Environment and Natural Resources Trust Fund

2026 Request for Proposal

General Information

Proposal ID: 2026-525

Proposal Title: SkyWindFarm: Clean, Scalable High-Altitude Wind Energy for Minnesota

Project Manager Information

Name: Sayan Biswas

Organization: TerraCare Energy LLC

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Project Basic Information

Project Summary: SkyWindFarm is an innovative airborne wind energy system delivering carbon-free, cost-effective power without land use conflicts, preserving wildlife, and ensuring reliable energy, supporting Minnesota's environmental goals and resource conservation.

ENRTF Funds Requested: $399,000

Proposed Project Completion: June 30, 2028

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.

Minnesota has committed to achieving 80% carbon-free electricity by 2030 and 100% by 2040 under the Clean Energy Bill passed in February 2023. With 27% of the state's population living in rural areas, transitioning these communities to carbon-free energy presents significant challenges. Key obstacles include transmission constraints and land use conflicts. While Minnesota possesses abundant wind resources, its existing grid struggles to efficiently distribute power, particularly from rural wind sites far from population centers. Additionally, competition for land—between agriculture, conservation, and residential development—creates tensions over wind farm installations.

Rural Minnesota also experiences strong, year-round winds between 500 and 5,000 feet, yet air traffic is minimal at these altitudes, offering an untapped opportunity for airborne wind energy. We propose SkyWindFarm, a novel, modular design that uses vertical axis wind turbines (VAWTs) in high-altitude clusters to optimize energy capture. This technology avoids land use conflicts, remains outside public sight, is easy to install and requires minimal maintenance, and delivers carbon-free energy directly to local microgrids. SkyWindFarm is designed to make rural Minnesota grid-independent, affordable, and cleaner, providing reliable and sustainable energy without disrupting the ecosystem or air traffic.

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.

SkyWindFarm introduces a novel, adaptive, and modular airborne wind energy system designed to capture wind energy from altitudes 500 to 5,000 feet, where wind speeds are significantly higher than at ground level. Each SkyWindFarm unit consists of several key modules: a flotation module with a lighter-than-air shell, a stability module to control drift and elevation, an energy module with vertical axis wind turbines (VAWTs) connected to a high-efficiency air-core permanent magnet direct-drive generator, a tethered power transfer module for energy storage and grid connection, and a ground control module with advanced sensors (e.g., power-meter, communication system, weather station, GPS, load-cell, accelerometers, gyroscopes).

SkyWindFarm's unique VAWT cluster configuration improves stability, reduces moving parts (eliminating gearboxes), and optimizes performance. The system is highly scalable, capable of generating megawatts of energy at a cost of around $25/MWh.

SkyWindFarm requires no land acquisition, has minimal impact on wildlife, and operates at adjustable altitudes to withstand inclement weather. In the past 18 months, co-founders Biswas and Dagade have designed and tested a scaled prototype, with a patent filed. The project aims to develop a full-scale unit capable of producing 10-100 kWh per day, enough to power a Minnesota household or small farm.

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?

SkyWindFarm promotes the protection and conservation of Minnesota's natural resources by providing carbon-free energy without harming wildlife, avoiding land acquisition, and preserving the scenic beauty of rural areas. It eliminates the challenges associated with traditional wind farms, such as wildlife (bats and birds) collisions and land-use conflicts. Additionally, SkyWindFarm ensures reliable power during natural disasters and offers a cost-effective solution, with installation costs an order of magnitude lower than conventional wind energy. This innovative approach benefits Minnesota's air, land, and communities, aligning with the state's environmental goals.

Activities and Milestones

Activity 1: Development, instrumentation, and integration of full-scale SkyWinFarm unit

Activity Budget: $200,000

Activity Description:
We will follow a structured approach to develop a full-scale alpha prototype of SkyWindFarm. This includes refining design, testing, launching, and market analysis. The prototype will use IoT-connected AI with GPS and satellite data to autonomously adjust altitude for maximum efficiency.

The project involves experimentation, including stability and stress testing, system performance evaluation, and real-world deployment. System modeling will help optimize control strategies, predict ideal operating conditions, and improve efficiency and stability. Over the past 1.5 years, we have overcome early-stage technical challenges, and SkyWindFarm is now in its 8th design iteration.

Our next goal is to validate its performance at high altitudes, where wind energy potential is strong, temperatures are low, and wind gusts are intense. We will also test the system's durability and long-term viability. The estimated cost to build the prototype is $120,000.

Success will be measured by a 10% efficiency increase and 15% higher power output compared to other airborne and ground-based wind systems while maintaining an LCOE below $35/MWh. We will test the prototype in North Branch, MN, with our master electrician connecting it to the local grid. Data will be collected over several days to weeks for evaluation.

Activity Milestones:

Description	Approximate Completion Date
Set up and optimize full-scale SkyWindFarm unit and remote-control data acquisition	December 31, 2026
Complete testing of the energy transfer module and control system in a laboratory environment	January 31, 2027
Complete testing of the energy transfer module and control system in a laboratory environment	April 30, 2027
Activity 1 summary report	May 31, 2027

Activity 2: Comprehensive full-scale field testing of SkyWindFarm flight performance and energy output testing

Activity Budget: $50,000

Activity Description:
We plan to conduct an extensive flight test of the SkyWindFarm prototype over several days to assess its real-world performance under varying conditions. The testing will focus on optimizing key operating parameters such as altitude (ranging from 500 to 5,000 meters), wind speed thresholds (targeting 8-25 m/s for optimal energy capture), and power generation efficiency.

Our goal is to measure the system's energy output in kilowatt-hours (kWh) under different atmospheric conditions. Based on wind speed data and system modeling, we expect the prototype to generate between 10-100 kWh per day, depending on altitude and wind conditions. This is equivalent to powering a Minnesota household (average 30 kWh/day) or a small farm.

We will systematically test different configurations, including turbine speed adjustments, yaw and pitch control for

stability, and automated altitude shifts to find the most efficient operating conditions. Data will be collected using onboard sensors (GPS, wind speed, power meters, load cells) and transmitted in real time for analysis.

The prototype will be flown at North Branch, MN, where wind patterns are favorable. A master electrician will connect the system to the grid, ensuring accurate power measurement and compliance with grid standards.

Activity Milestones:

Description	Approximate Completion Date
Deploy SkyWindFarm system for field testing	April 30, 2027
Complete the first field testing campaign	October 31, 2027
Calibrate and optimize the SkyWindFarm performance results	November 30, 2027
Complete 4-6 field flight testing over a period of six months	December 31, 2027
Activity 2 summary report	December 31, 2027

Activity 3: Full-scale model testing and demonstration at the airborne wind energy consortium

Activity Budget: $50,000

Activity Description:
We plan to collaborate with Sandia National Laboratories to establish an Airborne Wind Energy (AWE) Consortium, bringing together industry experts, researchers, and policymakers to evaluate SkyWindFarm's full-scale prototype. This initiative will create a standardized framework for performance assessment, enabling future permitting and commercialization of airborne wind energy systems.

As part of this effort, we will transport and deploy the prototype at Sandia's wind energy test site, leveraging their expertise in atmospheric testing, computational modeling, and system validation. The prototype will undergo rigorous performance evaluation, including:

- Energy Output Testing: Measuring real-time power generation (kW) under different wind conditions, targeting continuous operation at 100–5000 meters altitude.
- Aerodynamic and Structural Integrity: Evaluating system stability in turbulent winds, withstanding gusts up to 50 m/s.
- Grid Integration Analysis: Testing power transmission efficiency from airborne turbines to ground-based microgrids.
- Environmental Impact Assessment: Ensuring minimal disturbance to airspace, wildlife, and communities.

The goal is to develop standardized testing protocols to support FAA and DOE regulatory approvals, paving the way for widespread adoption of AWE technology. Successful validation at Sandia will enhance investor confidence and accelerate commercial deployment.

Activity Milestones:

Description	Approximate Completion Date
Set up hardware for consortium field testing	August 31, 2027
Complete testing at the consortium	December 31, 2027
Complete at least two relevant assessment needed for commercial deployment	January 31, 2028
Activity 3 summary report	February 28, 2028

Activity 4: Optimize design and conduct multiple test flights to measure power output

Activity Budget: $25,000

Activity Description:
This activity focuses on refining the SkyWindFarm prototype for optimal performance through iterative design improvements and real-world flight testing. we will conduct several test flights to evaluate power generation, stability, and efficiency under different atmospheric conditions.

Design optimization:
1) Refine turbine aerodynamics, power electronics, and tether control.
2) Integrate real-time data acquisition systems (GPS, satellite, and onboard sensors) to enhance autonomous operation.

Flight tests:
3) fly at 100m–5000m altitudes to analyze power output variations.
4) measure power generation (targeting 10–100 kWh/day) under different wind speeds.
5) test dynamic adjustments for altitude, pitch, and yaw to maximize energy harvesting.

Data collection and analysis:
6) monitor voltage, current, power curves, and efficiency metrics in real time.
7) evaluate system load response, turbulence handling, and energy storage integration.
8) compare field results with simulated performance to refine control strategies.

Final adjustments:
9) implement design tweaks based on test data.
10) prepare for long-duration operation and grid connection.

This activity ensures SkyWindFarm's reliability, efficiency, and commercial viability for scalable deployment.

Activity Milestones:

Description	Approximate Completion Date
Complete field testing and data analysis	March 31, 2028
Power performance data validation and performance sensor package development	April 30, 2028
Detailed testing of SkyWindFarm package in the field, calibrating and optimizing the power output	May 31, 2028
Activity 4 summary report	May 31, 2028

Activity 5: Attend trade shows and industry conferences

Activity Budget: $50,000

Activity Description:
Attending trade shows and industry conferences is a vital step in promoting SkyWindFarm and building connections with key stakeholders. These events provide an opportunity to showcase our technology to investors, policymakers, and industry experts, helping us refine our approach and gain momentum for commercialization.

At these conferences, we will present the latest SkyWindFarm prototype, sharing performance data on energy output, operational stability, and environmental impact. By highlighting our competitive levelized cost of energy (LCOE) of under $35/MWh, we aim to position SkyWindFarm as a scalable, cost-effective alternative to traditional ground-based wind systems. This will also allow us to gather feedback from industry leaders, improving both the design and commercialization strategy.

These events also offer insights into evolving regulatory frameworks and market trends in the airborne wind energy

space. Networking with experts and attending technical sessions will help us stay aligned with industry standards and requirements for permitting and grid integration.

Additionally, trade shows are excellent for securing pilot project opportunities. By engaging with wind farm developers, grid operators, and investors, we can identify potential test sites for full-scale deployment and build valuable partnerships, driving SkyWindFarm toward rapid scaling and commercialization.

Activity Milestones:

Description	Approximate Completion Date
Successfully showcase SkyWindFarm prototype at key trade shows and secure partnerships or pilot project opportunities	May 31, 2028

Activity 6: Reporting, IP and patent filing, results dissemination, and journal paper writing

Activity Budget: $24,000

Activity Description:
This phase of the project will focus on final data analysis and report writing. We aim to refine our optimized design, integrating hardware-specific insights gained from this study. Our goal is to package this technology and file a patent to secure intellectual property rights.

Beyond fulfilling the LCCMR Fund's deliverable requirements, the team will actively engage in disseminating the project's findings by preparing manuscripts for peer-reviewed journals and sharing the results with a broad range of key stakeholders. This will include industry partners such as Xcel Energy, Minnesota Department of Commerce, and other renewable energy utilities and operators across the region. In addition, the team will communicate with policy makers and government agencies, such as the Minnesota Public Utilities Commission (PUC), to ensure that the advancements in airborne wind energy technology are well understood and considered in future energy policy frameworks.

The team will also share findings with academic institutions and research organizations, including Sandia National Laboratories and National Renewable Energy Laboratory (NREL), to collaborate on further technical developments and testing. Furthermore, environmental advocacy groups will be involved in understanding the sustainability and ecological benefits of SkyWindFarm, emphasizing the system's minimal impact on wildlife and the environment.

Activity Milestones:

Description	Approximate Completion Date
File IP and patents before any public disclosure of research results	September 30, 2027
Finished writing the first draft of the journal/conference article	March 31, 2028
Activity 5 summary report	May 31, 2028
Final project report	June 30, 2028

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Tyler Nelson	Real Vision Drones LLC	Tyler Nelson is the CEO of Real Vision Drones LLC and a master electrician. With his expertise in electrical systems and drone technology, he leads the company in developing innovative solutions for energy production and infrastructure. Tyler plays a key role in implementing electrical connections for projects like SkyWindFarm.	Yes
Yash Dagade	Duke University	Yash Dagade, Co-Founder and CTO of SkyWindFarm technology, is currently studying at Duke University. He brings a strong technical background to the company, contributing his expertise in energy and environmental technologies, driving the innovation and development of solutions like SkyWindFarm for sustainable energy production.	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?

The SkyWindFarm project will scale the technology with a full-scale prototype, validating its performance and sharing findings with key stakeholders like Xcel Energy and the Minnesota Department of Commerce. Future commercialization will involve securing venture capital, government grants, and industry partnerships, ensuring long-term sustainability and integration into the energy market.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
LiDAR Technology to Help Prevent Wildlife Fatalities from Wind Turbines	M.L. 2024, , Chp. 83, Art. , Sec. 2, Subd. 08m	$525,000

Project Manager and Organization Qualifications

Project Manager Name: Sayan Biswas

Job Title: Co-Founder & CEO

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

Dr. Sayan Biswas is an expert in clean energy, aviation, and laser-based sensing technologies. He is the co-founder of SkyWindFarm and CEO of TerraCare Energy LLC. As a faculty member of Mechanical Engineering at the University of Minnesota, Dr. Biswas brings extensive experience in large-scale energy systems and optical sensors. His research is supported by the DOE, ONR, NASA, and LCCMR. To date, he has published over 20 journal articles and 40+ conference papers. With a background that includes over 3 years at Sandia National Laboratories and 5+ years at Purdue University, Dr. Biswas is dedicated to advancing technologies from the lab to market. He actively contributes to technical committees and local organizations in Minnesota.

Organization: TerraCare Energy LLC

Organization Description:

TerraCare Energy LLC is a startup focused on developing innovative renewable energy and environmental technologies. The company aims to create scalable, cost-effective solutions like SkyWindFarm, an airborne wind energy system. TerraCare Energy's mission is to drive the adoption of clean energy while minimizing environmental impact and reducing

carbon footprints. Through research and development, the company collaborates with industry leaders, academic institutions, and government agencies to accelerate the transition to sustainable energy and combat climate change.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Sayan Biswas		Principal Investigator			25%	0.8		$180,000
Tyler Nelson		Master Electrician			25%	0.4		$25,000
Yash Dagade		Co-principal investigator			25%	0.5		$20,000
							Sub Total	**$225,000**
Contracts and Services								
							Sub Total	-
Equipment, Tools, and Supplies								
	Tools and Supplies	The project will require screws, bolts, and machining tools for assembly and testing. These tools are essential for fabricating, securing components, and making adjustments to ensure the prototype's optimal performance.	The purpose of these items is to assemble and secure the SkyWindFarm prototype components, ensuring structural integrity and functionality during testing. They are essential for the effective construction and operation of the system.					$25,000
							Sub Total	**$25,000**
Capital Expenditures								
		The budget for the full-scale prototype of SkyWindFarm is estimated at $120,000. This cost covers materials, design, and manufacturing of the prototype, including specialized components such as vertical axis wind turbines (VAWTs), lightweight high-efficiency air-core permanent magnet direct drive generators, and the flotation and stability modules. The budget also includes costs for testing and integration, such as IoT-connected AI systems for weather data collection, sensors, and GPS equipment. Additional expenses will be allocated for site preparation and logistics at the test location in North Branch, MN, as well as for the operational costs of	The purpose of the full-scale prototype of SkyWindFarm is to demonstrate the viability of airborne wind energy systems and their potential to provide scalable, carbon-free energy. By creating a working prototype, we aim to validate the design, optimize performance, and assess its ability to generate reliable power in high-altitude wind conditions. This prototype will serve as a proof of concept for future commercial deployment, showcasing the ability to harness wind energy	X				$120,000

		testing, stability analysis, and power output measurements. Moreover, part of the budget will be dedicated to system-level simulations and modeling to optimize the performance of the prototype before full deployment. The project will also allocate funds for collaboration with industry experts and stakeholders to evaluate the system's efficiency, durability, and scalability.	without land acquisition, minimal environmental impact, and at a significantly lower installation cost compared to traditional ground-based wind turbines. Additionally, the prototype will be used to test system stability, energy efficiency, and the integration of advanced technologies such as IoT-connected AI and weather data sensors. The insights gained from this prototype will be crucial for refining the design, expanding the technology's applications, and securing the necessary approvals and					
							Sub Total	**$120,000**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
	Miles/ Meals/ Lodging	Field testing fuel and personal vehicle costs, to deploy SkyWinFarm	Field testing fuel and personal vehicle costs are necessary to transport the SkyWindFarm prototype and team to test locations, such as North Branch, MN. These expenses ensure the safe and timely deployment of the prototype for real-world testing and data collection.					$5,000
							Sub Total	**$5,000**
Travel Outside Minnesota								
	Conference Registration Miles/ Meals/ Lodging	One trip per year for two PIs and a manager to a relevant conference/trade show to disseminate the results	To share research results	X				$20,000
							Sub Total	**$20,000**

Printing and Publication								
	Publication	Open source journal let everyone access the research results at free of cost	For sharing knowledge					$4,000
							Sub Total	**$4,000**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$399,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request
Capital Expenditures		The budget for the full-scale prototype of SkyWindFarm is estimated at $120,000. This cost covers materials, design, and manufacturing of the prototype, including specialized components such as vertical axis wind turbines (VAWTs), lightweight high-efficiency air-core permanent magnet direct drive generators, and the flotation and stability modules. The budget also includes costs for testing and integration, such as IoT-connected AI systems for weather data collection, sensors, and GPS equipment. Additional expenses will be allocated for site preparation and logistics at the test location in North Branch, MN, as well as for the operational costs of testing, stability analysis, and power output measurements. Moreover, part of the budget will be dedicated to system-level simulations and modeling to optimize the performance of the prototype before full deployment. The project will also allocate funds for collaboration with industry experts and stakeholders to evaluate the system's efficiency, durability, and scalability.	This cost is essential to ensure the accurate development, testing, and performance validation of the SkyWindFarm prototype, which is critical for demonstrating its feasibility and achieving the project's long-term objectives of clean, scalable energy. **Additional Explanation :** The capital equipment purchased with the appropriation, including the full-scale prototype components, will continue to be utilized for ongoing testing, design optimization, and performance validation of SkyWindFarm. These assets will remain integral to future research and development efforts, allowing for further iterations of the technology and real-world deployment trials. Additionally, the equipment will be used in collaboration with industry partners and for educational purposes, fostering continued innovation and refinement of airborne wind energy systems.
Travel Outside Minnesota	Conference Registration Miles/Meals/Lodging	One trip per year for two PIs and a manager to a relevant conference/trade show to disseminate the results	This would be key to find commercial partners

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	**-**
Non-State				
			Non State Sub Total	**-**
			Funds Total	**-**

Total Project Cost: $399,000

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: b577678a-dbc.pdf

Alternate Text for Visual Component

The visual showcases the SkywindFarm concept, previous prototype system demonstrations, power output measurements, simulations, and includes two video links—one for the first demo flight and another for the SkywindFarm concept....

Financial Capacity

Title	File
Financial Capacity Note	758bf976-7ca.pdf

Supplemental Attachments

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

Title	File
NREL Airborne Wind Energy Report	d45fd360-42e.pdf
Reasons for airborne wind energy	42331644-140.pdf
DOE report on AWE	09f7d4d1-b77.pdf
SkyWindFarm Videos / Movies	70bdfe5c-94b.pdf
Resolution Letter TerraCare Energy	7625f568-ff2.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 Commissioner's Plan 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:

Sayan Biswas, TerraCare Energy LLC

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