International Copper
Association
Copper Alliance

Power
of Zero

COPPER—
THE PATHWAY TO NET ZERO

March 2023

Glossary

Abbreviations

ADAT: asset decarbonization assessment tool

CAPEX: capital expenditures

ESG: environmental, social, governance

EV: electric vehicle

GHG: greenhouse gas emissions

IACS: International Annealed Copper Standard

ICA: International Copper Association

ICMM: International Council on Mining and Metals

ICSG: International Copper Study Group

IEA: International Energy Agency

IFC: International Finance Corporation

LCA: life cycle assessment

LME: London Metal Exchange

MACC: Marginal Abatement Cost Curve

OECD: Organization for Economic Co-operation and Development

OPEX: operational expenses

PPA: Power Purchase Agreement

PV: photovoltaic

UN: United Nations

Terminology

Alternative fuels: e-fuels, biogas, biomethane, hydrogen and ammonia produced with non-fossil energy, hydrotreated vegetable oil (HVO), biochar

Archetypes: short for "archetypical production processes," combinations of major production stages and technologies of copper production

Copper industry: includes copper mines, smelters, refiners, recycling facilities and fabricators of semi-finished products from copper and copper alloys

Copper producers: includes copper mines, smelters, refiners and recycling facilities

Copper production: the production of refined copper from copper ore extracted from mines or copper scrap generated through recycling

Electricity mix: the mix of energy sources used to produce electricity in a particular country or region

End-of-life recycling rate: the share of copper-containing products reaching the end of their life cycle that is collected, separated and processed into copper scrap

End-of-life recycling input rate: the share of refined copper production originating from old scrap

Energy or clean energy transition: the transition from an economy based on fossil fuels to a climate neutral one

Decarbonized electricity: electricity generated from fossil-free energy sources

Mill-head grade: the metal content of mined copper ore going into a mill for processing

New scrap: scrap originating from waste in the fabrication of semi-finished and end-use products

Old scrap: scrap originating from the recycling of copper-containing products reaching end of life

Primary copper sources: copper ore from mining operations

Recycling input rate: the share of refined copper production originating from recycled material, both old and new scrap

Refined copper: copper with at least 99.99 percent purity, which results from a smelting and refining process

Scope 1 emissions: direct GHG emissions from owned or controlled sources

Scope 2 emissions: indirect GHG emissions associated with the purchase of electricity, steam, heat or cooling

Scope 3 emissions: all indirect GHG emissions not included in Scope 2 that occur in the value chain of a company, both upstream and downstream

Secondary copper sources: copper scrap from recycling

Semi-finished products: products fabricated from refined copper, sometimes alloyed with other metals, in the form of wire, rod, tube, sheet, plate, strip, castings, powder or other shapes. They are further transformed by downstream industries to produce copper-containing end-use products.

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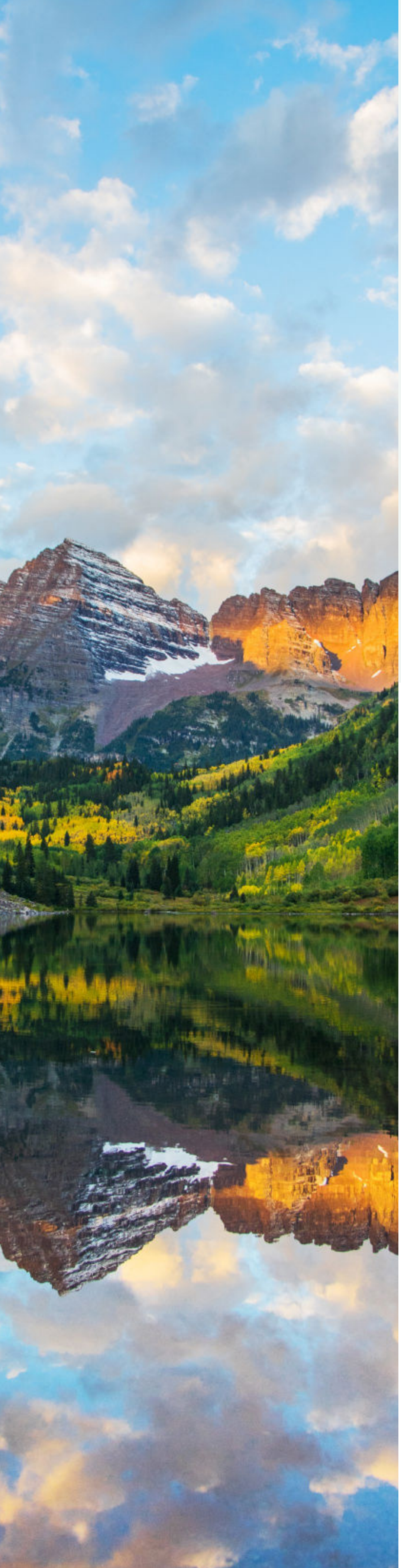


Introduction

The International Copper Association (ICA) and its members have developed this roadmap, *Copper—The Pathway to Net Zero* (further the *Pathway*), through a pragmatic analytical approach that leverages the knowledge of copper-producing companies as well as public data sets of industry experts such as MineSpans. ICA members represent approximately 50 percent of the worldwide refined copper production and are uniquely positioned to collect and analyze data related to carbon emissions. This document outlines ICA members' commitment to decarbonizing the production of copper—a key raw material critical to the energy transition—and presents strategies for bringing the carbon footprint as close as possible to net zero by 2050 for copper mining, smelting, refining and recycling.

Developing a global roadmap for the copper industry to reduce carbon emissions over the next 30 years poses a critical challenge. It requires rigorous data collection, in-depth analysis and modeling to chart potential pathways for a clean energy transition across the sector. Any forecast of the industry's capacity to reduce carbon emissions—and strategies for achieving targets—must address issues related to production, changes in technology and global trends.

ICA first assessed the current worldwide greenhouse gas (GHG) emissions of the copper industry with the support of environmental sustainability consultancy Quantis. Analysts collected emissions data from ICA members for each major step of the production process using 2018 as the baseline, as the COVID pandemic and lockdowns that followed likely skewed the figures from the subsequent years. They incorporated data on local electricity grid emission factors published by the International Energy Agency (IEA) and the model of global copper stocks and flows built by the Fraunhofer Institute to assess the 2018 carbon footprint of the entire copper industry. They also gathered data on Scope 3 GHG emissions from purchased goods and services, fuel- and energy-related activities, transport upstream and downstream in the value chain, operational waste and end-of-life treatment of sold products, six categories that represent the bulk of Scope 3 emissions for copper producers.

Once performed, this carbon footprint assessment was developed into an emissions profile for 14 types of production processes, which include various stages and technologies ("archetypes"—see **Annex 1**) and cover copper mining, refining, smelting and copper recycling. The production stage "mining," for example, includes open pit mining, underground mining with room and pillar technology, underground mining with block caving technology, and underground mining with long hole stoping.

The analysis then assessed options to reduce copper production's GHG emissions within four abatement categories: alternative fuels, decarbonized electricity, equipment electrification and energy-efficiency gains. No offsets were considered in this assessment.

This analysis considers emission abatement options for each archetype, their potential to lower emissions and their total cost of ownership (TCO) to establish the Unconstrained Marginal Abatement Cost Curve (MACC). Drawing on the Unconstrained MACC the study then calculates a Constrained MACC for each region of the world that considers the electricity grid emission intensity, availability of each abatement option and its long term TCO. This analysis establishes a pathway to reduce Scope 1 and 2 GHG emissions for each archetype in each region and presents:

- The most effective emission abatement options
- The recommended timeline and sequences for implementing these options, with two intermediate milestones for 2030 and 2040 and a third target by 2050
- The financial investment required to reach these targets

By combining the Constrained MACCs of all regions in the world, the analysis develops a global overview that demonstrates:

- The Scope 1 and 2 GHG emissions abatement potential by 2030, 2040 and 2050
- The portfolio of technologies with the potential to achieve this reduction
- A first estimate of the financial investments at the global level required to implement such technologies

The analysis estimates Scope 1 and 2 GHG emissions abatement potential through a bottom-up analysis drawing on information about copper production assets, reported mine development projects and country-by-country forecasts on the evolution of grid emission factors. By contrast, it provides a top-down analysis of Scope 3 GHG emissions that identifies emission abatement options for each of the Scope 3 categories it examines. Most of these options will require partnerships between copper producers, suppliers and customers of the industry.

This detailed analysis by serves as a basis for a decarbonization pathway by the global copper industry. The *Pathway* outlines the commitments ICA members will undertake to work toward the goal of net-zero GHG emissions by 2050 across the sector. The *Pathway* is, however, not intended to be prescriptive on how to decarbonize specific copper production sites as individual producers know best which decarbonization measures to implement across their assets. Rather, it analyzes available decarbonization options to propose a general trajectory toward net-zero emissions for the global copper production industry. The *Pathway* also determines the strategies and conditions required, including financial investments, equipment, technologies and access to decarbonized electricity. It highlights the sector-wide efforts necessary to reach climate-neutral copper production by 2050 given the limitations the current portfolio of decarbonization technologies pose.

We, the members of ICA, expect the GHG emissions-reduction trajectories of individual ICA members to vary because of the significant differences that exist between the geographical regions in which copper is produced, e.g., in terms of the projected development of affordable and reliable renewable energy sources. Our collective trajectory is, therefore, indicative for the industry as a whole, and individual members remain responsible for setting their own intermediate GHG emissions reduction targets toward net zero.

Any forecast of the industry's capacity to reduce carbon emissions—and strategies for achieving targets—**must address issues related to production, changes in technology and global trends.**

Executive Summary

Copper is essential for a vast array of decarbonizing technologies. When taken together, these technologies have the potential to account for two-thirds of global greenhouse gas emissions' abatement by 2050. The production of this crucial raw material accounts for around 0.2 percent of worldwide greenhouse gas emissions (97 Mt in 2018). The copper industry is actively working to reduce these emissions.

The members of the International Copper Association (ICA), the leading advocate for the copper industry worldwide, commit to a goal of reaching net zero Scope 1 and 2 greenhouse gas emissions by 2050 and to actively engage with their value chain partners to bring Scope 3 emissions as close as possible to net zero by 2050. Furthermore, ICA members have set intermediate decarbonization ambitions for the years 2030 and 2040, for Scope 1, 2 and 3 emissions, which are outlined in this document, *Copper—The Pathway to Net Zero.*

This collective engagement is the result of a global in-depth, robust analysis performed by ICA and its members, and based on a comprehensive set of facts and sound hypotheses.

Copper—The Pathway to Net Zero defines a pragmatic approach to decarbonizing copper production by outlining which decarbonization options can be activated by when, with what impact on greenhouse gas emissions and at what cost. This decarbonization pathway must be accomplished in the context of a doubling of copper demand—from 25 million tonnes in 2020 to 50 million tonnes in 2050—driven by critical decarbonization technologies such as wind turbines, photovoltaic panels, heat pumps, electric vehicles and energy-efficient equipment.

This *Pathway to Net Zero* demonstrates the commitment of ICA members to act on climate change. Copper producers are already taking action to reduce their carbon footprint through initiatives such as equipment electrification, decarbonization of electricity, use of alternative fuels and energy efficiency measures. ICA members commit to deploying these and additional decarbonizing measures in a responsible and sustainable manner, noting the increasing acceptance of The Copper Mark®, the world's leading third-party assurance framework for copper production.

ICA members are working on a mechanism to ensure transparent and regular reporting of their progress in decarbonizing copper production, through a coherent and aligned methodology for measuring carbon footprint. In addition, *The Pathway to Net Zero* will be regularly updated to integrate changes in technology and external variables, e.g., decarbonization of the power grid.

Success in decarbonization depends not only on the efforts of copper producers but also on the fulfilment of critical framework conditions on which ICA will proactively work with key stakeholders.

- Decarbonization technologies such as green hydrogen and battery electric mining vehicles need to be available at scale.
- Decarbonized electricity needs to be supplied in sufficient quantities and at affordable prices.
- Collection rates of copper-containing products at their end of life must be improved to increase the contribution of recycling to decarbonization.
- Flexible and affordable financing must be available for capacity increases and innovation, while a pool of skilled staff is needed to drive the transition.
- Effective and efficient regulatory frameworks need to be in place to allow for transparent carbon pricing, reasonable permitting deadlines, access to public funds for innovation in decarbonization, stable licensing and royalty schemes, and consistent chemical and product regulations.

ICA members look forward to actively engaging with suppliers, customers, communities and policy makers to achieve the decarbonization of copper production by 2050 and to provide a key raw material, in increasing quantities, to enable the decarbonization of many sectors of the economy.

Power of Zero

Copper—The Pathway to Net Zero defines a **pragmatic approach** to decarbonizing copper production.

SECTION 1

The Role of Copper and Its Industry

Why does society need copper, today and in the future, and how is it produced? This section provides a brief overview of the role of copper and its industry in our society.

Copper Use in Society

Copper has been in use for at least 10,000 years and continues to serve society's needs. It has unique physical and chemical properties, including electrical conductivity, thermal conductivity, corrosion resistance, machinability and castability [*1* , *p.12 – 20*]. These high-performance properties make copper an essential material in a wide variety of applications necessary for quality of life and sustainable economic growth.

In 2020, about 70 percent of copper sales was destined for electrical applications [*2*]. As the best metallic electrical conductor after precious metals, copper sets the standard of electrical conductivity (International Annealed Copper Standard–IACS) [*3*]. It can be found throughout the entire electricity system—from power generation, over transmission and distribution networks, to electricity end use. Copper is recognized as a key material for creating an energy efficient, reliable and safe power supply to communities around the world.

BUILDINGS & INDUSTRY

- Electrical Installations
- Appliances
- Solar Heating
- Air Conditioning
- Heating
- Water and Gas
- Motors

ELECTRICITY SYSTEM

- Renewable Generation
- Transmission and Distribution System
- Submarine and Underground Cable
- Grid Storage

TRANSPORT

- Railways (Catenary)
- Automotive Harness
- Automotive Batteries
- Electric Car Motors

MISCELLANEOUS

- Telecommunications
- Electronic Appliances
- Farming and Agriculture
- Aquaculture
- Marine Applications
- Architecture
- Interior Design

Figure 1—Overview of Copper Uses

Copper has **unique physical and chemical properties,** including electrical conductivity, thermal conductivity, corrosion resistance, machinability and castability.

COPPER IN THE ENERGY TRANSITION

Copper's superior electrical conductivity makes it an essential material for the energy transition to carbon neutrality. The transition relies to a large extent on renewable power generation (e.g., wind, solar photovoltaic) and the electrification of energy end use (e.g., heat pumps, electric vehicles), all of which use substantial amounts of copper (see **Annex 2** for more details).

Copper enables a more energy-efficient electricity system, triggering carbon emission savings at a negative cost in the short term and reducing the need for renewable energy generation capacity in the longer term.

In short, copper use in a vast array of technological solutions has the collective potential to reduce worldwide GHG emissions by two-thirds.

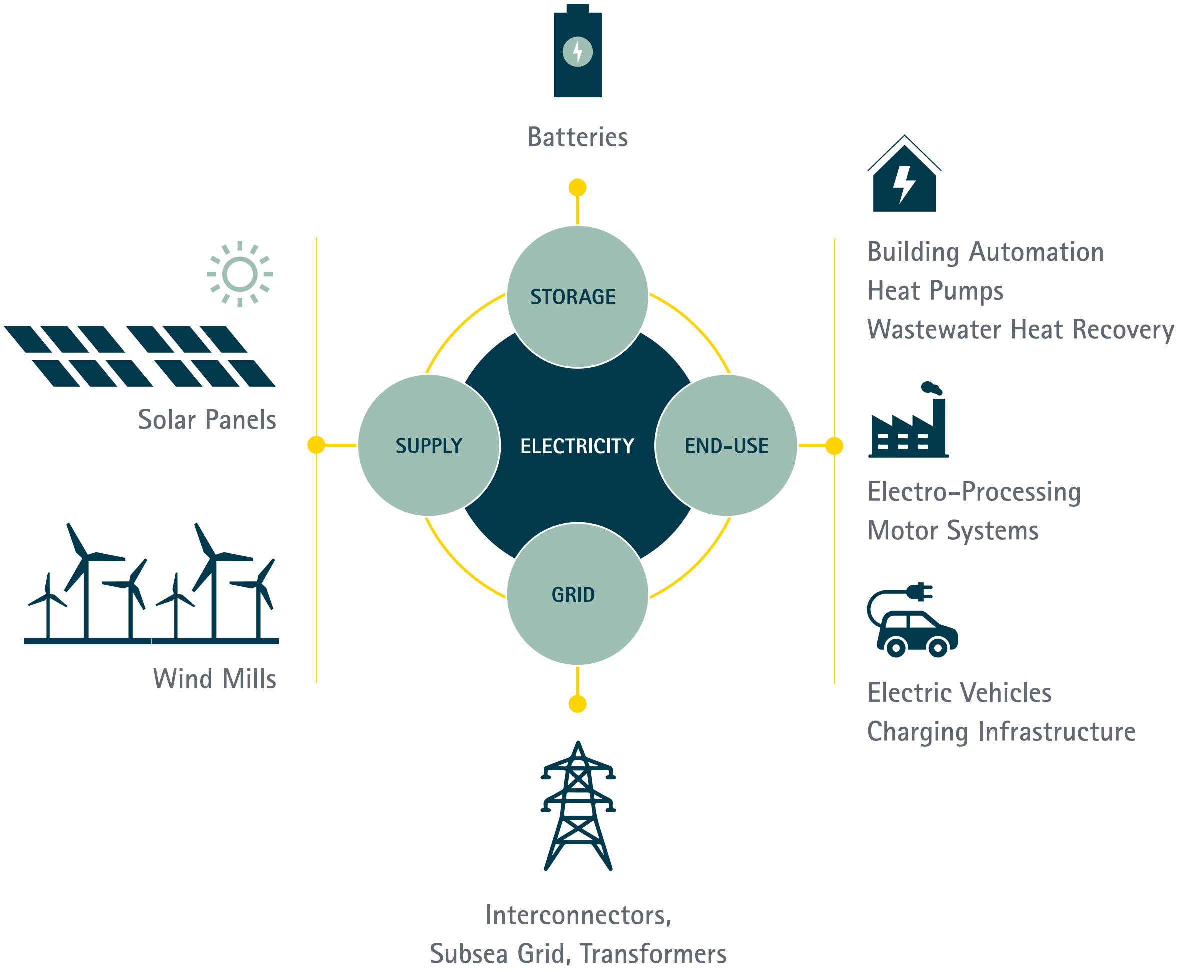


Figure 2—Copper in the Energy Transition

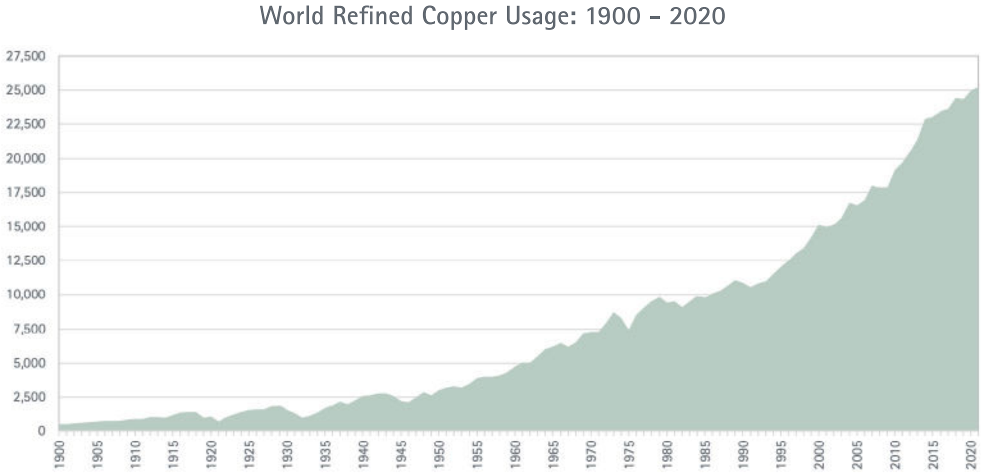


Figure 3—World Refined Copper Usage 1900 – 2020, Per Thousand Metric Tonnes of Copper (*Source: ICSG*)

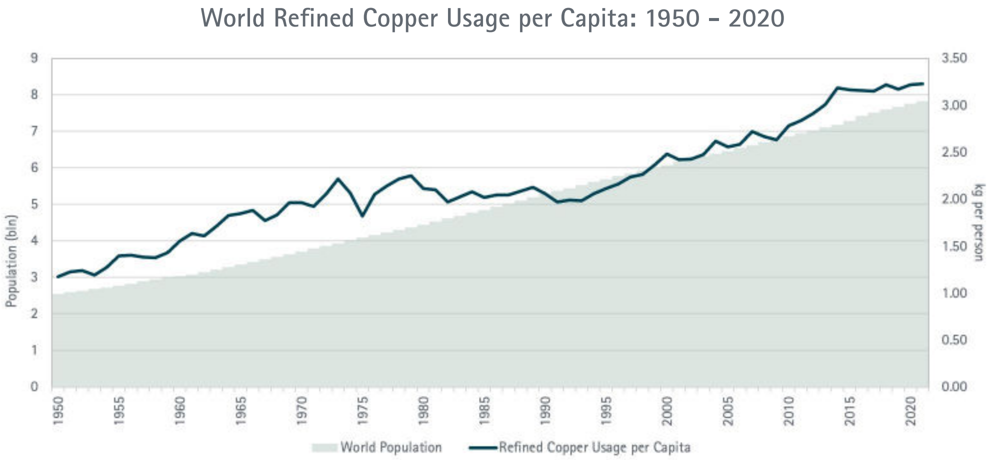


Figure 4—World Refined Copper Usage Per Capita 1950 – 2020 (the amount of copper used by industry divided by the total population excluding copper used in finished products per person) (*Sources: ICSG and U.S. Census Bureau*)

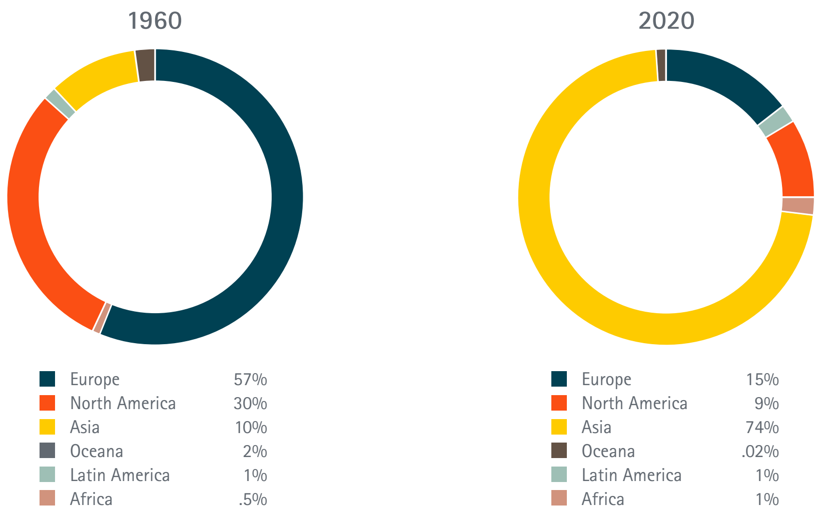


Figure 5—Refined Copper Usage by Region, 1960 Versus 2020 (*Source: ICSG*)

COPPER USE IN NUMBERS

Global annual refined copper usage has been consistently rising from 0.5 million metric tonnes in 1900 to about 2 million metric tonnes after World War II to 25 million tonnes 2020. This corresponds to a compound annual growth rate of 3.4 percent over this 120-year period.

This increase is due in part to the growth in global population as well as growth in copper usage per capita. In 1950, the average annual refined copper usage per capita was 1.15 kg. By 2020, this number was closer to 3.25 kg.

Growth in copper demand differs greatly across regions (see **Figure 5**). For the past 25 years, growth can be mainly attributed to the Asian market, where demand has expanded eight-fold over the past four decades, largely driven by industrial expansion in China (*source: ICSG Copper Factbook*).

As a result of the energy transition, population growth and economic development, the annual refined copper demand is expected to double by 2050 compared to 2020, as shown in **Figure 6**. If measures are taken to restrict global temperature rise to 1.5°C, demand for refined copper by 2050 could be even higher, increasing to 57 million tonnes

Other recent analyses [*16, page 90*] estimate copper demand will double even before 2050. This forecast assumes a strong regulatory push up to 2030 and an aggressive rollout of renewables and electrification in the very near term. The *Pathway* develops a bottom-up, forward-looking demand model that accounts for the time constraints related to the deployment of decarbonization technologies.

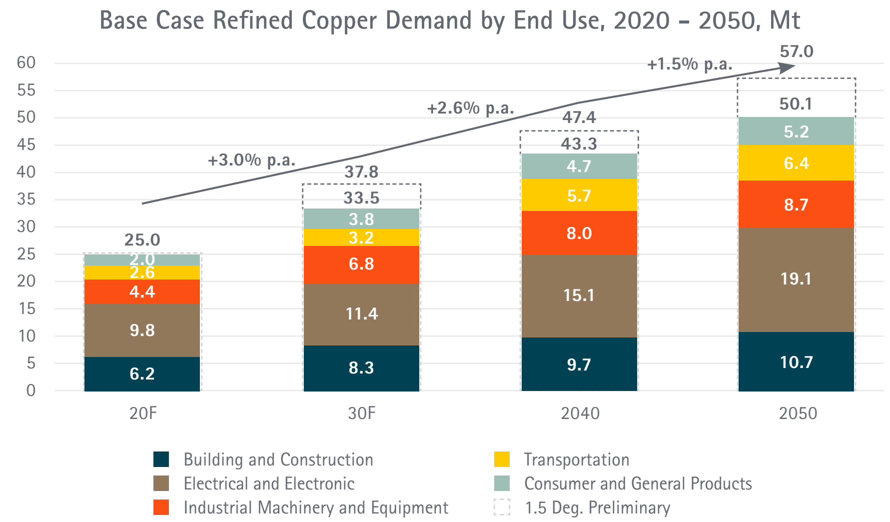


Figure 6—The Expected Rise in Annual Refined Copper Demand Between 2020 and 2050 (*Source: MineSpans Copper Demand Model Q3 2021*)

The Copper Industry

Copper is produced from two sources: copper ore—also called primary copper sources—and copper-containing scrap—also called secondary copper sources. Both sources are usually combined by copper producers and generate the same quality of copper metal, as copper can be recycled infinitely without loss of properties.

The copper industry includes copper mines, smelters, refiners, recycling facilities and fabricators of semi-finished products from copper and copper alloys, such as tubes, wire rods and bars. Copper is an important contributor to the national economies of mature, newly developed and developing countries. Mining, processing, recycling and the transformation of metal into a multitude of products creates jobs and generates wealth. Nearly one million people work directly for the global copper industry, from mining to fabrication [*4*]. At least one more million people are employed indirectly.

Mining, processing, recycling and the transformation of metal into a multitude of products **creates jobs and generates wealth**.

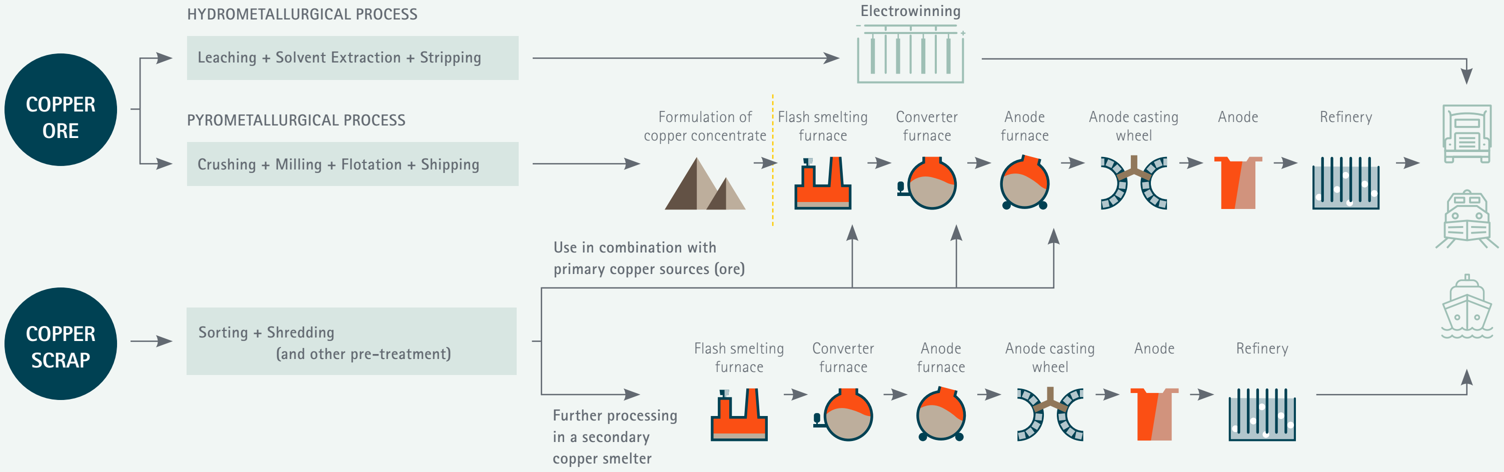


Figure 7—The Three Production Processes of Refined Copper.

THE COPPER PRODUCTION PROCESS

Production from primary sources starts with the extraction of copper-bearing ores from open-pit or underground mines. The ores typically contain between 0.25 and 1 percent of pure copper. Subsequently, two different production routes exist (pyrometallurgical and hydrometallurgical), depending on the characteristics of the raw material—sulfide or oxide ores.

Production from secondary sources is fed by copper scrap originating either from semi-finished or finished products manufacturing waste ("new scrap"), or from copper-containing products reaching the end of their life ("old scrap"). After initial treatment, which usually includes sorting and shredding, the copper scrap enters the pyrometallurgical production process at different stages.

The three production routes to refined copper are shown in **Figure 7** and more details on copper production processes can be found in **Annex 3**. Worth underlying is the "metal carrier" character of copper: its production generates a range of important metallic byproducts—including gold, silver, cobalt, molybdenum, platinum group metals, selenium, tellurium—as well as more complex byproducts such as sulfuric acid and iron silicate.

Copper's infinite recyclability is a major advantage. About 80 percent of copper is used in an unalloyed form [*5*], facilitating the recycling process. Even for alloyed copper or copper containing other materials, recycling without downgrading its quality is still possible and efficient. This means the unwanted elements can be removed to recover the copper in its pure state, ready to be re-used in any kind of application. Because of its high degree of recyclability, the copper in use in various applications is not lost but can be considered an additional source of copper for further use, often referred to as society's "urban mine."

Sixteen percent of copper demand can be fulfilled through the recycling of copper scrap from end-of-life products (10-year average in 2018, see **Figure 8**). This figure is limited because copper demand has been increasing substantially over the years, this results in a smaller volume of copper-containing products reaching end of life as compared to the amount of new copper-containing products entering the market. Another 16 percent of copper demand can be fulfilled through the recycling of fabrication scrap. Adding up both numbers shows a total *recycling input rate* of 32 percent [*5, p. 59*].

> Two different production routes exist, depending on the characteristics of the raw material—**sulfide or oxide ores.**

Although the end-of-life recycling rate needs to grow to meet increasing demand and conserve existing resources, recycled copper alone will not meet growing demand. The first re-use of extracted copper can be decades later—a long average lifetime is beneficial for reducing the environmental impact of production but has a negative effect on copper availability from secondary sources. The World Bank Group calculated that even a 100 percent end-of-life recycling rate would only reduce the demand for copper from primary sources by 26 percent by 2050 [6]. Moreover, no process is 100 percent efficient, and losses in collection, separation and re-processing of copper scrap will always exist. For this reason, copper produced from mineral ores will still be required, along with recycled copper scrap, to fulfill the growing needs.

More detailed information on copper production and on international trade flows of copper concentrate and refined copper are shown in **Annex 4**.

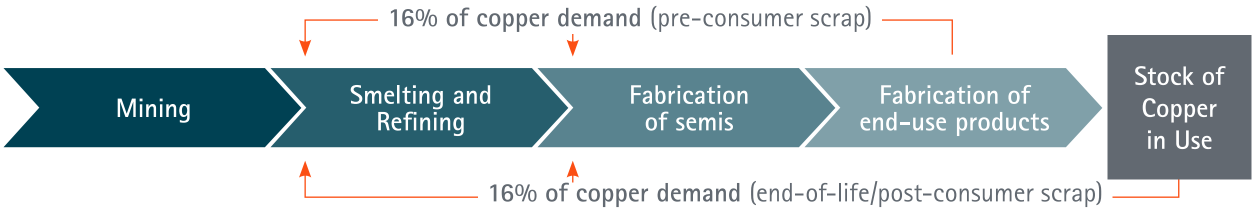


Figure 8—Industry Global Flow of Copper

SECTION 2

The Copper Industry Decarbonization Challenges

ICA members recognize their global stewardship responsibility in embracing sustainability objectives.

As an illustration, in 2020, The Copper Mark®, an independent third-party assurance framework, was launched with the support of ICA. The Copper Mark is designed to provide all stakeholders with the confidence that certified copper production sites operate according to internationally accepted, responsible industrial practices. In this wider context of sustainable production, ICA members have taken the initiative of assessing how copper production can be decarbonized.

This section analyzes how the copper industry can decarbonize its production processes. It first describes current GHG emissions and models the evolution of emissions over time based on a "no-decarbonization actions" ("no-action") scenario. The section then presents pathways to Scope 1 and Scope 2 emission abatement and explores strategies to reduce Scope 3 emissions. It addresses capital expenditure and partnerships which will be critical to emissions reduction. The section also reviews options for the decarbonization of the copper industry in China, a major player in the sector internationally.

GHG Emissions of Copper Production Today

The global copper industry emitted an estimated 112 million tonnes of CO_2e (Scopes 1, 2 and 3 included) in 2018. The production of refined copper generated 97 million tonnes, about 85 percent of total emissions. The remaining 15 million tonnes were produced during the fabrication of semi-finished products such as wire, tubes, sheets, castings and powders.

GHG emissions from refined copper production represent 2 percent of the total emissions of the metals and mining sector and 0.2 percent of the total global anthropogenic emissions. Copper generates a fraction of the worldwide GHG emissions and greatly contributes to their reduction. As explained in the previous section, copper is a key raw material for a wide set of technologies that, taken together, enable the abatement of about two thirds of the global GHG emissions.

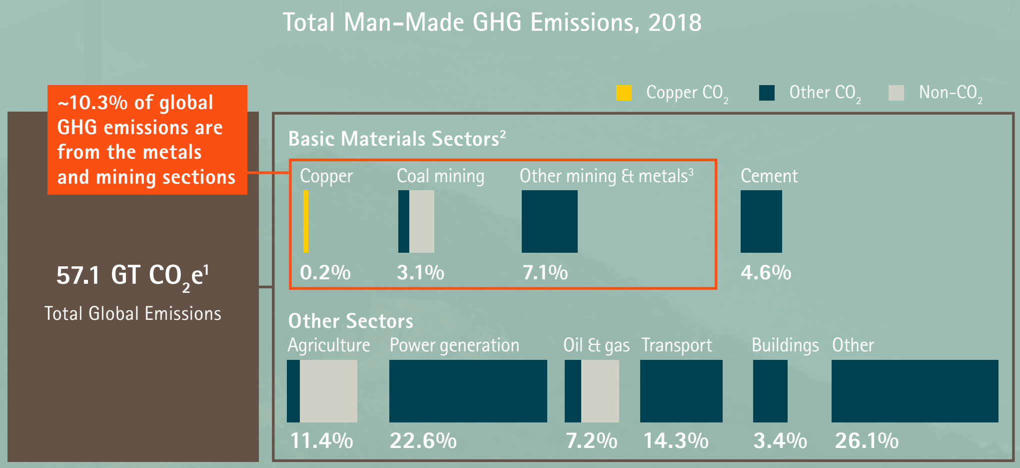
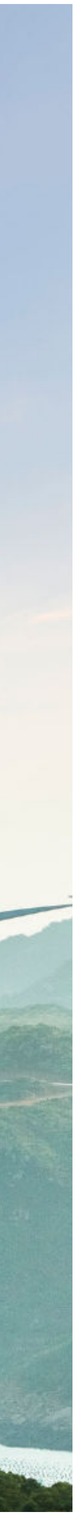


Figure 9—Share of GHG Emissions of the Copper Industry (*Source: MineSpans, McKinsey Energy Insights*)

[1] Scope 1 emissions: CO_2: 41.25%, CH_4: 30.39%, HFCs: 2.21% and N_2O: 2.53% GWP: 100
[2] Metals, mining
[3] Steel, aluminum and other metals



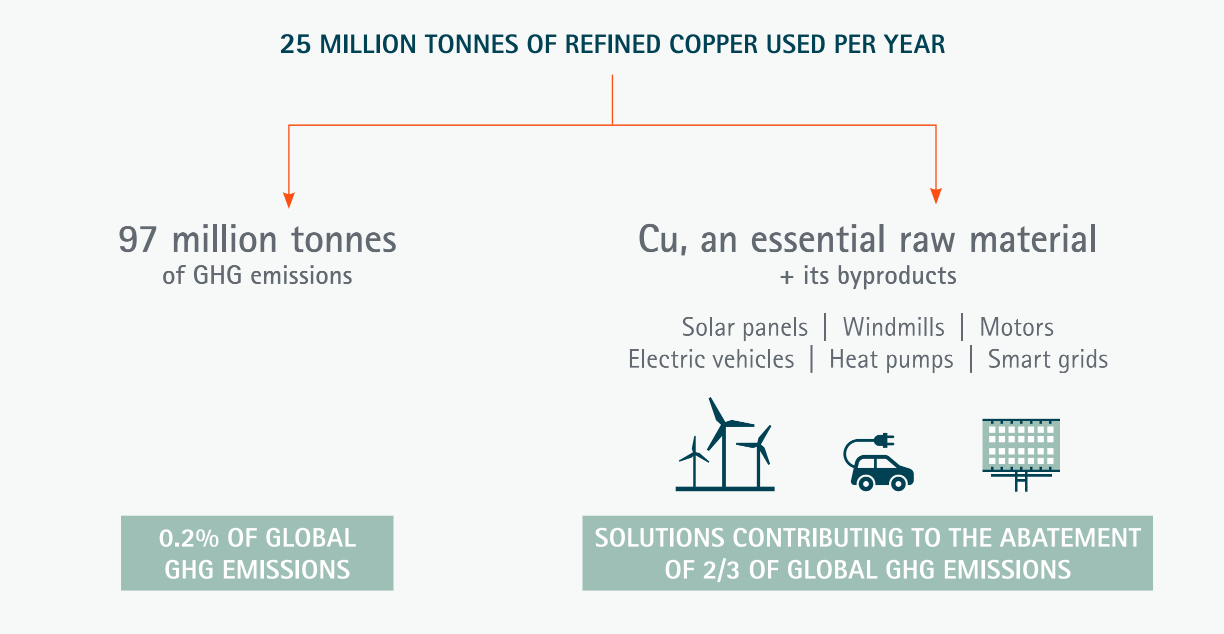


Figure 10—Cost-Benefit Analysis of Copper GHG Emissions

The largest portion—46 percent—of the 97 million tonnes of GHG emitted by copper producers were Scope 2 emissions, indirect emissions associated with the purchase of electricity, steam, heat and cooling. Scope 3 emissions—other indirect emissions outside of Scope 2—represent 31 percent of GHG emissions generated by copper production. Scope 1 emissions—direct emissions from owned or controlled sources—represent 23 percent of GHG emissions by the industry. This report analyzes Scope 3 emissions from data on six categories identified as material to copper production: purchased goods and services, fuel- and energy-related activities, upstream transport, downstream transport, waste generated in operations and end-of-life treatment of sold products. It excludes an analysis of "use of sold products" due to a current lack of reliable data.

Scopes 1, 2 and 3 have been defined at the full copper production level, meaning the range of processes from mining, smelting, refining to recycling described in **Section 1, Figure 7**. Since some copper producers focus on mining and the production of concentrates—and others on smelting and refining only—the classification by these companies of their GHG emissions as Scopes 1, 2 and 3 will differ from the definition used here.

Of these 97 million tonnes of GHG emissions, 70 percent were generated by mining sites, 23 percent stemmed from the smelting and refining stages of production and the remaining 7 percent occurred in upstream and downstream transport and in the end-of-life treatment of sold products.

Global Scope 1, 2 and 3 Copper CO_2e Emissions, 2018, *Million Tonnes*

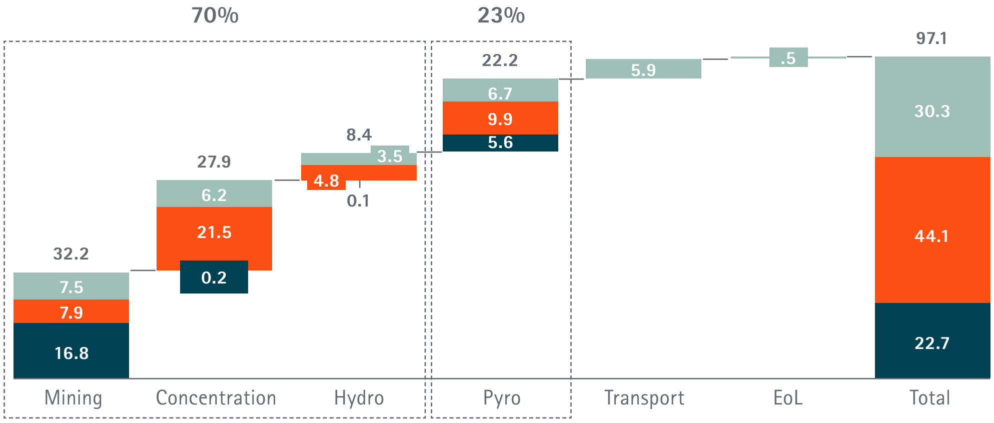


Figure 11—Global Scope 1, Scope 2 and Scope 3 CO_2e Emissions of Copper in 2018 (*Source: Quantis*)

In 2018 the GHG average emission intensity of refined copper production was 4.6 tonnes of CO_2e per tonne of copper. This compares with 5.4 tonnes of CO_2e in 1990, a reduction of 13.4 percent over the 28-year period. This reduction stemmed from an increase in copper production from secondary sources, changes in the electricity mix and ongoing measures by copper miners to improve the energy and emission efficiency of production.

Average GHG Emission Intensity of Refined Copper *t CO_2e/t Cu*

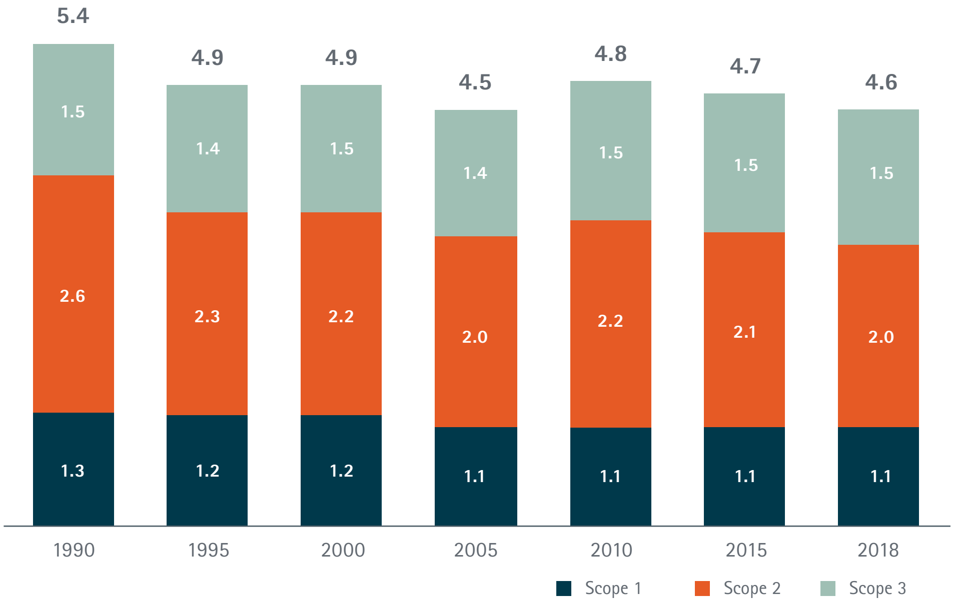


Figure 12—GHG Emissions – Past Performance

Copper production enables the extraction of other metals that are critical for society, the manufacturing of byproducts (e.g., sulfuric acid and iron silicates) and recovery of heat from smelting for use in other applications like district heating. The emissions associated with by- and co-generated products amounted to 19.3 million tonnes of CO_2e in 2018 and are assumed as avoided emissions elsewhere, as those products representing an important share of those markets are incidentally provided by the copper industry.

Baseline for Computing the Abatement Potential

NO-ACTION SCENARIO

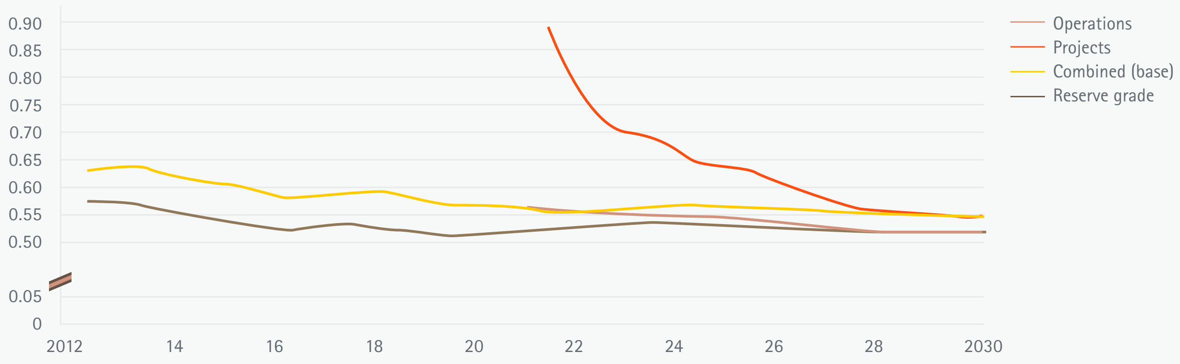
The production of refined copper is expected to double between 2020 and 2050, leading to an annual production of 50 million tonnes, with 10 million tonnes of the total originating from copper scrap. Over this period, two major factors will affect the CO_2e intensity of copper production: 1) the decline of the mill-head grade of copper ore will continue to drive up emissions, and 2) the shift toward fossil-free sources by national electricity grids will lower CO_2e intensity in the sector.

Mill-head grade of copper ore has steadily been decreasing to an average of 0.58 percent in 2020. A further decrease is expected up to 2030, followed then by a stabilization around 0.53 percent in the period to 2050. Such a decrease would result in an additional 10 to 20 million tonnes of CO_2e emissions by the copper industry by 2050.

The production of refined copper is expected to double between 2020 and 2050, **leading to an annual production of 50 million tonnes**, with 10 million tonnes of the total originating from copper scrap.

DEEP-DIVE: MILL-HEAD GRADE OF COPPER ORE

The mill-head grade is the metal content of mined copper ore entering the grinding mill for processing. The lower the grade, the more energy is required to produce one tonne of pure copper, hence the overall objective by mining companies to reach the highest ore grade possible. The average mill-head grade of existing mining operations declined by 9 percent between 2012 and 2020, down to 0.58 percent, and is expected to decrease by another 10 percent by 2030. This reduction will be mitigated, in part, by the higher mill-head grade of new mining projects, as miners start digging where the expected yield is the highest. New mining projects with a start date in 2021 have an expected mill-head grade of approximately 0.9 percent. The addition of new projects to existing mining operations will bring the average mill-head grade of copper ore to be 0.55 percent in 2030, a decline of 4 percent compared to 2020. No substantial further decline of mill-head grade is expected between 2030 and 2050 as the estimated grade of the copper reserves will likely stabilize at around 0.50 to 0.55 percent.



Global Primary Copper Mine Millhead Grade, 2012 – 30, *Percent in weight of ore mined*

Figure 13—Evolution of Copper Mine Mill-Head Grade (Operational Mines, New Projects and Reserve Grade) (*Source: MineSpans*).

At the same time, the carbon intensity of electricity grids around the world is expected to decrease from 200 to 600 kg CO_2/MWh today to less than 100 kg CO_2/MWh by 2050 following a rise in the use of fossil-free energy sources (see **Figure 14** below). Countries with many planned renewable energy power plants, such as Spain and Chile, will see the fastest and strongest decline. Additional grid investments and maturing battery storage technologies will significantly lower the carbon intensity of the electricity mix. By 2050, these changes are forecast to cut the annual carbon emissions of copper production by 50 to 80 million tonnes of CO_2e emissions, a substantial reduction.

Additional grid investments and maturing battery storage technologies will **significantly reduce the carbon intensity** of the electricity mix.

Forecasted CO_2 Intensity of National Energy Grids, 2012 – 30, *kg CO_2/MWh*

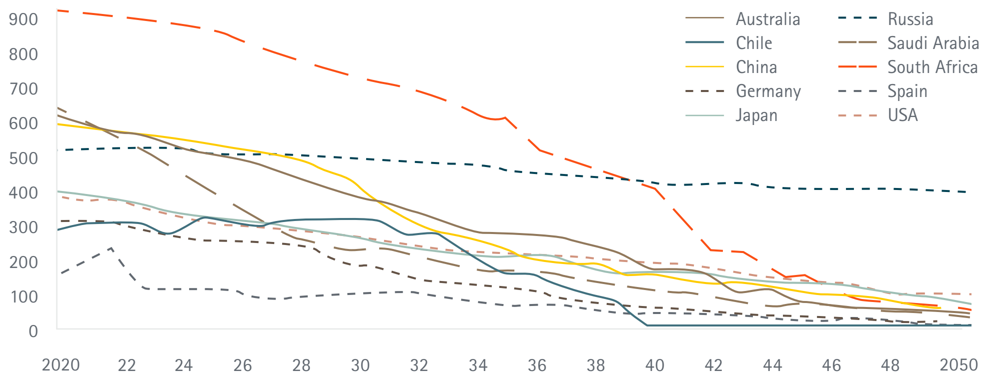


Figure 14—Expected Evolution of the CO_2 Emission Intensity of Electricity Grids (*Source: MineSpans*).

Figure 15 illustrates the impact of these variables on emissions from 2018 to 2050.

Global Copper Scope 1, 2 and 3 Emissions, 2018 – 50—No-Action Scenario

CONCEPTUAL

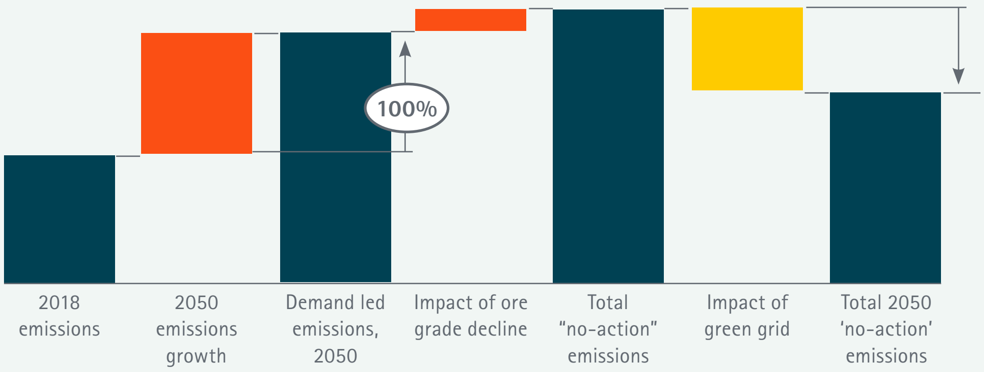


Figure 15—Modeling Emissions: 2018 - 2050

DEFINING THE BASELINE

A bottom-up estimation of baseline emissions was constructed, combining copper production assets, reported mine development projects and country-by-country forecasts on the evolution of grid emission factors. This estimation yields a figure of 102 million tonnes of CO_2e emissions per annum by 2050 for refined copper production in a no-action scenario. From 2018 to 2050, the emissions volume generated by copper production is expected to follow a bell-shaped curve as shown in **Figure 16**:

- Total emissions will increase until 2030 as production increases faster than the decarbonization of the power grid
- From 2030 onward, improvement of the grid emission factor will more than offset the increase in emissions from production growth
- However, total emissions by 2050 will be higher than in 2018 in a no-action scenario.

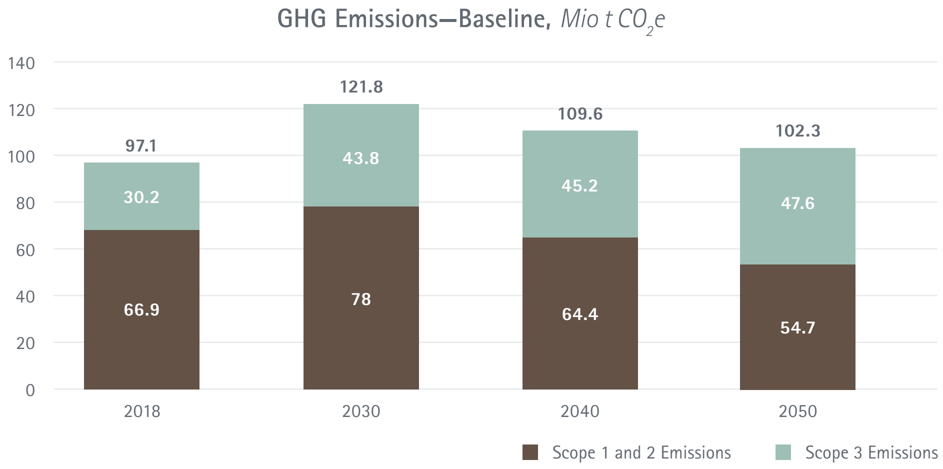


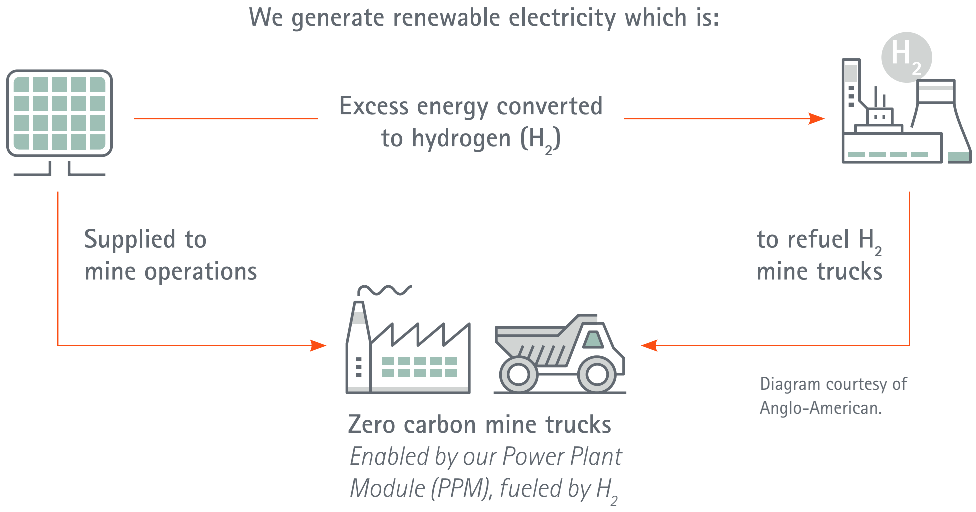
Figure 16—Baseline: Worldwide GHG Emissions from Copper Production in a No-Action Scenario (*Source: MineSpans*)

Abating Scope 1 and 2 Emissions

The analysis indicates a significant percentage of Scope 1 and 2 emissions from global copper production can be reduced by using four types of market-ready and developing technologies:

Alternative fuels. This includes the move from diesel to transition fuels like biodiesel for trucks, excavators and drills as well as the shift to green hydrogen for haulage trucks. In smelting furnaces, green hydrogen could replace natural gas; other natural gas systems could switch to biogas; biochar could replace coke. The following diagram highlights ***Anglo-American's*** efforts in this field.

AN INTEGRATED MINE DECARBONIZATION SOLUTION



We generate renewable electricity which is:

Excess energy converted to hydrogen (H_2)

Supplied to mine operations

to refuel H_2 mine trucks

Zero carbon mine trucks
Enabled by our Power Plant Module (PPM), fueled by H_2

Diagram courtesy of Anglo-American.

Equipment electrification. Examples include the introduction of battery or pantograph fully electric trucks to replace diesel trucks for haulage and electric furnaces to replace natural gas furnaces. Such equipment should of course be supplied by decarbonized electricity.

*ICA member **Boliden's** pantograph mine haulage truck.*

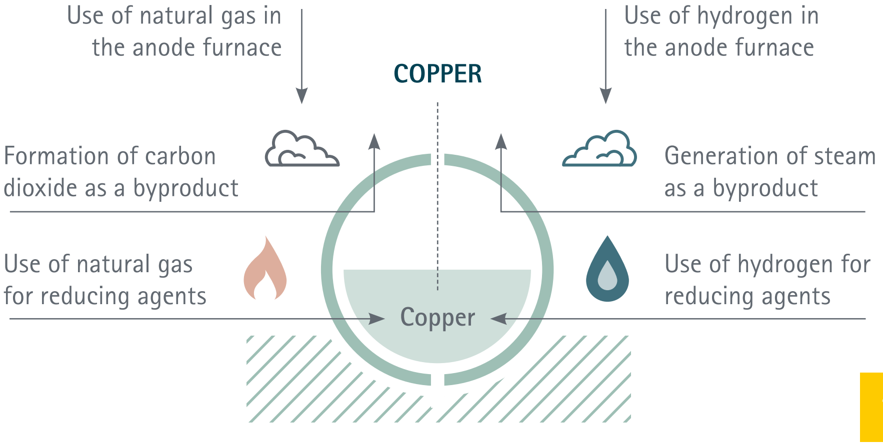
Decarbonized electricity. This includes the switch from standard to carbon-free purchased electricity through Power Purchase Agreements (PPAs) as well as the installation of wind and solar energy farms at copper production sites. Such measures would allow copper producers to reduce the CO_2e intensity of used electricity faster than if they purchased it from the grid without a specific purchase agreement.

ICA members are implementing renewable energy solutions at the mine site.

- ***Codelco*** uses 200MW of renewable energy to power its Chuquicamata mine through a purchase power agreement in place since 2021.
- ***KGHM*** has the only solar plant in Poland based on Industry 4.0 technology, directly connected to its Legnica smelter and providing 3 GWh of electricity annually since 2020.
- ***BHP*** has been supplying its Escondida and Spence mines in Chile with 100 percent renewable energy since 2021, saving 3 million tonnes of CO_2e annually.
- ***Mitsubishi Materials*** Irigama solar power plant in Japan's Miyagi prefecture, opened in 2015, and provides 6930 kW of electricity.
- In 2019, ***Rio Tinto's*** Kennecott Utah Copper mine retired its coal-fired power plant and began powering its operation via renewable energy certificates purchased from Rocky Mountain Power, reducing its annual carbon footprint by as much as 65 percent.
- ***Grupo México´s*** has invested $260 million in Fenicias, a wind farm located in Nuevo Leon, Mexico. This 168MW wind farm will provide 600 GWh per year of green electricity to the company´s nearby mining and metallurgical operations. Once in operation in 2023, Fenicias will reduce approximately 250k tCO_2e of Grupo's Mexico's emissions per year, which represents 16 percent of its 2021 Scope 2 emissions or 6 percent the mining division´s Scope 1 and 2 emissions.
- ***Antofagasta's*** Zaldivar copper mine (2020) was the first copper mine in Chile to operate with 100 percent renewable energy, saving 350,000 tonnes of CO_2 annually.

Energy efficiency. Examples include the improvement of milling efficiency using high-chromium grinding media and the installation of in-pit crushing and conveying systems to avoid truck haulage, when applicable. For example, ICA member ***Freeport-McMoRan*** has reduced energy consumption by 20 percent with innovative high-pressure grinding rolls.

By 2030, an estimated 30 to 40 percent of emissions can be reduced compared to the baseline mainly through the switch to green electricity, via production on site or PPAs. Alternative fuels (like biodiesel or green hydrogen) and equipment electrification play a limited role in this first period due to constraints on the availability of these fuels and technologies. ICA member ***Aurubis*** is testing the use of hydrogen as a reducing agent in the anode furnace. The diagram to the right outlines the process.



By 2040, production at scale of battery electric or fuel cell trucks, coupled with increased availability of green hydrogen, will enable a reduction of emissions by 70 to 80 percent compared to the baseline. The contribution of alternative fuels and equipment electrification will further expand in the period from 2040 to 2050, while abatement potential via clean electricity will decrease due to the further decarbonization of the power grid.

By 2050, emissions can be reduced by 85 to 95 percent compared to the baseline, via further electrification and increased availability of green hydrogen. Across the 2020 to 2050 period, further abatement of Scope 1 and 2 emissions can be achieved through efficiency gains that typically represent between 7 and 12 percent of the total abatement potential.

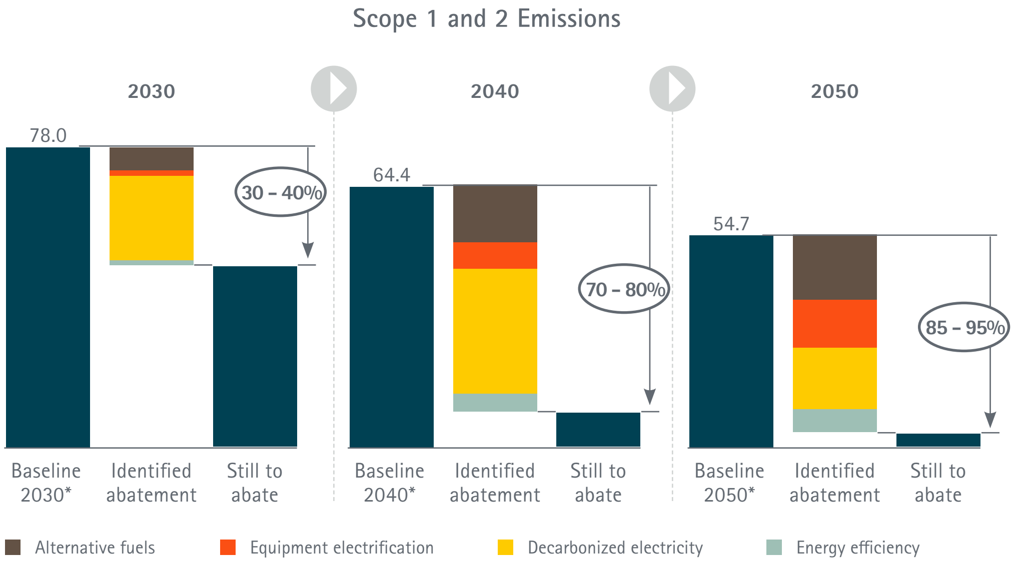
Photo courtesy of ***Teck Resources****.*

Teck is partnering with mining peers, mobile equipment manufacturers, transportation suppliers and others to advance and accelerate the development of low-carbon vehicles such as an electric boom truck designed for underground operation. ***Vale's*** Green Energy Vehicle Program operates approximately 50 Green Energy Vehicles (GEVs) in underground mines, over 40 of which are Battery-Electric Vehicles (BEVs). Vale has been employing electromobility at their mine sites since the 1990s. Their initiatives are part of companywide efforts to reduce Scope 1 and 2 emissions 33 percent by 2030.

By 2050, emissions can be reduced by 85 to 95 percent compared to the baseline, via further electrification and increased availability of green hydrogen. Across the 2020 to 2050 period, further abatement of Scope 1 and 2 emissions can be achieved through efficiency gains that typically represent between 7 and 12 percent of the total abatement potential.

Photo courtesy of ***Vale****.*

By 2050, **emissions can be reduced by 85 to 95 percent** compared to the baseline, via further electrification and increased availability of green hydrogen.



* 'no-action' scenario

Figure 17—Potential for Scope 1 and 2 Emission Abatement by 2030, 2040 and 2050 Compared to a No-Action Scenario (*Source: MineLens Asset Decarbonization Tool; Team Analysis*)

Based on this analysis, **the members of ICA commit to a goal of bringing copper production to net zero Scope 1 and 2 GHG emissions by 2050.** Research and development efforts will be prioritized to unlock additional decarbonization technologies that should allow us to reach a full reduction of Scope 1 and 2 emissions.

1. This 2050 target is a *collective* goal reflecting the decarbonization measures that ICA member companies are pursuing. Scope of activities, operating conditions and the speed of decarbonization of the available power grids vary both among copper producers and across regions. These factors will impact the intermediate emission reduction that each member company can achieve by 2030 and 2040. Hence the emission abatement trajectory in **Figure 17** should *not* be used as a benchmark to assess the interim performance of individual companies toward the 2050 net-zero goal.

2. This target is based on current decarbonization technologies and analysis of their availability at scale, cost and abatement potential. This model of trajectory toward net-zero emissions is thus indicative and subject to change as these variables may fluctuate over time.

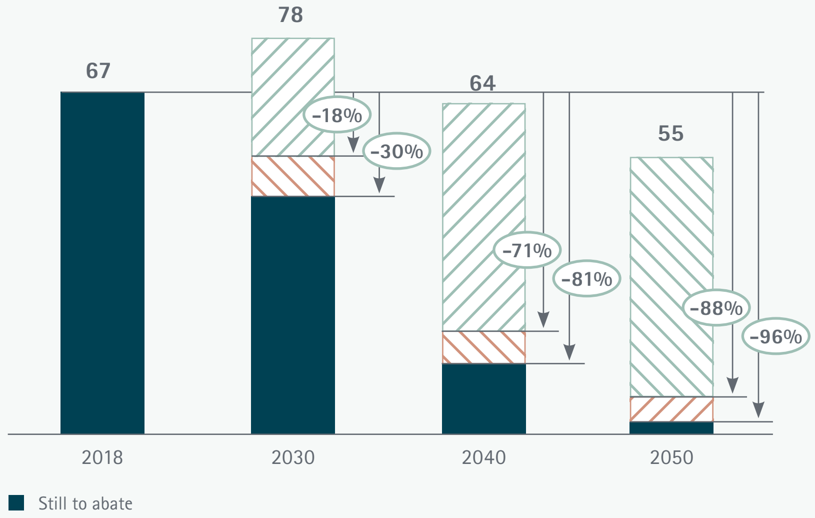
COMPARISON OF SCOPE 1 AND 2 ABATEMENT POTENTIAL TO THE REFERENCE YEAR 2018

Although the analysis performed chose to measure the abatement potential in year 2030, 2040 and 2050 in percentage of the GHG emissions that would have been generated without decarbonization initiatives ("no-action scenario" baseline), it is also common practice to measure this potential as a percentage of the emissions generated during a reference year—the year 2018 for this analysis.

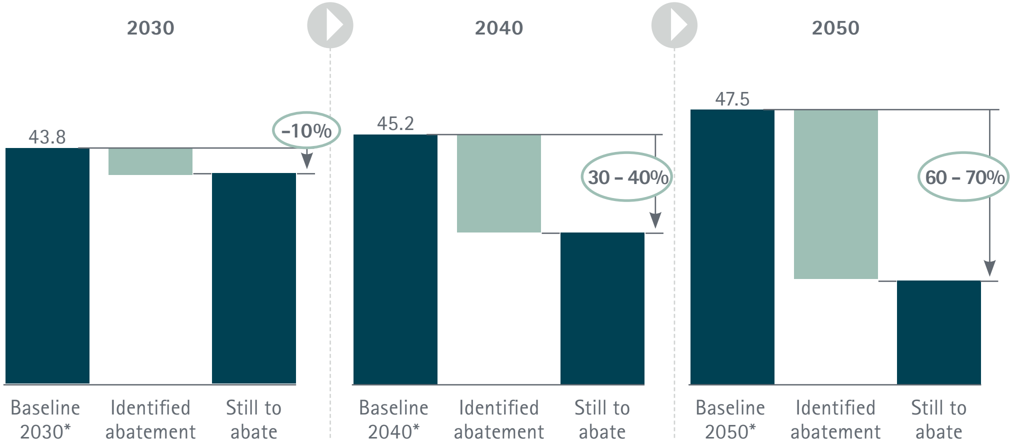
For the sake of completeness, we present this alternative comparison, although we give preference for a reduction percentage of a "no-action scenario" baseline (baseline which evolves across time), as it takes the evolution of production volumes and of CO_2 intensity of power grids into account.

In this graph, the total volume of (for example) still to abate 2030 emissions, computed as 30 to 40 percent lower than the emissions in a no-action scenario (78 million tonnes—see **Figures 16 and 17**), ranges from 46.8 (-40 percent) to 54.6 (-30 percent) million tonnes. This range is 18 to 30 percent lower than the 67 million tonnes emitted in 2018.

Scope 1 and 2 Emissions Abatement Potential *in % of 2018 Emissions, Mio t CO_2e*



Scope 3 Emissions



* 'no-action' scenario

Figure 18—Scope 3 Emissions Abatement Potential by 2030, 2040 and 2050 Compared to a No-Action Scenario
(*Source: MineLens Asset Decarbonization Tool; Team Analysis*)

Combining these levers could allow the copper sector to reduce Scope 3 emissions by around **10 percent by 2030, 30 to 40 percent by 2040 and 60 to 70 percent by 2050.**

Abating Scope 3 Emissions

Addressing the reduction of Scope 3 emissions presents additional challenges when compared to Scopes 1 and 2. First, interdependence between actors in the value chain requires a partnership approach to maximize potential abatements, which are not under the control of copper producers. The scope of these partnerships can be extensive if tier-2 and tier-3 suppliers collaborate to reduce emissions. Second, the availability of up-to-date, quality data on emissions factors from various suppliers, service providers or customers is still limited. This constraint makes the measurement of Scope 3 emissions and the identification of abatement solutions even more challenging.

Notwithstanding these difficulties, an initial assessment of the abatement potential for Scope 3 emissions was performed based on purchased goods and services, fuel- and energy-related activities, transport upstream and downstream in the value chain, operational waste and end-of-life treatment of sold products, the categories that produce the bulk of Scope 3 emissions within the copper sector. It identified major decarbonization levers related to decarbonized electrification, near shoring, alternative production technologies or fuels, efficiency gains. In addition, increased circularity can reduce emissions in the treatment of end-of-life products or in waste generated in operations.

Combining these levers could allow the copper sector to reduce Scope 3 emissions by around 10 percent by 2030, 30 to 40 percent by 2040 and 60 to 70 percent by 2050.

Active partnerships across the copper value chain have the potential to improve the capacity of the industry to reduce Scope 3 emissions. Establishing and managing such collaborations, however, will require substantial resources as well as agreements to ensure goals are reached. Contractual relationships with suppliers and customers should address problems related to compliance.

ICA members will actively engage with the copper industry value chain with the ambition of **reducing Scope 3 emissions toward net zero by 2050.**

This ambition should be understood as incorporating the following considerations:

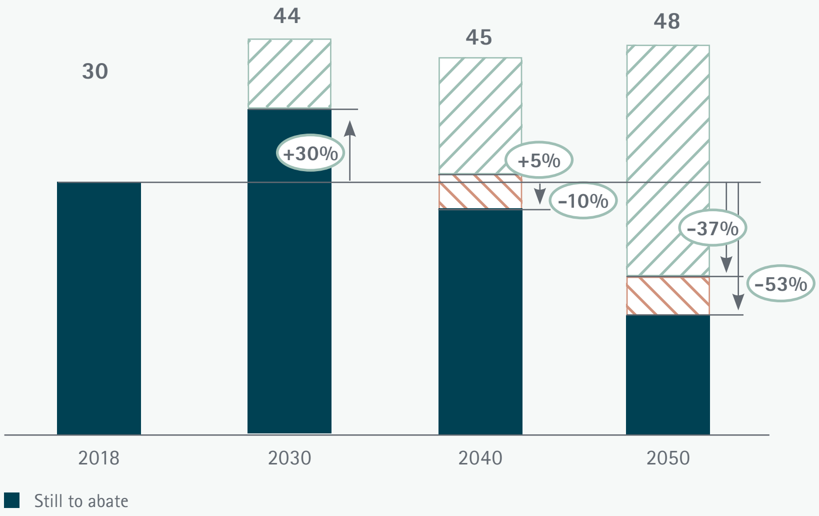
1. As for Scopes 1 and 2, this is a *collective* ambition that should *not* be interpreted as a benchmark to assess the performance of individual members companies of ICA in reducing their Scope 3 emissions.
2. This ambition has been defined to the best of our current knowledge, which is constrained by the challenges in addressing Scope 3 emissions noted above. As ICA members develop better techniques for measuring emissions and partnerships to abate them, they will review and likely revise this ambition. Thus, the industry pathway may shift over time and will depend on the establishment of partnerships to build capacity. ICA members will work with their partners to identify further decarbonization solutions to close the gap to net zero by 2050.

COMPARISON OF SCOPE 3 ABATEMENT POTENTIAL TO THE REFERENCE YEAR 2018

As for Scopes 1 and 2, we present, for the sake of completeness, the alternative comparison of Scope 3 emissions abatement potential as a percentage of such emissions generated in 2018.

In this graph, the total volume of (for example) still to abate 2030 emissions, computed as 10 percent lower than the emissions in a no-action scenario (44 million tonnes—see **Figures 16 and 18**), amount to 39.6 million tonnes. This number is 30 percent higher than the 30 million tonnes emitted in 2018.

Scope 3 Emissions Abatement Potential *in % of 2018 Emissions, Mio t* CO_2e



Combining the trajectories for Scope 1 and 2 and for Scope 3 and using "per tonne" metrics, the CO_2e intensity of the copper cathode has the potential to drop from 4.4 tonnes of CO_2e per tonne of copper today to below 0.4 tonne by 2050, as shown in **Figure 19** below.

Here again, the intermediate values shown for 2030 and 2040 are indicative, as they significantly depend on specific hypotheses (such as the the speed of decarbonization of local power grids) to be fulfilled.

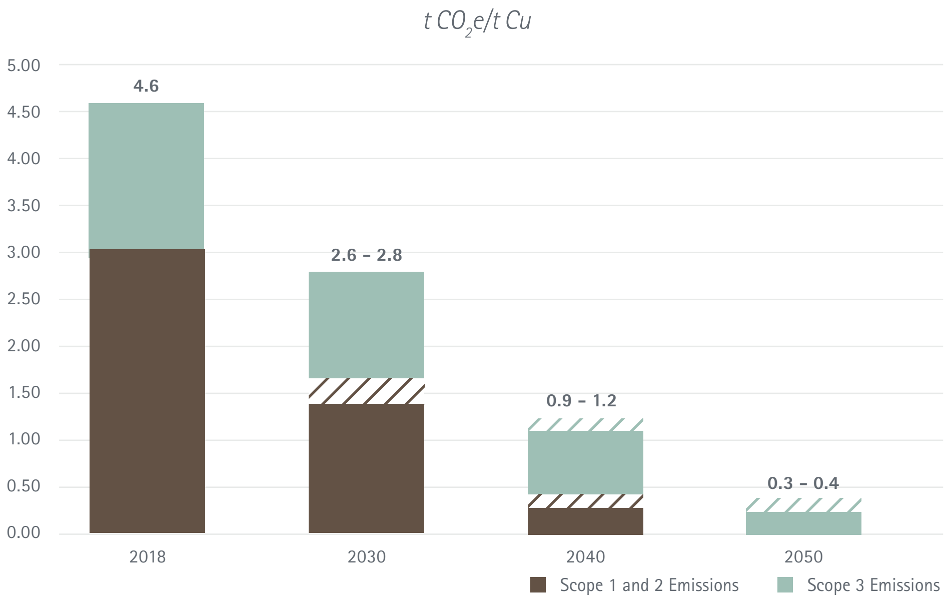


Figure 19—Forecasted Evolution of Carbon Intensity of Copper Cathode (*Source: McKinsey Asset Decarbonization Tool; Team Analysis*)

ICA members recognize that further measures will be required to bring copper production to net zero by 2050. They commit to pursuing research and development to further reduce Scope 1 and 2 emissions and to establishing extensive partnerships with relevant stakeholders to lower Scope 3 emissions. This to bring the decarbonization efforts of the ICA members in full alignment with the Paris Agreement.

This target to decarbonize production hinges on a set of key framework conditions, including, for example, access to abatement technologies at scale, renewable power infrastructure and a stable, efficient regulatory environment. These framework conditions are addressed in detail in the next section.

ICA members will work toward this target through a comprehensive commitment to sustainability. In pursuing decarbonization solutions, they undertake not only to mitigate negative impacts on other environmental categories—such as water, land or air—and local communities, but also to maximize the positive impacts of emissions' reductions by improving conditions such as air quality and access to energy infrastructure. For example, *Glencore*, an ICA member, is committed to the socio-economic development of the countries in which they operate. In the DRC, they worked with local government to support the rehabiliation of two turbines at the INGA dam, enabling the generation of 460 MW of electricity with 50 MW going directly to the population of Kolwezi.

ICA members support The Copper Mark®, a voluntary third-party assurance framework established to promote the responsible production of copper and transparent reporting, which significantly contributes to sustainability. ICA members also recognize and adhere to core principles related to the transition to carbon neutrality for all stakeholders. This will be the focus of forthcoming projects, as noted in **Section 4** (The Way Forward).

ICA members also recognize and adhere to **core principles related to the transition to carbon neutrality** for all stakeholders.

Required Means for Reaching the Decarbonization Target

Decreasing Scope 1 and 2 emissions for global copper production to reach net zero by 2050 will require substantial financial resources. ICA members currently estimate an aggregate investment by copper producers of at least $110 billion at constant currency cost will be necessary to reach this target over the period from 2023 to 2050. The breakdown by category and production steps is shown in **Figure 20**.

The minimum investment of $110 billion is in addition to covering recurring capital expenditures to maintain operations ("maintenance Capex"). This estimate does also not include capital costs required to develop at scale the technologies that will enable copper producers to decarbonize (e.g., green hydrogen, battery-electric trucks) or to install the supporting infrastructure to deploy these technologies (e.g., distribution of decarbonized grid power).

Several factors may cause this estimate to increase:

- Further research and development will be critical to bringing the emission reduction potential closer to 100 percent
- New decarbonization solutions may be identified and implemented
- Abatement of Scope 3 could trigger some joint investments with suppliers or customers
- Base materials costs could keep rising above the industrial price index

This shows that decarbonization will require significant investments beyond the capital expenditure needed to expand production capacity to meet growing copper demand, estimated at $460 billion between 2020 to 2050 (see **Figure 21**). However, ICA members believe these capital expenditures for decarbonization can be managed with an acceptable rate of return provided framework conditions are met.

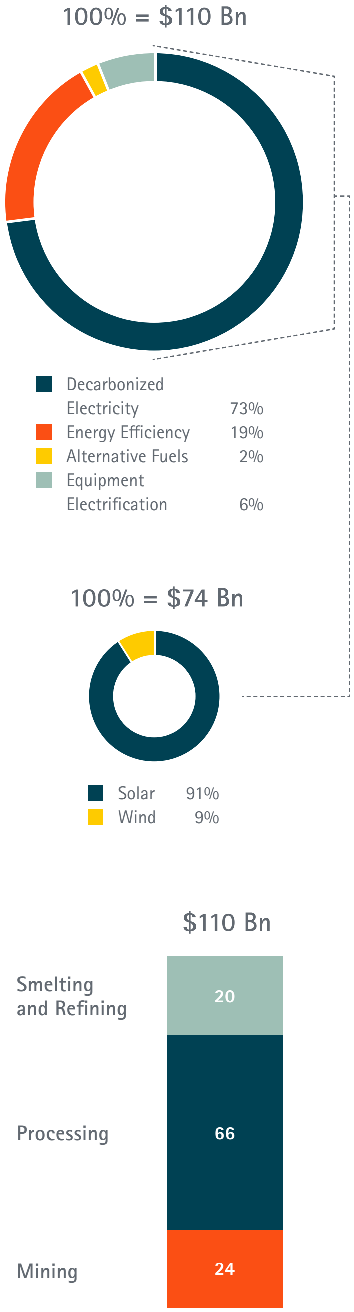


Figure 20—Estimated Capital Expenditures to Abate Scope 1 and 2 Emissions By 2050 (*Source: MineSpans; MineLens; Team Analysis*)

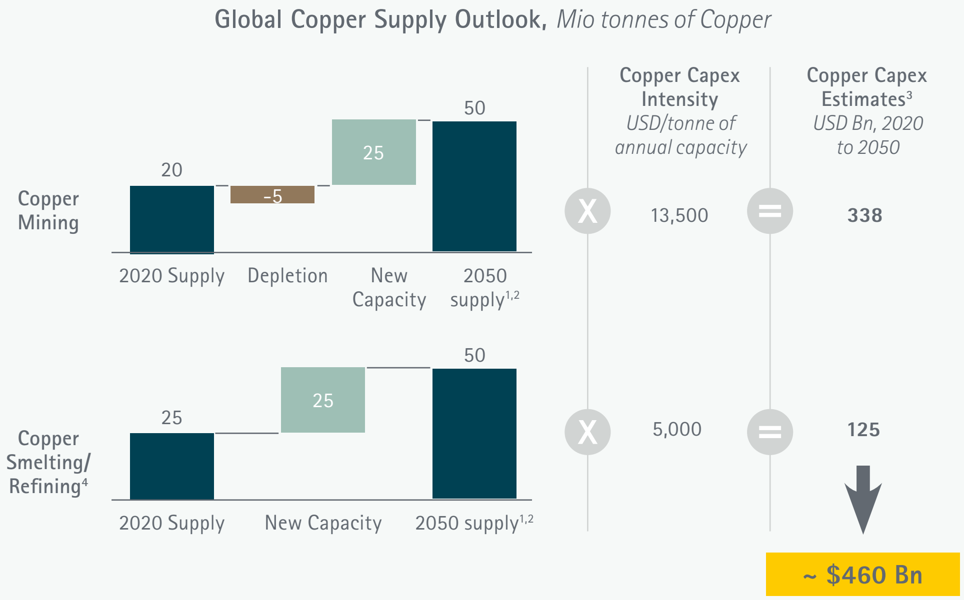


Figure 21—Estimated Capital Expenditure Required to Expand Copper Production to Meet The Growing Demand (*Source: MineSpans Copper Demand Model Q3 2021*)

1 Based on the Base case for Refined copper demand by end use, 2020 - 2050, Mt
2 Assume supply equals demand, includes 10Mt of supply estimated to come from scrap in 2050
3 Does not include specific Capex for secondary scrap facilities, nor Sustaining Capex
4. Smelting & refining capacity to process concentrate and scrap volumes

The Decarbonization of the Chinese Copper Industry

Although ICA does not have Chinese producers among its members, any global analysis must consider potential scenarios for the decarbonization of copper production in China from 2018 to 2050. While only 6 percent of copper ore is mined in China, almost 50 percent of the world output of refined copper takes place in Chinese smelting and refining plants (see detailed data for the year 2018 in **Annex 4, Figures A and B**).

In 2018, Chinese copper producers emitted close to 21 million tonnes of GHG (about 9.6 million tonnes in mining, 11.2 million tonnes in smelting and refining), 22 percent of the industry's global emissions. Under a no-action scenario, the volume of these emissions would follow a trajectory as illustrated in **Figure 22**, over the period from 2018 to 2050. For the sake of simplicity, this trajectory has been computed on the hypothesis of a constant mix of smelting technologies.

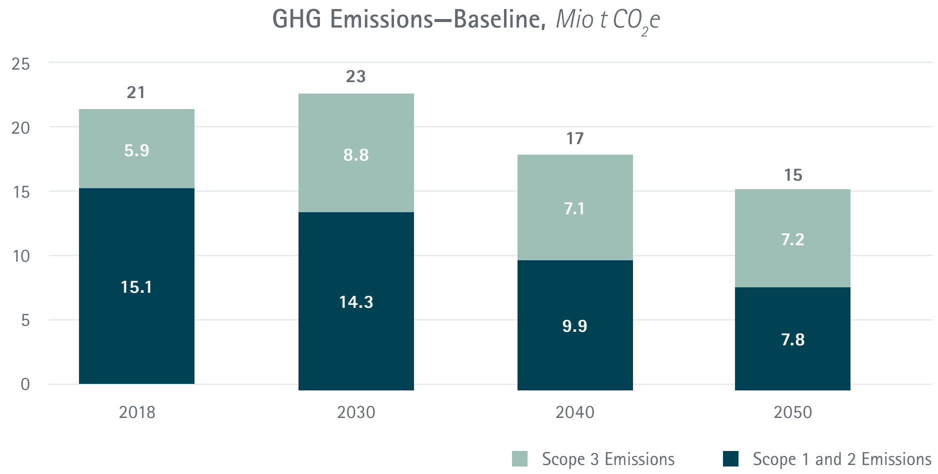


Figure 22—Baseline: GHG Emissions from Chinese Copper Production in a No-Action Scenario (*Source: MineSpans and MineLens*)

Compared to the global baseline, in a no-action scenario, the 2050 volume of GHG emissions in China will be lower than in 2018 despite the increase in production expected from growing copper demand. This reduction will stem from the extensive use of smelting and refining in Chinese copper production that entail a lower level of emissions (see **Figure 11**) and from plans to decarbonize the Chinese power grid, as shown in **Figure 23**.

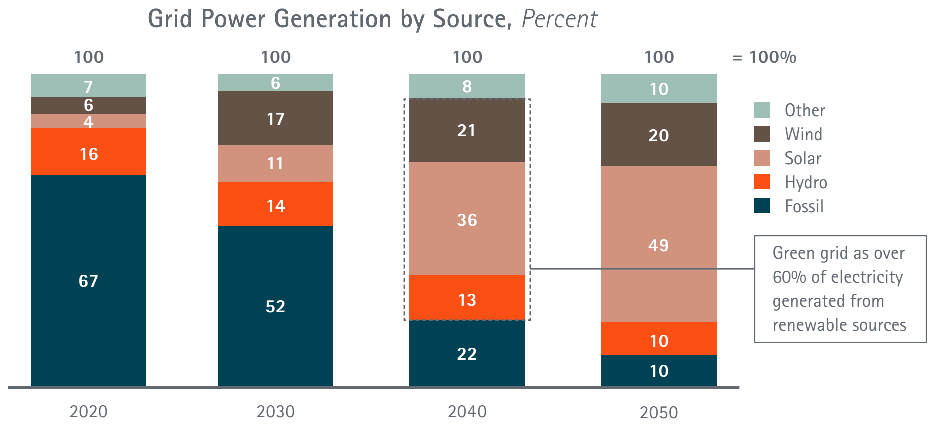
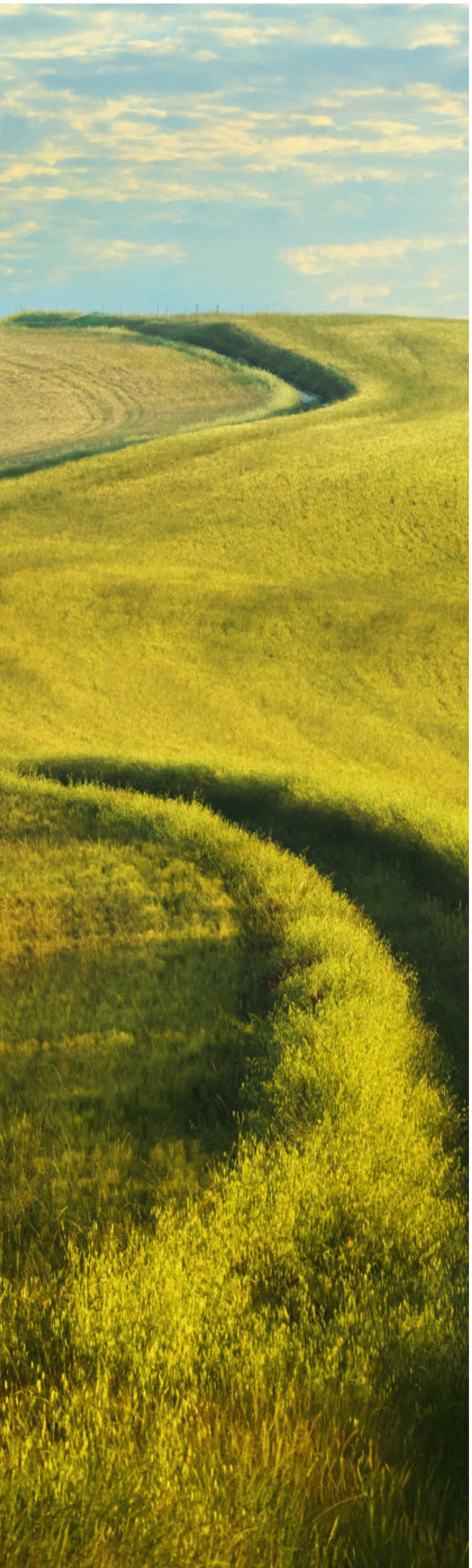


Figure 23—Evolution of China's Energy Mix (*Source: MineSpans*)

This section describes the outcome, for the Chinese copper industry, of the global analysis performed to establish the *Pathway to Net Zero*. **It does not represent the views of the Chinese copper producers or authorities.** ICA and ICA members recognize that the considerations developed in this section can diverge from these views.



Scope 3 emissions for Chinese production are measured for the categories of purchased goods and services, fuel- and energy-related activities, upstream and downstream transport, waste generated in operations and end-of-life treatment of sold products at ***full production level*** *and do not include the emissions from imported copper concentrates. The 21 million tonnes of GHG mentioned above, therefore, represent the net addition to global emissions generated by all copper production activities taking place in China.*

The abatement potential for Scope 1 and 2 emissions follows a similar trajectory to the model for global changes presented in **Figure 17**, albeit with a slower start as 20 to 30 percent will be reduced by 2030 but with an acceleration to 85 to 95 percent by 2040, rates that will continue into 2050.

The emissions reduction potential during the first decade is slightly lower than at the global level, 20 to 30 percent compared to 30 to 40 percent. This discrepancy largely stems from the slower power grid decarbonization, limited availability of alternative fuels such as hydrotreated vegetable oil (HVO) for mining trucks and high cost of shifting from natural gas, fuel oil or coke to biogas in smelting operations. Some electrification of mining equipment and efficiency improvements such as the shift to high chromium grinding media for ball mills in the production of concentrates, aid the reduction of Scope 1 emissions. However, the impact of these changes on the total volume of emissions will be limited by the low share of mining in the Chinese copper production value chain.

Increased investments in solar energy from 2030 to 2040 and further decarbonization of the power grid will lead to a significant abatement of Scope 2 emissions. Improved availability of battery electric trucks in copper mines will further reduce Scope 1 emissions (the mining sector represents 40 percent of total Scope 1 GHG emission in China), although the switch to hydrogen as an alternative fuel will be limited by availability constraints and high costs.

Over the period from 2040 to 2050, continued investments in battery electric or fuel-cell mining trucks—and better availability at scale—will continue to reduce Scope 1 emissions. On-site solar farms and additional grid decarbonization will lower Scope 2 emissions. However, hydrogen as alternative fuel for the smelting process will remain a high-cost abatement option.

Abatement potential for Scope 3 emissions for purchased goods and services, fuel- and energy related activities, transport upstream and downstream in the value chain, operational waste and end-of-life treatment of sold products is expected to follow the trajectory of global copper production, reaching a 70 percent reduction potential by 2050.

Combining both analyses generates an abatement trajectory for China that projects a reduction of 75 to 85 percent of total GHG emissions by 2050, a decrease comparable to that of the global copper industry. The first decade, however, will see a more gradual reduction of 15 to 25 percent as the Chinese power grid will decarbonize from a higher carbon intensity (see **Figure 14**). Acceleration in the second decade is expected to achieve a reduction of 60 to 70 percent of GHG emissions.

Increased investments in solar energy from 2030 to 2040 and further decarbonization of the power grid will lead to a **significant abatement** of Scope 2 emissions.

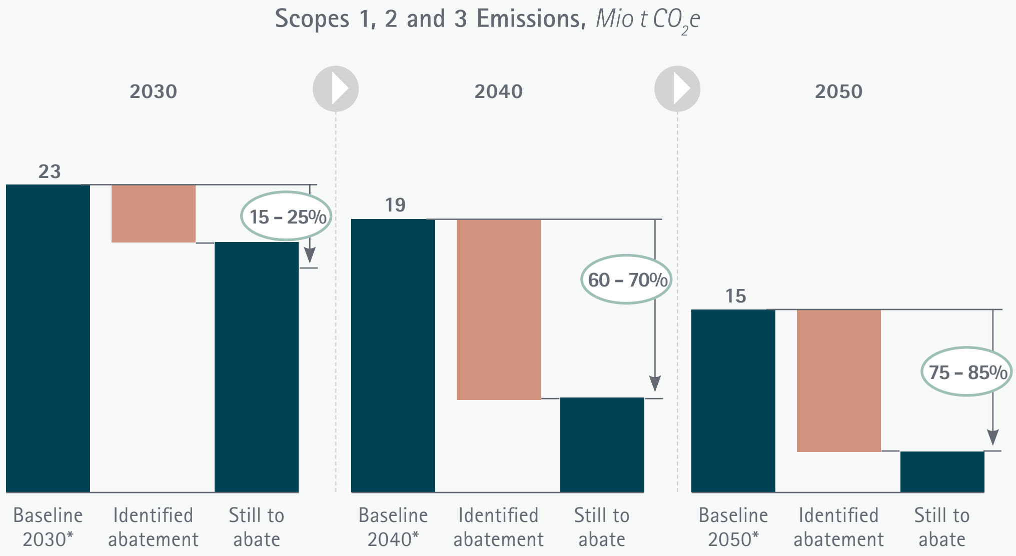


Figure 24—Abatement Potential of Scope 1, 2 & 3 Emissions for Chinese Copper Production, Compared to a "No Action" Scenario (*Source: MineSpans*)

Up to 2050, Chinese copper producers will need to invest an estimated $13 to 14 billion to reach this level of decarbonization of their processes, which would account for 12 to 13 percent of the global decarbonization Capex. Two thirds of these investments will occur in smelting and refining operations.

This decarbonization analysis of Chinese copper production assesses the timing, scope and commitments required to reduce GHG emissions from 2018 to 2050, the time horizon used in the analysis of the global copper industry. China has committed to reaching climate neutrality by 2060.

This analysis assists ICA members that deliver concentrates to the Chinese smelters to evaluate the potential evolution of their Scope 3 emissions from the processing of sold products. It does not provide recommendations regarding current or future plans of Chinese producers to decarbonize their production processes.

Framework Conditions for the ICA Decarbonization Goal

Key enabling conditions will be required for ICA members to decarbonize their copper production.

Access to Technology and Energy

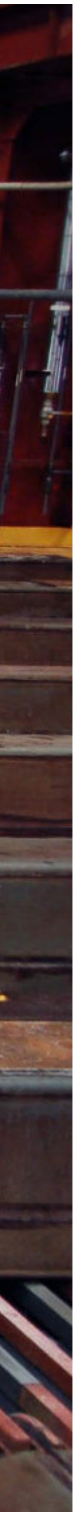
1. **Decarbonization technologies must be available from manufacturers at sufficient scale.** Battery electric trucks, on-site storage systems for fossil-free energy and wind turbines are a few examples of technologies that need to be produced at scale to keep pace with rising production capacity and to meet the growing demand driven by the clean energy transition. As an example, by 2050, open pit copper mines will require 16,000 zero-emission haulage trucks, twice the number currently in use.

2. **An electricity-intensive process, copper production requires access to clean electricity** that is cost effective, available at scale and supplied through adequate infrastructure. Copper production sites consumed 128,150 GWh of electricity in 2018, a figure expected to grow to 261,000 GWh in 2050. A portion of this growth, 19,000 GWh per year, will be triggered by increased electrification of operations to reduce GHG emissions.

Because Scope 2 emissions represent 46 percent of copper industry emissions today, the speed at which electricity grids decarbonize is critical and should be accelerated whenever possible.

Electricity Needs, *GWh/year*

Figure 25—Estimated Electricity Needs of Copper Producers by 2050 (*Source: MineLens Estimates*)



Copper Industry Operating Conditions

The end-of-life collection rates of copper-containing products must increase. Refined copper production from secondary sources requires less energy than that needed from primary sources. It does not require the mining and concentration of copper ore, processes that account for about 60 percent of the total GHG emissions of refined copper production. Also, production from high grade scrap—rather than copper ore—reduces 70 to 85 percent of the emissions from smelting and refining. This ratio is lower (10 to 50 percent) when low grade scrap is used.

Consequently, increasing the input rate of recycled scrap in the production process lowers its carbon emission intensity while meeting the growing demand for copper. To achieve this, product designs that facilitate recycling and incentives for end-of-life collection are needed, together with improved separation techniques for the treatment of multi-metal scrap streams.

This analysis of the decarbonization potential assumes the recycling input rate originating from old copper scrap will increase from 16 percent—the 10-year average recorded in 2018—to a maximum of 23 percent around 2040 (see **Annex 5**). Further increase in this indicator will require more effective regulatory and market incentives, a joint task for policymakers, copper producers and end-of-life product collectors.

Flexible investment funds should be available to copper producers. Between 2020 and 2050, the copper industry will need to invest around $460 billion to meet increasing demand and an additional $ 110 billion -at least- to reach decarbonization targets, an average of $20 billion per year. Given the critical contribution of copper to the energy transition and the ambitious plans of ICA members to decarbonize production, copper producers should be granted access to investment funds integrating environmental, social and governance (ESG) criteria to support innovative research and development and these substantial capital expenditures.

Copper production sites need highly skilled staff. Addressing the decarbonization challenge requires skills, such as data mining, carbon footprint measurement and monitoring, energy storage, electrification infrastructure, that are new to the sector. Training and education programs can build the capacity of staff. Copper producers will need to hire new employees with new skill sets, and support from local educational institutions will be indispensable. The growth in copper production will also create new employment opportunities that could partly offset personnel reductions at mines that extract fossil fuels such as combustion coal.

Effective and Efficient Regulatory Framework

The copper sector requires a regulatory framework that facilitates and sustains decarbonization while ensuring the industry can meet the growing demand for production.

1. Transparent **carbon pricing** should become common practice—preferably coordinated worldwide—to encourage investment to support decarbonization and create a level-playing field in the integration of externalities into product costing.

2. Access to public funds should prioritize support for the development of **innovative decarbonization solutions.**

3. **A faster permitting process** for new mining assets and expansions is critical to enable the copper industry to meet growing demand.

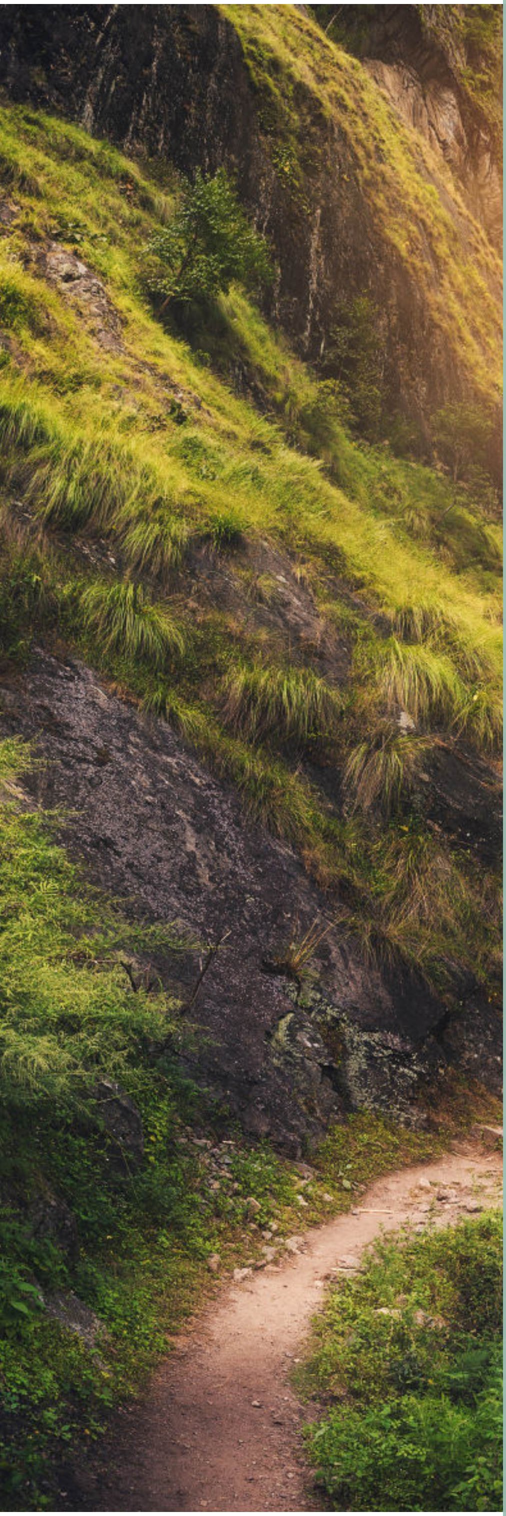
4. **Facilitation of accelerated installation** of on-site **electricity generation** capacity, a key emission abatement lever, should be promoted.

5. A **stable regulatory environment** is necessary, given the substantial capital expenditures for capacity expansion and for process decarbonization. In this context, fair and stable royalties as well as long-term mining licenses will be required. Lawmakers should also consider introducing protection mechanisms against external shocks such as extreme energy price volatility.

6. **Consistent chemical and product regulations** must allow an optimized and responsible contribution of copper and its byproducts, such as iron silicates, to the transition toward carbon neutrality.

The Way Forward

This *Pathway* brings additional foresight on a challenging but critical journey toward carbon neutrality on which copper producers have already embarked. However, this forward-looking path presents unknowns and unanswered—how will technologies evolve for process decarbonization and storage of energy generated by renewable, intermittent sources? How fast will the reduction of GHG emissions in maritime transport accelerate? Will equipment manufacturers be able to meet the growing demand for fossil-free trucks across the mining industry? This section offers initial measures ICA members will undertake to achieve the reduction of GHG emissions.



Measuring Progress

Measurement on the path to decarbonization is critical. As a first step, **ICA members have developed** comprehensive guidance for calculating the carbon footprint of copper production, incorporating industry standards such as the GHG Protocol and the initial work on Scope 3 emissions accounting and reporting by the International Council for Mining and Metals (ICMM). ICA members will consider ways to improve data availability on the material Scope 3 category "use of sold products." Additionally, they will explore strategies to align their methods for measuring carbon footprint with those being developed by other organizations. Copper producers and their stakeholders across the globe must share a clear understanding of how to measure GHG emissions.

The second step to measuring progress will be the establishment of a regular and transparent monitoring mechanism by the end of 2024 to enable coherent reporting on ICA members' moves *as a group* toward meeting their *collective* decarbonization targets. This mechanism will ensure data authenticity and verifiability.

> Copper producers and their stakeholders across the globe must share a **clear understanding** of how to measure GHG emissions.

Decarbonization and Responsible Production

ICA members will ensure that interventions to reduce GHG emissions adhere to responsible production practices, for example, through commitment to The Copper Mark®.

As annual copper output is expected to increase to enable the clean energy transition, ICA members are committed to supporting and enhancing the communities and environments around their assets. They will continue to promote ethical standards across the industry. ICA members will foster dialogues with policymakers and representatives of civil society to gain an understanding of their goals and concerns. These discussions will address issues related to the equitable sharing of investments in capital and human resources required in the transition to net-zero GHG emissions.

Updating the Pathway to Net Zero

This *Pathway* provides a model of an abatement trajectory based on data that is subject to change over time. Moving forward, ICA members anticipate that better measurements of GHG emissions—and data on additional variables related to decarbonization—will become available and enable more extensive analysis.

ICA members commit to reviewing and updating the *Pathway* every five years, or more frequently as needed, to track and analyze relevant changes across the global industry.

Developing Partnerships

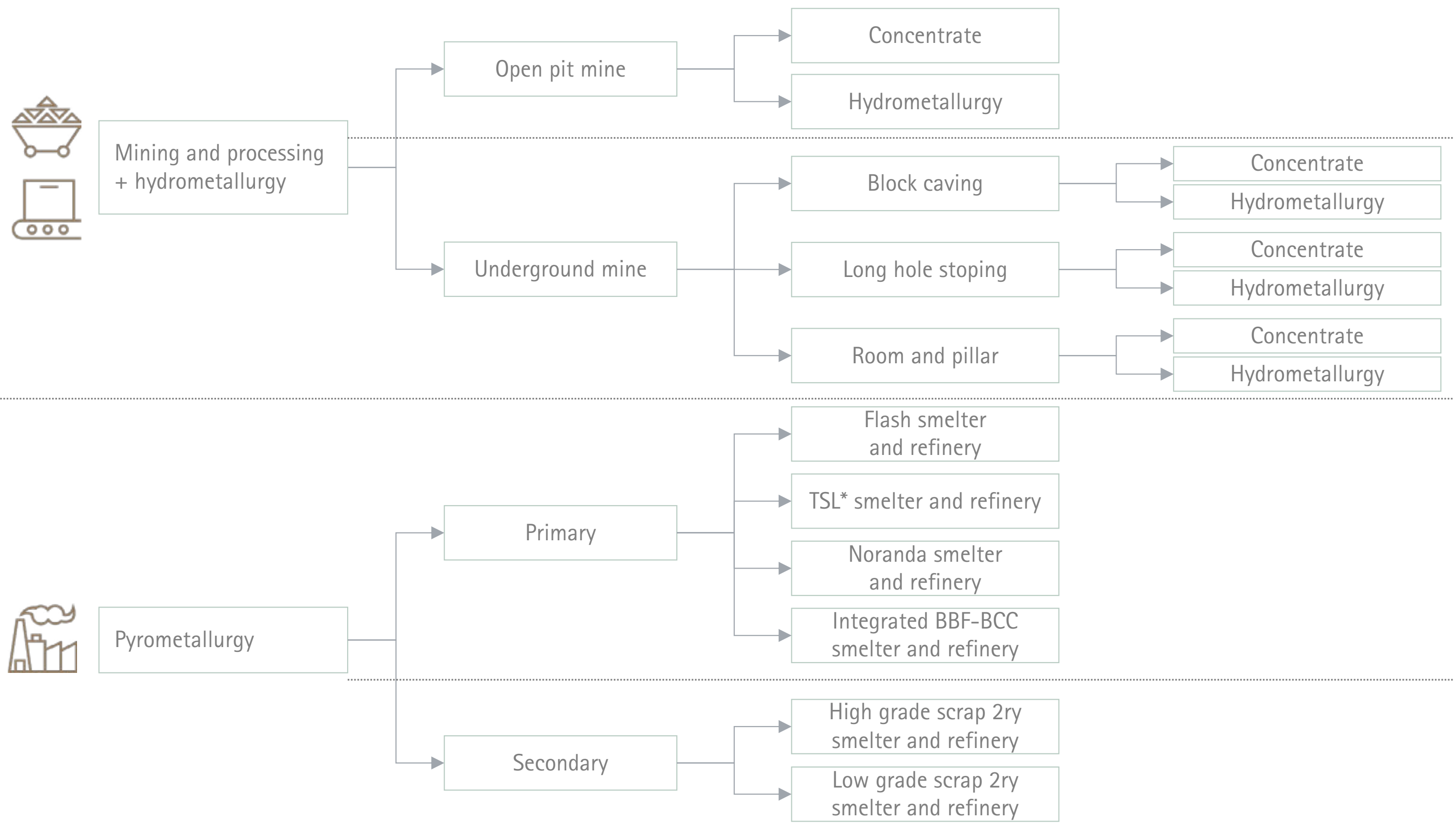
Partnerships will be key to addressing the challenge of decarbonization. Such collaborations require common objectives and rules, co-creation strategies and an understanding of the business models and constraints of partners, including suppliers, customers and financial institutions.

These partnerships should not be limited to business stakeholders. ICA members invite policymakers, academic institutions and civil society organizations to pursue innovative partnerships to work to reduce GHG emissions to net zero by 2050. Strong communication and collaboration will be critical to enabling these partnerships to be impactful and sustainable.

Governments, civil society and industry have placed climate change at the top of their agendas. ICA members fully recognize the breadth, depth and urgency of this challenge and are currently acting to decarbonize copper production. This *Pathway* confirms ICA members' commitment to play an active, responsible role in continuing to supply a key raw material for the transition to carbon neutrality, while bringing its carbon footprint as close as possible to net zero by 2050. ICA members collectively commit to decreasing the Scope 1 and 2 emissions of copper production activities to net zero by 2050 and to engaging with all relevant stakeholders with an ambition to reduce Scope 3 emissions toward net zero by 2050. These ambitions put copper in a leading position in the nonferrous metals sector regarding mitigating climate change.

In addition to our individual efforts and our collective ambition to reduce GHG emissions, ICA members will work to establish a broad coalition between copper producers, other industries, policymakers and representatives of civil society to make the objectives of the Paris Agreement a reality for copper production and use by 2050. ICA and its members will take the initiative to convene and support any action-oriented partnerships designed to achieve this critical goal.

ANNEX 1: Archetypical Production Processes



*TSL = top-submerged lance

Figure A—Archetypes Covering the Main Mining, Processing, Smelting and Refining Methods of Copper Production (*Source: MineSpans*)

We have built archetypes to cover the main **mining, processing, smelting and refining** methods.

*TSL = top-submerged lance (*Source: MineSpans*)

ANNEX 2: Copper in the Energy Transition

Copper is needed in a variety of applications that play an essential role in the transition toward a carbon-neutral energy system:

1. In **renewable power generation**, copper is present in the electrical conductors of wind generators, photovoltaic (PV) modules, transformers, inverters, cables and connectors. PV plants and on-shore wind turbines use about three tonnes of copper per megawatt of installed capacity and an off-shore wind turbine requires approximately five tonnes. In addition, the weather dependent and variable output of solar and wind power creates the need to install three times more megawatts for the same amount of energy produced. In short, the power generation systems of the future will use more copper per megawatt and have more megawatts installed [*6*].

2. Copper is a key material in **transmission and distribution networks**. The variability and distributed character of renewable energy sources necessitates a reinforcement of the electricity grid to guarantee that electrical power can be delivered to all end-users at any time [*6*]. A 1,100 MVA high-power transformer typically needs 60 tonnes of copper [*7*], a 400 kVA distribution transformer contains typically 480 kg of copper [*8*]. Copper also is used for busbars in power grid substations and for underground and subsea power cables.

3. The variability of renewable energy sources also requires large amounts of **electrical storage capacity** to balance the grid. Lithium batteries usually contain about 0.5 kg of copper per kWh [*9*].

4. The rapid decarbonization of electricity from renewable power sources makes **electrification** a fast and effective pathway to decarbonize energy end use. OECD economies are electrifying passenger transport and building heating and cooling systems at steady speed. An **electric vehicle** (EV) uses 62.5 to 75 kg of copper, compared to 25 to 30 kg of copper for a combustion engine vehicle [*10*]. **Heat pumps** typically use 14 to 21 kg of copper per unit [*11*].

5. **Highly efficient cables, motors and transformers** typically use 20 - 50 percent more copper than conventional ones [*13*], as the energy losses are reduced by increasing the cross-section of the electrical conductors.

> The rapid decarbonization of electricity from renewable power sources makes electrification **a fast and effective pathway to decarbonize energy end use**.

ANNEX 3: Copper Production

Production from primary sources starts with the extraction of copper-bearing ores from open-pit or underground mines. The ores typically contain between 0.25 and 1 percent of pure copper. Subsequently, two different production routes exist, depending on the characteristics of the raw material—sulfide or oxide ores.

In the most common case, a *pyrometallurgical process* is applied. The sulfide ore is crushed and ground before undergoing a flotation process to obtain what is called copper concentrate, containing 20 - 40 percent of copper. The copper concentrate is then shipped to smelting and refining plants, which are usually situated closer to end markets. There, the material undergoes a smelting process resulting in *copper matte*, containing 50 - 70 percent copper. If necessary, this process is preceded by a roasting step to eliminate carbon present in the ore. During a converting process, the matte is further transformed into blister copper with 98.5 - 99.5 percent purity. In the next step, the *blister copper* is either fire-refined or re-melted and cast into anodes for an electrolysis process. The anodes are immersed in an electrolyte solution and subjected to a strong electrical current. Under these circumstances, copper atoms dissolve from the anode to form copper ions. These migrate toward the cathodes where they are deposited as pure copper atoms. This results in refined copper cathodes with more than 99.99 percent purity.

When starting from oxide ores or low-grade sulfide ores, copper production takes another route. A *hydrometallurgical process* consisting of leaching, solvent extraction, stripping and a particular type of electrowinning (the SX-EW process) purifies the ore, resulting in refined copper cathodes with a 99.99 percent purity level. In 2020, approximately 16 percent of refined copper was produced this way (ICSG estimate [*12, p. 10*]).

Copper production generates a range of important metallic byproducts—including gold, silver, cobalt, molybdenum, platinum group metals, selenium, tellurium—as well as more complex byproducts, such as sulfuric acid and iron silicate, which are mostly separated during the smelting and refining process. Some byproducts, including selenium and tellurium, have limited or no dedicated mining and processing assets and are to a large extent supplied through the production of other metals. [*13*] This "metal carrier" characteristic of copper represents a significant contribution to resource efficiency.

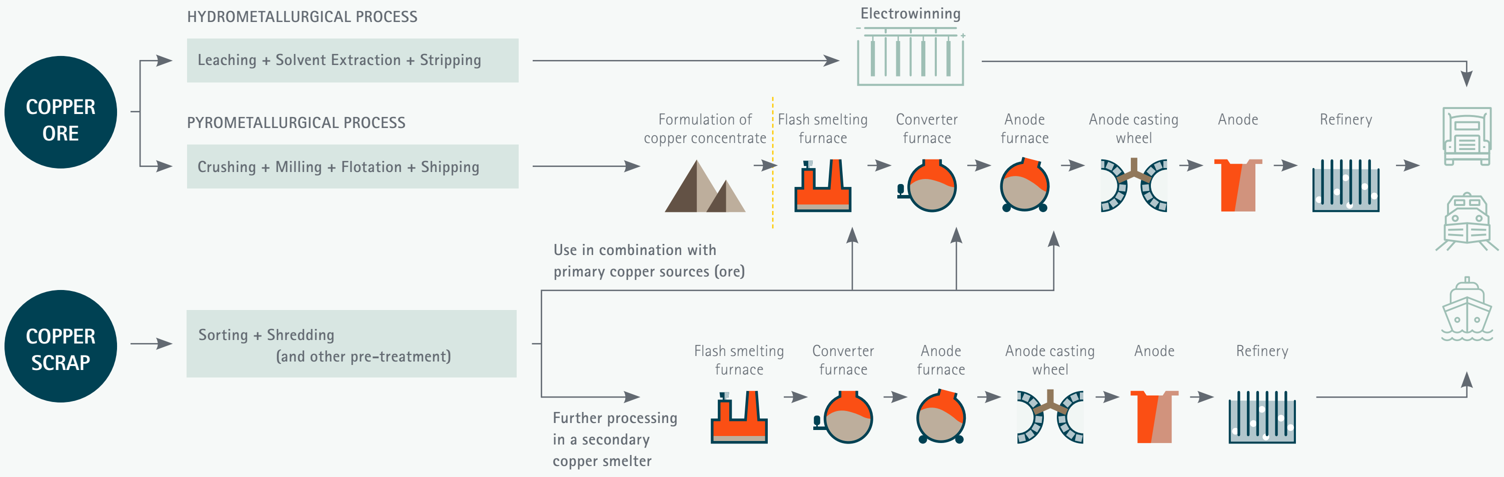


Figure A—The Major Production Processes of Refined Copper.

Copper scrap originates either from semi-finished or finished products manufacturing waste ("new scrap"), or from copper-containing products reaching the end of their life ("old scrap"). After initial treatment, which usually includes sorting and shredding, the copper scrap enters the pyrometallurgical production process at different stages. Low and medium grade copper scrap is mixed with concentrate at the start of the smelting process or is treated in a dedicated "secondary" smelting furnace. High grade copper scrap can be mixed with blister copper for further processing into anodes for electrolysis, as described above. New and old scrap of the highest purity can even reach the same quality as refined copper cathodes and be directly melted to produce semi-finished products, without the need for any preliminary refining process. Copper production from secondary sources requires less energy than that needed for copper from primary sources. The energy and CO_2e emissions savings grow more substantial with the increasing purity of the copper scrap and can reach up to 85 percent [*14*]. The exact quantity of energy and greenhouse gas savings depend on the product, composition and recycling route [*15*].

The refined copper is shipped to fabricators that will melt it to produce copper and copper alloy semi-finished products in the form of wire, rod, tube, sheet, plate, strip, castings, powder or other shapes. These are further transformed by downstream industries to create end-use products such as cables, connectors, electric motors, transformers and photovoltaic panels.

Copper production generates a range of **important metallic byproducts,** as well as more complex byproducts—this "metal carrier" characteristic of copper represents a **significant contribution to resource efficiency.**

ANNEX 4: Copper Production and Trade

In 2018, global copper mine production reached 20.8 million tonnes [*5, p. 59*], with Chile and Peru as the largest producers. Latin America accounted for 47.4 percent of the copper mine production in 2018 (see **Figure A**).

The copper production in 2018 was 29.5 million tonnes, including 8.7 million tonnes originating from secondary copper sources [*5, p. 59*]. China leads this market, producing 48.5 percent of world copper in 2018 (see **Figure B**).

Most of copper trade originates in South America. Copper concentrate flows from South America to Asia and refined copper moves from South America to Asia, Europe and North America (see **Figure C**).

Location of Copper Mining

Latin America	47.4%
Sub-Saharan Africa	15.1%
North America	8.3%
CIS	8.1%
Other Asia	6.5%
China	5.6%
Oceania	3.1%
Eastern Europe	2.2%
MENA	2.1%
Western Europe	1.1%
India	0.5%
North-East Asia	0.0%

Figure A—Copper Mine Production by Region In 2018 (*Source: MineSpans*).

Location of Copper Smelting & Refining

Latin America	10.8%
Sub-Saharan Africa	3.4%
North America	3.7%
CIS	5.7%
Other Asia	3.4%
China	48.5%
Oceania	1.0%
Eastern Europe	4.9%
MENA	3.1%
Western Europe	5.4%
India	1.8%
North-East Asia	8.2%

Figure B—Refined Copper Production by Region in 2018 (*Source: MineSpans*).

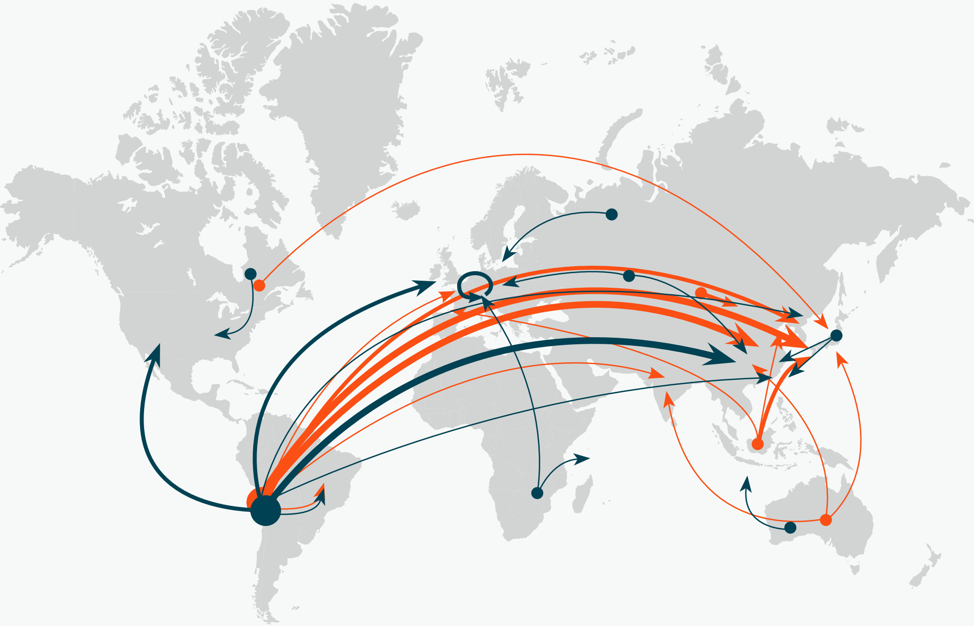
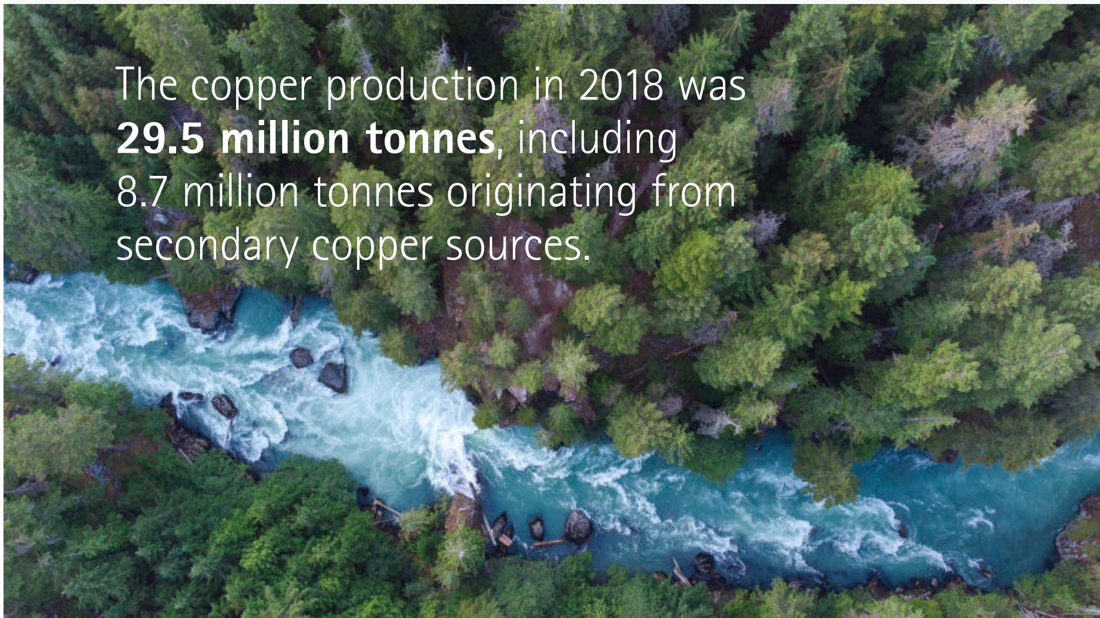


Figure C—International Trade Flows of Copper Concentrate (orange) and Refined Copper (blue) (*Source: ICSG*).



The copper production in 2018 was **29.5 million tonnes**, including 8.7 million tonnes originating from secondary copper sources.

ANNEX 5: Copper Recycling

Over the period from 2000 to 2020, the end-of-life recycling input rates averaged around 15 percent. Estimating future recycling rates is complicated due to uncertainties about key variables:

- The scrap supply is highly dependent on the copper price.
- The evolution toward shorter product lifetimes, if not countered by sustainability concerns, will increase the scrap supply.
- Product designs will vary and increasing product complexity makes collection and recycling more complex.
- Incentives positively impact the end-of-life collection rates.

MineSpans expects the end-of-life recycling input rate to increase to a maximum of 23 percent over the next 30 years (see **Figure A**).

In the best-case scenario, an end-of-life recycling rate of 25 percent could be reached by 2050 which would lower annual demand for copper from primary sources by an additional 3 million tonnes (see **Figure B**).

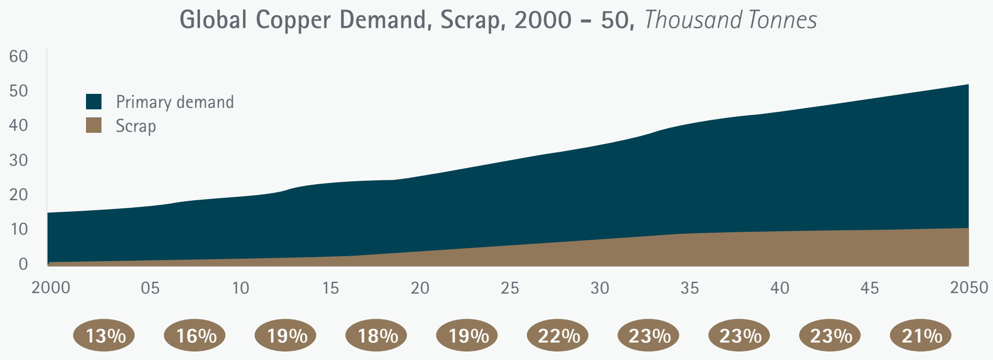


Figure A—Estimated Evolution of the End-of-Life Recycling Input Rate (*Source: MineSpans Copper Demand Model Q3 2021*)

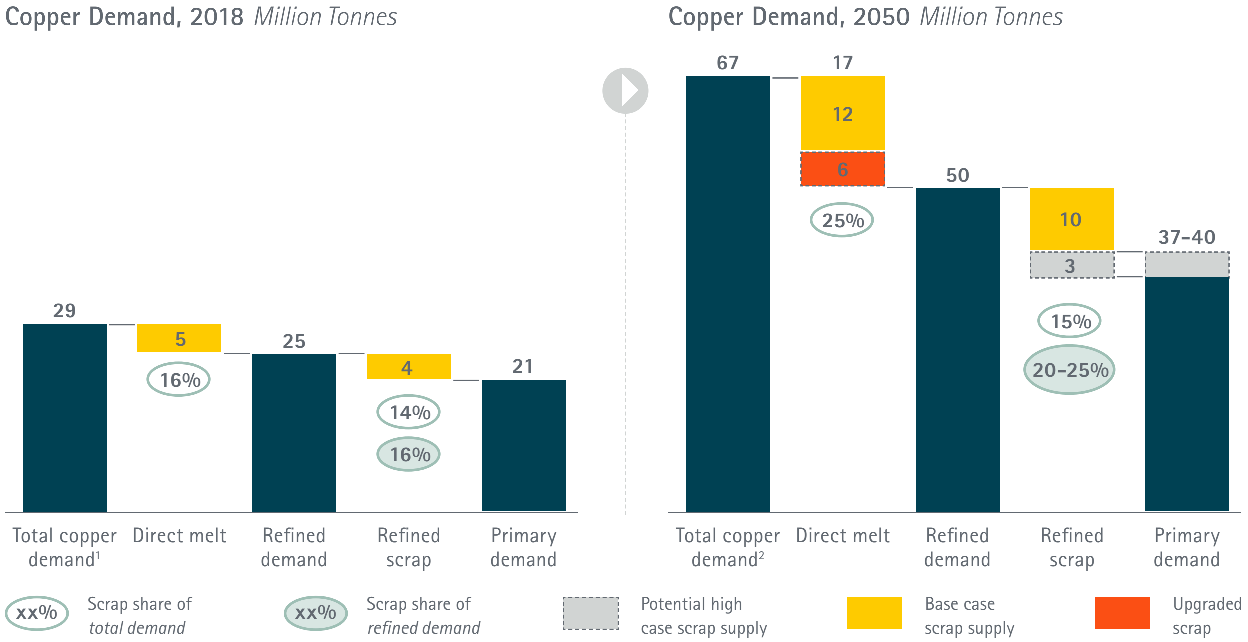


Figure B—Reduction in Demand for Copper from Primary Sources in the Best-Case Scenario of 25 Percent End-of-Life Recycling Input Rate (*Source: MineSpans, ICA/IWCC End Use Dataset, ICSG*).

1 Based on ICA end-use dataset
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ICA members represent approximately 50 percent of the worldwide refined copper production and are uniquely positioned to collect and analyze data related to carbon emissions.

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