REPORT

Life Cycle Assessment of Aurubis Copper Cathode

What is Life Cycle Assessment?

LCA is a decision-making tool used to identify environmental burdens and evaluate the potential environmental impacts of goods or services over their life cycle.

The benefit of using an LCA approach means that negative impacts can be identified and possibly minimized while avoiding the transfer of these impacts from one life cycle stage to another. When applied to product design, production processes and a decision-making aid, LCA is a meaningful tool for implementing effective sustainability strategies.

Goal

To evaluate our environmental performance and contribution to sustainable development, we carried out a life cycle assessment (LCA) for our main product cathode copper using data from 2022. This assessment is an update of our previous LCA.

This study helps in tracking the improvement progress and identifying opportunities for further improving our environmental performance. The study will also provide the basis for the development of profiles of downstream copper products. The results are intended to be published and disclosed to the public.

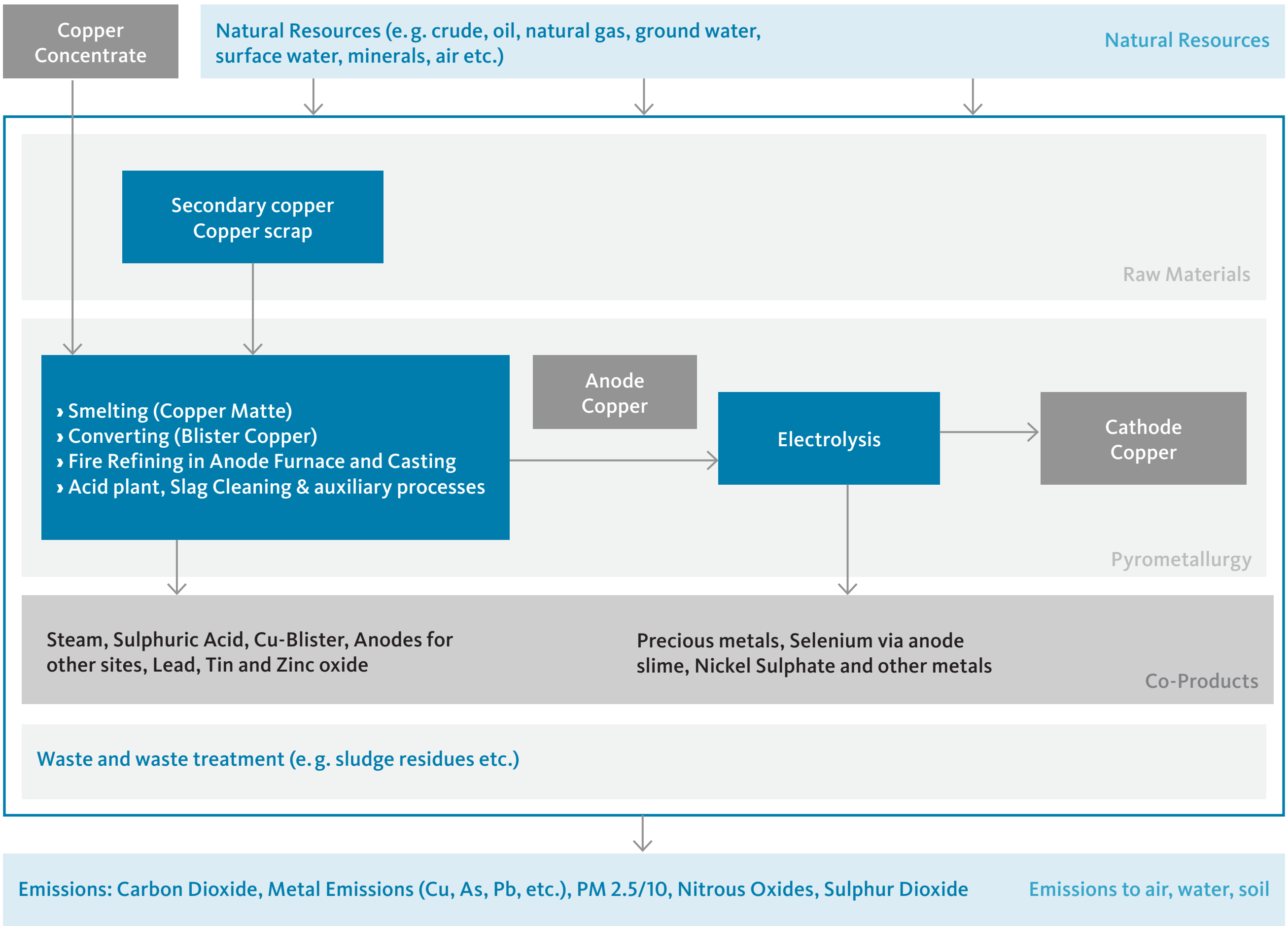
This study was performed with the help of Sphera. The study is consistent with the methodology adopted by the International Copper Association.

Scope

The study was conducted in conformance with the standards ISO 14040 (ISO 14040:2021 Environmental management — Life cycle assessment —Principles and framework) and ISO 14044 (ISO 14044:2021 Environmental management — Life cycle assessment —Requirements and guidelines) on LCA.

Product and declared unit	Copper Cathode (99.99 % Cu), 1 ton
Aurubis cathode profile	The weighted average of cathodes produced at Hamburg, Pirdop, Olen, Luenen and Beerse plants
Considered production system (system boundaries)	Cradle-to-gate, production of copper cathode
Time coverage	Reference calendar year 2022

The system boundary of the study included a cradle-to-gate life cycle inventory from the extraction of the copper ore at the mine to the production of copper cathode, both primary and secondary. It does not include the manufacture of downstream products, use, end-of-life, or secondary copper-containing materials recovery schemes.



Process description

Copper cathode is produced by pyrometallurgical smelting and refining of primary and secondary raw materials. The processes include smelting, converting, fire refining, and electrolytic refining. Primary raw materials are sulphidic copper concentrates. Secondary raw materials are scrap and other complex end-of-life metal-containing products or industrial residues with different content of copper and other metals.

The production processes are designed to recover copper. However, due to the unique properties of copper to capture other valuable metals (silver, gold, PGMs, selenium, tellurium), those are recovered as co-products in the refining operations. So, the copper smelters in addition to high-purity cathode copper produce silver, gold, selenium, and tellurium and /or extract other co-metal products such as lead and tin. Primary smelters also recover sulphuric acid. Lead and tin are usually recovered from intermediates of secondary copper refining processes.

More information is available in the Environmental Report and EMAS Environmental Statement.[1]

Life cycle inventory

Aurubis produces cathode copper via the pyrometallurgical primary and secondary routes.

Specific primary data were collected for all Aurubis copper cathode production sites — Hamburg, Pirdop, Luenen, Olen and Beerse. The data collection covered representative annual data for the calendar year 2022. The data covered all relevant processes associated with cathode copper production:

- Raw material drying/pre-treatment
- Smelting
- Converting
- Sulfuric acid plant
- Slag cleaning
- Anode furnace and anode casting
- Copper electrolysis and spent electrolyte treatment
- All related auxiliary processes: On-site wastewater treatment (treatment of process waters, direct cooling water, and surface runoff water), Gas cleaning systems (for primary and secondary off-gases), Waste Heat Boiler and Auxiliary Boilers

[1] www.aurubis.com/en/responsibility/reporting-kpis-and-esg-ratings

The data included all known inputs and outputs for the processes. Inputs are the use of energy (fuels, electricity, steam), water, primary and secondary raw materials, fluxes, reagents, etc. Outputs are the products, co-products, intermediates, emissions to air and water, and waste.

The upstream processes include:

- Production of raw materials: copper concentrate, scrap, purchased blister and anodes
- Production and supply of fuels
- Production and supply of electricity
- Production and supply of chemicals, auxiliaries
- Transport of raw materials

Production and maintenance of capital goods is excluded from the study. It is expected that these impacts are negligible compared to the impacts associated with running the equipment over its operational lifetime. Packaging is also excluded. As this is a cradle-to-gate study, transport to the customer is outside the system boundary.

For the input of copper concentrate, specific CO_2 equivalent emission factors are available for 30 mines, which represents 70 % of the copper concentrate input of Aurubis in 2022. The factors are sourced from the Skarn database[2] [t CO_2 eq / t Cu in concentrate] for the year 2022.

Since these emission factors considered only Scope 1 and Scope 2 emissions it was necessary to apply a correction of 23 % for the missing Scope 3 emissions based on the average profile of ICA concentrate. The CO_2 equivalent emission factor applied for the remaining concentrate is based on the global average data set from the International Copper Association[3] with reference year 2019.

For all other impact categories, no specific data were available for copper concentrate, therefore the most recent global average data set from the International Copper Association was used, with reference year 2019. The modeling considered the actual copper contained in the dry concentrate input to Aurubis plants.

The input of purchased primary blister/anodes was modelled with the profile of anodes from the Pirdop plant. The input of purchased secondary blister/anodes was modelled with the average profile of blister/anodes from the Luenen and Beerse plants.

Purchased electricity is assessed based on specific market-based CO_2 equivalent emission factors. The share of electricity produced from waste heat steam turbines in Hamburg, Luenen and Pirdop, as well as the share of electricity produced on-site by windmills in Olen and PV plant in Pirdop were considered carbon-free. Background processes e.g. fuels, and auxiliary materials were modeled using LCA for Experts MLC database 2023.1 (former GaBi database)

Steam production is modeled based on primary data. Steam is mainly produced onsite from waste heat recovery and auxiliary boilers and used on-site. Steam in Olen is produced on-site by a cogeneration plant and a specific emission factor was available. Steam recovered from the Acid plant in the Hamburg plant is delivered for district heating (for the supply Hafen City East). This steam was credited for the conventional production of heat from natural gas.

For the transport of input raw materials, primary activity data were collected for delivered raw materials during the calendar year 2022, including mode of transport (truck, ship, rail cars), region/country and approximated distance. Secondary GaBi data sets for truck, rail, and bulk ship carriers were used.

Data for fuels and auxiliary materials such as lime, chemicals, etc. are obtained from the MLC database 2023.1. The direct CO_2 emissions from the combustion of fuels and carbon present in the raw materials are calculated based on specific information about fuel consumption by source, net calorific value and emission factor (in accordance with reports on greenhouse gas emissions pursuant to Directive 2003/87).

The Life cycle inventory is not included in the report due to confidentiality reasons.

[2] www.skarnassociates.com/products/copper
[3] copperalliance.org/wp-content/uploads/2023/05/ICA-LCI-GlobalSummary-202305-F.pdf

Treatment of Co products

The objective of the study is to quantify the inputs and outputs associated specifically with copper cathode production.

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

In order to compile life cycle inventory data for a single product system (in this case copper cathode), it is necessary to properly address this multi-functionality

Allocation and system expansion by substitution was applied in the life cycle inventory of copper cathode to fairly account for the wide range of co-products.

Table 1: Summary of co-product treatment methods

Process	Co-products	Treatment method
Smelting	Lead Lead-Tin alloy Zn oxide Sold anodes	System expansion › Primary lead › Lead-Tin mix › primary zinc Mass allocation
Sulphuric acid plant	Sulphuric acid Steam for district heating	System expansion › Sulphuric acid mix › Steam, natural gas
Electrolytic refining	Precious metals, Selenium, Tellurium (via anode slime) Nickel sulphate	Economic allocation › 10-year average market value

The market value was based on the average metal price for the 10 years (2011 -2020) and fixed to reduce variability and influence on the results. The sources used to determine the reference price are:

- the London Metal Exchange (LME) listings: copper, tin, zinc, lead
- the London Bullion Market Association listings: gold, silver

Sensitivity

The study by the International Copper Association (ref. year 2013[4]) performed sensitivity checks on key methodological choices, especially on using a different approach for the treatment of coproducts such as sulphuric acid, precious metals in anode slime, nickel sulphate. It concluded that system expansion for sulphuric acid and economic allocation for precious metals and nickel sulphate is more sound, stable and reliable.

In the 2019 study, a sensitivity check was done for the iron silicate, and it was concluded not to include a credit with gravel because of various other applications and consistency with the LCA for iron silicate.

No additional sensitivity check was performed in the 2022 study. It is deemed that the conclusions from the sensitivity analyses conducted in the previous study remain valid for this study.

Data quality

Data quality is judged by its completeness, reliability, consistency, and representativeness. To cover these requirements and to ensure reliable results, specific primary data in combination with consistent background LCA information from the MLC database 2023.1 were used.

Completeness: Data has been collected for all relevant processes. To ensure data consistency, all primary data were collected with the same level of detail. Each unit process was checked for mass balance and completeness of the emission inventory.

Reliability: All gate-to-gate data for the Aurubis production sites have been collected from verified sources and measured data such as emission declarations, and technical and metal balances. The environmental profile of global copper concentrate was obtained from the most recent and reliable dataset from the International Copper Association.

Representativeness: The primary data were collected for the 2022 calendar year. All secondary data come from the MLC database 2023.1 and are representative of the years 2019-2023. The data represented the technological and geographical location of the operations. All primary and secondary data were collected specifically for the countries or regions under study and were modelled to be specific to the technologies under study. Where country/region-specific or technology-specific data were unavailable, proxy data were used.

The LCA model was created using the LCA For Expert Software system for Life Cycle Assessment, developed by Sphera Solutions GmbH. The MLC database 2023.1 provides the life cycle inventory data for all background data including materials and energy/electricity.

[4] copperalliance.org/wp-content/uploads/2021/07/ICA-EnvironmentalProfileHESD-201803-FINAL-LOWRES-1.pdf

Life Cycle Impact Assessment

The key environmental aspects were assessed with the Environmental Footprint impact assessment method (3.0) along 16 impact categories.

The Environmental footprint method (3.0) is the most advanced impact assessment method adopted by the European Commission. The previous version of our LCA study used the now-outdated characterization method from the Centre for Environmental Studies (CML) at Leiden University in the Netherlands. For comparability throughout this transition, both CML and EF 3.0 impact assessment methods were reported in last year's life cycle assessment.

The following key impact categories were selected because they represent a broad range of relevant environmental impacts and are each determined by a well-established scientific approach: Global warming potential, Acidification potential, Eutrophication potential, Photochemical Ozone creation potential, Resource use fossil, and Water use.

Results for all 16 indicators are included in the report. However, it is important to note that "abiotic depletion potential" and "toxicity" impacts are not sufficiently robust and accurate to be used for metals.

Table 2: Key Life Cycle Assessment Impact Categories

Impact Category	Description
Global Warming Potential	A measure of greenhouse gas emissions, such as CO2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. This may in turn have adverse impacts on ecosystem health, human health and material welfare.
Eutrophication Potential	Eutrophication covers all potential impacts of excessively high levels of macronutrients, the most important of which nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems increased biomass production may lead to depressed oxygen levels, because of the additional consumption of oxygen in biomass decomposition.
Acidification Potential	A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline and the deterioration of building materials.
Photochemical Ozone Formation	A measure of emissions of precursors that contribute to ground level smog formation (mainly ozone O3), produced by the reaction of VOC and carbon monoxide in the presence of nitrogen oxides under the influence of UV light. Ground level ozone may be injurious to human health and ecosystems and may also damage crops.
Ressource use, fossil	A measure of the total amount fossil resources non-renewable (e.g., petroleum, natural gas, etc.) extracted from the earth used for the primary energy production.
Water use	Deprivation water consumption.

Study Results

The life cycle impact results for the key impact categories for copper cathode as Aurubis weighted average for the reference year 2022 (right bar) are presented below and compared to results for the year 2021 (left bar).

Figure 1: Results for 1 ton of Aurubis average copper cathode (2021) and (2022), (Environmental footprint EF 3.0)

The impacts are also split to analyze contributions from direct emissions, copper concentrate/blister, upstream energy, transports, purchased electricity, others (auxiliary materials, water input, waste), and the credits given for co-products. The results for all impact categories for the copper cathode are presented below:

Table 3: Results for 1 ton of Aurubis average copper cathode (2022), (Environmental footprint EF 3.0)

Acidification	Mole of H+ eq./t Cu	9.76E+00
Climate Change - total	kg CO_2 eq. t Cu	1.495E+03
Climate Change, biogenic	kg CO_2 eq./t Cu	3.60E+00
Climate Change, fossil	kg CO_2 eq./t Cu	1.53E+03
Climate Change, land use and land use change	kg CO_2 eq./t Cu	2.19E+01
Ecotoxicity, freshwater - total	CTUe/Cu	9.41E+03
Ecotoxicity, freshwater inorganics	CTUe/t Cu	6.42E+03
Ecotoxicity, freshwater metals	CTUe/t Cu	2.86E+03
Ecotoxicity, freshwater organics	CTUe/t Cu	1.25E+02
Eutrophication, freshwater	kg P eq./t Cu	1.07E-02
Eutrophication, marine	kg N eq./t Cu	2.82E+00
Eutrophication, terrestrial	Mole of N eq./t Cu	3.04E+01
Human toxicity, cancer - total	CTUh/t Cu	7.82E-07
Human toxicity, cancer inorganics	CTUh/t Cu	2.30E-17
Human toxicity, cancer metals	CTUh/t Cu	2.35E-07
Human toxicity, cancer organics	CTUh/t Cu	5.47E-07
Human toxicity, non-cancer - total	CTUh/t Cu	1.94E-05
Human toxicity, non-cancer inorganics	CTUh/t Cu	8.24E-06
Human toxicity, non-cancer metals	CTUh/t Cu	1.11E-05
Human toxicity, non-cancer organics	CTUh/t Cu	1.41E-07
Ionising radiation, human health	kBq U235 eq./t Cu	8.15E+01
Land Use	Pt/t Cu	5.04E+03
Ozone depletion	kg CFC-11 eq./t Cu	5.61E-09
Particulate matter	Disease incidences/t Cu	1.46E-04
Photochemical ozone formation, human health	kg NMVOC eq./t Cu	7.66E+00
Resource use, fossils	MJ/t Cu	1.48E+04
Resource use, mineral and metals	kg Sb eq./t Cu	6.03E-01
Water use	m^3 world equiv./t Cu	1.25E+03

Interpretation

The impact of cathode copper is dominated by the concentrate (mining and concentration) and purchased blister. Emissions associated with purchased electricity and grid mix also play an important role.

For the Carbon footprint/Global warming potential, the concentrate production and emissions from purchased electricity are the most significant contributor.

The Resource use, fossil included non-renewable energy resources for fuel production and electricity generation.

For the Acidification potential, results are mainly driven by the concentrate production, direct SO_2 emissions from smelting, as well as SO_2 emissions from purchased electricity.

Results for Eutrophication potential are driven by NOx emissions associated with diesel combustion, during mining and transport of concentrates to the smelter. Purchased electricity contributes for country grids with a high coal power plant share.

Results for Photochemical Ozone creation potential are mainly driven by direct SO_2 emissions from smelting, as well as SO_2 emissions from purchased electricity.

Water use is mainly driven by the mining and concentrate production.

Conclusion

The goal of the study was to evaluate the environmental profile of copper cathode and track the progress in comparison with the previous study.

The environmental impacts of Aurubis Copper cathode are significantly lower than the global industry average from the International Copper Association[5] for all impact categories.

The updated environmental impact of Aurubis's copper cathode for 2022 is lower than the profile from 2021 for some of the impact categories such as Acidification and Climate Change.

This is mainly due to continuous efforts for the reduction of direct emissions of pollutants such as sulfur dioxide and dust as well as greenhouse gas emissions.

A project for capturing fugitive emissions from the primary smelter production hall in Hamburg was commissioned in October 2021 and is a major contributor to reduction of emissions to air.

We also invested in energy-efficient and low-carbon technologies at all sites across Aurubis Group and implemented measures to save energy, facilitated the switch to renewable energy (e.g building of windmills, electricity production from waste heat, an electric steam boiler). A 10 MW solar plant was constructed at the Aurubis site in Pirdop (Bulgaria) and came on stream at the end of 2021. The industrial heat project at Aurubis Hamburg, using the excess heat from production processes for district heating also has a major contribution to decarbonization by providing a CO_2-free industrial heat to the HafenCity East.

The results for Resource use, fossil are higher for 2022, mainly related to the environmental impacts of the upstream natural gas energy carrier that changed due to the update of the country specific consumption mixes, update of the pipeline distances, and changes in the background data. Moreover, in Europe there is a significant trend in the increase of LNG imports.

With regard to water use, the rainwater-use project in Lünen allowed to retain and increase the rainwater volume used and decrease the water usage from the public water network. Continuous improvement measures are implemented at all sites to reduce water withdrawal, increase water re-use and optimize the cooling water. The results for water use for 2022 cannot be compared with the 2021 results because of different modeling of rain water and application of regionalized flows.

At the same time, our recycling as well as the efficiency of metal recovery contributed to the lower the environmental profile of copper cathode. The recycled content of the copper cathode production for the financial year 2021/22 was 44 %. The efforts of Aurubis to convert the raw materials as completely as possible into marketable products and enhance metals recovery also help to reduce our overall footprint of cathode copper.

[5] copperalliance.org/wp-content/uploads/2023/05/ICA-LCI-GlobalSummary-202305-F.pdf

Critical review

An independent, external auditor reviewed the methodology, data quality, and modelling aspects of the study.

Name and contact information of the auditor:

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Alejandro Ibanez Cuesy

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The review was performed according to ISO 14040 (2021) and ISO 14044 (2021).

Note:
The Certificate of Validity can be found as an Annex to this document.

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CERTIFICATE OF VALIDITY

DIN EN ISO 14040:2021 / DIN EN ISO 14044:2021
(product-related life cycle assessment - LCA)

Evidence that the application conforms to the regulations was delivered, and is herewith certified according to the TÜV NORD CERT Prüf- und Umweltgutachtergesellschaft mbH - procedure for

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Range of application

Life Cycle Assessment „Production of Copper Cathode“ (Vers. 3, 12/04/2023)

The requirements of the above-mentioned standards were evidently fulfilled by a critical review with regard to

- the scientifically justified and technically valid methods used in carrying out the LCA;
- the appropriateness of the data used in relation to the objective of the study;
- the consideration of the objective of the LCA and the identified limitations in the interpretations.

The LCA report (Ref: Report LCA Copper Cathode 12/04/2023) is transparent and self-consistent.

This declaration of validity refers exclusively to the functional unit at point in time of the LCA report.

Report No. 3536 1273-1

TÜV NORD CERT Prüf- und Umweltgutachtergesellschaft mbH

Hannover, 2023-12-05

Mr. Dr. Hirtz
Environmental verifier