Environment and Natural Resources Trust Fund

2026 Request for Proposal

General Information

Proposal ID: 2026-423

Proposal Title: Microwave-Enhanced Chemical Recycling of Decommissioned Wind Turbine Blades

Project Manager Information

Name: Min Addy

Organization: U of MN - College of Food, Agricultural and Natural Resource Sciences

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Project Basic Information

Project Summary: This project aims to develop and evaluate microwave-enhanced solvolysis and pyrolysis technologies for the recycling high-quality fibers and chemical building blocks from decommissioned wind turbine blades.

ENRTF Funds Requested: $300,000

Proposed Project Completion: June 30, 2028

LCCMR Funding Category: Small Projects (G)

Secondary 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 emerged as a leader in wind energy, increasing wind power generation nearly 20-fold since 2000, with wind now supplying 25% of the state's electricity. As turbines reach their 25–30 year lifespan, the first generation of wind turbines faces decommissioning, leading to a surge in turbine blade waste. By 2050, the cumulative decommissioning material from wind turbines could reach 133 million tons nationwide, posing significant economic and environmental challenges. For instance, Xcel Energy estimates that it will cost $71 million to decommission the 134 turbines at its Noble facility.

Wind turbine blades, primarily composed of fiber-reinforced composites (FRPs) made of carbon or glass fibers embedded in thermoset resins, are notoriously difficult to recycle due to their durability and complex structure. Conventional disposal methods, such as landfilling and incineration, are unsustainable and fail to recover valuable materials. While mechanical recycling is cost-effective, it primarily produces low-value materials and cannot meet large-scale recycling demands. Conversely, chemical recycling methods like solvolysis and pyrolysis offer greater material recovery potential. However, challenges such as high energy consumption, fiber degradation, and limited market adoption remain.

Addressing the growing wind turbine blade waste problem requires advancements in energy-efficient recycling processes and high-value material recovery strategies.

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.

This project aims to advance the chemical recycling of fiber-reinforced composites (FRPs) by integrating microwave heating into solvolysis and pyrolysis. With its selective and volumetric heating capabilities, microwave heating can reduce processing times, lower reaction temperatures, improve resin decomposition control, and better preserve fiber mechanical properties.

As wind turbine blade technology advances, carbon fiber is replacing glass fiber to enhance strength and reduce weight. With a market value ten times that of glass fiber, carbon fiber recovery is essential for the economic viability of FRP recycling and requires a tailored approach. We propose two microwave-enhanced recycling technologies: microwave-enhanced solvolysis for glass fiber-reinforced composites (GFRPs), and microwave-enhanced pyrolysis for carbon fiber-reinforced composites (CFRPs). The solvolysis process will use microwave-absorbing green solvents to accelerate resin breakdown, recovering intact glass fibers and valuable compounds like bisphenol A. The pyrolysis process will leverage the selective microwave absorption of carbon fibers to efficiently remove resin and recover high-strength carbon fibers.

Both processes will be optimized for energy efficiency, scalability, and cost-effectiveness. A techno-economic and environmental analysis will be conducted to assess feasibility and market potential, focusing on identifying sustainable, high-volume markets for recovered materials to ensure the long-term success of wind turbine blade recycling.

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?

This project advances the protection and conservation of Minnesota’s natural resources by tackling the growing issue of wind turbine blade waste. By developing microwave-enhanced solvolysis and pyrolysis technologies, the project will enable the recovery of high-quality carbon and glass fibers, reduce reliance on landfills, and promote material reuse. These innovative processes will minimize environmental impact and greenhouse gas emissions associated with traditional disposal methods like landfilling and incineration, supporting a circular economy. Furthermore, the project will identify sustainable secondary markets for recovered materials, ensuring long-term economic and environmental benefits.

Activities and Milestones

Activity 1: Development of Microwave-Enhanced Solvolysis for Glass Fiber-Reinforced Composites (GFRPs)

Activity Budget: $140,000

Activity Description:
This activity aims to develop and optimize a microwave-assisted solvolysis process for recovery of high-quality glass fibers and valuable chemical compounds like bisphenol A from GFRPs. We will begin with the selection and optimization of green solvents such as acetic acid, hydrogen peroxide, and tartaric acid, chosen for their ability to dissolve the resin matrix while maintaining fiber integrity. To address heat and mass transfer limitations during the solvolysis process, swelling pre-treatments will be applied to increase surface area and soften the resin, while mechanical stirring will ensure uniform microwave heating and prevent hot spots. Small molecules, including nitrogen-containing agents, will be introduced to selectively cleave cross-linking bonds, facilitating resin breakdown under mild conditions (70–110°C) and achieving up to 99% degradation. The recovered glass fibers will undergo mechanical testing for tensile strength, Young's modulus, and strain-to-failure, while chemical compounds extracted from the resin will be analyzed using GC-MS to determine their purity and reuse potential. The optimized process will recover high-quality glass fibers with minimal strength loss (less than 5%) and valuable chemical feedstocks, providing a cost-effective, sustainable solution for GFRP recycling.

Activity Milestones:

Description	Approximate Completion Date
Select and test solvents	December 31, 2026
Optimize microwave parameters	February 28, 2027
Development of swelling pretreatment	May 31, 2027
Finalize solvolysis process	August 31, 2027

Activity 2: Development of Microwave-Enhanced Pyrolysis for Carbon Fiber-Reinforced Composites (CFRPs)

Activity Budget: $130,000

Activity Description:
This activity focuses on developing a microwave-assisted pyrolysis process for recycling carbon fiber-reinforced composites (CFRPs). Carbon fibers, acting as microwave susceptors, enable rapid and uniform heating of the resin matrix at lower temperatures (300–500°C), minimizing fiber degradation and reducing energy consumption compared to conventional pyrolysis. The process takes advantage of the high dielectric loss and electrical conductivity of carbon fibers, which allow them to absorb microwave energy efficiently and selectively heat the resin matrix without excessive thermal damage to the fibers. To maximize resin decomposition and minimize energy costs, key process variables—including microwave power, temperature, residence time, and sample loading—will be optimized. The recovered carbon fibers will be assessed for mechanical integrity, including tensile strength and surface quality, while pyrolysis oils rich in phenolic compounds and aromatic hydrocarbons will be analyzed using GC-MS to evaluate their potential use as chemical feedstocks or alternative fuels. The optimized process will recover high-strength carbon fibers with minimal degradation (less than 15% tensile strength loss) and generate valuable pyrolysis oils, supporting a cost-effective and sustainable CFRP recycling pathway.

Activity Milestones:

Description	Approximate Completion Date
Design and build lab-scale pyrolysis system	February 28, 2027
Optimize pyrolysis parameters	May 31, 2027
Characterize recovered fibers	June 30, 2027
Finalize pyrolysis process	December 31, 2027

Activity 3: Techno-Economic and Environmental Analysis and Market Development

Activity Budget: $30,000

Activity Description:

This activity evaluates the economic feasibility and market potential of microwave-assisted recycling technologies for glass fiber-reinforced polymers (GFRPs) and carbon fiber-reinforced polymers (CFRPs). A comprehensive techno-economic analysis will assess operational costs, energy efficiency, and potential revenue from recovered materials, benchmarking these processes against conventional recycling methods and virgin material production. Market opportunities for recovered glass and carbon fibers will be explored across key industries, including construction, automotive, and aerospace, while potential applications as chemical feedstocks in the petrochemical and fine chemical sectors will also be examined. The goal is to identify sustainable, high-volume secondary markets for recovered fibers and chemical compounds, ensuring long-term industry adoption. To support industrial implementation, the scalability of microwave-assisted processes will be evaluated, emphasizing seamless integration into existing recycling workflows. By bridging the gap between research and industry, this study aims to establish the economic and environmental viability of microwave-enhanced recycling technologies, driving their adoption at scale.

Activity Milestones:

Description	Approximate Completion Date
Conduct techno-economic analysis	February 28, 2028
Identify secondary markets for recovered materials	March 31, 2028
Publish final economic and environmental assessment	May 31, 2028
Final report	June 30, 2028

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Roger Ruan	University of Minnesota	Co-PI	No

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?

Upon completing the feasibility study, the microwave-enhanced solvolysis and pyrolysis technologies will be scaled up and integrated into industrial recycling systems. Collaboration with wind energy companies, recycling facilities, and manufacturers will enable the recovery of glass and carbon fibers and valuable chemicals, establishing a sustainable supply chain. Ongoing development will be supported by federal funding, renewable energy initiatives, and private investment. The University of Minnesota's technology commercialization office will assist in securing intellectual property and licensing opportunities. Outreach efforts via workshops, conferences, and publications will drive technology transfer and regulatory support, ensuring long-term viability and environmental benefits.

Project Manager and Organization Qualifications

Project Manager Name: Min Addy

Job Title: Research Associate Professor

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

Dr. Addy is a Research Associate Professor in the Bioproducts and Biosystems Engineering Department at the University of Minnesota. She has over 20 years of research experience in waste reduction, biomass-to-biofuel conversion, and renewable energy. Her research focuses on microwave-assisted pyrolysis for converting woody biomass, plastics, and other waste materials into high-value fuels and chemicals. She has also worked extensively on gasification and pyrolysis of waste, microalgae cultivation for wastewater treatment and biofuel production, and anaerobic digestion for animal manure treatment and biogas generation. In addition to her work in waste conversion and biofuels, Dr. Addy has expertise in air quality control, particularly in the use of non-thermal plasma and microwave technologies for nitrogen fixation and air disinfection. Her research also extends to food safety, where she has explored the application of intense pulsed light to inactivate harmful bacteria and other pathogens in various food products, including non-fat dry milk, wheat flour, and almonds.

Dr. Addy has published over 100 peer-reviewed journal articles and four book chapters. She has also taught Renewable Energy Technologies and Food Process Engineering for more than 10 years. She has extensive knowledge of advanced air purification techniques involving plasma and microwave technologies, as well as innovative methods for repurposing decommissioned wind turbine components through chemical processes. She has successfully led multidisciplinary research projects and mentoring multiple students. With extensive project management experience, she has coordinated research teams, overseen experimental design, and ensured the successful execution of proposed projects.

Organization: U of MN - College of Food, Agricultural and Natural Resource Sciences

Organization Description:

The Center for Biorefining is a University of Minnesota research center affiliated with the College of Food, Agricultural and Natural Sciences and helps coordinate the University efforts and resources to conduct exploratory fundamental and applied research and provide education on science and technology for environment protection and circular economy; stimulate collaboration among the University researchers, other public sector investigators, and private investigators

involved in biobased production technology development; promote technology transfer to industries; and foster economic development in rural areas. The Center's research programs are founded by DOE, USDA, DOT, DOD, LCCMR, IREE, Xcel Energy, and other federal and state agencies, NGOs, and private companies. The Center is equipped with state of the arts analytical instruments, and processing facilities ranging from bench to pilot scale.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Lead PI - .84 FTE dependent on grant fudning		Direct/coordinate all research and personnel			36.6%	0.3		$29,992
Co-PI - summer salary only		oversee specific area of reseach			36.6%	0.1		$29,778
Post doc		conduct experiments and analysis			25.9%	2		$165,417
							Sub Total	**$225,187**
Contracts and Services								
tbd lab services	Internal services or fees (uncommon)	analysis				-		$6,000
							Sub Total	**$6,000**
Equipment, Tools, and Supplies								
	Equipment	components	to develop and test lab system					$42,000
	Tools and Supplies	lab supplies, including catalysts, chemicals, consumable supplies for analytical instruments, gloves, masks	to accurately and safely conduct proposed research					$24,813
							Sub Total	**$66,813**
Capital Expenditures								
							Sub Total	**-**
Acquisitions and Stewardship								

							Sub Total	**-**
Travel In Minnesota								
	Miles/ Meals/ Lodging	tbd	to collect retired turbine blades and provide an outreach demonstration					$2,000
							Sub Total	**$2,000**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$300,000**

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	**-**

Total Project Cost: $300,000

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: ab6f59cc-c83.pdf

Alternate Text for Visual Component

Illustration of microwave-enhanced recycling processes for both glass fiber-reinforced composites (GFRPs) and carbon fiber-reinforced composites (CFRPs). The diagram showcases the process flow from decommissioned wind turbine blades to the recovery of high-quality fibers and valuable chemical compounds, highlighting the role of microwave heating in improving energy efficiency and fiber preservation....

Supplemental Attachments

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

Title	File
Letter of Authorization to Submit	6996fbbf-cb4.pdf
Audit	0db268f7-ac6.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:

Wendy Moylan, Juer Liu, University of Minnesota

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