REPORT

Life Cycle Assessment of Aurubis Silver and Gold

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 produced precious metals silver, and gold using data from 2022. This assessment is linked to the study for our main product copper cathode and is consistent with the methodology adopted by the International Copper Association.

This study helps in tracking the improvement progress and identifying opportunities for further improving our environmental performance. The results are intended to be published and disclosed to the public.

This study was performed with the help of Sphera.

Scope

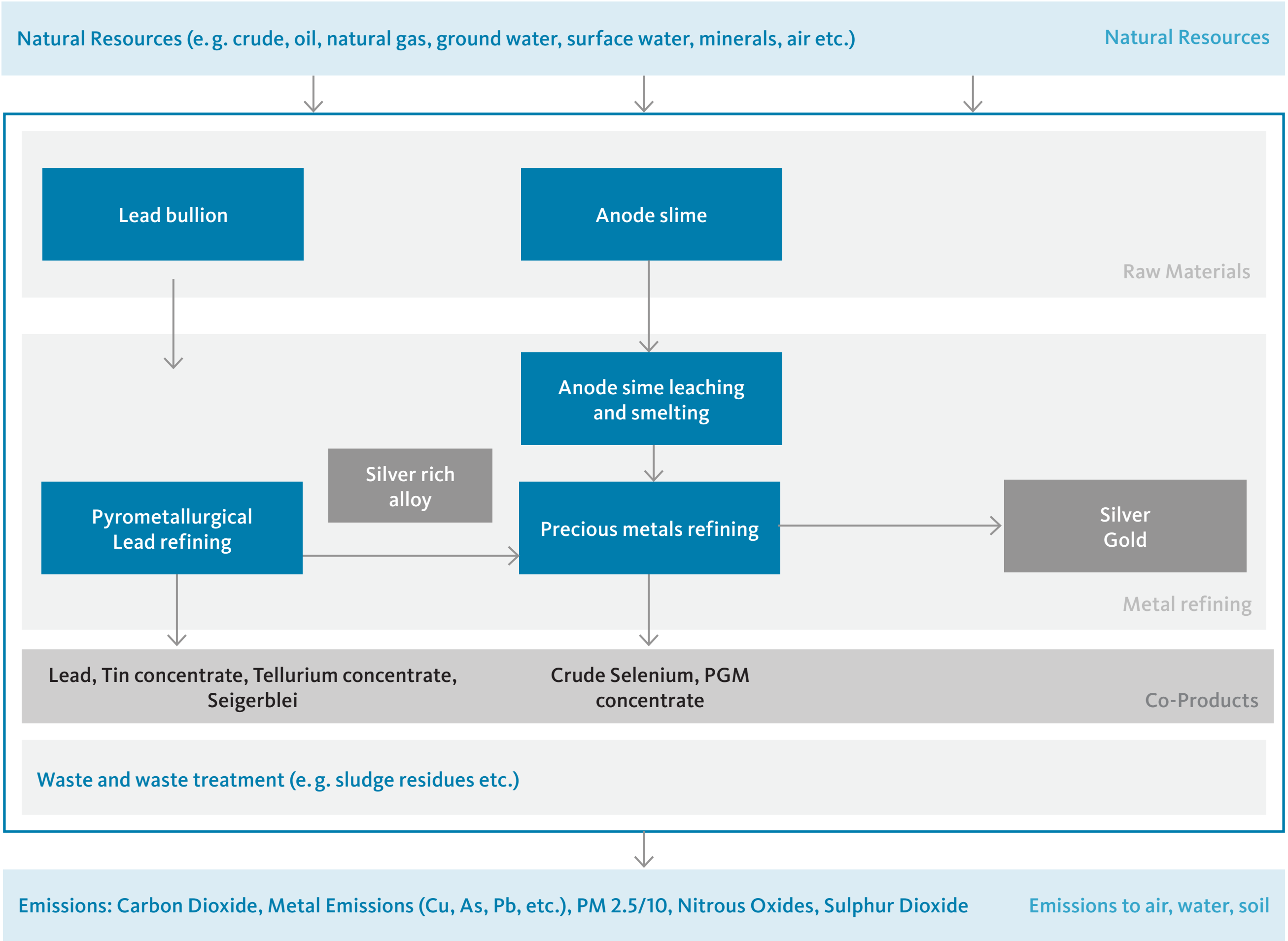
The study was conducted in conformance with the standards ISO 14040 (ISO 14040:2021 Environmental management — Life cycle assessment — Principles and framework) and ISO 14044 (ISO 14044:2021 Environmental management — Life cycle assessment — Requirements and guidelines) on LCA.

Product and declared unit	Silver (99.99 % Ag granules, 99.9 % Ag bars), 1 kg Gold (99.99 % Au, granules and bars), 1 kg
Aurubis profile	Silver and Gold produced at the Hamburg plant
Considered production system (system boundaries)	Cradle-to-gate, production of silver and gold
Time coverage	Reference calendar year 2022

The system boundary of the study included a cradle-to-gate life cycle inventory from the extraction of raw materials to the production of silver and gold. This LCA study is directly linked to the LCA study for the copper cathode where economic allocation has been applied to the anode slime from the copper electrolysis and lead bullion from the secondary smelter.

This study takes the allocated profile of anode slime and lead bullion and includes further refining steps for the production of silver and gold.

It does not include the manufacture of downstream products, use, end-of-life, or secondary copper-containing materials recovery schemes.



Process description

The precious metal refinery is designed to refine both the precious metal-enriched anode slimes from copper production and the precious metal-enriched alloy from lead refining.

Pyrometallurgical lead refining consists of a series of kettles where the lead bullion is melted and given sequential treatments to remove specified impurities. In addition to refined lead, several coproducts are produced such as tin concentrate, tellurium concentrate, and silver-rich alloy.

The anode slimes are first decopperised and smelted in a TBRC furnace to retain the precious metals rich alloy. The selenium is volatilized, collected during gas scrubbing, and precipitated as crude selenium.

The precious metal containing alloys from the anode slime smelting and the lead refining are smelted in a second furnace where the rich silver dore/ raw silver is refined. Silver and Gold are finally produced by electrolytic refining and leaching and selective reduction. Platinum group metals are separated as a PGM concentrate. The final silver and gold products are melted and cast of granules/bars.

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

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

Life cycle inventory

Aurubis produces silver and gold via the pyrometallurgical and hydrometallurgical refining processes.

Specific primary data were collected for the Aurubis production site in Hamburg. The data collection covered representative annual data for the calendar year 2022. The data covered all relevant processes associated with silver and gold production:

- Lead refining
- Anode slime leaching
- Dore production (volatilization and recovery of selenium/ tellurium and pre-step for Ag and Au production)
- Ag and Au refining (Ag, Au and PGM concentrate)
- 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

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: anode slime, lead bullion, purchased silver dore and lead bullion
- 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 are 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 processing of Aurubis anode slimes, the specific allocated profile of anode slime from the copper electrolysis was used for all sites for the reference year 2022. The modeling considered the actual share of anode slime from different Aurubis sites.

For the processing of Aurubis lead bullion, the specific allocated profile of lead bullion from the secondary copper smelter in Hamburg (RWN) was used for the reference year 2022.

For the input of purchased secondary lead bullion from third parties, no specific data were available, therefore the global average data set (80 % secondary lead) from the International Lead Association was used.

The input of purchased silver dore was modelled with the profile of primary silver from the GaBi database corrected for the silver content. This is a conservative approach given that 40% of the purchased dore was from a secondary origin, however no data set for secondary silver was available.

Purchased electricity is assessed based on specific market-based CO_2 equivalent emission factor. Background processes e.g. fuels, and auxiliary materials were modeled using the LCA for Experts MLC database 2023.1 (former GaBi database). Steam is assessed based on background data for steam production with 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 data sets for truck, rail, and bulk ship carriers from the MLC database 2023.1 were used.

Data for fuels and auxiliary materials such as flux, 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.

Treatment of CO products
The objective of the study is to quantify the inputs and outputs associated specifically with silver and gold production.

The refining processes result in the recovery of several coproducts. In order to compile life cycle inventory data for a single product system (in this case silver and gold), it is necessary to properly address this multi-functionality.

Economic allocation was applied in the life cycle inventory of silver and gold to fairly account for the wide range of co-products.

Table 1: Summary of co-product treatment methods

Process	Co-products	Treatment method
Lead refining	Lead Tin concentrate Tellurium concentrate Seigerblei	Economic allocation › 10-year average market value
Precious met-als refining	Crude Selenium PGM concentrate	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 on the co-product cathode copper (ref. year 2013[2]) performed sensitivity checks on key methodological choices. 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 database 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 site in Hamburg as well as upstream primary data for the anode slimes and lead billion have been collected from verified sources and measured data such as emission declarations, and technical and metal balances. The environmental profile of purchased lead bullion was obtained from the most recent and reliable dataset from the International Lead Association. The environmental profile of purchased silver was obtained from the MLC 2023.1 database.

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.

[2] 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 CO_2 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 O_3), 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 Aurubis Gold 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 kg of Aurubis Silver (2021) and (2022), (Environmental footprint EF 3.0)

The results for all impact categories for Aurubis Silver for the reference year 2022 are shown below:

Table 3: Results for 1 kg of Aurubis Silver (2022), (Environmental footprint EF 3.0)

Acidification	Mole of H+ eq./kg Ag	1,.2E+00
Climate Change - total	kg CO_2 eq./kg Ag	1.986E+02
Climate Change, biogenic	kg CO_2 eq./kg Ag	3.74E-01
Climate Change, fossil	kg CO_2 eq./kg Ag	1.97E+02
Climate Change, land use and land use change	kg CO_2 eq./kg Ag	2.77E+00
Ecotoxicity, freshwater - total	CTUe/kg Ag	1.33E+03
Ecotoxicity, freshwater inorganics	CTUe/kg Ag	9.47E+02
Ecotoxicity, freshwater metals	CTUe/kg Ag	3.61E+02
Ecotoxicity, freshwater organics	CTUe/kg Ag	1.87E+01
Eutrophication, freshwater	kg P eq./kg Ag	1.42E-03
Eutrophication, marine	kg N eq./kg Ag	3.56E-01
Eutrophication, terrestrial	Mole of N eq./kg Ag	3.84E+00
Human toxicity, cancer - total	CTUh/kg Ag	1.16E-07
Human toxicity, cancer inorganics	CTUh/kg Ag	3.31E-18
Human toxicity, cancer metals	CTUh/kg Ag	4.30E-08
Human toxicity, cancer organics	CTUh/kg Ag	7.27E-08
Human toxicity, non-cancer - total	CTUh/kg Ag	3.57E-06
Human toxicity, non-cancer inorganics	CTUh/kg Ag	7.84E-07
Human toxicity, non-cancer metals	CTUh/kg Ag	2.77E-06
Human toxicity, non-cancer organics	CTUh/kg Ag	2.01E-08
Ionising radiation, human health	kBq U235 eq./kg Ag	9.76E+00
Land Use	Pt/kg Ag	7.58E+02
Ozone depletion	kg CFC-11 eq./kg Ag	9.22E-10
Particulate matter	Disease incidences/kg Ag	2.24E-05
Photochemical ozone formation, human health	kg NMVOC eq./kg Ag	1.01E+00
Resource use, fossils	MJ/kg Ag	2.23E+03
Resource use, mineral and metals	kg Sb eq./kg Ag	1.06E-01
Water use	m^3 world equiv./kg Ag	1.65E+02

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

Figure 2: Results for 1 kg of Aurubis Gold (2021) and (2022), (Environmental footprint EF 3.0)

The results for all impact categories for Aurubis Silver for the reference year 2022 are shown below:

Table 4: Results for 1 kg of Aurubis Gold (2022), (Environmental footprint EF 3.0)

Acidification	Mole of H+ eq./kg Au	1.42E+02
Climate Change - total	kg CO_2 eq./kg Au	1.541E+04
Climate Change, biogenic	kg CO_2 eq./kg Au	2.90E+01
Climate Change, fossil	kg CO_2 eq./kg Au	1.53E+04
Climate Change, land use and land use change	kg CO_2 eq. /kg Au	5.81E+01
Ecotoxicity, freshwater - total	CTUe/kg Au	1.03E+05
Ecotoxicity, freshwater inorganics	CTUe/kg Au	7.34E+04
Ecotoxicity, freshwater metals	CTUe/kg Au	2.80E+04
Ecotoxicity, freshwater organics	CTUe/kg Au	1.45E+03
Eutrophication, freshwater	kg P eq./kg Au	1.10E-01
Eutrophication, marine	kg N eq./kg Au	2.80E+01
Eutrophication, terrestrial	Mole of N eq./kg Au	3.02E+02
Human toxicity, cancer - total	CTUh/kg Au	8.94E-06
Human toxicity, cancer inorganics	CTUh/kg Au	2.57E-16
Human toxicity, cancer metals	CTUh/kg Au	3.30E-06
Human toxicity, cancer organics	CTUh/kg Au	5.64E-06
Human toxicity, non-cancer - total	CTUh/kg Au	2.72E-04
Human toxicity, non-cancer inorganics	CTUh/kg Au	6.08E-05
Human toxicity, non-cancer metals	CTUh/kg Au	2.10E-04
Human toxicity, non-cancer organics	CTUh/kg Au	1.56E-06
Ionising radiation, human health	kBq U235 eq./kg Au	7.57E+02
Land Use	Pt / kg Au	5.88E+04
Ozone depletion	kg CFC-11 eq./kg Au	7.15E-08
Particulate matter	Disease incidences/kg Au	1.74E-03
Photochemical ozone formation, human health	kg NMVOC eq./kg Au	7.95E+01
Resource use, fossils	MJ/kg Au	1.73E+05
Resource use, mineral and metals	kg Sb eq./kg Au	8.25E+00
Water use	m^3 world equiv./kg Au	1.28E+04

Interpretation

The impact of silver and gold for all impact categories is dominated by the anode slime. The profile of the lead bullion also contributes. Purchased material (dore), direct emissions, purchased electricity and upstream energy have a minor contribution.

Conclusion

The goal of the study was to evaluate the environmental profile of Silver and Gold and allow tracking of the progress and further improvement.

The carbon footprint of Aurubis silver is significantly lower than the global market mix data set from the ecoinvent data base (2021) of 447.93 kg CO_2 eq./kg silver. The carbon footprint of Aurubis Gold is significantly lower than the published result by the World Gold Council for the global gold market mix of 36,415 t CO_2 eq./kg gold.

This is because we 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).

The updated environmental impact of Aurubis's silver and gold are lower than the profile from 2021 for most of the impact categories except Resource use fossil, Acidification and Summer smog.

This improvement is mainly because of the lower allocated profile of anode slime from the copper cathode assessment for the reference year 2022.

The operations have taken continuous efforts for the reduction of direct emissions of pollutants such as dust, SO_2 as well as greenhouse gas emissions.

The higher result for Acidification (for silver) and Summer smog (for gold) for 2022 is a result of higher contribution from purchased dore and lead bullion. 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.

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 has an important role in the results of our life cycle assessment.

The recycled content of silver and gold from the Aurubis Group for fiscal year 2021/22 was 56 % for silver and 24 % for gold.

Critical review

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

Name and contact information of the auditor:

Dr. Winfried Hirtz
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 Gold and Silver“ (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: Production of Silver and Gold 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 1273-4

TÜV NORD CERT Prüf- und Umweltgutachtergesellschaft mbH

Hannover, 2023-12-05

Mr. Dr. Hirtz
Environmental verifier