Environment and Natural Resources Trust Fund

2023 Request for Proposal

General Information

Proposal ID: 2023-228

Proposal Title: Vertical Axis Wind Turbine for Greater Minnesota

Project Manager Information

Name: Richard James

Organization: U of MN - College of Science and Engineering

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Project Basic Information

Project Summary: Using origami design methods and modern experimental fluid dynamics, we will design a high efficiency vertical axis wind turbine for power generation in urban, suburban, exurban and rural Minnesota

Funds Requested: $720,000

Proposed Project Completion: June 30, 2026

LCCMR Funding Category: Air Quality, Climate Change, and Renewable 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.

Climate change is affecting Minnesota natural resources in alarming ways. Native plants and animals are disappearing, record high temperatures are being recorded, and wildfires, exemplified by the 3,200 acre Greenwood fire (2021), are appearing with greater frequency. Owing to climate change, the scientifically validated First Street Foundation Wildfire Model rates as in "moderate danger" the whole of the Arrowhead stretching west to Beltrami County, a swath of central Minnesota from Wadena County to the Twin Cities, south to the driftless area. Wabasha County, especially, is in "major danger". To eventually reverse climate change will require widespread solutions. In adversity there is opportunity, and we see it as a major opportunity to deploy near zero emission, distributed methods of energy conversion widely in Minnesota. Whereas large horizontal axis wind turbines (HAWT) are now deployed for utility-scale power generation, vertical axis wind turbines (VAWTs) offer distinct advantages for smaller-scale operations including simplicity, ease of operation and maintenance, and possible wide deployment by individuals and municipalities in rural (e.g., power for irrigation, farm machinery) and urban, suburban and exurban areas where HAWTs would not be tolerated. It is well accepted that existing VAWTs are not well optimized either for power output or reliability.

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 propose to design and optimize a vertical axis wind turbine at reasonable cost using novel methods based on origami design of structures developed by James and his students (Figure 1). These structures are foldable -- therefore easily machinable in the flat state -- and easily transportable, but that fold to achieve a precisely defined shape. The deployed tiles can be curved to yield optimal aerodynamic performance specifically under Minnesota wind conditions. Longmire is a world leading expert in experimental fluid dynamics and wind tunnel testing. Wind tunnel testing of scale models guided by rigorous scientific scaling principles is a powerful method to evaluate particular designs. We propose to bring these modern scientific methods to the design of a vertical axis wind turbine, optimized for maximal power delivery under Minnesota wind conditions. We will protect the resulting designs by UMN patent rights, and we will utilize the outstanding programs of the Office for Technology Commercialization at UMN to attract capital and launch a company. To educate the public and Minnesota youth about climate change, green energy, origami design, fluid dynamics, and the vertical axis wind turbine in particular, we will partner with the Science Museum of Minnesota.

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?

Climate change provides the greatest overall challenge to Minnesota natural resources. Already, native species are disappearing, lakes and rivers are burdened by non-native species from warmer climates, fire is destroying major forests, and smoke from western fires pollutes our air. These events emphasize that climate change in Minnesota is also a world-wide problem. Thus, for the long-term health of our state, we need worldwide solutions. The VAWT is one such solution. VAWTs offer many potential advantages over HAWTs for conservation: lower carbon cost of manufacture and installation, possible wide deployment, and less danger to birds and bats.

Activities and Milestones

Activity 1: Origami design and simulation of VAWTs

Activity Budget: $432,091

Activity Description:

Origami design of structures is a new field that goes far beyond the ancient art of paper folding. It embraces the design of complex structures foldable from flat sheets, the use of curved tiles (the blades of a VAWT, Figure 1), the design of hinges where tiles and other structural components meet, the accurate calculating of power produced, and the prediction of stresses, deformations and fatigue life of the resulting structure. When combined with modern computational and experimental methods of fluid dynamics, including turbulence models, it becomes possible to optimize the power produced by a VAWT within a quite general family of designs. Building on his past work in this area, James will directly participate himself and oversee the work of a graduate student and Step-UP intern for the origami design of a VAWT that maximizes the power produced, accounting for the measured wind conditions in Minnesota. Coordinated closely with Longmire, James will build prototypes suitable for wind tunnel testing (see below) based rigorously on the fundamental scaling laws of fluid dynamics and solid mechanics. The successful designs will be evaluated by intellectual property experts at the Office of Technology Commercialization at UMN.

Activity Milestones:

Description		Completion Date
A.	Development of origami designs for the VAWT	December 31, 2023
B.	Study of designs using computational fluid dynamics	June 30, 2024
C.	Build models of initial prototypes	August 31, 2024
D.	Optimization of VAWT designs within a broad family of designs	June 30, 2025
E.	Complete advanced optimal designs	December 31, 2025
F.	Analysis of fatigue and failure	June 30, 2026

Activity 2: Wind tunnel evaluation of VAWT models

Activity Budget: $287,909

Activity Description:

A detailed study of the scaling laws, including fluid-structure interaction and blade deflections, will be initiated by Longmire/James early in the project to provide accurate extrapolation of wind tunnel results to full scale behavior of a VAWT. These scaling laws will also determine the selection of materials. Origami turbine designs will be mounted within a wind tunnel (Figure 1) with large cross section and high flow speed capabilities. Model turbines will be allowed to rotate freely or be powered at specific rotation rates with a stepper motor. Turbine torque and power output will be monitored as a function of rotation rate and tunnel flow velocity. Power output for select designs will be correlated with velocity variations in the turbine wake in order to inform improvements and design optimization. To predict long-term fatigue and performance under extreme conditions, deformation of the turbine vanes will also be monitored in situ and correlated with wind speed. Detailed velocity variations and structural deformations will be measured using state-of-the-art techniques developed and employed by Longmire's research group over many years. All tests and analysis will be performed by Longmire, a graduate student, and participating undergraduate students.

Activity Milestones:

Description		Completion Date
A.	Procurement and preparation of sensors for VAWT testing	December 31, 2023
B.	Study of scaling laws including fluid-structure interaction	December 31, 2023
C.	Wind tunnel testing of initial prototypes	December 31, 2024
D.	Wind tunnel testing of advanced designs	December 31, 2025

E.	Tests of advanced designs under extreme conditions	June 30, 2026

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Professor Ellen Longmire	Department of Aerospace Engineering and Mechanics, University of Minnesota	Co-Investigator	Yes

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?

Guided by the scaling laws of fluid dynamics and elasticity, wind tunnel testing is a highly reliable method of designing aerodynamic structures. It gives precise predictions of behavior and power output of full-scale structures. During the project we will accumulate valuable data that can be used to give designs of full scale VAWTs. This data, together with the intellectual property protected under the project, will enable full-scale commercialization and deployment in Minnesota. We will encourage our graduate students on the project to consider leading these ventures aided by the outstanding programs of the Office for Technology Commercialization at UMN.

Project Manager and Organization Qualifications

Project Manager Name: Richard James

Job Title: Distinguished McKnight University Professor

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

Richard D. James is Distinguished McKnight University Professor in the Department of Aerospace Engineering and Mechanics at the University of Minnesota. He has an Sc.B. in Engineering from Brown University and a Ph.D. in Mechanical Engineering from the Johns Hopkins University. He has authored or co-authored over 175 articles, with 16,000 citations. He has given 55 plenary/named lectureships, and he was awarded the Humboldt Senior Research Award (2006/7), the Warner T. Koiter Medal from American Society of Mechanical Engineers (2008), the William Prager Medal from the Society of Engineering Science (2008), the Brown Engineering Alumni Medal (2009) and the Theodore von Karman prize from Society for Industrial and Applied Mathematics (2014). In 2019, he received a Vannevar Bush Faculty Fellowship for work on the Mathematical Design of Materials; this is the highest academic award of the DoD (approx. 10 awarded per year nationally in all fields of science, engineering and biology). James has also led major US national multidisciplinary projects in areas of materials science, engineering and mathematics. Regarding the subject of this proposal, James has a passionate interest in sustainability. With his students he discovered new methods of the direct conversion of heat to electricity (without a separate electric generator) using phase transformations in multiferroic materials. For this work he was awarded a US patent on ferroelectric energy conversion together with Bharat Jalan. James is frequently asked to give lectures, and contribute popular articles, to audiences of all ages in areas of science and mathematics, including origami design.

Organization: U of MN - College of Science and Engineering

Organization Description:

The research and development for the vertical axis wind turbine described here will be supervised by Profs. Longmire and James. James' responsibility will encompass origami design, simulation and construction, and Longmire will supervise work on fluid dynamic aspects and wind tunnel testing. Both PIs will be directly involved in all the research,

and the researchers will meet once per week year-round to review progress and set next goals. The Department of Aerospace Engineering and Mechanics houses two wind tunnels with large cross-section and a Laboratory for Turbulent and Complex Flows (Figure 1). In addition, Prof. Longmire has received permission from the St. Anthony Falls Hydraulic Laboratory to use their wind tunnel facilities. The Minnesota Supercomputing Institute, of which James is a member, houses exceptional facilities for computational studies which will be used for studies of fluid-structure interaction. For the construction of origami designs we will make use of an extensive collection of 3D printers available in the College of Science and Engineering, the UMN Medical Devices Center and Medical School as well as the facilities of the Anderson Innovation Labs and the CSE Shop. All facilities needed to perform this research are available at the University of Minnesota.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Principal Investigator		Richard James, Principal Investigator			33.5%	0.24		$102,729
Co-Investigator		Ellen Longmire, Co-Investigator			33.5%	0.24		$93,463
Graduate Research Assistant		Graduate Research Assistant, Department of Aerospace Engineering and Mechanics			23.6%	18		$163,844
Graduate Research Assistant		Graduate Research Assistant, Department of Aerospace Engineering and Mechanics			23.6%	18		$163,844
Undergraduate Research Assistant		Step-UP Intern			0%	0.36		$7,728
Undergraduate Research Assistant		Step-UP Intern			0%	0.36		$7,728
							Sub Total	**$539,336**
Contracts and Services								
College of Science and Engineering (UMN) machine shop and 3D printing services	Internal services or fees (uncommon)	Machining of structures and sensors, 3D printing				0		$115,000
							Sub Total	**$115,000**
Equipment, Tools, and Supplies								
	Tools and Supplies	Materials and supplies for construction of VAWTs	Sheet stock, bulk parts, sensor components					$65,664

							Sub Total	**$65,664**
Capital Expenditures								
							Sub Total	**-**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
							Sub Total	**-**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$720,000**

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				
			Non State Sub Total	**-**
			Funds Total	**-**

Attachments

Required Attachments

Visual Component

File: b4688df2-fce.pdf

Alternate Text for Visual Component

Preliminary origami designed structures and wind tunnels for use on this project...

Optional Attachments

Support Letter or Other

Title	File
Institutional support letter	86adf21d-7f4.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Does your project have potential for royalties, copyrights, patents, or sale of products and assets?

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?

Yes, Sponsored Projects Administration

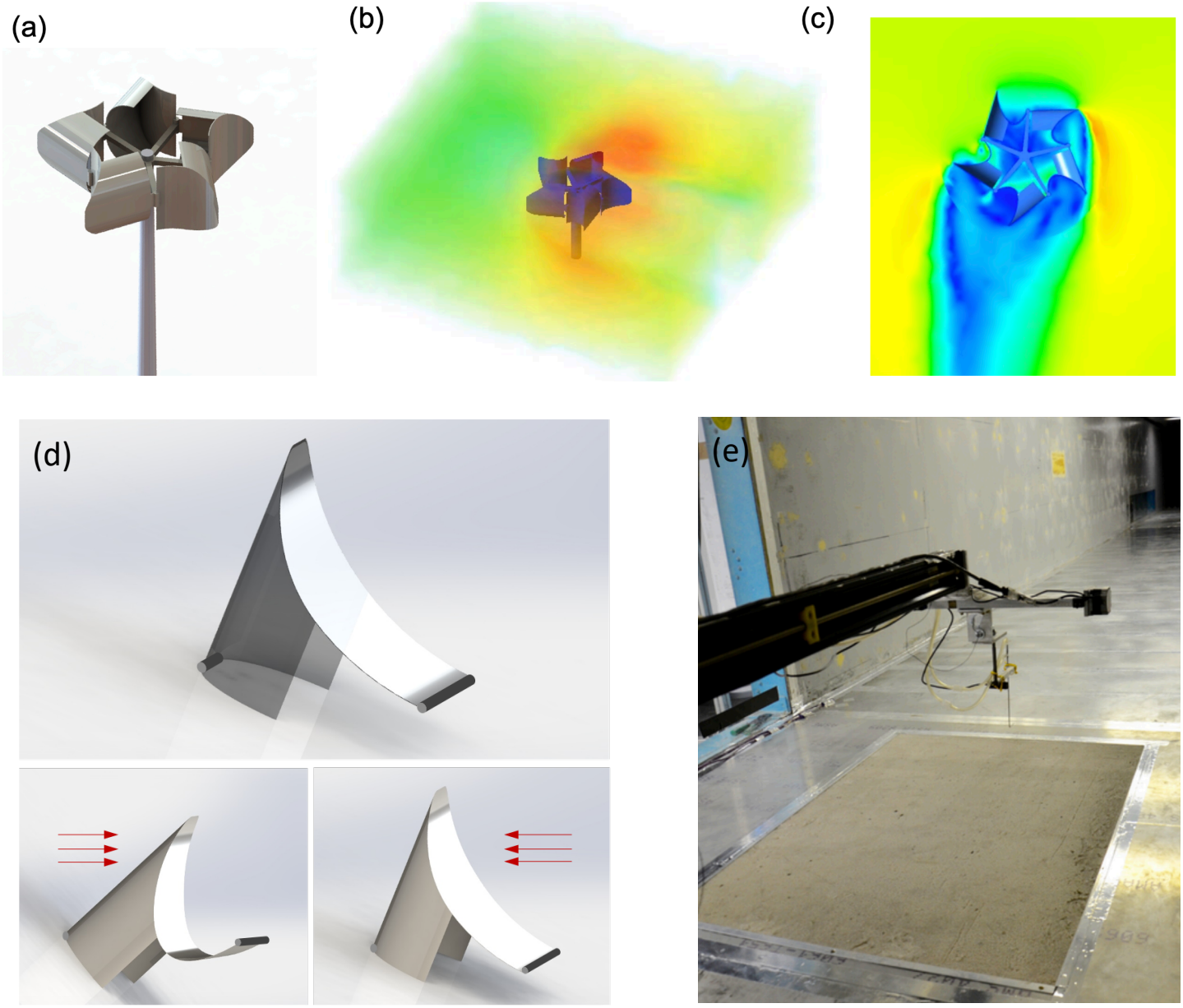

Figure 1. (a)-(c) Origami designed vertical axis wind turbine and flow field, simulated using computational fluid dynamics: this behavior is reasonable but far from a final design. (d) Origami designs permit deforming blades. (e) Wind tunnel in St. Anthony Falls Hydraulic Laboratory available to us. (f) Wind tunnel in the department of Aerospace Engineering and Mechanics that we will use for testing.