Environment and Natural Resources Trust Fund
2017 Request for Proposals (RFP)

Project Title: **ENRTF ID: 138-E**

Wind-loading Study for Environmental Management and Engineering Innovation

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

Total Project Budget: $ 397,270

Proposed Project Time Period for the Funding Requested: 3 years, July 2017 - June 2020

Summary:

We will utilize a unique facility of wind research station to study wind loading for environmental management and engineering innovation, with a focus on wind turbines, solar arrays, and infrastructures.

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Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

The visual uses four parts of figures to illustrate the activities in the project. The first part shows the research on the fundamental characteristics of the wind and how they translate into loads on structures. This activity will focus on Minnesota seasons, temperature, ground roughness, humidity, etc. The second part shows studies of real wind loads on wind turbines and solar arrays. Data will be used for validating numerical models and developing guidance for engineering design. The third part shows development of models using CFD for wind loading analysis on solar arrays and wind turbines. Open-source models will be developed for use by practitioners. The fourth part shows that research results will be published and shared with stakeholders and practitioners. The Eolos turbine is the closest utility scale turbine to the Twin Cities and public tours will be provided.

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

PROJECT TITLE: Wind-loading Study for Environmental Management and Engineering Innovation

I. PROJECT STATEMENT

We propose to **utilize a unique facility of wind research station** located in Rosemount **to perform study on wind loading for environmental management and engineering innovation in Minnesota.**

In 2011, the University of Minnesota (UMN), **through an $8M US Department of Energy grant, established the Eolos Wind Research Field Station** in UMore Park, a UMN-owned research property in Dakota County, with 80 acres of land dedicated to the Field Station. The Field Station includes a 130-m (426-ft) meteorological tower and an interconnected 2.5 MW horizontal axis wind turbine 80-m high, both heavily instrumented with state-of-the-art measurement devices. The site was established originally to support university-industry collaboration in wind energy and this has been achieved, however **there is tremendous opportunity to expand the scope of the site** to include critical research in **atmospheric boundary layer (ABL) in changing climate**, the associated effects on **wind loads on buildings and other infrastructures**, and **innovations in renewable energy technologies**.

The goal of this project is to **leverage on the Eolos Wind Research Field Station** to generate much needed knowledge and innovation that will lead to better environmental and infrastructure management, lowering lifecycle costs of wind energy and solar energy systems, and increasing the life span of renewable energy systems by optimizing designs to the actual wind loads experienced in Minnesota. Because the Field Station is the closest utility-scale wind turbine to the Twin Cities and because UMN is the only university nation-wise that owns a real turbine for research, we propose to **create greater public awareness and access to the research conducted at the site**. We will host public tours of the solar and wind related research at the site. A website will be created and frequently updated with research activities. Finally, **all data will be collected as "community data"** and will be made available to interested parties and organizations.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: Research on **characterizing ABL for prediction of structural loads** **Budget:** $158,908

We will conduct field study at several locations within the Eolos Field Station to better understand how larger scale weather and ground roughness contribute to wind shear (vertical variation of velocity), which is the input to structural load modeling. Based on the data, a predictive model will be developed. The research results will be compared with current structural design methods to identify areas of improvement to structural design code.

Outcome	Completion Date
1. Collect and validate data on wind shear under various atmospheric and roughness conditions.	Dec. 31, 2018
2. Develop predictive model for wind shear.	June 30, 2019
3. Make recommendations on improvement of structural design code.	June 30, 2020

Activity 2: Measurements and modeling of **loading on wind turbines and solar arrays** **Budget:** $198,635

For renewal energy applications, we will collect field data on wind characteristics and the resulting wind loads on the Eolos wind turbine and an instrumented model solar array system. Measurement techniques will include super-large-scale PIV, ground-based LIDAR, meteorological tower instrumentation, turbine blade and tower instrumentation, and turbine SCADA data. Data collected in the field will be used to develop and validate a numerical model developed by our research team.

Outcome	Completion Date
1. Collect data on loading on the wind turbine blades, rotor, and foundation under various wind conditions.	March 31, 2019
2. Collect data on loading on ground mounted solar array under various array configurations (row spacing, height above ground) and various wind conditions.	Sept. 31, 2019

3. Develop and validate high-fidelity models for prediction of wind loads on wind turbines and solar arrays.	March 31, 2020

Activity 3: Disseminate, outreach, and education **Budget:** $39,727

During the initial stage of the project, a website will be created describing the project and will be updated quarterly. We will host **public tours to the Field Station** featuring the ongoing research. At the conclusion of the project, the findings of the research will be summarized in separate **reports for wind energy and for solar energy** and will be in the form of **recommendations for improvements** to the structural loading methodologies. The numerical tools developed for both wind and solar energy will be described, and we will **make the model open-source for use by public and private organizations**.

Outcome	Completion Date
1. Set up website for project updates and data sharing.	Dec. 31, 2017
2. Establish public tours to the Field Station.	June 30, 2018
3. Make our predictive models open-source, produce online tutorials, and offer workshops.	Dec. 31, 2019
4. Complete reports on wind loads and dissimilate to state agencies, civil engineers, and wind energy and solar energy industries.	June 30, 2020

III. PROJECT STRATEGY

A. Project Team/Partners

This work will be carried out by a **collaborative team of academic researchers and engineers** with **complementary expertise**. Professor Lian Shen will serve as the Project Manager and PI. He will be responsible for project reporting and deliverables, and supervising the postdoctoral associate and graduate student on the modeling and data analysis research. Jeff Marr is Associate Director of Engineer and Facilities at SAFL-UMN and will serve as Co-PI supervising engineering activities at the Field Station. Chris Milliren is a project engineer with expertise on the met tower, wind turbine, and the full data sensor/data acquisition systems. Richard Christopher is the technician for operating and maintaining the Field Station. Patrick Arnold, an IT specialist, will provide technical support for the Eolos data systems. The project will be performed in close collaboration with state agencies, other researchers, and industrial partners in Minnesota.

B. Project Impact and Long-Term Strategy

This study will take a critical and transformative step towards improving the ability to estimate and predict the loading from wind on **infrastructures in changing climate** and the wind loads in **renewable energy industries**. The research will impact several groups:

- **Structural engineers** will have better insight into the loading on the blades, towers, and foundations of wind turbines. The wind loads and lift and drag forces on solar arrays can also be better predicted.
- **Manufacturers and designers** of these renewable energy systems will have better information that they can use to optimize their designs for actual loads. Reducing the need to overdesign solar framing or turbine foundation reduces installation costs and thus will lead to lowering the cost of energy.
- Better information on loading provided to **state agencies and regulators** will lead to better confidence in the safety of deployed systems. This also reduces costs of design, project financing, and overall costs of energy.

Wind loading is a large area of research that includes renewable energy structures but can be easily expanded to include other structures such as complex building, bridges, and towers. Our long-term goal is to build a nationally recognized expertise in wind loading research and innovation in Minnesota. The work described here will serve as a critical step towards this goal.

C. Timeline Requirements

This project will be conducted over a 3-year period from July 1, 2017 to June 30, 2020.

2017 Detailed Project Budget

Project Title: Minnesota Wind Research for Engineering Innovation and Environmental Management

IV. TOTAL ENRTF REQUEST BUDGET: 3 years

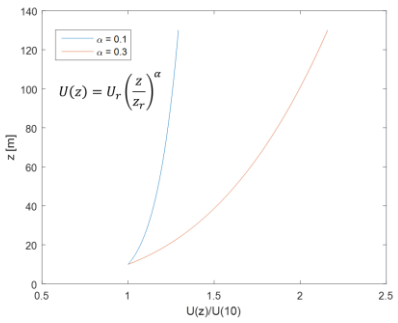
BUDGET ITEM	AMOUNT
Personnel:	
Prof. Lian Shen, project manager (75% salary, 25% benefit); 5.6% FTE (i.e., 0.5 months for summer salary) for each of 3 years	$ 25,668
Jeffrey Marr, co-investigator (75% salary, 25% benefit); 4.2% FTE (i.e., 0.5 months of calendar year) for each of 3 years	$ 18,510
Chris Milliren, engineer and manager of Eolos Field Station and data collection system (82% salary, 18% benefit); 20.8% FTE (i.e., 2.5 months of calendar year salary) for each of 3 years	$ 41,409
Richard Christopher, scientist and lead technician for operating and maintaining Eolos Field Station (82% salary, 18% bnefit); 20.8% FTE (i.e., 2.5 months of calendar year) for each of 3 years	$ 41,409
Patrick Arnold, information technology specialist for developing computer infrastructures (82% salary, 18% bnefit); 8.3% FTE (i.e., 1 month of calendar year) for each of 3 years	$ 19,510
Dr. Zixuan Yang, Postdoctoral Associate, physical experiment and computational modeling (82% salary, 18% benefit); 50% FTE (i.e., 6 months of calendar year) for each of 3 years	$ 90,797
Graduate Research Assistant, data analysis (60% salary, 40% benefit including tuition); 37.5% FTE for each of 3 years	$ 114,967
Professional/Technical/Service Contracts: N/A	$ -
Equipment/Tools/Supplies: Cost of rental for specialized wind measurement equipment, LiDAR and SODAR, from Barr Engineering and/or NRG systems ($20,000). Cost of additional safety equipment including harnesses, helmets and fall-arrest systems to allow staff and visitor to access turbine site ($15,000). Cost of research data aquisition supplies including stress and strain gages, data loggers, and supplies necesseary to mount hardware ($5,000). Cost of consumable research supplies, including network switches, mounting hardware, tools etc. ($5,000).	$ 45,000
Acquisition (Fee Title or Permanent Easements): N/A	$ -
Travel: N/A	$ -
Additional Budget Items: N/A	$ -
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 397,270

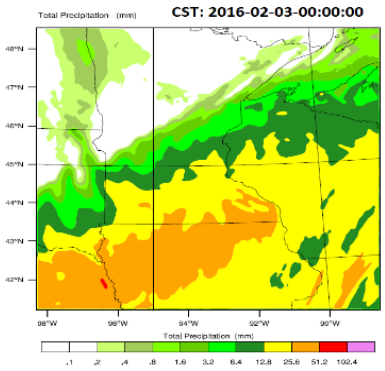
V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period: Study on wind and snow loading on ground mounted solar arrays submitted to UMN-Renewable Development Fund Block Grant. This project is listed as other funding that for projects related to the proposed work for informational purposes and not intended as a cost share commitment for the proposed project.	$630,000	Pending
Other Non-State $ To Be Applied To Project During Project Period: Wind turbine generated sound, **Xcel** Renewable Development Fund. This project is listed as other funding that for projects related to the proposed work for informational purposes and not intended as a cost share commitment for the proposed project.	$625,102	Secured
Other State $ To Be Applied To Project During Project Period: N/A	$ -	N/A
In-kind Services To Be Applied To Project During Project Period: The University of Minnesota nomally charges overhead for Facilities and Administrative of the modified total direct cost (i.e., the total direct cost less graduate fringe, captipal equipment, subawards over $25,000 and on-site facilities rental). The amount, if F&A expenses would have been allowed on the project, would be $177,147. The University will waive the F & A expenses and will provide office space, IT services, and administrative/financial services in support of the project.	$ 177,147	Secured
Funding History: N/A	$ -	N/A
Remaining $ From Current ENRTF Appropriation: N/A	$ -	N/A

Wind-loading Study for Environmental Management and Engineering Innovation

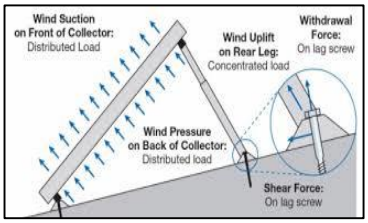
WIND PHYSICS





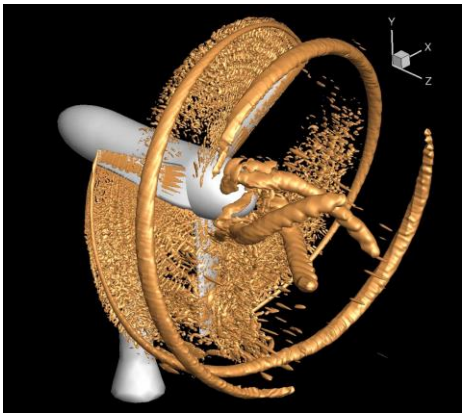
Activity 1: Research on the fundamental characteristics of the wind and how they translate into loads on structures. This activity will focus on Minnesota seasons, temperature, ground roughness, humidity, etc. Figures: Wind shear (left) and prediction of storm event (right).

WIND LOADING



Activity 2: Detailed studies of real wind loads on wind turbines and solar arrays will be carried out t the Eolos field station. Data will be used for validating numerical models and developing guidance for engineering design. Figures: Eolos turbine taken from met tower (Left) and simple loading on a solar array (right).

MODELING



Activity 2: Development of models using CFD for wind loading analysis on solar arrays and wind turbines. Field data will be used as validation. Open-source models will be developed for use by practitioners. Figures: wake generated by a turbine rotor (left) and wind loading simulation on non-rotating rotor (right).

DISSEMINATE

Activity 3: Research results will be published and shared with stakeholders and practitioners. Project will also engage interested public through tours of the research site (Figures). The Eolos turbine is the closest utility scale turbine to the Twin Cities. Tours of the research site and turbine will be incorporated into this project.

PROJECT MANAGER QUALIFICATIONS

This project will be led by Professor **Lian Shen** as program manager. Shen currently holds the position of Associate Director for Research in St. Anthony Falls Lab (SAFL) and Benjamin Mayhugh Associate Professor in Department of Mechanical Engineering at University of Minnesota, Twin Cities. He also serves at the Director of the Eolos Wind Energy Research Consortium. Shen 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 Civil Engineering at the Johns Hopkins University (JHU) in 2004. In 2012, he was recruited by the University of Minnesota to join its faculty. Shen is a world-expert in the study of environmental fluid flows and renewable energy. Over the past decade, he has performed extensive research on atmospheric boundary layer and wind energy, with projects over $10M supported by Department of Energy, Department of Defense, and National Science Foundation.

Jeff Marr is Associate Director of Engineering and Facilities at SAFL-UMN and will serve as Co-PI with responsibility for research conducted at the Field Station. Marr oversees SAFL's Engineering Services Team, which is comprised of 15 professional staff scientists and engineers. He is an experienced project manager for large, multi-investigator research projects and has worked as research staff for over 17 years at the University. He also served as the lead Project Manager for the $8M University-DOE Wind Energy Consortium Project (Eolos) and is the PI on several wind energy research efforts. Marr is a licensed Professional Engineer in Civil Engineering (Minnesota) and hold a MS in Civil Engineering from the University of Minnesota.

ORGANIZATION DESCRIPTION

The project will be carried out by a University of Minnesota research team. Both SAFL and Eolos seek to conduct important research in areas of environmental and energy-focused fluid mechanics where basic/fundamental research can be extended into innovation and implementation. Our team works on a range of projects from local to international, private and public sponsors. Much of our research is conducted for Minnesota-based public and private organizations. We are effective communicators and understand the importance of making research accessible to project stakeholder and the public through use of familiar language, websites, and social media. As a university we are also teachers and have experience in formal and informal education.

The University offers several highly unique facilities for this project. The Eolos Wind Research Field Station is located at UMore Park, a 5,000-acre University-owned property in Rosemount, MN. Eighty acres of property have been dedicated to the Field Station, which includes a 2.5 MW Clipper Liberty wind turbine 80m tall and a 130m (426ft) meteorological tower. The turbine and met tower are extremely unique in that they are fully owned and operated by UMN for the purposes of conducting wind research. To our knowledge, no other University in the United States has this capability. The site is heavily instrumented with sensors and data collection systems – much more so than a standard utility turbine. The met tower is taller than most met towers and has sensors that extend to the tip of the sweep area of the turbine rotor. The turbine has many sophisticated sensors throughout the machine including throughout each blade and within the foundation of the turbine. All data collected at the site, which is logged at 1 Hz (1 sample per second), is stored on University servers in a massive SQL database. The site collect roughly 1.3 Gbytes of data per day and the data is used to support UMN and collaborative research efforts.

The SAFL is a leading interdisciplinary research and research training facility of the College of Science and Engineering at UMN with demonstrated ability to conduct specialized research projects that call upon fundamental research and application. In addition to many physical modeling facilities, SAFL also has established its own high performance computation clusters allowing dedicated capabilities in advanced numerical simulation research and application. SAFL has dedicated IT personnel to maintain this unique facility. The SAFL Clusters will be utilized heavily in this project.