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Life Cycle Inventory of Molybdenum Products for Metallurgical Applications: Update Study

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Executive Summary
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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. Because it assesses each stage of the life of a product, LCA can offer valuable information about the production and supply chain of a product, helping to inform stakeholders about its environmental strengths and challenges over its life.

For nearly two decades, the non-ferrous and ferrous metals industries have adopted 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 a Life Cycle Inventory (LCI), which is the first stage of an LCA, on three metallurgical molybdenum feedstock products. In 2008, the Association updated the LCI to increase representativeness, update facility and background data, and adjust modeling approaches, based on evolving methodologies. This externally peer-reviewed 2018 LCI update study, summarised in this document, uses current facility and background data and 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.[1,2,3]

Given the popularity of LCA as a powerful environmental assessment tool, there is considerable demand for high quality, current environmental LCA-related information 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 builders and designers 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 sustainable and environmental programs. Likewise, consumers use LCA-based environmental criteria to determine purchasing decisions by way of comparative LCAs, Environmental Product Declarations, and – imminently – Product Environmental Footprints.[4] In short, environmental assessment information based on LCA has become more the norm than the exception.

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:

a. roasted molybdenite concentrates (RMC), also known as "technical grade molybdenum oxide" or "tech oxide", in powder form;

b. RMC in briquette form; and

c. ferromolybdenum.

The 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.

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 14040:1997(E), 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; and

- Calculating the final inventory.

2. Life Cycle Impact Assessment (LCIA) 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 categorising inventory flows and characterising them according to their overall impact to the category. Examples include global warming potential, natural resources depletion, and eutrophication potential. LCIA was not included within the scope of this LCI study update.

3. 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 actually identifies a process preceding the inventory analysis phase: *Goal and Scope Definition*. Individualising *Goal and Scope Definition* as a separate stage was specially 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.[5,6] The study meets the following essential requirements formalised 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; and
- Reporting requirements are stated.

The study was externally peer reviewed by James Salazar of Coldstream Consulting, Ltd, in British Columbia, Canada. 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; and
- The study report is transparent and consistent.

The primary molybdenum data collected and modeled for this study is sourced from facilities in eight countries spanning Asia, Europe, North America, and South America, and represents approximately 30% of total global molybdenum produced and 46% of global production minus China.[7] Data were collected for the years 2015 or 2016 – based on the most representative production year – and came from primary and byproduct mines and conversion facilities. A typical range of operating configurations were included.

This LCI is considered to be the most comprehensive, current record of environmental inflows and outflows associated with the production of molybdenum products for metallurgical applications. However, it should be borne in mind that LCA, like any other scientific/quantitative study, is a far from perfect tool. There is inherently some margin of error due to various limitations such as imperfections of data and unavailability of some relevant data.

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; and
- Individual company results production and re-checking of discrepancies.

LCI models were built in GaBi, a commercially-available LCA software, and utilized the GaBi LCA database. 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 broadening the geographical coverage and number of participating companies.

Availability of Data

Requests for LCI data are to be made on-line via the IMOA website. The normal procedure is to complete an on-line data request form describing the intended application of the data. This will help to ensure that the IMOA methodology and results can be applied appropriately and will be compatible with the goals of the study.

Conclusions

The externally peer-reviewed IMOA 2018 LCI Study Update has generated a large, rigorous and representative database. With an understanding of the 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 and 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 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 enhancement of these standards and the molybdenum industry intends to continue encouraging this trend in its future program of work.

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[1] PE International (2014) Harmonization of LCA Methodologies for Metals, v. 1.01, February 2014, for International Council for Mining & Metals (ICMM).

[2] https://doi.org/10.1007/s11367-015-0990-8 - 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

[3] LCA of Metals and Metal Products: Theory, Method and Practice. International Journal of Life Cycle Assessment, Nov 2016, Volume 21, Issue 11.

[4] The Product Environmental Footprint is a European Commission policy-driven initiative in the advanced stage of development as of this writing. The objective of the initiative is to establish 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: http://ec.europa.eu/environment/eussd/smgp/index.htm

[5] ISO 14040:1997(E), the International Standard of the International Standardisation Organisation, Environmental management – Life cycle assessment – Principles and framework.

[6] ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines.

[7] Data from IMOA (March 2018).