Environment and Natural Resources Trust Fund

M.L. 2026 Final Work Plan

General Information

ID Number: 2026-540

Staff Lead: Tom Dietrich

Date this document submitted to LCCMR: May 25, 2026

Project Title: Novel Piezoelectric Energy Converters for Minnesota Waters

Project Budget: $475,000

Project Manager Information

Name: Lian Shen

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Project Reporting

Reporting Schedule: April 1 / October 1 of each year.

Project Completion: June 30, 2029

Final Report Due Date: August 14, 2029

Legal Information

Legal Citation: M.L. 2026, Chp. 104, Sec. 2, Subd. 07b

Appropriation Language: $475,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for the St. Anthony Falls Laboratory to model and evaluate the viability of an innovative renewable energy approach using an underwater piezoelectric filament canopy to sustainably harness the untapped wave energy resources of Lake Superior and similar regions.

Appropriation End Date: June 30, 2029

Narrative

Project Summary: This project will model and evaluate an innovative renewable energy approach—an underwater piezoelectric filament canopy—to sustainably harness the untapped wave energy resources of Lake Superior and similar regions.

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

Minnesota's goal of achieving 100% carbon-free electricity by 2040, along with the growing push for energy independence, underscores the urgency of expanding renewable energy solutions statewide. Currently, Minnesota obtains 33% of its energy from renewable sources, yet Lake Superior, a vast reservoir of untapped wave energy, remains largely overlooked. Minnesota's North Shore waves offer a consistent renewable power source, averaging 260 MW annually and surging up to six times higher during winter storms.

Wave Energy Converters (WECs) are innovative technologies primarily designed for ocean coastlines, such as those in Scotland or the Pacific Northwest. Unfortunately, we cannot simply install the WECs for ocean coasts, as Lake Superior has distinct design parameters, benefits, and challenges. The lake features smaller wave heights and shorter periods—approximately one-third the scale observed along ocean coasts—requiring smaller, specialized WECs with tailored control systems. Additionally, Lake Superior presents an engineering challenge due to the formation of winter ice along its shore. Because wave energy availability peaks dramatically during winter (6 kW/m in December, 0.6 kW/m in June), developing resilient WEC technology capable of operating continuously in icy conditions is essential to fully harness this promising and abundant renewable energy resource.

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 a novel Wave Energy Converter (WEC) designed specifically for Lake Superior's unique wave and environmental conditions: an underwater canopy composed of piezoelectric filaments. Utilizing polyvinylidene difluoride (PVDF), a piezoelectric material that generates electricity when mechanically bent, these filaments efficiently convert wave-induced movements into electrical energy. With piezoelectric patches running down both sides of a long, bendable panel, the piezoelectric filament energy converter is well-studied and can generate electricity in both a steady current and an oscillatory wave field. A "canopy" array of piezoelectric stems is well-suited for the shores of Lake Superior. The canopy could generate electricity from small waves in the summer months, large waves in November, and from currents that run under ice. Additionally, Lake Superior's freshwater and relatively calm conditions enhance the durability and lifespan of the piezoelectric materials compared to the erosive and harsh oceanic environments. Our proposed project will utilize advanced computational fluid dynamics modeling to optimize the canopy design. Additionally, a detailed economic analysis will be performed to evaluate capital investments, maintenance costs, projected energy production, and environmental benefits. Extensive dissemination activities, including technical reports, policy briefs, scientific publications, and community engagement, will effectively communicate project outcomes to stakeholders and policymakers.

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 advance the public purpose of protecting, conserving, preserving, and enhancing Minnesota's natural resources by exploring a novel renewable energy solution. Specific outcomes include a comprehensive viability assessment of the piezoelectric canopy wave energy converter, strategic site recommendations for optimal energy harvesting with minimal ecological disruption, and detailed analyses of environmentally friendly materials and canopy configurations. Additionally, insights on ice interactions ensure the technology's year-round sustainability. Collectively, these outcomes support informed policy decisions, foster the adoption of renewable energy, reduce dependency on fossil fuels, and protect Lake Superior's pristine ecosystem and the state's broader environmental health.

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?

During the Project and In the Future

Activities and Milestones

Activity 1: Identify Lake Superior Wave Characteristics to Determine the Design and Simulation Conditions of Wave Energy Converter

Activity Budget: $125,000

Activity Description:
The objective of this activity is to gather comprehensive data on Lake Superior's wave characteristics, which are essential for accurately modeling the piezoelectric canopy Wave Energy Converter (WEC). Key wave parameters, including significant wave height, dominant wave period, mean wave direction, water depth, wind speed, fetch, and spectral wave information, will be collected from existing NOAA datasets and scientific literature. Three promising WEC deployment sites will be selected based on wave energy availability, proximity to electricity infrastructure, environmental impact, and community acceptance. Additionally, critical technical parameters of the piezoelectric filaments, such as the patch type, internal resistance, capacitance, and coupling factors, will be determined through comprehensive reviews of industry standards and scientific literature. Material selections for the filaments' core structure will be evaluated based on durability, mechanical flexibility, and hydrodynamic performance. Relevant dimensionless parameters will be formulated to ensure rigorous simulation conditions and accuracy.

Activity Milestones:

Description	Approximate Completion Date
Collection and review of NOAA buoy measurement and simulation wave data	June 30, 2027
Selection of optimal WEC deployment sites	September 30, 2027
Determination of filament and piezoelectric specifications	December 31, 2027
Dimensionless parameters formulation and validation	March 31, 2028

Activity 2: Modeling of Piezoelectric Canopy and Energy Generation Potential

Activity Budget: $150,000

Activity Description:
The goal of this activity is to develop a high-fidelity computational model that predicts the performance of the piezoelectric canopy under the wave conditions of Lake Superior. Direct numerical simulations will model the dynamic interactions between waves and filaments at the selected sites. Initial simulations will quantify baseline performance metrics for individual filaments, with subsequent simulations assessing the influence of canopy arrangements and piezoelectric patch placement. Specific outcomes include optimized filament layout, maximized electrical energy generation, and detailed characterizations of wave-filament and filament-filament interactions. These findings will directly inform design refinements and optimization strategies, ensuring efficient and robust energy harvesting. A comprehensive performance evaluation framework will be established to systematically assess model predictions against initial theoretical expectations.

Activity Milestones:

Description	Approximate Completion Date
Initial numerical model setup and baseline simulations	December 31, 2027
Simulation under diverse wave conditions	June 30, 2028
Optimization of filament canopy layout and energy output	September 30, 2028

Activity 3: Analysis of Wave Energy Converter Performance in Ice-Covered Lake Conditions

Activity Budget: $125,000

Activity Description:

This activity will evaluate how the seasonal ice coverage of Lake Superior impacts the underwater piezoelectric canopy wave energy converter (WEC). Extensive modeling will simulate hydrodynamic conditions under both fixed shore-attached ice and drifting ice formations. We will study the interactions between canopy filaments and under-ice currents, the wave attenuation effects due to adjacent open water, and the potential impacts of ice movement. Outcomes will include quantifying power generation capabilities throughout the ice season, demonstrating the inherent advantage of the underwater canopy design in consistently generating renewable energy even during harsh winter conditions. Strategies to leverage the canopy's underwater placement to avoid detrimental ice interactions and enhance operational reliability will be emphasized, significantly boosting public confidence and policy support for year-round renewable energy production.

Activity Milestones:

Description	Approximate Completion Date
Identification of winter hydrodynamic conditions	June 30, 2027
Simulations of canopy performance in ice conditions	March 31, 2028
Recommendations for design optimizations enhancing winter reliability	March 31, 2029

Activity 4: Comprehensive Optimization, Economic Analysis, and Knowledge Dissemination

Activity Budget: $75,000

Activity Description:

The final activity integrates all previous findings into a holistic evaluation of the piezoelectric canopy's viability as a sustainable wave energy solution for Lake Superior. Advanced optimization techniques will refine filament materials, canopy arrangements, and piezoelectric configurations to maximize energy efficiency, cost-effectiveness, and long-term operational reliability. A detailed economic analysis will evaluate capital investments, maintenance costs, projected energy production, and environmental benefits, providing policymakers with clear insights for decision-making. Extensive dissemination activities, including technical reports, policy briefs, scientific publications, and community engagement initiatives, will effectively communicate project outcomes to stakeholders and policymakers. This knowledge transfer will support informed decisions on adopting and scaling this innovative renewable energy technology. ENRTF funds will be used for educational purposes but not for any lobbying for recommended policy changes.

Activity Milestones:

Description	Approximate Completion Date
Integrated performance and optimization analysis	September 30, 2028
Completion of economic feasibility study	December 31, 2028
Dissemination of project outcomes to policymakers and stakeholders	June 30, 2029

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.
We will ensure that data and results generated by the project are communicated broadly and effectively to stakeholders.

Scientific and technical dissemination includes: (1) Peer-reviewed publications: Results of wave energy converter modeling and environmental assessments will be submitted to scientific journals for publication. (2) Conference presentations: Findings will be presented at professional conferences to ensure visibility and encourage collaboration. (3) Technical reports and policy briefs: We will summarize outcomes, cost–benefit analyses, and environmental tradeoffs.

Stakeholder engagement and applied communication efforts will include: (1) Agency and policymaker briefings to share recommendations for sustainable site selection and technology deployment. (2) Industry and nonprofit partnerships to share technical outcomes with renewable energy developers, lake stewardship organizations, and regional conservation groups. (3) Provide platforms for two-way knowledge exchange and invite feedback.

Public communication and education efforts will include: (1) Create plain-language summaries and infographics to explain the technology, environmental benefits, and potential applications in Minnesota. (2) Present results through local events and lab tours.

Documentation and data management efforts will include: (1) Data archiving: All computational models, raw data, and final analyses will be deposited in a public repository (e.g., University of Minnesota Digital Conservancy) for open access and long-term preservation. (2) Standard formats: Data will be documented following open-science best practices to ensure usability by future researchers, agencies, and the public.

In all the print and electronic media, publications, signage, and other communications of this project, we will acknowledge the Environment and Natural Resources Trust Fund through: (1) use of the trust fund logo, and/or (2) attribution language per the ENRTF Acknowledgment Guidelines.

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?
The outcomes of this project will be broadly disseminated through scientific publications, reports accessible to policymakers, and presentations at conferences. Following the completion of this computational modeling study, the natural progression would be prototype development, physical testing, and field deployment. Implementation may be pursued through collaborations with industry partners, governmental agencies, and local stakeholders. Funding for subsequent phases could be sourced from government grants, private-public partnerships, renewable energy investment initiatives, and collaborative research programs. We will actively share our findings and recommendations with stakeholders to facilitate and encourage the implementation and continued advancement of this promising renewable energy technology.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Project Manager		Oversee the whole project, supervise the research team, lead the research, and responsible for project reporting			26.8%	0.12		$40,348
Postdoctoral Associate		Design and establish computational model			20.2%	3		$244,531
Graduate Student Research Assistant		Carry out computer simulations			18.8%	1.5		$156,772
Undergraduate Student Assistant		Assist data analysis			0%	0.33		$12,383
Computer Scientist		Assist computational model setup and data sharing			24.4%	0.18		$18,817
							Sub Total	**$472,851**
Contracts and Services								
							Sub Total	-
Equipment, Tools, and Supplies								
	Equipment	SSD Drives	The budget is for the purchase of SSD drives for data storage and sharing.	X				$2,149
							Sub Total	**$2,149**
Capital Equipment								
							Sub Total	-
Acquisitions and Stewardship								
							Sub Total	-

Travel In Minnesota								
							Sub Total	**-**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$475,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request
Equipment, Tools, and Supplies		SSD Drives	The SSD drives can be readily attached to my existing computers to store the data generated by this project. The data size will be large, so the hardware purchase is necessary. SSD drives can also be used for data sharing with others when needed. The hardware will be used exclusively for this project; it won't be used for any other purpose. The requested dedicated physical hardware for SSD drives is a straightforward, cost-effective solution for storing and sharing the data for this project.

Non ENRTF Funds

Category	Specific Source	Use	Status	$ Amount
State				
			State Sub Total	**-**
Non-State				
In-Kind	Unrecovered F&A	Support of SAFL facilities where research will be conducted.	Secured	$232,197
			Non State Sub Total	**$232,197**
			Funds Total	**$232,197**

Total Project Cost: $707,197

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: ffc3e3cb-f25.pdf

Alternate Text for Visual Component

The top-left image is a picture of seagrass, upon which our piezoelectric energy converter array is based. The top-right shows two diagrams of the modeled filaments. The bottom-left shows a map of wave energy in the Great Lakes. The bottom-right is an illustration model of ice scenario modeling....

Supplemental Attachments

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

Title	File
Letter of University of Minnesota SPA	161d0acf-edb.pdf
Lian Shen - 2026-540 - Research Addendum - Revised - Final	2ed0fd05-6b2.docx

Difference between Proposal and Work Plan

Describe changes from Proposal to Work Plan Stage

(1) The budget was adjusted from $500,00 to $475,000.
(2) Indicated that there may be patents as a result of the project.
(3) In Activity 4, a statement that "ENRTF funds will be used for educational purposes but not for any lobbying for recommended policy changes" was added.
(4) Add a descritpion on the dissemination efforts.
(5) In the Dissemination section, a statement has been added regarding how the Environment and Natural Resources Trust Fund will be acknowledged through use of the trust fund logo or attribution language on project print and electronic media, publications, signage, and other communications per the ENRTF Acknowledgment Guidelines.
(6) The SSD drives have been moved to ‘Budget > Capital, Tools, Equipment, and Supplies’ and an explanation has been provided.

Additional Acknowledgements and Conditions:

The following are acknowledgements and conditions beyond those already included in the above workplan:

Do you understand and acknowledge the ENRTF repayment requirements if the use of capital equipment changes?

N/A

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?

N/A

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

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?

Yes, Sponsored Projects Administration

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 project:

Victoria Troxler

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