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Transition Metals Outlook 2024

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Section 1. Introduction

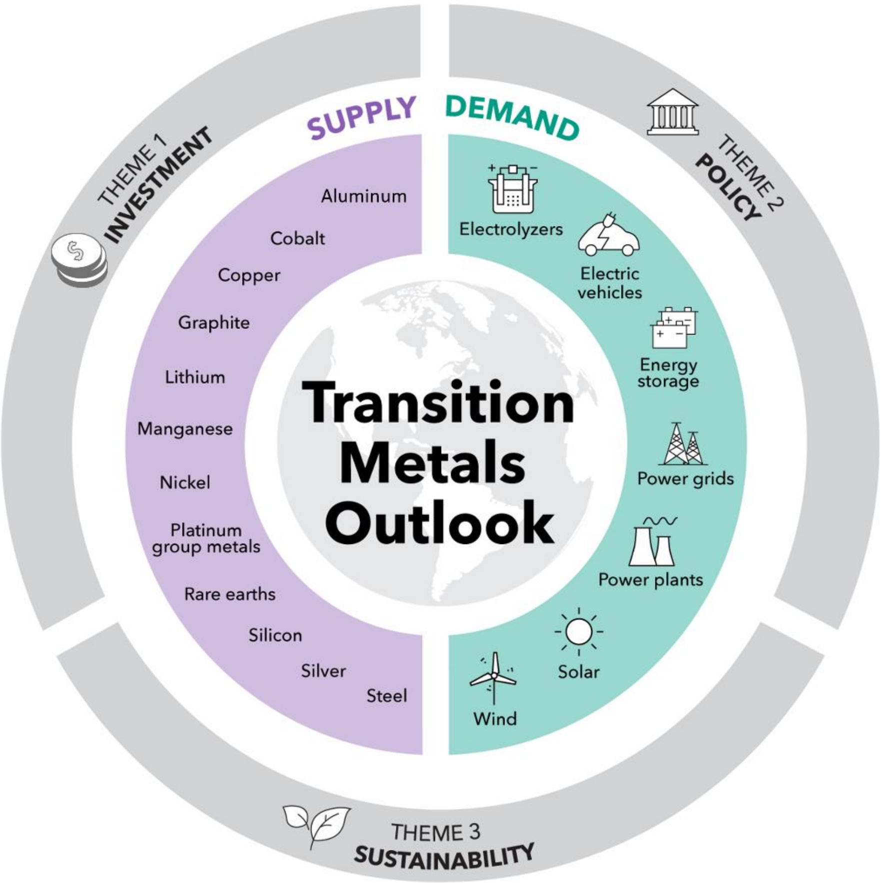
1.1. What is TMO 2024?

The *Transition Metals Outlook* (better known as TMO) is BNEF's annual long-term outlook for the role of metals in the energy transition. It empirically determines how the shift to a low-carbon economy will drive demand for metals and answers the question of whether there will be enough supply to meet demand.

The 2024 edition of TMO assesses seven energy and transport technologies clustered around three broad areas: power generation and storage, the power grid, and transport (Figure 1). Under power generation and storage, we analyze wind, solar, gas, coal, electrolyzers and stationary energy storage. Under transport, we explore demand from vehicles, as well as from the batteries that go into them. Finally, for power grids, we estimate demand from underground, overground and subsea cables. Demand from other traditional sectors like construction and industrial equipment is also calculated but not detailed in this report.

On the supply side, we develop a 25-year view for the major metals that cut across various end uses.

Figure 1: Transition Metals Outlook 2024 framework



Source: BloombergNEF

1.2. What is new in TMO 2024?

The new areas covered in this year's outlook are:

- **Supply forecast update**: BNEF has updated the supply curves for lithium, nickel, cobalt, manganese, copper, aluminum and steel.
- **Platinum group metals**: BNEF has introduced a view on the demand for platinum group metals from both traditional and transition-related end-use segments.
- **Country spotlights on demand**: This report features spotlights on the growth in demand for energy transition metals in the US, Europe, Southeast Asia and China.
- **Data viewer**: A data viewer has been compiled for users to view the data used in the report at a granular level.
- **New themes**: This latest edition introduces new thematic highlights on the investment required to meet raw materials demand, how to construct policy support to achieve supply chain security, and sustainable mining practices to preserve biodiversity.

1.3. Scenarios and outlooks at BNEF

This research forms part of the library of energy transition scenarios at BNEF. The core scenario used in our research is the Economic Transition Scenario. This lays out how commercially available technologies could be deployed based on the underlying economic fundamentals of the energy transition, in the absence of new policy regimes.

In addition to that economics-led pathway, BNEF has developed a range of global, sector-based, and country-level scenarios, including detailed modeling in the transport sector. Scenarios are future-focused simulations combining a number of uncertain parameters into an internally consistent narrative. They are predominantly used for medium- to long-term investigative studies and may also include sensitivities to key variables. Scenarios differ from forecasts, which are usually shorter-term predictions of what we think will happen.

BNEF's flagship *New Energy Outlook* presents two carefully calibrated scenarios, rather than a range of outcomes based on sensitivities. Our scenarios are therefore best understood as reference scenarios, instead of sensitivities or stress-testing scenarios.

Scenarios from BNEF's New Energy Outlook

For more, see BNEF's *New Energy Outlook 2024* (web | terminal)

The outlook for the power generation, power storage and power grid sectors in this report builds on the results from our *New Energy Outlook 2024*. That report presents country-level harmonized pathways for nine economies, showing what a credible pathway to net zero could look like.

The *New Energy Outlook* (better known as NEO) is BNEF's long-term scenario analysis on the future of the energy economy covering electricity, industry, buildings and transport, and the key drivers shaping these sectors until 2050. As part of NEO, we use our in-house NEFM-2 power model to determine a least-cost system that can reliably meet electricity demand throughout the year.

NEO 2024 covers two main scenarios:

The Economic Transition Scenario (ETS) is our base-case assessment of how the energy economy could evolve from today as a result of cost-based technology change to 2050. It combines near-term market activity, the uptake of new consumer-facing energy products, least- cost system modeling and trend-based analysis to describe the deployment and diffusion of commercially available technologies and their tipping points.

This pathway incorporates near-term policy where legislated and designed to affect competitive economics, but does not assume either country-level, or corporate, long-run energy and climate objectives are necessarily met. Technology transition only occurs in this scenario where it lowers system cost or offers an attractive payback proposition for consumers. In this way, the ETS describes how the energy sector might evolve in the absence of further major climate policy intervention – in a world where clean technologies can compete on a level playing field.

BNEF scenarios take a demand-led modeling approach. Population and economic activity across the world continue to expand, driving up demand for energy-intensive commodities such as steel, cement, aluminum and chemicals. So, too, does the demand for the movement of goods and people by road, rail, air and sea. With population growth and higher GDP comes an increase in commercial and residential building stock, and with that a rise in demand for space and water heating, electricity for lighting and appliances, and either gas or electricity for cooking. In our modeling, countries' electricity-intensity of GDP evolves in line with changes to the dominant forms of economic activity, and energy efficiency improves over time throughout the economy via incremental improvements on both the demand and supply side.

Carbon prices are included where compliance schemes are already in place, driven by market fundamentals. Greenhouse gas emissions under NEO's latest ETS are consistent with a 67% chance of limiting the global temperature rise to 2.6C by 2100.

The Net Zero Scenario (NZS) describes an economics-led evolution of the energy economy to stay within a carbon-emissions constraint and achieve net-zero emissions in 2050, with no overshoot or reliance on net-negative emissions after 2050. We take a sector-led approach to decarbonization, meaning countries' carbon budgets are largely determined by the sectoral make-up of their economies, and the expected growth in those sectors. Neither historical responsibility nor availability of finance is taken into consideration.

The NZS combines faster and greater deployment of renewables, nuclear and other low-carbon dispatchable power technologies with the uptake of cleaner fuels, most notably hydrogen and bioenergy, in end-use sectors. Carbon capture and storage emerges toward the end of the 2020s, allowing some continued fossil-fuel use in electricity generation and industry. Additionally, accelerated electrification and increased recycling of materials further contribute to emissions reductions. The NZS is therefore not an extension of the ETS; it describes a fundamentally different energy economy.

While the technological choices in the NZS are primarily guided by economics, we also account for countries' strategic priorities and strengths, firm and legislated existing policy, and local resources.

The NZS shows a plausible, global pathway – with country-level detail for key economies – to achieve the main goals of the Paris Agreement and stay well below 2C of planetary warming. Greenhouse gas emissions under NEO's latest NZS are consistent with a 67% chance of limiting the global temperature rise to 1.75C by 2100. This trajectory is also consistent with a 33% chance of staying within 1.5C, and a better-than-67% chance of staying below 2C.

The more ambitious Paris Agreement target of limiting global warming to 1.5C looks increasingly out of reach, but concerted action can still put the world on a track that approaches this benchmark and avoids the worst effects of climate change.

Scenarios from BNEF's Electric Vehicle Outlook

For more, see BNEF's *Electric Vehicle Outlook 2024* (web | terminal)

The outlook for the transport sector in this report builds on the results from our *Electric Vehicle Outlook 2024* (better known as EVO), which combines near-term forecasts with a long-term scenario. From 2024 to 2027, EVO includes a bottom-up forecast for each vehicle segment and country. This takes into account factors like current and upcoming EV models available, policy and incentive frameworks, historical growth rates, consumer adoption patterns, and more. From 2028, EVO splits into two long-term scenarios:

Economic Transition Scenario (ETS): This is the main scenario described in this report. It assumes no new policies or regulations are enacted that impact the market. It also does not assume any long-term climate targets are hit, or that any combustion vehicle phase-out targets that have been announced by countries, states, cities or companies are achieved. Instead, adoption is primarily driven by techno-economic trends and market forces. Unless otherwise stated, the charts and analysis in this report refer to the ETS. Most analysis in the ETS stops at 2040, but we have extended this to 2050 in some areas to compare with our Net Zero Scenario.

Net Zero Scenario (NZS): This scenario investigates what a potential route to net-zero emissions by 2050 might look like for the road transport sector. It looks primarily at economics as the deciding factor for which drivetrain technologies are implemented to hit the 2050 target. The NZS is one of a number of possible pathways that could meet this goal, and we are not claiming this is the most likely. Calculations for metals demand in TMO 2024 use the NZS modeling from both the NEO and EVO reports.

Section 2. Executive summary

6 billion metric tons

Global demand for energy transition metals across 2024 to 2050 in a net-zero emissions pathway

2032

Expected year of primary supply deficit for lithium in a world on track for net zero by 2050

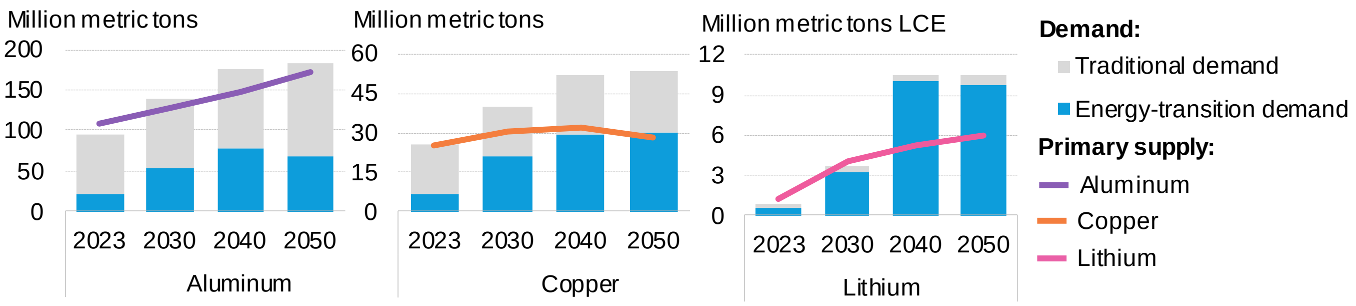
$2.1 trillion

Investment needed in energy transition metal sectors between now and 2050 to meet demands of net zero

Metals are fundamental to many of the technologies that will underpin the global shift to a low-carbon economy – everything from wind turbines and electric vehicles to power grids and electrolyzers that produce green hydrogen. But key energy transition metals face a tightening of primary supply, with potential deficits for aluminum, copper and lithium this side of 2030 and early in the next decade. Increased recycling will be essential to help address market imbalances, as will investment in new reserves. To build the mines of tomorrow, the mining industry must invest in exploration today. BloombergNEF estimates $2.1 trillion is needed for energy transition metal sectors between now and 2050 to meet the demands of a net-zero emissions world.

- If the deployment of clean technologies is driven by the cost-competitiveness of technologies – what BNEF calls its Economic Transition Scenario – the world could require 3 billion metric tons of metals across 2024 to 2050. That doubles in a pathway where net-zero emissions are reached by mid-century, to 6 billion tons.
- Thanks to the ongoing electrification of transport, lithium demand is set to expand the most over the coming two and a half decades, with a 17-fold jump between 2023 and 2050 in BNEF's Net Zero Scenario. Fellow battery metal manganese also sees exponential growth in this pathway, with demand surging 15-fold.
- Amid the present slowdown in EV sales growth and China's property sector woes, a near-term oversupply of several energy transition metals has subdued prices and driven miners to curb output at more expensive operations. But with demand poised to recover and keep climbing in the long run, there is a risk known reserves will be depleted over the coming decades.
- A prolonged deficit of metals could lead to higher prices, raising the cost of clean technologies and potentially slowing their adoption. Investment in primary metals supply needs to ramp up, as does recycling activity, to avoid the expected supply squeeze (Figure 2). But scaling up mining efforts needs to be done responsibly, safeguarding biodiversity. Achieving net zero could see the land required for energy transition metals extraction more than triple to 162,000 square kilometers by 2050 – an area roughly the size of Uruguay.
- *(Corrections were made to this report on October 10, 2024 and are listed on Appendix C.)*

Figure 2: Primary supply of selected energy-transition metals and demand in BNEF's Net Zero Scenario



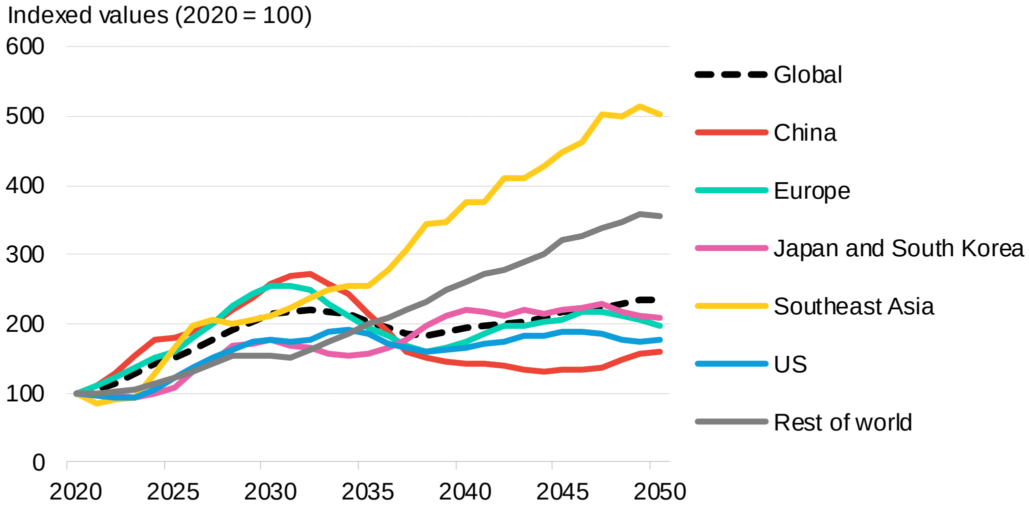
Source: BloombergNEF. Note: LCE is lithium carbonate equivalent. The Net Zero Scenario is an economics-led evolution of the energy economy to achieve net-zero emissions globally by 2050.

Metals consumption in Southeast Asia grows the fastest in the 2030s

Each region faces a unique set of challenges to secure the metals needed for the energy transition as the pace of demand growth varies substantially. China's consumption outgrew the global average between 2020 and 2023 but is expected to peak in 2030 in the Economic Transition Scenario (Figure 3). China will have to avoid overcapacity for metals production beyond this peak as domestic demand saturates.

By contrast, the likes of Europe and the US are setting aggressive targets to build domestic metals supply to adequately meet their growing needs. Southeast Asia records the fastest market expansion in later decades in the Economic Transition Scenario. With a large-scale upstream mining industry, the region could create additional value by adding metals processing and component manufacturing capacity.

Figure 3: Growth of energy transition metals demand relative to 2020 levels under BNEF's Economic Transition Scenario, by region



Source: BloombergNEF. Note: Demand growth is calculated using the three-year rolling average, indexed to 2020 demand, excluding platinum group metals.

Supply of metals will keep growing despite low prices today

The metals and mining industry is grappling with several near-term pressures. Lower demand projections from sectors such as electric vehicles have resulted in depressed prices for key battery metals and minerals, while infrastructure and property sector woes in China have adversely impacted demand for industrial metals.

As the low-price environment persists, operational capacity has been curbed at costly mines and assets, adding to supply risks. While the longer-term impacts of this curtailed activity add to the uncertainty, the trajectory of supply points to continual growth (Table 1).

Table 1: Comparison of metals supply in 2023 and 2050

Commodity	Units	Total annual supply		Percentage growth
		2023	2050	2023 vs 2050
Steel	Metric tons	1,901,152,085	2,238,541,845	18%
Aluminum	Metric tons contained metal	108,189,794	173,070,319	60%

Commodity	Units	Total annual supply		Percentage growth
		2023	2050	2023 vs 2050
Copper	Metric tons contained metal	24,888,624	32,332,187	30%
Nickel	Metric tons contained metal	5,775,372	9,467,234	64%
Cobalt	Metric tons contained metal	333,402	608,066	82%
Lithium	Metric tons LCE	1,156,982	6,536,075	465%
Manganese	Metric tons contained metal	32,649,981	36,358,170	11%
Graphite	Metric tons contained metal	3,061,160	7,010,178	129%
Platinum	Metric tons contained metal	6,939,078	7,154,930	3%
Palladium	Troy ounces	9,226,436	10,540,870	14%

Source: BloombergNEF. Note: LCE is lithium carbonate equivalent. Total supply in the 2023 edition of the Transition Metals Outlook (TMO) 2023 included only primary supply. TMO 2024 includes both primary and secondary supply. Graphite, platinum and palladium were not part of detailed supply analysis in TMO 2023.

Majority of metals demand will not be met by existing supply

Despite the growth in supply over the next two and half decades, there will still not be enough metals to meet rising demand, especially under a pathway to net-zero emissions by 2050. This could negatively impact the uptake of clean energy technologies. For several metals, additional investment to build on 2023 supply levels is needed as early as this year to ensure supply can meet demand (Table 2). The threat of a prolonged deficit could lead to higher prices and spur a corresponding increase in the cost of clean energy technologies, ultimately slowing their adoption.

Table 2: Estimated year when metals supply will lag demand if there are no capacity additions and primary supply remains at 2023 levels – BNEF's Economic Transition Scenario and Net Zero Scenario

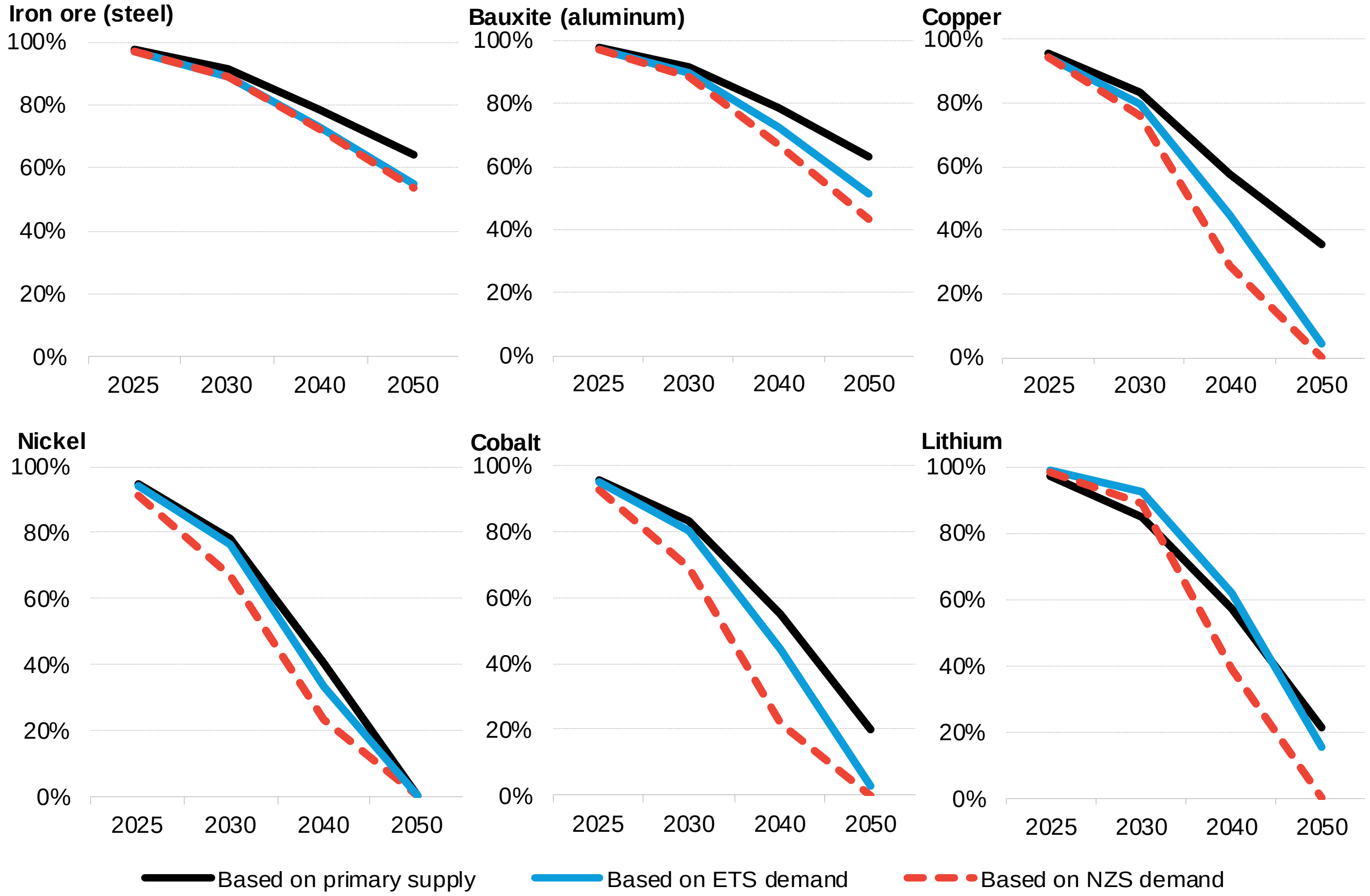
Metal	Scenario	2024-2030	2031-2040	2041-2050
Steel	ETS	2024		
	NZS	2024		
Aluminum	ETS	2024		
	NZS	2024		
Copper	ETS	2024		
	NZS	2024		
Lithium	ETS	2025		
	NZS	2025		
Graphite	ETS	2028		
	NZS	2026		
Nickel	ETS		2030	
	NZS	2028		
Cobalt	ETS			2050
	NZS		2034	
Manganese	ETS			
	NZS			

Source: BloombergNEF. Note: Primary supply is based on mined nameplate capacity, apart from aluminum, graphite and steel, which is based on refined capacity. ***Green*** *indicates sufficient supply in that decade based on 2023 primary supply levels;* ***red*** *is insufficient supply. ETS refers to the Economic Transition Scenario, NZS is the Net Zero Scenario.*

More exploration required to replace depleting reserves of minerals

There are not enough reserves to meet the growing demand for metals such as copper, nickel and cobalt (Figure 4). To build the mines of tomorrow, the mining industry must invest in exploration today. This will ensure existing reserves are replaced as supply increases. Investment in exploration has declined over the last five years due to falling commodity prices. This will affect the discovery of new deposits needed to build mines in the medium term.

Figure 4: Depletion of remaining reserves for selected metals



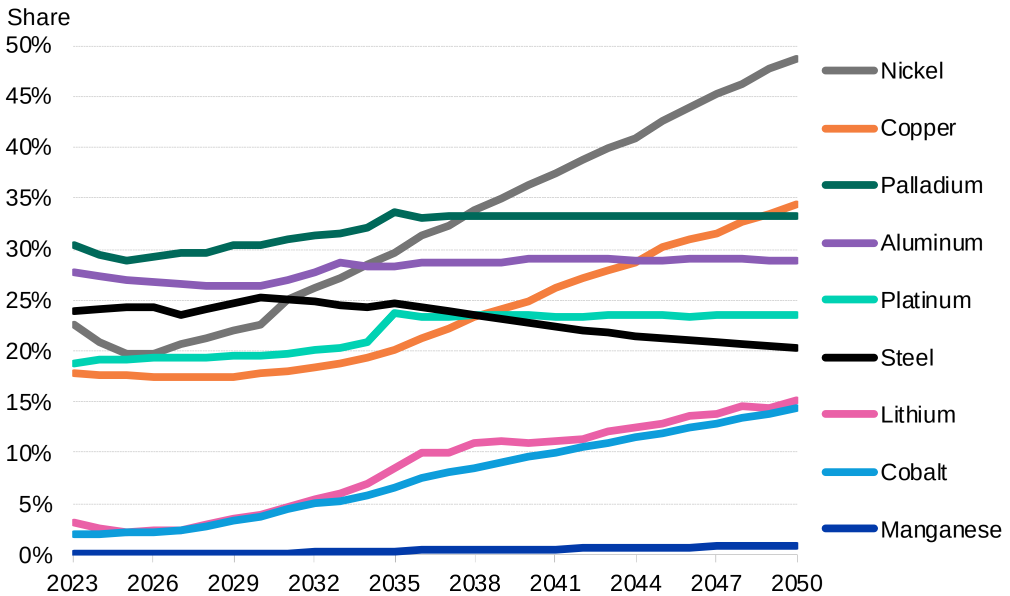
Source: BloombergNEF. Note: ETS is Economic Transition Scenario, NZS is Net Zero Scenario. Charts show percentage of annual reserves that remain compared to 2023.

Recycling will help meet demand while lowering metals emissions

Secondary production benefits metals markets in two main ways, by creating more and lower-emissions supply. In terms of the market balance, it helps fill the supply gap that primary production cannot meet on its own. This allows for additional supply sources that have lower capital intensities and an easier commissioning and ramp-up compared with starting a mine from the ground up.

BNEF expects output from secondary sources to become an integral part of the supply chain for energy transition metals (Figure 5). As the lithium-ion battery recycling market grows, the availability of raw materials from spent batteries will increase as well. Capital outlay is only needed to commission a plant, making it cheaper than spending on other various pre-production phases of mining.

Figure 5: Secondary production share in total output, by metals market



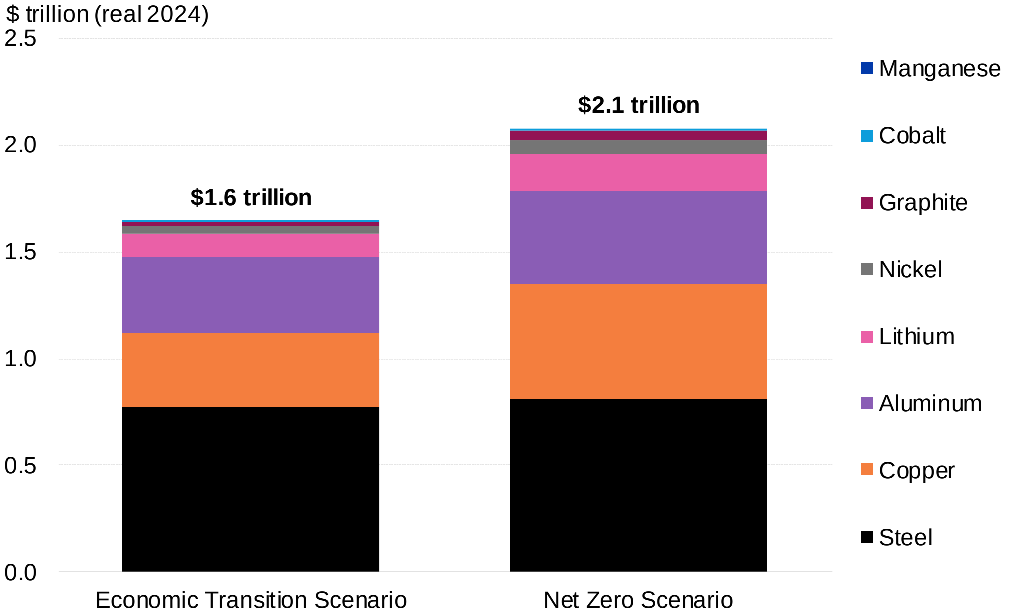
Source: BloombergNEF. Note: Steel and aluminum recycling are based on BNEF's Economic Transition Scenario in the New Energy Outlook 2024 (web | terminal). Copper and nickel scrap generation is based on collected scrap. Secondary production for lithium, cobalt, manganese, nickel and copper based on the discounted rate from the Lithium-Ion Battery Recycling Availability Model (web | terminal).

Over $2.1 trillion required by 2050 to meet metals demand in a net-zero emissions pathway

At least $2.1 trillion of investment is required across energy transition metal sectors over 2024-2050 to meet total demand under BNEF's Net Zero Scenario. This is 10 times less than the capital necessary to build and deploy renewable energy technologies under the same net-zero pathway. But the focus of metals investment needs to shift further upstream to ensure the building blocks exist to realize demand further down the value chain. Without sufficient funding to expand the primary supply of metals critical for the shift to a low-carbon economy, progress could be jeopardized.

Steel requires the most investment across both BNEF's scenarios, although spending is only 5% higher in the net-zero pathway across 2024-2050, at $812 billion. By contrast, the investment needed in the copper industry leaps 52% in the Net Zero Scenario, to $537 billion, driven by the significantly higher demand for copper for electricity grids.

Figure 6: Cumulative energy transition metal investment between 2024 and 2050 under BNEF's Economic Transition Scenario and Net Zero Scenario



Source: BloombergNEF. Note: Investment in aluminum, cobalt, copper, graphite, lithium, manganese, nickel and steel are considered. Only investment in mined supply is considered, except for aluminum, graphite and steel, where only investment in refined supply is considered. Investment in palladium, platinum, silicon, silver and rare earths is not considered. This figure applies global mine and refinery capital expenditure benchmarks to capacity additions required to meet demand in a given year.

Supply chain security will require international collaboration

A secure supply of energy transition metals needs to be realized at a national and global level to meet growing demand. Current production is highly concentrated, leaving supply chains vulnerable to disruptions and the journey to a low-carbon economy at risk.

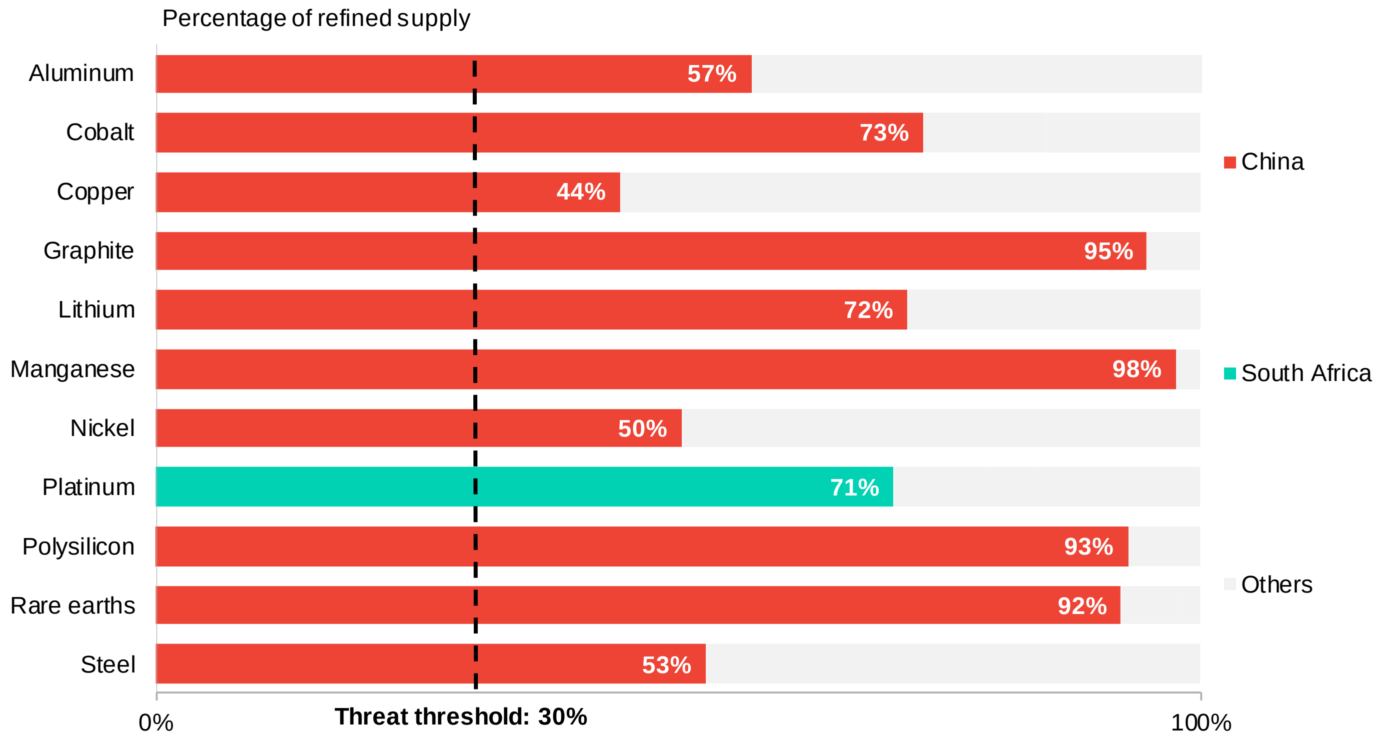
Of the 11 energy transition metals with mined supply tracked in this outlook, eight are exposed to significant supply chain risk, according to BNEF analysis.[1] This is defined as the market share of the top producing country for the given metals exceeding a 30% threat threshold – a limit established according to a US Department of Justice and Federal Trade Association interpretation of the Herfindahl-Hirschman index, a common measure of market concentration that determines competitiveness within a sector.

Mined supply for cobalt, platinum, rare earths and silicon are the most at risk, with a massive 69-80% of extraction of these metals occurring in a singular region. The concentration worsens when looking at refined supply, with all the energy transition metals tracked by BNEF surpassing the 30% threshold by a sizable margin (Figure 7).

1 Graphite is excluded here as only refined production is considered in this report. The platinum group metals are treated as one here, with platinum the chosen representative.

Better public-private sector and intergovernmental alignment is essential to find the sweet spot between localization and globalization that can drive progress towards security of supply for energy transition metals.

Figure 7: Refined supply of energy transition metals in 2023, by top producing country



Source: International Energy Agency, US Geological Survey, World Platinum Investment Council, BloombergNEF. Note: For nickel, only Class 1 refined supply is considered. For rare earths, only elements used in permanent magnets are considered: praseodymium, neodymium, terbium and dysprosium. For silicon, only polysilicon is considered, though other refined energy transition-related products exist. Platinum is the chosen representative for the platinum group metals. Silver is not included because the market is largely focused on mined supply, with the assumption that primary supply is mostly dictated by the flow of material from mines. Supply data from BNEF is de-risked, except polysilicon. The threat threshold is based on the interpretation of the Herfindahl-Hirschman index in the US Department of Justice and Federal Trade Association's Merger Guidelines.

Responsible mining practices will safeguard biodiversity

The acceleration of the energy transition will spur the development of new mines to satisfy growing demand for metals. But the mining of these metals could exacerbate nature-based risks, particularly as a result of water use and biodiversity loss.

BNEF identified Chile as the country with the highest exposure to land disturbance in conservation areas if metals extraction continues to expand. It is currently the world's largest copper producer and number two for lithium, based on BNEF analysis. Of the land currently occupied by existing copper and lithium operations in Chile (represented by $0km^2$ in Table 3) and their related infrastructure, approximately 45% overlaps with either designated protected areas or areas in biodiversity-sensitive regions prioritized for conservation.

As metals extraction grows, balancing economic incentives with environmental accountability becomes more urgent to alleviate the pressures on land use and mitigate the mining industry's nature impact. Investment in sustainable mining practices is vital. These practices include sustainable land-use planning, technology investment to reduce waste and improve production efficiencies, and the purchase of biodiversity offsets.

Table 3: Intersection of copper and lithium mining activities with protected areas in Chile

Protected areas	Existing land use Expansion					
	$0km^2$	$1km^2$	$2km^2$	$3km^2$	$4km^2$	$5km^2$
National park						
Lakes and wetlands						
Transitional or protected zone						
Inland water						

Source: UN Food and Agriculture Organization, BloombergNEF. Note: The number of intersections identified ranged from zero to five. Red indicates five intersections, orange is three to four intersections, yellow is two and green is zero to one intersection.

Contents

About us

Contact details

Client enquiries:

- Bloomberg Terminal: press <Help> key twice
- Email: support.bnef@bloomberg.net

Yuchen Huo	Associate, Metals and Mining	yhuo25@bloomberg.net
Allan Ray Restauro	Associate, Metals and Mining	arestauro@bloomberg.net
Ellie Gomes-Callus	Associate, Metals and Mining	egomescallus@bloomberg.net
Rosemary Katz	Senior Associate, Metals and Mining	rkatz67@bloomberg.net
Peng Xu	Senior Associate, Metals and Mining	pxu38@bloomberg.net
Kwasi Ampofo	Head of Metals and Mining	kampofo1@bloomberg.net

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