Environment and Natural Resources Trust Fund
2020 Request for Proposals (RFP)

Project Title: **ENRTF ID: 188-E**

Coping with Cold Weather in Minnesota Wind Energy

Category: E. Air Quality, Climate Change, and Renewable Energy

Sub-Category:

Total Project Budget: $ 399,562

Proposed Project Time Period for the Funding Requested: June 30, 2023 (3 yrs)

Summary:

This project will use laboratory, field, and modeling studies to investigate and mitigate impacts of ice accumulation on wind turbine blades, a common issue in Minnesota and other cold regions.

Name: Jeffrey Marr

Sponsoring Organization: U of MN

Job Title:

Department: College of Science and Engineering

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Location:

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

The figure illustrates the challenges posed by cold weather to wind energy, plan for the proposed experiment and modeling study, and the expected outcomes including engineering tools and mitigation strategy.

_____ Funding Priorities	_____ Multiple Benefits	_____ Outcomes	_____ Knowledge Base
_____ Extent of Impact	_____ Innovation	_____ Scientific/Tech Basis	_____ Urgency
_____ Capacity Readiness	_____ Leverage	_____ TOTAL	_____%

PROJECT TITLE: COPING WITH COLD WEATHER IN MINNESOTA WIND ENERGY

I. PROJECT STATEMENT

Wind plants are growing rapidly in Minnesota
Wind power has become one of the main renewable energy sources in Minnesota, accounting for nearly 18% of the total electricity production in the state and it continues to grow. The strength of wind energy in Minnesota is one of the reasons why we are on track to meet its "25 percent by 2025" renewable portfolio standard.

Extreme winter weather condition pose challenges for wind farms
Minnesota is one of the three coldest states in the U.S. and is in the top 10-15 states for annual snowfall. Our average monthly temperatures in winter are below 15°F. Extreme cold events, well below average, often occur in the winter when polar air sweeps across the upper Midwest. The most recent polar vortex event, which occurred at the end of January 2019, reached 20-year low temperatures between -13°F to -56°F. Many wind farms were not able to operate in these conditions.

Impact of cold weather on wind turbines
A primary challenge for wind turbines during cold weather is ice accumulation on blades. Ice forms under certain weather and precipitation conditions and often results in the need to shut down the turbine. The exact processes and conditions leading to ice accumulation, the hazards resulting from the ice, and possible mitigation strategies are not well understood. We know that ice build-up results in uneven loading on turbine blades and tower, increasing wear and tear on the turbine. Ice shedding during operation or "ice throw" is a major safety hazard for wind farm operators yet we know very little about the processes involved. Shut down of turbines because of detected ice accumulation results in revenue losses, which are estimated to be between 0.5% and 50% of annual production. Our ability to predict ice formation and, indirectly, the prediction of when wind energy farms may need to be shut down due to ice, is poor and this research seeks to improve capabilities.

Objectives of project
This project aims to investigate ice accumulation on wind turbine blades and develop predictive tools to help manage this hazard. We propose to: 1) measure air velocity, temperature, and moisture near wind turbines to reveal the icing process on wind turbine blades under various cold weather conditions; 2) develop an accurate model for the momentum, heat, and moisture transport of air in wind plants that affects the ice formation on turbine blades; 3) quantify the ice formation process on wind turbine blades; 4) investigate the amounts of ice accretion and the ice shapes on wind turbine blades; and 5) develop a mitigation strategy for minimizing the impact of ice on power production using a combination of forecasting, detection, and mitigation methods.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: Laboratory measurements in wind tunnel and field measurements at wind research field station
SAFL is equipped with a large wind tunnel that allows control and measurement of air speed and temperature around wind turbine models. Humidity sensors will be used to measure the moisture transport near model wind turbines. Ice formation on the blades of wind turbine models will be measured, and the shape and mass of the ice deposits will be quantified, together with the lift and drag forces of the iced turbine blades. Field data will be collected during the winter at the UMN wind research field station, located in Rosemount, MN, using our 2.5 MW wind turbine and 130 m metrological tower. Data will also be collected from wind farms in Minnesota through collaboration with industry partners.

ENRTF BUDGET: $156,691

Outcome	Completion Date
1. A unique dataset of air velocity, temperature, and moisture near wind turbines.	March 31, 2021
2. A complete characterization of the icing process on the blades of wind turbines	March 31, 2022

Activity 2: Develop modeling and prediction tools for air flows and ice formation on turbine blades

We will develop a computational model to describe the air flows in wind farms and near turbine blades. The model will compute heat and moisture transport along the blade surface, and will describe both "rime icing" due to fog droplets and "glaze icing" due to precipitation. Based on the model, two engineering prediction tools will be developed. One will describe how wind turbines interact with the local atmosphere in cold weather. The other will quantify the ice formation process on wind blades. The computational model and the engineering prediction tools will be calibrated via the comparisons with the laboratory and field measurements data obtained in Activity 1.

ENRTF BUDGET: $147,355

Outcome	Completion Date
1. A computational model to simulate the momentum, heat, and moisture transport of air in wind plants and the ice on turbine blades	June 30, 2022
2. An engineering prediction tool to describe cold air flows around turbines	Sept. 30, 2022
3. An engineering prediction tool to describe ice formation on turbine blades	Dec. 31, 2022

Activity 3: Develop strategies for coping with low temperature for wind turbines

Based on the measurement data obtained in Activity 1 and using the engineering tools developed in Activity 2, we will assess the various methods for anti-icing and de-icing of wind turbines, including heating blades internally, special coatings added during manufacturing, and de-icing spray after construction. The sensitivity of ice accumulation to meteorological variables will be studied, and the model predictions will be compared to data from icing wind tunnel experiments in SAFL and from the field study of wind turbine icing at the UMN station. A Minnesota site-specific database indicating wind speed, heat transfer, moisture transport, and ice formation will be created for wind turbines. Specific guidelines for site suitability evaluation of future wind plants in extreme cold weather will be provided based on the database.

ENRTF BUDGET: $95,516

Outcome	Completion Date
1. Assessment and recommendation of methods for anti-icing and de-icing of wind turbines	Sept. 30, 2022
2. Minnesota site-specific database for wind speed, air temperature and humidity, and ice formation for wind turbines	Mar 31, 2023
3. Environmental report for wind turbines under low temperature and icy conditions to provide guidelines for existing and future wind plants	June 30, 2023

III. PROJECT PARTNERS AND COLLABORATORS:

The proposed study will be carried out in collaboration with the Minnesota energy industry. We have ongoing collaborations with local consultants, Xcel Energy, and DOE national laboratories and will incorporate these same partners into this new project.

IV. LONG-TERM- IMPLEMENTATION AND FUNDING:

This project will be completed within three years. The knowledge generated on the formation of ice on blades is information sought worldwide but especially applicable to MN and upper Midwest wind farms. We believe the research products generated (e.g. computation tools, site-specific database, and mitigation strategies) are a substantial contribution to wind energy with benefits for our regulated utilities and citizens of the state. The project will also establish Minnesota as a leader in cold regions wind energy research and development.

V. SEE ADDITIONAL PROPOSAL COMPONENTS:

A. Proposal Budget Spreadsheet
B. Visual Component or Map
F. Project Manager Qualifications and Organization Description

Attachment A: Project Budget Spreadsheet
Environment and Natural Resources Trust Fund
M.L. 2020 Budget Spreadsheet
Legal Citation:
Project Manager: Jeffrey Marr
Project Title: Coping with Cold Weather in Minnesota Wind Energy
Organization: University of Minnesota
Project Budget: $399,562
Project Length and Completion Date: 3 years; June 30, 2023
Today's Date: April 12, 2019

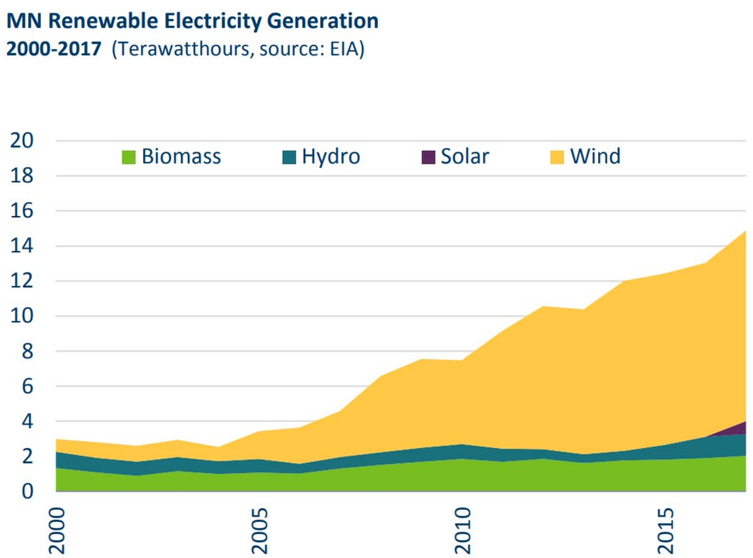
ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Budget	Amount Spent	Balance
BUDGET ITEM			
Personnel (Wages and Benefits)	$ 386,062	$ -	$ 386,062
Jeff Marr, Program Manager (74% salary, 26% benefits); 6.25% FTE, 3 weeks per year. Marr is the Associate Director of Engineering and Facilities at SAFL. He has expertise in wind energy, river dynamics, sediment transport, and project management. Marr will oversee the project. ($39,569)			
Lian Shen, Co-PI (74% salary, 26% benefits); 3.7% FTE, 0.33 month per year. Shen is the Director of SAFL. He has expertise in modeling. ($22,874)			
Postdoctoral Associate, experiment and modeling research (80% salary, 20% benefit); 100% FTE for each of 3 years. ($192,098)			
Graduate student, modeling study (84% salary, 16% benefit); 3 summers month per year for 3 years. ($20,892)			
Undergraduate Assistant, measurement and data analysis (100% salary); 3 months for each of 3 years. ($14,400)			
Engineer, equipment maintanence and data analysis (88% salary, 12% benefit); 40% FTE for each of 3 years. ($100,066)			
Professional/Technical/Service Contracts			
	$ -	$ -	$ -
Equipment/Tools/Supplies			
Cost of two anemometers ($1,000 each), four humidity sensors ($250 each), data aquaistion system ($2,000), materials and cost for fabicating turbine models ($2,500), components for Eolos wind turbine ($2,000), and componenst for Lidar ($2,500) for measurements in this project.	$ 12,000	$ -	$ 12,000
Capital Expenditures Over $5,000			
	$ -	$ -	$ -
Fee Title Acquisition			
	$ -	$ -	$ -
Easement Acquisition			
	$ -	$ -	$ -
Professional Services for Acquisition			
	$ -	$ -	$ -
Printing			
	$ -	$ -	$ -
Travel expenses in Minnesota			
Tranportation within Minnesota state for field data collection and research meetings in the state. Estimation of cost for 3 years: Mileage $0.58/mile x 1000 miles =$580; Incidental expense during travel $170; Lodging $750.	$ 1,500	$ -	$ 1,500
Other			
	$ -	$ -	$ -
COLUMN TOTAL	$ 399,562	$ -	$ 399,562

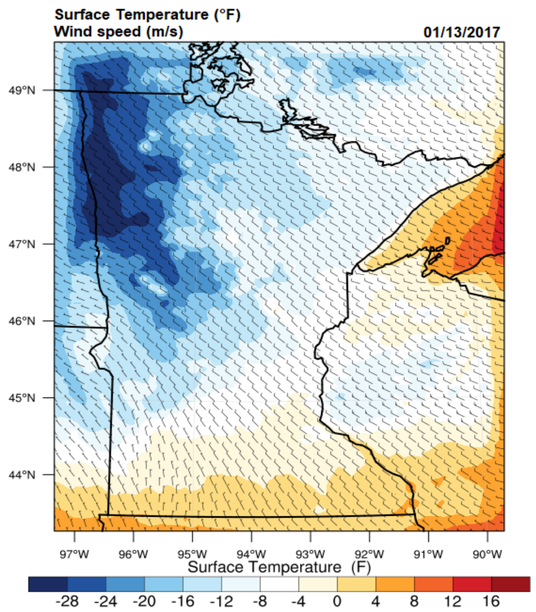
SOURCE AND USE OF OTHER FUNDS CONTRIBUTED TO THE PROJECT	Status (secured or pending)	Budget	Spent	Balance
Non-State:		$ -	$ -	$ -
State:		$ -	$ -	$ -
In kind: The University of Minnesota does not charge the State of Minnesota its typical overhead rate of 54% of the total modified direct costs.		$ 215,763	$ -	$ 215,763

Other ENRTF APPROPRIATIONS AWARDED IN THE LAST SIX YEARS	Amount legally obligated but not yet spent	Budget	Spent	Balance
		$ -	$ -	$ -

Coping with Cold Weather in Minnesota Wind Energy

Motivation

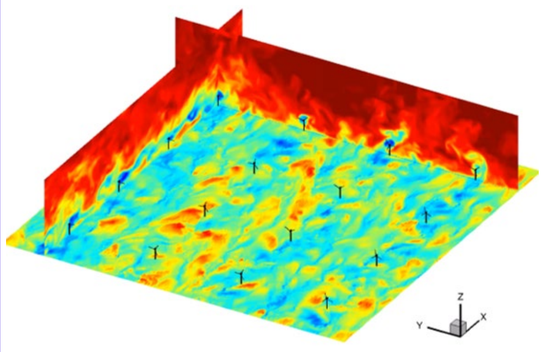




Minnesota is on track to meet its “25% by 2025” clean energy goals, but the state’s cold climate poses severe challenges to wind power generation.

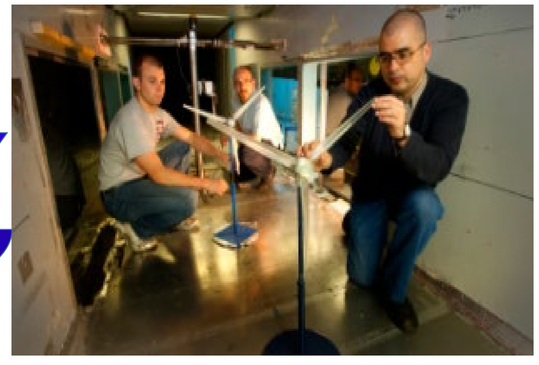
Low temperature can cause icing on blades, generator damage, and reduced power output.

Plan



predict

validate



Modeling of wind plant

Experiment at SAFL

Expected outcomes

- Models and engineering tools to predict ice formation on wind turbine blades under extreme cold weather conditions, such as polar vortex.
- Assessment of impacts of ice formation on wind power output.
- Mitigation strategies and guidelines for wind plant design and operation in cold weather in Minnesota.

PROJECT MANAGER QUALIFICATIONS

Jeffrey Marr is a licensed professional civil engineer in Minnesota and serves as the Associate Director of Engineering and Facilities at the St. Anthony Falls Laboratory (SAFL), University of Minnesota (UMN). He received both his BS (1996) and MS (1999) from the University of Minnesota, Department of Civil Engineering and has worked at SAFL for 23 years. Marr's research interests are broad and include topics in hydraulics and sediment transport, wind energy, river and delta systems, tailing ponds, deep water gravity currents, and reservoir sedimentation and erosion. In wind, Marr serves as the manager of the UMN wind engineering research program. Recent projects include work in physical modeling experiments in transportation hydraulics, wind turbine noise, and complex fluid mechanics research involving public and private organizations. Jeff Marr manages SAFL's Applied Research and Engineering group, which supports faculty research and carries out applied research with public and private sponsors. Marr is an experienced project manager and principal investigator, having served as lead manager for the $16M renovation of SAFL completed in 2014 and the $8M project to establish UMN's wind energy research field station including our 2.5MW research turbine at UMore Park in Rosemount, MN.

Lian Shen will also participate in this study. Shen is the Director of the St. Anthony Falls Laboratory and a Professor in the Department of Mechanical Engineering at University of Minnesota, Twin Cities. He earned his Doctor of Science degree from Massachusetts Institute of Technology (MIT) in 2001. After three years of postdoctoral training at MIT, he joined the faculty of Johns Hopkins University in 2004. In 2012, he was recruited by University of Minnesota to join its faculty. Shen is a world expert on the study of environmental fluid flows and renewable energy. He is currently serving on the national committee of ASCE Environmental & Water Resources Institute on CFD Applications in Water and Wastewater Treatment. He is also on the editorial boards of three internal academic journals. Shen has organized several national and international conferences and symposiums.

ORGANIZATION DESCRIPTION

This project will be performed at the St. Anthony Falls Laboratory (SAFL, http://www.safl.umn.edu) at University of Minnesota. SAFL is an interdisciplinary fluid mechanics research and educational institution. It has 22 faculty members and 35 research and administrative staff members. SAFL is a world-renowned research laboratory specialized in environmental and engineering fluid mechanics. SAFL researchers have been performing many innovative environmental studies for the state of Minnesota. Some of the projects were/are funded by the Minnesota Environment and Natural Resources Trust Fund.

The proposed research leverages on the unique and advanced capability of measuring environmental flows at SAFL, which has 16,000 ft^2 of research space dedicated to physical modeling and experimentation. The facility, which has recently been upgraded with a $16M renovation, has a wind tunnel and 15 general purpose flumes, tanks, and channels readily configurable to the needs of the projects. The SAFL wind tunnel is equipped with the ability to control and measure air velocity and temperature.

The proposed project will use the UMN wind energy research station, which is a premier research facility of SAFL. To help advance its goal of 20% wind power by 2030 in the United States, the Department of Energy awarded an $8 million grant to SAFL to build a wind research station containing a utility scale wind turbine and a 130 m meteorological tower in Rosemount, MN. The Clipper Liberty 2.5 MW turbine built is heavily instrumented in order to collect an immense amount of data and assist in research. The turbine began operating and collecting data in October 2011. This project will use the field measurement data of UMN wind station.