COPPER (Cu) IN SOLAR MODULES

THE CRITICALITY OF SECONDARY COPPER: Bridging the Supply Gap in an Electrifying World

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EXECUTIVE SUMMARY

Global copper demand is set to rise sharply through 2030–2040 as electrification, renewable energy, electric vehicles, and grid expansion accelerate worldwide. In the IEA's highest-ambition NZE scenario, demand exceeds 44 Mt by 2040, driven by the massive materials intensity of clean-energy technologies. Demand is also becoming more geographically diverse, with India and Southeast Asia emerging as fast-growing consumers alongside traditional hubs such as China, Europe, and the United States. Australia remains a major exporter but is rapidly becoming a growing domestic copper user due to its large-scale renewable energy build-out.

In stark contrast, global primary copper supply is increasingly constrained. Declining ore grades, rising production costs, long permitting timelines, limited new discoveries, and growing ESG pressures mean that mine output is projected to peak in the late 2020s and then fall steadily. Even under optimistic assumptions, primary mining cannot keep pace with demand in the APS or NZE scenarios, resulting in large structural deficits.

Secondary copper — from recycling and urban mining — is therefore becoming essential. Recycled copper currently supplies less than 17% of demand, but this share is expected to grow as large volumes of solar panels, EVs, batteries, and electrical infrastructure reach end-of-life (EoL). Yet even with strong policy support, secondary supply still falls far short of what is required to close the supply gap. In the NZE 2040 scenario, an estimated 22 Mt of demand remains unmet after accounting for both primary and projected secondary supply.

This supply–demand imbalance has major strategic implications. Without rapid expansion of recycling capacity, improved product design for disassembly, stronger policy frameworks, and continued investment in responsible mining, copper shortages could slow the pace of the global energy transition and increase the cost of clean-energy technologies.

Meeting future copper needs will require coordinated action across governments, industry, investors, and the recycling sector. Secondary copper must become a central pillar of global supply, complemented by responsible primary production and robust circular-economy systems capable of supporting the world's net-zero ambitions.

1. GLOBAL COPPER DEMAND OUTLOOK (2030, 2035, 2040)

The outlook for global copper demand is characterized by robust growth across all examined scenarios, primarily propelled by the global shift towards electrification and sustainable energy systems.

Projections for total refined copper demand indicate a significant increase by 2030, with further escalations by 2035 and 2040, particularly under scenarios with heightened climate ambitions.

1.1 Detailed Demand Projections

The International Energy Agency (IEA) provides three primary scenario pathways for future metals demand, each reflecting different levels of policy ambition and climate action:

- **Stated Policies Scenario (STEPS):** Incorporates existing policies and measures already in place today, without assuming future enhancements.
- **Announced Pledges Scenario (APS):** Assumes full delivery of all announced climate and energy pledges, including NDCs and long-term net-zero commitments.
- **Net Zero Emissions by 2050 Scenario (NZE):** A pathway aligned with limiting warming to 1.5°C, requiring rapid electrification, grid expansion, and renewable deployment.

Under these scenarios, projected total copper demand is as follows:

Table 1.1.1: Copper Demand Projections (IEA 2024 updates [1]).

SCENARIO	2030	2035	2040
STEPS	~32,000 kt	~34,500 kt	~36,000 kt
APS	~34,000 kt	~38,000 kt	~41,000 kt
NZE	~36,500 kt	~41,500 kt	~44,000+ kt

The NZE scenario continues to generate the highest projected levels of copper demand because it represents the most ambitious pathway for global electrification and decarbonisation. As countries pursue rapid deployment of renewable energy, large-scale grid expansion, electric vehicles, battery storage, heat pumps, and hydrogen technologies, the materials intensity of the energy transition becomes visible.

Copper is essential to each of these systems, and the NZE scenario effectively demonstrates what happens when nations adopt the technologies required to keep global warming to 1.5°C: demand for copper rises sharply and persistently.

The surge in the APS and NZE projections does not reflect normal cyclical variation. Instead, it highlights a structural shift in the role copper plays in the global economy. Historically, copper demand was heavily influenced by construction, manufacturing, and general industrial activity. Today, clean energy technologies are rapidly overtaking traditional sectors as the dominant consumers of copper (solar farms, wind turbines, EV motors, high-voltage cables, charging infrastructure, data centres, and modernised transmission networks). As a result, the composition of copper demand is changing, and its future trajectory is tied directly to climate ambition.

This transition also has implications for price dynamics and sensitivity. Copper used in essential clean energy applications tends to be less vulnerable to demand destruction during periods of high prices or economic downturn. Electrification targets, renewable energy mandates, and EV sales requirements continue irrespective of short-term market fluctuations. This means a larger share of copper demand becomes policy-driven rather than purely market-driven, increasing the resilience of total demand over time.

Another important element is the shift in quality expectations. As the share of copper used in high-performance applications grows — such as high-conductivity wiring, EV drivetrains, and renewable integration systems — the need for consistent, high-purity copper increases as well. This places additional pressure on supply chains, which are already constrained by declining ore grades, long project lead times, and growing environmental and social scrutiny around mining.

These trends reinforce a central conclusion: the world will not be able to meet the copper requirements of the APS or NZE scenarios through primary mining alone. Secondary copper — produced from recycling and urban mining — must grow substantially, and quickly, to fill the gap. In this context, emerging secondary streams, including copper recovered from solar modules and their associated balance-of-system components, become strategically important contributors to global supply security.

1 Sources: IEA Critical Minerals Market Review 2024; IEA World Energy Outlook 2024 (materials annex).

1.2 Regional Demand Dynamics

China remains the world's largest consumer of refined copper, accounting for roughly half of global demand in 2024. Its dominance reflects the scale of its construction sector, manufacturing base, renewable energy deployment, and grid expansion activities. However, China's share of global copper consumption is expected to gradually shift as other regions enter periods of accelerated industrial and electrification-driven growth. Although China will continue to be the single largest market, its proportional share is likely to plateau or modestly decline as global demand broadens geographically.

In particular, India and Southeast Asian economies — especially Vietnam — are emerging as major future demand centres. India's rapid industrialisation, urbanisation, expansion of renewable energy, and accelerating adoption of electric mobility are expected to substantially increase its copper needs. Under the IEA's STEPS pathway, India's share of global refined copper demand is projected to rise from around 3% in 2024 to more than 10% by 2050, making it one of the fastest-growing copper markets in the world. Vietnam is undergoing a parallel transformation, driven by a shift in global supply chains, strong electronics manufacturing growth, and extensive infrastructure development. Its share of global copper demand is expected to increase from approximately 1% today to about 6% by 2050.

Demand in advanced economies such as the United States and the European Union is also projected to grow, though at a more measured pace. Their copper consumption is increasingly tied to electrification initiatives: large-scale grid reinforcement, EV adoption, charging networks, renewable generation, and electrified heating. While their overall industrial copper footprint is mature, the clean energy transition creates a new layer of structural demand that offsets stagnation in traditional sectors.

Australia occupies a somewhat unique position in this regional picture. It is a major producer and exporter of copper concentrates and ores, yet historically has been a modest consumer of refined copper in absolute terms. That balance is beginning to shift at the margin. Australia's very high uptake of rooftop solar, rapid growth in utility-scale renewables, and the need to reinforce and extend transmission infrastructure are all adding incremental domestic copper demand on top of its traditional mining, construction and manufacturing uses. The build-out of large-scale solar and wind projects, interconnectors between states, and emerging electrification of transport and industry point to a future in which Australia is not only a critical supplier of copper to the region, but also a steadily growing consumer linked directly to its own net zero commitments.

The regional diversification of copper demand has important strategic implications. On one hand, a broader distribution of consumption reduces the systemic risk associated with heavy dependence on a single dominant market. On the other hand, the emergence of new high-growth demand hubs introduces logistical, infrastructural, and geopolitical challenges. Transport corridors, smelting and refining capacity, and trade infrastructure in India, Vietnam, and neighbouring economies will need substantial investment to manage increased copper imports and processing volumes. As global demand becomes more geographically diffuse, copper supply chains will have to evolve in complexity, reach, and resilience to support a more multipolar consumption landscape.

2. PRIMARY COPPER SUPPLY: PROJECTIONS AND HEADWINDS

The global primary copper supply, sourced from mining operations, is facing a complex array of challenges that are expected to constrain its ability to meet the rapidly growing demand projected for the coming decades. While there are numerous projects in various stages of development, their collective output, even under optimistic scenarios, points towards a tightening market.

2.1 Expected Mined Copper Supply

Projections for future primary copper supply are commonly expressed through two reference cases: a Base Case and a High Production Case. The Base Case includes output from currently operating mines and projects that are either fully financed or already under construction, reflecting a conservative and highly probable production pathway. The High Production Case incorporates additional mines and expansions that are considered technically viable and at relatively advanced planning stages, but still face greater uncertainties related to financing, permitting, environmental approvals, community acceptance, or geopolitical constraints.

Using updated analysis from the IEA (2024), global primary mined copper supply under these two cases is projected as follows:

Table 2.1.1: Projected Global Primary Copper Mine Supply (kt)[2].

SUPPLY CASE	2030	2035	2040
Base Case	~23,000 kt	~19,000 kt	~15,000 kt
High Production Case	~25,000 kt	~21,000 kt	~16,500 kt

The data reinforces a central concern: even under favourable conditions, primary mine supply exhibits limited growth, followed by a pronounced decline after the early 2030s. In the Base Case, global mined copper supply is expected to peak in the late 2020s at just over 24 million tonnes, after which output gradually decreases to below 19 million tonnes by the mid-2030s. The High Production Case offers only marginally more optimistic outcomes, with supply still declining after 2030 despite the inclusion of additional potential projects.

The structural reasons behind this downward trajectory are well documented. Declining ore grades across major producing regions, rising operating costs, deepening deposits, water and energy constraints, stricter environmental regulations, and increasing community scrutiny all contribute to slowing growth. Moreover, the long lead times associated with copper mining — typically 12 to 15 years from discovery to commercial production — limit the industry's capacity to respond quickly to rising demand. Many new deposits are also located in jurisdictions with elevated geopolitical, environmental, or ESG-related risks, further complicating development.

These supply-side challenges stand in stark contrast to the robust demand growth anticipated in most IEA scenarios. Even under the more optimistic High Production Case, primary mining alone cannot meet the projected needs of the global energy transition. This widening supply–demand gap highlights the necessity of scaling secondary copper production through recycling, urban mining, and circular material systems. In regions like Australia, where large quantities of copper are embedded in renewable energy infrastructure such as solar modules and associated electrical systems, the strategic importance of secondary copper will continue to grow.

2.2 Critical Constraints on Primary Supply Growth

A range of structural constraints continues to limit the expansion of primary copper supply, even in the face of strong, policy-driven global demand. These challenges reinforce the conclusion that future copper supply growth from mining will be modest at best and insufficient to meet the requirements of high-ambition climate pathways.

- **Declining Ore Grades:** One of the most pervasive issues in global copper mining is the continued decline in average ore grades. The industry has experienced a drop of roughly 40% in average grades since the early 1990s, and this trend shows no sign of reversing. Lower grades force operators to mine and process far larger volumes of rock to produce the same amount of copper, which increases energy use, water consumption, equipment wear, and waste volumes. As a result, mine operations become more complex, more resource-intensive, and more expensive.
- **Rising Capital and Operating Costs:** The combination of lower ore grades, deeper deposits, and growing technical complexity has driven capital expenditure (CAPEX) and operating expenditure (OPEX) sharply higher. Stripping ratios in major open-pit operations have risen steadily across key supply regions, requiring more waste removal per tonne of ore. At the same time, higher energy costs, rising labour costs, increased use of specialised reagents, and more stringent environmental controls have added further pressure. In Latin America (home to a large share of global supply) average brownfield capital intensity has increased by more than 60% since 2020. This means that even expansions at existing operations now demand heavier reinvestment, eroding profitability and raising the financial barriers to sustaining production. These trends increase the likelihood of industry consolidation or greater reliance on state-supported investment vehicles in countries seeking to secure strategic copper supplies.
- **Limited New Discoveries:** Global exploration success has declined significantly. Between 1990 and 2023, 239 major copper deposits were identified, but only 14 were discovered in the last decade. Moreover, many of the deposits discovered recently are lower-grade, located in more technically challenging geologies, or situated in jurisdictions with significant

2 Sources: IEA Critical Minerals Market Review 2024.

ESG or geopolitical risk. With the pipeline of large, high-quality discoveries thinning, the long-term prospects for meaningful supply growth from new greenfield projects are becoming increasingly constrained.

- **Extended Project Lead Times:** Copper mining projects require exceptionally long development timelines. From initial discovery to commercial production, new mines typically take 15 to 20 years — sometimes longer when complex feasibility studies, regulatory reviews, and community negotiations are involved. The extended lead time makes it difficult for supply to respond to sudden demand acceleration. Even robust investment today would only begin to influence production in the 2040s, leaving a substantial gap between near-term climate objectives and the real-world pace at which new mining capacity can come online.
- **Permitting, Environmental, and Social Challenges:** Permitting new mines has become significantly more challenging worldwide. Projects face increasingly rigorous environmental requirements related to water use, biodiversity protection, tailings management, and carbon footprint. In addition, social licence is now a decisive factor, with community resistance, indigenous rights processes, and civil society activism affecting timelines and, in some cases, causing outright project cancellations. The combination of environmental scrutiny and social expectations introduces layers of uncertainty that are difficult to quantify but have become central in determining a project's viability.

The convergence of these constraints (declining ore quality, escalating production costs, a shrinking pipeline of new discoveries, prolonged development cycles, and stringent ESG requirements) strongly indicates that the era of abundant, inexpensive primary copper is ending. Even the High Production Case, which assumes more aggressive development of new mines and expansions, remains vulnerable to the very same pressures. Relying on this optimistic scenario to bridge the future supply gap without addressing these underlying structural issues represents a material risk for policymakers and industry.

These conditions place structural upward pressure on the long-term copper price floor. They also enhance the relative attractiveness of secondary copper, which offers shorter investment cycles, lower environmental impacts, greater geographic diversification, and a critical buffer against the limitations of primary mining. In this context, scaling secondary supply — including recovery from emerging waste streams such as solar PV modules — will be indispensable to ensuring global copper availability through the energy transition.

2.3 Geographical Concentration and Diversification Prospects

Global copper mining remains heavily concentrated in a small number of regions, creating structural vulnerabilities in supply chains. Chile continues to be the world's largest copper producer, although its output has plateaued in recent years due to declining ore grades, water scarcity in the Atacama Desert, and operational constraints at several major mines. Peru, traditionally the second-largest producer, has experienced varying levels of political instability and community opposition, which have contributed to project disruptions and delays. In parallel, the Democratic Republic of Congo (DRC) has rapidly expanded its production capacity and is now firmly establishing itself as the world's second-largest copper supplier. This shift reflects both the scale of the DRC's high-grade sediment-hosted deposits and the influx of foreign investment, particularly from Chinese operators.

China itself, while not among the very largest producers, contributes a meaningful share of global mined copper and plays a crucial strategic role as the dominant processor, refiner, and consumer of copper concentrates. Its influence spans the entire copper value chain, from project financing to smelting capacity and downstream manufacturing.

Efforts to diversify primary copper supply are gaining momentum, especially across Africa. Zambia is undergoing a resurgence driven by new investments, revitalised operations, and ambitions to restore the country's status as a major global producer. The DRC is continuing its rapid expansion, with several large-scale projects and processing facilities under development. Other African nations — such as Uganda, Namibia, and Botswana — are increasingly exploring opportunities to bring new copper deposits into production. South America outside of Chile and Peru, including Argentina and Ecuador, also shows growing promise, supported by favourable geology and emerging investor interest.

Despite this potential, diversification efforts face substantial obstacles. African projects, in particular, must contend with infrastructure deficits (including limited power availability, inadequate transport networks, and insufficient port capacity) as well as regulatory unpredictability and varying levels of political stability. Many of the continent's high-grade deposits are sediment-hosted systems that can deliver strong early-stage production but may deplete more rapidly compared to the massive, long-life porphyry deposits characteristic of Chile and Peru. These geological differences complicate long-term planning and can reduce the ability of new regions to offset supply declines elsewhere.

Taken together, global copper production remains highly geographically concentrated, and while diversification is underway, its progress is neither fast nor guaranteed. New supply from emerging regions will require significant capital investment, long-term policy stability, and coordinated infrastructure development. Until such conditions are consistently met, the global copper market will continue to be shaped by its reliance on a handful of key producing countries, with associated geopolitical and supply-chain risks.

3. THE EXPANDING ROLE OF SECONDARY COPPER SUPPLY

Secondary copper, derived from the recycling of EoL products and manufacturing scrap, is increasingly recognized as a vital component of the global copper supply chain. Its importance is set to grow substantially in the coming decades as primary supply constraints tighten and demand, particularly from clean energy applications, continues to surge.

3.1 Current Status and Projected Growth

Secondary copper currently plays a vital but still limited role in meeting global copper demand. In 2024, the share of secondary copper excluding direct-use scrap (copper recovered from recycling EoL products rather than melted directly from clean manufacturing scrap) remained below 17% of total refined supply. This marks a slight decline from around 18% in 2015, reflecting several constraining factors. Rapid growth in total copper demand has structurally outpaced the availability of recyclable EoL material, while periods of lower metal prices have weakened scrap collection incentives. Trade restrictions on scrap flows, rising energy and shipping costs, and delays in implementing robust domestic scrap-collection systems in major markets such as the EU and United States have further limited recycling outputs.

Despite these short-term headwinds, secondary copper is expected to become significantly more important over the coming decades. As large volumes of renewable-energy assets, electric vehicles, cables, and appliances installed during the 2010–2030 period begin to reach EoL, the global pool of recyclable copper will expand rapidly. Policy momentum toward circularity — especially in the APS and NZE pathways — further reinforces this trajectory.

The IEA projects the following levels of secondary copper supply (including both direct-use scrap and recycled EOL material):

Table 3.1.1: Projected Secondary Copper Supply (kt)[3].

SCENARIO	2030	2035	2040
STEPS	~5,400	~5,500	~8,700
APS	~5,900	~10,000	~11,000
NZE	~5,900	~12,000	~11,000

Under the STEPS scenario, the share of secondary copper excluding direct-use scrap is projected to rise steadily, reaching nearly 35% of total demand by 2050. This increase is largely driven by the natural maturing of installed infrastructure: more products reaching EoL produces more recyclable copper, even without major changes in policy.

The APS and NZE scenarios show a far more pronounced expansion in secondary supply. In these pathways, stronger policy support for recycling, improved scrap-collection systems, investment in domestic reprocessing capacity, and accelerated turnover of clean-energy technologies all lead to significantly higher recycling volumes. These scenarios also assume the implementation of measures such as extended producer responsibility, mandatory recovery targets, landfill restrictions, and enhanced design-for-disassembly standards. As a result, both APS and NZE see secondary copper supply rise to levels materially higher than in STEPS — helping to narrow, though not eliminate, the gap between demand and available primary supply.

The broader implication is clear: secondary copper transitions from a supplementary source today to a central pillar of supply security over the coming decades. Its growing role reflects not only increased material availability but also an expanding policy commitment to circular economy principles and climate-aligned resource strategies.

3 Source: IEA Critical Minerals Market Review 2024.

3.2 Drivers of Secondary Supply Growth

A range of structural, technological, and policy factors is expected to accelerate the expansion of secondary copper supply over the coming decades. Together, these drivers reflect a global shift toward circular resource systems and a recognition that primary mining alone cannot meet future demand.

- **Policy and Regulation:** Government action remains one of the most influential levers for expanding secondary copper supply. Countries and regions are increasingly implementing policies to raise recycling rates, reduce landfill dependence, and reshape product stewardship. These measures include mandatory recovery targets for copper-containing products, landfill taxes or outright bans on copper-rich waste streams, extended producer responsibility schemes, and regulatory frameworks encouraging design-for-disassembly and design-for-recycling in new appliances, vehicles, and renewable energy technologies. The EU's revised Waste Framework Directive, the US focus on domestic scrap retention, and emerging national circular economy strategies all exemplify this tightening regulatory environment. As these policies mature, they are expected to significantly increase both collection rates and material recovery efficiency.
- **Technological Advancements:** Rapid innovation across the recycling value chain is improving the technical and economic viability of secondary copper production. Advances in sensor-based sorting, machine vision, artificial intelligence, and robotics now allow recyclers to identify, sort, and separate complex scrap with far greater precision. At the processing stage, new hydrometallurgical and pyro-metallurgical techniques can extract copper more efficiently from mixed-material waste streams such as printed circuit boards, EV motors, and renewable energy components. Improvements in delamination, chemical leaching processes, and high-selectivity smelting technologies also enable higher purity outputs with lower energy consumption. Collectively, these innovations help reduce costs, improve yields, and broaden the range of EoL products that can be economically recycled.
- **Economic Incentives:** Market dynamics remain a fundamental driver of recycling activity. High copper prices increase the financial attractiveness of collecting and processing scrap, prompting greater participation from informal and formal sectors alike. Sustained price appreciation — driven by global electrification and tightening primary supply — supports capital investment in new recycling capacity. Conversely, periods of prolonged low prices tend to discourage collection, incentivise exports of unprocessed scrap, and reduce the utilisation rates of recycling facilities. In this sense, strong long-term demand for copper under energy-transition scenarios creates the economic conditions that favour growth in secondary supply.
- **Growing Feedstock Availability:** Perhaps the most structurally important driver is the expanding volume of copper-rich products reaching EoL. Over the next two decades, the world will see substantial increases in waste streams containing copper: renewable energy infrastructure (solar panels, wind turbines, transformers), electric vehicles and their motors, battery systems, power electronics, data-centre equipment, and extensive transmission and distribution cabling. Much of this equipment was installed or manufactured during the accelerating clean-energy build-out of the 2010s and early 2020s and will begin entering recycling cycles in significant quantities from the 2030s onward. As this wave of EoL material becomes available, it will greatly enlarge the feedstock base for secondary copper production.

3.3 Potential and Importance of Secondary Supply

The strategic importance of secondary copper cannot be overstated:

- **Reduced Reliance on Primary Mining:** Scaling up recycling directly lessens the pressure on primary mining operations, mitigating some of the environmental and social impacts associated with extraction.
- **Enhanced Supply Security:** For regions heavily reliant on copper imports, a robust domestic recycling industry can significantly improve supply security and reduce exposure to geopolitical risks or disruptions in primary supply chains.
- **Environmental Benefits:** Recycling copper is substantially less energy-intensive than primary production. For instance, recycled energy transition minerals can incur 80% fewer greenhouse gas emissions compared to primary materials.
- **Contribution to Supply-Demand Balance:** Recycled copper can reduce the need for new mining activity by 5–30% by 2040 in the STEPS, and by as much as 35% for copper by 2050 in scenarios aligned with climate pledges.

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3.4 Challenges in Scaling Secondary Supply

Despite its potential, scaling up secondary copper supply faces several hurdles:

- **Collection and Sorting:** Economically collecting dispersed EOL products and efficiently sorting complex scrap streams remain significant challenges. The heterogeneity of scrap and the presence of contaminants can complicate processing.
- **Infrastructure Deficiencies:** Many regions lack adequate infrastructure for systematic collection, transportation, and advanced processing of copper scrap.
- **Economic Viability:** The profitability of recycling operations can be volatile, influenced by fluctuating scrap and primary copper prices, energy costs, and the cost of new technologies.
- **Policy and Consumer Behaviour:** Insufficient regulatory mandates, lack of consumer awareness or incentives for recycling, and limited coordination across the value chain can hinder the growth of secondary supply.

The projected growth in secondary supply is substantial, but it hinges on effectively addressing these systemic inefficiencies. Failure to do so could mean that even with an increasing volume of EOL scrap, the actual contribution of secondary copper falls short of its potential, thereby worsening the primary supply deficit. Furthermore, a potential mismatch exists between the timing of EOL scrap availability from long-lifecycle products (like buildings and power infrastructure) and the more immediate demand surges from rapid EV and renewables deployment. This temporal lag suggests that while secondary supply is crucial for the long term, it may not fully buffer primary supply shocks in the medium term, underscoring the continued, urgent need for primary supply development alongside aggressive recycling efforts. The increasing complexity of modern products also makes copper recovery more challenging, necessitating rapid co-evolution of design-for-recycling principles and advanced separation technologies to maximise the net benefit of recycling.

4. QUANTIFYING THE COPPER SUPPLY GAP AND THE SECONDARY SUPPLY IMPERATIVE

To understand the scale of the challenge facing the copper market and the critical role of secondary sources, it is essential to quantify the anticipated gap between total demand and primary (mined) supply. This analysis reveals the extent to which recyclers and other secondary producers will need to ramp up their output.

4.1 Calculating Primary Supply Requirements and Shortfalls

The primary supply requirement is the amount of copper that needs to come from new mining operations after accounting for the contribution from secondary sources (recycling and scrap). It is calculated as:

- Primary Supply Requirement = Total Demand – Projected Secondary Supply
- Primary Supply Shortfall (Base Case) = Primary Supply Requirement – Expected Primary Mined Supply (Base Case)
  - A positive shortfall indicates unmet demand.

Table 4.1.1: Primary Supply Shortfall Table.

SCENARIO	YEAR	TOTAL DEMAND (KT)	SECONDARY SUPPLY (KT)	PRIMARY REQUIREMENT (KT)	BASE CASE MINED SUPPLY (KT)	SHORTFALL (KT)
STEPS	2030	32,000	5,400	**26,600**	23,000	**3,600**
	2035	34,500	5,500	**29,000**	19,000	**10,000**
	2040	36,000	8,700	**27,300**	15,000	**12,300**
APS	2030	34,000	5,900	**28,100**	23,000	**5,100**
	2035	38,000	10,000	**28,000**	19,000	**9,000**
	2040	41,000	11,000	**30,000**	15,000	**15,000**
NZE	2030	36,500	5,900	**30,600**	23,000	**7,600**
	2035	41,500	12,000	**29,500**	19,000	**10,500**
	2040	44,000	11,000	**33,000**	15,000	**18,000**

Key Insights from Table 4.1.1:

1. The supply shortfall widens dramatically after 2030: Even in STEPS, the most conservative demand scenario, the shortfall triples between 2030 and 2040.
2. APS and NZE shortfalls become extremely large: In the NZE scenario, the 2040 shortfall reaches 18 million tonnes, slightly larger than all copper currently mined globally in a single year.
3. The Base Case mined supply projection is nowhere near sufficient: Declining ore grades, permitting constraints, and rising costs push primary supply downward just as demand accelerates.
4. Secondary supply becomes essential, not optional: Without large-scale recycling and circular systems, the supply gap cannot be bridged — even with High Production mining scenarios.

4.2 Analysis of Feasibility and Challenges

A comparison between the required scale of secondary copper supply and the projected secondary supply reveals a profound structural tension in the global copper system. Even under optimistic assumptions for recycling growth, the volumes of secondary copper expected in the coming decades fall far short of the levels needed to balance demand in high-ambition climate scenarios.

The NZE 2040 case illustrates the magnitude of this challenge most clearly. Based on updated calculations, the total primary supply requirement in this scenario is approximately 33,000 kt. Yet the projected secondary supply for NZE in 2040 amounts to only 11,000 kt. This leaves an uncovered gap of roughly 22 million tonnes, a deficit so substantial that it cannot be bridged by planned mining projects, anticipated recycling improvements, or incremental efficiency gains alone. Even before considering constraints on scrap availability, energy inputs, or collection systems, the sheer scale of the shortfall underscores how deeply misaligned current trajectories are with the material requirements of rapid global decarbonisation.

This imbalance reveals a critical insight: even with strong policy support, accelerated recycling, and expanding EoL material flows, secondary supply will not—on its current path—grow fast enough to close the widening supply gap in the APS and NZE scenarios. Without breakthroughs in primary supply that go well beyond today's High Production Case, or a dramatic and unprecedented acceleration in circular economy performance, copper constraints could become a binding limitation on the pace of electrification. In the absence of such changes, the system would be forced to rely on some combination of demand reduction, slower technology deployment, or shifts to less copper-intensive alternatives—none of which align with the timelines required for a 1.5°C pathway.

The scale of secondary supply required in mid-century climate scenarios therefore implies the need for a fundamental re-engineering of the copper value chain. This includes widespread adoption of design-for-recycling approaches, ensuring products, especially those central to the energy transition, can be dismantled cleanly and their copper content recovered with high efficiency. It also necessitates massive investment in urban mining infrastructure to collect, sort, and process the far larger volumes of EoL equipment that will enter waste streams from the 2030s onward. Achieving consistently high collection rates may further require new business models such as product-as-a-service, deposit-return systems, advanced traceability platforms, and policy frameworks that guarantee recyclers access to high-quality feedstock.

Ultimately, the challenge is not only technical but systemic. Meeting the copper needs of a net-zero world will demand coordinated transformation across product design, manufacturing, waste management, policy, finance, and consumer behaviour. Without such an integrated approach, copper availability may emerge as a material constraint on global decarbonisation ambitions.

5. STRATEGIC IMPLICATIONS AND RECOMMENDATIONS

The projected widening gap between primary copper supply and accelerating global demand — combined with a rising but still insufficient contribution from secondary sources — carries profound implications for market stability, industrial development, and climate-aligned policymaking. Managing this challenge will require coordinated action across governments, the mining sector, recyclers, manufacturers, investors, and research institutions. The following analysis synthesizes the strategic risks and opportunities emerging from this transition.

5.1 Market Stability and Price Volatility

A structural deficit in primary copper supply is expected to exert sustained upward pressure on copper prices over the medium and long term. Although secondary supply can soften price shocks, its responsiveness is inherently cyclical and strongly dependent on copper's market value. High prices incentivize scrap collection and recycling, while lower prices diminish economic motivation and can lead to reductions in collection activity, facility utilisation, and investment in recycling capacity.

Price volatility is therefore likely to become a persistent feature of the copper market. This instability presents challenges for sectors central to the clean energy transition, which are increasingly copper-intensive. Higher copper prices translate into increased costs for electric vehicles, battery systems, renewable energy installations, and grid infrastructure. These cost pressures could slow deployment rates or require additional public subsidies to maintain momentum in net-zero pathways. As a result, managing copper price volatility becomes not only an economic issue but a climate strategy necessity.

5.2 The Imperative for Scaling the Recycling Industry

The widening supply–demand gap highlights the enormous growth opportunity, and necessity, for the global copper recycling sector. Meeting future demand requires the recycling industry to undergo a substantial transformation. This transformation depends first on significant capital investment to expand and modernise collection and sorting systems, including the integration of advanced robotics, AI-driven sorting, and sensor-based separation technologies. At the processing stage, investment in next-generation metallurgical technologies is critical to economically recover copper from increasingly complex EoL products such as EV motors, renewable energy components, and printed circuit boards.

A more skilled workforce will also be needed to operate these higher-technology facilities, manage material flows, and maintain sophisticated processing assets. Furthermore, the creation of regional recycling hubs (integrating collection, dismantling, sorting, processing, and refining) can reduce logistics costs, minimise emissions, and build regional resilience by retaining materials within domestic or regional markets. Together, these developments would significantly enhance the scale, efficiency, and strategic contribution of secondary copper supply.

5.3 Policy Directions for a Balanced and Resilient Copper System

Governments play a central role in shaping an environment that simultaneously supports sustainable primary production and accelerates the shift toward secondary supply. Policy frameworks must operate across three fronts: enhancing secondary copper flows, enabling responsible primary production, and managing demand through material efficiency.

- **Enhancing Secondary Supply:** Legally binding recycling targets, minimum recycled-content requirements, and well-designed extended producer responsibility schemes can all drive higher recovery rates. Strengthening collection systems — through investment in municipal infrastructure, consumer incentives, deposit-return models, and mandatory take-back programs — is essential to increase the volume and quality of available scrap. Harmonising international scrap-quality standards and easing barriers to scrap trade can support a more efficient, transparent global market for recycled copper. Governments can further accelerate progress by funding R&D, promoting design-for-recycling, and supporting the deployment of advanced sorting and metallurgical technologies.
- **Supporting Sustainable Primary Supply:** While secondary supply is critical, primary mining will remain indispensable. Governments should streamline permitting processes to make them more efficient, transparent, and predictable, while maintaining stringent environmental and social safeguards. Targeted investments in geological surveys can help identify new resources, particularly in underexplored jurisdictions. Mechanisms that help de-risk strategic mining projects (such as political risk insurance, public-private financing frameworks, and infrastructure support) can facilitate responsible supply diversification outside of the current dominant regions.
- **Managing Demand:** Reducing the copper intensity of clean-energy technologies can help moderate future demand. Material-efficiency measures, such as improved engineering design, enhanced manufacturing efficiency, and reduced metal losses in production, all contribute to lowering total material requirements. Substitution with alternative materials (e.g., aluminium in certain cables or motor components) may also play a role where performance is not compromised. Broader adoption of circular-economy models—including remanufacturing, refurbishment, and product life

extension — can further reduce overall material throughput.

5.4 Investor Implications

The evolving copper landscape presents a new range of investment opportunities and risks. The recycling value chain — from collection and disassembly to advanced hydrometallurgical and pyrometallurgical processing — offers significant room for growth. Innovations that enable the economic extraction of copper from low-grade ores, tailings, and waste rock also represent promising opportunities, particularly in jurisdictions seeking to maximise the utility of existing mining footprints.

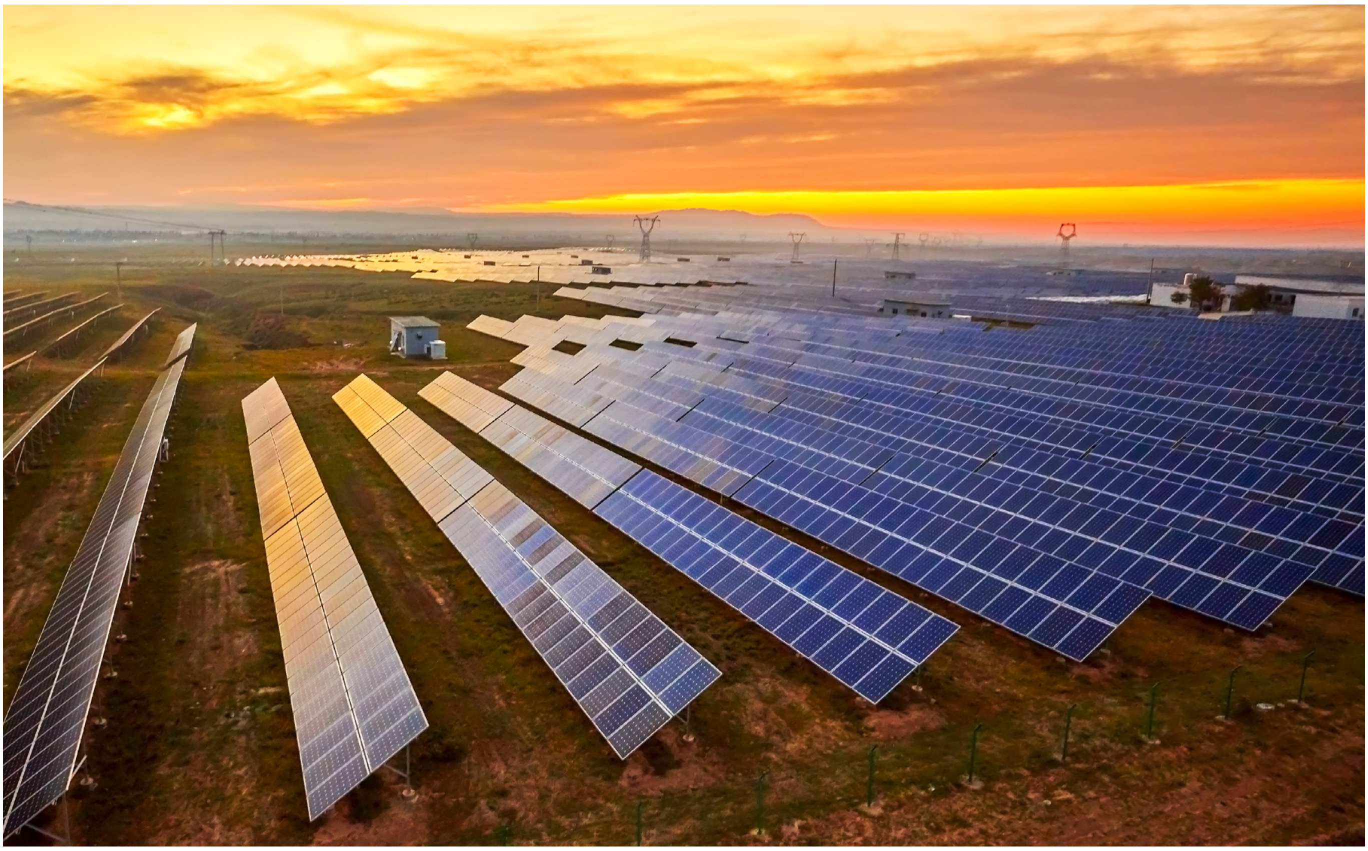
Investors will increasingly prioritise projects with strong ESG credentials, recognising that social licence and regulatory compliance significantly influence operational stability and project lifespan. Given the inherently long lead times in mining and recycling infrastructure development, a long-term investment horizon is essential for capturing value in this evolving sector.

5.5 Call to Action

The looming copper supply challenge is a systemic issue that requires a holistic, "whole-of-value-chain" approach. Policies that focus solely on primary mining or solely on recycling will be insufficient. Instead, coordinated strategies must encompass product design, material efficiency, collection, processing, and reuse in an integrated framework. The success of scaling secondary copper supply depends heavily on building transparent, efficient, and well-regulated global scrap markets that ensure fair pricing and consistent availability of high-quality feedstock.

Failing to proactively address the copper deficit risks imposing significant inflationary pressures on clean-energy technologies, potentially slowing technology adoption and undermining climate targets. Copper supply security is therefore no longer a narrow commodity issue but a matter of strategic economic importance directly tied to the global energy transition.

A concerted, collaborative effort among governments, industry, investors, researchers, and civil society is urgently required to navigate this complex landscape and secure a resilient, sustainable copper supply for the decades ahead.



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