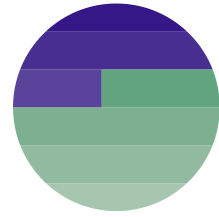




Copper Development  
Association Inc.  
Copper Alliance



thinkstep



# Life Cycle Assessment Copper Tube and Sheet

On behalf of the Copper Development Association



**Client:** Copper Development Association  
**Title:** Life Cycle Assessment of Copper Tube and Sheet  
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**On behalf of thinkstep AG and its subsidiaries**

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## List of Acronyms

ADP	Abiotic Depletion Potential
AP	Acidification Potential
CDA	Copper Development Association
ELCD	European Life Cycle Database
EoL	End-of-Life
EP	Eutrophication Potential
GaBi	Ganzheitliche Bilanzierung (German for holistic balancing)
GHG	Greenhouse Gas
GWP	Global Warming Potential
ICA	International Copper Association
ILCD	International Cycle Data System
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NMVOC	Non-Methane Volatile Organic Compound
ODP	Ozone Depletion Potential
POCP	Photochemical Ozone Creation Potential
SFP	Smog Formation Potential
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
VOC	Volatile Organic Compound



# Glossary

## *Life cycle*

A view of a product system as “consecutive and interlinked stages ... from raw material acquisition or generation from natural resources to final disposal” (ISO 14040:2006, section 3.1). This includes all material and energy inputs as well as emissions to air, land and water.

## *Life Cycle Assessment (LCA)*

“Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle” (ISO 14040:2006, section 3.2)

## *Life Cycle Inventory (LCI)*

“Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle” (ISO 14040:2006, section 3.3)

## *Life Cycle Impact Assessment (LCIA)*

“Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product” (ISO 14040:2006, section 3.4)

## *Life cycle interpretation*

“Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations” (ISO 14040:2006, section 3.5)

## *Functional unit*

“Quantified performance of a product system for use as a reference unit” (ISO 14040:2006, section 3.20)

## *Allocation*

“Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems” (ISO 14040:2006, section 3.17)

## *Closed-loop and open-loop allocation of recycled material*

“An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties.”

“A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials.”

(ISO 14044:2006, section 4.3.4.3.3)





### *Foreground system*

“Those processes of the system that are specific to it ... and/or directly affected by decisions analyzed in the study.” (JRC 2010, p. 97) This typically includes first-tier suppliers, the manufacturer itself and any downstream life cycle stages where the manufacturer can exert significant influence. As a general rule, specific (primary) data should be used for the foreground system.

### *Background system*

“Those processes, where due to the averaging effect across the suppliers, a homogenous market with average (or equivalent, generic data) can be assumed to appropriately represent the respective process ... and/or those processes that are operated as part of the system but that are not under direct control or decisive influence of the producer of the good...” (JRC 2010, pp. 97-98). As a general rule, secondary data are appropriate for the background system, particularly where primary data are difficult to collect.

### *Critical Review*

“Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment” (ISO 14044:2006, section 3.45)



# 1. Goal of the Study

As an association of copper producers and manufacturers committed to promoting the sustainable use of copper materials, the Copper Development Association (CDA) is interested in developing a life cycle assessment for copper tubes and sheets with a focus on communicating to North American markets. Consequently, CDA commissioned thinkstep to evaluate the environmental profile of two product types in accordance with ISO 14040/44 and ISO 21930 (ISO, 2006; ISO, 2006; ISO, 2017).

The primary goal of this study is to assess the potential environmental impacts of two products as averages from several manufacturers' plants. It was not possible to obtain more recent primary data from manufacturers than 2007, and participating companies may not represent a majority of North American production, nor CDA's membership. As such, the analyses only provide a benchmark for results and do not represent an industry average. Additionally, due to the age of the primary data, this study will not be used to support the publication of an Environmental Product Declaration (EPD). Nevertheless, the Product Category Rules (PCR) for Part A: Life Cycle Assessment Calculation Rules and Report Requirements (UL Environment, 2018) and Part B: Building Metals (UL Environment, 2014) were consulted while defining the goal and scope of the study. The analyses were carried out using a "cradle-to-gate with options" system boundary.

The external audience for this study is the building and construction community as it will be used to meet the LEED v4.1 Building Product Disclosure and Optimization - Environmental Product Declarations credit, option 1. The intended internal audience for this report includes CDA internal stakeholders involved in marketing and communications, in operations, and in design. We further strongly recommend making this report available upon request to all third parties to whom LCA results are communicated, regardless of the form of communication.

This study does not intend to support comparative assertions to be disclosed to the public. However, the results will be disclosed to the public, which the building community may use to compare CDA's products with similar products internally.



## 2. Scope of the Study

The following sections describe the general scope of the project to achieve the stated goals. This includes, but is not limited to, the identification of specific product systems to be assessed, the product function(s), functional unit and reference flows, the system boundary, allocation procedures, and cut-off criteria of the study.

### 2.1. Product System(s)

---

The study evaluates the potential environmental impacts of two product types:

- **Copper tubes, consisting of copper alloy UNS C12200 or C12000**, according to ASTM B88. All alloys are 99.9% copper, with phosphorus being the only alloying addition, up to a maximum of 0.04%.
- **Copper sheets, consisting of a minimum of 99.5% copper**, according to ASTM B370.

The reported results represent average production scenarios across three participating companies for each product.

### 2.2. Declared Unit

---

Specific functions for each product category were not defined and are not necessary under the “cradle-to-gate with options” system boundary (ISO, 2017). Products were therefore evaluated on a per-unit basis.

Declared units for each product type are as follows:

- 1 kg of copper sheets [UNSPSC: 30262300]
- 1 kg of copper tubes [UNSPSC: 40182000, 40182500]

The following Construction Specifications Institute MasterFormat® designations may apply, depending on product use, for sheet:

- 07 31 16 Metal Shingles
- 07 41 13 Metal Roof Panels
- 07 42 13 Metal Wall Panels
- 07 46 00 Siding
- 07 61 00 Sheet Metal Roofing
- 07 61 13 Standing Seam Sheet Metal Roofing
- 07 61 16 Batten Seam Sheet Metal Roofing
- 07 61 19 Flat Seam Sheet Metal Roofing
- 07 62 00 Sheet Metal Flashing and Trim
- 07 62 20 Sheet Metal Gutters and Downspouts
- 07 63 00 Sheet Metal Roofing Specialties
- 07 64 00 Sheet Metal Wall Cladding
- 07 64 13 Standing Seam Sheet Metal Wall Cladding
- 07 64 16 Batten Seam Sheet Metal Wall Cladding
- 07 64 19 Flat Seam Sheet Metal Wall Cladding
- 07 70 00 Roof and Wall Specialties and Accessories
- 07 71 23 Manufactured Gutters and Downspouts
- 07 95 13 Expansion Joint Cover Assemblies



The following Construction Specifications Institute MasterFormat® designations may apply, depending on product use, for tube:

- 21 13 13 Wet-Pipe Sprinkler Systems
- 21 13 16 Dry-Pipe Sprinkler Systems
- 21 13 19 Preaction Sprinkler Systems
- 21 13 23 Combined Dry-Pipe and Preaction Sprinkler Systems
- 21 13 26 Deluge Fire-Suppression Sprinkler Systems
- 21 13 29 Water Spray Fixed Systems
- 21 13 36 Antifreeze Sprinkler Systems
- 22 11 13 Facility Water Distribution Piping
- 22 11 16 Domestic Water Piping
- 22 11 19 Domestic Water Piping Specialties
- 22 13 16 Sanitary Waste and Vent Piping
- 22 13 19 Sanitary Waste Piping Specialties
- 22 14 13 Facility Storm Drainage Piping
- 22 14 16 Rainwater Leaders
- 22 51 13 Swimming Pool Piping
- 22 52 13 Fountain Piping
- 22 67 13 Processed Water Piping for Laboratory and Healthcare Facilities
- 23 11 13 Facility Fuel-Oil Piping
- 23 11 23 Facility Natural-Gas Piping
- 23 11 26 Facility Liquefied-Petroleum Gas Piping
- 23 21 13 Hydronic Piping
- 23 22 13 Steam and Condensate Heating Piping
- 33 05 17 Copper Utility Pipe and Tubing
- 33 14 13 Public Water Utility Distribution Piping
- 33 14 16 Site Water Utility Distribution Piping
- 33 14 17 Site Water Utility Service Laterals
- 40 05 17 Copper Process Pipe and Tubing

### 2.3. System Boundaries

The manufacturing stage includes raw material supply, inbound transport of materials to the manufacturer, and manufacturing. Additionally, manufacturing waste processing and final disposal are also evaluated. Benefits and loads beyond the system boundary (Module D) are also included in the analysis. Distribution to the customer, use, and demolition are not included inside system boundaries. Modules A1-A3 includes cradle-to-gate information for copper tube and sheet production, beginning at the copper mine through production of the semi-fabricated products. A more detailed list of the system boundaries is summarized in Table 2-1.

PRODUCTION STAGE			CONSTRUCTION STAGE		USE STAGE							END OF LIFE STAGE				OPTIONAL SUPPLEMENTARY INFORMATION BEYOND THE SYSTEM BOUNDARY (POTENTIAL NET BENEFITS)	
Extraction and upstream production	Transport to factory	Manufacturing	Transport to site	Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport to waste process or disposal	Waste processing	Disposal	Potential net benefits from reuse, recycling and/or energy recovery beyond the system boundary	
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	
X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	X	X

Figure 2-1: Life cycle modules according to ISO 21930



Letter-number combinations in the table represent building assessment module designations as defined by ISO 21930 (Figure 2-1). Raw material production and energy generation are included for each stage inside system boundaries. Product use is excluded from the analysis, as is construction and maintenance of capital equipment, human labor, and employee commute. Manufacturing facility overhead, however, is included since overhead energy consumption could not be separated from manufacturing energy consumption.

**Table 2-1: System boundaries**

Included	Excluded
✓ A1: Raw material supply	✗ A4: Transport to building site; transport of construction waste; offsite storage
✓ A2: Transport to manufacturer	✗ A5: Construction-installation process
✓ A3: Manufacturing	✗ B1-B7: Use stage
✓ C4: Disposal	✗ C1: Demolition
✓ D: Recycling potential	✗ C2: Transport of discarded product
	✗ C3: Waste processing
	✗ Construction and maintenance of capital equipment
	✗ Maintenance and operation of support equipment
	✗ Human labor and employee commute

Reference service life is not declared, as per the guiding PCR document.

### 2.3.1. Time Coverage

This study is intended to represent production in 2016.

### 2.3.2. Technology Coverage

This study is intended to represent typical copper tube and sheet production in North America.

### 2.3.3. Geographical Coverage

This study is intended to represent production and use in North America.

## 2.4. Allocation

### 2.4.1. Multi-output Allocation

No multi-output allocation had to be applied in the foreground systems (i.e., tube and sheet fabrication processes). Manufacturing data collected and modeled represents facilities dedicated to producing the products under study. Co-product allocation for any background systems (e.g., copper cathode production) can be found in separate documentation for those datasets.

Allocation of background data (energy and materials) taken from the GaBi 2019 databases is documented online at <http://www.gabi-software.com/support/gabi/gabi-database-2019-lci-documentation/>.



## 2.4.2. End-of-Life Allocation

End-of-Life allocation generally follows the requirements of ISO 14044, section 4.3.4.3. Open scrap inputs from the production stage are subtracted from scrap to be recycled at end of life to give the net scrap output from the product life cycle, which is then submitted to recycling. The original burden of the primary material input is allocated between the current and subsequent life cycle using the mass of recovered secondary material to scale the substituted primary material, i.e., applying a credit for the substitution of primary material so as to distribute burdens appropriately among the different product life cycles. These subsequent process steps are modeled using industry average inventories.

## 2.5. Cut-off Criteria

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No cut-off criteria are defined for this study. As summarized in section 2.3, the system boundary was defined based on relevance to the goal of the study. For the processes within the system boundary, all available energy and material flow data have been included in the model. In cases where no matching life cycle inventories are available to represent a flow, proxy data have been applied based on conservative assumptions regarding environmental impacts.

The choice of proxy data is documented in Section 3. The influence of these proxy data on the results of the assessment has been analyzed and is discussed in Section 5.

## 2.6. Selection of LCIA Methodology and Impact Categories

---

The inventory metrics and life cycle impact assessment categories to be assessed are governed by the PCR. These categories include:

- Life cycle impact assessment
  - Global Warming Potential (GWP100)<sup>1</sup>
  - Ozone Depletion Potential (ODP)
  - Acidification Potential (AP)
  - Eutrophication Potential (EP)
  - Tropospheric Ozone (Smog) Formation Potential (SFP)
  - Resource Depletion Potential, Fossil Fuels (RDP, fossil)
- Resource use
  - Renewable primary energy used as energy carrier (fuel) (RPR<sub>E</sub>)
  - Renewable primary resources with energy content used as material (RPR<sub>M</sub>)
  - Non-renewable primary resources used as an energy carrier (fuel) (NRPR<sub>E</sub>)
  - Non-renewable primary resources with energy content used as material (NRPR<sub>M</sub>)
  - Secondary material (SM)
  - Renewable secondary fuels (RSF)
  - Non-renewable secondary fuels (NRSF)
  - Recovered energy (RE)
  - Use of net fresh water resources (FW)

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<sup>1</sup> Note that biogenic carbon emissions are not relevant for this product and are therefore not reported.



- Other environmental information
  - Hazardous waste disposed (HWD)
  - Non-hazardous waste disposed (NHWD)
  - High-level radioactive waste, conditioned, to final repository (HLRW)
  - Intermediate- and low-level radioactive waste, conditioned, to final repository (ILLRW)
- Output materials
  - Components for reuse (CRU)
  - Materials for recycling (MR)
  - Materials for energy recovery (MER)
- Exported energy (EE)

As the region under study is North America, environmental performance is assessed using the TRACI 2.1 (Bare, 2012) impact assessment methodology, with the exception of GWP which uses the latest IPCC values (IPCC, 2013).

It shall be noted that the impact categories represent impact *potentials*, i.e., they are approximations of environmental impacts that could occur if the emitted molecules would (a) follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach).

LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

## 2.7. Interpretation to Be Used

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No normalization, grouping, or further quantitative cross-category weighting is applied. Instead, each impact is discussed in isolation, without reference to other impact categories, before final conclusions and recommendations are made.

## 2.8. Data Quality Requirements

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The data used to create the inventory model shall be as precise, complete, consistent, and as representative as possible with regards to the goal and scope of the study under given time and budget constraints.

- Measured primary data are considered to be of the highest precision, followed by calculated data, literature data, and estimated data. The goal is to model all relevant foreground processes using measured or calculated primary data.
- Completeness is judged based on the completeness of the inputs and outputs per unit process and the completeness of the unit processes themselves. The goal is to capture all relevant data in this regard.
- Consistency refers to modeling choices and data sources. The goal is to ensure that differences in results reflect actual differences between product systems and are not due to inconsistencies in modeling choices, data sources, emission factors, or other artefacts.
- Reproducibility expresses the degree to which third parties would be able to reproduce the results of the study based on the information contained in this report. The goal is to provide enough transparency with this report so that third parties are able to approximate the reported results.



This ability may be limited by the exclusion of confidential primary data and access to the same background data sources.

- Representativeness expresses the degree to which the data matches the geographical, temporal, and technological requirements defined in the study's goal and scope. The goal is to use the most representative primary data for all foreground processes and the most representative industry-average data for all background processes. Whenever such data were not available (e.g., no industry-average data available for a certain country), best-available proxy data were employed.

An evaluation of the data quality with regard to these requirements is provided in section 5 of this report.

## 2.9. Type and format of the report

---

In accordance with the applicable ISO requirements (ISO, 2006) this document aims to report the results and conclusions of the LCA completely, accurately and without bias to the intended audience. The results, data, methods, assumptions and limitations are presented in a transparent manner and in sufficient detail to convey the complexities, limitations, and trade-offs inherent in the LCA to the reader. This allows the results to be interpreted and used in a manner consistent with the goals of the study.

## 2.10. Software and Database

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The LCA model was created using the GaBi ts Software system for life cycle engineering, developed by thinkstep AG. The GaBi 2019 LCI database provides the life cycle inventory data for several of the raw and process materials obtained from the background system.

## 2.11. Critical Review

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This study has been evaluated for conformance to ISO 21930 and the ISO 14040/14044 standards by Thomas Gloria, Ph.D., of Industrial Ecology Consultants (ISO, 2006; ISO, 2006). The review has been conducted in accordance with ISO/TS 14071 (ISO, 2014). The Critical Review Report containing the comments and recommendations of the independent expert(s) as well as the practitioner's responses is available upon request from the study commissioner in accordance with ISO/TS 14071.



## 3. Life Cycle Inventory Analysis

### 3.1. Data Collection Procedure

---

Data used for this project represents a mix of primary data collected from CDA members on the production of copper products (gate-to-gate) and background data from the GaBi 2019 databases. All appropriate means were employed to improve the data quality and representativeness as described below. Manufacturing facility data were collected in a consistent manner and level of detail to ensure high quality data. All submitted data were checked for completeness, plausibility using mass balance, and benchmarking. If gaps, outliers, or other inconsistencies occurred, thinkstep engaged with CDA members to resolve any open issues. thinkstep also utilized the US EPA's Toxics Release Inventory (TRI) to fill in any data gaps related to toxic emissions.

### 3.2. Product Systems

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#### 3.2.1. Overview of Product Systems

Figure 3-1 illustrates the life cycle of the copper product systems. Distribution, use, and demolition are not included within the system boundaries (see section 2.3). Modules A1-A3 represent the cradle-to-gate inventories for copper tube and sheet production, beginning at the mine through production of the semi-fabricated products.

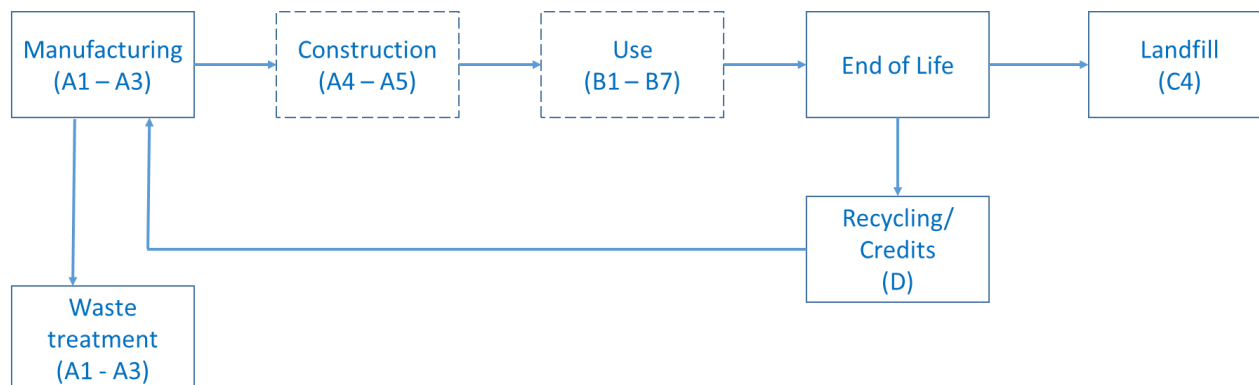


Figure 3-1: Life cycle overview of copper products

#### 3.2.2. Copper Sheet Manufacturing

The manufacturing process begins by heating and melting refined copper (cathode/ingot) and recovered copper scrap (industrial, post-industrial, and post-consumer) to molten form a specific chemical composition. The molten copper is then poured into molds and allowed to solidify to create copper slabs (cake/ingot). The slabs are then heated in a furnace to a hot-roll temperature of approximately 1,650 °F (899 °C) and then rolled down in several passes, wherein the thickness is reduced by decreasing the gap between the opposing rollers. The thermal oxidation due to the high temperatures in heating and hot-



rolling causes a scale to form on the surface of the copper, which is removed by milling before the metal is subjected to any other surface treatment, further cold-rolling, or cold-rolling and annealing to reach final dimensional, physical, and mechanical properties. The removed scale is recovered, if possible, and sent to a specialty recycler. A small portion may ultimately be disposed of in an inert landfill. In this process, several tenths of a millimeter are removed from each side. From this point, the copper sheets of intermediate thickness are further processed by annealing and cold rolling to reach final dimensional, physical, and mechanical properties. Annealing is an intermediate heat treatment in which the copper sheets/strip 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. This process is carried out in a protected atmosphere (nitrogen gas) to prevent a renewed thermal oxidation of the surface. The annealed sheets/strip are then cold rolled to reduce the material to its final thickness. In Annex B (Confidential, removed) Table B-1 presents all inputs and outputs associated with sheet production.

### **3.2.3. Copper Tube Manufacturing**

In the first step of copper tube production, refined copper (cathode/ingot) and recovered copper scrap (industrial, post-industrial, and post-consumer) are heated and melted to molten form at approximately 2050 °F (1120 °C) and phosphorus is added to reach a specific chemical composition. The molten copper is poured (cast) into water-cooled molds and allowed to solidify into a shape for further hot working into a tube shell. The material accumulated by removal during the tube shell preparation is looped back for remelting. The tube shell thereafter undergoes cold-drawing processes to reduce wall thickness and diameter to the required dimensions and specifications. The die size determines the tube outer diameter while the size of the mandrel/plug determines the inner diameter. The desired hardness and softness of the tube can be attained through subsequent annealing processes. Hard tubes undergo no further treatment. In Annex B (Confidential, removed) Table B-2 presents all inputs and outputs associated with production.

### **3.2.4. Waste Treatment and Recycling/Credits**

For both products, waste flows generated at the product stage are captured and treated appropriately. Where possible, drosses and filter dusts are sent for metal recovery while other wastes are sent to inert landfills. Metal contents for the recovered dross and filter dust were unavailable, therefore no credit or burden were modeled for these outputs.

The inbound copper is comprised of 61% and 84% copper scrap respectively for copper tube and copper sheet, including the scrap inputs contained in the global average cathode dataset. The copper cathode dataset has a scrap input of 0.2 kg per kg of cathode. The remaining inputs of copper scrap are based on data collected from the participating companies. The burden of scrap use is accounted for by subtracting from the total credit at module D.

### **3.2.5. Transportation**

Transportation data were not available from manufacturers and therefore a weighted average distance was estimated instead. To assess the transport distances, it was necessary to determine both the proportion of refined copper obtained from each source as well as the distance from the source to the appropriate manufacturer. The former data were obtained from the USGS 2015 Minerals Yearbook for copper, which was used to determine the proportion of copper originating from each of the top six international sources of refined copper and from the 18 leading US copper-producing mines (USGS, 2017). After establishing the major ports associated with each manufacturer and international source, as



well as the approximate locations of the domestic sources, the one-way travel distances from source to manufacturer were ascertained through the use of Google Maps. The production percentages and travel distances were then used to calculate weighted averages for the necessary distances of truck and ship travel to deliver the copper to each manufacturer. These distances were then integrated into the GaBi model.

Inbound transport for other auxiliary materials was assumed to be 100 miles as no companies were able to provide this data.

### **3.2.6. Installation and Use**

The installation process and use phase of the copper products lie outside the scope of this study. Both copper sheets and tube are inherently non-emitting products. Any potential leaching of substances to water and soil are controlled by drinking water, surface water, and stormwater regulations. For more information on potential hazards, see the Health Product Declarations (HPDs) for Copper Water Tube and Copper Sheet and Strip published by CDA and available in the HPD Collaborative's Public Repository<sup>2</sup> (CDA, 2018a; CDA, 2018b).

### **3.2.7. End-of-Life**

At the life cycle level, copper was modeled using the net scrap allocation approach (Koffler & Finkbeiner, 2017). An end-of-life collection rate of 90% is assumed for the copper, of which a fraction is recovered as copper scrap to be recycled in a closed loop process, depending on the input requirements to manufacturing. The remaining scrap results in a credit to the life cycle equal to the embodied burden of copper cathode used in manufacturing, less reprocessing burden from scrap collection, processing, remelting, and ingot casting. The 10% not captured in the recycling loop are modeled to be disposed at an inert landfill.

The collection rate was determined from a mix of publications and expert opinion. A 2013 study on global copper flows conducted by Fraunhofer Institute conservatively estimated the recycling rate for construction and demolition (C&D) copper waste at 65% (Glöser, Soulier, & Tercero Espinoza, 2013). A 2005 study by the International Copper Study Group (ICSG) focused on Western Europe found that roofing, flashing, guttering, and cladding – the primary uses of copper sheet – had a recovery efficiency of 96% and plumbing and heating (copper tube) had a recovery efficiency of 95% when manually sorted and 90% when mechanically sorted (Ruhrberg, 2005). Using the logic that sheet and tube tend to be larger pieces that can be easily separated from C&D waste and that the US would have comparable rates of recycling of copper as Western Europe, past discussion with representatives of the Fraunhofer Institute resulted in an estimate of 90% for recycling rate<sup>3</sup>.

Finally, the UL Environment Part A PCR specifies 85% for metal recycling unless other information is provided (UL Environment, 2018). This further validates that 90% is not an unreasonable estimate, particularly given the price of copper scrap compared to that of other construction metals.

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<sup>2</sup> <https://www.hpd-collaborative.org/hpd-public-repository/>

<sup>3</sup> Personal communication with Marcel Soulier on August 25, 2016.



### 3.3. Background Data

#### 3.3.1. Fuels and Energy

National and regional averages for fuel inputs and electricity grid mixes were obtained from the GaBi 2019 databases. Table 3-1 shows the most relevant LCI datasets used in modeling the product systems. Electricity consumption was modeled using regional grid mixes that account for imports from neighboring countries and regions.

Documentation for all GaBi datasets can be found at <http://www.gabi-software.com/support/gabi/gabi-6-lci-documentation/>.

**Table 3-1: Key energy datasets used in inventory analysis**

Energy	Dataset	Data Provider	Reference Year
<b>Electricity</b>	US: Electricity grid mix – MROW, NYUP, RFCE, RFCW, SRTV, and from hard coal	thinkstep AG	2016
<b>Technical heat</b>	US: Thermal energy from natural gas	thinkstep AG	2016

#### 3.3.2. Raw Materials and Processes

The most relevant raw material production data are associated with copper cathode. The data come from the International Copper Association and represent the 2013 global production average.

Data for upstream and downstream raw materials and unit processes were obtained from the GaBi 2019 database. Table 3-2 shows the most relevant LCI datasets used in modeling the product systems.

Documentation for all GaBi datasets can be found at <http://www.gabi-software.com/support/gabi/gabi-6-lci-documentation/>.

**Table 3-2: Key material and process datasets used in inventory analysis**

Material / Process	Geographic Reference	Dataset	Data Provider	Reference Year
<b>Carbon</b>	DE	Activated carbon	thinkstep AG	2018
<b>Ammonium chloride</b>	DE	Ammonium chloride (Salmiac, Solvay-process)	thinkstep AG	2018
<b>Boron</b>	DE	Boric acid (estimation)	thinkstep AG	2011
<b>Solvent</b>	US	Butane at refinery	thinkstep AG	2018
<b>Slaked lime</b>	DE	Calcium hydroxide (Ca(OH) <sub>2</sub> ; dry; slaked lime) (EN15804 A1-A3)	thinkstep AG	2018
<b>Canola oil</b>	US	Canola (rapeseed) oil, refined (economic allocation)	thinkstep AG	2018
<b>Coagulant</b>	DE	Coagulant mix	thinkstep AG	2018
<b>Copper, primary</b>	GLO	Copper (99.99%; cathode)	ICA	2013
<b>Carbon carrier</b>	US	Hard coal mix	thinkstep AG	2016



Material / Process	Geographic Reference	Dataset	Data Provider	Reference Year
<b>Hydrogen</b>	US	Hydrogen (steam reforming from natural gas)	thinkstep AG	2018
<b>Hydrogen peroxide</b>	US	Hydrogen peroxide (100%; H2O2) (integrated prod., 70% H2 chemical synthesis, 40% raw solut.)	thinkstep AG	2018
<b>Limestone</b>	US	Limestone flour (50µm)	thinkstep AG	2018
<b>Lubricants</b>	US	Lubricants at refinery	thinkstep AG	2016
<b>Manganese</b>	ZA	Manganese	thinkstep AG	2018
<b>Nickel</b>	GLO	Nickel mix	thinkstep AG	2018
<b>Nitrogen</b>	US	Nitrogen (gaseous)	thinkstep AG	2018
<b>Oxygen</b>	US	Oxygen (gaseous)	thinkstep AG	2018
<b>Zinc</b>	RNA	Redistilled zinc	thinkstep AG	2018
<b>Phosphate</b>	GLO	Rock phosphate mix (32,4 % P2O5)	thinkstep AG	2018
<b>Sand</b>	US	Silica sand (Excavation and processing)	thinkstep AG	2018
<b>Silicon</b>	GLO	Silicon mix (99%)	thinkstep AG	2018
<b>Soda</b>	US	Soda (Na2CO3)	thinkstep AG	2018
<b>Sodium hydroxide</b>	US	Sodium hydroxide (caustic soda) mix (100%)	thinkstep AG	2018
<b>Sulfuric acid</b>	US	Sulphuric acid aq. (96%)	thinkstep AG	2018
<b>Tin</b>	GLO	Tin	thinkstep AG	2018

### 3.3.3. Transportation

Average transportation distances and modes of transport are included for the transport of the raw materials, operating materials, and auxiliary materials to production and assembly facilities. The transport of the raw materials to production and assembly facilities and transport of manufacturing waste to the disposal or recycling sites are included in the analysis. Vehicles used included a tractor trailer, dump truck, and container ship. The GaBi 2019 database was used to model transportation. Truck transportation within North America was modeled using the GaBi US truck transportation datasets. Fuels were modeled using the geographically appropriate datasets, as seen in Table 3-3.

**Table 3-3: Key transportation datasets used in inventory analysis**

Mode / Fuel	Dataset name	Primary source	Year	Geography
Truck (US)	Truck - heavy/bulk (EPA SmartWay)	thinkstep	2018	US
Truck (Global)	Truck-trailer, Euro 4, 34 - 40t gross weight / 27t payload capacity	thinkstep	2018	GLO
Diesel	Diesel mix at filling station	thinkstep	2016	US
Ship	Bulk commodity carrier, average, ocean going	thinkstep	2018	GLO



Mode / Fuel	Dataset name	Primary source	Year	Geography
Heavy fuel oil	Heavy fuel oil at refinery (0.3wt.% S)	thinkstep	2016	US

### 3.3.4. Disposal and Recovery

Disposal processes were obtained from the GaBi 2019 database. These processes were chosen to correspond to the material being disposed – specifically copper tube and sheet. Since copper does not decompose in a landfill, there are no energy recovery credits from landfill gas capture and combustion. Table 3-4 reviews relevant disposal and recycling crediting datasets used in the model.

**Table 3-4: Key end-of-life datasets used in inventory analysis**

Material disposed	Dataset name	Primary source	Year	Geography
Copper, non-hazardous materials	Glass/inert on landfill	thinkstep	2018	US
Hazardous material	Hazardous waste (non-specific) (no C, worst scenario)	thinkstep	2018	US
Copper, for recovery	Copper cathode (primary)	ICA (International Copper Association)	2013	Global

## 3.4. Life Cycle Inventory Analysis Results

ISO 14044 defines the Life Cycle Inventory (LCI) analysis results as the “outcome of a life cycle inventory analysis that catalogues the flows crossing the system boundary and provides the starting point for life cycle impact assessment”. As the complete inventory comprises hundreds of flows, the below tables only display a selection of flows based on their relevance to the subsequent impact assessment in order to provide a transparent link between the inventory and impact assessment results.

**Table 3-5: LCI results of copper sheet (in kg)**

Type	Flow	Manufacture A1-A3	End-of-Life C4	Net Credits D
<b>Resources</b>	Crude oil [MJ]	7.32E+00	3.81E-02	-1.14E+00
	Hard coal [MJ]	1.23E+01	4.80E-03	-1.01E+00
	Lignite [MJ]	1.39E+00	1.97E-03	-1.95E-01
	Natural gas [MJ]	1.17E+01	2.36E-02	-1.04E-01
	Uranium [MJ]	4.30E+00	1.73E-03	4.67E-02
	Non renewable resources	1.15E+02	2.50E-02	-2.35E+01
	Renewable resources	2.36E+01	1.07E-02	-1.07E+00
	Water	2.95E+03	1.98E+00	-1.37E+02
<b>Emissions to air</b>	Carbon dioxide	2.53E+00	4.21E-03	-2.23E-01
	Methane	5.08E-03	9.50E-06	-2.88E-04
	Nitrogen monoxide	3.63E-04	1.59E-07	-6.58E-06
	Nitrogen oxides	7.50E-03	1.59E-05	-1.18E-03



Type	Flow	Manufacture A1-A3	End-of-Life C4	Net Credits D
	Nitrous oxide (laughing gas)	1.53E-04	5.67E-08	-2.59E-05
	R 114 (dichlorotetrafluoroethane)	4.53E-11	0.00E+00	-9.49E-12
	Sulphur dioxide	1.87E-02	8.45E-06	-3.20E-03
<b>Emissions to water</b>	Ammonium / ammonia	4.32E-05	7.70E-09	-4.92E-06
	Chemical oxygen demand (COD)	3.86E-03	1.02E-06	-4.92E-04
	Nitrate	2.83E-04	2.34E-07	-2.52E-05
	Nitrogen organic bound	8.01E-05	1.13E-07	-9.88E-06
	Phosphate	1.52E-05	2.65E-08	-2.27E-06
	Phosphorus	1.04E-05	1.30E-09	-6.12E-07
	Water	2.87E+03	2.00E+00	-1.28E+02

Table 3-6: LCI results of copper tube (in kg)

Type	Flow	Manufacture A1-A3	End-of-Life C4	Net Credits D
<b>Resources</b>	Crude oil [MJ]	9.00E+00	3.81E-02	-5.47E+00
	Hard coal [MJ]	1.36E+01	4.80E-03	-4.86E+00
	Lignite [MJ]	1.31E+00	1.97E-03	-9.32E-01
	Natural gas [MJ]	1.78E+01	2.36E-02	-4.99E-01
	Uranium [MJ]	4.03E+00	1.73E-03	2.24E-01
	Non renewable resources	1.55E+02	2.50E-02	-1.13E+02
	Renewable resources	2.60E+01	1.07E-02	-5.12E+00
	Water	1.36E+03	1.98E+00	-6.57E+02
<b>Emissions to air</b>	Carbon dioxide	3.12E+00	4.21E-03	-1.07E+00
	Methane	6.73E-03	9.50E-06	-1.38E-03
	Nitrogen monoxide	3.71E-04	1.59E-07	-3.15E-05
	Nitrogen oxides	9.54E-03	1.59E-05	-5.63E-03
	Nitrous oxide (laughing gas)	1.92E-04	5.67E-08	-1.24E-04
	R 114 (dichlorotetrafluoroethane)	6.14E-11	0.00E+00	-4.55E-11
	Sulphur dioxide	2.16E-02	8.45E-06	-1.53E-02
<b>Emissions to water</b>	Ammonium / ammonia	4.75E-05	7.70E-09	-2.36E-05
	Chemical oxygen demand (COD)	4.57E-03	1.02E-06	-2.36E-03
	Nitrate	2.91E-04	2.34E-07	-1.21E-04
	Nitrogen organic bound	8.74E-05	1.13E-07	-4.73E-05
	Phosphate	1.70E-05	2.65E-08	-1.09E-05
	Phosphorus	1.11E-05	1.30E-09	-2.93E-06
	Water	1.27E+03	2.00E+00	-6.11E+02



## 4. LCIA Results

This section contains the results for the impact categories and additional metrics defined in section 2.6. It shall be reiterated at this point that the reported impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach).

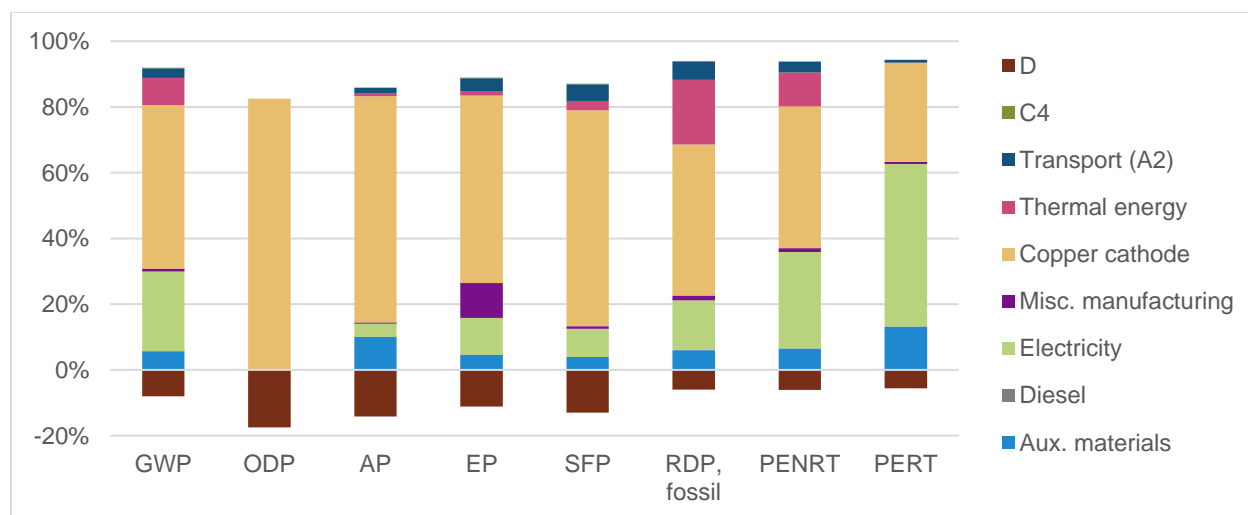
LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

### 4.1. Copper Sheet Results

Table 4-1, Table 4-2, and Table 4-3 present the results per 1 kg of copper sheet. Acronyms are defined in Section 2.6. Figure 4-1 presents detailed results. The most significant driver of impact within the manufacturing stage is the input of cathode, followed by electricity and thermal energy inputs.

**Table 4-1: Environmental impacts, per 1 kg copper sheet**

Parameter	Unit	Manufacturing A1-A3	End-of-Life C4	Net Credits D
<b>GWP100</b>	kg CO <sub>2</sub> eq	2.72E+00	4.52E-03	-2.39E-01
<b>ODP</b>	kg CFC-11 eq	4.52E-11	-2.31E-16	-9.50E-12
<b>AP</b>	kg SO <sub>2</sub> eq	2.49E-02	2.02E-05	-4.10E-03
<b>EP</b>	kg N eq	8.67E-04	1.03E-06	-1.09E-04
<b>SFP</b>	kg O <sub>3</sub> eq	1.99E-01	4.04E-04	-2.97E-02
<b>RDP, fossil</b>	MJ [LHV]	2.91E+00	8.81E-03	-1.87E-01



**Figure 4-1: Copper sheet detailed results**



**Table 4-2: Resource use, per 1 kg copper sheet**

Parameter	Unit	Manufacturing A1-A3	End-of-Life C4	Net Credits D
<b>RPR<sub>E</sub></b>	MJ [LHV]	5.02E+00	5.35E-03	-2.99E-01
<b>RPR<sub>M</sub></b>	MJ [LHV]	0.00E+00	0.00E+00	0.00E+00
<b>NRPR<sub>E</sub></b>	MJ [LHV]	3.94E+01	7.59E-02	-2.57E+00
<b>NRPR<sub>M</sub></b>	MJ [LHV]	0.00E+00	0.00E+00	0.00E+00
<b>SM</b>	kg	8.40E-01	0.00E+00	0.00E+00
<b>RSF</b>	MJ [LHV]	0.00E+00	5.47E+00	1.91E-06
<b>NRSF</b>	MJ [LHV]	0.00E+00	2.87E+00	7.98E-03
<b>RE</b>	MJ [LHV]	0.00E+00	0.00E+00	0.00E+00
<b>FW</b>	m <sup>3</sup>	2.18E+00	0.00E+00	0.00E+00

Note that the secondary material input includes secondary copper inputs to cathode production, not just the inputs of clean scrap at manufacturing.

**Table 4-3: Output flows and waste categories, per 1 kg copper sheet**

Parameter	Unit	Manufacturing A1-A3	End-of-Life C4	Net Credits D
<b>HWD</b>	kg	1.11E-06	2.46E-10	-2.25E-07
<b>NHWD</b>	kg	1.05E-01	1.00E-01	-9.53E-03
<b>HLRW</b>	kg	2.02E-06	8.53E-10	2.16E-08
<b>ILLRW</b>	kg	1.68E-03	6.79E-07	1.81E-05
<b>CRU</b>	kg	0.00E+00	0.00E+00	0.00E+00
<b>MR</b>	kg	0.00E+00	7.51E-02	0.00E+00
<b>MER</b>	kg	0.00E+00	0.00E+00	0.00E+00
<b>EE</b>	MJ [LHV]	0.00E+00	0.00E+00	0.00E+00

## 4.2. Copper Tube Results

Table 4-4, Table 4-5, and Table 4-6 present the results per 1 kg of copper tube. Figure 4-2 presents detailed results. The most significant driver of impact within the manufacturing stage is the input of cathode, followed by electricity and thermal energy inputs.

**Table 4-4: Environmental impacts, per 1 kg copper tube**

Parameter	Unit	Manufacturing A1-A3	End-of-Life C4	Net Credits D
<b>GWP</b>	kg CO <sub>2</sub> eq	3.37E+00	4.52E-03	-1.14E+00
<b>ODP</b>	kg CFC-11 eq	6.13E-11	-2.31E-16	-4.55E-11
<b>AP</b>	kg SO <sub>2</sub> eq	2.93E-02	2.02E-05	-1.96E-02
<b>EP</b>	kg N eq	1.02E-03	1.03E-06	-5.20E-04
<b>SFP</b>	kg O <sub>3</sub> eq	2.51E-01	4.04E-04	-1.42E-01
<b>RDP, fossil</b>	MJ [LHV]	4.08E+00	8.81E-03	-8.96E-01

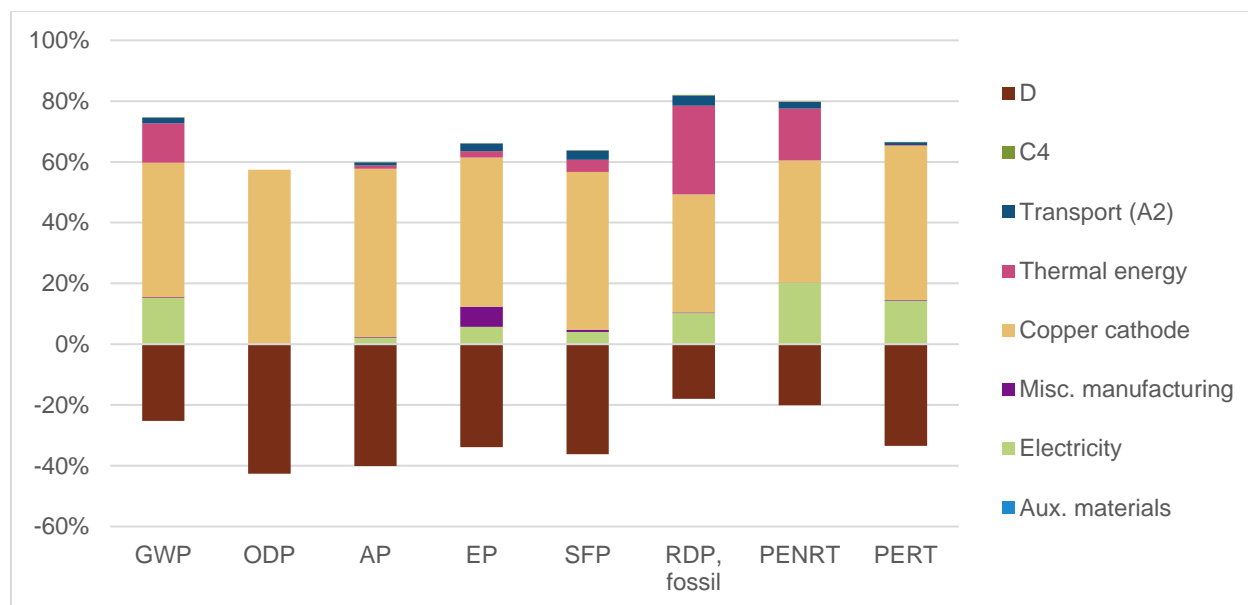


Figure 4-2: Copper tube detailed results

Table 4-5: Resource use, per 1 kg copper tube

Parameter	Unit	Manufacturing A1-A3	End-of-Life C4	Net Credits D
RPR <sub>E</sub>	MJ [LHV]	2.85E+00	5.35E-03	-1.43E+00
RPR <sub>M</sub>	MJ [LHV]	0.00E+00	0.00E+00	0.00E+00
NRPR <sub>E</sub>	MJ [LHV]	4.90E+01	7.59E-02	-1.23E+01
NRPR <sub>M</sub>	MJ [LHV]	0.00E+00	0.00E+00	0.00E+00
SM	kg	6.12E-01	0.00E+00	0.00E+00
RSF	MJ [LHV]	0.00E+00	5.47E+00	1.91E-06
NRSF	MJ [LHV]	0.00E+00	2.87E+00	7.98E-03
RE	MJ [LHV]	0.00E+00	0.00E+00	0.00E+00
FW	m <sup>3</sup>	4.37E-02	8.33E-06	-2.88E-02

Note that the secondary material input includes secondary copper inputs to cathode production, not just the inputs of clean scrap at manufacturing.

Table 4-6: Output flows and waste categories, per 1 kg copper tube

Parameter	Unit	Manufacturing A1-A3	End-of-Life C4	Net Credits D
HWD	kg	1.55E-06	2.46E-10	-1.08E-06
NHWD	kg	1.13E-01	1.00E-01	-4.56E-02
HLRW	kg	1.89E-06	8.53E-10	1.04E-07
ILLRW	kg	1.58E-03	6.79E-07	8.65E-05
CRU	kg	0.00E+00	0.00E+00	0.00E+00
MR	kg	0.00E+00	3.59E-01	0.00E+00
MER	kg	0.00E+00	0.00E+00	0.00E+00
EE	MJ [LHV]	0.00E+00	0.00E+00	0.00E+00



## 5. Interpretation

### 5.1. Identification of Relevant Findings

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This study assessed a multitude of inventory and environmental indicators. The primary drivers were the input of copper cathode, electricity, and thermal energy. Due to the copper cathode input, the amount of recycled content is a key determiner of overall impacts. Additionally, the collection rate for recycling at EoL affects the amount of credit, or potentially burden, associated with module D.

### 5.2. Assumptions and Limitations

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The primary data was collected in 2007 but is intended to represent 2016 production practices. As the technology used for sheet and tube production has not changed, it is assumed this would not significantly alter results. Note that participation was limited by those CDA members willing to provide data, however, participating companies did represent a majority of CDA member market share for the year of production. The amount of scrap used may alter significantly across producers and from year to year, which would affect the results.

Transportation distances of copper material inputs to the fabrication facilities were not collected with the primary data. Best estimates were derived using the geographical locations and known sources (imports and domestic production) of copper cathode in North America, specifically the United States.

The specific recycling rate for copper tube and sheet in North America is unknown, thus an estimate is used in this study. Given the high value of copper and its high recycling efficiency (i.e., ability to be recycled infinitely, without any downgrading of quality with each recycling iteration), a recycling rate of 90% is used in this study. This is assumed to be a reasonable assumption but could vary by product function and region.

### 5.3. Data Quality Assessment

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Inventory data quality is judged by its precision (measured, calculated or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied) and representativeness (geographical, temporal, and technological).

To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent background LCA information from the GaBi 2019 database were used. The LCI datasets from the GaBi 2019 database are widely distributed and used with the GaBi 6 Software. The datasets have been used in LCA models worldwide in industrial and scientific applications in internal as well as in many critically reviewed and published studies. In the process of providing these datasets they are cross-checked with other databases and values from industry and science.



### 5.3.1. Precision and Completeness

- ✓ **Precision:** As the majority of the relevant foreground data are measured data or calculated based on primary information sources of the owner of the technology, precision is considered to be high. Seasonal variations and variations across different manufacturers were balanced out by using yearly weighted averages. All background data are sourced from GaBi databases with the documented precision.
- ✓ **Completeness:** Each foreground process was checked for mass balance and completeness of the emission inventory. No data were knowingly omitted. Completeness of foreground unit process data is considered to be high. All background data are sourced from GaBi databases with the documented completeness.

### 5.3.2. Consistency and Reproducibility

- ✓ **Consistency:** To ensure data consistency, all primary data were collected with the same level of detail, while all background data were sourced from the GaBi databases.
- ✓ **Reproducibility:** Reproducibility is supported as much as possible through the disclosure of input-output data, dataset choices, and modeling approaches in this report. Based on this information, any third party should be able to approximate the results of this study using the same data and modeling approaches.

### 5.3.3. Representativeness

- ✓ **Temporal:** All primary data were collected for the year 2007, though technology for copper tube and sheet production has not changed since then. Note that fluctuations in scrap content will change from year to year and producer to producer. All secondary data come from the GaBi 2019 databases and are representative of the years 2013-2018. Specifically, the ICA copper cathode dataset has a reference year of 2013, as more recent data is not available. Background energy datasets are representative of 2016. As the study intended to compare the product systems for the reference year 2016, temporal representativeness is considered to be moderate.
- ✓ **Geographical:** All primary and secondary data were collected specific to the countries or regions under study. Where country-specific or region-specific data were unavailable, proxy data were used. The largest driver of impact, the copper cathode dataset, is a globally representative dataset. It was not known where the participating companies were purchasing their cathode from, therefore it was assumed to align with global production. Geographical representativeness is considered to be moderate.
- ✓ **Technological:** All primary and secondary data were modeled to be specific to the technologies or technology mixes under study. The copper cathode dataset represents 21% of annual global production volume and is considered to be 95% technologically representative and 79%



geographically representative of world production<sup>4</sup>. Where technology-specific data were unavailable, proxy data were used. Technological representativeness is considered to be high.

## 5.4. Model Completeness and Consistency

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### 5.4.1. Completeness

All relevant process steps for each product system were considered and modeled to represent each specific situation. The process chain is considered sufficiently complete and detailed with regard to the goal and scope of this study.

### 5.4.2. Consistency

All assumptions, methods and data are consistent with each other and with the study's goal and scope. Differences in background data quality were minimized by predominantly using LCI data from the GaBi 2018 databases. System boundaries, allocation rules, and impact assessment methods have been applied consistently throughout the study.

## 5.5. Conclusions, Limitations, and Recommendations

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### 5.5.1. Conclusions

The goal of this study was to conduct an LCA on copper tube and sheet products to share with the building and construction industry, allowing consumers to better inform decisions about the environmental impacts associated with the products they choose.

### 5.5.2. Limitations

This study is representative of the production of only three U.S. facilities for each product. It is therefore intended to serve as a benchmark only, and it does not represent the industry average for North America.

### 5.5.3. Recommendations

Producers of copper tube and sheet should focus on their input of copper cathode. There may be opportunities to purchase from specific suppliers who have higher secondary contents than the global average. Additionally, focusing on reducing energy use would be another opportunity to reduce overall environmental impacts.

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<sup>4</sup> GLO: Copper (99.99%; cathode) ICA. <http://gabi-documentation-2019.gabi-software.com/xml-data/processes/6915520a-5ccc-4535-b0f9-ec06d9c7f892.xml>  
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# Annex A: Critical Review Statement



## Industrial Ecology Consultants

June 5, 2019

Maggie Wildnauer  
Consulting Team Lead, Americas | thinkstep  
170 Milk Street | Boston, MA 02109

### Verification Report: Life Cycle Assessment Copper Tube and Sheet

The LCA Practitioner, **thinkstep**, commissioned Industrial Ecology Consultants to perform an external independent critical review of the Life Cycle Assessment report of **Copper Tube and Sheet** on behalf of the **Copper Development Association**.

**The review of the study was performed to demonstrate conformance** with the following standards and product category rules (PCR):

- Institute Construction and Environment e.V. (IBU) (2013). *PCR Guidance-Texts for Building-Related Products and Services Part B: Requirements on the EPD for Building metals*. v1.5 October, 2013
- International Organization for Standardization. (2000). *Environmental labels and declarations -- General principles* (ISO 14020:2000).
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- International Organization for Standardization. (2006). *Environmental management -- Life cycle assessment -- Principles and framework* (ISO 14040:2006).
- International Organization for Standardization. (2006). *Environmental management -- Life cycle assessment -- Requirements and guidelines* (ISO 14044:2006).
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- International Organization for Standardization. (2017). *Sustainability in building construction -- Environmental declaration of building products*. (ISO 21930:2017).
- UL Environment. (2017). *Product Category Rules for Building-Related Products and Services. Part A: Life Cycle Assessment Calculations Rules and Report Requirements*. Standard 10010, v3.2. Sept. 27, 2018.
- UL Environment. (2015). *Addendum: Product Category Rules for preparing an environmental product declaration (EPD) for PCR: Part B: Requirements on the EPD for Building Metals*. v1.0 August 12, 2014.

The independent third-party verification was conducted by an external expert per ISO 14044:2006 Section 6.2: Critical review by internal or external expert:

Thomas P. Gloria, Ph.D.  
Founder, Chief Sustainability Engineer  
Industrial Ecology Consultants



## Industrial Ecology Consultants

### REVIEW SCOPE

The intent of this review was to provide an independent external third-party critical review of the completed LCA study report to ensure conformance to the fundamental requirements per ISO 14044:

- The methods used to carry out the LCA were consistent with the applicable international standards;
- The methods used to carry out the LCA were scientifically and technically valid;
- The data used were appropriate and reasonable in relation to the goal of the study;
- The interpretations reflected the limitations identified and the goal of the study; and
- The study report was transparent and consistent.

And to further review the LCA study report for conformance to EPD relevant standards and PCR requirements documents.

### REVIEW PROCESS

The review involved the verification of the thinkstep LCA report utilizing a summary requirements matrix assembled by Industrial Ecology Consultants. This review did not include an assessment of the Life Cycle Inventory (LCI) model, however, it did include a detailed analysis of the individual datasets identified and used to complete the study.

### VERIFICATION STATEMENT

Based on the independent verification objectives, the **Life Cycle Assessment of Copper Tube and Sheet** was verified to be **in conformance** with the applicable ISO standards and requirements documents referenced above. The plausibility, quality, and accuracy of the LCA-based data and supporting information are confirmed.

As the External Independent Third-Party Reviewer, I confirm that I have sufficient knowledge and technical experience of apparel products, the ISO standards and the geographical area intended to carry out this verification.

Sincerely,

Thomas P. Gloria, Ph.D.  
Founder, Chief Sustainability Engineer  
Industrial Ecology Consultants





## Self-declaration of reviewer independence and competencies (ISO/TS 14071)

Report Title and Date:

Life Cycle Assessment Copper Tube and Sheet by thinkstep Inc., on Behalf of the Copper Development Association Inc. May 30th 2019

I, the signatory, hereby declare that:

- I am not a full-time or part-time employee of the commissioner or practitioner of the LCA study (external reviewers only)
- I have not been involved in defining the scope or carrying out any of the work to conduct the LCA study at hand, i.e, I have not been part of the commissioner's or practitioner's project team(s)
- I do not have vested financial, political or other interests in the outcome of the study

My competencies relevant to the Critical Review at hand include knowledge of and proficiency in:

- ISO 14040 and ISO 14044
- LCA methodology and practice
- Critical Review practice
- Environmental, technical and other relevant performance aspects of the product system(s) assessed
- Language used for the study

I declare that the above statements are truthful and complete. I will immediately notify all parties involved (commissioner of the critical review, practitioner of the LCA study, fellow reviewer(s)), as applicable, if the validity of any of these statements changes during the course of the review process.

Date: June 4th, 2019

Name (print): Thomas Gloria

Signature:  Digitally signed by Thomas Gloria  
Date: 2019.06.04 21:12:54 -04'00'