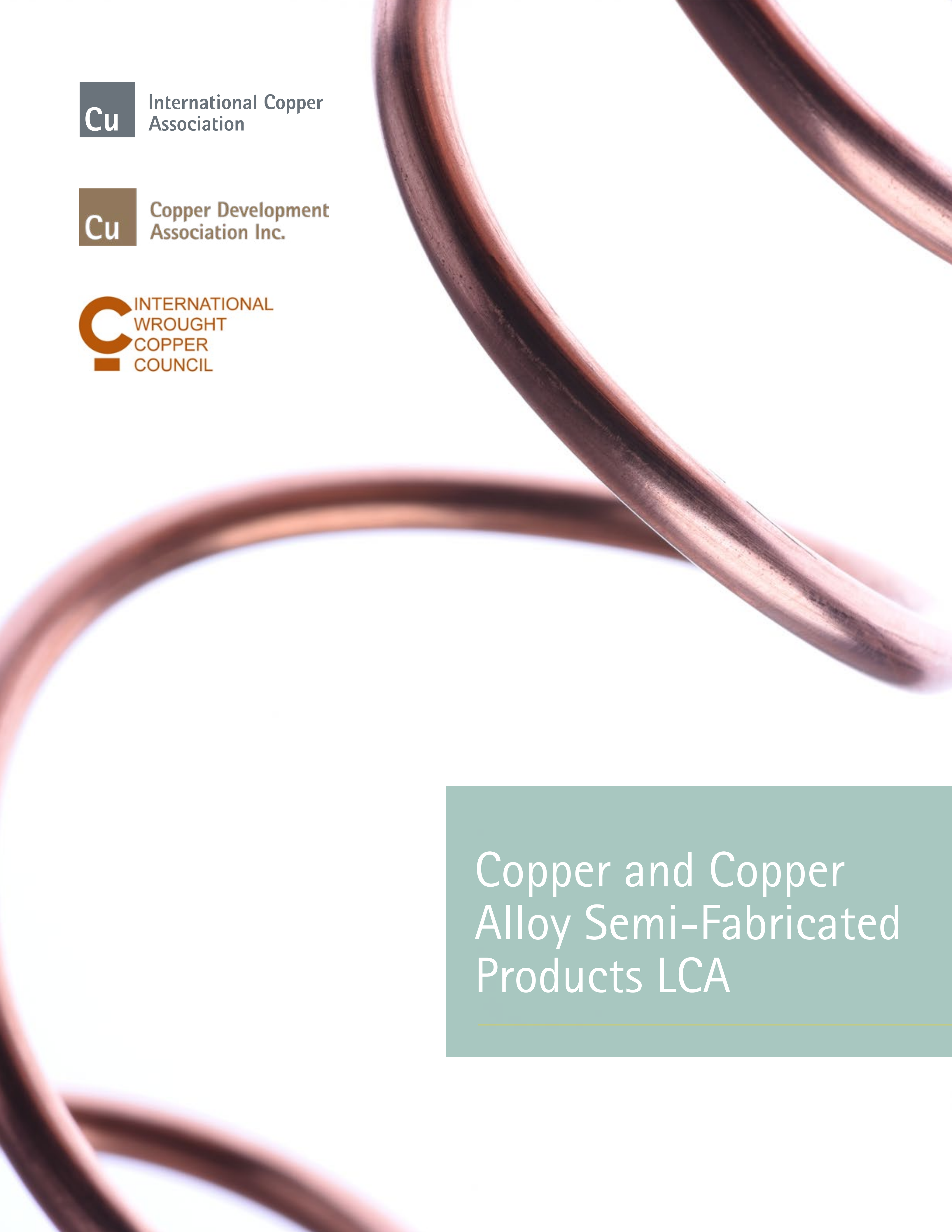



International Copper Association

Copper Development Association Inc.

International Wrought Copper Council


# Copper and Copper Alloy Semi-Fabricated Products LCA

In 2021 the International Copper Association (ICA), in collaboration with the International Wrought Copper Council (IWCC) and the Copper Development Association (CDA) USA, conducted an LCA study to quantify resource use, energy and environmental emissions associated with the production of copper and copper alloys semi-fabricated products.

The study is a "cradle-to-gate" life cycle inventory (LCI) from the extraction of the copper ore at the mine (covered by the separate concentrate and cathode LCA study) to the production of copper and copper alloy semi-fabricated products. The geographical scope of the project is intended to be representative of regional –North America – and global production of copper and copper alloys semi-fabricated products by members of three associations ICA, IWCC and CDA USA. Data was collected for four types of semi-fabricated products: wire rod; tube; rod, bars and sections (RBS), flat-rolled products (plate, sheet, strip and foil) (FRP), and for three material types as follows:

- **Copper** (copper content of 99.5% or higher)
- **Brass** (zinc content of 30%-42% and lead content of 0.5%-3.0%)
- **Lead-free Brass** (zinc content of 30%-42% and silicon content of 0%-4%)

The data sampling included annual representative data respectively for the years 2019, 2020 or 2021.

The study follows an attributional LCA approach and was conducted in accordance with the International Standards ISO 14040:2006 and ISO 14044:2006, incorporating some elements of the Product Environmental Footprint (PEF) Guide, such as an LCIA approach.

The study underwent a critical review from Prof. Dr. Markus Berger from University of Twente, Netherlands, an independent life cycle assessment specialist in line with ISO 14044 and ISO/TS 14071.

## Copper and Copper-based Alloy Semis

Copper and copper-based alloys are used in a variety of applications that are necessary for a reasonable standard of living. Its continued production and use are essential for society's development. How society exploits and uses its resources, while ensuring that tomorrow's needs are not compromised, is an important factor in ensuring society's sustainable development. Recycling copper and its alloys extends the efficiency of their use, results in energy savings, and contributes to ensuring that we have a sustainable source of metal for future generations. Copper and its alloys are important contributors to the national economies of mature, newly developed, and developing countries. Mining, processing, recycling and the transformation of metal into a multitude of products create jobs and generate wealth. These activities contribute to building and maintaining a country's infrastructure, and create trade and investment opportunities. Today approximately 30 million tons of copper and copper-based alloys are produced in different forms (**Figure 1**). 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.

The study does not include China. The production volumes and the covered volume in this LCA study are shown in **Table 1**.

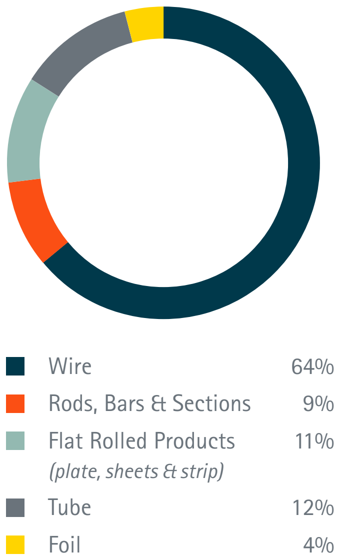



**Figure 1:** Copper and copper alloy Semis production statistics (world copper factbook 2023)

*Copper and its alloys are important contributors to the national economies of mature, newly developed, and developing countries.*

**Table 1:** Production volumes of semis and volume covered in this LCA study

| Semis | Production Volumes | | LCA Study Coverage | | | |
|---|---|---|---|---|---|---|
| | Global (excl. China) [ktonnes] | North America [ktonnes] | Global (excl. China) [ktonnes] | Percentage | North America [ktonnes] | Percentage |
| Copper Wire Rod | 9,244 | 1,517 | 2,278 | 25% | 842 | 56% |
| Copper Tube | 1,229 | - | 297 | 24% | - | - |
| Copper FRP | 1,211 | - | 234 | 19% | - | - |
| Alloy FRP | 1,035 | -- | 136 | 13% | - | - |
| Alloy RBS | 2,100 | - | 787 | 37% | - | - |

## The Copper Life Cycle

The copper value chain encompasses six major life cycle phases: mining, smelting and refining, semi-fabrication, product manufacture, use phase, and recycling (**Figure 2**). Recycling takes place both at smelters for copper production and at fabricators for production of semi-fabricated (called also semi-finished) products. The LCI of copper cathode 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 efficiency of energy using products, making those products more sustainable in their use phase.

## The Production of Copper and Copper-Based Alloy Semis

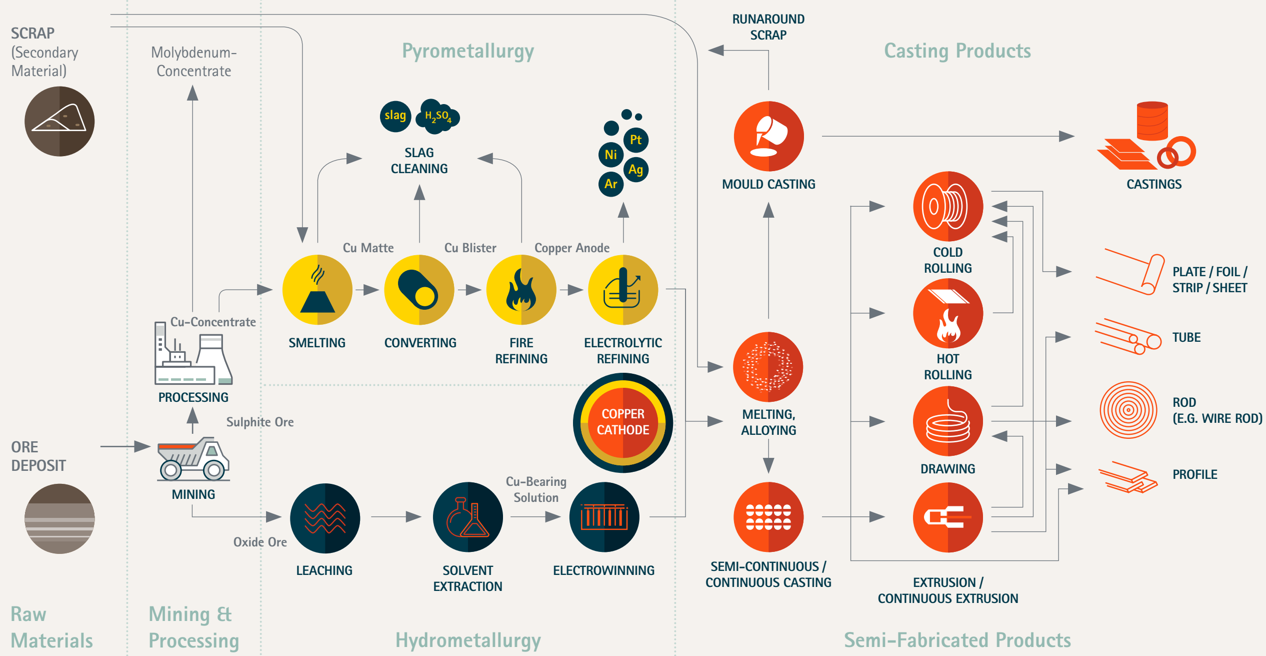



**Figure 2:** The copper semi production chain

## Semi-Fabrication Life cycle Stage

The semi-fabrication life cycle stage consists of casting molten metal into a format that is subsequently mechanically transformed into one of the following shapes with the desired surface finish that meets the demands of the end-use manufacturing stage: flat rolled product, rod/bars, wire, tube or pipe.

## Semi-Fabrication Melting and Casting

Within the melting and casting step of the semi-fabrication life cycle stage, molten metal is managed to achieve a desired chemical composition and then cast into solid forms. Copper inputs typically consist of slide metal forms but can also be molten metal as in the case of wire rod cast directly at a vertically integrated mine and smelter site. Solid metal inputs include cathode and scrap. Scrap handling prior to being charged into a furnace may include manual and mechanical steps including: sorting, stripping, shredding, and magnetic separation. The scrap may then be compressed into briquettes in a hydraulic press. Molten metal may be retained in a holding furnace as required. While in the molten state, flux is added to the copper and air is introduced to oxidize impurities. These impurities are then removed as slag. In addition to impurities, the slag will also contain low levels of copper. To recover the copper from the slag, the slag will leave the semi-fabrication life cycle and be sent back to the refining steps of the copper production life cycle state. Also in the molten state, various alloying elements may be added to the melt to enhance the performance characteristics in later life cycle stages. Once the molten metal meets the chemical composition requirements, it is poured into a cast to be solidified. In the case of rod and some pipe, this casting step is a continuous process in which the mold continuously moves as the metal solidifies. Following solidification and prior to advancing to the next step of metalworking, some products may require surface preparation.

Examples of typical scrap produced during the semi-fabrication casting steps include rejected sections from the head and foot of the format, chips from sawing, copper removed from the surface during surface preparation steps, rejected castings and formats or material from cleaning batches. Extremely low levels of copper will be lost to the external environment, known as melt loss.

*Scrap handling prior to being charged into a furnace may include manual and mechanical steps including: sorting, stripping, shredding, and magnetic separation.*

## Semi-Fabrication Metalworking

Once solidified, the cast material will likely undergo a series of metalworking steps to achieve the final shape and dimensions of the semi-fabricated product. These steps are specific to the semi-fabricated product.

**Flat Rolled Products (FRP)** are produced from the copper material slabs and ingots cast in the previous step. The slabs are heated in a furnace and then rolled down in several passes, wherein the thickness is reduced by decreasing the gap between the opposing rollers. The high temperatures (approximately 900°C) in heating and hot rolling may cause thermal oxidation to form on the surface of the copper, which is removed by milling. The copper material sheets of intermediate thickness are then further processed to reach final dimensional, physical, and mechanical properties. Annealing is an intermediate heat treatment in which the copper sheets are heated to a temperature (well below the melting point of the copper) for a specific length of time sufficient to increase ductility and decrease hardness to improve workability. The annealed sheets are then cold rolled to reduce the material to its final thickness. The final thickness determines whether the semi-fabricated product is considered a plate, sheet, or foil.

**Rods, Bars and Sections (RBS)** are produced within the continuous casting process in the previous step or through an additional hot extrusion step. Rods and bars produced via the continuous cast process may be cut to length at this point or may undergo additional metalworking steps resulting in a final product. When rods and/or bars are produced via hot extrusion, billets produced in the casting step are transferred to the extrusion press and heated to make the metal sufficiently malleable for extrusion into smaller diameter rods. Extrusion is a hot deformation process where the heated billets are forced through a die to produce the desired shape and size. Depending on the size required, the rod will be extruded either straight or coiled. Once extrusion is complete, the rod/bar is cooled in a controlled manner and sent through acid cleaning to remove oxidation from the extruded surface. The rod is then cold drawn through a die to reduce its diameter and increase its length to meet dimensional, mechanical property, and machinability requirements. The rods/bars are then passed through a straightening machine which uses rollers to increase straightness—a critical requirement for downstream processing. Finally, the straightened rods/bars are typically chamfered and bundled.

**Wire Rod** is typically produced in a continuous cast process. However, instead of being cut to length like a typical rod, wire rod is further processed to form copper wire. As the copper bar solidifies and moves off the wire mold it is drawn away to a rolling mill. The bar is rolled down in several steps to the final diameter – typically 8 mm. At the end the rod is cooled and waxed to protect the surface from oxidation. At this point the wire rod product may be coiled and packaged for additional transformation to further reduce the diameter of the wire rod to meet the specifications of copper wire. The wire rod is then passed through a series of dies in a process called drawing. The wire is reduced in diameter as it passes through each successive die, elongating and shaping it. This process increases the length and reduces the diameter of the wire, while also improving its mechanical properties. The drawn wire may undergo annealing, a heat treatment process to relieve internal stresses and improve its ductility and flexibility. Depending on the application, the wire may be coated with a layer or protective material. The final wire can be spooled onto large reels or cut into specific lengths, depending on the requirements of the end user.

**Tubes and Pipes**, like rods, start with a billet produced in the semi-fabrication casting step and subsequently undergoing additional metalworking steps. The billet is heated to become more malleable. The heated billet is then forced through a shaped die using a hydraulic or mechanical press. This process is called extrusion and results in the copper taking on the shape of the die. In the case of copper tubes, the extrusion die typically has a round opening to form the tube shape. The extruded copper tube is rapidly cooled, which helps to set its shape and improve its mechanical properties. Continuing to form the tube and pipe to a desired diameter and wall thickness, the tube shape will go through several draws using a combination of plugs and/or dies until the final dimensions are made. During the redraw or resizing (draw schedule), the tube may undergo a straightening process to correct any deformations or irregularities that may have occurred during the extrusion. Straight length copper tube/pipe is cut to the desired lengths, and its dimensions are checked to ensure they meet the required specifications. Copper tube/pipe that are coiled or straight lengths that are re-tempered (softened) may be subjected to an annealing process to improve its mechanical properties for reforming or installation. This involves heating the tube to a specific temperature for a determined amount of time and then gradually cooling it. The temperature and time for annealing is determined by the volume of copper being annealed.

Depending on the application, most copper semi-fabricated products will undergo additional surface treatments, such as coating, plating, or polishing, to enhance their appearance, corrosion resistance, or other properties. The semi-fabricated copper products are often cut or sheared to the desired lengths. This step is crucial for preparing the material for further processing or for the final application. Finally, the semi-fabricated copper products are packaged and prepared for shipment to customers or downstream manufacturing processes.

*Examples of typical scrap from metalworking include clippings, trimmings, stampings, borings, turnings, and spent etchant (pickling solutions).*

## Life Cycle Assessment

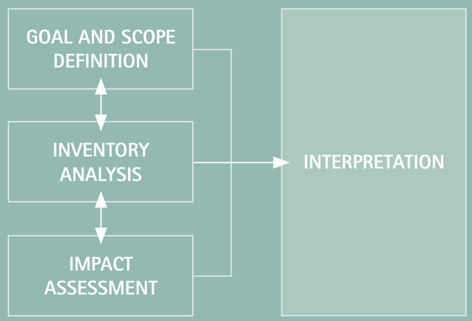
LCA is a tool used to identify environmental burdens and evaluate the potential environmental impacts of goods or services over their life cycle from cradle to grave. LCA has been standardized under the International Organization for Standardization (ISO) and forms the conceptual basis for a number of 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 3**.

**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 3:** Life Cycle Stages




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

## Goal and Scope Definition

The LCI serves to evaluate the environmental impacts associated with copper/copper alloy semi-fabricated product manufacturing. It provides copper industry stakeholders, and LCA practitioners with:

- Most up-to-date LCI data for the semi-fabricated products of copper and copper alloys;
- Adoption of the LCI data of the copper/copper alloy semi-fabricated products in the mainstream LCI databases; and
- The basis for the future development of "cradle-to-grave" environmental profiles of copper-containing intermediate and end-use products.

This work is intended to promote state-of-the-art practice LCI methods and provide guidance to LCI communication and uses of the information.

The results are not intended to support comparative assertions for public disclosure. Nonetheless, the LCI datasets of the copper/copper alloy semi-fabricated products might be used by third parties to support comparative assertion, e.g., based on copper end-use applications. Such comparisons should only be made on a cradle-to grave life cycle basis using an appropriate functional unit and must be carried out in accordance with the ISO 14040/44 standards, including an additional critical review by a panel (ISO 14040:2006 and ISO 14044:2006).

## Methodology and Functional Unit

The study follows an attributional LCA approach and was conducted in accordance with the International Standards ISO 14040:2006 and ISO 14044:2006, incorporating some elements of the Product Environmental Footprint (PEF) Guide, such as an LCIA approach in order to prepare for future PEF-compliant assessments.

For all products studied, the functional unit (declared unit) was identical to the reference flow: the production of one metric tonne of copper/copper alloy semi-fabricated product at the factory gate.

For systems with multiple outputs (e.g. RBS and FRP) coming out of the production (i.e., rolling, extrusion) step, mass allocation method was applied.

*LCA is a tool used to identify environmental burdens and evaluate the potential environmental impacts of goods or services over their life cycle from cradle to grave.*

## Life Cycle Impact Assessment (LCIA)

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 as can be seen in Tables 2-8. 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 mature and relevant to climate change, environmental quality (air, soil, and water), and policy relevance, which are all topics of high public and institutional interest.

It is important to note that "abiotic depletion potential" and "toxicity" impacts are not sufficiently robust and accurate to be used for metals.

**System Boundaries**

| Included | Excluded |
|---|---|
| Production and transportation of input metals (e.g., copper cathode) | Non-metallurgical operations (e.g., canteen, administration, etc.) |
| Effluents and emissions to air | Production of capital equipment |
| On and offsite power production | Personnel lodging, transport, etc. |
| Water usage and treatment | Packaging of products |
| Production and transportation of auxiliary materials (consumed in production, e.g., lubricants for machinery) | Use and end-of-life of semi-fabricated products |
| Offsite waste disposal (could include hazardous waste) | |
| Internal transportation of materials (i.e., within a facility) | |
| Overhead of manufacturing facilities (e.g., energy for lighting) | |
| Processing of materials and intermediates at each unit operation | |
| Transportation and pre-treatment of externally sourced secondary metal containing materials (i.e., not recovered internally) | |

## Study Results

All inventory (LCI) tables are in **Annex I** and the relative contributions of the impacts drivers are in **Annex II**.

The LCIA results for one tonne of wire rod, RBS, FRP and tube according to EF 3.0 method and blue water metrics are presented in **Table 2** through to **Table 8**. Results calculated using the CML can be assessed on request.

It should be noted that the comparison of one tonne of two different semi-fabricated products is not intended, as they serve different functions and typically results are significantly dependent on the amount of cathode and scrap input.

**Table 2:** LCIA Results for 1 metric tonne of **COPPER WIRE ROD** according to EF 3.0 method and blue water metrics – global North America (RNA) averages

| Impact Category | Global | RNA | Unit |
|---|---|---|---|
| **EF 3.0 – Acidification** | 39.4 | 53.5 | Mole of H+ eq. |
| **EF 3.0 – Climate Change** | 3,622 | 4,115 | kg $CO_2$ eq. |
| **EF 3.0 – Eutrophication, Freshwater** | 0.02 | 0.03 | kg P eq. |
| **EF 3.0 – Eutrophication, Marine** | 5.7 | 7.1 | kg N eq. |
| **EF 3.0 – Eutrophication, Terrestrial** | 61.8 | 76.9 | Mole of N eq. |
| **EF 3.0 – Ozone Depletion** | 2.6E-09 | 6.2E-09 | kg CFC-11 eq. |
| **EF 3.0 – Photochemical Ozone Formation, Human Health** | 17 | 21.5 | kg NMVOC eq. |
| **EF 3.0 – Resource Use, Fossils** | 40,548 | 50,022 | MJ |
| **Other – Blue Water Consumption** | 48.2 | 55.8 | metric tonnes |
| **Other – Blue Water Use** | 6,089 | 8,810 | metric tonnes |

**Table 3:** LCIA Results for 1 metric tonne of **BRASS RBS** according to EF 3.0 method and blue water metrics – global averages

| Impact Category | Global | Unit |
|---|---|---|
| **EF 3.0 – Acidification** | 5.9 | Mole of H+ eq. |
| **EF 3.0 – Climate Change** | 1,061 | kg $CO_2$ eq. |
| **EF 3.0 – Eutrophication, Freshwater** | 4.1E-03 | kg P eq. |
| **EF 3.0 – Eutrophication, Marine** | 1.5 | kg N eq. |
| **EF 3.0 – Eutrophication, Terrestrial** | 15.7 | Mole of N eq. |
| **EF 3.0 – Ozone Depletion** | 8.7E-10 | kg CFC-11 eq. |
| **EF 3.0 – Photochemical Ozone Formation, Human Health** | 3.9 | kg NMVOC eq. |
| **EF 3.0 – Resource Use, Fossils** | 13,736 | MJ |
| **Other – Blue Water Consumption** | 63.5 | metric tonnes |
| **Other – Blue Water Use** | 2,984 | metric tonnes |

**Table 4:** LCIA Results for 1 metric tonne of **PB-FREE BRASS RBS** according to EF 3.0 method and blue water metrics – global averages

| Impact Category | Global | Unit |
|---|---|---|
| EF 3.0 – Acidification | 15.7 | Mole of H+ eq. |
| EF 3.0 – Climate Change | 2,104 | kg $CO_2$ eq. |
| EF 3.0 – Eutrophication, Freshwater | 8.5E-03 | kg P eq. |
| EF 3.0 – Eutrophication, Marine | 3 | kg N eq. |
| EF 3.0 – Eutrophication, Terrestrial | 32.5 | Mole of N eq. |
| EF 3.0 – Ozone Depletion | 1.8E-09 | kg CFC-11 eq. |
| EF 3.0 – Photochemical Ozone Formation, Human Health | 8.4 | kg NMVOC eq. |
| EF 3.0 – Resource Use, Fossils | 26,121 | MJ |
| Other – Blue Water Consumption | 99.2 | metric tonnes |
| Other – Blue Water Use | 5,617 | metric tonnes |

**Table 5:** LCIA Results for 1 metric tonne of **COPPER FRP** according to EF 3.0 method and blue water metrics – global averages

| Impact Category | Global | Unit |
|---|---|---|
| EF 3.0 – Acidification | 36.2 | Mole of H+ eq. |
| EF 3.0 – Climate Change | 3,918 | kg $CO_2$ eq. |
| EF 3.0 – Eutrophication, Freshwater | 0.02 | kg P eq. |
| EF 3.0 – Eutrophication, Marine | 5.2 | kg N eq. |
| EF 3.0 – Eutrophication, Terrestrial | 56.2 | Mole of N eq. |
| EF 3.0 – Ozone Depletion | 4.1E-09 | kg CFC-11 eq. |
| EF 3.0 – Photochemical Ozone Formation, Human Health | 15.4 | kg NMVOC eq. |
| EF 3.0 – Resource Use, Fossils | 49,412 | MJ |
| Other – Blue Water Consumption | 48.5 | metric tonnes |
| Other – Blue Water Use | 8,236 | metric tonnes |

**Table 6:** LCIA Results for 1 metric tonne of **BRASS FRP** according to EF 3.0 method and blue water metrics – global averages

| Impact Category | Global | Unit |
|---|---|---|
| EF 3.0 – Acidification | 9.5 | Mole of H+ eq. |
| EF 3.0 – Climate Change | 2,855 | kg $CO_2$ eq. |
| EF 3.0 – Eutrophication, Freshwater | 4.1E-03 | kg P eq. |
| EF 3.0 – Eutrophication, Marine | 3.4 | kg N eq. |
| EF 3.0 – Eutrophication, Terrestrial | 36.5 | Mole of N eq. |
| EF 3.0 – Ozone Depletion | 5.6E-10 | kg CFC-11 eq. |
| EF 3.0 – Photochemical Ozone Formation, Human Health | 8.9 | kg NMVOC eq. |
| EF 3.0 – Resource Use, Fossils | 34,816 | MJ |
| Other – Blue Water Consumption | 167 | metric tonnes |
| Other – Blue Water Use | 8,510 | metric tonnes |

**Table 7:** LCIA Results for 1 metric tonne of **PB-FREE BRASS FRP** according to EF 3.0 method and blue water metrics – global averages

| Impact Category | Global | Unit |
|---|---|---|
| **EF 3.0 – Acidification** | 11.8 | Mole of H+ eq. |
| **EF 3.0 – Climate Change** | 2,800 | kg $CO_2$ eq. |
| **EF 3.0 – Eutrophication, Freshwater** | 7.7E-03 | kg P eq. |
| **EF 3.0 – Eutrophication, Marine** | 3.3 | kg N eq. |
| **EF 3.0 – Eutrophication, Terrestrial** | 36 | Mole of N eq. |
| **EF 3.0 – Ozone Depletion** | 8.8E-10 | kg CFC-11 eq. |
| **EF 3.0 – Photochemical Ozone Formation, Human Health** | 8.9 | kg NMVOC eq. |
| **EF 3.0 – Resource Use, Fossils** | 34,631 | MJ |
| **Other – Blue Water Consumption** | 153 | metric tonnes |
| **Other – Blue Water Use** | 7,441 | metric tonnes |

**Table 8:** LCIA Results for 1 metric tonne of **COPPER TUBE** according to EF 3.0 method and blue water metrics – global,averages

| Impact Category | Global | Unit |
|---|---|---|
| **EF 3.0 – Acidification** | 27.7 | Mole of H+ eq. |
| **EF 3.0 – Climate Change** | 2,763 | kg $CO_2$ eq. |
| **EF 3.0 – Eutrophication, Freshwater** | 0.02 | kg P eq. |
| **EF 3.0 – Eutrophication, Marine** | 4 | kg N eq. |
| **EF 3.0 – Eutrophication, Terrestrial** | 43.3 | Mole of N eq. |
| **EF 3.0 – Ozone Depletion** | 3.E-09 | kg CFC-11 eq. |
| **EF 3.0 – Photochemical Ozone Formation, Human Health** | 11.8 | kg NMVOC eq. |
| **EF 3.0 – Resource Use, Fossils** | 32,944 | MJ |
| **Other – Blue Water Consumption** | 30.4 | metric tonnes |
| **Other – Blue Water Use** | 5,037 | metric tonnes |

**Table 9:** LCI results of 1 metric tonne of **COPPER** products – wire rod, tube and FRP – at a global level

| Type | Flow | Copper Wire Rod | Copper Tube | Copper FRP | Unit |
|---|---|---|---|---|---|
| **Energy Resources (Gross Calorific Value)** | Crude Oil (Resource) | 10,878 | 7,836 | 10,546 | MJ |
| | Hard Coal (Resource) | 12,944 | 8,620 | 13,285 | MJ |
| | Lignite (Resource) | 3,068 | 2,378 | 2,842 | MJ |
| | Natural Gas (Resource) | 14,421 | 14,446 | 23,598 | MJ |
| | Peat (Resource) | 13 | 9 | 12 | MJ |
| | Uranium (Resource) | 2,529 | 2,409 | 3,250 | MJ |
| | Primary Energy from Hydro Power | 3,564 | 2,640 | 3,663 | MJ |
| | Primary Energy from Solar Energy | 4,797 | 4,124 | 6,683 | MJ |
| | Primary Energy from Wind Power | 2,012 | 1,672 | 2,356 | MJ |
| **Material Resources** | Limestone (Calcium Carbonate) | 220 | 143 | 195 | kg |
| | Sand | 184 | 91 | 123 | kg |
| | Water Use (Input) | 6,187,740 | 5,113,572 | 8,344,092 | kg |
| **Deposited Goods** | Overburden (Deposited) | 16,611 | 11,924 | 16,126 | kg |
| | Tailings (Deposited) | 74,305 | 43,097 | 58,497 | kg |
| **Emissions to Air** | $CO_2$ | 3,291 | 2,507 | 3,556 | kg |
| | $CH_4$ | 5 | 4 | 6 | kg |
| | $N_2O$ | 0.3 | 0.2 | 0.3 | kg |
| | $NO_x$ | 13 | 9 | 12 | kg |
| | $SO_2$ | 22 | 15 | 20 | kg |
| | NMVOC | 1 | 0.7 | 0.9 | kg |
| | CO | 6 | 4 | 5 | kg |
| | Dust (>PM10) | 0.3 | 0.3 | 0.3 | kg |
| | Dust (PM10) | 0.06 | 0.03 | 0.04 | kg |
| | Dust (PM2,5 - PM10) | 0.6 | 0.4 | 0.6 | kg |
| | Dust (PM2.5) | 1 | 0.8 | 1 | kg |
| | Arsenic | 0.03 | 0.03 | 0.03 | kg |
| | Copper | 0.01 | 0.04 | 3.5E-03 | kg |
| | Lead | 2.3E-03 | 1.7E-03 | 2.2E-03 | kg |
| | Zinc | 1.3E-03 | 1.9E-03 | 1.8E-03 | kg |
| **Emissions to Fresh Water** | Ammonium/ Ammonia ($NH_4$+/$NH_3$) | 0.08 | 0.06 | 0.07 | kg |
| | Nitrate ($NO_{3-}$) | 0.8 | 0.6 | 0.8 | kg |
| | Phosphate ($PO_4^{3-}$) | 0.02 | 0.01 | 0.02 | kg |
| | Biological Oxygen Demand | 0.3 | 0.2 | 0.2 | kg |
| | Chemical Oxygen Demand | 6 | 4 | 5 | kg |
| | Arsenic | 0.01 | 8.1E-04 | 1.1E-03 | kg |
| | Copper | 2.5E-03 | 7.7E-04 | 9.6E-04 | kg |
| | Lead | 1.1E-03 | 6.5E-04 | 9.1E-04 | kg |
| | Zinc | 8.7E-04 | 5.9E-04 | 7.4E-04 | kg |

**Table 10:** LCI results of 1 metric tonne of **COPPER ALLOY FRP** products – at a global level

| Type | Flow | Brass FRP | Lead-Free Brass FRP | Unit |
|---|---|---|---|---|
| Energy Resources (Gross Calorific Value) | Crude Oil (Resource) | 2,412 | 2,626 | MJ |
| | Hard Coal (Resource) | 11,589 | 10,921 | MJ |
| | Lignite (Resource) | 1,427 | 2,805 | MJ |
| | Natural Gas (Resource) | 18,851 | 17,586 | MJ |
| | Peat (Resource) | 51 | 39 | MJ |
| | Uranium (Resource) | 3,209 | 3,336 | MJ |
| | Primary Energy from Hydro Power | 3,335 | 2,814 | MJ |
| | Primary Energy from Solar Energy | 6,246 | 5,740 | MJ |
| | Primary Energy from Wind Power | 1,365 | 1,945 | MJ |
| Material Resources | Limestone (Calcium Carbonate) | 60 | 75 | kg |
| | Sand | 16 | 29 | kg |
| | Water Use (Input) | 8,545,708 | 7,484,437 | kg |
| Deposited Goods | Overburden (Deposited) | 12,949 | 13,181 | kg |
| | Tailings (Deposited) | 2,941 | 9,132 | kg |
| Emissions to Air | $CO_2$ | 2,653 | 2,600 | kg |
| | $CH_4$ | 5 | 4 | kg |
| | $N_2O$ | 0.1 | 0.1 | kg |
| | $NO_x$ | 8 | 8 | kg |
| | $SO_2$ | 2 | 4 | kg |
| | NMVOC | 0.2 | 0.2 | kg |
| | CO | 1 | 2 | kg |
| | Dust (>PM10) | 0.2 | 0.2 | kg |
| | Dust (PM10) | 0.5 | 0.4 | kg |
| | Dust (PM2,5 - PM10) | 0.3 | 0.3 | kg |
| | Dust (PM2.5) | 0.2 | 0.3 | kg |
| | Arsenic | 3E-03 | 6E-03 | kg |
| | Copper | 0.04 | 0.03 | kg |
| | Lead | 4E-02 | 0.03 | kg |
| | Zinc | 5.6E-02 | 0.04 | kg |
| Emissions to Fresh Water | Ammonium/ Ammonia ($NH_4$+/$NH_3$) | 0.02 | 0.03 | kg |
| | Nitrate ($NO_{3-}$) | 0.3 | 0.3 | kg |
| | Phosphate ($PO_4^{3-}$) | 0.01 | 0.01 | kg |
| | Biological Oxygen Demand | 0.02 | 0.06 | kg |
| | Chemical Oxygen Demand | 1 | 2 | kg |
| | Arsenic | 7E-03 | 5.2E-03 | kg |
| | Copper | 2.8E-03 | 2.2E-03 | kg |
| | Lead | 1.4E-03 | 1.2E-03 | kg |
| | Zinc | 7.2E-02 | 0.05 | kg |

**Table 11:** LCI results of 1 metric tonne of **COPPER ALLOY RBS** products – at a global level

| Type | Flow | Brass RBS | Lead-Free Brass RBS | Unit |
|---|---|---|---|---|
| Energy Resources (Gross Calorific Value) | Crude Oil (Resource) | 1,373 | 4,161 | MJ |
| | Hard Coal (Resource) | 3,509 | 7,869 | MJ |
| | Lignite (Resource) | 1,115 | 2,367 | MJ |
| | Natural Gas (Resource) | 7,157 | 10,856 | MJ |
| | Peat (Resource) | 18 | 29 | MJ |
| | Uranium (Resource) | 1,644 | 2,833 | MJ |
| | Primary Energy from Hydro Power | 1,361 | 2,611 | MJ |
| | Primary Energy from Solar Energy | 2,782 | 4,611 | MJ |
| | Primary Energy from Wind Power | 1,003 | 1,809 | MJ |
| Material Resources | Limestone (Calcium Carbonate) | 35 | 89 | kg |
| | Sand | 15 | 60 | kg |
| | Water use (Input) | 3,004,091 | 5,664,915 | kg |
| Deposited Goods | Overburden (Deposited) | 5,182 | 11,008 | kg |
| | Tailings (Deposited) | 5,253 | 19,605 | kg |
| Emissions to Air | $CO_2$ | 971 | 1,928 | kg |
| | $CH_4$ | 2 | 3 | kg |
| | $N_2O$ | 0.04 | 0.1 | kg |
| | $NO_x$ | 3 | 7 | kg |
| | $SO_2$ | 2 | 8 | kg |
| | NMVOC | 0.1 | 0.4 | kg |
| | CO | 0.8 | 2 | kg |
| | Dust (>PM10) | 0.1 | 0.2 | kg |
| | Dust (PM10) | 0.2 | 0.3 | kg |
| | Dust (PM2,5 - PM10) | 0.1 | 0.3 | kg |
| | Dust (PM2.5) | 0.1 | 0.4 | kg |
| | Arsenic | 3.5E-03 | 0.01 | kg |
| | Copper | 0.02 | 0.02 | kg |
| | Lead | 0.01 | 0.02 | kg |
| | Zinc | 0.03 | 0.03 | kg |
| Emissions to Fresh Water | Ammonium/ Ammonia ($NH_4$+/$NH_3$) | 0.01 | 0.03 | kg |
| | Nitrate ($NO_{3-}$) | 0.2 | 0.4 | kg |
| | Phosphate ($PO_4^{3-}$) | 5.4E-03 | 0.01 | kg |
| | Biological Oxygen Demand | 0.04 | 0.07 | kg |
| | Chemical Oxygen Demand | 0.9 | 2 | kg |
| | Arsenic | 2.4E-03 | 3.8E-03 | kg |
| | Copper | 1E-03 | 1.7E-03 | kg |
| | Lead | 6E-04 | 1E-03 | kg |
| | Zinc | 0.02 | 0.04 | kg |

**Figure 4:** Relative LCIA results of 1 t **GLOBAL WIRE ROD** according to EF 3.0 method

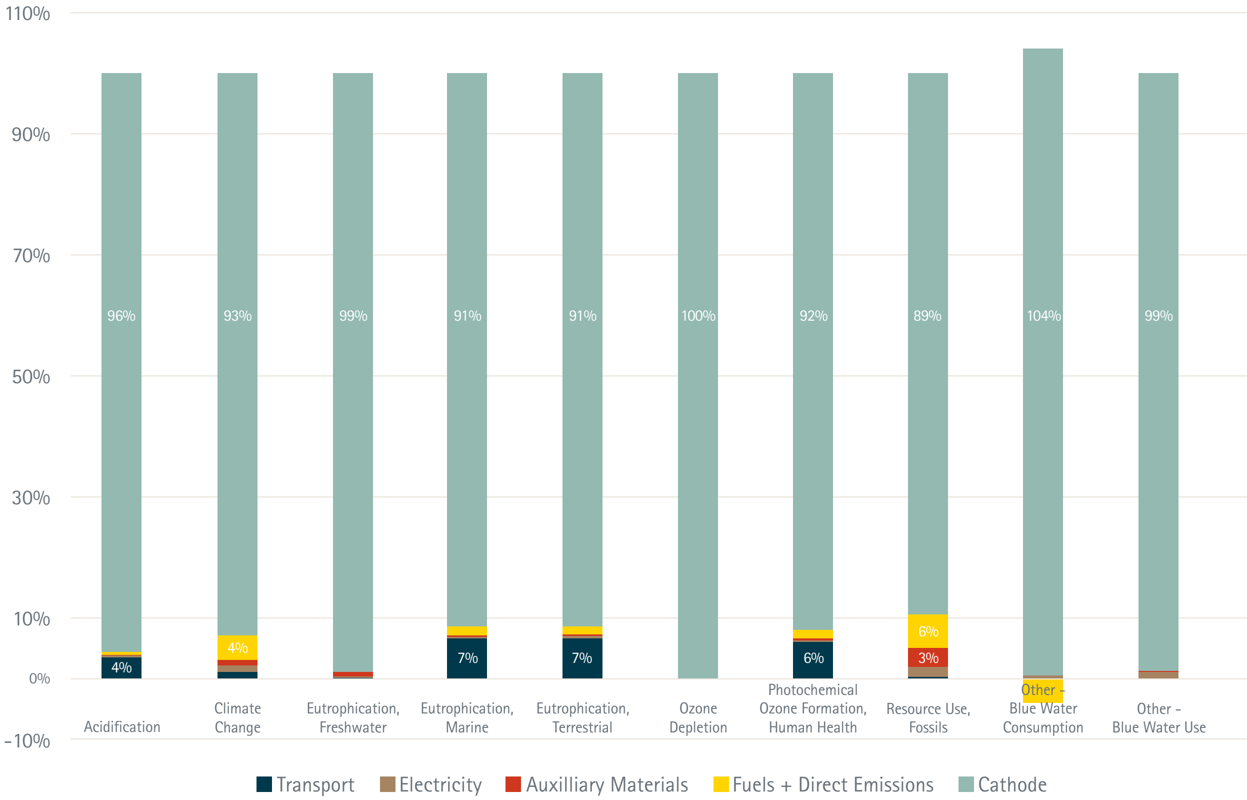



**Figure 5:** Relative LCIA results of 1 t **NORTH AMERICAN WIRE ROD** according to EF 3.0 method

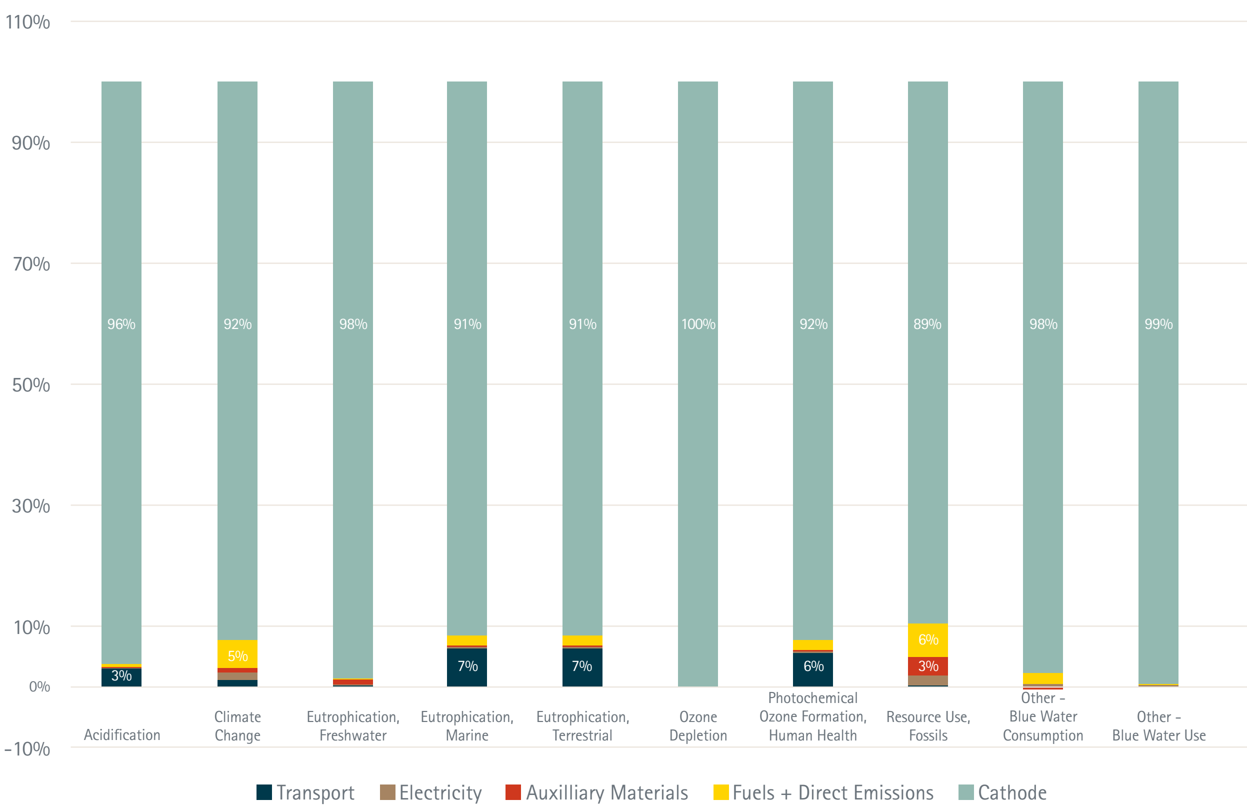


**Figure 6:** Relative LCIA results of 1 t **GLOBAL BRASS RBS** according to EF 3.0 method

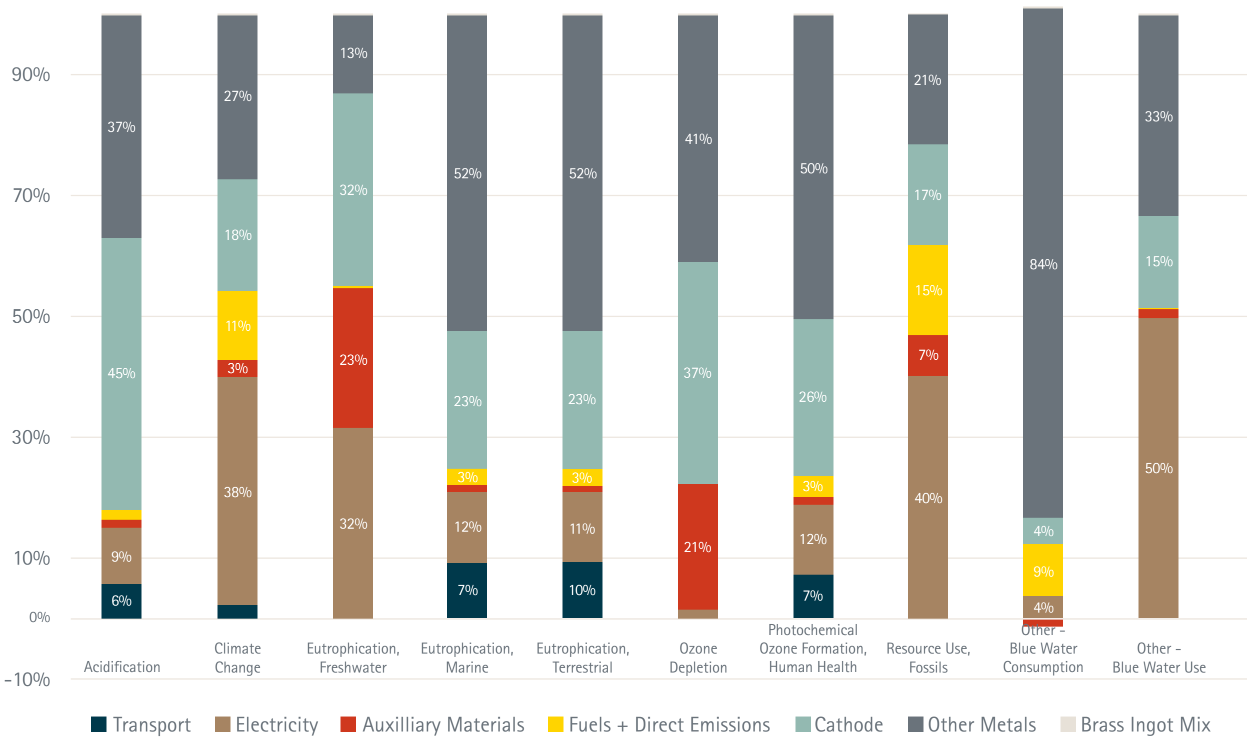



**Figure 7:** Relative LCIA results of 1 t **GLOBAL PB-FREE BRASS RBS** according to EF 3.0 method

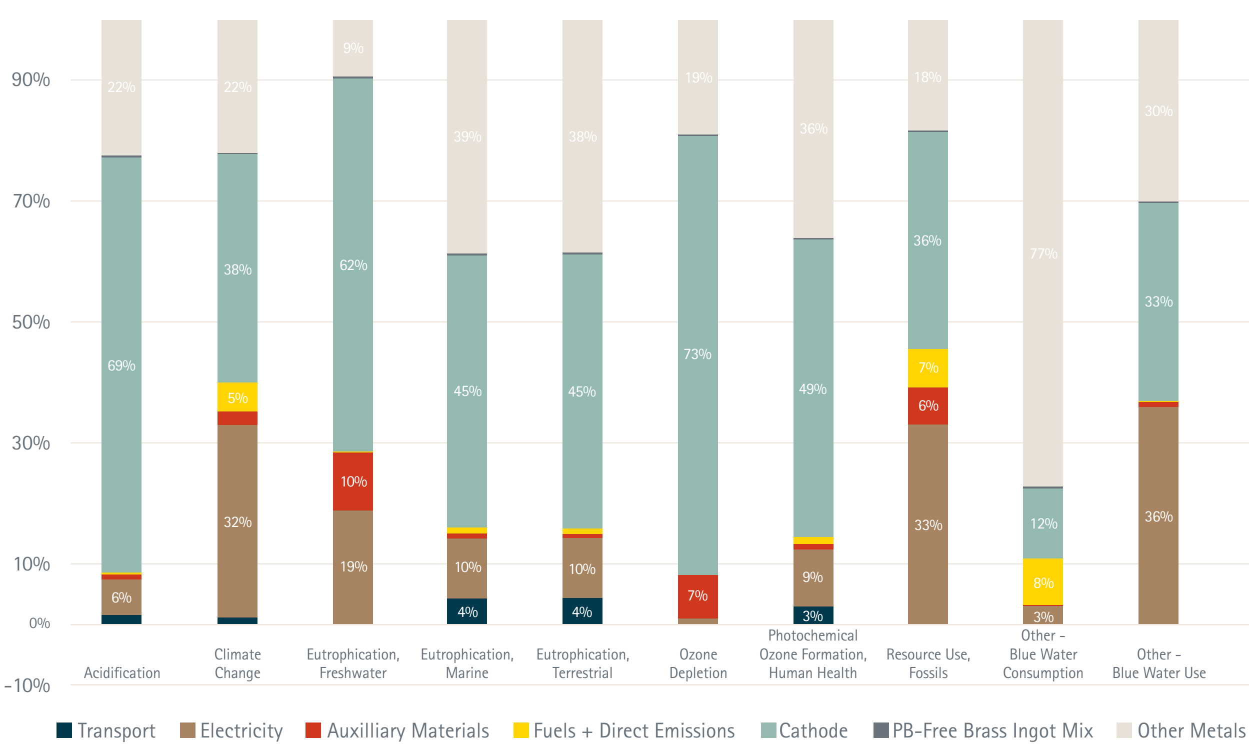


**Figure 8:** Relative LCIA results of 1 t **GLOBAL COPPER FRP** according to EF 3.0 method

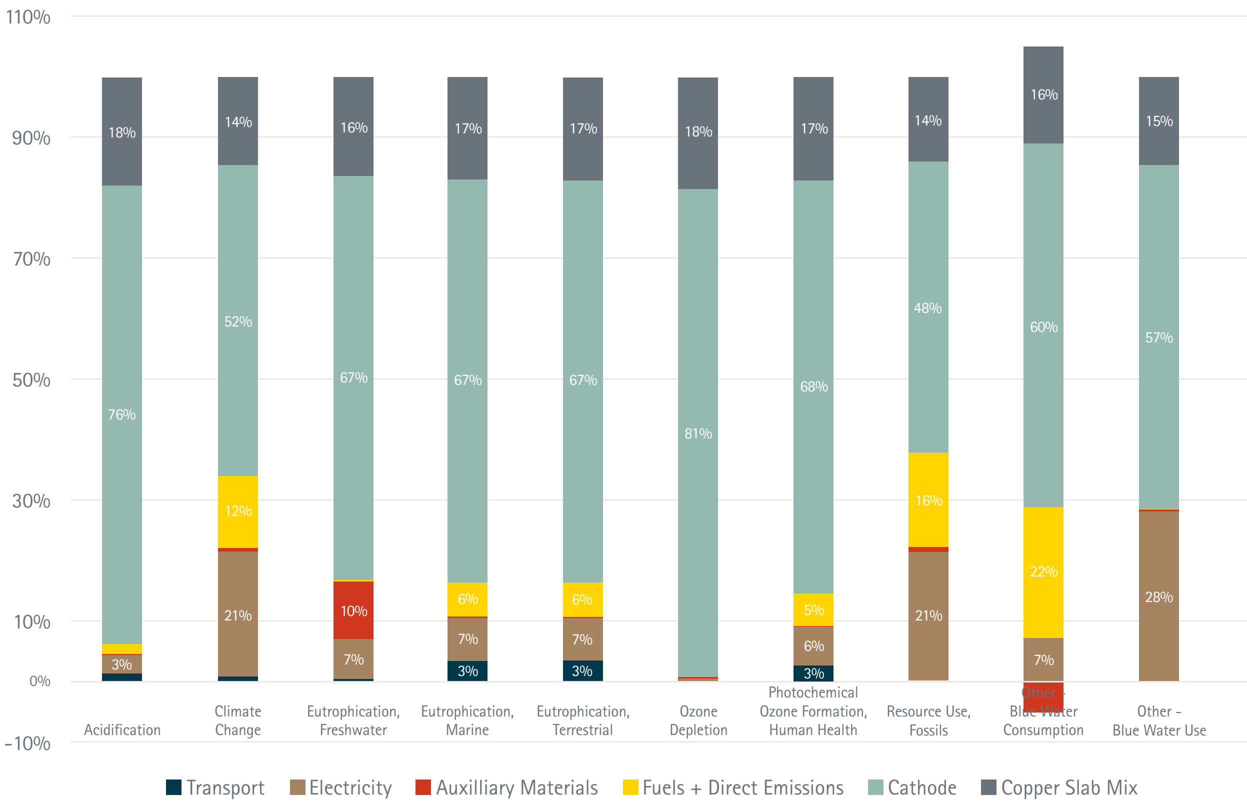



**Figure 9:** Relative LCIA results of 1 t **GLOBAL BRASS FRP** according to EF 3.0 method

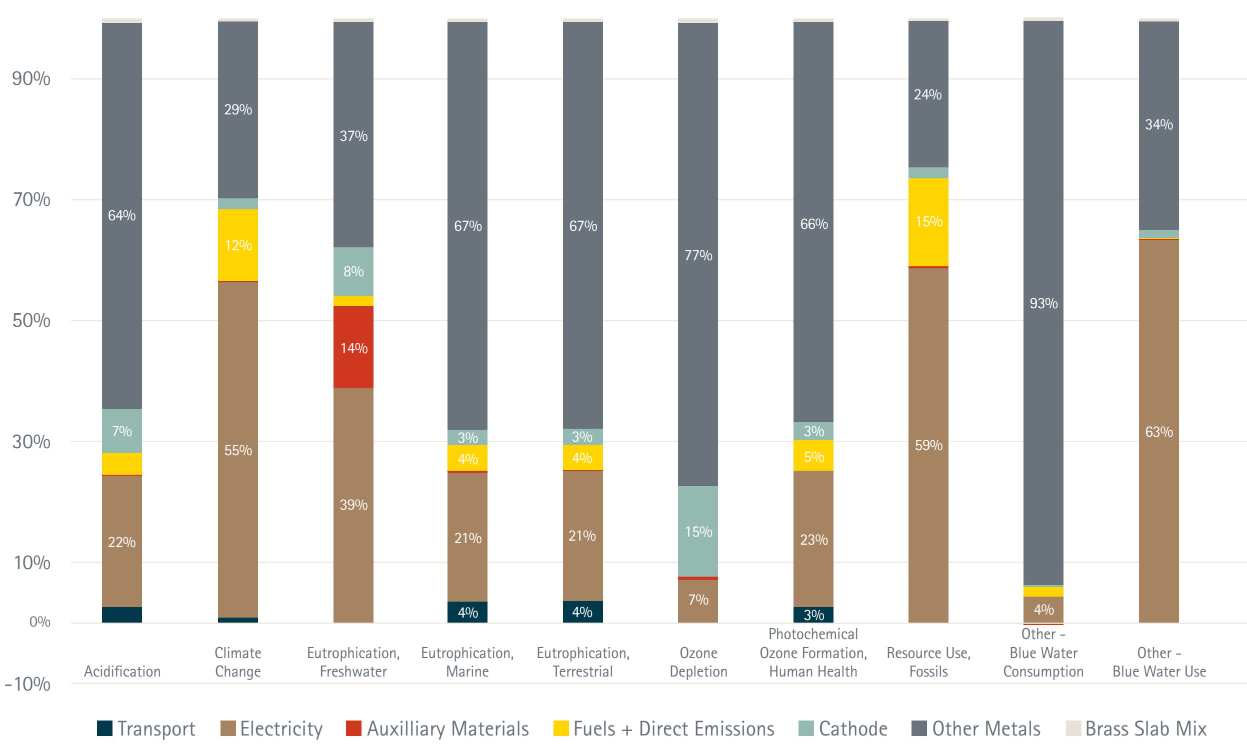


**Figure 10:** Relative LCIA results of 1 t **GLOBAL PB-FREE BRASS FRP** according to EF 3.0 method

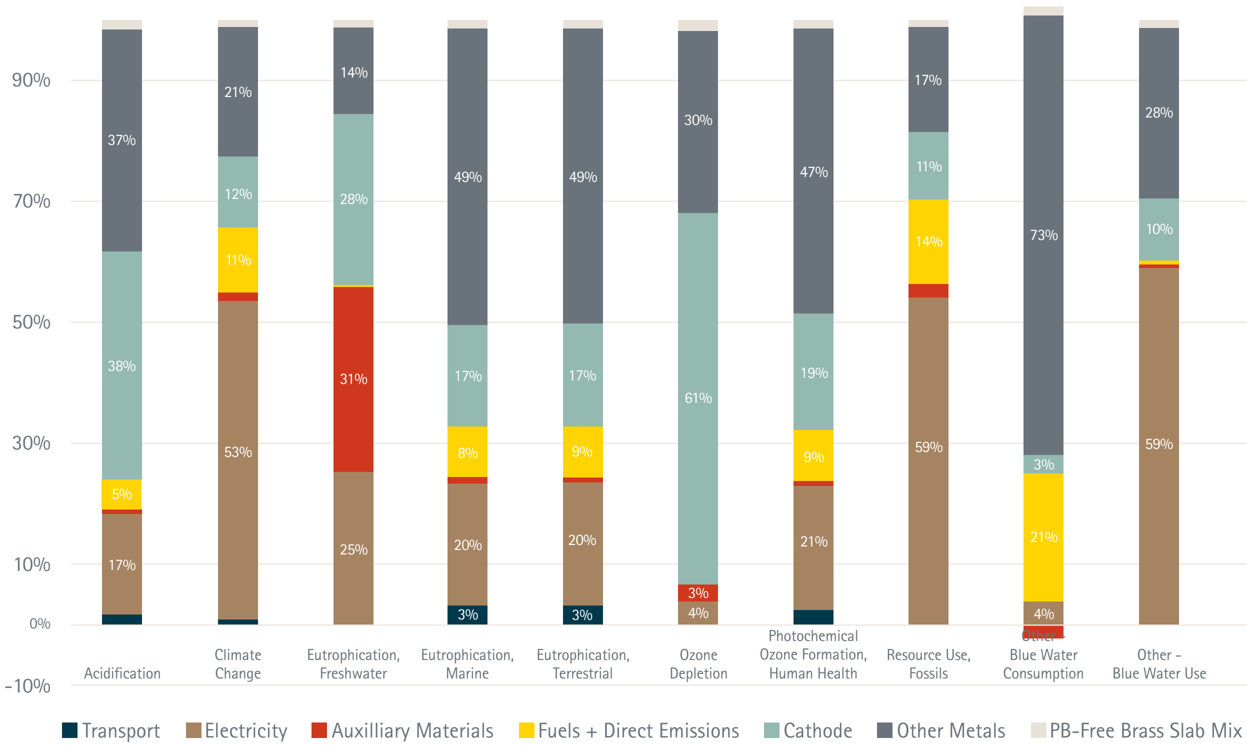



**Figure 11:** Relative LCIA results of 1 t **GLOBAL COPPER TUBE** according to EF 3.0 method

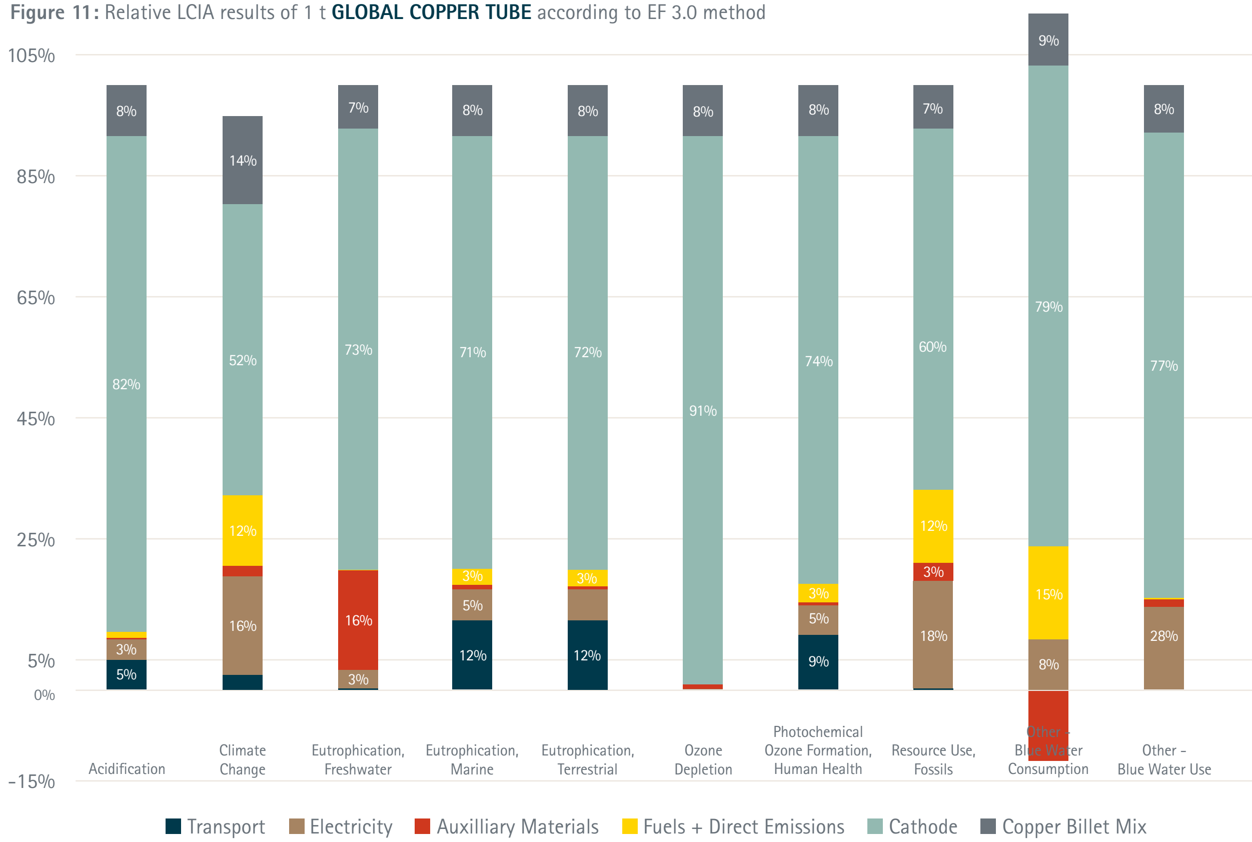


**Table 12:** Summary of results contributors in percentages – **COPPER WIRE** – at a global level

| | Main Contribution to Overall Results (Activity Data) | Main Input/Output to Overall Results (Emission/Flow) |
|---|---|---|
| **EF 3.0 – Acidification** | Copper cathode – 96% | Sulphur dioxide – 72%, Nitrogen oxides – 25% |
| **EF 3.0 – Climate Change** | Copper cathode – 93% | Carbon dioxide – 91%, Methane – 5% |
| **EF 3.0 – Eutrophication, Freshwater** | Copper cathode – 99% | Phosphorus – 72%, Phosphate – 28% |
| **EF 3.0 – Eutrophication, Marine** | Copper cathode – 91%, Transport – 7% | Nitrogen oxides – 90%, Nitrogen monoxide – 5%, Nitrate – 3%, Ammonium/ammonia – 1% |
| **EF 3.0 – Eutrophication, Terrestrial** | Copper cathode – 91%, Transport – 7% | Nitrogen oxides – 91%, Ammonia – 4% |
| **EF 3.0 – Ozone Depletion** | Copper cathode – 100% | R-114 (dichlorotetrafluoroethane) – 96% |
| **EF 3.0 – Photochemical Ozone Formation, Human Health** | Copper cathode – 92%, Transport – 6% | Nitrogen oxides – 78%, Sulphur dioxide – 10%, NMVOC – 6%, Nitrogen monoxide – 3% |
| **EF 3.0 – Resource Use, Fossils** | Copper cathode – 89%, Fuels & direct emissions – 6% | Natural gas – 32%, Hard coal – 31%, Crude oil – 24%, Lignite – 7%, Uranium – 6% |
| **Other – Blue Water Consumption** | Copper cathode – 104%, Fuels & direct emissions – -4% | River water |
| **Other – Blue Water Use** | Copper cathode – 99% | River water, Lake water |

**Table 13:** Summary of results contributors in percentages – **COPPER TUBE** – at a global level

| | Main Contribution to Overall Results (Activity Data) | Main Input/Output to Overall Results (Emission/Flow) |
|---|---|---|
| **EF 3.0 – Acidification** | Copper cathode – 82%, Copper billet – 8%, Transport – 5% | Sulphur dioxide – 73%, Nitrogen oxides – 24% |
| **EF 3.0 – Climate Change** | Copper cathode – 61%, Electricity – 16%, Fuels & direct emissions – 5% | Carbon dioxide – 91%, Methane – 5% |
| **EF 3.0 – Eutrophication, Freshwater** | Copper cathode – 73%, Auxiliary materials – 16%, Copper billet – 7% | Phosphorus – 70%, Phosphate – 30% |
| **EF 3.0 – Eutrophication, Marine** | Copper cathode – 71%, Transport – 12%, Copper billet – 8% | Nitrogen oxides – 86%, Nitrogen monoxide – 9% |
| **EF 3.0 – Eutrophication, Terrestrial** | Copper cathode – 72%, Transport – 12%, Copper billet – 8% | Nitrogen oxides – 87%, Nitrogen monoxide – 9% |
| **EF 3.0 – Ozone Depletion** | Copper cathode – 91%, Copper billet – 8% | R-114 (dichlorotetrafluoroethane) – 97% |
| **EF 3.0 – Photochemical Ozone Formation, Human Health** | Copper cathode – 74%, Transport – 9%, Copper billet – 8%, Electricity – 5% | Nitrogen oxides – 75%, Sulphur dioxide – 11%, NMVOC – 8%. Nitrogen monoxide – 5% |
| **EF 3.0 – Resource Use, Fossils** | Copper cathode – 60%, Electricity – 18%, Fuels & direct emissions – 12%, Copper billet – 7% | Natural gas – 40%, Hard coal – 25%, Crude oil – 22%, Uranium – 7%, Lignite – 6%, |
| **Other – Blue Water Consumption** | Copper cathode – 79%, Fuels & direct emissions – 15%, Copper billet – 9%, Electricity – 8%, Auxiliary materials – -12% | River water |
| **Other – Blue Water Use** | Copper cathode – 77%, Electricity – 14%, Copper billet – 8% | River water, Lake water |

**Table 14:** Summary of results contributors in percentages – **COPPER FRP** – at a global level

| | Main Contribution to Overall Results (Activity Data) | Main Input/Output to Overall Results (Emission/Flow) |
|---|---|---|
| **EF 3.0 – Acidification** | Copper cathode – 76%, Copper slab – 18% | Sulphur dioxide – 72%, Nitrogen oxides – 24% |
| **EF 3.0 – Climate Change** | Copper cathode – 52%, Electricity – 21%, Copper slab – 14%, Fuels & direct emissions – 12% | Carbon dioxide – 91%, Methane – 6% |
| **EF 3.0 – Eutrophication, Freshwater** | Copper cathode – 67%, Copper slab – 16%, Auxiliary materials – 10%, Electricity – 7% | Phosphorus – 66%, Phosphate – 34% |
| **EF 3.0 – Eutrophication, Marine** | Copper cathode – 67%, Copper slab – 17%, Electricity – 7%, Fuels & direct emissions – 6% | Nitrogen oxides – 89%, Nitrogen monoxide – 6% |
| **EF 3.0 – Eutrophication, Terrestrial** | Copper cathode – 67%, Copper slab – 17%, Electricity – 7%, Fuels & direct emissions – 6% | Nitrogen oxides – 90%, Nitrogen monoxide – 6% |
| **EF 3.0 – Ozone Depletion** | Copper cathode – 81% Copper slab – 18% | R-114 (dichlorotetrafluoroethane) – 97% |
| **EF 3.0 – Photochemical Ozone Formation, Human Health** | Copper cathode – 68%, Copper slab – 17%, Electricity – 6%, Fuels & direct emissions – 5% | Nitrogen oxides – 77%, Sulphur dioxide – 11%, NMVOC – 8% |
| **EF 3.0 – Resource Use, Fossils** | Copper cathode – 48%, Electricity – 21%, Fuels & direct emissions – 16%, Copper slab – 14% | Natural gas – 43%, Hard coal – 26%, Crude oil – 19%, Uranium – 7%, Lignite – 5% |
| **Other – Blue Water Consumption** | Copper cathode – 60%, Fuels & direct emissions – 22%, Copper slab – 16%, Electricity – 7% | River water, Lake water |
| **Other – Blue Water Use** | Copper cathode – 57%, Electricity – 28%, Copper slab – 15% | River water, Lake water |

**Table 15:** Summary of results contributors in percentages – **BRASS FRP** – at a global level

| | Main Contribution to Overall Results (Activity Data) | Main Input/Output to Overall Results (Emission/Flow) |
|---|---|---|
| **EF 3.0 – Acidification** | Other metals – 64%, Electricity – 22%, Copper cathode - 7% | Nitrogen oxides – 63%, Sulphur dioxide – 33% |
| **EF 3.0 – Climate Change** | Electricity – 55%, Other metals – 29%, Fuels & direct emissions – 12% | Carbon dioxide – 93%, Methane – 6% |
| **EF 3.0 – Eutrophication, Freshwater** | Electricity – 39%, Other metals – 37%, Auxiliary materials – 14%, Copper cathode – 8% | Phosphate – 52%, Phosphorus – 48%, |
| **EF 3.0 – Eutrophication, Marine** | Other metals – 67%, Electricity – 21% | Nitrogen oxides – 92%, Nitrogen monoxide – 4% |
| **EF 3.0 – Eutrophication, Terrestrial** | Other metals – 67%, Electricity – 21% | Nitrogen oxides – 94%, Nitrogen monoxide – 4% |
| **EF 3.0 – Ozone Depletion** | Other metals – 77%, Copper cathode – 15%, Electricity – 7% | Chloromethane (methyl chloride) – 74%, R-114 (dichlorotetrafluoroethane) – 26%, |
| **EF 3.0 – Photochemical Ozone Formation, Human Health** | Other metals – 66%, Electricity – 23%, Auxiliary materials – 5% | Nitrogen oxides – 90%, NMVOC – 4%, Sulphur dioxide – 2% |
| **EF 3.0 – Resource Use, Fossils** | Electricity – 59%, Other metals – 24%, Fuels & direct emissions – 15% | Natural gas – 48%, Hard coal – 32%, Uranium – 9%, Crude oil – 6%, Lignite – 4% |
| **Other – Blue Water Consumption** | Other metals – 93%, Electricity – 4% | River water |
| **Other – Blue Water Use** | Electricity – 63%, Other metals – 34% | River water, Lake water |

**Table 16:** Summary of results contributors in percentages – **LEAD-FREE BRASS FRP** – at a global level

| | Main Contribution to Overall Results (Activity Data) | Main Input/Output to Overall Results (Emission/Flow) |
|---|---|---|
| **EF 3.0 – Acidification** | Copper cathode – 38%, Other metals – 37%, Electricity – 17%, Fuels & direct emissions – 5% | Nitrogen oxides – 49%, Sulphur dioxide – 47% |
| **EF 3.0 – Climate Change** | Electricity – 53%, Other metals – 21%, Copper cathode – 12%, Fuels & direct emissions – 11% | Carbon dioxide – 93%, Methane – 6% |
| **EF 3.0 – Eutrophication, Freshwater** | Auxiliary materials – 31%, Copper cathode – 28%, Electricity – 25%, Other metals – 14% | Phosphorus – 62%, Phosphate – 38% |
| **EF 3.0 – Eutrophication, Marine** | Other metals – 49%, Electricity – 20%, Copper cathode – 17%, Fuels & direct emissions – 8% | Nitrogen oxides – 92%, Nitrogen monoxide – 4%, Nitrate – 2% |
| **EF 3.0 – Eutrophication, Terrestrial** | Other metals – 49%, Electricity – 20%, Copper cathode – 17%, Fuels & direct emissions – 9% | Nitrogen oxides – 92%, Nitrogen monoxide – 4% |
| **EF 3.0 – Ozone Depletion** | Copper cathode – 61%, Other metals – 30% | R-114 (dichlorotetrafluoroethane) – 61%, Chloromethane (methyl chloride) – 38% |
| **EF 3.0 – Photochemical Ozone Formation, Human Health** | Other metals – 47%, Electricity – 21%, Copper cathode – 19%, Fuels & Direct Emissions – 9% | Nitrogen oxides – 88%, Sulphur dioxide – 4%, NMVOC – 3%, Nitrogen monoxide – 2% |
| **EF 3.0 – Resource Use, Fossils** | Electricity – 54%, Other metals – 17%, Fuels & direct emissions – 14%, Copper cathode – 11% | Natural gas – 46%, Hard coal – 30%, Uranium – 10%, Crude oil – 7%, Lignite – 7% |
| **Other – Blue Water Consumption** | Other metals – 73%, Fuels & Direct Emissions – 21%, Electricity – 4% | River water |
| **Other – Blue Water Use** | Electricity – 59%, Other metals – 28%, Copper cathode – 10% | River water, Lake water |

**Table 17:** Summary of results contributors in percentages – **BRASS RBS** – at a global level

| | Main Contribution to Overall Results (Activity Data) | Main Input/Output to Overall Results (Emission/Flow) |
|---|---|---|
| **EF 3.0 – Acidification** | Copper cathode – 45%, Other metals – 37%, Electricity – 9% | Sulphur dioxide – 53%, Nitrogen oxides – 41%, Nitrogen monoxide – 4% |
| **EF 3.0 – Climate Change** | Electricity – 38%, Other metals – 27%, Copper cathode – 18%, Fuels & direct emissions – 11% | Carbon dioxide – 92%, Methane – 6% |
| **EF 3.0 – Eutrophication, Freshwater** | Electricity – 32%, Copper cathode – 32%, Auxiliary materials – 23%, Other metals – 13% | Phosphate – 56%, Phosphorus – 44% |
| **EF 3.0 – Eutrophication, Marine** | Other metals – 52%, Copper cathode – 23%, Electricity – 12%, Transport – 9% | Nitrogen oxides – 88%, Nitrogen monoxide – 8%, Nitrate – 3% |
| **EF 3.0 – Eutrophication, Terrestrial** | Other metals – 52%, Copper cathode – 23%, Electricity – 11%, Transport – 10% | Nitrogen oxides – 89%, Nitrogen monoxide – 8%, Ammonia – 3% |
| **EF 3.0 – Ozone Depletion** | Other metals – 41%, Copper cathode – 37%, Auxiliary materials – 21% | R-114 (dichlorotetrafluoroethane) – 63%, Chloromethane (methyl chloride) – 17%, R-22 (chlorodifluoromethane) – 16%, Halon (1301) – 4% |
| **EF 3.0 – Photochemical Ozone Formation, Human Health** | Other metals – 50%, Copper cathode – 26%, Electricity – 12%, Transport -7% | Nitrogen oxides – 84%, Sulphur dioxide – 5%, Nitrogen monoxide – 5%, NMVOC – 4% |
| **EF 3.0 – Resource Use, Fossils** | Electricity – 40%, Other metals – 21%, Copper cathode – 17%, Fuels & direct emissions – 15% | Natural gas – 47%, Hard coal – 24%, Uranium – 12%, Crude oil – 9%, Lignite – 7% |
| **Other – Blue Water Consumption** | Other metals – 84%, Fuels & direct emissions – 9%, Copper cathode – 4%, Electricity – 4% | River water |
| **Other – Blue Water Use** | Electricity – 50%, Other metals – 33%, Copper cathode – 15% | River water, Lake water |

**Table 18:** Summary of results contributors in percentages – **LEAD-FREE BRASS RBS** – at a global level

| | Main Contribution to Overall Results (Activity Data) | Main Input/Output to Overall Results (Emission/Flow) |
|---|---|---|
| **EF 3.0 – Acidification** | Copper cathode – 69%, Other metals – 22%, Electricity – 6% | Sulphur dioxide – 64%, Nitrogen oxides – 32% |
| **EF 3.0 – Climate Change** | Copper cathode – 38%, Electricity – 32%, Other metals – 22%, Fuels & Direct Emissions – 5% | Carbon dioxide – 92%, Methane – 6% |
| **EF 3.0 – Eutrophication, Freshwater** | Copper cathode – 62%, Electricity – 19%, Auxiliary materials – 10%, Other metals – 9%, | Phosphorus – 59%, Phosphate – 41% |
| **EF 3.0 – Eutrophication, Marine** | Copper cathode – 45%, Other metals – 39%, Electricity – 10%, Transport – 4% | Nitrogen oxides – 89%, Nitrogen monoxide – 6%, Nitrate – 3% |
| **EF 3.0 – Eutrophication, Terrestrial** | Copper cathode – 45%, Other metals – 38%, Electricity – 10%, Transport – 4% | Nitrogen oxides – 90%, Nitrogen monoxide – 6%, Ammonia – 3% |
| **EF 3.0 – Ozone Depletion** | Copper cathode – 73%, Other metals – 19%, Auxiliary materials – 7% | R-114 (dichlorotetrafluoroethane) – 80%, Chloromethane (methyl chloride) – 12%, R-22 (chlorodifluoromethane) – 6% |
| **EF 3.0 – Photochemical Ozone Formation, Human Health** | Copper cathode – 49%, Other metals – 36%, Electricity – 9%, Transport – 3% | Nitrogen oxides – 81%, Sulphur dioxide – 7%, Nitrogen monoxide – 4%, NMVOC – 4% |
| **EF 3.0 – Resource Use, Fossils** | Copper cathode – 36%, Electricity – 33%, Other metals – 18%, Fuels & direct emissions – 7%, Auxiliary materials – 6% | Natural gas – 37%, Hard coal – 29%, Crude oil – 15%, Uranium – 11%, Lignite – 8% |
| **Other – Blue Water Consumption** | Other metals – 77%, Copper cathode – 12%, Fuels & direct emissions – 8%, Electricity – 3% | River water |
| **Other – Blue Water Use** | Electricity – 36%, Copper cathode – 33%, Other metals – 30% | River water, Lake water |

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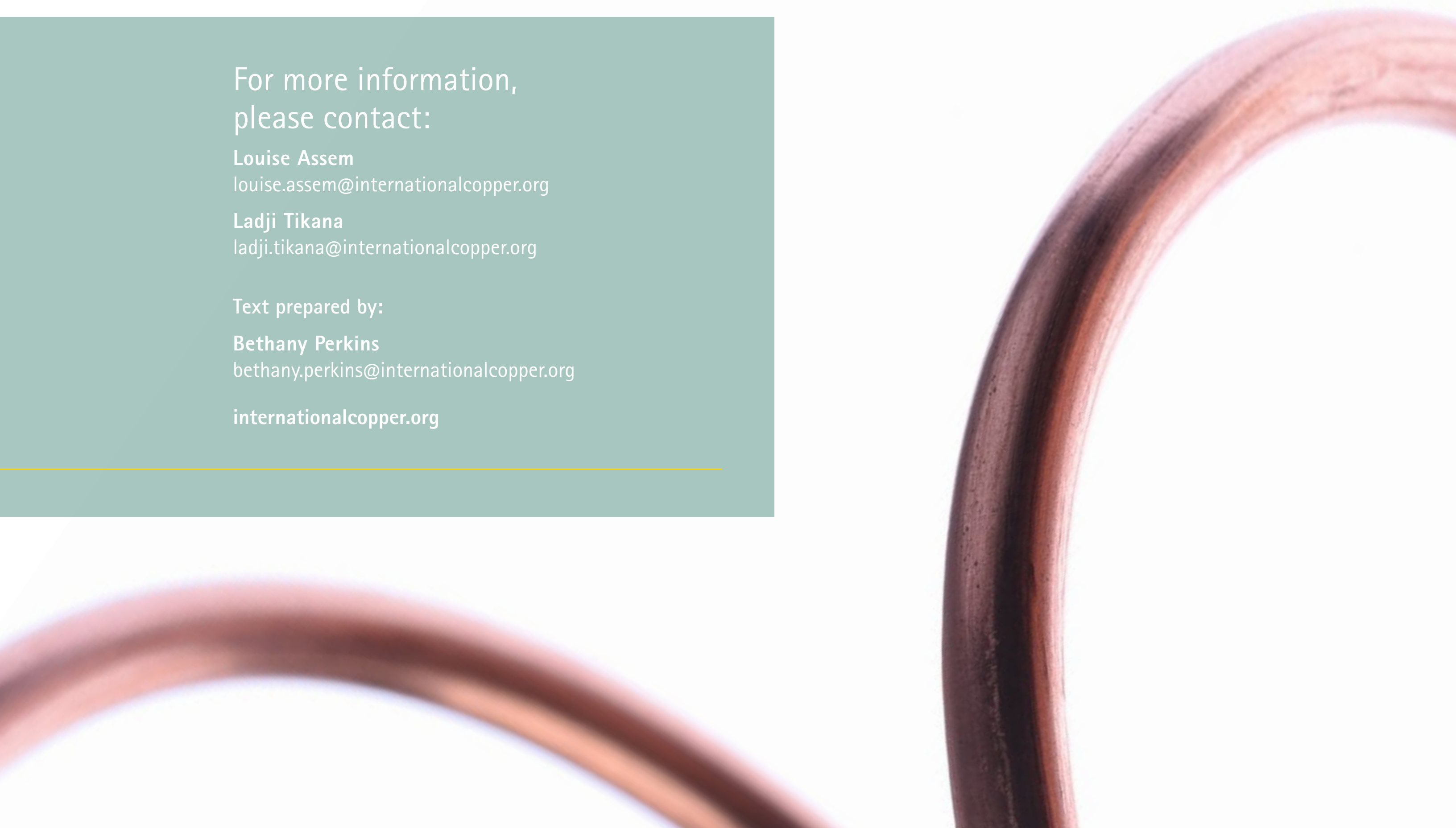

## For more information, please contact:


**Louise Assem**
louise.assem@internationalcopper.org

**Ladji Tikana**
ladji.tikana@internationalcopper.org

Text prepared by:

**Bethany Perkins**
bethany.perkins@internationalcopper.org


**internationalcopper.org**