Environment and Natural Resources Trust Fund

2024 Request for Proposal

General Information

Proposal ID: 2024-226

Proposal Title: Recovering Salts from Highly Saline Wastewater

Project Manager Information

Name: Natasha Wright

Organization: U of MN - College of Science and Engineering

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Project Basic Information

Project Summary: We aim to develop a method of recovering useful salts from concentrated saline waste, increasing the economic sustainability of high water-recovery softening, sulfate removal, and industrial wastewater treatment.

Funds Requested: $241,000

Proposed Project Completion: June 30, 2027

LCCMR Funding Category: Water Resources (B)

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.

Levels of chloride and sulfate (both salts) in Minnesota waterways is a concern due to the potential for harm to aquatic life (chloride) and the quality of water used for growing wild rice (sulfate). These impacts are the result of linear systems in which resources are extracted, used, and disposed of as waste.

Increased chloride comes from sources including the salt used for winter road maintenance, water softeners, industry, and agriculture. Sulfate also has multiple sources to surface water, including industrial and domestic waste, and use of groundwater for agricultural, industrial, and domestic needs. Because water treatment plants are not equipped with the technology to remove dissolved salts, chloride and sulfate entering these facilities discharge to waterways.

An opportunity exists to reduce this discharge to waterways by installing advanced water treatment technology (such as reverse osmosis, RO). Doing so, however, would result in a liquid waste stream (brine) that contains all the removed contaminants in highly concentrated form. Treating and disposing of this brine is expensive. An ENTRF-funded report indicates that brine management would represent >46% of the total capital cost and >81% of the operational cost of newly installed RO systems at sample sites (MPCA, 2018).

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.

Existing brine management systems are linear; they do not consider the potential useful recovery and reuse of the original salt inputs. We propose to push this linear system to become a circular system, one that aims to keep resources in use for as long as possible, minimizing waste and degradation of the environment.

Our previous ENTRF-funded project explored the use of convection enhanced evaporation (CEE) to reduce the capital and energetic cost of brine management in Minnesota. The system uses packed surfaces to increase the evaporative surface area for a given area of land by >50x. We have modeled and experimentally validated the evaporative performance of the CEE system. As water evaporates from the surfaces, the remaining brine becomes “supersaturated” increasing the tendency of salts to crystallize. This has historically been viewed as a maintenance problem that leads to expensive chemical clean-in-place procedures, but what if this didn’t have to be the case? In this proposal, we expand on our previous work to consider the intentional crystallization of salts on evaporation surfaces for the purpose of useful recovery. We will study this possibility by working to understand the temperature and time-varying behavior of salt crystallization in mixed-salt brines.

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?

In this proposal, we aim to understand salt crystallization in mixed-salt brines as the next step in achieving our long-term objective of sustainable, circular, systems for managing brine from industrial sources and advanced water treatment plants. This could allow for: (i) reduced discharge of salts to the environment, (ii) on-site recovery of salts for reuse, and (iii) reduced concentration of sparingly soluble salts in the primary water treatment train (e.g. RO), enabling higher water recovery. All three of these potential outcomes would serve to reduce the extraction of water and/or salts, and move Minnesota toward a circular economy.

Activities and Milestones

Activity 1: Develop and validate a model that couples the thermodynamic and kinetic behavior of mixed-salt crystallization.

Activity Budget: $139,832

Activity Description:
The extent of crystallization for a specific salt mixture depends on both thermodynamic models (e.g. saturation indices at a specific temperature) and kinetic behavior (e.g. nucleation rate and crystal growth at a specific time). While models exist for individual salts at specific temperatures, they do not cover the range of temperatures expected in brine evaporation systems, nor the behavior of mixed-salt solutions.

We will develop a model to describe the temporal crystallization of salts in aqueous solutions. This requires combining published thermodynamic models with kinetic models already under development in our lab. Once combined, we aim to account for the solubility of multiple inorganic salts (sodium chloride, calcium sulfate, etc.) in mixed salt brines. The new model will: (i) load the PhreeqC database and calculate the saturation indices for salts at each step change in solute concentration and (ii) integrate with empirical kinetic models of nucleation and crystal growth obtained from experiments in our lab, to calculate the mass of the crystallized salt at each time step. Validation of modeled results will be completed using bench-top experiments. Saline solutions containing representative mixed salts will be allowed to crystallize and the crystals formed will be evaluated using x-ray diffraction.

Activity Milestones:

Description	Approximate Completion Date
Model loads PhreeqC database and solves mixed-salt systems thermodynamically.	December 31, 2024
Crystallization kinetics prediction model developed from the lab's existing experimental data.	June 30, 2025
Models of Milestones 1 and 2 coupled to provide temporal prediction of crystallized salt composition.	September 30, 2025
Model validated using representative mixed salt brines.	December 31, 2025

Activity 2: Develop and validate a model that couples the behavior of salt crystallization and water evaporation.

Activity Budget: $101,168

Activity Description:
As water evaporates, the remaining brine becomes "supersaturated" increasing the tendency of salts to crystallize. Additionally, the temperature of the brine decreases, having lost energy to the evaporated water. In this activity, we aim to couple the temperature- and time-dependent crystallization model developed in Activity 1, with our lab's existing model for convection enhanced (CEE) systems to predict the thermodynamics and kinetics of salt crystallization in such evaporative brine reduction technologies. To validate the integrated model, we will conduct benchtop experiments in which we precisely control evaporation rate using vacuum pumps, and filter and analyze the formed crystals in terms of their composition and size. We will additionally introduce various substrates to study the impact of surface properties on the crystal growth and morphology. The crystal mass formed on the substrate will be compared with the modeled results.

Activity Milestones:

Description	Approximate Completion Date
Crystallization model of Activity 1 coupled with existing evaporation models.	June 30, 2026

Experimental validation of crystallization model assuming homogeneous nucleation and crystal growth (ie without substrates).	December 31, 2026
Experimental validation of crystallization model assuming heterogeneous nucleation and crystal growth (ie with substrates).	June 30, 2027

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?

We will pursue National-scale funding for this project through the Bureau of Reclamation, a federal agency particularly interested in saline brine management. This agency has previously supported our field testing of convection enhanced evaporation (CEE) systems. We also hope to work with a team at the Carlson School of Management to determine realistic value propositions for the technology.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Managing Highly Saline Waste From Municipal Water Treatment	M.L. 2021, First Special Session, Chp. 6, Art. 5, Sec. 2, Subd. 04a	$250,000

Project Manager and Organization Qualifications

Project Manager Name: Natasha Wright

Job Title: Assistant Professor of Mechanical Engineering

Provide description of the project manager's qualifications to manage the proposed project.

B.S., Mechanical Engineering, 2012, University of St. Thomas, St. Paul, MN
S.M., Mechanical Engineering, 2014, Massachusetts Institute of Technology, Cambridge, MA
PhD, Mechanical Engineering, 2018, Massachusetts Institute of Technology, Cambridge, MA
Post-Doctoral Associate, Environmental Engineering, 2019, University of Minnesota

Dr. Natasha Wright will be responsible for the overall project coordination. Her research focuses on the design of decentralized desalination (salt removal) systems, with a specialty in thermal and membrane-based separation processes and their pairing with renewable energy sources. Over the last 10 years, she has piloted combined energy generation / water treatment systems in the United States, India, and Gaza. Recent work has focused on reducing the cost of small-scale desalination systems via the redesign of system sub-components. This work has resulted in numerous design awards including Forbes 30 Under 30 and the Lemelson Prize at MIT, three patents, and several papers in the field of Desalination.

Organization: U of MN - College of Science and Engineering

Organization Description:

The University of Minnesota is one of the largest, most comprehensive, and most prestigious public universities in the United States (http://www1.umn.edu/twincities/01_about.php). The laboratories and offices of the PI contain all of the necessary fixed and moveable equipment and facilities needed for the proposed studies.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Project Manager		Project coordination, guide development of model extension, supervise graduate students. 1 month/year, 3 years, including UMN rate of 36.8% benefits.			27%	0.24		$48,746
Graduate Research Assistant		Analytical model extension, experimental testing, data synthesis. Includes UMN rate of 24.1% benefits plus tuition.			44%	1.26		$143,679
Undergraduate Researcher		Assist with experimental data collection. 1 students for 10 hours/wk at $15/hr over 2 years.			0%	0.5		$15,600
							Sub Total	**$208,025**
Contracts and Services								
							Sub Total	**-**
Equipment, Tools, and Supplies								
	Tools and Supplies	Prototyping materials, consumable supplies, sensors and data acquisition equipment, scientific characterization facilities use fees, operating costs for laboratory instruments required for analyses and experiments	Tools and supplies required to experimentally validate the salt crystallization models.					$19,975
							Sub Total	**$19,975**
Capital Expenditures								
							Sub Total	**-**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								

	Conference Registration Miles/ Meals/ Lodging	2 conferences, attendances by project manager and graduate student.	Attendance at local conferences to disseminate project findings.					$3,000
							Sub Total	**$3,000**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
	Publication	Publications charges (x2)	To make published journal articles immediately available via open access to maximize data availability and dissemination.					$10,000
							Sub Total	**$10,000**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$241,000**

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				
In-Kind	University of Minnesota	Because the project is overhead free, laboratory space, electricity, and other facilities/administrative costs (55% of direct costs excluding permanent equipment and graduate student tuition benefits) are provided in-kind.	Secured	$108,725
			Non State Sub Total	**$108,725**
			Funds Total	**$108,725**

Attachments

Required Attachments

Visual Component

File: 92d511db-980.pdf

Alternate Text for Visual Component

The figure shows the difference between linear systems, in which a resources (salt) is used for an industrial process or road maintenance, and then discharged to waterways, vs. a circular system, in which the same resource is used and then recovered during the brine management step, limiting discharge to waterways....

Optional Attachments

Support Letter, Photos, Media, Other

Title	File
University of Minnesota Support Letter	ad1bfe87-474.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

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

Yes

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

Yes

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

No

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 design, construction, or renovation of a building, trail, campground, or other capital asset costing $10,000 or more?

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?

No