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IMOA
THE VOICE OF THE MOLYBDENUM INDUSTRY

Life Cycle Inventory & Carbon Footprints of Molybdenum Products for Metallurgical Applications:

Update Study

Executive Summary

2024

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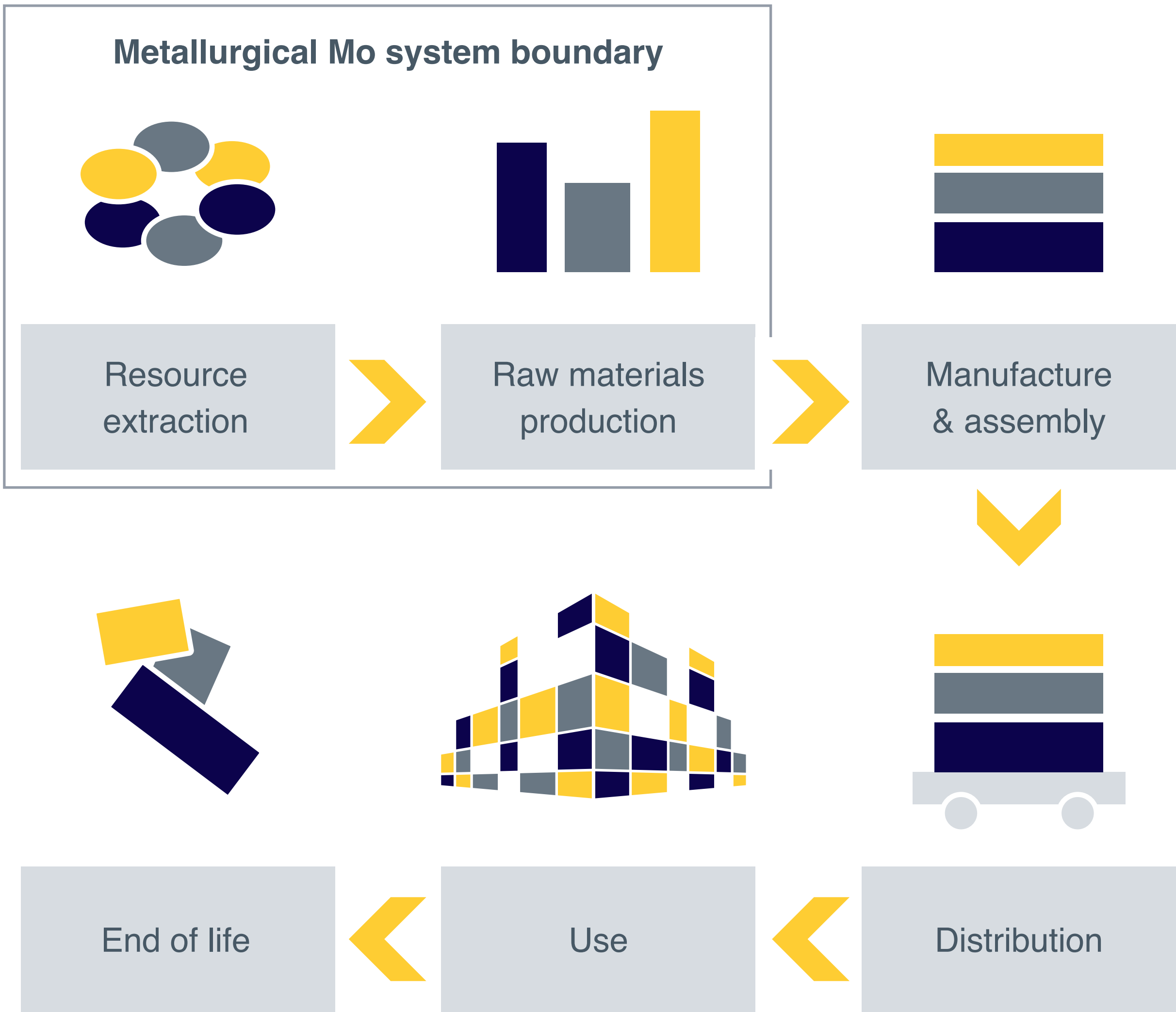
Introduction

Life Cycle Assessment (LCA) has become one of the most valuable environmental tools for assessing the environmental footprint of a product or process. LCA provides quantitative and scientific analyses of the environmental impacts of products and their associated industrial systems. LCA is the foundation for the calculation of product carbon footprints (PCFs). LCA can assess each stage of the life of a product.



As such, LCA offers valuable information and insights about the production and supply chain of a product, helping to inform stakeholders about the environmental strengths and challenges over its life.

Since the early 2000’s, the non-ferrous and ferrous metals industries have been using LCA as a powerful and comprehensive environmental tool to supply environmental information to customers, stakeholders, and researchers; measure environmental performance; and, internally, help identify areas of improvement. In 2000, the International Molybdenum Association (IMOA) completed its first Life Cycle Inventory (LCI), which is the initial stage of an LCA, on three metallurgical molybdenum feedstock products. In 2008, 2018, and 2024, the Association performed updates of the LCI to increase representativeness, update facility and background data, and adjust modeling approaches based on evolving science and industry-specific methodologies.

The externally peer-reviewed 2024 update study, summarized in this document, uses current facility and background data. It ensures, where appropriate, modeling and methodology consistent with other LCAs in the metals sector, using the guidance of a metals and minerals industry-wide LCA “harmonization” guidance document.[1,2]

Given the popularity of LCA as a powerful environmental assessment tool, there is considerable demand for high quality, current environmental LCA-related information, including PCF, within all industrial sectors. The building and construction industry, which includes the vast array of materials, products, and industries pertaining to the built environment, has embraced LCA as a means to identify green solutions and improvements for new and existing buildings. Materials suppliers use LCA to highlight positive environmental attributes of their products in buildings, and designers and builders are selecting materials based on these environmental attributes.

Companies and organizations of all industry sectors use LCA data to measure environmental performance of products and processes as part of their sustainability and environmental programs. Likewise, consumers use LCA-based environmental criteria to determine purchasing decisions by way of comparative LCAs, PCFs, Environmental Product Declarations, and Product Environmental Footprints.[3] In short, environmental assessment information based on LCA has become more the norm than the exception for policy and product decision-making.

Goal & Scope

The aim of this study was to provide the molybdenum industry, LCA practitioners and databases, and molybdenum related stakeholders with LCIs of three molybdenum products for metallurgical applications, using current, robust data on molybdenum production.

The products studied include:

- **Roasted molybdenite concentrates (RMC) in powder form**

  Also known as “technical grade molybdenum oxide” or “tech oxide”, RMC is added to steel and iron as an alloying agent to increase strength, hardness, electrical conductivity and resistance to corrosion and wear. It is in powder form, going to customers for chemical production, stainless steel production, etc., or as an intermediate product to be further transformed into briquettes or ferromolybdenum.

- **RMC Briquettes**

  Also known as tech oxide briquettes, RMC briquettes are added to steel and iron as an alloying agent to increase strength, hardness, electrical conductivity and resistance to corrosion and wear.

- **Ferromolybdenum in chip form**

  Ferromolybdenum is added to steel and iron as an alloying agent to increase strength, hardness, electrical conductivity and resistance to corrosion and wear. Molybdenum content of this product may range from 60 – 75%.

A new feature of the IMOA LCI 2024 Update is that data on the precursor substance for the above products, i.e. molybdenite concentrate (MoS_2), is now also available as a separate mineral extraction and beneficiation process unit.

Table 1: Product identifiers and synonyms

Chemical Name	Identifiers	Synonyms
Molybdenum Disulfide	For roasting: **CAS No.** 1309-56-4 **EC No.** 215-172-4	Molybdenite concentrate Unroasted molybdenite concentrate UMC Moly concs Mo (IV) disulfide Mo disulfide Moly sulfide
Molybdenum Sulfide, (MoS_2), roasted	**CAS No.** 86089-09-0 **EC No.** 289-178-0	Roasted molybdenite concentrate Roasted moly concs RMC Technical grade moly oxide Tech oxide
Molybdenum Sulfide, (MoS_2), roasted, briquette form	**CAS No.** 86090-09-0 **EC No.** 289-178-0	Roasted molybdenite concentrate, briquette form RMC briquettes Tech oxide briquettes
Ferromolybdenum	**CAS No.** 11121-95-2 **EC No.** 304-589-8	FeMo Ferromoly

The IMOA LCI is cradle-to-gate, encompassing the processes that include resource extraction from the earth through to the point at which the products are ready for shipment to customers. The LCI is based on current data for process technologies, energy and materials consumed, and environmental outputs. The geographical scope of the study is global production of molybdenum, excluding China, Mongolia, and CIS.

The cradle-to-gate results are intended to be used in the evaluation of potential impacts associated with molybdenum products and their applications. When used with studies that adhere to appropriate methodologies such as the ISO 14000 standards, this data can be the basis for industry benchmarking, molybdenum-containing product analyses, and management of environmental improvement programs.

The results of this study are available to LCA practitioners through the **IMOA website** in addition to LCA databases.

Methodology

LCA is an analytical tool used to comprehensively quantify and interpret the environmental flows to and from the environment, including air emissions, water effluents, solid waste, and the consumption/depletion of energy and other resources, over the life cycle of a product or process. In LCA, the system boundaries may encompass production and extraction of raw materials, manufacturing of intermediate products, transportation, distribution, use, and a final “end-of-life” stage which often includes multiple parallel paths such as recycling, incineration, landfilling, etc.

An LCA involves three main phases according to ISO 14044, Section 3:

1

Life Cycle Inventory (LCI)

The “phase of the LCA involving the compilation and quantification of inputs and outputs, for a given product system throughout its life cycle.” This phase includes:

- Defining the project system boundaries as specified by the goal and scope of the project (i.e., defining which steps are included in the system and which are not)
- Collecting data required for each step included in the system
- Calculating the final inventory

Life Cycle Impact Assessment (LCIA)
This is the part of the LCA that aims to understand and evaluate "the magnitude and significance of the potential environmental impacts of a product system." The LCIA stage involves categorizing inventory flows and characterizing them according to their overall impact to the category, and examples include global warming potential (also known as the CFP), acidification potential, and eutrophication potential. Except for global warming potential, LCIA was not included within the scope of this LCI study update, but the LCI results are intended to be calculated into LCIA categories, especially when incorporated into an LCA software package or database.

Life Cycle Interpretation
is the LCA stage in which the "findings of either the inventory analysis or the impact assessment, or both, are combined in line with the defined goal and scope in order to reach conclusions and recommendations." Examples of life cycle interpretation include contribution analyses and scenario analyses, both of which are used to help understand the results of this study. This LCI study update does include interpretation.

ISO's representation of LCA identifies a process preceding the inventory analysis phase: Goal and Scope Definition. Individualizing Goal and Scope Definition as a separate stage was specifically intended as a reminder that the key project objective parameters should be carefully established and clearly stated at the outset of an LCA, to guide the subsequent stages. All stages of an LCA should be scoped by the particular use or uses for which the study is intended, and that use of the data may entail some results interpretation.

The study conforms to the International Organization for Standardization (ISO) 14040 and 14044 standards on LCA.[4,5] The study meets the following essential requirements formalized by these ISO Standards:

- The project aims at taking an inventory of the environmental inflows and outflows associated with the cradle-to-gate production of a product
- The goal and scope of the project are precisely defined at the beginning of the project
- Assumptions are clearly stated, and the methodology is as transparent as allowed whilst protecting confidential data
- System boundaries, functional unit, and allocation rules are rigorously defined and described
- Pertinent data are collected and their quality is rigorously assessed
- Reporting requirements are stated

The study was externally peer reviewed by James Salazar of WAP Sustainability Consulting. The peer review process ensured the following (ISO 14044, Section 6.1):

- The methods used to carry out the LCA are consistent with ISO 14044
- The methods used to carry out the LCA are scientifically and technically valid
- The data used are appropriate and reasonable in relation to the goal of the study
- The interpretations reflect the limitations identified and the goal of the study
- The study report is transparent and consistent

The primary molybdenum data collected and modeled for this study is sourced from 24 facilities in 10 countries spanning Asia, Europe, North America, and South America, and represents approximately 25% of total global molybdenum produced and 50% of global production minus China, Mongolia, and CIS.[6] Data were collected for the year 2022 and came from a mix of primary and byproduct mines and conversion facilities. A typical range of operating configurations were included.

Policymakers, customers, and researchers rely on LCA for valuable environmental information on product systems. It should be borne in mind that the LCA, like any other scientific or quantitative study, has limitations. In all LCA studies there is an inherent margin of error due to various limitations such as imperfections and unavailability of some relevant data. This is true for all LCA studies, and these limitations are accepted and acknowledged as part of the LCA process. That said, this study is the most comprehensive, current record of environmental inflows and outflows associated with the production of molybdenum products for metallurgical applications, and it should be the go-to source for the LCI of these products.

Aggregation, Modeling & Results

Unit processes included mining the molybdenite ore, concentrating the ore, roasting into RMC, briquetting, and ferromolybdenum production.

Aggregation of production data included:

- Calculation of production-weighted averages for each unit process
- Rigorous data checks, cross-checks, and mass and energy balance calculations
- Reporting of statistical information for each LCI flow monitored
- Individual company results production and re-checking of discrepancies

The product systems were built in the LCA for Experts commercial LCA software, and utilized the LCA for Experts database.[7] The cut-off criteria of 99.5 percent of the mass of inputs were exceeded. The LCI results provide industry-average cradle-to-gate data for the defined set of energy and material inputs, air emissions, water effluents and deposited material for the three molybdenum products.

The high level of data and data quality checking, coupled with robust background data on materials and energy, makes IMOA's molybdenum LCI the most representative LCI study carried out for these products on an industry-wide basis, and provides a sound foundation for LCA studies relating to molybdenum.

IMOA proposes to continue reviewing and updating the LCI data on a regular basis to take into account expanding and improved monitoring procedures. Where possible, such reviews will include further broadening the geographical coverage and number of participating companies.

Product Carbon Footprints

Product Carbon Footprints have been calculated for the three metallurgical molybdenum products plus molybdenite concentrate. The 2024 update study saw a decrease in PCF from the 2018 study due to electricity grids using increasingly higher shares of renewable energy sources, more efficient processing, and commitments by several participating companies to renewable energy use through valid contractual instruments, such as Renewable Energy Certificates (RECs)[9], amongst other factors.

Table 2: Carbon footprint per kg product

Year	Unit	1 kg Molybdenite Concentrate (~50% Mo)	1 kg RMC (~60% Mo)	1 kg RMC briquette (~59% Mo)	1 kg FeMo (~67% Mo)
2024	kg CO_2-eq	2.84	3.79	4.03	7.41
2018	kg CO_2-eq	Not calculated	4.96	5.04	8.04
% reduction between 2018 & 2024 values		n/a	↓24%	↓20%	↓8%

The Global Warming Potential, or CFP, factors come from the International Panel on Climate Change (IPCC) Sixth Assessment Report (AR6).[8] The CFP was calculated using the entire inventory output from the product systems, including the main greenhouse gases: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), in CO_2-equivalents.

Availability of Data

To support full cradle-to-grave LCAs involving molybdenum products, IMOA makes its complete LCI datasets available through its website by completing this **Data Request Form** and describing the intended application of the data, and also through numerous LCA databases, including LCA for Experts Database, DATASMART, and Industry Data.

Conclusions

The externally peer-reviewed IMOA 2024 LCI Study Update has generated a large, rigorous and representative database. With an understanding of the strengths and limitations of the study, the results can be used to assist decision-making and evaluate the performance of molybdenum products through their life cycle (i.e., from cradle through use and end-of-life) in the context of sustainable development practices. The results also provide the opportunity for participating companies and other molybdenum producers to benchmark and evaluate improvement measures to their processes and product systems.

The significant reductions achieved in product carbon footprints are a very positive reflection of ongoing de-carbonization initiatives by IMOA member companies.

The goal of IMOA's LCI program is to keep the database current and further enhance the methodology and understanding of the study. Recommendations for improvement concerning both the documentation and the data are welcome.

For LCA to be used as a reliable tool for decision-making, high quality data, sound methodology, and transparent reporting are essential. This study is a major step towards enhancing this practice, and the molybdenum industry intends to continue encouraging this trend in its future program of work.

Endnotes

[1] Santero, N., & Hendry, J. (2016). Harmonization of LCA methodologies for the metal and mining industry. International Journal of Life Cycle Assessment. A formal update of this harmonization guidance document, under the auspices of the International Council of Mining and Metals (ICMM), upon which the methodology of this IMOA LCI update is based, is expected to be published in 2025.

[2] International Molybdenum Association (IMOA) Life Cycle Assessment program and perspectives on the LCA harmonization effort. International Journal of Life Cycle Assessment, Nov 2016, Volume 21, Issue 11, pages 1554 1558. Found at: https://doi.org/10.1007/s11367-015-0990-8

[3] The Product Environmental Footprint is a European Commission policy-driven initiative that has established a common methodology to enable organizations to assess the environmental performance of products using the life cycle approach. For more information on PEFs, please see: https://green-business.ec.europa.eu/environmental-footprint-methods/pef-method_en.

[4] ISO 14040:2006/Amd1:2020, the International Standard of the International Standardisation Organisation, Environmental management – Life cycle assessment – Principles and framework.

[5] ISO 14044:2006/Amd1:2017/Amd2:2020, Environmental management – Life cycle assessment – Requirements and guidelines – Amendment 2.

[6] Data provided by IMOA (July 2024).

[7] Sphera, LCA for Experts Software System and Database for Life Cycle Engineering 1992-2024 (previously named GaBi).

[8] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, In press, doi:10.1017/9781009157896.

[9] ISO 14067:2018(E) Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification, Sec. 6.4.9.4.

Prepared for

IMOA
THE VOICE OF THE MOLYBDENUM INDUSTRY

International Molybdenum Association
454-458 Chiswick High Road
London, W4 5TT, United Kingdom
Email: info@imoa.info
www.imoa.info

By

FOUR ELEMENTS LLC

Four Elements Consulting, LLC
1619 22nd Avenue East
Seattle, WA 98112, USA
Email: anne@fourelementsllc.com
www.fourelementsllc.com