach close to full decarbonization in steelmaking with hydrogen reduced iron (H-DRI) and renewable energy, production costs could increase by 30 to 40 percent, and in copper and lithium, production costs could increase by 10 to 20 percent.

Research shows less than 15 percent of customers indicate a willingness to pay premiums of around 10 percent for low-carbon materials

However, regulatory measures could change the outlook

Willingness-to-pay ("WtP") additional premium if green materials are in deficit by 2030,[1]
% of respondents[2]



Our recent survey of leading industry players shows a limited willingness-to-pay for greener materials. In fact, less than 15 percent of surveyed decision makers indicate they would be willing to pay a premium of around 10 percent if there was a scarcity of green materials by 2030.

However, increasing publicly announced measures such as the EU ETS and CBAM could significantly change this outlook by imposing higher costs on companies based on their carbon emissions. In response, companies might seek to either switch to sourcing low-carbon-footprint materials or invest in innovative solutions to reduce process emissions.

[1]Some segments such as automotive and energy equipment players stand out as having a higher willingness-to-pay than other sectors.
[2]36 respondents in steel, 27 in aluminum, and 15 in copper.
[3]"Higher extra premium" is $100/ton for steel, $150/ton for aluminum, and $300/ton for copper. "Some extra premium" defined as $50/ton for steel, $100/ton for aluminum, and $200/ton for copper.
Source: McKinsey global survey of decision makers in materials sales and purchases, March 2024

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