Environment and Natural Resources Trust Fund

2027 Request for Proposal

General Information

Proposal ID: 2027-524

Proposal Title: Energy-Efficient Electrochemical PFAS Destruction for Minnesota Water Protection

Project Manager Information

Name: Xiaojia Wang

Organization: U of MN - College of Science and Engineering

Office Telephone: (612) 625-1583

Email: wang4940@umn.edu

Project Basic Information

Project Summary: Develop energy-efficient electrochemical technology to permanently destroy PFAS in Minnesota groundwater by optimizing electrode materials, reactor design, and PFAS transport, enabling scalable treatment systems that protect Minnesota water.

ENRTF Funds Requested: $297,000

Proposed Project Completion: June 30, 2030

LCCMR Funding Category: Small Projects (G)
Secondary Category: Water (B)

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.

Contamination of water resources by per- and polyfluoroalkyl substances (PFAS) has become a major environmental and public health concern in Minnesota and across the United States. PFAS are widely used in industrial processes and consumer products because of their resistance to heat, oil, and water. However, these same properties make PFAS extremely persistent in the environment, which is why they are often called “forever chemicals”. The U.S. Environmental Protection Agency (EPA) has identified compounds such as PFOA and PFOS as priority contaminants due to their links to cancer, immune system effects, and developmental impacts. Current groundwater remediation technologies, including activated carbon and ion-exchange resins, remove PFAS from water but do not destroy them. Instead, they concentrate PFAS into residual media that must still be treated or disposed of. Permanent destruction is therefore considered the most effective long-term solution for protecting Minnesota’s water resources. Electrochemical oxidation can destroy PFAS directly in water by converting them into fluoride ions and carbon dioxide. However, current systems require high energy and often show incomplete mineralization due to inefficient transport of PFAS to the reactive region near the electrode surface. Improving transport to this reaction zone is therefore critical

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 proposes a new strategy to make electrochemical PFAS destruction more energy-efficient by improving how PFAS molecules reach and react at the electrode surface where degradation occurs. Rather than focusing only on developing new electrode materials, the project will systematically investigate how electrode materials, water flow, and interfacial reaction conditions (such as temperature and concentration) influence PFAS destruction efficiency. The research will begin by comparing two advanced electrode materials under identical operating conditions. Boron-doped diamond (BDD) electrodes represent the current benchmark for PFAS destruction but are expensive and difficult to scale. Magnéli-phase titanium oxide (Ti_4O_7) electrodes are a promising alternative because they are more affordable and easier to manufacture, but their performance and energy efficiency remain less understood. By directly comparing these materials, we will identify the key factors controlling efficient PFAS degradation. The project will then redesign electrode structures and reactor flow conditions to improve PFAS transport to the reactive surface. Advanced modeling tools will simulate water flow, PFAS transport, and electrochemical reactions to guide reactor design. Finally, the optimized electrode configuration will be integrated into a prototype treatment reactor demonstrating a scalable and energy-efficient approach for PFAS destruction relevant to groundwater remediation in 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?

This project will help protect Minnesota’s water resources by developing technology that permanently destroys PFAS contamination in water. Current treatment methods mainly capture PFAS and create waste that must be managed later. In contrast, this project focuses on breaking PFAS down into harmless components. The research will produce practical design guidelines and a prototype treatment system that reduces the energy required for PFAS destruction, making the technology more affordable for water utilities and communities. By enabling more effective and permanent removal of PFAS, the project will help protect drinking water supplies and preserve Minnesota’s natural water resources for future generations.

Activities and Milestones

Activity 1: Benchmarking intrinsic PFAS destruction kinetics using BDD and Ti4O7 electrodes under controlled electrochemical reactor condition

Activity Budget: $99,320

Activity Description:
Activity 1 will establish a controlled electrochemical platform to quantify and compare the intrinsic PFAS destruction performance of boron-doped diamond (BDD) and Magnéli-phase titanium suboxide (Ti4O7) electrodes. A laboratory-scale electrochemical flow reactor will be constructed in which hydrodynamics, current density, electrolyte composition, and reactor geometry are identical for both electrode materials. This design ensures that differences in PFAS degradation arise primarily from electrode properties rather than external transport effects. Representative long-chain PFAS, including PFOA and PFOS, and short-chain PFAS, including PFBA and PFBS, will be tested. PFAS concentration changes will be quantified using liquid chromatography-mass spectrometry (LC-MS), while fluoride release will be measured to evaluate defluorination and the extent of mineralization during electrochemical oxidation. Although BDD is recognized as a benchmark PFAS destruction electrode, reported destruction efficiencies and energy costs vary substantially across studies because reactor designs and operating conditions are rarely standardized. As a result, the intrinsic performance gap between BDD and Ti4O7 remains poorly quantified. Energy consumption will be evaluated using energy per log removal of PFAS, expressed in kilowatt-hours per cubic meter per log reduction. These results will establish a rigorous performance baseline for subsequent electrode and reactor engineering.

Activity Milestones:

Description	Approximate Completion Date
Controlled electrochemical reactor constructed and validated	December 31, 2027
Characterization of electrode material morphology, along with thermal properties measurements	June 30, 2028
PFAS degradation and defluorination datasets obtained and quantitative performance established for BDD and Ti4O7 electrodes	June 30, 2028
Activity 1 summary report	June 30, 2028

Activity 2: Engineer Ti4O7 electrode structures and hydrodynamics to minimize transport limitations and reduce energy consumption

Activity Budget: $95,875

Activity Description:
Activity 2 focuses on engineering Ti4O7 electrode structures and reactor hydrodynamics to minimize mass transport limitations and improve the energy efficiency of electrochemical PFAS destruction. Previous research indicates that PFAS degradation often occurs within a thin reaction region near the anode surface where reactive radicals are generated and electron transfer reactions take place.4 Consequently, improving the transport of PFAS molecules to this reaction region is critical for enhancing degradation efficiency. To address this challenge, we will investigate several Ti4O7 electrode architectures including flat-plate electrodes and porous electrodes operating under both flow-by and flow-through configurations. These geometries alter the thickness of the hydrodynamic boundary layer and can enhance mass transport rates to the reactive electrode surface. Experimental measurements will quantify PFAS removal kinetics, fluoride release, mineralization efficiency, and energy consumption under different reactor configurations. In parallel, multiphysics simulations will be conducted using COMSOL to couple fluid flow, electrochemical reactions, temperature field, and PFAS transport. Thermal transport properties of electrode materials will be measured using time-domain thermoreflectance (TDTR), enabling accurate electro-thermal modeling of temperature distributions within the reactor.

The combined experimental and modeling approach will identify optimal Ti4O7 electrode architectures capable of achieving high PFAS destruction efficiency with minimal energy input.

Activity Milestones:

Description	Approximate Completion Date
Electrode architecture and reactor configurations developed and characterized	December 31, 2028
Correlations between electrode architecture, mass transport, and PFAS destruction performance established	June 30, 2029
Integrated electro-thermal multiphysics model developed and validated	June 30, 2029
Activity 2 summary report	June 30, 2029

Activity 3: Build and evaluate a prototype electrochemical reactor using optimized Ti_4O_7 electrodes for scalable PFAS destruction

Activity Budget: $98,573

Activity Description:
Activity 3 will translate the fundamental insights and optimized electrode architectures developed in Activities 1 and 2 into a prototype electrochemical reactor suitable for scalable PFAS destruction. The reactor will incorporate the Ti4O7 electrode geometry and hydrodynamic configuration identified as most energy efficient through experimental and modeling studies. The prototype system will be tested using synthetic groundwater matrices that replicate the ionic composition commonly found in Minnesota aquifers. This step is important because background ions such as chloride, sulfate, and bicarbonate can influence electrochemical oxidation processes and affect PFAS degradation pathways. Performance of the prototype reactor will be evaluated by measuring PFAS removal efficiency, fluoride release, mineralization, and energy consumption per volume of treated water. In addition, the stability and durability of Ti4O7 electrodes will be assessed during extended operation to evaluate their suitability for practical water treatment applications. The results will demonstrate the feasibility of achieving energy-efficient electrochemical PFAS destruction using engineered Ti4O7 electrodes and optimized reactor configurations. These outcomes will provide a scalable pathway for implementing electrochemical treatment technologies capable of permanently destroying PFAS contaminants in Minnesota groundwater systems.

Activity Milestones:

Description	Approximate Completion Date
A prototype electrochemical reactor designed and constructed	October 31, 2029
Prototype reactor performance validated in representative groundwater matrices	June 30, 2030
Reactor durability and scalability assessed for practical implementation	June 30, 2030
Activity 3 summary report	June 30, 2030

Activity 4: Reporting, Results Dissemination, and Outlook for Technology Translation to Real-World Implementation

Activity Budget: $3,232

Activity Description:
Activity 4 will focus on data analysis, reporting, and broad dissemination of project findings. Results from this project will be shared broadly to ensure that the knowledge and technologies developed can benefit Minnesota's water management and environmental protection efforts. Findings will be disseminated through peer-reviewed journal publications, conference presentations, and technical reports that are accessible to researchers, water utilities, state

agencies, and environmental organizations working on PFAS remediation. We will engage with Minnesota water treatment professionals and regulatory agencies, through workshops and presentations to share practical insights on energy-efficient PFAS destruction technologies and their potential applications for groundwater remediation. Data, reactor design guidelines, and modeling tools generated in this project will be documented and archived through university repositories to ensure long-term accessibility. If novel reactor designs or electrode configurations demonstrate clear technological advantages, we will pursue intellectual property protection through patent applications to enable future technology transfer and practical implementation. All publications, presentations, outreach materials, and project communications will acknowledge support from the Environment and Natural Resources Trust Fund.

Activity Milestones:

Description	Approximate Completion Date
Documentation and progress reports for Activity 1	June 30, 2028
Documentation and progress reports for Activity 2	June 30, 2029
Documentation and progress reports for Activity 3	June 30, 2030
Patent filing (before paper submission), paper draft writing, and manuscript submission	June 30, 2030
Final project report	June 30, 2030

Dissemination

Describe your plans for dissemination, presentation, documentation, or sharing of data, results, samples, physical collections, and other products and how they will follow ENRTF Acknowledgement Requirements and Guidelines.
Our Activity 4 will focus on data analysis, reporting, and broad dissemination of project findings. Results from this project will be shared broadly to ensure that the knowledge and technologies developed can benefit Minnesota's water management and environmental protection efforts. Findings will be disseminated through peer-reviewed journal publications, conference presentations, and technical reports that are accessible to researchers, water utilities, state agencies, and environmental organizations working on PFAS remediation. We will engage with Minnesota water treatment professionals and regulatory agencies, through workshops and presentations to share practical insights on energy-efficient PFAS destruction technologies and their potential applications for groundwater remediation. Data, reactor design guidelines, and modeling tools generated in this project will be documented and archived through university repositories to ensure long-term accessibility. If novel reactor designs or electrode configurations demonstrate clear technological advantages, we will pursue intellectual property protection through patent applications to enable future technology transfer and practical implementation. All publications, presentations, outreach materials, and project communications will acknowledge support from the Environment and Natural Resources Trust Fund.

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?
This 36-month project (July 1, 2027-June 30, 2030) will deliver practical design strategies for energy-efficient electrochemical destruction of PFAS in contaminated water. The optimized Ti_4O_7 electrode architectures and reactor configurations developed in this work will support pilot-scale testing with Minnesota water utilities and environmental engineering partners. Project data on PFAS destruction efficiency, energy consumption, and electrode durability will provide a technical foundation for scaling electrochemical treatment systems for groundwater remediation. Follow-on funding will be pursued through the National Science Foundation and the United States Environmental Protection Agency, as well as through industry partnerships supporting advanced water treatment technologies.

Project Manager and Organization Qualifications

Project Manager Name: Xiaojia Wang

Job Title: Professor in Mechanical Engineering

Provide description of the project manager's qualifications to manage the proposed project.
Professor Xiaojia Wang will lead the project. She has significant experience in advancing the frontiers of thermal transport science and energy conversion technologies. At the U of MN, she leads an interdisciplinary research group that bridges innovative experiments with advanced modeling to investigate thermal energy transport in functional materials, across interfaces, and within integrated devices. By combining materials science, nanotechnology, and device engineering, her work addresses the global challenges in energy efficiency and renewable technologies, driving advancements in applications such as solid-state energy conversion, electronic cooling, thermal switching devices, and next-generation computing architectures.

Prof. Wang has established a high recognition in thermal science and energy research. Her group has published ~60 research articles in top-tier journals, many of which have been featured as Editor's Picks and Highlighted Articles. She has secured research funding from federal agencies (NSF, DARPA), industry (3M, ASRC, and Seagate), and foundations.

She has advised ~10 graduate and 10+ undergraduate students, many of whom have received prestigious fellowships and secured positions at national labs and leading companies (e.g., Intel, Lam Research, and Seagate). Professor Wang has a proven track record of translating fundamental discoveries into real-world solutions through partnerships with leading Minnesota-based industrial corporations, including Seagate, Medtronic and 3M.

Organization: U of MN - College of Science and Engineering

Organization Description:
The University of Minnesota, Twin Cities (U of MN) is a premier public land-grant research university located in Minneapolis and Saint Paul, recognized as one of the most comprehensive research universities in the nation. The College of Science and Engineering (CSE) is a global leader in research, education, and technological innovation, with 12 departments spanning engineering, physical sciences, computer science, and mathematics. Home to over 8000 students and many cutting-edge research centers, CSE drives technological innovation and breakthroughs in energy, artificial intelligence, nanotechnology, climate, biomedical engineering, quantum computing, and sustainability. The college consistently ranks among the top public STEM institutions in the US. CSE is also committed to excellence in education, providing hands-on learning, interdisciplinary collaboration, and entrepreneurial opportunities to its students. The Department of Mechanical Engineering is a world leader in thermal science and engineering research, known for its impactful areas in renewable energies, environment & sustainability, next-generation manufacturing, robotics, and biomedical engineering. The Department of Chemical Engineering and Materials Science is a top-tier, internationally competitive department, leading advancements in fluid mechanics, transport, catalysis, bioengineering, renewable energy, polymer synthesis and processing, and advanced semiconductor research.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Xiaojia Wang		Principal Investigator			27.8%	0.12		$35,715
Graduate Student		Research Assistant (1)			45.52%	1.5		$203,086
							Sub Total	**$238,801**
Contracts and Services								
							Sub Total	**-**
Equipment, Tools, and Supplies								
	Equipment	(1) 2C BM FC EC 50 mL Two-compartment Bottom Mount Front Contact Electrochemical Cell with 50 mL water-based electrolyte / (D) 15 mm x 15 mm, quantity: 1 ($3,520 per piece); (2) Boron-Doped Diamond (BDD) plate, dimension: 15 mm x 15 mm x 0.5 mm, quantity: 1 ($1,550 per piece); (3) Silver / Silver Chloride Refillable Reference Electrode - 6 mm diameter 70 mm height, quantity: 1 ($240 per piece); and (4) Metal Wire Auxiliary Electrode: 50HX15 0.6/250 mm water-based electrolyte / Platinum (99.9%) / 1-mm diameter gold plated pin, quantity: 1 ($690 per piece). Total price is $6,000.	These components will be used to assemble a laboratory-scale electrochemical reactor for controlled PFAS oxidation experiments. The electrochemical cell and electrode set are required to construct a controlled laboratory reactor for electrochemical PFAS destruction experiments. The two-compartment cell enables separation of anode and cathode reactions, while the BDD working electrode, Ag/AgCl reference electrode, and platinum auxiliary electrode allow precise electrochemical control. This setup is necessary to quantify PFAS degradation kinetics, defluorination, and energy consumption. The system will be used throughout the project to benchmark PFAS destruction performance and evaluate reactor conditions that improve energy-efficient PFAS degradation relevant to Minnesota water protection.					$6,000

	Tools and Supplies	The requested budget for materials and supplies supports the construction and operation of laboratory-scale electrochemical reactors and the execution of controlled PFAS destruction experiments relevant to Minnesota water protection. These supplies fall into three main categories: (1) Electrochemical reactor components, including boron-doped diamond (BDD) and Magneli-phase titanium suboxide (Ti_4O_7) electrodes, flow-cell reactors, reactor housing, tubing, seals, fittings, counter and reference electrodes, and electrical connectors required to establish stable electrochemical oxidation systems. (2) Water chemistry preparation and experimental consumables, including electrolytes, salts, and groundwater simulants representative of Minnesota water chemistry (e.g., chloride, sulfate, and bicarbonate), as well as laboratory consumables used during repeated reactor operations. (3) Supplies for PFAS testing and sample preparation, including PFAS reference standards (PFOA, PFOS, PFBS), solid-phase extraction cartridges, and PFAS-free filtration materials used to prepare contaminated water samples and enable accurate quantification of PFAS destruction during electrochemical oxidation experiments. The budgets for Year 2 and Year 3 include a 2% inflation adjustment to account for rising material and supply costs.	These materials and supplies are essential for constructing electrochemical testing systems and performing systematic studies of PFAS destruction under environmentally relevant conditions. They will enable evaluation of advanced electrode materials and reactor designs that improve PFAS degradation efficiency while minimizing energy consumption. Experiments will be conducted using water chemistries representative of contaminated water in Minnesota, ensuring that the results are directly applicable to regional remediation challenges. Major laboratory instruments required for thermal characterization and solution Analysis are already available in the PI's laboratory and shared university facilities. PFAS concentration measurements will be conducted through campus analytical facilities, with associated costs included under Scientific Services.					$24,484
							Sub Total	**$30,484**
Capital Equipment								
							Sub Total	**-**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								

	Conference Registration Miles/ Meals/ Lodging	An annual travel budget of $3,000 is allocated to support conference attendance and industry engagement for the team. The requested travel budget will cover one conference trip per year for the PI and her student ($3,000). Estimated expenses include conference registration of $400 (for one student) and $900 (for PI), ground transportation $200 × 2 = $400, and meals $200 × 2 = $400. The budgets for Year 2 and Year 3 include a 2% inflation adjustment to account for rising travel costs.	Expanding research impact through broader dissemination of research knowledge, findings, and products. Enhancing student professional development to strengthen Minnesota's future workforce. Building connections with potential collaborators and industry partners to drive innovation and commercialization.					$9,181
							Sub Total	**$9,181**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
	Publication	Publication cost in open-access journals.	We would like to maximize the visibility of our research outcomes by publishing in open-access journals, ensuring free and unrestricted access for all readers.					$3,232
							Sub Total	**$3,232**
Other Expenses								
		Scientific Services	To systematically evaluate electrochemical PFAS destruction and optimize reactor performance for Minnesota water treatment, this project will utilize advanced analytical and characterization tools available through on-campus facilities. These scientific services are essential for accurate PFAS quantification, detailed electrochemical analysis, and materials characterization of electrode surfaces during reactor operation. On-campus facilities at the Minnesota Nano Center (MNC) will be used for several key					$15,302

			processes: (1) Thin-film deposition of transducers for thermal characterization using sputtering and thermal evaporation; (2) Etching and surface treatment using oxygen plasma processing to refine interfaces. On-campus facilities located at the Characterization Facility (CharFac) will also be used for key analytical processes, including (1) Surface and structural characterization of electrode materials using SEM, EDX, and AFM to investigate electrode degradation, scaling, and morphology changes during PFAS oxidation; (2) Spectroscopic characterization methods such as Raman spectroscopy and optical measurements to study electrode surface chemistry and reaction intermediates; and (3) sample preparation and complementary materials analysis required to understand electrochemical reactor performance. These measurements are essential for determining PFAS removal efficiency and verifying complete destruction during electrochemical oxidation experiments. The estimated service fees are $5,000 per year for use of campus facilities and analytical services. The budgets for Year 2 and Year 3 include a 2% inflation adjustment to account for potential increases in service costs.					
							Sub Total	**$15,302**
							Grand Total	**$297,000**

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				
In-Kind	Unrecovered F&A calculated at 54% MTDC	Support of ME facilities where research will be conducted.	Secured	$124,489
			Non State Sub Total	**$124,489**
			Funds Total	**$124,489**

Total Project Cost: $421,489

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: 9599eca0-021.pdf

Alternate Text for Visual Component

This visual highlights PFAS contamination in Minnesota and the limitations of current treatment methods. We propose an electrochemical oxidation system that converts PFAS-rich water into benign products. By engineering electrode materials and optimizing PFAS mass transport, we aim to demonstrate a scalable, low-cost, and energy-efficient pathway for PFAS destruction....

Supplemental Attachments

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

Title	File
Quote for electrochemical cell and BDD plates	b4e37e12-113.pdf
UMN SPA Support Letter	ebbddf4b-689.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:

ME proposal staff (Alexandra Sullivan <sull1129@umn.edu>) and UMN SPA (Josh Gates <gates191@umn.edu>) for budget preparation and approval.

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