Environment and Natural Resources Trust Fund

2025 Request for Proposal

General Information

Proposal ID: 2025-206

Proposal Title: Managing PFAS in Stand-Alone Digesters for Resource Circularity

Project Manager Information

Name: Roger Ruan

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

Office Telephone: (612) 804-2270

Email: RUANX001@UMN.EDU

Project Basic Information

Project Summary: Investigate sustainable methods for organic waste treatment in anaerobic digesters to recover energy and resources. Additionally, study the presence and transformation of PFAS during these processes to promote resource circularity.

ENRTF Funds Requested: $250,000

Proposed Project Completion: June 30, 2027

LCCMR Funding Category: Small Projects (H)

Secondary 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.

Anaerobic digestion is a crucial process for addressing per- and polyfluoroalkyl substances (PFAS) in water environment, warranting significant attention and concern. Stand-alone and on-farm anaerobic digesters are increasingly built in food companies, farms, and related industries to effectively manage food waste, manure and other organic waste streams. This process not only facilitates the treatment of various organic wastes but also allows for the recovery of energy and nutrients, make this process both marketable and valuable in application. However, organic and food waste streams emerge as significant sources of PFAS substances contamination, as materials and feedstocks such as contact materials, food packaging, and food waste substantially contribute to overall PFAS levels. Advanced sustainable methodologies are vital to eliminate PFAS from digestates and reduce residual PFAS in final products, ensuring energy recovery and resource circularity in waste treatment processes. This is particularly critical for stand-alone and on-farm anaerobic digesters in Minnesota.

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.

To address the aforementioned limitations and challenges, the proposed solution comprises three key steps: pretreatment of waste for PFAS separation , enhanced anaerobic digestion for resource recovery and PFAS sedimentation, and quantification of residual PFAS in biomass and final products for impact assessment. Prior to anaerobic digestion, sustainable methods such as nanobubble technology and surface active foam fractionation will be incorporated and optimized for PFAS separation to lower its concentrations in waste. During anaerobic digestion, synthetic microbial consortium, sledge biochar, and pyrolysis processes will be introduced to promote energy and nutrient recovery and also facilitate the sedimentation and reduction of PFAS concentrations. Following AD treatment processes, the AD effluent containing elevated levels of COD, ammonia, and other nutrients, will undergo stepwise processes to achieve sequential nutrient removal and produce valuable microalgal biomass. PFAS levels in the obtained biomass and products will be assessed to evaluate PFAS impacts and assess product marketability. The objective of this project is to enhance organic waste treatment processes within stand-alone and on-farm anaerobic digesters in Minnesota, offering significant advantages in terms of efficiency and sustainability.

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?

The proposed project will enhance organic waste treatment processes within anaerobic digesters and manage PFAS presence and transformation within treatment systems. The outcomes will include: (1) establishing sustainable pretreatment methods to effectively separate PFAS from waste; (2) developing integrated bioprocessing approach to significantly enhance energy and resource recovery while achieving PFAS sedimentation; (3) attaining minimal PFAS content in obtained biomass and final products for the valorization of organic and food waste. Managing PFAS-containing waste in anaerobic digesters in Minnesota will significantly enhance waste treatment sustainability and facilitate circular resource utilization.

Activities and Milestones

Activity 1: Pretreatment of waste to improve degradation and separate PFAS from waste feedstocks

Activity Budget: $100,000

Activity Description:

The waste pretreatment process will occur in a sealed stainless-steel vessel, enabling PFA adsorption and separation, along with vacuum stripping of gaseous ammonia, hydrogen sulfide, and other odorous gases. Our lab has previously developed a thermal-assisted vacuum stripping system. We will adapt and integrate this system with sustainable PFAS pretreatment technologies to achieve dual objectives. Specifically, nanobubble technology and surface active foam fractionation, in conjunction with sonolysis and conventional techniques, will be employed and integrated to generate enriched PFAS concentrate and effectively separate PFAS from waste feedstocks, thus alleviating subsequent AD treatment burdens.

Furthermore, advanced computational simulation and calculation tools will be utilized for treatment optimization and performance improvement. Previously, we successfully employed modeling and simulation techniques for the pilot concentrated high-intensity electric field (CHIEF) system, estimating intrinsic liquid flow behavior, electric field strength, and heat transfer within the system. In this study, molecular dynamics simulation and quantum chemical calculations will be employed to explore PFAS properties at the air-water interface and their dynamics behavior across gas-liquid-solid phases. The predicted PFAS removal efficiency will then be validated for process optimization and performance enhancement, ultimately facilitating the adsorption and separation of PFAS from waste feedstocks.

Activity Milestones:

Description	Approximate Completion Date
Pretreatment system for vacuum stripping and PFAS sorption are developed	August 31, 2025
Sustainable PFAS pretreatment technologies are examined and optimized	October 31, 2025
Computational simulation and calculation are employed for process optimization	December 31, 2025

Activity 2: Enhance anaerobic digestion coupled with pyrolysis processes for resource recovery and PFAS removal

Activity Budget: $140,000

Activity Description:

The pretreated waste will undergo anaerobic digestion coupled with pyrolysis processes to enhance resource recovery efficiency and remove PFAS. A synthetic microbial consortium comprising volatile fatty acids (VFA) -tolerant microalgae Chlorella strains and methanogenic Methanosarcina sp. will be designed and constructed for enhancing anaerobic digestion. Our previous research has found that Chlorella vulgaris preserved in our lab can utilize high concentrations of ammonia and VFAs exhibiting potential growth under dark and anaerobic heterotrophic conditions for biohydrogen production. However, its consortium with hydrogenotrophic/acetoclastic Methanosarcina strains for enhancing bioenergy production and PFAS sedimentation has not been thoroughly investigated. This project aims to address this gap by utilizing this microbial consortium, which will also serve as sustainable biosorbents for the bioaccumulation and translocation of PFAS.

Moreover, sludge biochars, supplemented with encapsulated plant proteins as necessary, will be utilized for absorbing and sedimenting long-chain and short-chain PFAS compounds. Key process parameters, particularly lower pH values and increasing ionic strength (e.g., Mg^{2+}, Ca^{2+}), will be investigated to influence hydrophobicity and electrostatic interactions for PFAS sedimentation.

Furthermore, pyrolysis processes, combined with photocatalysis and non-thermal plasma, will be utilized to treat solid digestate containing sludge and microbial biomass, facilitating PFAS destruction and the resource recovery.

Activity Milestones:

Description	Approximate Completion Date
Synthetic microbial consortium are developed and applied for AD treatment	March 31, 2026
Sludge biochars and process optimization are employed for PFAS sedimentation	June 30, 2026
Pyrolysis combined with other processes are examined for PFAS reduction and resource recovery	September 30, 2026

Activity 3: Develop stepwise processes for sequential nutrient utilization and further quantify residual PFAS in final products for risk evaluation

Activity Budget: $10,000

Activity Description:

Anaerobic digestion effluent collected will be further treated by stepwise processes involving microalga cultivation and advanced oxidative processes under optimal conditions. (1) Toxic ammonia will first be eliminated through 1st heterotrophic Chlorella vulgaris cultivation. Two strategies will be employed: short-term ammonia tolerance acclimation and the addition of glycerol as carbon source and osmoticum to enhance C. vulgaris' ability to alleviate ammonia toxicity and promote ammonia utilization. (2) The remaining COD/VFAs in the supernatant will be further removed in the 2nd stress cultivation of C. zofingiensis. Our previous study has demonstrated that this microalga exhibits the capability to utilize VFAs while accumulating lipids and carotenoids (e.g., astaxanthin, α/β-carotene). Culture conditions and their implications will be examined and optimized accordingly. High-intensity blue light irradiation will be employed to enhance COD assimilation and conversion to lipid/carotenoid-rich biomass. (3) Residual PFAS removal will be achieved through novel AOP processes, particularly non-thermal plasma and catalytic concentrated high-intensity electric field processes developed in our lab. Optimized treatment conditions will be employed to maximize efficiency and minimize costs. Experimental data acquired will be used to evaluate treatment performance in PFAS removal and resource recovery and provide useful information for the development of resource circularity.

Activity Milestones:

Description	Approximate Completion Date
Stepwise process systems for sequential nutrient removal are developed	October 31, 2026
Advanced oxidation processes for remaining residual PFAS removal and water reclamation are developed and optimized	March 31, 2027
The biotransformation and partitioning of PFAS in resulting products are evaluated for risk assessment	May 31, 2027
Further R&D and commercialization strategy will be recommended in the final project report	June 30, 2027

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 project aims to develop an integrated bioprocessing approach for PFAS management in anaerobic stand-alone and on-farm digesters, with the aim of recovering value and promoting resource circularity. Successful implementation and demonstration of the proposed process would be of interest to diverse industries in Minnesota. To facilitate widespread adoption of this technology for organic and food waste treatment, we plan to seek additional future funding opportunities in the future. Our ultimate goal is to significantly promote energy recovery and resource circularity in waste treatment processes, contributing to environmental sustainability and circular economy development.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Methods to Destroy PFAS in Landfill Leachates	M.L. 2022, , Chp. 94, Art. , Sec. 2, Subd. 04a	$200,000

Project Manager and Organization Qualifications

Project Manager Name: Roger Ruan

Job Title: Professor and Director

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

Dr. Roger Ruan is a Fellow of the National Academy of Inventors, the American Society of Agricultural and Biological Engineers, the Institute of Food Technologists, the International Association of Advanced Materials, and Vebleo, and have received many other awards, including International Bioprocessing Association's Pandey Award, CAFS Professional Achievement, Scientist of IAAM, etc. Dr. Ruan's research areas include renewable energy and environment technologies for sustainable development and circular economy. His research has focused on biomass and solid wastes such as plastic wastes pyrolysis and gasification for chemicals, materials, fuels, and energy production; wastewater treatment and utilization through novel anaerobic digestion, microalgae cultivation; airborne and other pathogen disinfection and pollutant control; innovative catalytic non-thermal plasma, low temperature microwave and pulse microwave, photocatalytic intensive pulse light, and NMR/MRI technologies development and applications in nitrogen fixation, food safety assurance, and food quality improvement; and food engineering and various value-added processing. Dr. Ruan has published over 600 papers in refereed journals, two books, and 28 book chapters, and holds 19 US patents. He is also a top-cited author in engineering and technologies, with an h-index of 96, i10-index of 480, and over 37,000 citations. He has received over 200 projects totaling over $45 million in various funding for research, including major funding from USDA, DOE, DOT, DOD, LCCMR, and industries. He was the project manager of several earlier LCCMR funded projects which resulted in the issuance of US patents and licensing of technologies. He has the technical expertise and project management experience to ensure the execution of proposed project.

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 and help coordinate University efforts and resources to conduct exploratory fundamental and applied research; provide education on bioenergy, biochemicals and biomaterials; stimulate collaboration among the University researchers, other public sector investigators, and private investigators in biobased production technology development; promote technology transfer to industries; and foster economic development in rural areas. The Center's research programs have been 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.

The Department of Bioproducts and Biosystems Engineering, in CFANS, discovers and teaches solutions for the sustainable use of renewable resources and the enhancement of the environment. We discover innovative solutions to address challenges in the sustainable production and consumption of food, feed, fiber, materials, and chemicals by integrating engineering, science, technology, and management into all degree programs.

https://bbe.umn.edu/biobrief

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Professor/Faculty		PI - summer salary			37.1%	0.1		$27,831
Professional Researcher		Manage lab, develop methodology, conduct research and analysis			37.1%	1		$83,494
Post doctoral researcher		research			27.1%	1.5		$129,007
							Sub Total	**$240,332**
Contracts and Services								
							Sub Total	**-**
Equipment, Tools, and Supplies								
	Tools and Supplies	Purchase of lab and miscellaneous supplies, including food waste and other feedstocks for anaerobic digestion, chemicals, consumable supplies for analytical instruments, PPEs, etc.	For running experiments and operating the systems.					$9,668
							Sub Total	**$9,668**
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	**$250,000**

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: $250,000

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: 537d1de7-7f3.pdf

Alternate Text for Visual Component

This figure depicts the integrated bioprocessing approach designed to effectively manage PFAS during the anaerobic digestion of organic waste to achieve energy recovery and resource circularity, aiming to enhance organic waste treatment processes within stand-alone and on-farm anaerobic digesters in Minnesota ultimately, contributing to environmental sustainability and circular economy development....

Supplemental Attachments

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

Title	File
SPA Cover Letter - PFAS	94c739b2-034.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

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

No

Do you understand and acknowledge IP and revenue-return and sharing requirements in 116P.10?

N/A

Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF?

N/A

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:

Paul Chen, Juer Liu, Wendy Moylan, University of Minnesota