Environment and Natural Resources Trust Fund

2026 Request for Proposal

General Information

Proposal ID: 2026-494

Proposal Title: Energy 2-in-1: Hybrid Perovskites Harness Sunlight and Waste Heat

Project Manager Information

Name: Xiaojia Wang

Organization: U of MN - College of Science and Engineering

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Project Basic Information

Project Summary: Developing an innovative 2-in-1 system that captures both sunlight and waste heat to generate electricity. Using advanced dual-function materials, this innovation boosts efficiency, reduces energy costs, and accelerates decarbonization.

ENRTF Funds Requested: $630,000

Proposed Project Completion: June 30, 2029

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?
During the Project and In the Future

Narrative

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

According to the US Energy Flow Charts (https://flowcharts.llnl.gov/), over half of the energy consumed in the US is lost as waste heat from transportation, industrial processes, and residential and commercial activities. At the same time, energy demand continues to surge, particularly with the rapid growth of artificial intelligence – in Minnesota alone, the Star Tribune reported that at least 10 new data centers are planned for the state, potentially placing substantial strain on energy resources. To address this growing challenge, we propose an innovative 2-in-1 energy system that can simultaneously harness sunlight and waste heat to generate clean and cost-effective electricity. By leveraging dual-function materials such as hybrid organic-inorganic perovskites (HOIPs), our proposed project integrates solar panels with thermoelectric devices (which convert heat into electricity), offering a more efficient and economical alternative to conventional solar cells. With the addition of a thermoelectric module, we anticipate a ~7-10% increase in power-generation efficiency for this integrated 2-in-1 energy system, complementing the ~20% optimal efficiency of standalone solar cells. This innovation can potentially reduce energy costs and lower carbon emissions across residential buildings, industrial operations, and power grids, paving the way for a more sustainable and energy-efficient future.

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 will develop an innovative 2-in-1 energy system that captures both solar energy and waste heat to generate clean and affordable electricity with record-high efficiency, leveraging the combined expertise of university PIs (U of MN) and industrial experts (3M). Unlike traditional solar panels that lose excess heat, our proposed 2-in-1 system repurposes that waste heat can significantly boost power output. This system uses hybrid organic-inorganic perovskites (HOIPs), a class of emerging materials as versatile alternatives to conventional materials like silicon (for solar cells) and bismuth telluride (for thermoelectric devices). HOIPs offer several advantages, including efficient energy conversion (~20% for solar cells and projected ~7-10% for thermoelectric generators), low-cost and scalable materials synthesis (fabrication using solution-based and vapor-deposition techniques), low processing temperature (~150°C, compared to over 1400°C for silicon growth), and flexibility (enabling lightweight and adaptable energy solutions). For device integration, we will implement the Tandem Design consisting of layered components, where the solar panel (top) generates electricity, and the thermoelectric generator (bottom) captures heat (~80°C) from solar cells and converts it into additional power. By maximizing energy utilization, this approach delivers a cost-effective, high-efficiency, and potentially scalable solution that combines materials innovation, device engineering, and performance optimization.

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?

Minnesota has made significant progress in expanding renewable energy for power generation since 2005. With Minnesota's 2050 energy pledge to achieve net-zero emissions and 100% clean energy, rising energy demands pose a critical challenge. Our project provides an innovative solution by developing an integrated 2-in-1 system that captures both solar energy and waste heat, maximizing efficiency while reducing reliance on fossil fuels. This project directly supports Minnesota's sustainability goals, helping to lower carbon emissions, conserve natural resources, and enhance energy reliability – all in alignment with state energy policies for a cleaner and more resilient future for Minnesota's communities and environment.

Activities and Milestones

Activity 1: Activity 1: Synthesis, Characterization, and Optimization of HOIP Materials for Photovoltaic (PV) Applications (Holmes, Wang)

Activity Budget: $190,000

Activity Description:
Activity 1 focuses on developing high-efficiency HOIPs for PV applications. We will start with synthesizing methylammonium lead iodide ($MAPbI_3$), which has demonstrated superior photovoltaic performance compared to lead-free HOIPs (e.g., tin-based), achieving power conversion efficiencies of ~20%. While potentially compatible with large area, high throughput processing, the use of toxic solvents like N,N-dimethylformamide (DMF) impose environmental concerns, and general issues associated with control over film morphology and composition. To overcome these problems, Co-PI Holmes has developed a vapor-transport deposition (VTD) approach which is solvent-free and can produce HOPI thin films with controlled morphologies and compositions. Additional encapsulation strategies can further address environmental safety. We will optimize VTD synthesis conditions pioneered by the Holmes to fabricate $MAPbI_3$ films with controlled morphologies and compositions, directly impacting light absorption and charge transport. Structural and property characterizations will be conducted using instruments such as SEM, UV-Vis-NIR spectroscopy, and high-fidelity thermal measurement facilities (pioneered by PI Wang) to analyze morphology, composition, optical, electrical, thermal properties. We will answer key questions: How do different morphologies and compositions affect $MAPbI_3$ efficiency? What VTD conditions will lead to best materials properties of HOIP for PV applications?

Activity Milestones:

Description	Approximate Completion Date
Synthesis of baseline $MAPbI_3$ thin films using VTD	September 30, 2026
Characterization of morphology and composition, along with studies on properties related to photovoltaic (PV) performance	December 31, 2027
Optimization of $MAPbI_3$ films and identification of highest-performing PV formulations for device integration	December 31, 2027

Activity 2: Synthesis, Characterization, and Optimization of HOIP Materials for Thermoelectric (TE) Applications (Wang, Holmes)

Activity Budget: $180,000

Activity Description:
Activity 2 explores HOIPs for TE applications. We will prioritize methylammonium tin iodide ($MASnI_3$) as a model material, which has been reported to achieve a record-high ZT of ~1 at room temperature, beneficial for low-grade waste heat recovery (<150°C). Here, ZT is a key performance metric for TE materials, determined by the material's Seebeck coefficient, electrical conductivity, and thermal conductivity. A higher ZT translates to better heat-to-electricity conversion efficiency. As a lead-free HOIP, $MASnI_3$ is also more eco-friendly for waste heat recovery. $MASnI_3$ films with controlled morphologies and compositions will be synthesized by Holmes using VTD. Property measurements for determining the Seebeck coefficient, thermal conductivity, and electrical resistivity will be led by Wang. Combining with structural characterization, she will be able to link structural modifications to thermal and charge transport properties, with a goal to identify the optimal carrier concentrations via doping to improve electrical conductivity while maintaining low thermal conductivity and thus high ZT. Our key questions include: What structural modifications enhance thermoelectric performance? How can we balance electrical and thermal transport for maximum efficiency? The results will provide the foundation for the integrated 2-in-1 system, enabling dual-energy harvesting from sunlight and waste heat.

Activity Milestones:

Description	Approximate Completion Date
Synthesis of baseline $MASnI_3$ thin films using VTD	December 31, 2026
Characterization of morphology and composition, along with studies on properties related to TE performance	March 31, 2028
Optimization of $MASnI_3$ films and identification of highest-performing TE formulations for device integration	March 31, 2028

Activity 3: Device Fabrication and Integration of the 2-in-1 Energy systems (Wang, Holmes)

Activity Budget: $230,000

Activity Description:
Activity 3 focuses on assembling a PV-TE energy system in the Tandem configuration, where the PV cell (top layer) generates electricity from sunlight, and the TE module (bottom layer) converts excess heat (at a temperature of ~80°C) into additional power. A key challenge is ensuring efficient thermal and electrical coupling between the two components since the device ZT will be weighted average of the material's ZT across the temperature range. We will explore the incorporation of optimized HOIP formulations obtained from the first two activities into an integrated Tandem device. Device characterization will include current-voltage measurements, power output analysis, and real-time, in-situ thermal mapping using a high-resolution IR camera. At the end of this project, we aim to demonstrate a prototype device with improved efficiency, via refining layer thickness, contact engineering, and thermal barriers. Key research questions include: How does device architecture influence efficiency? What interface materials optimize heat transfer? Our preliminary findings on device aspects will set up the foundation for future studies of optimization, durability (e.g., cycling and humidity exposure), and scalability of integrated PV-TE systems for real-word operation conditions.

Activity Milestones:

Description	Approximate Completion Date
Concept development and initial design of Tandem 2-in-1 (PV+TE) system architecture	September 30, 2028
Device testing and optimization	June 30, 2029
Final prototype device demonstration	June 30, 2029

Activity 4: Reporting, Results Dissemination, and Outlook for Technology Translation to Real-World Implementation (Wang, Holmes)

Activity Budget: $30,000

Activity Description:
Activity 4 will focus on data analysis, reporting, and broad dissemination of project findings. We will prepare manuscripts for peer-reviewed journals and present key results at conferences and workshops to maximize our research impact and attract potential collaborators and industrial partners. Routine meetings will be held throughout the project between University PIs and 3M industrial collaborators. Dr. Lin Zhao and Dr. Timothy Hebrink from 3M will provide industrial insights on system durability, scalability, and real-world feasibility, particularly addressing humidity exposure and material degradation, which will help refine the integrated system for practical applications beyond the laboratory. We also envision that the outcome of this project will present cross-cutting opportunities to other technologies including standalone TE generation, light sensing, and building-integrated energy solutions. We will actively pursue commercialization opportunities, leveraging UMN's Industrial Partnership for Interfacial and Materials Engineering (IPRIME, where Holmes serves as a program leader) to explore licensing and industry collaboration as the project

develops. Beyond 3M, we also plan to engage with other Minnesota-based energy and technology companies to further expand the impact and market potential of our innovations.

Activity Milestones:

Description	Approximate Completion Date
Documentation and progress reports for Activity 1	December 31, 2027
Documentation and progress reports for Activity 2	March 31, 2028
Documentation and progress reports for Activity 3	June 30, 2029
Patent filing (before paper submission), paper draft writing, and manuscript submission	June 30, 2029
Final project report	June 30, 2029

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Russell Holmes	Department of Chemical Engineering and Materials Science, University of Minnesota	Professor Russell Holmes, a Distinguished McKnight University Professor, is a leading expert on hybrid organic-inorganic perovskites (HOIPs) for solar cells and light-emitting devices. He will lead HOIP synthesis using vapor-transport deposition (VDT) approaches, along with material characterization and photovoltaic performance evaluation to optimize device efficiency and functionality.	Yes
Lin Zhao	3M	Dr. Lin Zhao, an expert in optical and thermal technologies at 3M, will serve as our industrial partner. He will actively engage in routine project discussions, provide industrial perspectives, and offer consulting on device integration and reliability testing. 3M will consider commercialization opportunities for our proposed materials and prototype devices.	No
Timothy Hebrink	3M	Dr. Timothy Hebrink, a senior staff scientist at 3M, will be another industrial partner with extensive expertise in materials engineering and technology innovation. He will also deliver industry-driven insights on device testing and material properties, and help explore commercialization opportunities to bridge research with real-world applications.	No

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?

This 36-month project (July 1, 2026 - June 30, 2029) will provide practical design strategies for harvesting solar and waste heat energy using an integrated, efficient system, while establishing scientific foundation linking material properties and device performance. The results will support future grant applications to federal agencies including the National Science Foundation, the Department of Energy, and the Department of Defense, which fund research in advanced materials and renewable energy technologies. With additional funding, we aim to refine and scale up this technology for real-world applications in buildings, factories, and power grids, contributing to a more sustainable and energy-efficient future.

Project Manager and Organization Qualifications

Project Manager Name: Xiaojia Wang

Job Title: Associate Professor in Mechanical Engineering

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

Professor Xiaojia Wang will serve as the project lead. She has significant experience in advancing the frontiers of thermal transport science and energy conversion technologies. At the U of MN, she leads an interdisciplinary research group that bridges innovative experiments with advanced modeling to investigate thermal energy transport in functional materials, across interfaces, and within integrated devices. By combining materials science, nanotechnology, and device engineering, her work addresses the global challenges in energy efficiency and renewable technologies, driving advancements in applications such as solid-state energy conversion, electronic cooling, thermal switching devices, and next-generation computing architectures.

Prof. Wang has established a high recognition in thermal science and energy research. Her group has published over 50 research articles in top-tier journals, many of which have been featured as Editor's Picks and Highlighted Articles. She has secured research funding from federal agencies (NSF, DARPA), industry (3M, ASRC, and Seagate), and foundations.

She has advised ~10 graduate and 10+ undergraduate students, many of whom have received prestigious fellowships and secured positions at national labs and leading companies (e.g., Intel, Lam Research, and Seagate). Professor Wang has a proven track record of translating fundamental discoveries into real-world solutions through partnerships with leading Minnesota-based industrial corporations, including Seagate (thermal management and magnetic engineering for heat-assisted magnetic recording) and 3M (advanced thermal interface materials for effective cooling).

For the proposed project, she will drive the thermoelectric studies of hybrid perovskite materials provided by Co-PI Holmes and demo of device integration. She will leverage her group's state-of-the-art experimental and computational facilities to test and optimize the thermoelectric performance of integrated energy systems. As the project lead, Prof. Wang will oversee the project management and planning, coordinate collaborations between academic PIs and industry partners, and ensure the execution of project goals, including technical progress and reporting.

Organization: U of MN - College of Science and Engineering

Organization Description:
The University of Minnesota, Twin Cities (U of MN) is a premier public land-grant research university located in Minneapolis and Saint Paul, and is recognized as one of the most comprehensive research universities in the nation. The College of Science and Engineering (CSE) is a global leader in research, education, and technological innovation, with 12 departments spanning engineering, physical sciences, computer science, and mathematics. Home to over 8000 students and many cutting-edge research centers, CSE drives technological innovation and breakthroughs in energy, artificial intelligence, nanotechnology, climate, biomedical engineering, quantum computing, and sustainability. The college consistently ranks among the top public STEM institutions in the US. CSE is also committed to excellence in education, providing hands-on learning, interdisciplinary collaboration, and entrepreneurial opportunities to its students. The Department of Mechanical Engineering is a world leader in thermal science and engineering research, known for its impactful research and innovations in renewable energy, environment & sustainability, next-generation manufacturing, robotics, and biomedical engineering. The Department of Chemical Engineering and Materials Science is a top-tier, internationally competitive department, leading advancements in fluid mechanics, transport, catalysis, bioengineering, renewable energy, polymer synthesis and processing, and advanced semiconductor research.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Xiaojia Wang		Principal Investigator			26.79%	0.12		$31,872
Russell Holmes		Co-PI			26.79%	0.12		$43,512
ME Graduate Student		Research Assistant			43.01%	1.5		$186,769
CEMS Graduate Student		Research Assistant			40.98%	1.5		$203,878
							Sub Total	**$466,031**
Contracts and Services								
							Sub Total	**-**
Equipment, Tools, and Supplies								
	Tools and Supplies	The requested budget for materials and supplies includes three primary categories based on research activities: (1) Materials and supplies for synthesizing high-quality HOIP thin films, including precursor chemicals, solvents, and substrates necessary for both solution-based and vapor-phase fabrication approaches; (2) Materials and supplies for carrying out optical, electrical, and thermal measurements and structural characterization of the synthesized HOIP materials, including conductive adhesives (e.g., silver paste and gold pads) to form stable electrical contacts for reliable electrical and Seebeck measurements; reference samples for thermal measurements; sample mounts for SEM and probes for AFM characterization; (3) Supplies for integrating device components, including photoresists, etching solutions, masks, and encapsulation polymers; thermal interface materials such as heat spreader	The materials and supplies requested are essential for HOIP material synthesis, property and structural characterization, device fabrication, and performance testing in this project. They will enable (1) High-quality synthesis of stable, efficient perovskite materials for dual-function PV and TE application; (2) Accurate measurement of photovoltaic and thermoelectric properties to optimize energy conversion performance; (3) Seamless integration of the PV-TE system to evaluate its real-world feasibility and efficiency gains. No additional budget is required for equipment and instruments for HOIP synthesis and thermal/electrical measurements, as they are already functional in the PIs’					$55,088

		and thermal tapes; device testing accessories, including power meters, electrical resistors, and multimeters for measuring overall system efficiency. The budgets for Year 2 and Year 3 include a 2% inflation adjustment to account for rising travel costs.	research labs. Structural characterization and part of PV performance testing will use campus facilities, with related budget detailed under “Scientific Services”. The budget for an IR camera for real-time temperature mapping is provided under “Capital expenditures”.					
							Sub Total	**$55,088**
Capital Expenditures								
		Infrared (IR) Camera for temperature imaging of fabricated PV+TEG devices, FLIR A655sc w/25° Lens, 640x480, -40° to 650°C, quantity: 1; Close-up IR lens with case, quantity: 1; Corresponding data acquisition system (included); Software for imaging processing, visualization, and data reduction (included); Mounting accessories (included).	This IR camera will be used for accurate temperature mapping of the integrated PV+TEG device	X				$26,311
							Sub Total	**$26,311**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
	Conference Registration Miles/ Meals/ Lodging	An annual travel budget of $6,000 is allocated to support conference attendance and industry engagement for the team. The requested travel budget will cover one conference trip per year for the PI and her student ($3,000), and the Co-PI and his student ($3,000). Estimated expenses include conference registration of $400 × 2 = $800 (for two students) and $900 × 2 = $1,800 (for PI and Co-PI), ground transportation $200 × 4 = $800, and meals $200 × 4 = $800. The travel budget will also fund trips to 3M and other industrial companies (e.g., Xcel Energy, Anderson Windows, All Energy Solar, Cargill, Kraemer Mining & Materials) to promote our research and gather insights from industrial	Expanding research impact through broader dissemination of research knowledge, findings, and products. Enhancing student professional development to strengthen Minnesota’s future workforce. Building connections with potential collaborators and industry partners to drive innovation and commercialization.					$18,362

		experts and stakeholders ($1,800). The budgets for Year 2 and Year 3 include a 2% inflation adjustment to account for rising travel costs.						
							Sub Total	**$18,362**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
	Publication	Publication cost in open-access journals	We would like to maximize the visibility of our research outcomes by publishing in open-access journals, ensuring free and unrestricted access for all readers.					$3,000
							Sub Total	**$3,000**
Other Expenses								
		Scientific Services	To successfully fabricate, evaluate, and optimize hybrid organic-inorganic perovskites (HOIPs) for photovoltaic (PV) and thermoelectric (TE) applications, as well as their integration into a 2-in-1 energy system, we will utilize advanced tools available from on-campus facilities. These services are essential for ensuring high-quality material synthesis, in-depth structural and property characterization, and accurate device performance evaluation. On-campus facilities at the Minnesota Nano Center (MNC) will be used for the following Key processes: (1) Thin-film deposition for transducers used in thermal studies HOIPs and thermal interfaces using tools such as sputtering and thermal evaporation; (2) Etching and surface treatment using oxygen plasma processing to refine interfaces; (3) Patterning of electrical					$61,208

			contacts and interconnections for PV cells and TE modules; (4) Encapsulation and polymer processing for improved device stability and integration. On-campus facilities located at Characterization Facility (CharFac) will also be used for key processes, including (1) Structural and compositional analysis of HOIPs using SEM, EDX, and AFM-based surface analysis; (2) Optical and electronic property characterization using ellipsometry, solar simulator, Raman and photoluminescence, and UV-Vis-NIR optical spectroscopy, to assess material bandgap and light absorption; (3) Temperature-controlled electrical measurements using probe stations to evaluate thermoelectric and photovoltaic device performance under varying conditions. The estimated service fees are $20,000 ($10,000 for MNC and $10,000 for CharFac) per year for PI (Wang) and Co-PI (Holmes), respectively. The budgets for Year 2 and Year 3 include a 2% inflation adjustment to account for potential cost increases.					
							Sub Total	**$61,208**
							Grand Total	**$630,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request
Capital Expenditures		Infrared (IR) Camera for temperature imaging of fabricated PV+TEG devices, FLIR A655sc w/25° Lens, 640x480, -40° to 650°C, quantity: 1; Close-up IR lens with case, quantity: 1; Corresponding data acquisition system (included); Software for imaging processing, visualization, and data reduction (included); Mounting accessories (included).	As part of the material and device testing, this IR camera will be used for real-time, in-situ temperature mapping of the integrated photovoltaic (PV) and thermoelectric (TE) system during operation. Accurate thermal data inquiry is crucial for enhancing PV cell efficiency through improved thermal management and optimizing heat-to-electricity conversion in the TE module. Together, this equipment is essential for improving the overall performance of the integrated system and achieving the projected efficiency improvement, a breakthrough in 2-in-1 systems for dual-energy harvesting. **Additional Explanation :** This IR camera enable high-resolution, real-time temperature mapping of the integrated photovoltaic (PV) and thermoelectric (TE) energy system during operation. It will be a key tool throughout the project, providing essential data to optimize performance and enhance efficiency over the entire program period.

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	**-**
Non-State				
In-Kind	Unrecovered F&A calculated at 54% MTDC	Support of ME facilities where research will be conducted.	Secured	$265,897
			Non State Sub Total	**$265,897**
			Funds Total	**$265,897**

Total Project Cost: $895,897

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: de5acbfc-fc3.pdf

Alternate Text for Visual Component

Visual Component...

Supplemental Attachments

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

Title	File
Walz unveils plan for all carbon-free electricity by 2050	17cfd2b6-56a.pdf
Minnesota's 100% clean electricity	24395f9e-532.pdf
Energy Flow Chart	5caee7d9-47e.pdf
3M Support Letter	4ba6eb5b-53e.pdf
LOI_UMN_SPA	7dfcdc36-1b2.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?

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 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:

Russell Holmes, Department of Chemical Engineering and Materials Science, University of Minnesota

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