Environment and Natural Resources Trust Fund

2025 Request for Proposal

General Information

Proposal ID: 2025-205

Proposal Title: Microwave-Assisted Decontamination System for Destructing Soil Contaminants

Project Manager Information

Name: Roger Ruan

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 demonstrate a continuous conveyor belt-type catalytic microwave-assisted decontamination system for remediating various contaminants in soil.

ENRTF Funds Requested: $989,000

Proposed Project Completion: June 30, 2028

LCCMR Funding Category: Methods to Protect or Restore Land, Water, and Habitat (F)

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.

Contemporary landscapes face a growing threat from a vast array of soil contaminants including micro- and nano-plastics, per- and poly-fluoroalkyl substances (PFAS), dioxins, pentachlorophenol (PCP), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), volatile organic compounds (VOCs), polychlorinated dibenzofurans (PCDFs), and the unsettling prions. Originating from industrial and consumer products, these contaminants pose substantial environmental and health risks. For instance, PFAS, known as "forever chemicals," exhibit remarkable resilience, persisting in organisms and causing severe health complications. Similarly, dioxins accumulate in organisms, posing significant health risks. PCP, once used as a wood preservative, contaminates soil and water sources, endangering both the environment and human health. PAHs, emitted from sources like vehicle emissions, are carcinogenic and can seep into soil. PCBs, entirely human-made, have their composition determined by production processes. VOCs emitted from fuel combustion and industrial activities further exacerbate soil and groundwater contamination, threatening ecosystems and human health. The unique concern of prions in soil adds another layer of complexity to the issue. Consequently, many countries are implementing standards to monitor and regulate soil contaminants. The widespread contamination renders many sites unusable, designated solely for landfill purposes. Addressing these pollutants is crucial to safeguarding society and the environment from these harmful impacts.

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.

Our proposed solution addresses the urgent challenge of soil contamination by introducing an innovative microwave-assisted catalytic decontamination system. This method not only safeguards soil integrity but also secures our food supply by eliminating harmful contaminants.

Utilizing microwaves, renowned for their efficacy in industrial processes, we will heat the soil to convert contaminants into harmless substances in the presence of various catalysts and microwave absorbers. Compared to conventional heating methods, the microwave-assisted heating for deconstructing pollutants offers significant advantages, including: 1) The soil decontamination is made greener through electrification enabled by microwave irradiation-assisted process, using environmentally friendly low-carbon intensity grid electricity, a promising net-zero grid by 2030; 2) Selective, volumetric, and rapid heating by microwaves and our patented reactor design ensure uniform temperature distribution, reliable process operation, and high energy efficiency; 3) The process features a continuous, modular, and portable design that is easily scalable.

Expanding upon these preliminary trials and insights gained, we will design and build a pilot-scale system for demonstration purposes, starting with small-scale testing in the lab and aiming for larger-scale implementation to ensure continuous decontamination processes at the site of concern. This project will lay the groundwork for scalable and cost-effective soil remediation strategies.

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 aims to contribute valuable scientific insights through exploratory research, focusing on three key aspects. Firstly, it seeks to elucidate the process of decontaminating various pollutants such as micro and nano plastics, PFAS, dioxins, PCP, PAH, PCBs, VOCs, and PCDFs from contaminated soil, considering factors such as catalyst structure, temperature, residence time, and other variables influencing removal efficiency. Secondly, the project aims to develop a cost-effective and mobile pilot-scale system to demonstrate the feasibility of scaling up the decontamination process. Finally, the project will culminate in research findings and public education contributing to the knowledge base of these contaminants.

Activities and Milestones

Activity 1: Laboratory-scale application of microwave-assisted catalytic decontamination system for the removal of soil contaminants

Activity Budget: $280,000

Activity Description:
Building upon our extensive experience in developing catalytic microwave-assisted pyrolysis systems for solid waste, our goal is to design an advanced catalytic microwave-assisted decontamination system capable of efficiently destructing various contaminants in soil, including micro and nano-plastics, PFAS, dioxins, PCP, PAH, VOCs, and PCDFs. The key process variables encompass microwave power input, temperature, residence time, sample load rate, sample-to-microwave absorber ratio, and catalyst type and load.
We recognize that high-temperature treatment may lead to the formation of new contaminants more toxic and persistent than the parent compounds, escalating operating costs due to extended treatment time or disposal of formed byproducts. Therefore, we will exclusively utilize low to medium temperatures (300–500°C) for our treatments and thoroughly investigate the efficacy of our proposed method in removing these contaminants and in minimizing the generation of toxic byproducts.
Additionally, we will analyze soil and catalyst samples at each step, including key components such as volatile gases produced during the microwave-assisted decontamination process. Furthermore, we will strive to optimize the microwave-assisted decontamination processes to eliminate the generation of toxic byproducts. Moreover, we may design a secondary ex-situ catalytic reactor to neutralize hazardous volatiles, further mitigating the potential risk volatile substances from the system.

Activity Milestones:

Description	Approximate Completion Date
Contaminated soil sample collection	August 31, 2025
Develop and improve a catalytic microwave-assisted decontamination system	December 31, 2025
Conduct experiments on catalytic microwave-assisted decontamination system and optimize the process	December 31, 2026

Activity 2: Designing and constructing a pilot-scale demonstration of a continuous conveyor belt-type catalytic microwave-assisted decontamination system

Activity Budget: $500,000

Activity Description:
Expanding on our laboratory-scale experiments and optimized data, we will design and develop a continuous conveyor belt-type microwave-assisted decontamination system for field experimental demonstration. This system will enable the treatment of large sample sizes in a continuous process, maintaining the efficiency observed in lab experiments. Contaminated soils will pass through the continuous microwave-assisted decontamination system, where contaminants will be decomposed at low to medium temperatures.
We may encounter a few issues with scaling up, and the system will be optimized by fine-tuning temperatures, soil residence time/feeding rate, and microwave absorbents. This activity aims to meet the same treatment efficiency that was obtained in lab trials and reduce environmental impacts under real-world conditions. Thorough product analysis will be conducted using various analytical technologies, such as Gas Chromatography-mass spectrometry (GC-MS), Liquid Chromatography-mass spectrometry (LC-MS), and Mass spectrometer for contaminant analysis before and after treatment.
The pilot-scale catalytic microwave-assisted decontamination system will provide crucial data to validate the technical

and economic viability of this technology at a larger throughput. It will also involve assessing other contaminant generation by the treatment, providing crucial data for subsequent manuscript publication. This study could be one-of-a-kind in examining soil decontamination from various contaminants at both scales.

Activity Milestones:

Description	Approximate Completion Date
Design and construction of a pilot-scale conveyor belt-type continuous microwave-assisted decontamination system	August 31, 2027
Pilot system improvement and demonstration	December 31, 2027

Activity 3: Conducting techno-economic and environmental analysis from the proposed technology

Activity Budget: $209,000

Activity Description:

In this phase, our focus will be on designing a comprehensive conversion process and developing simulations to establish mass and energy balances. These simulations will provide valuable insights into energy consumption and operational costs, facilitating a thorough techno-economic analysis. Meanwhile, emissions from the proposed system, including carbon dioxide and contaminants related to fluorine and chlorine, will be closely monitored to facilitate an environmental analysis. Furthermore, we will compile the results and findings obtained from both the laboratory-scale and pilot-scale experiments into a detailed report. This report will be crafted with the intention of publication, ensuring that our research contributes to the scientific community's understanding of soil decontamination methods and their economic feasibility.

Activity Milestones:

Description	Approximate Completion Date
Generate information for techno-economic and environmental analysis	March 31, 2028
Final Report on this project with manuscript publication	June 30, 2028

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 primary objective of this initiative is to develop an efficient pilot-scale catalytic microwave-assisted decontamination system that is both cost-effective and practical. This system will be designed to be mobile and will feature a conveyor belt setup, enabling on-site soil treatment without the need for transportation. Collaboration with industry partners will be pivotal in overcoming engineering challenges, securing financial backing, and garnering support from agencies such as the Environmental Protection Agency (EPA) and the United States Department of Agriculture (USDA) to facilitate further scaling of the system. The ultimate goal is to transition this technology to a commercial stage.

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								
Roger Ruan		Principal Investigator			37.1%	0.3		$83,916
Part time Researcher		Manage lab, conduct research and analysis			37.1%	1.5		$134,266
Graduate Research Assistant		Research Assistant			46%	3		$173,637
Post doctoral student		Conduct research and analysis and prepare manuscripts/reports			27.1%	3		$233,386
							Sub Total	**$625,205**
Contracts and Services								
							Sub Total	**-**
Equipment, Tools, and Supplies								
	Tools and Supplies	Purchase of lab and miscellaneous supplies, including catalysts, chemicals, consumable supplies for analytical instruments, PPE including gloves and masks.	For running experiments and operating conversion systems					$23,795
	Equipment	Microwave-assisted reactor vessel, insulation materials, magnetrons, control systems, motors, mixers, feeders, valves, and other essential parts.	Components required for the assembly of a compact, pilot-scale demonstration system designed for catalytic microwave-assisted hydrodeoxygenation					$290,000
	Tools and Supplies	Up to 2 units computer hardware	Data storage, run analytics, interface with manufactured equipment					$3,000
	Tools and Supplies	Non-capital components of lab system	For testing and development of lab system					$44,000
							Sub Total	**$360,795**
Capital Expenditures								
							Sub Total	**-**

Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
	Miles/ Meals/ Lodging	Mileage, per diem for trips for the project team	Collection and transport of feedstock					$3,000
							Sub Total	**$3,000**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$989,000**

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: $989,000

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: eccb36d6-07c.pdf

Alternate Text for Visual Component

The schematic illustrates the research approach of soil decontamination using a microwave-assisted system. In this project, we aim to decontaminate soil from various toxins using our distinctive catalytic microwave-assisted decontamination process....

Supplemental Attachments

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

Title	File
SPA Cover Letter - Soil Contaminants	e8546ae3-0f8.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