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CRADLE-TO-GATE LIFE CYCLE ASSESSMENT OF NIOBIUM PENTOXIDE FOR NEXT-GENERATION BATTERIES

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INTRODUCTION

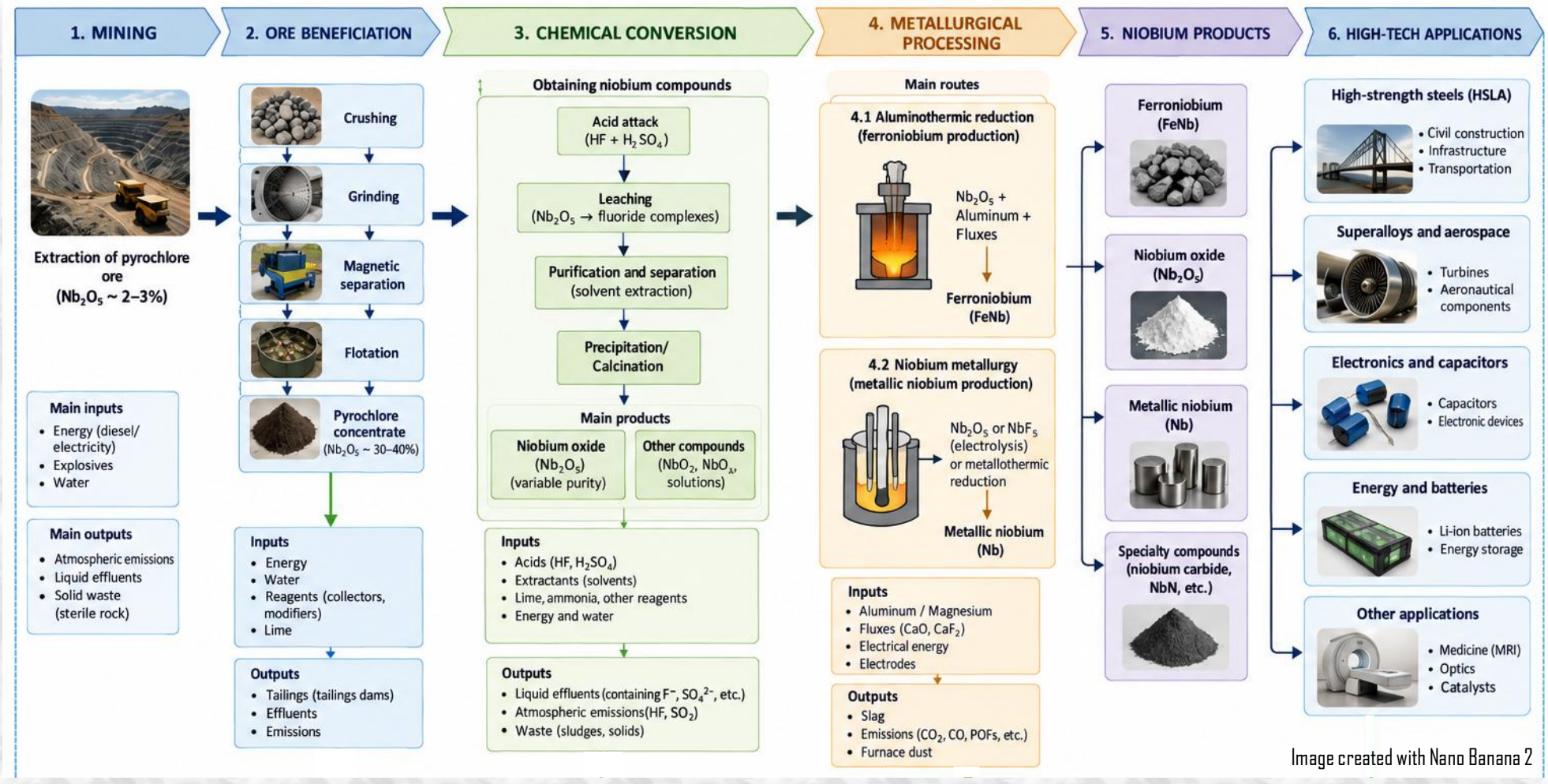


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OBJECTIVES

The study was conducted as per ISO 14044 considering raw material extraction, beneficiation, and chemical processing until purification steps required to obtain battery-grade Nb_2O_5.

EXPERIMENTAL

GOAL AND SCOPE DEFINITION

- LCA framework according to ISO 14044 [1].
- System boundary: cradle-to-gate (Mining, processing and refining).
- Functional unit: 1 kg of high-purity Nb_2O_5 and 1,0 kg of battery-grade graphite.

LIFE CYCLE INVENTORY (LCI)

- Inputs and outputs adapted from [2,3].
- Chemicals, energy and waste treatments datasets from database Ecoinvent 3.7.1.

LIFE CYCLE IMPACT ASSESSMENT (LCIA)

- Impact indicators were calculated using the IPCC 2021 (ISO 14067) for Carbon Footprint (CFP, kg CO_2 eq.), Cumulative Energy Demand (CED, MJ eq.), and USEtox for Human Toxicity (HT, cases).
- Uncertainty calculation by Monte Carlo Simulation.

RESULTS AND DISCUSSION

The environmental assessment indicated that Nb_2O_5 presents higher impacts than graphite across all evaluated indicators, with a carbon footprint 3.7 times higher (Table 1). This environmental burden stems primarily from chemical reagent consumption and energy use during purification stages. Nevertheless, Nb_2O_5 delivers key technical benefits in battery applications, such as high electrochemical stability, fast-charging capabilities, and enhanced operational safety.

Impact Indicator	Nb_2O_5	Graphite
CFP (kg CO_2 eq.)	5,74 ± 0,51	1,53 ± 0,24
CED (kg CO_2 eq.)	79,61 ± 10,98	51,91 ± 11,74
HT (cases)	2,81 x 10^{-9}	0,75 x 10^{-9}

Table 1. Comparison of environmental indicators between Nb_2O_5 and graphite (cradle-to-gate).

CONCLUSIONS

The results indicate that although Nb_2O_5 offers promising electrochemical advantages for application in batteries, its production currently involves higher environmental burdens in several impact categories. However, it is worth pointing out that Nb_2O_5 and graphite differ substantially in physical properties and roles in battery systems, requiring further LCA studies to compare their environmental burdens normalized by the amount of function or efficiency they can provide. Also, future improvements in process efficiency, energy sourcing, and material recovery may significantly reduce the environmental footprints of Nb_2O_5 production and enhance its sustainability in advanced energy storage technologies.

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