Critical Materials Innovation Hub

CMI Projects Year 11

Focus Area 1 – Enhancing and Diversifying Supply

Advancing Mineral Characterization and Beneficiation

1.1.5 Enhanced domestic extraction of platinum group metals, nickel, copper and cobalt from primary sources

Project Description: This project will develop enhanced methods to extract platinum group metals (PGMs) as well as high value by products, such as nickel (Ni), cobalt (Co) and copper (Cu) from domestic U.S. sources. Ultramafic deposits containing copper and nickel sulfide minerals are globally the most important sources of PGMs. In the United States, the two primary producers of PGMs, nickel and cobalt are Sibanye Stillwater in Montana and the Lundin Eagle Mine in Michigan. This project will partner with these producers.

1.1.6 Extraction of rare earth phosphate minerals from primary and secondary sources

Project Description: This project will develop a cost-effective approach for the flotation of phosphate minerals containing rare earth elements (REE) sourced from conventional and unconventional sources including ores, tailings and processing streams. Emphasis is on improving the economics of producing concentrates via design of selective collectors, aiming to develop improved beneficiation technologies for monazite recovery that can be licensed to domestic REE producers. For this purpose, researchers will develop a multimodal platform for building an in-depth understanding of the key molecular interactions at the mineral interfaces. This platform will integrate analytical, computational, advanced surface-sensitive spectroscopic, and mineral processing capabilities.

1.1.7 Improving beneficiation efficiency via preferential breakage and physical separation

Project Description: This project is directed towards improving rare earth recovery at the Rare Element Resources (RER) Bear Lodge project while also increasing process energy and water use efficiency. Studies will explore preferential breakage using high pressure grinding roll systems and stirred milling, possibly paired with sortation and flotation. Potentially, the project will identify the combined impact of using these new and developing techniques in combination for the benefit of rare earth production in the United States.

1.1.9 Diversifying lithium supply from brines to hard-rock minerals: mechanochemical extraction of lithium at low temperature (MELLT) from α-Spodumenes

Project Description: In the United States, brines are the primary source for lithium extraction. However, their long lead times and low lithium extraction yields limit their ability to meet the recent surge in demand. To ensure supply chain sustainability, it is crucial that new hard rock assets, namely spodumenes, are utilized. The major barrier to the implementation of lithium extraction from hard-rock minerals is the significant energy consumption and hazardous waste generation associated with the current industrial methods. To address these challenges, this project will employ mechanochemical reaction that bypasses the most energy demanding step while simultaneously reducing the overall chemical waste.

1.1.10 Enabling lithium mudstone: the nation's largest lithium resource (Project ELM)

Project Description: High-precision geological and mineralogical characterization methods will guide the development and testing of several distinct hypothesis-driven extraction approaches for the nation's largest lithium resource. This approach motivates thorough examination of lithium mudrock mineralogy and thermochemistry to inform novel methods of lithium separation. The major goals of the proposed work will follow from two simultaneous technical tasks. One is characterizing the nature of lithium (Li) and other critical materials from the McDermitt caldera deposit. The other is testing novel metallurgical extraction methods for Li from these resources.

Innovative Separations and Recoveries

1.2.1 Advanced leaching methods to recover critical materials from mineral sources

Project Description: Leaching is the first step in chemically extracting rare earth elements (REEs) from mineral sources. As such, it presents the first opportunity to begin the arduous task of intra-element separation. This opportunity is squandered with conventional leaching practices that rely on the use of strong mineral acid and base lixiviants with little-to-no REE selectivity. This project seeks to design, develop, and implement novel lixiviants to achieve separative leaching of target REEs from mineral feedstocks such as bastnaesite. To achieve this goal, researchers will employ organic and inorganic synthesis, coordination chemistry, automation, and high-throughput techniques.

1.2.2 Enhancing critical mineral separation for sustainable extraction

Project Description: Rare earth element (REE) separations remain a grand challenge (https://iastate.box.com/v/cmi-grand-challenges), accounting for the major cost in producing purified REEs from ore. The current state-of-the-art for industrial REE separations utilizes solvent extraction with phosphonic acids, a complex process notorious for its excessive chemical consumption, wastewater effluents, and hundreds of processing steps required to produce individual purified REEs. This project seeks to facilitate domestic REE production by developing a technology for the separation of all critical REEs using a two-ligand approach that combines lipophilic and hydrophilic neutral ligands with contrasting selectivity.

1.2.3 Recovery and separation of gallium and germanium from zinc wastes

Project Description: The ultimate objective of this project is to selectively recover gallium (Ga) and germanium (Ge) from zinc wastes of different sources. To achieve this objective, the proposed research will: develop and optimize flowsheets for selective separation of Ga and Ge through multistage mineral and hydrometallurgical processing and link the new flowsheets to current operations at domestic refineries, perform Techno-Economic Analysis (TEA) to evaluate the economic feasibility of the developed flowsheets, and perform Life Cycle Assessment (LCA) to assess the environmental impacts of the developed processes against conventional sources of Ga and Ge.

1.2.4 Total utilization of phosphogypsum waste for production of rare earth elements, fertilizers, and construction materials

Project Description: This project is designed to integrate recovery of critical elements into total utilization of the huge phosphogypsum (PG) waste from phosphate mining with five major objectives: reduce radionuclides in PG thus removing a hurdle to its use; maximize REE leaching recovery; develop technologies for REE extraction from the leachate and production of mixed rare earth oxide/salt or individual rare earth metals (MREO/MRES/REMs); make fertilizers using PG with significant CO_2 sequestration; and produce low-cost cement and concrete using PG as raw material with dramatic reduction in carbon footprint compared to the current commercial operations.

1.2.8 Selective separation of platinum group metals, precious metals, and critical elements from selenium crude residue at Kennecott Utah Copperton Concentrator

Project Description: This project will: develop improved approaches to sustainably extract PGMs (platinum (Pt) and palladium (Pd)), selenium (Se), tellurium (Te), and precious metals (gold (Au) and silver (Ag)) from Se crude residue (Se sludge) produced from anode slime processing at Kennecott Utah Copperton Concentrator (KUCC), develop Techno-Economic Analysis (TEA) model to assess economic impacts of the proposed processes, and develop comparative Life Cycle Assessment (LCA) model to evaluate the environmental impacts of the proposed processes as compared to currently used practices.

Focus Area 2 – Developing Substitutes

Materials Discovery and Maturation

2.1.1 Novel chemistry and processes to enable nanostructures for permanent magnets

Project Description: The project will reduce the use of neodymium (Nd), praseodymium (Pr), and dysprosium (Dy) in permanent magnets using a nanostructure engineering approach. Specific objectives include developing high temperature magnets with minimum use of Dy and replacing Nd with lanthanum (La) and cerium (Ce) in neodymium iron boron (NdFeB) magnets for less demanding applications. Both novel chemistry and novel fabrication method will be explored to develop novel processes and their corresponding chemistries to enable scalable manufacturing of nanograined magnets, design the grain boundary phase for enhancing the coercivity of critical-element-lean magnets and develop the process to put these grain boundary phases at the desired location.

2.1.2 Accelerated discovery and development of low-cost, low-criticality competitor to the $Nd_2Fe_{14}B$-based magnets

Project Description: The project aims for discovery and further development of a new permanent magnet materials that will compete with the current technologies, i.e., neodymium iron boron (NdFeB) magnets and/or samarium-cobalt (SmCo) magnets, whereas being significantly less expensive and utilizing only minimal amounts (10 - 15 wt.%) of critical metals like neodymium (Nd), dysprosium (Dy), Sm and Co. This is a science-based approach of looking for new, undiscovered, critical rare-earth poor, iron-rich binary, ternary and higher compounds and/or new or unappreciated ferromagnets containing abundant and non-critical elements. The benefit of such a discovery is deployment of magnets that can substitute for today's supply-chain dependent, critical rare-earth based magnets.

2.1.3 Systems level modeling and prototyping

Project Description: This project will use systems level modeling and prototyping as means for developing alternatives or substitutes for rare earth elements (REE). This includes developing new designs/topologies that enable reduced use of permanent magnets, hence their REE contents. It also includes modifying existing designs such that newly developed or recycled magnets can be used to meet performance requirements. Therefore, this approach offers both the opportunity to reduce the critical REE contents of permanent magnets and the avenue for deploying lower-performing, cost-effective magnets.

Decarbonized Rare Earth Metals Production

2.2.5 Bypassing electrolysis: one-step calciothermic route to NdFeB powders from Nd_2O_3

Project Description: The primary objective of the proposed research is to develop a domestic one-step environmentally-friendly production methodology, which can directly convert neodymium oxide (Nd_2O_3) into neodymium iron boron (NdFeB) hard-magnetic powders. The proposed innovative method employs a calciothermic reduction process circumventing expensive and environmentally detrimental production of Nd metal, typically performed in industry through electrolysis, while mitigating greenhouse gas emissions by effectively eliminating the necessity for additional energy-intensive steps like strip casting. The implementation of the proposed calciothermic reduction technology in the United States will reduce reliance of U.S. economy on foreign suppliers of materials for permanent magnets.

2.2.6 Decarbonized metallothermic reduction of recycled rare earths

Project Description: The main goals of this project are develop kg-level production at ambient conditions of anhydrous rare earth fluoride from the recycled rare earth-containing waste streams without any hydrofluoric acid or ammonium bifluoride use; demonstrate commercial-grade rare earth metal production; and decarbonize rare earth metal production technology from the recycled materials through the synergetic adjustment of recovery and reduction steps (the target is 50-80% reduction of carbon intensity). The outcome of this project will be a successful demonstration of commercial-grade rare earth metal production (kg-scale batches), supported by Techno-Economic Analysis (TEA) and Life Cycle Assessment (LCA).

2.2.8 A novel 'continuous' reactor for molten salt electrowinning of neodymium metal enabling low-cost, scalable and sustainable domestic metal production

Project Description: This project will develop a novel electrochemical reactor for 'continuous' production of neodymium metal from domestic ores. Continuous processing has the advantage of superior energy efficiency, reduced cost, improved control, and ease of process scalability. The electrochemical reactor will employ a molten salt electrolyte comprising chloride species instead of conventional oxyfluorides. This enables an environmentally-friendly, sustainable process that is free of greenhouse gas emissions. The research team will design the electrochemical reactor, build and demonstrate its operation, and optimize a proprietary anode coating to function efficiently at the operating conditions needed for 'continuous' molten neodymium metal production. Complementary tasks will include materials characterization to confirm metal product purity, develop new methods for proprietary anode coating fabrication, and a collaboration within the Critical Materials Innovation Hub for Techno-Economic Analysis (TEA) and Life Cycle Assessment (LCA). Upon successful completion, this project will enable the deployment of a domestic rare-earth metal production process helping to safeguard the U.S. critical materials supply chain.

Novel Processing

2.3.4 Tailored synthesis in nanoparticle permanent magnets (NPPM)

Project Description: This project will leverage expertise in materials synthesis, characterization and modeling to realize nanoparticle permanent magnets (NPPM) primarily composed of earth abundant elements (iron and nitrogen). The project will address the challenges in forming dense, grain aligned magnets without decomposing the magnetic phase or degrading magnetic properties. Processing informed by atomistic modeling will guide the formation, growth, and stability of the NPPM and their grain boundary phases. Methods for maintaining coercivity during compaction to reach 90% alignment by volume and 95% densification will be guided by advanced characterization to inform models and validate novel processing routes.

2.3.7 Accelerated magnetic development via microstructure design

Project Description: The project bridges the gap between discovery and synthesis of bulk permanent magnets through microstructure design. While the discovery aspect of permanent magnets is typically based on intrinsic magnetic properties of materials, producing magnets for practical use requires microstructural development of extrinsic magnetic properties during synthesis. This project will accelerate the synthesis process through rational microstructure design that combines multi-scale and multi-physics simulations, thus reducing the labor- and cost- intensive experimental works. Ultimately, researchers will accelerate the opportunities for novel magnets to be developed, including rare earth-based, rare earth free and exchange-coupled magnets.

Focus Area 3 – Building a Circular Economy

Green Chemistry Approaches

3.1.2 Biological separation of clean-energy-critical rare earth elements

Project Description: The goal of this project is to develop an economical and environmentally sustainable protein-based process for rare earth element (REE) separation from electronic waste (E-waste). Researchers will target separations that range from relatively "easy" (i.e., neodymium (Nd) v. dysprosium (Dy)) to highly challenging (i.e., Dy v. terbium (Tb), and Nd v. praseodumium (Pr)) using size-reduced lanmodulin proteins. By combining the acid-free leaching process with the all-aqueous protein-based REE separation process, researchers anticipate the development of an end-to-end process with significantly lower chemical consumption and environmental impact relative to conventional hydrometallurgical processes.

3.1.3 Thin film semiconductor recycling

Project Description: This project seeks to develop an electrochemical path to effectively substitute or reduce chemically intensive recycling methods currently applied for the recovery of cadmium (Cd) and tellurium (Te) in thin film CdTe-based photovoltaic (PV) panels. The goal is to lower cost and environmental impacts through reduced chemical use, milder/safer operation and lower waste generation. Work will be performed with First Solar, a current manufacturer and recycler of PV panels. This partnership will ensure this technology is relevant to improving the existing circular economy.

3.1.5 Lithium recovery from diluted sources

Project Description: This project aims at extracting lithium (li) from the costless brine, produced water, or lithium mining waste solutions, which will help solve the supply chain issue for lithium by unlocking domestic resources. Li is the only critical metal in the cathode common to all current types, making it the hardest to replace. The project features carbon dioxide ($CO_{2)}$ capture and mineralization, acid generation, and recyclability on a major portion of chemicals. So, this green process will not only contribute to solving the Li supply chain issue, but also fit in the scope of the Net-Zero World in 2050.

Process Intensification and Preprocessing to Improve Manufacturing Efficiency

3.2.4 Capture and fractionation of lanthanide salts with dimethyl ether-driven fractional crystallization (DME-FC)

Project Description: In this project, solvent-driven fractional crystallization (FC) and electrochemical membrane reactor (EMR) technology will be advanced to recover mineral salts, including lanthanides from dilute complex wastewater sources, remove impurities and lanthanides from lanthanide containing leach solutions, and drive selective lanthanide-lanthanide separation. The major limitation of commercializing solvent-driven FC is the cost of removing and recovering trace solvent from treated solutions. This project will advance the use of dimethyl ether (DME), a condensable gas with significant water solubility that can be easily recycled to solve this limitation. Part of this project will use EMR to extract rare earth elements from bauxite residue, also called red mud. This solid waste generated during alumina extraction from bauxite contains about 1 kg rare earth elements per ton.

3.2.6 Highly selective separation and recovery of rare earth elements for clean energy

Project Description: In this project, novel Membrane Solvent Extraction (MSX) technologies will be evaluated based on the previous experience and in-depth understanding of MSX for rare earth element (REE) extraction from various feedstocks to recover high purity heavy rare earth directly from intra-lanthanide separations. The effect of process conditions such as type of extractant, different extractants (cationic and neutral extractants), type of extractant diluent, different feedstocks, feed solution concentration, feed/strip pH, extractant composition, and feed/strip residence time will be investigated to achieve high extraction rates and separation factors for dysprosium (Dy) over other metal constituents in respective processes. Preliminary Techno-Economic Analysis (TEA) will be performed to assess the cost-effective of the MSX process.

Manufacturing Methods to Enable Insertion of Recycled Products into Supply Chains

3.3.1 Sustainable graphite production for lithium-ion battery anodes using lignin or polyethylene wastes

Project Description: Graphite is at heart of modern energy technologies, including energy storage devices and energy conversion processes. The supply chain of natural graphite is controlled by few countries and energy extensive synthesis process (Acheson process, >3000 °C) is the only technique to synthesize this highly demanded commodity, a critical material listed by U.S. Department of Energy (https://www.energy.gov/cmm/what-are-critical-materials-and-critical-minerals). The overarching goal of this project is to develop a new sustainable graphite synthesis process that can utilize renewable sources (biomass) and polyethylene (PE) wastes and convert them to pure and highly crystalline graphite suitable for energy-related applications including battery anodes for fast charging application for electric vehicles (EVs).

Focus Area 4 – Crosscutting Research

Enabling Science

4.1.1 Advanced computational thermodynamics and kinetics

Project Description: This crosscutting project will develop, validate, and exercise computational thermodynamics, microstructure evolution and ab initio methods, and alloy optimization software packages, including their integration into high-performance software packages, to improve efficiency in rare earth metal production and design and processing of new and existing magnets. By design, this project welcomes collaborations across the Critical Materials Innovation Hub and is not topic limited. The modeling tools developed will be used to study new materials for alloy design and integrate new models for process optimization. This work focuses on rare earth metal production and REE and critical REE-free permanent magnet formulations.

4.1.2 Automated and artificial intelligence (AI)-accelerated separation of critical materials

Project Description: The goal for a net-zero carbon emission economy by 2050 requires the rapid maturation and deployment of next-generation energy technologies in less than three decades. The successful achievement of this goal is highly dependent on developing and applying innovative methods to dramatically improve the supply chain of critical materials by sustainable recovery and mining. The overarching goal of this project is to automate and accelerate the complete research, development and demonstration (RD&D) workflow at the lab scale by employing data-driven and artificial intelligence (AI) enabled methods to develop advanced extractants and sustainable separation processes.

4.1.5 Critical materials process thermodynamics (CMPT)

Project Description: This project aims to gather thermodynamic data and use this information to help other Critical Materials Innovation Hub projects solve processing-related problems. Very frequently, a process's thermodynamic analysis can reduce the time required to solve a problem and provide a more complete understanding of the process. The thermodynamics team will build on its critically evaluated databank by providing simulations and expanding its database. These efforts enable CMI researchers to have realistic process modeling to create better experimental designs for solving process-related problems.

Criticality and Supply Chain Analysis

4.2.3 Market and supply chain analysis of critical materials

Project Description: This project will provide decision-making tools at the system level that ultimately will help mitigate supply chain risks, utilize materials more efficiently, and increase the likelihood of adoption of CMI technologies. Main methodologies will include stakeholder engagement approach to identify supply chain bottlenecks, operations research and market modeling to understand market/technology landscape over time, and dynamic integration of Life Cycle Assessment (LCA) and market modeling to inform technology development. By adopting a proactive approach to material supply chain dependencies/interactions, the project looks to mitigate supply chain concerns, ensure sustained progress and the pursuit of promising avenues of research and development activities for CMI technologies, and quantify supply chain impacts of CMI technologies at national or global levels.

4.2.7 Enhancing criticality assessment – from backward-looking to anticipatory perspectives

Project Description: This project will research understanding the history of materials criticality, and developing ways to reliably predict the future criticality of minerals in the U.S. economy. Compared to existing analyses, this project will will be more forward looking and focused on identifying what might become critical, more in-depth by focusing on specific supply chains in specific energy-technology areas, and broader by evaluating the environmental and social dimensions of critical materials as well as supply chain risks and resiliency. This will build on enhanced criticality assessment in the U.S. Department of Energy's America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition (https://www.energy.gov/policy/securing-americas-clean-energy-supply-chain).

Economic, Environmental, and Social Impact Analysis

4.3.4 Techno-Economic Assessment (TEA) and Life Cycle Assessment (LCA) of Critical Materials Innovation Hub technologies

Project Description: This project is focused on assisting R&D teams of the Critical Materials Innovation Hub to advance the technology readiness level (TRL) of their technologies via Techno-Economic Assessment (TEA), Life Cycle Assessment (LCA), and/or Design of Experiment (DOE) methods. This project involves collaborations with other CMI projects to improve economic and environmental performance of innovative technologies and processes. Advanced approaches/methods such as DOEs, sensitivity analysis, process simulation, risk analysis, and supply chain analysis will be utilized in support of the project.

4.3.6 Ecosystem impacts of critical material recovery and processing

Project Description: The goal of this research is to evaluate newly developed critical material recovery technologies to avoid producing the next contaminant of emerging concern. While collaborating with mining and materials researchers, this project will use a series of ecological toxicity tests to assess potential environmental impacts of new critical material recovery or recycling technologies. The knowledge can be used to identify lower impact critical material processing techniques and/or waste remediation strategies. This project benefits society by providing a basis for understanding how critical material recovery affects the environment and how remediation strategies can aid in the detoxification of processing waste.

4.3.8 Social acceptance of critical battery mineral developments in the United States

Project Description: The goal of domestic production of critical minerals faces frequent challenges around community acceptance due to economic, social, and environmental justice concerns. This project focuses on understanding community perspectives around critical mineral developments in the United States, which is a necessary precondition to achieve the specific goals of Justice40 and general aspirations around community benefits. Through a mixed method study of current and proposed projects in Idaho, Minnesota, and Missouri, this project will identify the conditions under which social acceptance is obtained or withheld and why, as well as the opportunities for communities to participate in and benefit from these developments.