Environment and Natural Resources Trust Fund

2027 Request for Proposal

General Information

Proposal ID: 2027-465

Proposal Title: Sustainable Recovery of Critical Mineral Elements from Wastes

Project Manager Information

Name: Xinyuan Zheng

Organization: U of MN - College of Science and Engineering

Office Telephone: (612) 301-3836

Email: zhengxy@umn.edu

Project Basic Information

Project Summary: This project plans to develop sustainable technologies to recover critical mineral elements from Minnesota waste streams, including mining residues and wastewater, reducing pollution while transforming wastes into valuable resources.

ENRTF Funds Requested: $599,000

Proposed Project Completion: June 30, 2030

LCCMR Funding Category: Energy (E)

Project Location

What is the best scale for describing where your work will take place?

Statewide

What is the best scale to describe the area impacted by your work?

Statewide

When will the work impact occur?

In the Future

Narrative

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

Minnesota has a long legacy of mining as the state is the largest producer of iron ore and taconite in the U.S. Minnesota generates large volumes of waste from mining, industrial operations, and municipal biosolids treatment, including tailings, coal ash, electronic waste, and sewage sludge ash. These wastes often contain trace concentrations of critical elements, including rare earth elements, cobalt, nickel, and gallium, which are essential for renewable energy production and global energy transition. However, the concentrations of these metals are often too low and their mining is inefficient, costly, and environmentally damaging. As a result, these valuable metals are often lost to landfills or remain in waste streams, while residual metals can contribute to soil and water contamination. Minnesota's mining operations, including legacy tailings from the Mesabi Iron Range and other nonferrous mineral exploration sites produce materials with both environmental risk and resource potential. Developing sustainable technologies to recover critical minerals from these waste streams presents a significant opportunity to reduce pollution, minimize waste accumulation, and create new domestic sources of materials essential for clean energy systems. This approach supports Minnesota's transition toward renewable energy while advancing circular economy strategies and strengthening supply chain resilience for critical minerals.

What is your proposed solution to the problem or opportunity discussed above? Introduce us to the work you are seeking funding to do. You will be asked to expand on this proposed solution in Activities & Milestones.

We propose to develop and validate a sustainable, microbial-based system to recover critical minerals from Minnesota-relevant waste streams, including mining tailings, coal combustion ash, electronic waste leachates, and sewage sludge ash. Filamentous fungi and other microbial species will be screened for their capability to capture multiple metals simultaneously through biosorption and bioaccumulation, leveraging their filamentous morphology, high biomass yields, and cell wall functional groups that effectively bind metal ions.

The project will integrate geochemical analysis, microbial cultivation, and downstream processing to create a complete recovery pathway. Selected microbial strains will be tested using both synthetic and real waste streams to evaluate metal uptake efficiency under realistic conditions. Metal-enriched biomass will then be processed using hydrothermal liquefaction and environmentally friendly solvent extraction to recover and purify critical mineral elements (such as rare earth elements and others).

This approach transforms low-value waste into a domestic source of critical mineral elements and renewable energy products. By combining biological recovery with green processing technologies, the project reduces environmental impacts, minimizes metal contamination, and supports circular economy strategies that advance Minnesota's clean energy goals and resource sustainability.

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state's natural resources?

This project will protect and enhance Minnesota's natural resources by reducing metal contamination in mining and industrial waste streams. Microbial based recovery of critical minerals will prevent potentially toxic metals from entering soil and water, while simultaneously recovering valuable elements for reuse. The project will generate verified data on critical mineral concentrations in Minnesota waste, identify effective microbial strains for metal capture, and demonstrate environmentally sustainable recovery processes. By valorizing waste and mitigating pollution, the project advances the conservation and sustainable management of the state's land, water, and mineral resources, supporting Minnesota's long-term environmental and clean energy transition.

Activities and Milestones

Activity 1: Development of analytical protocols for quantifying critical mineral elements

Activity Budget: $209,349

Activity Description:
This activity is to establish reliable analytical protocols for quantifying critical mineral elements (CRE) in waste materials and experimental products generated during the project. Accurate measurements are essential for evaluating the abundance, distribution, and recovery efficiency of critical elements in complex waste matrices.

Standardized procedures will be developed for sample preparation, digestion, and trace-element analysis of both solid and liquid samples. Analytical measurements will be conducted in the PI's geochemistry laboratory at UMN using high-sensitivity techniques, primarily inductively coupled plasma mass spectrometry (ICP-MS). Method validation will include calibration with multi-element standards, analysis of certified reference materials, replicate measurements, and rigorous quality-control procedures to ensure analytical accuracy and reproducibility.

The outputs of this activity will include validated analytical protocols and a dataset of baseline concentrations of rare earth elements (REEs) and other critical metals in representative waste materials. These methods will also be applied to products generated in Activities 2 and 3, including microbial biomass, hydrochar, recovered metal fractions, and process fluids, to quantify metal accumulation and track elemental partitioning during treatment processes. Activity outcomes will be evaluated through analytical precision and reproducibility. These outputs will provide the quantitative foundation for evaluating recovery efficiency and environmental benefits of the proposed technologies.

Activity Milestones:

Description	Approximate Completion Date
Develop standardized sample preparation and ICP-MS analytical protocols for critical mineral elements	September 30, 2027
Validate analytical methods using calibration standards, certified reference materials, and replicate analyses	October 31, 2027
Quantify critical mineral concentrations in representative Minnesota waste streams	December 31, 2027
Quantify critical minerals in bio-accumulation experimental products	July 31, 2029
Quantify critical metals in extraction products	April 30, 2030

Activity 2: Microbial cultivation to enrich critical minerals

Activity Budget: $178,962

Activity Description:
This activity will evaluate filamentous fungi and other microbe species for their ability to accumulate critical mineral elements (CRE) from synthetic and real industrial wastewater and develop a robust microbial-based process for CRE recovery. We will screen ~100 microbial strains, selecting ~10 candidates from genera such as Aspergillus, Penicillium, Trichoderma, Rhizopus, and Mucor based on reported metal biosorption or accumulation. Strains will be cultured in batch flasks with synthetic wastewater containing representative CRE, and CRE concentrations in liquid and biomass will be quantified using ICP-MS at Zheng's lab. High-performing strains will undergo mechanistic studies using FTIR, XPS, and SEM-EDS to distinguish surface adsorption, ion exchange, precipitation, and intracellular sequestration.

Following screening, promising biosorption- and bioaccumulation-dominated strains will be tested in real industrial wastewater, collected in activity 1 to assess robustness under complex chemical conditions. Lab-scale bioreactors will then be used to optimize process configurations, operational parameters, and both batch and continuous operation modes. This phased approach, from screening to mechanistic understanding to process optimization, will establish

microbial CRE accumulation as a viable method for recovering critical materials from diverse waste streams while generating kinetic and mass-balance data for potential scale-up.

Activity Milestones:

Description	Approximate Completion Date
Microbial screening for CRE accumulation	December 31, 2028
Mechanism study of CRE accumulation in microbial biomass	March 31, 2029
Bioconversion processing optimization	June 30, 2029

Activity 3: Hydrothermal liquefaction and extraction/purification of REEs and other critical metals

Activity Budget: $210,689

Activity Description:
The critical mineral–enriched algal biomass will be converted into value added bio-oil and a mineral concentrated hydrochar through hydrothermal liquefaction (HTL). HTL conditions, including temperature, pressure, residence time, and solids loading, will be optimized to promote efficient depolymerization of organic components while retaining REEs (and other critical elements) in the solid fraction. By limiting mineral dissolution during liquefaction, critical minerals will preferentially partition into the hydrochar, producing a metal enriched bio-ore. The generated bio oil will be recovered and characterized for yield, elemental composition, and heating value to enhance overall process economics through co-production of renewable fuels.

The hydrochar will then serve as the feedstock for green solvent extraction using biodegradable deep eutectic solvents (DESs), which are effective for dissolving metal oxides. DES systems will be tailored to selectively dissolve target critical minerals while minimizing co extraction of competing metals. Key physicochemical parameters such as viscosity, polarity, complexation strength, extraction efficiency, and phase behavior will be quantified and incorporated into a machine learning framework to predict and optimize recovery performance. Liquid-liquid extraction will be optimized to achieve selective separation and purification of the recovered metals.

Finally, we will develop a fully integrated TEA model to evaluate economic performance.

Activity Milestones:

Description	Approximate Completion Date
Optimize the HTL process to maximize metal recovery and bio-oil production.	March 31, 2029
Develop and optimize metal leaching and separation using DES solvent and liquid-liquid extraction.	March 31, 2030
Develop a Techno-Economic Analysis model to evaluate the process economic viability.	June 30, 2030

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Bo Hu	University of Minnesota	Co-PI	Yes
Xiaowen Chen	University of Minnesota	Co-PI	Yes

Dissemination

Describe your plans for dissemination, presentation, documentation, or sharing of data, results, samples, physical collections, and other products and how they will follow ENRTF Acknowledgement Requirements and Guidelines.
Project results will be shared with stakeholders who can apply the findings to improve management of Minnesota's natural resources. Data on critical mineral element concentrations, recovery efficiencies, and process performance will be communicated to relevant state agencies, such as the Minnesota Pollution Control Agency and other resource management partners, as well as to industry and wastewater utilities managing mining residues and industrial waste streams. These interactions will help ensure that project outcomes inform practical strategies for reducing metal contamination and recovering valuable resources from waste.

Results will be disseminated through peer-reviewed publications, conference presentations, technical reports, and publicly accessible project summaries hosted by the University of Minnesota. Analytical datasets and protocols developed during the project will be archived and made available to researchers and practitioners to support continued work on sustainable resource recovery.

Public outreach activities will include presentations and accessible summaries describing the environmental benefits of critical mineral recovery from waste streams. All publications, presentations, and outreach materials will acknowledge support from the Minnesota Environment and Natural Resources Trust Fund (ENRTF) and follow ENRTF acknowledgment guidelines. These dissemination efforts will help ensure project outcomes support improved environmental management, long-term data accessibility, and public awareness of work supported by the Trust Fund.

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this work be funded?
Project results will provide validated data and technologies for recovering critical mineral elements from Minnesota waste streams. Findings will be shared with state agencies, industry partners, and wastewater utilities to support adoption of sustainable metal recovery practices that reduce pollution and transform waste into valuable resources. Follow-up work to scale and demonstrate the technologies at pilot scale will be pursued through partnerships with industry and utilities and through competitive funding from federal agencies such as U.S. Department of Energy, National Science Foundation, and other programs supporting critical mineral recovery and circular economy technologies.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Novel Nutrient Recovery Process from Wastewater Treatment Plants	M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 04b	$200,000

Phytoremediation for Extracting Deicing Salt	M.L. 2022, , Chp. 94, Art. , Sec. 2, Subd. 08g	$451,000
Novel Nutrient Recovery Process from Wastewater Treatment Plants	M.L. 2024, , Chp. 83, Art. , Sec. 2, Subd. 04g	$486,000

Project Manager and Organization Qualifications

Project Manager Name: Xinyuan Zheng

Job Title: Associate Professor

Provide description of the project manager's qualifications to manage the proposed project.
The project will be managed by Dr. Xinyuan Zheng, tenured Associate Professor in the Department of Earth and Environmental Sciences at the University of Minnesota. Dr. Zheng received his Ph.D. in Earth Sciences from the University of Oxford and subsequently served as a postdoctoral researcher and assistant research scientist at the University of Wisconsin–Madison before joining the University of Minnesota in 2019. He is an internationally recognized geochemist specializing in the development and application of geochemical approaches, including novel isotope tracing methods, to investigate Earth surface processes such as chemical weathering, water–rock interactions, and environmental geochemistry.

Dr. Zheng directs the Zheng Isotope Geochemistry Laboratory, a state-of-the-art analytical facility representing an investment of approximately $2 million from the university and external funding agencies, including the National Science Foundation (NSF). The laboratory houses advanced mass spectrometry instrumentation capable of ultra-trace concentration analyses and high-precision isotope measurements across a wide range of elements in geological, environmental, and biological samples.

Dr. Zheng has authored and coauthored more than 30 peer-reviewed publications and serves as lead PI on multiple externally funded research projects, including the prestigious CAREER award from NSF. He has served on review panels for NSF and NASA and as an external reviewer for international funding agencies such as the German Research Foundation (DFG) and the Swiss National Science Foundation. His extensive experience managing complex research programs, coordinating multi-institutional collaborations, and training students and postdocs ensures the proposed project will be completed efficiently and deliver high-quality results to stakeholders and the public.

Organization: U of MN - College of Science and Engineering

Organization Description:
At the University of Minnesota, we look at the bigger picture. When we envision a better tomorrow, it includes disease-resistant crops, products that protect our health, lakes free from invasive species, and so much more. We use science and engineering to find answers to Minnesota's and the world's grand challenges and solve tomorrow's problems.

The lead PIs on this project come from two different colleges in the University of Minnesota (College of Science and Engineering and College of Food, Agriculture, and Natural Resource Science). This is a highly interdisciplinary project and requires the tremendous environment that the University of Minnesota provides for this type of collaboration.

The two colleges have a public impact through community engagement and extension efforts. We develop and deliver high quality, regionally and nationally-recognized research-based programs to meet current and emerging needs of industry and communities. We also have a long-standing tradition of close partnerships with alumni, industry professionals, organizations, government agencies, donors, and community members.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
PI (Zheng)		oversee all aspects of the project and leading critical metal analysis efforts			29%	0.15		$43,467
Co-PI (Hu)		leading bio-accumulation experiments and help integrate results in the broader context of the project			29%	0.09		$30,420
Co-PI (Chen)		leading metal extraction from biomass and help integrate results in the broader context of the project			28%	0.09		$21,474
Postdoc		responsible for carrying out bio-accumulation experiments and metal analysis under supervision of PIs, synthesize, and disseminate results through meetings and publications			22%	3		$265,085
graduate research assistant		primarily carrying out metal extraction experiments, but also assist in other project-related research activities where necessary, including relevant lab work and dissemination of research findings. The budget includes academic year and summer salary, tuition, and fringe benefits.			17%	1.5		$173,215
							Sub Total	**$533,661**
Contracts and Services								
lab services	Internal services or fees (uncommon)	Scientific services needed for this project will be provided by UMN core facilities, including material characterization facilities, biological and analytical services.				0.75		$9,000
							Sub Total	**$9,000**
Equipment, Tools, and Supplies								
	Tools and Supplies	lab supplies, including chemicals, standard materials, PPEs, other lab and instrument consumables (e.g., bottles, tubes, etc), mass spectrometer and other relevant experimental equipment parts and essential maintenance items that keep these instruments functional for this project.	essential lab supplies needed to complete the planned experiments and measurements					$53,339

							Sub Total	**$53,339**
Capital Equipment								
							Sub Total	**-**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
	Miles/ Meals/ Lodging	9 trips estimated for 3 years (3 trip per year, and 1-5 people, including PIs and trainees, during each trip), with estimated total milage of 1500. The rate estimate is based on standard GSA milage and per diem/lodging rates.	collect waste materials needed for research in this project from various waste suppliers					$1,500
	Conference Registration Miles/ Meals/ Lodging	1 trip for 5 people (PIs and trainees on this project), estimated 400 miles, and standard GSA milage and per diem/lodging rates.	attend one local meeting to present results from this project					$1,500
							Sub Total	**$3,000**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$599,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	**-**
Non-State				
			Non State Sub Total	**-**
			Funds Total	**-**

Total Project Cost: $599,000

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: f2cf06f5-cb2.pdf

Alternate Text for Visual Component

A workflow for recovering critical metals from Minnesota waste streams. Waste materials are treated with microbes that accumulate metals, followed by extraction using environmentally friendly methods. The project aims to reduce pollution and support a circular economy and national security by supplementing domestic critical metal supply....

Supplemental Attachments

Capital Project Questionnaire, Budget Supplements, Support Letter, Photos, Media, Other

Title	File
Institutional Support Letter	a2189235-738.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Do you understand that travel expenses are only approved if they follow the "Commissioner's Plan" promulgated by the Commissioner of Management of Budget or, for University of Minnesota projects, the University of Minnesota plan?

Yes, I understand the UMN Policy on travel applies.

Does your project have potential for royalties, copyrights, patents, sale of products and assets, or revenue generation?

No

Do you understand and acknowledge IP and revenue-return and sharing requirements in 116P.10?

N/A

Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF?

N/A

Does your project include original, hypothesis-driven research?

Yes

Does the organization have a fiscal agent for this project?

No

Does your project include the pre-design, design, construction, or renovation of a building, trail, campground, or other fixed capital asset costing $10,000 or more or large-scale stream or wetland restoration?

No

Do you propose using an appropriation from the Environment and Natural Resources Trust Fund to conduct a project that provides children's services (as defined in Minnesota Statutes section 299C.61 Subd.7 as "the provision of care, treatment, education, training, instruction, or recreation to children")?

No

Provide the name(s) and organization(s) of additional individuals assisting in the completion of this proposal:

N/A

Do you understand that a named service contract does not constitute a funder-designated subrecipient or approval of a sole-source contract? In other words, a service contract entity is only approved if it has been selected according to the contracting rules identified in state law and policy for organizations that receive ENRTF funds through direct appropriations, or in the DNR's reimbursement manual for non-state organizations. These rules may include competitive bidding and prevailing wage requirements

N/A