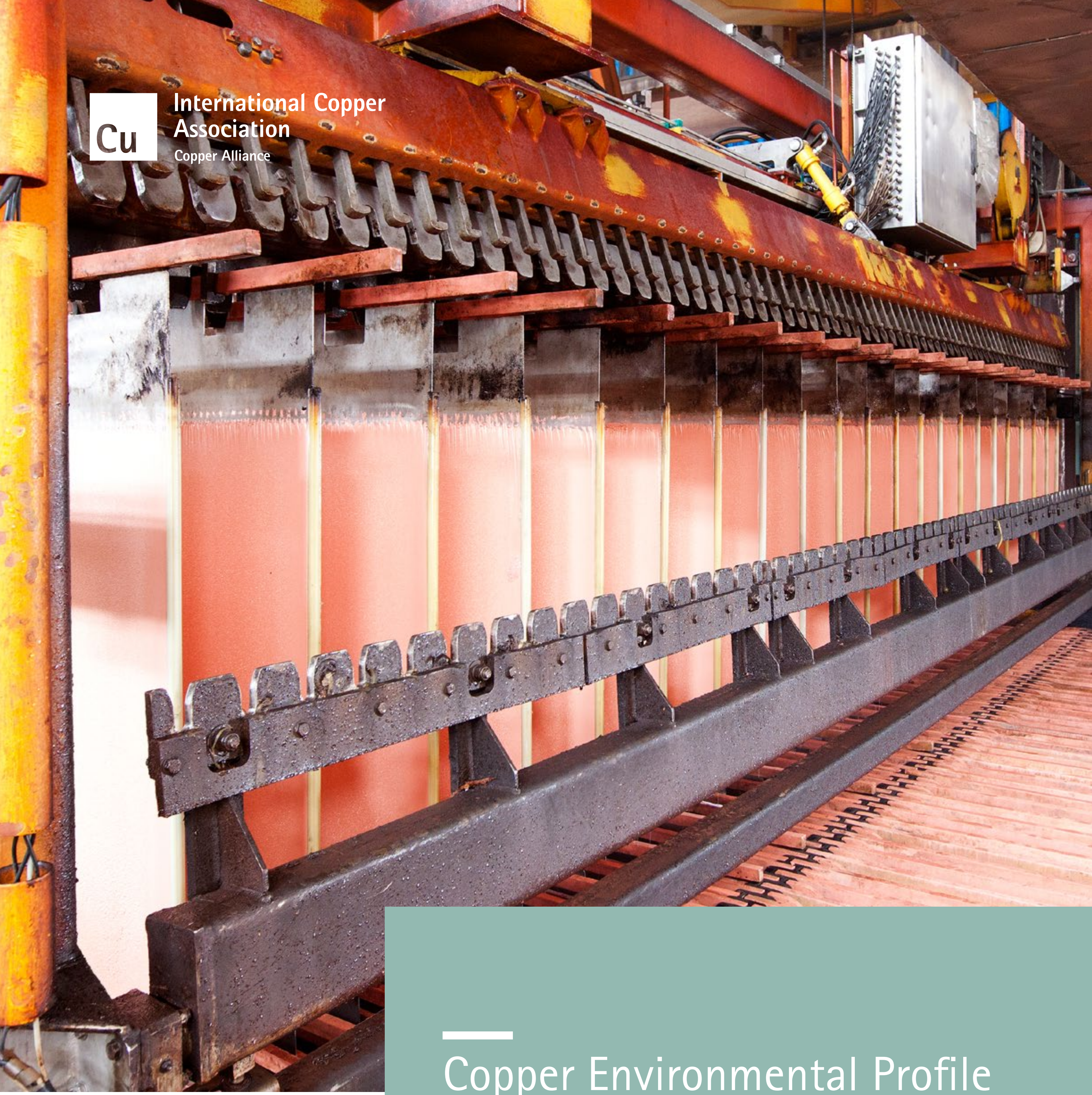
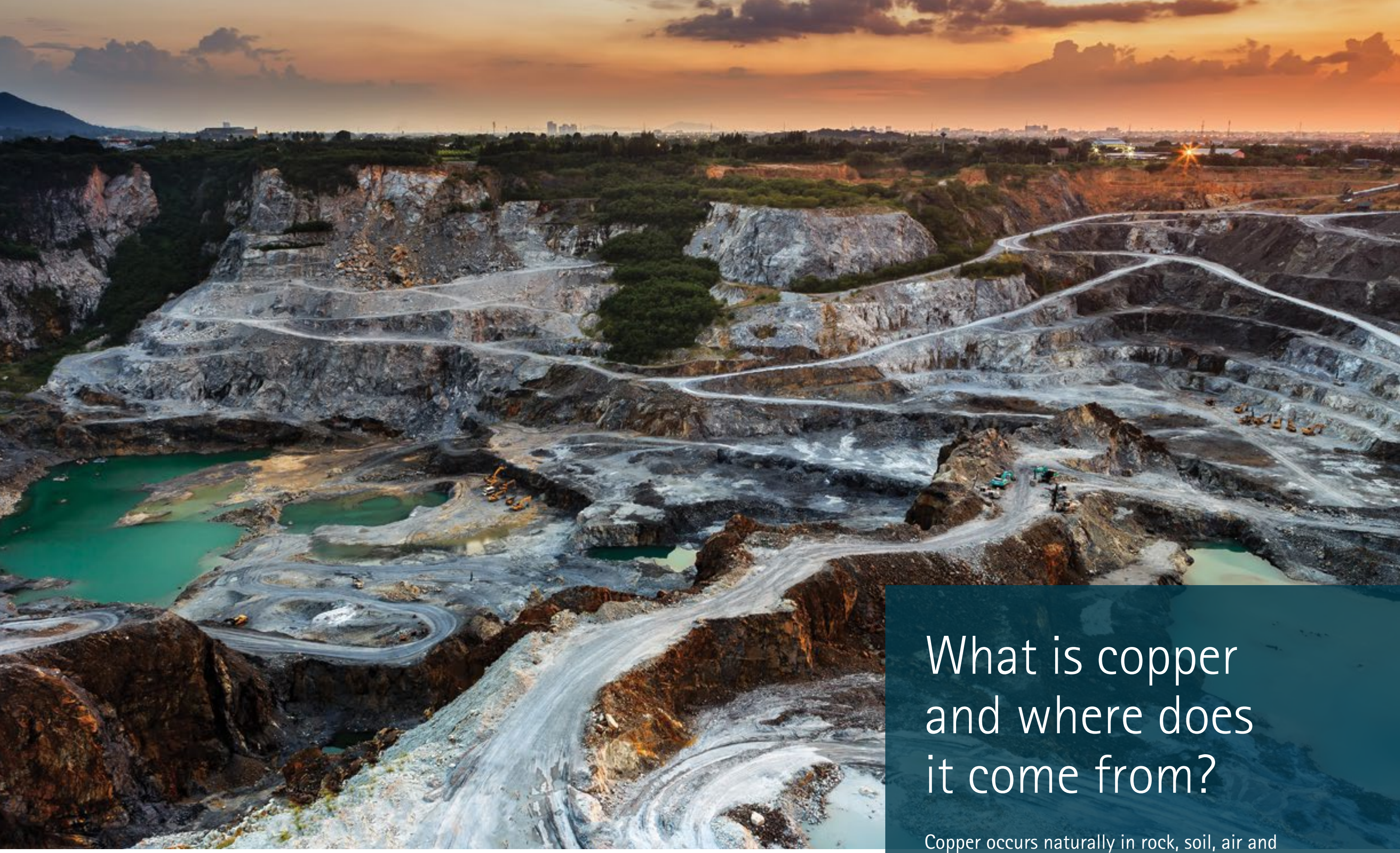


International Copper Association
Copper Alliance

Copper Environmental Profile

GLOBAL 2023



Introduction

The International Copper Association (ICA) is the leading advocate for the copper industry. ICA brings together the copper industry and its partners to make a positive contribution to the UN Sustainable Development Goals and support markets for copper.

ICA's 31 member companies represent the majority of the world's refined copper output and are among the largest copper producers and recyclers in the world. As part of its commitment to Sustainable Development, the copper industry is committed to providing data and information to enable users of copper to evaluate its impacts and benefits across the life cycle, from raw material extraction to end-of life recycling. This environmental profile summarizes the results of the International Copper Association's Copper Cathode Life Cycle Assessment (LCA). Considering that copper cathode is a crucial resource in the clean energy transition, this profile was developed to provide information and life cycle data from the mining stage to copper production to actors along the copper value chain. A more detailed dataset can also be obtained upon request to help downstream users of copper understand the environmental impacts of their products when conducting their own LCA studies.

What is copper and where does it come from?

Copper occurs naturally in rock, soil, air and water, and is an essential element for human, animal and plant health and well-being. On average the earth's crust contains 0.0068% (ca. 60 mg/kg) of copper *(Hammarstrom et al. 2019).*

In some areas, copper has been concentrated to higher levels by natural geological and geochemical processes. Concentrations above 0.2% (or 2,000 mg/kg), found at the earth's surface and underground, are exploited as ore bodies.

Copper ore deposits are widely spread throughout the world. Today's top copper-mining countries are Chile, Peru, China, D.R. Congo, U.S., Russia, Zambia, Australia, and Indonesia *(ICSG 2022).*

Copper is one of the few materials that can be recycled repeatedly without any loss of performance. There is no difference in the quality (physical and chemical properties) of recycled copper (secondary production) and mined copper (primary production), thus they can be used interchangeably. Around 30 percent of the world's annual copper demand is met through recycling.

Recycling copper is a highly efficient way of reintroducing a valuable material back into the economy and provides many environmental benefits. It saves energy, reduces emissions of greenhouse gases and other air pollutants, extends the life of natural resources, and keeps valuable land from being used for landfills.

Today, nearly 28 million tonnes of copper are used annually.

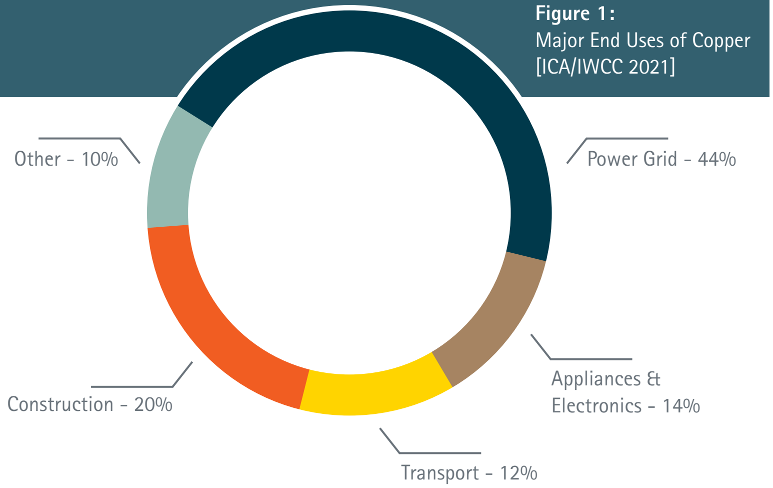
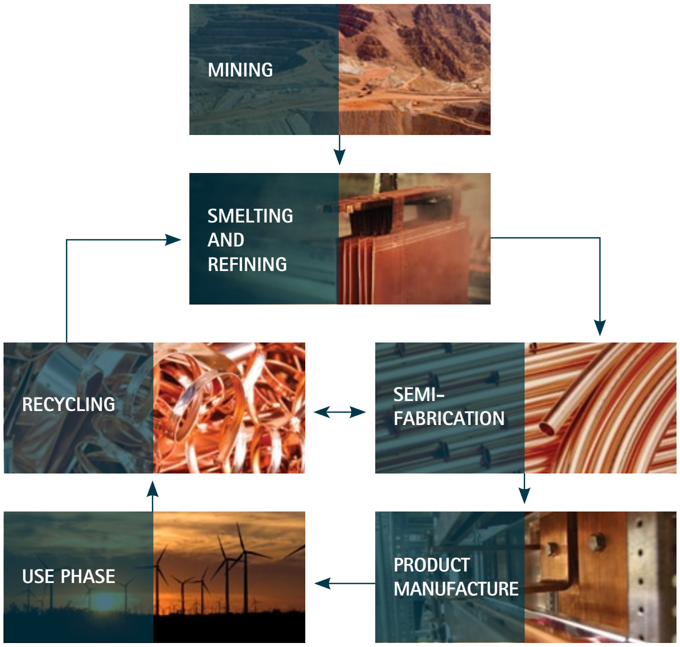


Figure 1: Major End Uses of Copper [ICA/IWCC 2021]

Figure 2: Copper Life Cycle



How is Copper Used?

Today, nearly 28 million tonnes of copper are used annually, of which 70 percent is used for electrical/conductivity applications and communications, as shown in **Figure 1**.

Copper has the highest electrical conductivity of any metal, apart from silver. This property makes copper the material of choice for the power grid (44 percent)—delivering electricity safely and efficiently to homes and businesses.

Electrical equipment—providing circuitry, wiring and contacts for appliances and consumer electronics accounts for 14 percent of copper usage.

12 percent is used by the transport sector. The high purity copper wire harness system in a train, car or truck carries the current from the battery throughout the vehicle to equipment such as lights, central locking, on-board computers and satellite navigation systems.

Another 20 percent of all the copper produced is used in buildings—for plumbing, roofing, and cladding. Copper provides light, durable, maintenance-free structures that are naturally good looking, long lasting and fully recyclable.

10 percent is used for coins, sculptures, jewelry, musical instruments, cookware, and other consumer goods.

The Copper Life Cycle

Copper has six major life cycle phases: mining, smelting and refining, semi-fabrication, product manufacture, use phase and recycling. Recycling takes place both at smelters for copper production and at fabricators for production of semi-finished products.

The International Copper Association's Copper Cathode Life Cycle Inventory (LCI) provides key environmental information from mining to smelting and refining and, therefore, serves as an important foundation for full product life cycle studies. As with any material, the potential environmental impacts of copper are best understood in relation to the product or application it is used in. For example, when used as copper wire, its electrical conductivity can improve the energy efficiency of energy using products, making those products more sustainable in the use phase.

How is Copper Produced?

From its original source in a mine to its use in a finished product such as wire or pipe, copper passes through several stages.

Primary copper production begins with extraction of copper-bearing ores. There are two basic ways of copper mining: surface and underground mining. Since copper occurs in relatively low concentrations over large areas, surface, or open-pit mining, is the predominant method of copper mining globally.

After mining, copper is produced by one of two process routes: pyrometallurgical or hydrometallurgical. Within the pyrometallurgical route, the mined ore is crushed and milled, followed by a concentration step using flotation. The obtained copper concentrates contain on average 30 percent copper, but grades can range from 20 - 40 percent *(ICSG, 2021)*.

In the following smelting process, copper is transformed into a "matte" containing 50 – 70 percent copper. The matte is either flash converted or processed in a converter resulting in blister copper of 98.5 – 99.5 percent copper content.

In the next step, the blister copper is fire refined by the traditional process route or re-melted and cast into anodes for electro-refining. The output of electro-refining is refined copper cathode, containing over 99.99 percent copper. Alternatively, the hydrometallurgical route extracts copper from mainly low-grade oxide ores and some sulfide ores through leaching, solvent extraction (also referred to as solution extraction), and electrowinning, often called the SX-EW process. The final product is the same as through the pyrometallurgical route—refined copper cathode containing over 99.99 percent copper. **Figures 2 and 3** show the basic steps in the production of refined copper cathode.

Secondary copper production utilizes a variety of secondary copper containing materials such as copper scrap from metals discarded in either semi-fabrication or finished product manufacturing processes ("new scrap") or obsolete end-of-life products ("old scrap"), as well as electronic scrap and other complex materials. Secondary copper containing materials are smelted in a furnace to matte or black copper and further processed in converters to blister. The blister is fire refined to anode copper for electro-refining. The output of the electro-refining step is copper cathode with 99.99% copper content.

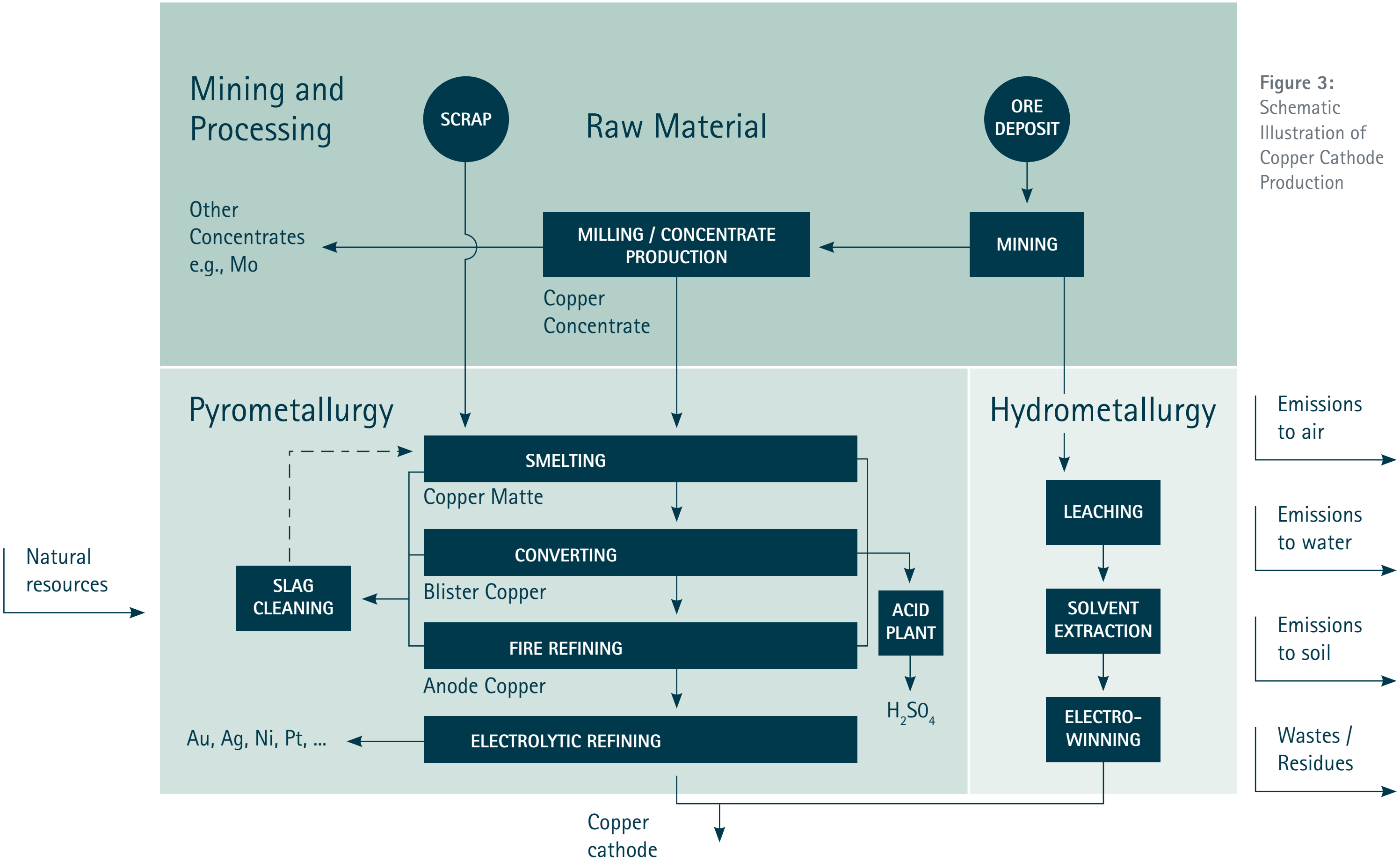


Figure 3: Schematic Illustration of Copper Cathode Production

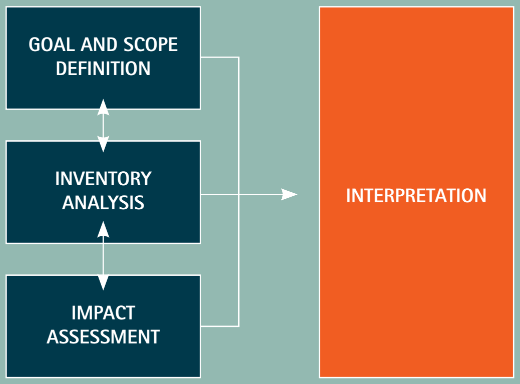
Life Cycle Assessment

LCA is a decision-making tool used to identify environmental burdens and evaluate the potential environmental impacts of goods or services over their life cycle from cradle to grave. LCA has been standardized under the International Organization for Standardization (ISO) and forms the conceptual basis for a number of management approaches and standards that consider the life cycle impacts of product systems.

There are four stages to a typical LCA study, as shown in **Figure 4**.

1. **Goal and Scope**—where the reference units, scope and boundaries, audience, and uses of the study are confirmed;
2. **Life Cycle Inventory Analysis**—where the product system is modeled and data are collected on all relevant inputs and outputs to the system;
3. **Life Cycle Impact Assessment**—where the potential environmental impacts associated with the system being studied are assessed; and
4. **Interpretation**—where the results are interpreted to help decision makers understand the most relevant contributors to the overall environmental profile and to determine the implications of changes to the system.

Figure 4: Life Cycle Assessment Framework*



ISO. (2006). ISO 14044. Environmental management – Life cycle assessment – Requirements and guidelines. International Organization for Standardization, Geneva

Goal and Scope Definition

In 2019 the International Copper Association (ICA) began to conduct its third LCA study to quantify resource use, energy, and environmental emissions associated with the production of copper concentrate and cathode from the extraction of the copper ore at the mine through to the copper factory gate *(Quantis 2022)*.

The system boundary of the study included a cradle-to-gate life cycle inventory from the extraction at the mine to the production of copper cathode, both primary and secondary. The study was conducted in conformance with the ISO 14040 series of standards on LCA and incorporates some elements of the Product Environmental Footprint (PEF) Guide, such as an LCIA approach and data quality assessment, in order to align with future assessments, e.g., PEF or others. The completed study underwent a critical independent expert review. The specific goals of the study were to:

- Create the most up-to-date LCI data for copper cathode production by ICA members;
- Foster the adoption of copper cathode LCI data in mainstream LCI databases; and
- Provide the basis for future development of cradle-to-grave profiles of copper-containing intermediate and end-use products.

The previous studies were carried out in 2017 (based on the year 2013) *(ICA, 2017)* and 2011 (based on the year 2005) *(PE International, 2012)*. However, it is not the intention, nor appropriate that results from the previous studies are compared to show a time series of the profiles of copper concentrate and cathode, since the participating sites and companies vary between studies. Rather, this report intends to provide an update of the environmental impacts from copper concentrate and cathode production, calculated using the most recent activity data that is available.

This study is intended to be representative of global copper cathode production by ICA members. Participating companies were located in North America, South America, Europe, Asia and Africa as can be seen in **Figure 5**. The data collection covered representative annual data for 2019 for all technological routes of the copper production process— the pyrometallurgical route, the hydrometallurgical route and secondary copper-cathode production. Background data were representative of the years 2017-2020. The data collected for this study represents a total copper cathode production of 5,633 kt, which is 23% of the total global production of copper cathode.

Two functional units are applied for the copper concentrate. The first is the production of one metric tonne of concentrate with an average copper content of 26%, while the second accounts for the actual copper content of the concentrate and is the production of one metric tonne of copper contained in the concentrate. The life cycle impact assessment included in this document examined how the production of copper cathode impacts environmental indicators, including primary energy demand, global warming, acidification, eutrophication, smog formation and ozone depletion.

Life Cycle Inventory

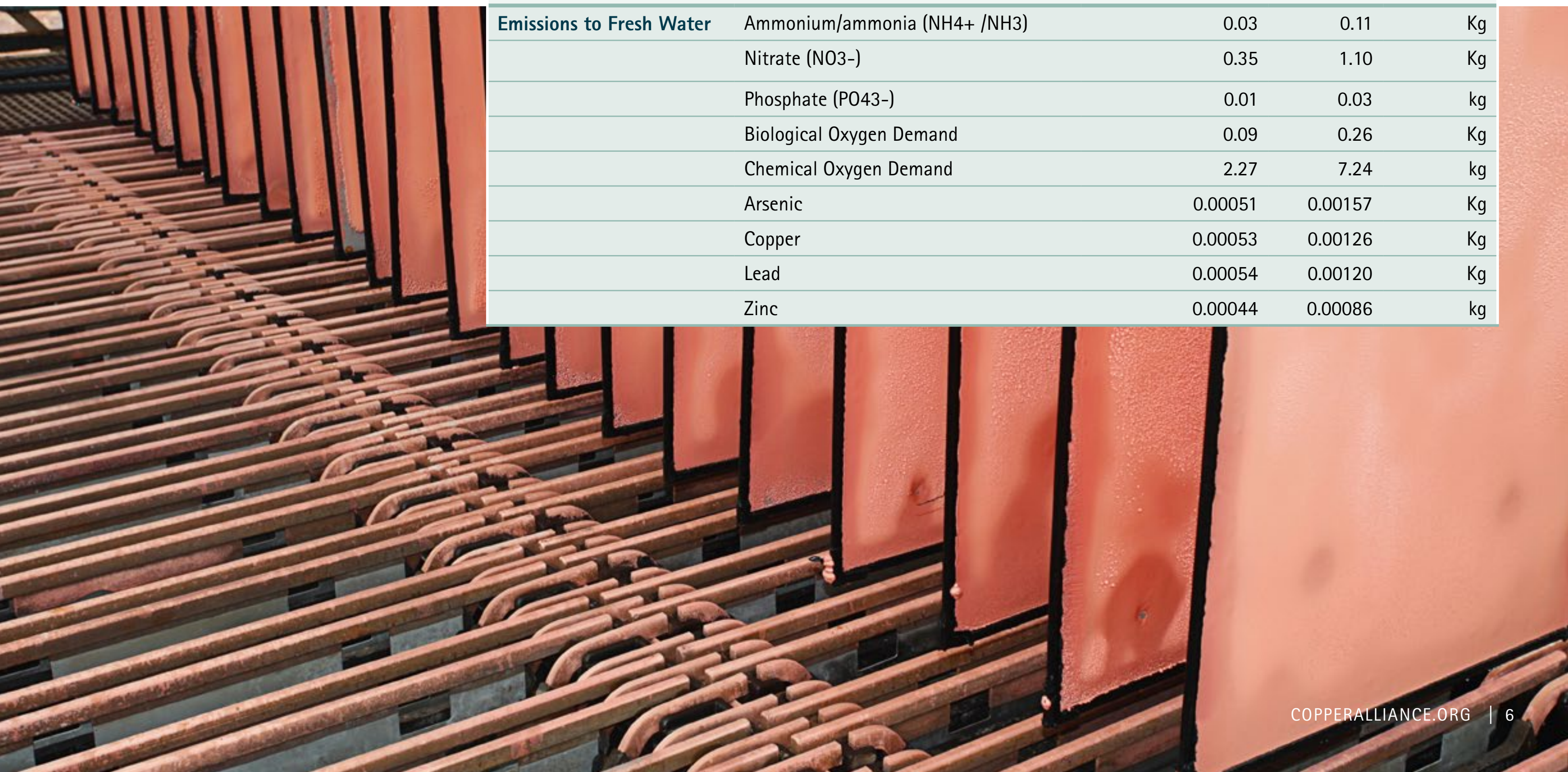
LCI is a key step in the LCA process. The LCI catalogues all the environmental inputs and outputs of a product system. Data may be collected firsthand from measurements and estimates of key activities, or the data may be based on information drawn from existing LCI databases.

For the global LCI on copper cathode, specific primary data for the study was provided by member companies of the International Copper Association and modeled using GaBi 2021.1 databases. The dataset includes production from five continents and represents 23 percent of the annual world production volume of copper cathode for the reference year 2019.

An excerpt of the complete LCI can be found in **Table 1**. Results are shown for copper cathode and copper concentrate.

Table 1: LCI Results of 1 Metric Ton of Copper Cathode and Copper Concentrate

Type	Flow	Concentrate (26% Cu)	Cathode	Unit
Energy Resources	Crude oil	3,873	14,505	MJ
	Hard coal	3,910	14,998	MJ
	Lignite	408	2,072	MJ
	Natural gas	4,048	15,633	MJ
	Peat	4	20	MJ
	Uranium	400	3,169	MJ
	Hydro Power	1,722	5,069	MJ
	Solar Power	1,872	6,175	MJ
	Wind Power	555	2,192	MJ
Material Resources	Limestone	85	288	kg
	Sand	-	193	kg
	Water Use	1,048,840	9,335,512	Kg
Deposited Goods	Overburden	11,196	20,560	Kg
	Tailings	52,611	93,522	Kg
Emissions to Air	CO_2	863	3,558	Kg
	CH_4	1.53	5.69	Kg
	N_2O	0.13	0.42	Kg
	NOx	3.69	15.68	Kg
	SO_2	2.86	31.22	Kg
	NMVOC	0.56	1.99	Kg
	CO	1.87	6.35	Kg
	Dust (>PM10)	0.08	0.37	Kg
	Dust (PM10)	0.01	0.07	Kg
	Dust (PM2,5 - PM10)	0.22	0.82	Kg
	Dust (PM2.5)	0.27	1.47	Kg
	Arsenic	0.00009	0.05546	Kg
	Copper	0.00021	0.00470	Kg
	Lead	0.00022	0.00333	Kg
	Zinc	0.00087	0.00240	kg
Emissions to Fresh Water	Ammonium/ammonia (NH4+ /NH3)	0.03	0.11	Kg
	Nitrate (NO3-)	0.35	1.10	Kg
	Phosphate (PO43-)	0.01	0.03	kg
	Biological Oxygen Demand	0.09	0.26	Kg
	Chemical Oxygen Demand	2.27	7.24	kg
	Arsenic	0.00051	0.00157	Kg
	Copper	0.00053	0.00126	Kg
	Lead	0.00054	0.00120	Kg
	Zinc	0.00044	0.00086	kg



Copper production and recycling enables the recovery of many valuable metal and nonmetal co-products from the primary and secondary raw materials such as precious metals (e.g., gold and silver), nickel sulphate, zinc, lead, tin, sulfuric acid and iron silicate.

The treatment of co-products was a key methodological issue for the copper cathode LCI. There are essentially three procedures for dealing with co-products: subdivision, allocation and system expansion by substitution. Both allocation and system expansion by substitution were applied in the copper cathode LCI to fairly account for the wide range of co-products, as shown in **Table 2**. The LCI presented in Table 1 and the study results are all calculated after applying the allocation and system expansion methodologies.

Table 2: Summary of Co-Product Treatment Methods

Process Level	Co-Products	Treatment Method
Mining	- Sulfide ore - Oxide ore	Mass of metal content allocation
Concentration	- Copper concentrate - Molybdenum concentrate	Mass of metal content allocation
Smelting Processes	- Lead/tin alloy (secondary smelting) - Steam	System expansion - Lead/tin mix - Steam
Sulfuric Acid Plant	- Sulfuric acid	System expansion
Electrolytic Refining	- Copper cathode - Precious metals (via anode sludge) - Nickel sulfate - Copper sulfate	Economic allocation - 10-year average

Critical Review

Prof. Dr. Matthias Finkbeiner, Technical University Berlin, Germany performed the review of the methodology, data quality and modeling aspects of the study as an independent expert reviewer. The review statement is available along with the report on request.

LCIA helps the copper industry pinpoint opportunities for improvement within its operations.

Life Cycle Impact Assessment (LCIA)

Following the LCI, a LCIA was completed to help ICA and its members determine which process or processes contribute the most to the potential environmental impacts. LCIA helps the copper industry pinpoint opportunities for improvement within its operations.

Estimates for potential environmental impacts are organized under eight main impact categories and energy demand described in **Table 3**. The methodology for this assessment, EF 3.0, is primarily based on the Product Environmental Footprint (PEF) impact assessment methodology framework, which assesses 16 different potential impact categories and is seen as an advanced update of impact assessment methods. The eight main impact categories detailed in this report were selected because they are considered relevant to climate change, energy efficiency, and nature, which are all topics of high public and institutional interest. Results for all 16 indicators are available upon request. However, it is important to note that "abiotic depletion potential" and "toxicity" impacts are not sufficiently robust and accurate to be used for metals.

NOTE: Previous versions of this study used the Centre for Environmental Studies (CML) at Leiden University in the Netherlands characterization method for LCIA, and results for each impact category using CML methodology are available upon request.

Table 3: Definitions of LCIA Impact Categories

Impact Category	Description
Climate Change	A measure of greenhouse gas emissions, such as CO_2 and methane, calculated using the IPCC 2001 Global Warming Potential Index (GWP100)
Eutrophication Potential	A measure of emissions that cause excessive richness of nitrogen and phosphorus to ecosystems, causing lower oxygen levels.
Acidification Potential	A measure of emissions to air known to contribute to acid rain.
Photochemical Ozone Creation Potential (POCP)	A measure of emissions of precursors that contribute to ground-level smog, produced by the reaction of nitrogen oxides and VOCs under UV light.
Ozone Depletion	A measure of air emissions that contribute to the depletion of the stratospheric ozone layer, causing higher levels of UVB ultraviolet rays to reach the earth's surface.
Blue Water Consumption	Blue water refers to surface and ground water and excludes rainwater. Consumption occurs when water is lost through evaporation or incorporated into a product and therefore is not returned to the original water source after being withdrawn.
Blue Water Use	Refers to the amount of surface and ground water withdrawn from its source to be used.
Resource Use, Fossil	A measure of the total amount fossil resources non-renewable (e.g., petroleum, natural gas, etc.) extracted from the earth used for the primary energy production.

Study Results

The absolute results of the global LCIA for copper concentrate and copper cathode are shown in **Table 4**. Typically, LCA practitioners refer to a copper concentrate with a certain copper content (around 24% to 36% copper) on a dry weight basis. However, when concentrates are sold and transported, they typically contain 8-10% water. The relative results for copper cathode, by process step and category, are shown in **Figure 5**.

The LCIA results help to focus the copper industry's attention toward addressing priority issues for improving environmental performance.

The study found that:

- Direct **Sulfur Dioxide** (SO_2) emissions released during smelting and not captured for use in the sulfuric acid plant contribute significantly toward **Acidification Potential**. The second largest driver for Acidification Potential is electricity, particularly within grids that rely on coal power plants. This is dependent on regional regulations and installed desulfurization technologies.

- **Photochemical Ozone Creation Potential** is also largely driven by direct SO_2 emissions as well as nitrogen oxides (NOx) and other volatile compounds. These results confirm the continuing importance of reducing on-site emissions of SO_2 by the copper industry.

- For the environmental impact category of **Climate Change**, emissions from purchased electricity are the most significant contributors. As a result, the environmental profile of copper is significantly determined by the electricity grid mix of the region in which the copper is produced. In addition to electricity, diesel combustion during mining was significant.

- For **marine and terrestrial Eutrophication Potential**, the results are driven by NOx emissions primarily associated with diesel combustion, both during mining and, for some sites, the intermediate transport of concentrate to the smelter. For **freshwater eutrophication**, the impacts are driven by phosphorus and phosphate emissions to water. These are primarily associated with wastewater treatment and diesel combustion.

- **Electricity** contributes around one-third of the burden, particularly for grids with high coal power plant shares.

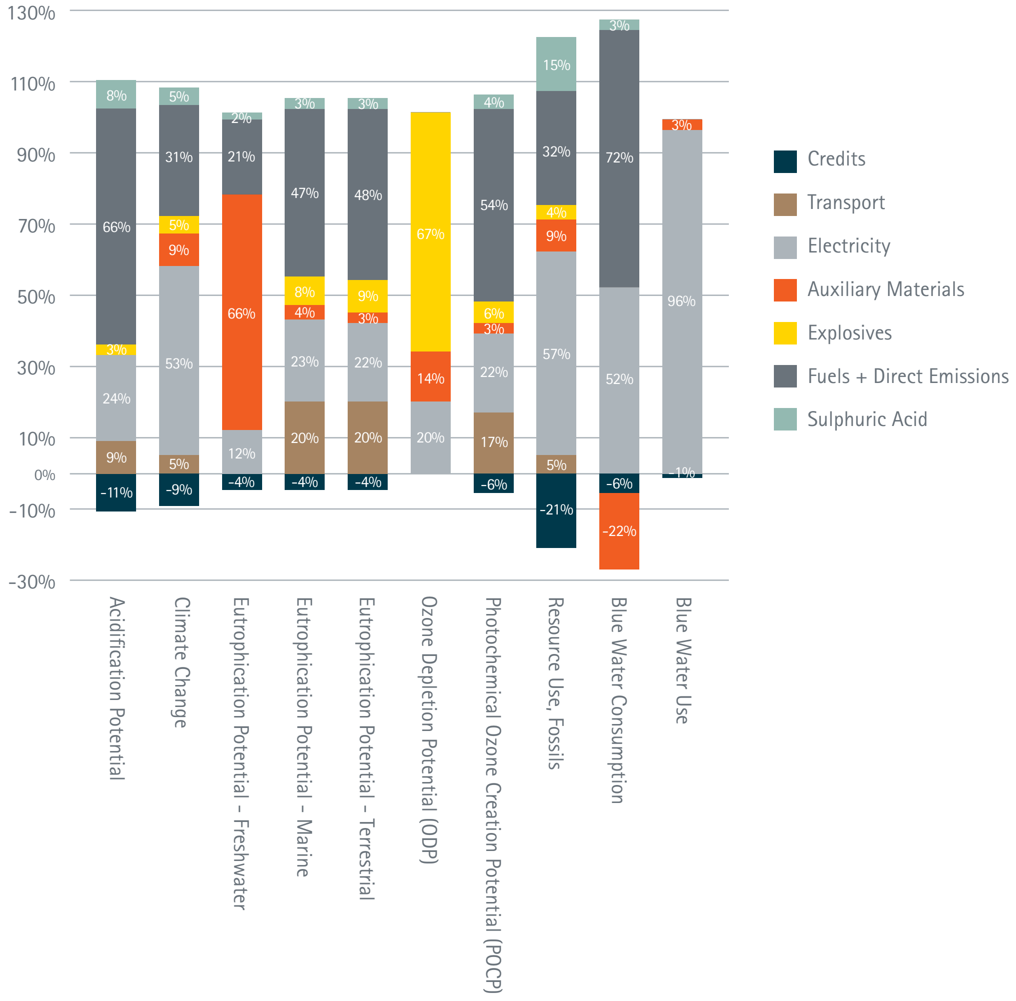
- For **Ozone Depletion Potential**, impacts are almost entirely due to the release of R 114 (dichlorotetrafluorethane) emissions and are highly dependent on the explosives used in mining operations. The presence of nuclear power plants within the electricity grid is also a contributor.

With the large contribution of emissions attributable to purchased electricity and transportation of concentrate, the study results highlight a role for the copper industry to play in advocating for environmentally preferable sources of electricity and fuel in the regions in which copper producers operate.

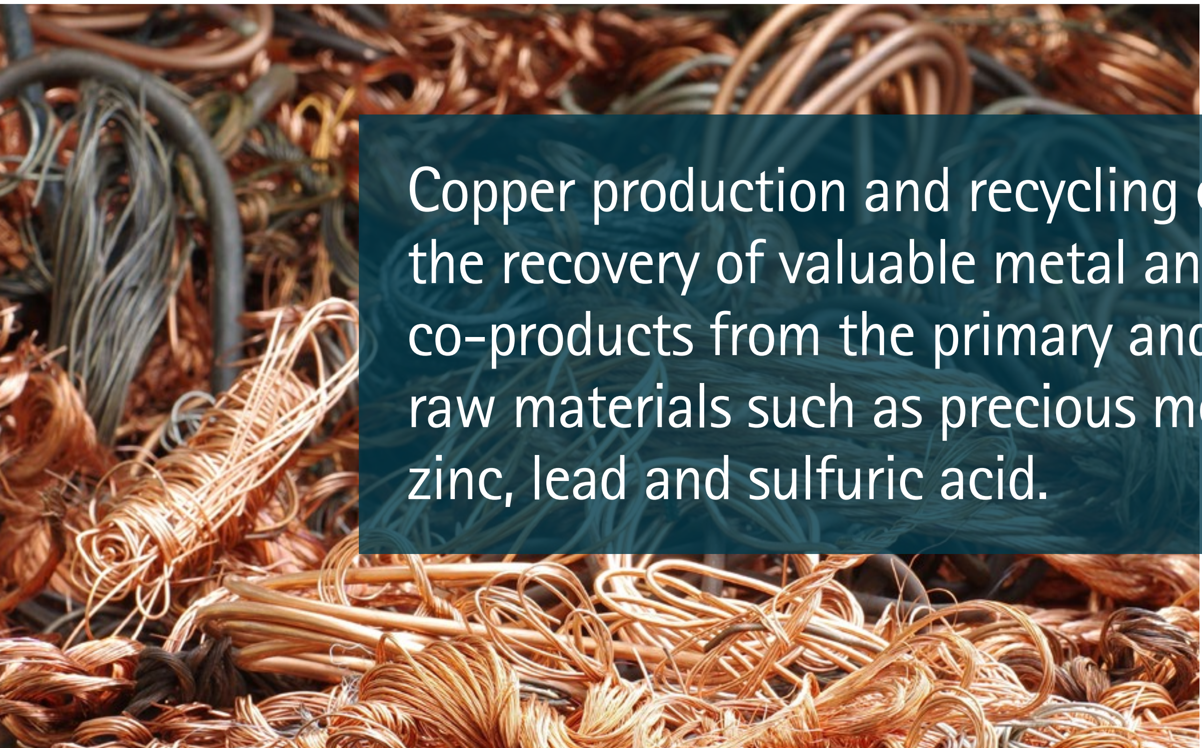
Table 4: Results of the LCIA for Copper Concentrate and Copper Cathode According to EF 3.0 Method

Impact Category	Results per metric tonne of Copper Concentrate (26% Cu)	Results per metric tonne of Copper Contained in Concentrate	Results per metric tonne of Copper Cathode (99.99% Cu)	Unit
Climate Change	980	3788	3,965	kg CO_2 eq.
Eutrophication Potential – Freshwater	0.01	0.03	0.03	kg P eq.
Eutrophication Potential – Marine	1.6	6.1	6.8	kg N eq.
Eutrophication Potential – Terrestrial	17.1	66	73.4	Mole of N eq.
Acidification Potential	6.8	26	53.8	Mole of H+ eq.
Photochemical Ozone Creation Potential (POCP)	4.5	18	20.7	kg NMVOC eq.
Ozone Depletion Potential (ODP)	2.1E-09	8E-09	6.5E-09	kg CFC-11 eq.
Blue Water Consumption	23.6	91.1	57.3	Metric tonnes
Blue Water Use	1035	4003	9,190	Metric tonnes
Resource Use, Fossils	11702	45252	46700	MJ

Figure 5: Relative Results for Copper Cathode, by Category



The results of this study provide a benchmark for the copper industry as they work to reduce environmental impacts. This is increasingly important as demand for copper is expected to more than double due to its essential role in the clean energy transition (ICA, 2023). Any efficiency improvements that can lead to decreased electricity consumption or fuel combustion emissions will have the most potential to decrease environmental impacts.



Copper production and recycling enable the recovery of valuable metal and nonmetal co-products from the primary and secondary raw materials such as precious metals, nickel, zinc, lead and sulfuric acid.

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