Environment and Natural Resources Trust Fund

2026 Request for Proposal

General Information

Proposal ID: 2026-522

Proposal Title: Data-Driven Design of Anti-Icing Coatings for Heat Pumps

Project Manager Information

Name: Jun Li

Organization: U of MN - College of Science and Engineering

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Project Basic Information

Project Summary: I will use a data-driven approach to design the most effective and durable anti-icing coating, which could solve the frosting challenge for air-source heat pumps in cold climates like Minnesota.

ENRTF Funds Requested: $466,000

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.

Around the world, about 180 million heat pumps were utilized for heating in 2020, and heat pump installations are expected to grow by 10–20% per year. To meet International Energy Agency's net zero objectives, the growth needs to be even higher (~ 58% year-to-year). Among different types of heat pumps, air source heat pump (ASHP) units enable individualized thermal comfort capabilities with very high energy efficiency and low initial installation cost, and thus have been widely utilized. However, a major challenge remains for ASHPs operating in cold climates such as Minnesota: when the ambient air temperature is low, frost can be formed on the surface of the evaporator coil. The frost formed on the evaporator thermally insulates the evaporator and drastically reduces the heat capability of the heat pump, which forces the heat pump to stop heating and run the defrost mode! The energy requirements for defrosting can increase the annual energy consumption of heat pumps by 10–20% when operating in relatively temperate countries/regions. Even higher energy consumption occurs in colder environments such as Minnesota. It is this "frosting penalty" that I aim to reduce or potentially eliminate to make heat pump an option for our state.

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.

In this proposed work, I plan to develop a durable, anti-icing coating that can significantly delay the formation of ice on the evaporator. Inhibiting the formation of ice on different macroscale surfaces can be quite challenging due to the complex nature of ice nucleation and propagation. I will use a data-driven approach to design the most effective and durable anti-icing coating, which could potentially solve the frosting problem for air-source heat pumps in cold climates like Minnesota.

Informed by the physical descriptors for ice nucleation from the literature, I will design and synthesize polymeric coatings with various surface features (e.g., functional groups and wettability). Surface texture, chemistry, or a combination of both will be varied to engender those surface features. I will build a microscope-high-speed-camera-thermometry experimental system and develop image processing technique to investigate the ice phenomenon. I will then perform high-throughput icing experiments on those coatings to generate the data to train a machine learning (ML) model. The ML model will help me optimize those surface features, thus designing the coating with the longest ice initiation time and highest durability. The outcome of our ML-assisted approach will be a recommendation for the best anti-icing polymeric coating to date.

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?

The project will create one of the most effective and durable anti-icing coatings to date for heat exchangers. This research will enhance the reliability and energy efficiency of heat pumps. In cold climates, heating electrification for buildings disproportionately reduces fossil fuel consumption compared to milder climates. Improvements in heat pumps will therefore drastically reduce the carbon emissions in cold climates. Similarly, improvements in electric vehicle (EV) heat pumps could ensure that EVs have adequate range in the winter with smaller batteries, reducing their cost and making them more accessible. Therefore, the outcomes will reduce carbon emissions in transportation as well.

Activities and Milestones

Activity 1: Fabrication of Polymeric Coatings

Activity Budget: $150,000

Activity Description:
Inhibiting the formation of ice on different cold substrates (sub-zero degree Celsius) can be challenging due to the complex nature of ice nucleation, propagation, its interactions with surface topography, chemistry, and varied environmental conditions. Most anti-icing coatings rely on surface texture, chemistry, or a combination of both to engender specific properties or enthalpic interactions with water.

With the development of polymer science, polymeric coatings have received much attention due to its versatility and ability to engender a wide range of properties. I will fabricate 400 types of polymeric coatings. Triplicated samples will be fabricated for each type of coating. From the past research in my group, we designed and fabricated a polyurethane (PU) network that was crosslinked by poly(ethylene glycol) (PEG). PEG is commonly used as an anti-freeze agent. The -OH groups on the PEG form hydrogen bonds with water and maintains water in the non-freezing state. PU will be chosen as one category of polymers for this project. Poly(methyl methacrylate) (PMMA) and polysiloxane and are the two categories of polymers that will be considered. I plan to to incorporate -OH groups or ion salt into both categories to engender the anti-icing properties.

Activity Milestones:

Description	Approximate Completion Date
Fabricate initial coatings based on the established fabrication procedure from the lab	January 31, 2027
Based on the design guidelines from the machine learning model, synthesize new coating substrates.	January 31, 2028
Based on the newer design guidelines from the machine learning model, synthesize optimized coating substrates.	December 31, 2028

Activity 2: Coating Characterization

Activity Budget: $96,000

Activity Description:
We will use Differential Scanning Calorimetry (DSC) to measure the glass transition temperature of our coatings and the freezing point of our polymer solutions that are used to synthesize coatings.

We will also use structural and compositional characterization using electron microscopy (TEM, SEM) and surface probe microscopy (AFM) to determine the coating morphology and microscopic structure.

Third, we will use Raman spectroscopy, bulk chemical analysis, and surface chemical analysis (XPS, EDS) to determine the coating composition and coating top surface composition.

Activity Milestones:

Description	Approximate Completion Date
Coating characterization for coatings fabricated in Activity 1 Milestone 1	March 31, 2027
Coating characterization for improved coatings fabricated in Activity 1 Milestone 2	March 31, 2028
Coating characterization for improved coatings fabricated in Activity 1 Milestone 2	January 31, 2029

Activity 3: Coating Performance Testing

Activity Budget: $120,000

Activity Description:
The test apparatus will be built upon the readily available resources in my lab. My group has built an apparatus for testing icing time on macroscale (cm) flat surfaces. The same cooling stage within the test apparatus can be retrofitted to conduct the proposed high-throughput icing experiments, i.e., measuring the freezing time of sessile droplets on the fabricated anti-icing coating.

Via an automated dispensing system, a 10 µL DI water droplet is deposited onto the coating mounted on the cooling stage. Then, the temperature of the cooling stage is dropped to a subzero Celsius temperature while the air temperature and humidity within the test chamber are maintained as constants. A high-speed camera will be used to shoot the whole process of temperature dropping and freezing. The ice initiation time will be quantified from the video.

A most common challenge for anti-icing coatings in the literature is the durability. Therefore, in this project, I aim to develop a coating that has high durability. To evaluate the durability of the different fabricated coatings, we plan on conducting Taber abrasion tests (ASTM D4060 – the industrial standard for evaluating coating durability). The wear index defined as percentage weight loss will be measure.

Activity Milestones:

Description	Approximate Completion Date
Build a microscope-high-speed-camera-thermometry experimental system and image processing technique to investigate ice nucleation.	January 31, 2027
Perform high-throughput icing experiments on those substrates. Generated data will train a machine learning model.	December 31, 2028
Verification tests for optimized coating samples.	May 31, 2029

Activity 4: Machine Learning-Assisted Design of Anti-icing Coatings

Activity Budget: $100,000

Activity Description:
Using a machine learning (ML) approach, I will conduct high-throughput icing tests on various coatings. 400 polymeric coatings will be tested in total. I will randomly pick the data of 320 substrates to train a Deep Neural Network (DNN) model that has already been built in my group. The model will be trained to predict ice nucleation time and wear index based on a number of input parameters. These include: surface temperature, droplet volume, cross-linker ratio, solution concentration, curing conditions, and a number of statistical surface roughness parameters: ten-point height (Sz), maximum height (St), skewness (Ssk) and kurtosis (Sku) of height distribution, and autocorrelation length (Sal, measure of statistical variation of height distribution across surface). All of these parameters can be measured with a laser or stylus profilometer. Each substrate will generate a group of these input parameters. Note that the DNN model for each polymer category may have varied input parameters.

Each substrate will be subjected to the sessile droplet icing test to determine ice initiation time, and the Taber abrasion test to determine wear index. The results of three repetitive runs of each test for each substrate will be recorded for robustness.

Activity Milestones:

Description	Approximate Completion Date

Build the machine learning (ML) model.	June 30, 2027
Based on experiments, interpret the model output. Identify the governing physical descriptors for ice initiation.	December 31, 2027
Informed by the physical descriptors, the student will design surface features.	December 31, 2027
Improve the ML model. Interpret the model output.	March 31, 2029

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Kenneth A. Schoeneck, Jr.	Trane U.S. Inc.	Advising on coatings, heat exchangers, and heat pump systems for industry, buildings, homes and transportation applications.	No
John Bauer	Daikin Applied Americas	Advising on heat exchangers and cold climate heat pumps utilizing low-global-warming-potential refrigerants.	No
Edward Haile	Resideo Global Climate Solutions	Advising on controls of air-source heat pumps for space and water heating.	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?
Trane, Daikin Applied, and Resideo have shown their support and interests in using the coating technology in their products if the project is successful. If additional work is needed, I plan to apply for funding from DOE Office of Energy Efficiency & Renewable Energy (EERE) and Building Technology Office (BTO) (e.g., Buildings Energy Efficiency Frontiers & Innovation Technologies Program). Additional funding can come from National Science Foundation (NSF) programs such as Interfacial Engineering and Designing Materials to Revolutionize and Engineer our Future. The first proposal submissions based on the proposed work would be made in Year 2 of the project.

Project Manager and Organization Qualifications

Project Manager Name: Jun Li

Job Title: Richard and Barbara Nelson Assistant Professor

Provide description of the project manager's qualifications to manage the proposed project.
Prof. Li received his Ph.D. and M.S. degrees from University of Illinois, Urbana-Champaign in mechanical engineering. Before joining the University of Minnesota, he held a Postdoctoral Research Fellow position in the Department of Materials Science and Engineering at the University of Michigan. He was a recipient of the 2023 James Joule Young Researcher Award which is awarded every four years from the International Institute of Refrigeration.

Prof. Li's research nowadays focuses on surface sciences, polymers, heat and mass transfer, and HVAC&R, with applications in anti-icing surfaces and carbon capture. His past research focused on liquid-vapor phase separation and distribution in microchannel heat exchangers and phase-change heat transfer. He was studying at the Air Conditioning and Refrigerant Center (ACRC), a world renowned HVAC&R focused research consortium, at University of Illinois. At University of Minnesota, he designs synthetic coatings to control ice formation and accretion and applies them to thermal fluid components and systems. Also, he studies membrane materials for carbon capture from post-combustion gases.

The proposed project aligns with Prof. Li's major research thrust. The design of the anti-icing coatings requires his knowledge in polymer science. The application of the coating on heat pumps requires his expertise in thermal fluids science and energy systems. In addition, his group has already started building preliminary machine learning models for icing phenomena and coating designs. Overall, the proposed project can synergistically combine his prior expertise in materials science, energy systems, and mathematical modeling.

Organization: U of MN - College of Science and Engineering

Organization Description:

The University of Minnesota is the main research and graduate teaching institution in the state of Minnesota. The Department of Mechanical Engineering is building on the past, responding to the present, and leading the way to the future by driving innovative research with significant real-world impact through our five impact areas: Energy Transition, Environment & Sustainability, Human Health, Next-Gen Manufacturing, and Robotics & Mobility. For Energy Transition, researchers in the Department of Mechanical Engineering performs research on a wide spectrum of innovative solutions for energy conversion and storage and seeks to improve the efficiency of existing technologies. Heat pump, being one type of energy conversion system with end use of heating & cooling, is an indispensable research area in the department. For Environment & Sustainability, from the atmosphere to ground water and everything in between, mechanical engineering is essential in the advancement of environment and sustainability studies. Mechanical Engineering researchers work on air and water pollution, seawater desalination, engine efficiency, alternative fuels, biodegradables, and more to combat climate change and work toward a greener future.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Jun Li		Principal Investigator			26.79%	0.15		$38,770
Graduate Students (2)		Research Assistants			43.01%	3		$373,539
							Sub Total	**$412,309**
Contracts and Services								
							Sub Total	-
Equipment, Tools, and Supplies								
	Equipment	Bungard RDC dipping coater	Control the lifting and dipping of the droplet dispensing system to realize automated droplet icing experiments					$6,000
	Equipment	Customized environmental chamber	The environment-controlled chamber will be used together with the microscope for the microscale heterogeneous ice nucleation study. It can test a range of air temperature and humidity					$3,000
	Equipment	ramé-hart Automated dispenser for water droplets	Deposit droplets on the coating surface					$3,000
	Equipment	OMEGA HX series Temp/RH/Barometric Pressure Transmitter	Measure the air temperature, humidity, and pressure in the environmental chamber					$1,340
	Equipment	PolyScience Circulation bath	Control the baseline temperature of the cooling stage					$5,000
	Equipment	NI cDAQ-9174 chassis	The chassis for building the data logger system					$1,576
	Equipment	NI-9212 temperature input module	The temperature input module for building the data logger system					$1,572
	Equipment	NI-9252 voltage input module	The voltage input module for building the data logger system					$1,440

	Equipment	Laird Thermal Systems DL-060-12-00 Peltier plate cooler	Sample can be attached to the cooler to control the temperature and observe the icing phenomena					$263
	Tools and Supplies	Materials for polymer syntheses	Materials for various polymer syntheses for the polymer coating fabrication. These expenses are an estimate based on previous supply purchases.					$7,500
	Tools and Supplies	Lab supplies	Including Miscellaneous consumables such as pipettes, centrifuge tubes, wipes, sample storage, tape, chemicals, etc. These expenses are an estimate based on previous supply purchases.					$5,000
							Sub Total	**$35,691**
Capital Expenditures								
							Sub Total	**-**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
							Sub Total	**-**
Travel Outside Minnesota								
	Conference Registration Miles/ Meals/ Lodging	ACS Spring 2029 Meeting. 1 trip. 3 people.	Biggest conference of the American Chemical Society (ACS). I plan to attend with my students to disseminate our research results.					$3,000
							Sub Total	**$3,000**
Printing and Publication								
							Sub Total	**-**

Other Expenses								
		Scientific Services	User fees at Characterization Facilities (X-ray Photoelectron Spectroscopy, Scanning Electron Microscopy, Atomic Force Microscopy, Differential Scanning Calorimetry, and Raman Spectroscopy): Characterization of various properties of the developed anti-icing surface materials at the UMN Characterization Facility and the UMN Polymer Characterization and Processing Facility. These expenses are an estimate based on previous user fees.					$15,000
							Sub Total	**$15,000**
							Grand Total	**$466,000**

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	Unrecovered F&A calculated at 54% MTDC	Support of ME facilities where research will be conducted.	Secured	$188,305
			Non State Sub Total	**$188,305**
			Funds Total	**$188,305**

Total Project Cost: $654,305

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: b2a61aec-74b.pdf

Alternate Text for Visual Component

Machine learning workflow that includes the design and testing for our anti-icing coatings...

Supplemental Attachments

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

Title	File
Resideo Letter of Support	c49036e0-46e.pdf
Daikin Applied Letter of Support	5e61db8c-001.pdf
Trane Letter of Support	f2f3f22f-91c.pdf
UMN Letter	4e48db27-fcb.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:

None.

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