



Environment and Natural Resources Trust Fund

2027 Request for Proposal

General Information

Proposal ID: 2027-131

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 effective and durable polymeric anti-icing coatings, which could potentially solve the frost problem for air-source heat pumps in cold climates like Minnesota.

ENRTF Funds Requested: \$510,000

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?

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 250 million heat pumps were utilized for heating in 2024, and heat pump installations are expected to grow by 10–15% per year. To meet International Energy Agency’s net-zero carbon emissions objective, 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 form on the surface of the evaporator coil. The frost that forms on the evaporator thermally insulates the evaporator and drastically reduces the heat capacity of the heat pump, which forces the heat pump to stop heating and run the defrost cycle. 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 my proposal aims to mitigate significantly to make heat pumps a realistic 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 durable, anti-icing coatings that can significantly delay the formation of ice on the evaporator. Inhibiting the formation of ice on evaporator Aluminum 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 polymeric anti-icing coatings, which could potentially solve the frost 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 techniques to investigate the icing 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 then help me optimize those surface features to design a coating that is the most anti-icing and durable. The outcome of this ML-assisted approach will be the designs of several best polymeric anti-icing coatings 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 outcome will be extremely effective and durable anti-icing coatings for heat exchangers to enhance the reliability and energy efficiency of heat pumps. Heat pumps are an essential part of realizing heating electrification for buildings as the pathway to renewable energy grids. Plus, heating electrification in cold climates (like Minnesota) reduces fossil fuel consumption significantly more than in mild climates. Similarly, this project outcome will help realize transportation electrification, too. Improvements in electric vehicle (EV) heat pumps can ensure EVs have adequate driving mileages in winters with smaller battery packs, potentially reducing their cost and making EVs more accessible.

Activities and Milestones

Activity 1: Design and Fabrication of Polymeric Anti-icing Coatings

Activity Budget: \$89,632

Activity Description:

Inhibiting the formation of ice on cold Aluminum surface (sub-zero degree Celsius) of the evaporator of a heat pump can be challenging due to the complex nature of ice nucleation, propagation, its interactions with surface topography, chemistry, and varied environmental conditions.

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 300 configurations of polymeric coatings. Polyurethane (PU) will be chosen as one category of polymers for this project. From the past research in my group, we designed and fabricated a poly(ethylene glycol)-PU (PEG-PU) coating that was crosslinked by PEG. PEG is commonly used as an anti-freeze agent. The ether linkages on the PEG and the urethane linkages form hydrogen bonds with water and maintain water in the non-freezable state. I plan to vary the PEG molecular weight, the isocyanate type, and the crosslink density to create various PU coating configurations. I will also design poly(vinyl alcohol) (PVA) and polysiloxane coatings as the two other categories of polymer coatings. I plan to incorporate ion salt or additional -OH groups into both categories to engender the anti-icing properties.

Activity Milestones:

Description	Approximate Completion Date
1.1 Fabricate initial PU coatings based on the established fabrication procedure from the lab.	January 31, 2028
1.2 Fabricate the initial PVA and polysiloxane coatings.	May 31, 2028
1.3 Based on the design guidelines from the machine learning model, fabricate new coatings.	January 31, 2029
1.4 Based on the newer guidelines from the machine learning model, fabricate optimized coatings.	December 31, 2029

Activity 2: Characterization of Polymeric Anti-icing Coatings

Activity Budget: \$144,764

Activity Description:

The polymeric anti-icing coatings I will develop rely on surface texture, chemistry, or a combination of both to engender specific properties or enthalpic interactions with water. I will need material characterization to investigate and confirm whether I have achieved the desired surface textures and/or chemistry. Triplicated samples will be fabricated for characterization for each coating configuration.

First, I will use contact angle goniometry to evaluate surface energy of the coatings. I will use Fourier Transform Infrared (FTIR) spectroscopy to identify urethane (C=O) and N-H stretching modes and the free carbonyl groups in PU for hydrogen bonds with water. I will use Atomic Force Microscope (AFM) imaging to probe surface topology and elastic modulus. I will use Scanning Electron Microscopy (SEM) in conjunction with EDX to determine the coating microscopic structure and the coating composition.

Second, to study enthalpic interactions with water, I will use Differential Scanning Calorimetry (DSC) to measure the glass transition temperature and the freezing of our coatings. DSC will also allow me to calculate the fraction of non-freezable water (the mechanism of why a coating can be anti-icing).

All properties measured above will be fed as the inputs to a machine learning model later.

Activity Milestones:

Description	Approximate Completion Date
2.1 Coating characterization for coatings fabricated in Activity 1 Milestones 1 and 2.	May 31, 2028
2.2 Coating characterization for improved coatings fabricated in Activity 1 Milestone 2.	March 31, 2029
2.3 Coating characterization for improved coatings fabricated in Activity 1 Milestone 3.	January 31, 2030

Activity 3: Testing of Anti-icing Performance of the Coating

Activity Budget: \$192,612

Activity Description:

The test apparatus will be built upon the readily available resources in my lab. My group has built a microscope testing platform for testing icing time on flat surfaces on microscale (μm). The same test platform will be retrofitted by a high-speed camera to conduct the proposed high-throughput icing experiments on the fabricated anti-icing coatings.

During a test, a flat coating sample is first mounted on a cooling stage with an environmental chamber. Then, the temperature of the cooling stage is dropped to a subzero Celsius temperature (controlled by a liquid nitrogen system) while the air temperature and humidity within the environmental chamber are maintained as constants. The high-speed camera will be used to capture the process of condensation freezing and the fast phase-change phenomena. The ice initiation time and droplet dynamics will be quantified from the video.

One most common challenge for polymer anti-icing coatings in applications is the durability. Therefore, in this project, I aim to develop highly durable polymer coatings. 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) and compare the ice initiation times before and after the abrasion.

Activity Milestones:

Description	Approximate Completion Date
3.1 Based on icing experiments, develop video processing techniques to investigate ice nucleation.	January 31, 2028
3.2 Perform high-throughput icing experiments on coatings. Generate data to train the ML model.	January 31, 2029
3.3 Submit a paper about the optimize polyurethane anti-icing coating.	July 31, 2029
3.4 Perform high-throughput icing experiments. Generate data to train the updated ML model.	November 30, 2029
3.5 Verification icing and abrasion tests for optimized coating samples.	March 31, 2030

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

Activity Budget: \$82,992

Activity Description:

Using a machine learning (ML) approach, I will conduct high-throughput icing tests on various coatings. 300 polymeric coating configurations will be tested in total. I will randomly pick the data of 240 substrates to train a Artificial Neural Network (ANN) model that will be built within my group. The model will be trained to predict ice nucleation time and the change of that after abrasion based on a number of input parameters. Those parameters include: cross-linker ratio, glass transition temperature, freezing point, non-freezable water molecules per coating repeating unit, advancing and receding contact angles, statistical surface roughness parameters including ten-point height (S_z), maximum height (S_t), skewness (S_{sk}) and kurtosis (S_{ku}) of height distribution, and autocorrelation length (S_{al} , measure of statistical variation of height distribution across surface), hardness, elastic modulus, surface temperature, and droplet volume. Each coating substrate will generate a set of these input parameters. Note that the ANN model for each polymer category may have

varied input parameters.

Each coating substrate will be subjected to the condensation-freezing test and the Taber abrasion test to generate outputs of ice initiation time and droplet dynamics. Triplicates will be tested for each coating configuration for reproducibility analysis and uncertainty analysis.

Activity Milestones:

Description	Approximate Completion Date
4.1 Build the machine learning (ML) model.	March 31, 2028
4.2 Interpret the model outputs by experiments. Identify governing physical descriptors for ice initiation.	January 31, 2029
4.3 Use ML model to design coatings for longest icing time and highest durability.	March 31, 2029
4.4 Improve the ML model. Interpret the model outputs and optimize the coating design.	December 31, 2029
4.5 Submit a paper about the ML approach to design anti-icing coatings.	May 31, 2030

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Deba Maitra	Trane U.S., Inc.	Advising on coatings, heat exchangers, and heat pump systems for industry, buildings, homes, and/or transportation applications.	No

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.

1. Dissemination and Presentation

I am an active member of my scientific communities in mechanical engineering, materials science, and chemical engineering. The findings and results will be disseminated to Minnesota state agencies, industries, and other interested parties, through open-access/closed-access publications and conference presentations.

In all my dissemination and presentation efforts, I will acknowledge the Environment and Natural Resources Trust Fund through use of the trust fund logo or attribution language on project print and electronic media, publications, signage, and other communications and outreach. I will adhere to the attribution language and social media tags for the ENRTF.

I am engaged in outreach activities to the general public. I will report results of this project and its benefits to a large set of stakeholders in the State of Minnesota. I will focus on HVAC companies such as my collaborator, Trane Technologies, in Minnesota who will benefit from the results. If any of these companies decides to use my anti-icing coating on their heat pumps, it will ensure longevity of my anti-icing coating made possible with the ENRTF.

I will try to attend in-state and out-of-state conferences, including the ACS Spring 2030 Meetings & Expo and the local meetings of ACS (American Chemical Society) Minnesota Section and local meetings of MRS (Materials Research Society). Founded in 1876, the ACS currently has more than 155,000 members at all degree levels and in all fields of chemistry, chemical engineering, and related fields. It is one of the world's largest scientific societies by membership. The ACS Spring 2030 Meetings & Expo is the biggest conference of the American Chemical Society (ACS) annually. Going there will expand the audience for our dissemination. It would be difficult to find an in-state academic conference that matches the number of audience in this conference. The Minnesota Local Section (#513) of the American Chemical Society serves chemists, chemical engineers, educators, and the general public in Minnesota and Western Wisconsin.

2. Documentation

Raw data for the material syntheses and coating fabrication protocols will be manually recorded into a laboratory notebook by the researcher, as well as entered into a computer file via Excel or Word and digitally stored as an .xls or .docx file. Raw sensor data and calibrated data from coating characterizations will be obtained using proprietary software and exported as .csv or .txt file for further analysis. For the microscopic condensation-freezing experiments, video files to capture ice initiation times and analyze the droplet dynamics will be stored as .mp4 files. The data of temperature and/or humidity will be collected by a datalogger. Post-processing of the video files will be conducted in ImageJ, and the output files will be stored in the proprietary file formats of ImageJ. Further analysis may be performed using Microsoft Excel, which would import LabVIEW data and save it as a .xls file. For all experiments, a laboratory notebook specific to this project will keep detailed notes on the experimental setup and location of the digital data.

Hardcopy data will be stored in laboratory notebooks. Electronic data will be generated and stored in a proprietary format depending on the instrument manufacturers, but in most cases it will be converted to ASCII, jpeg, and other common formats for manipulation, display, and archival storage. It will be stored in cataloged collections of micrographs, images, spectra, and simulations.

Digital data will be routinely backed up on local hard drives or remote storage devices. Output from analysis programs, spreadsheets, and data files used for any figure in a given publication will be cataloged by the publication name and archived on external hard drives or remote storage devices.

Hardcopies for experimental data (e.g., laboratory notebooks) will be stored indefinitely in the laboratory space in a safeguard against fire or water damage. Raw and analyzed data (e.g., photos, spreadsheets), along with uncertainty and error deduction results, will be backed-up on external hard drives as well as on a laboratory server and will be stored indefinitely.

Both experimental and modeling data will be organized in a logical manner with all relevant metadata attached to each file, and column labels that clearly explain the meaning of the data. These data back-ups will be moved to new media as new technology is developed. Archival publications will also be stored with data to provide information on the methods by which the data were obtained.

3. Sharing

Regarding sharing of my data, results, and samples, I will strictly follow Section F. Data Availability in the Environment and Natural Resources Trust Fund (ENRTF) Project Requirements.

The data will be published to the greater scientific community through peer-reviewed publications. In addition, raw and processed datasets will be provided as online supplemental material to the published manuscripts. Access to the data will be free, with no embargo periods involved in the proposed project. To my knowledge, there are no ethical or privacy issues with the sharing of data from this work. The datasets will neither be covered by copyright nor licensed.

I will acknowledge the Environment and Natural Resources Trust Fund through use of the trust fund logo or attribution language on project print and electronic media, publications, signage, and other communications and outreach. I will use the attribution language and social media tags in the ENRTF Acknowledgment Requirements and 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?

Trane Technologies have shown their support and interests in implementing 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), Building Technology Office (BTO), and Vehicle Technology Office (VTO). Additional funding can also come from National Science Foundation (NSF) programs such as Thermal Transport Processes (TTP), Interfacial Engineering, and Designing Materials to Revolutionize and Engineer our Future (DMREF). The first proposal submission for the additional work will be made in Year 2 of the project.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Facilitated Transport Hybrid Membranes for CO2 Separation	M.L. 2025, First Special Session, Chp. 1, Art. 2, Sec. 2, Subd. 07d	\$1,050,000

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. His Ph.D. 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. 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 is a recipient of the 2026 ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) New Investigator Award and the 2023 James Joule Young Researcher Award, an award granted every four years from the International Institute of Refrigeration.

At University of Minnesota, Twin Cities, Prof. Li's research focuses on surface sciences, functional polymers, heat and mass transfer, and HVAC&R, with applications in anti-icing surfaces and carbon capture. He designs synthetic polymeric coatings to control ice formation and accretion and applies them to thermal fluids 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 HVAC systems. In addition, his group has already started building machine learning models for icing phenomena and coating designs. Overall, the proposed project can synergistically combine his expertise in materials science, thermal fluids science, HVAC&R, 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			27.8%	0.18		\$41,189
Graduate Students (2)		Research Assistants			45.52%	3		\$406,172
							Sub Total	\$447,361
Contracts and Services								
UMN Characterization Facility	Internal services or fees (uncommon)	Scanning Electron Microscopy, Energy-dispersive X-ray Spectroscopy, Fourier Transform Infrared Spectroscopy, and Atomic Force Microscopy (\$10,000): Characterization of various properties of the developed anti-icing surface materials. These expenses are an estimate based on previous user fees.				3		\$10,000
UMN Polymer Characterization and Processing Facility	Internal services or fees (uncommon)	Differential Scanning Calorimetry (\$6,000): Characterization of various properties of the developed anti-icing surface materials. These expenses are an estimate based on previous user fees.				3		\$6,000
							Sub Total	\$16,000
Equipment, Tools, and Supplies								
	Tools and Supplies	Materials for polymer coating fabrication	Materials for various polymer syntheses for the polymer coating fabrication. These expenses are an estimate based on previous materials purchased and quotes received.					\$6,639
	Tools and Supplies	Lab supplies	Including miscellaneous consumables such as chemicals, pipettes, petri dishes, jars, centrifuge tubes, cutting tools, wipes, tapes, etc. These expenses are an estimate based on previous supply purchases.					\$5,000

							Sub Total	\$11,639
Capital Equipment								
		Photron FASTCAM Mini AX100 high-speed camera	To be mounted onto the existing microscope to retrofit the microscope-thermometry test platform to conduct icing experiments. The high-speed videos recorded by this camera can be used to investigate ice nucleation and droplet dynamics.	X				\$30,000
							Sub Total	\$30,000
Acquisitions and Stewardship								
							Sub Total	-
Travel In Minnesota								
	Conference Registration Miles/ Meals/ Lodging	ACS Minnesota Chapter Meeting, Fall 2029. One trip. Three people.	Local Minnesota Chapter Meeting of the American Chemical Society (ACS). I plan to attend together with the two Ph.D. students to disseminate our research results.					\$1,000
							Sub Total	\$1,000
Travel Outside Minnesota								
	Conference Registration Miles/ Meals/ Lodging	ACS Spring 2030 Meetings & Expo. One trip. One student.	Biggest conference of the American Chemical Society (ACS). One of the Ph.D. students plans to attend the surface/colloid science sessions to disseminate our research results.	X				\$2,000
							Sub Total	\$2,000
Printing and Publication								
	Publication	SPA Publication Costs	Open access publication fee. Disseminating the work and making our results publicly available.					\$2,000

							Sub Total	\$2,000
Other Expenses								
							Sub Total	-
							Grand Total	\$510,000

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request
Capital Equipment		Photron FASTCAM Mini AX100 high-speed camera	<p>This high-speed camera is an add-on to the existing microscope-thermometry testing platform to expand its capability. The specific objective of this high-speed camera is to capture the fast phase change phenomena and droplet dynamics, which cannot be captured by regular cameras. The captured information will be used to determine the key surface features that incurs ice nucleation and thus helping the design of the anti-icing coating. Therefore, this high-speed camera is necessary for this project.</p> <p>Additional Explanation : Since this high-speed camera is an add-on to the existing microscope-thermometry testing platform, it will be always kept in my lab for future usages through its useful life. I plan to continuously use the microscope-thermometry testing platform for a long term during my research program. This high-speed camera will be continuously used for the same type of condensation-freezing experiments, as well as desublimation and pure condensation experiments.</p>
Travel Outside Minnesota	Conference Registration Miles/Meals/Lodging	ACS Spring 2030 Meetings & Expo. One trip. One student.	This conference is one of the biggest conferences in Chemistry and Chemical Engineering in the nation. Going there will expand the audience for our dissemination. It would be difficult to find an in-state academic conference that matches the number of audience in this conference.

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	\$193,897
			Non State Sub Total	\$193,897
			Funds Total	\$193,897

Total Project Cost: \$703,897

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: [bdced979-06a.pdf](#)

Alternate Text for Visual Component

Machine learning (ML) workflow that includes the design, fabrication, characterization, testing, and ML analysis of polymeric anti-icing coatings....

Supplemental Attachments

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

Title	File
U of M Support Letter	d35c1b6c-32b.pdf
Letter of Support_Trane Technologies	4e436700-c13.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:

Alexandra Sullivan, Pre-Award Accountant, University of Minnesota, Twin Cities.

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