International Copper Association
Copper Alliance

Copper Environmental Profile

Introduction

The International Copper Association (ICA) is the leading organization for promoting the use of copper worldwide. Its mission is to bring together the global copper industry to develop and defend markets for copper and to make a positive contribution to society's sustainable development goals.

ICA's 39 member companies represent the majority of the world's refined copper output and are among the largest copper producers, fabricators, and wire and cable companies 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). The 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?

Where does copper come from?

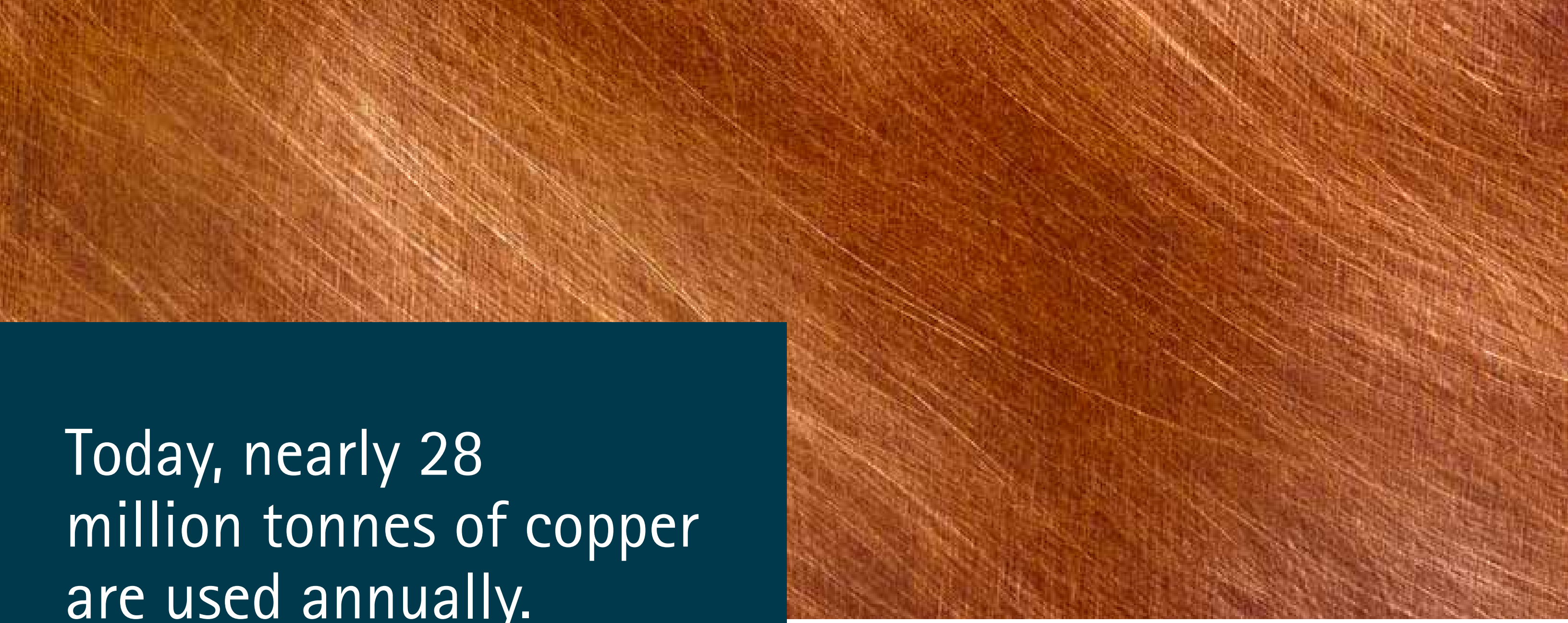
Copper is present naturally in rock and soil, air and water, and it is an essential material for human, animal and plant health and well being.

On average the earth's crust contains 0.0068% (ca. 60 mg/kg) of copper. 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. The top copper-mining countries are Chile, U.S., Peru, China, Australia, Indonesia, Russia, Canada and Zambia.

Like other metals, copper is 100 percent recyclable and retains its quality (its chemical and physical properties) when recycled. More than 30 percent of the world's annual copper demand is met through recycling.

Recycling copper 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.

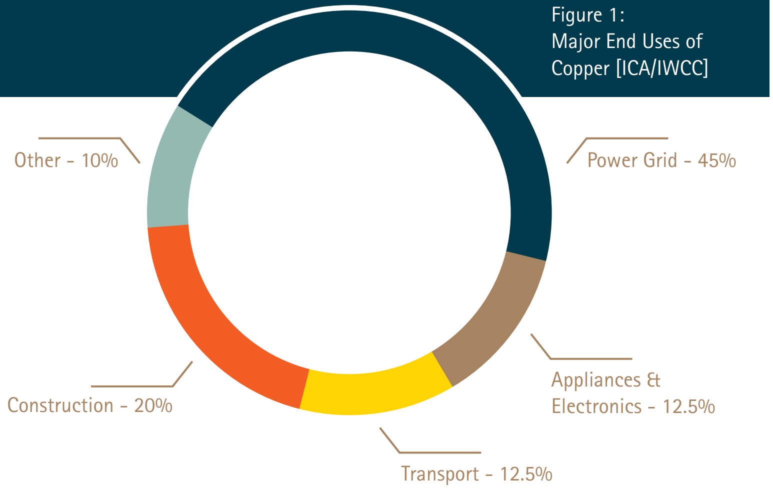
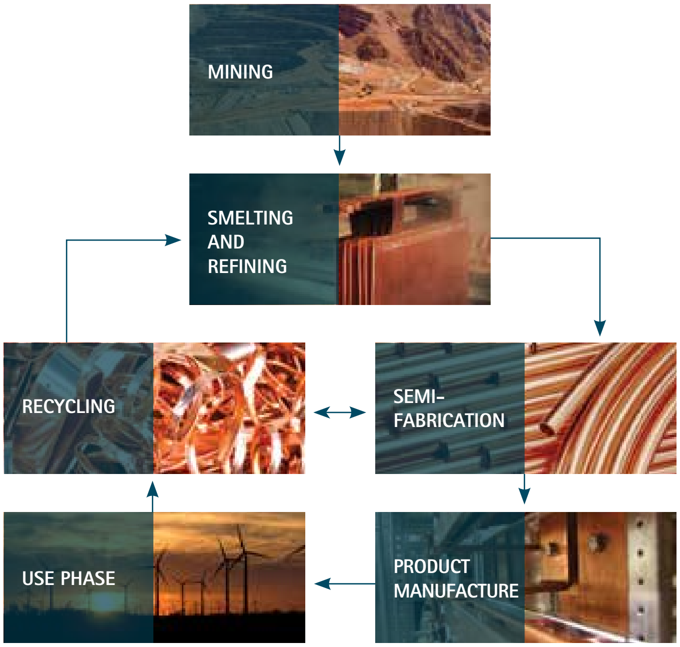


Figure 1:
Major End Uses of Copper [ICA/IWCC]

Figure 2:
Copper Life Cycle



How is copper used?

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

Nearly 70 percent of worldwide copper produced 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 (45 percent)—delivering electricity safely and efficiently to homes and businesses.

Electrical equipment—providing circuitry, wiring and contacts for appliances and consumer electronics accounts for 12.5 percent of copper usage.

The remaining 12.5 percent is used for 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.

The remaining 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 critical 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 home buried underground in a mine to its use in a finished product such as wire or pipe, copper passes through several stages.

Primary copper production starts with the extraction of copper-bearing ores. There are two basic ways of copper mining: surface and underground mining. Due to copper being spread in relatively low concentrations over large areas, surface, or open-pit mining, is the predominant mining method for copper in the world.

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, 2016). 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. Figure 2 shows 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.

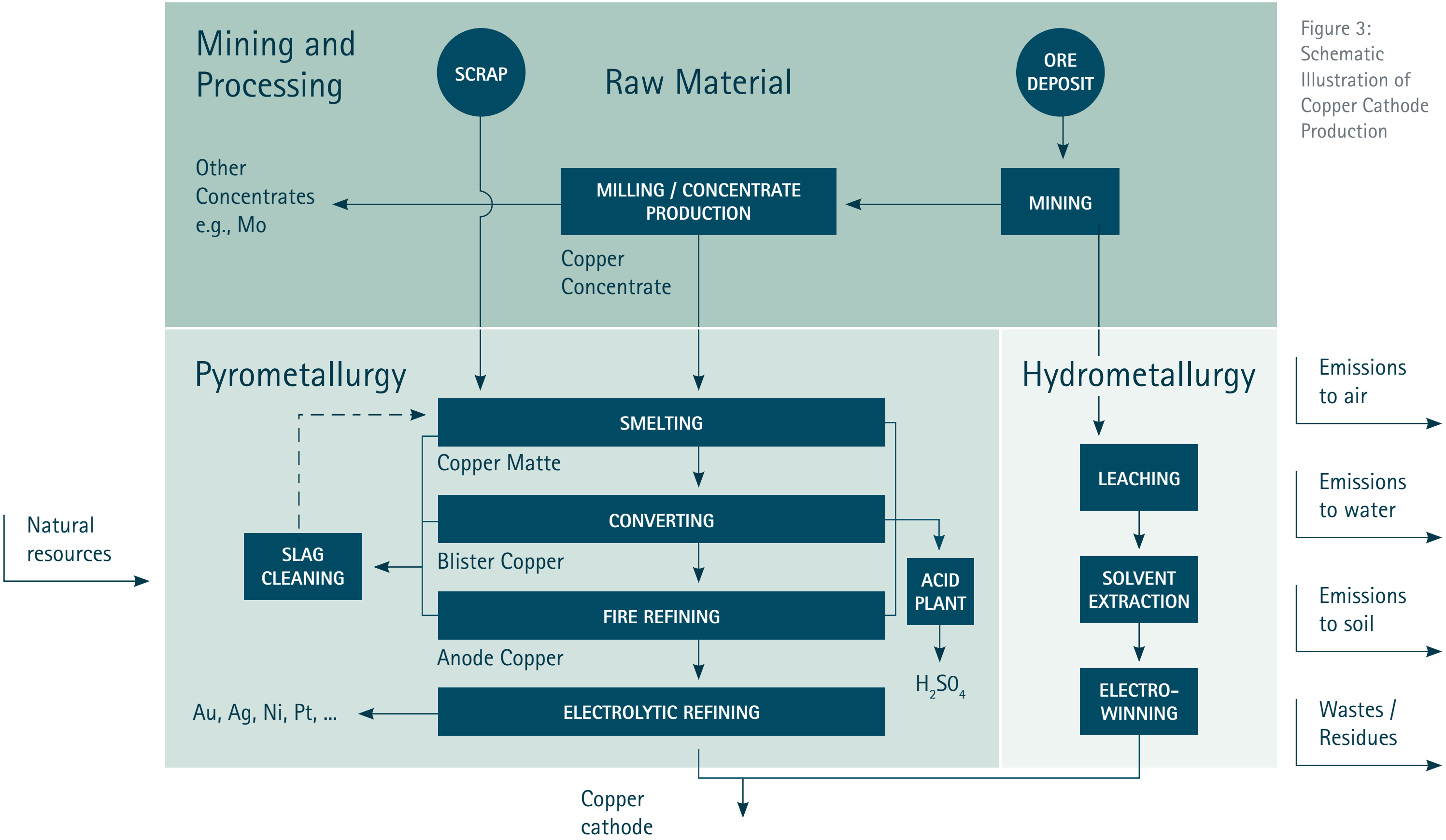


Figure 3: Schematic Illustration of Copper Cathode Production

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.**

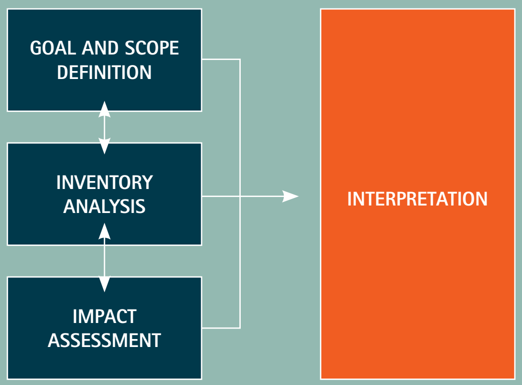
Goal and Scope—where the reference units, scope and boundaries, audience, and uses of the study are confirmed;

Life Cycle Inventory Analysis—where the product system is modeled and data are collected on all relevant inputs and outputs to the system;

Life Cycle Impact Assessment—where the potential environmental impacts associated with the system being studied are assessed; and

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

The system boundary of the study included a cradle-to-gate life cycle inventory from the extraction of the copper ore 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 underwent a critical review by an expert panel.

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 data collection covered representative annual data for 2013 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 2010 – 2013. The functional unit of the study was 1,000 kg of copper cathode.

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 2014 databases. The dataset includes production from four continents and represents 21 percent of the annual world production volume of copper cathode for the reference year 2013.

An excerpt of the complete LCI can be found in **Table 1**. Results are shown for copper cathode and copper concentrate, the main upstream material used to produce primary copper metal.

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

Type	Flow	Concentrate (28% Cu)	Cathode	Unit
Energy resources	Crude oil	4,700	15,000	MJ
	Hard coal	4,800	17,000	MJ
	Lignite	580	2,600	MJ
	Natural gas	2,700	11,000	MJ
	Uranium	200	1,500	MJ
	Primary energy from hydro power	1,100	2,800	MJ
	Primary energy from solar energy	290	950	MJ
	Primary energy from wind power	130	450	MJ
Material resources	Copper ore – Hydro route (0.4% Cu, avg.)	–	81,000	Kg
	Copper ore – Pyro route (0.6% Cu, avg.)	40,000	85,000	Kg
	Limestone	58	150	Kg
	Sand	0.6	190	Kg
	Water use (input)	850,000	2,100,000	Kg
	Secondary copper containing materials (Cu content variable)	–	210	Kg
Deposited goods	Overburden	2,100	6,300	Kg
	Slag	–	300	Kg
	Tailings	29,000	47,000	Kg
	Tailings (leaching)	–	110,000	Kg
	Waste rock	59,000	180,000	Kg
	Waste (deposited)	9.0	130	Kg
	Hazardous waste (deposited)	0.0029	0.0030	Kg
Emissions to air	CO_2	990	3,800	Kg
	CH_4	1.7	6.5	Kg
	N_2O	0.13	0.36	Kg
	NO_x	4.3	17	Kg
	SO_2	4.9	43	Kg
	NMVOC	0.54	1.8	Kg
	CO	1.8	12	Kg
	Dust (> PM10)	0.098	0.36	Kg
	Dust (PM10)	1.3	2.0	Kg
	Dust (PM2,5 - PM10)	0.20	0.64	Kg
	Arsenic	0.00015	0.14	Kg
	Copper	0.00050	0.0011	Kg
	Lead	0.00038	0.0021	Kg
	Zinc	0.0011	0.0029	Kg
Emissions to water	Ammonium/ammonia (NH_{4+} / NH_3)	0.021	0.069	Kg
	Nitrate (NO^{3-})	0.10	0.38	Kg
	Phosphate (PO_4^{3-})	0.011	0.031	Kg
	Biological Oxygen Demand	0.017	0.10	Kg
	Chemical Oxygen Demand	2.2	7.2	Kg
	Arsenic	0.00068	0.0078	Kg
	Copper	0.0010	0.0026	Kg
	Lead	0.00067	0.0017	Kg
	Zinc	0.00023	0.00081	Kg

Copper production and recycling enables the recovery of many metal and nonmetal valuable 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. 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 results shown in section 3.4 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	- Iron silicate (via slag) - Lead/tin alloy (secondary smelting) - Steam	System expansion - Gravel - 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

As noted above, an independent, external panel reviewed the methodology, data quality and modeling aspects of the study. The review panel consisted of four internationally recognized experts in the field of LCA and was chaired by Prof. Dr. Matthias Finkbeiner, Technical University Berlin, Germany. 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 five main impact categories and energy demand described in **Table 3**. These impact categories were selected because they represent a broad range of environmental impacts and are each determined by a well-established scientific approach. The Centre for Environmental Studies (CML) at Leiden University in the Netherlands characterization method for LCIA was used due to its wide acceptance in the global LCA community.

Table 3: LCIA Impact Categories

Impact Category	Description
Primary Energy Demand	A measure of the total amount of primary energy extracted from the earth, including nonrenewable and renewable resources, and considering the efficiency of electric power and heating processes.
Global Warming Potential	A measure of greenhouse gas emissions, such as CO2 and methane, calculated using the IPCC 2001 Global Warming Potential Index (GWP100).
Acidification Potential	A measure of emissions to air known to contribute to atmospheric acid deposition (acid rain).
Eutrophication Potential	A measure of emissions that cause hypertrophication, or excessive richness of nutrients (nitrogen and phosphorus), to the environment.
Photochemical Ozone Creation Potential	A measure of emissions of precursors contributing to low level smog, produced by the reaction of nitrogen oxides and VOCs under the influence of UV light.
Ozone Depletion Potential	A measure of the relative amount of degradation to the ozone layer a chemical can cause, with trichlorofluoromethane (R-11 or CFC-11) being fixed at an ODP of 1.0.

Study Results

The absolute results of the global LCIA for copper cathode are shown in **Table 4**. The relative results, by process step and category, can be seen 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 have significant contribution toward the environmental impact categories of Acidification Potential and Photochemical Ozone Creation Potential. This is dependent on regional regulations and installed desulfurization technologies. These results confirm the continuing importance of reducing on-site emissions of sulfur dioxide by the copper industry.

For the environmental impact category of Global Warming Potential, 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.

Eutrophication Potential results are driven by NO_x emissions primarily associated with diesel combustion, both during mining and, for some sites, the intermediate transport of concentrate to the smelter. Electricity contributes around one-third of the burden, particularly for grids with high coal power plant shares.

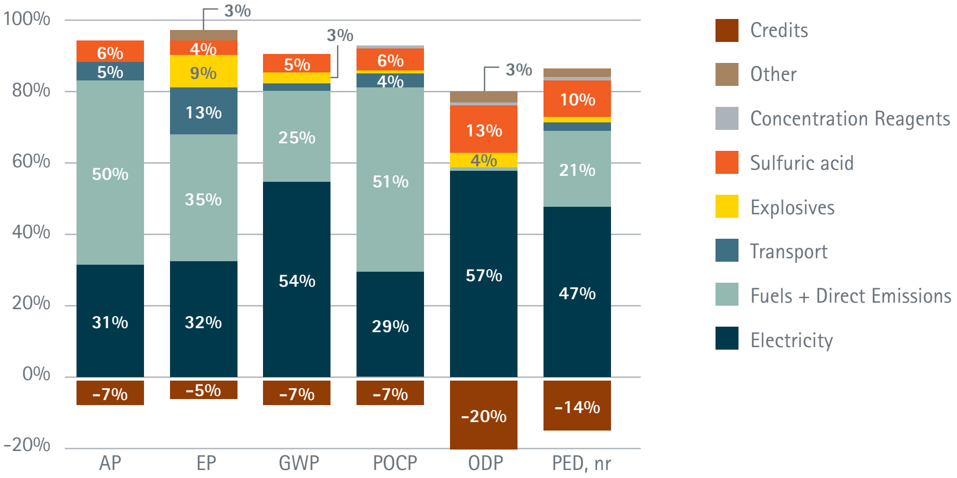
For Ozone Depletion Potential, impacts are almost entirely due to the release of R 114 (dichlorotetrafluorethane) emissions and are highly dependent on the presence of nuclear power plants within the electricity grid.

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

LCIA Impact Categories	Results per Metric Ton of Copper Concentrate (28% Cu)	Results per Metric Ton of Copper Cathode	Unit
Primary Energy Demand, nonrenewable (PED)	13,000	47,000	MJ
Global Warming Potential (GWP 100 years)	1,100	4,100	kg CO_2-Equiv.
Acidification Potential (AP)	8.2	61	kg SO_2-Equiv.
Eutrophication Potential (EP)	0.73	2.7	kg Phosphate-Equiv.
Photochemical Ozone Creation Potential (POCP)	0.60	3.5	kg Ethene-Equiv.
Ozone Depletion Potential (ODP)	1.7E-08	1.2E-07	kg CFC-11-Equiv.

Table 4: Results of the LCIA for Copper Cathode

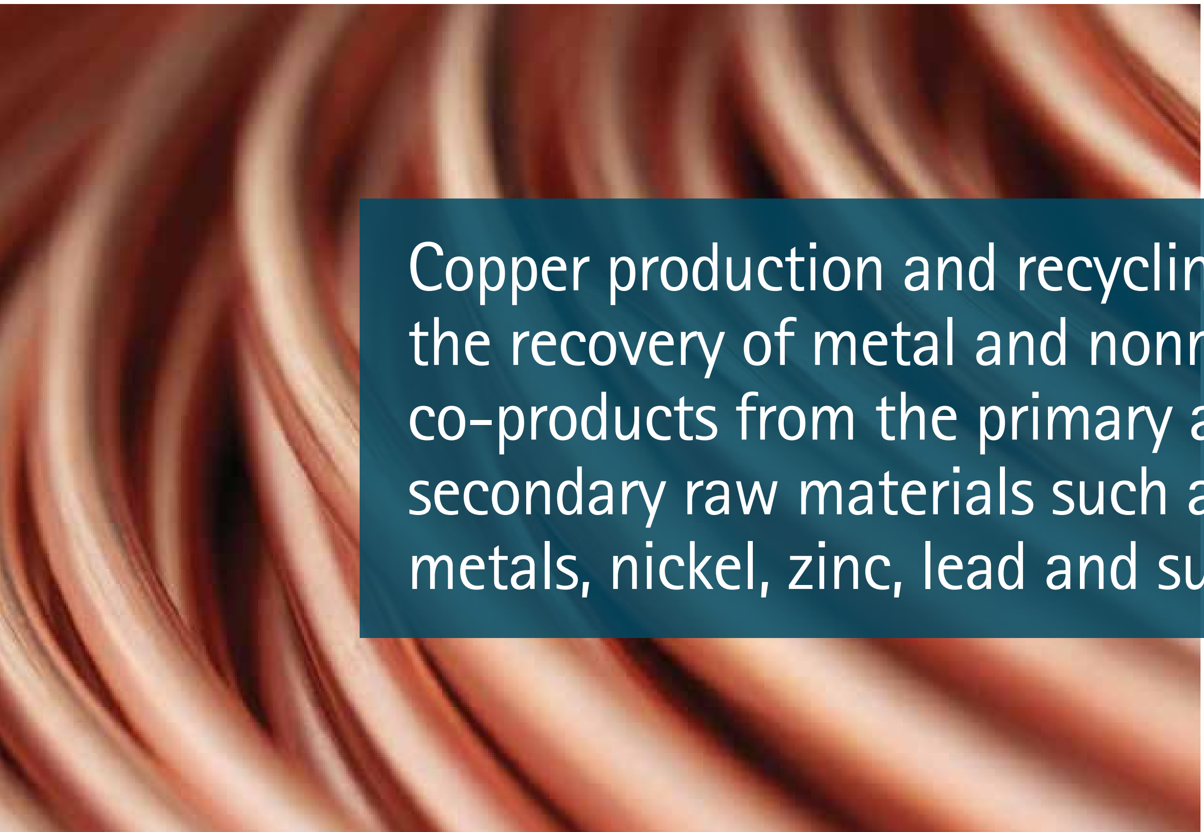
Figure 5: Relative Results for Copper Cathode, by Category



Future users of the cradle-to-gate inventory are free to apply other metrics as long as the limitations outlined are considered.

Abiotic depletion potential (ADP) was excluded from the study due to the lack of robustness and accuracy the metal and mining industry associates with the characterization factors used within the CML methodology (Drielsma, et al., 2016). Similar reasons explain the exclusion of toxicity impacts. Additionally, due to the lack of primary data available to some participating companies for water use and metal emissions, categories addressing water impacts were excluded from this analysis. Finally, land use change is excluded due to concerns with the robustness of the characterization factors within this methodology by the metals industry.

It should be noted that the inclusion of ADP, land use change and toxicity is recommended within the Product Environmental Footprint (PEF) methodology. However, its exclusion here aligns with the criticisms presented in the "Harmonization of LCA methodologies for the metal and mining industry" (Santero & Hendry, 2016) and the lack of maturity of these methodologies discussed in "EU Product Environmental Footprint—Mid-term Review of the Pilot Phase" (Lehmann, Bach, & Finkbeiner, 2016).



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

References

Drielsma, J., Russell-Vaccari, A., Drnek, T., Brady, T., Weihed, P., Mistry, M., & Perez Simbor, L. (2016). Mineral resources in life cycle impact assessment—defining the path forward. *The International Journal of Life Cycle Assessment*, 85-105. Retrieved from http://rd.springer.com/article/10.1007/s11367-015-0991-7

ICSG. (2017). *The World Copper Factbook*. Retrieved from http://www.icsg.org/index.php/component/jdownloads/viewdownload/170/2202

Lehmann, A., Bach, V., & Finkbeiner, M. (2016). EU Product Environmental Footprint—Mid-Term Review of the Pilot Phase. *Sustainability*, 8(1), 92.

Santero, N., & Hendry, J. (2016). Harmonization of LCA methodologies for the metal and mining industry. *The International Journal of Life Cycle Assessment*, 1-11. Retrieved from http://rd.springer.com/article/10.1007%2Fs11367-015-1022-4

For more information, please contact:

ANDREA VACCARI
International Copper Association
andrea.vaccari@copperalliance.org
www.sustainablecopper.org

LADJI TIKANA
Deutsches Kupferinstitut Berufsverband e.V.
ladji.tikana@copperalliance.de
http://copperalliance.eu/about-copper/life-cycle-centre