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COPPER: DEMAND, SUPPLY, AND STRATEGIC IMPORTANCE IN THE FUTURE ECONOMY

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ABSTRACT

Copper is a unique metal with exceptional physical and chemical properties, including high electrical and thermal conductivity, corrosion resistance, and recyclability. These characteristics make copper indispensable for modern technologies ranging from renewable energy systems and electric vehicles to AI-driven data centers and digital infrastructure.

Global copper reserves were estimated at 980 million metric tons in 2024, while identified and undiscovered resources exceeded 5,600 million metric tons. Global mine production reached 23 million metric tons, yet consumption surpassed 26 million metric tons, driven largely by China and other industrial economies. Average copper prices in 2024 stood at around $8,400 per metric ton, reflecting supply constraints and rising demand.

This thesis highlights copper's strategic role in achieving net-zero goals, emphasizing the paradox between rising demand for green technologies and resistance to mining expansion. Declining ore grades (down 40% since 1991), increasing labor and energy costs, and tariff pressures necessitate innovative extraction technologies, automation, and expanded recycling. The study underscores the importance of adopting international standards and sustainable practices to ensure long-term supply security.

Keywords: copper; critical minerals; global demand; energy transition; mining industry; technological innovation; artificial intelligence

1. INTRODUCTION

Copper (chemical symbol Cu, atomic number 29) is a flexible and ductile metal with a density of 8,960 kg/m³, melting point of 1356 K, and thermal conductivity of 394 W/m·K. Its crystal structure is face-centered cubic (FCC), which provides excellent mechanical strength and conductivity.

Copper's unique combination of properties — high electrical and thermal conductivity, corrosion resistance, recyclability, flexibility, and antimicrobial characteristics — makes it indispensable across a broad range of modern applications. It is not only a traditional industrial metal but a critical enabler of the future economy, particularly in the context of the global energy transition and digitalization.

This study examines copper's physical and chemical properties, its natural occurrence, global reserves and production data, demand drivers, and the strategic challenges associated with ensuring long-term supply security.

1.1 General Properties of Copper

Key physical and chemical characteristics of copper include:

- Atomic weight: 63.54
- Specific heat capacity: 0.383 kJ/(kg·K) at 293 K
- Linear expansion coefficient: 16.5×10^{-6} K^{-1}
- Young's modulus: 110×10^{9} N/m^2
- Electrical resistivity: 1.673×10^{-8} ohm·m
- Corrosion resistance and antimicrobial properties (widely applied in medicine)
- High recyclability without loss of properties

- Flexibility and ductility, making it suitable for wires, pipes, and alloys

1.2 Occurrence in Nature

Copper is found in various mineral forms within the Earth's crust:

- Sulfide deposits (chalcopyrite, bornite, chalcocite, covellite)
- Carbonate deposits (azurite, malachite)
- Silicate deposits (chrysocolla, dioptase)
- Native copper in pure metallic form

These diverse occurrences make copper one of the most widely mined and utilized metals globally.

1.3 Strategic Importance

Copper's unique combination of properties makes it indispensable for:

- Electrical wiring and power grids
- Renewable energy systems (solar, wind, hydro)
- Electric vehicles and charging infrastructure (EVs use 2–4 times more copper than conventional cars)
- AI and data centers (server racks, cooling systems, high-performance cables)
- Medical devices and antimicrobial surfaces

2. METHODOLOGY

This thesis integrates data from the International Copper Study Group (ICSG), the International Copper Association (ICA), and the U.S. Geological Survey (USGS).

Comparative analysis of production, reserves, consumption, and price trends was conducted, alongside forecasts of demand drivers such as renewable energy, artificial intelligence, and digital assets. Data from 2024 are used as the primary reference year.

3. RESULTS

Key quantitative findings for 2024 are summarized below:

- Global copper reserves: 980 million metric tons
- Identified and undiscovered resources: 5,600 million metric tons
- Global mine production: 23 million metric tons
- Global consumption: 26 million metric tons
- Average copper price: ~$8,400 per metric ton
- Ore grade decline since 1991: 40%
- Share of recycled copper in global supply: ~33%

The data indicate a structural supply deficit of approximately 3 million metric tons per year, reflecting a gap between production capacity and consumption growth driven by the energy transition, electrification, and digital infrastructure expansion.

4. DISCUSSION

Copper's strategic importance lies in its dual role: enabling the green transition while facing significant supply constraints. The paradox of net-zero ambitions versus societal resistance to mining expansion requires balanced policy responses at both national and international levels.

Declining ore grades — down 40% since 1991 — combined with increasing labor and energy costs and growing tariff pressures, necessitate innovative extraction technologies, automation, and expanded recycling capacity. AI-driven process optimization and autonomous mining systems represent promising avenues for improving operational efficiency and reducing unit costs.

The surge in demand from renewable energy infrastructure, electric vehicles, AI-driven data centers, and digital assets underscores copper's role as the "metal of the future." However, without

significant investment in exploration, processing innovation, and sustainable practices, supply deficits will persist and potentially widen over the coming decades.

Recycling currently accounts for approximately 33% of global copper use. Scaling up secondary production, particularly in regions with established manufacturing bases, can partially offset primary supply constraints while reducing the environmental footprint of the industry.

For countries such as Uzbekistan — which hosts significant copper resources, including large porphyry deposits under active evaluation — integrating into the global copper economy through the adoption of international standards such as JORC and alignment with ESG frameworks presents both substantial opportunities and inherent challenges.

5. CONCLUSION

Copper is not only a metal of the past but the key metal of the future. Its physical and chemical properties, combined with its centrality to energy transition, electrification, and digital infrastructure, position it as a strategically critical commodity for the global economy.

Key conclusions of this study are:

- Global copper consumption exceeds mine production, creating a structural supply deficit that is expected to grow
- Declining ore grades and rising production costs require accelerated adoption of innovative extraction and processing technologies
- Recycling must be substantially expanded to complement primary supply
- International standards and sustainable practices are essential for ensuring long-term supply security
- Countries with significant copper resources, such as Uzbekistan, stand to benefit from integrating into global copper value chains through transparent, internationally recognized assessment frameworks

Ensuring sustainable copper supply requires innovation, international cooperation, and adherence to global reporting and environmental standards.

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