Environment and Natural Resources Trust Fund

2024 Request for Proposal

General Information

Proposal ID: 2024-233

Proposal Title: Integrated Bioprocessing of Organic Wastes towards 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: Assess the effectiveness of novel integrated bioprocessing approaches for treatment and valorization of organic wastes towards resource circularity.

Funds Requested: $582,000

Proposed Project Completion: June 30, 2027

LCCMR Funding Category: Water Resources (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.

Organic wastes, such as food wastes and animal manures, are a significant source of environmental pollution in Minnesota. When these organic wastes break down, they release harmful compounds into the environment. Traditional approaches for composting and anaerobic digestion have several limitations and challenges, such as long processing times, low humification efficiency, and relatively low-value products. If these approaches are not used properly, the treatment of organic waste can result in high energy consumption, environmental pollution, and resource exhaustion.

Therefore, there is an urgent need for more efficient and sustainable approaches to processing organic waste in Minnesota. Innovative bioprocessing techniques, such as insect-mediated bioconversion, thermophilic anaerobic digestion, and stepwise microalgae cultivation for wastewater treatment, may hold promise for more effective and sustainable organic waste management. We can significantly mitigate the environmental impact of organic waste and support resource circularity in Minnesota. Nevertheless, there are still challenges and obstacles that need to be addressed before these techniques can be successfully implemented for the valorization of organic wastes towards resource circularity.

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 overcome the aforementioned limitations and challenges, an integrated bioprocessing approach will be proposed for the valorization of organic wastes towards resource circularity. The proposed bioprocessing will involve three steps. First, a cost-effective insect-mediated bioconversion process will be established to efficiently digest organic waste through optimizing process conditions. Second, high-temperature anaerobic digestion will be used to convert the remaining organic residuals into biogas, with biogas residues used as biofertilizers for mushroom and plant cultivation. Third, the anaerobic digestion effluent containing high concentrations of ammonia and COD will undergo a stepwise microalgal cultivation process to achieve efficient nutrient removal and production of valuable microalgal biomass. The integrated bioprocessing approach will enable efficient bioconversion of organic waste into valuable biomass with commercial potential, largely supporting resource circularity and circular economy development. Finally, all bioprocesses will be streamlined and integrated to establish a complete system for testing and desmontration.

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 strategy for biological treatment of organic wastes in Minnesota can increase efficiency while reducing treatment time and energy consumption. Optimization of existing process systems and adoption of less expensive systems can process larger volumes of organic waste, reducing pollution in local waterways and groundwater. Organic wastes can be effectively converted into nutrients for sustainable cultivation of protein-rich insect larvae, mushroom, plants, and microalgae, producing valuable biomass for renewable fertilizers, feeds, fuels, and materials. This integrated bioprocessing of organic waste will achieve high efficiency in resource circularity, facilitating circular economy development.

Activities and Milestones

Activity 1: Develop an insect-mediated bioconversion process for initial organic waste digestion and optimize process conditions to improve conversion efficiency

Activity Budget: $120,000

Activity Description:
Insect larvae have been shown to efficiently convert various organic wastes such as food waste, livestock manure, and agricultural waste, into protein and lipid-rich resources. This study will focus on establishing an insect-mediated bioconversion process and examining the conditions required for efficient organic waste digestion.
(1) Insect species: Two typical resource insects, i.e., black soldier fly and waxworm, with different growth rates, organic waste preference, and waste-conversion rates will be compared for organic waste treatment;
(2) Selected gut microbes enhancing insect growth: Certain gut microbes are known to produce degraded enzymes that enable insect larvae to convert organic waste into valuable biomass. Therefore, different microbial species will be compared and utilized for insect growth and organic waste degradation;
(3) Process conditions: The crucial factors that affect organic waste degradation, including temperature, organic waste type, moisture content, nutrient content, and carbon-to-nitrogen ratio will be examined to enhance organic waste bioconversion.

Activity Milestones:

Description	Approximate Completion Date
Different organic wastes will be obtained and their components analyzed	September 30, 2024
Proximate and ultimate analyses as well as experimentation will be conducted to determine the ideal	November 30, 2024
A bench scale insect-mediated digestion system for organic waste treatment will be developed and operational	December 31, 2024
Different conditions for insect-mediated bioconversion of organic wastes will be evaluated and optimized	March 31, 2025

Activity 2: Develop and optimize high-temperature anaerobic digestion assisted with ammonia/sulfide stripping for recalcitrant organic residual digestion and biogas production

Activity Budget: $150,000

Activity Description:
Anaerobic digestion is another advanced approach for treating organic waste, offering both environmental and economic benefits. This section focuses on optimizing the AD process and integrating it with other methods to enhance conversion.
(1) AD process optimization: As Activity 1 proceeds to optimize the insect-mediated digestion of organic wastes, Activity 2 will use our lab-developed high-temperature AD system assisted with ammonia/sulfide stripping to address anaerobic digestion of recalcitrant organic residuals from Activity 1. The crucial treatment conditions such as organic loading rate and operational time will be optimized for efficient treatment. After the AD process, biogas will be harvested for commercial applications. AD effluent, containing high concentrations of ammonia and COD, will be used as nutrients for subsequent microalgae-based cultivation.
(2) Biogas residues as biofertilisers: Biogas residues will serve as biofertilisers for mushroom/plant cultivation, and their effects on the growth of mushrooms and plants, as well as the culture conditions, will be investigated and optimized for resource recovery.

Activity Milestones:

Description	Approximate Completion Date
The high-temperature anaerobic digestion system will be developed for organic waste treatment	March 31, 2025
The high-temperature anaerobic digestion system will be developed for organic waste treatment Optimized treatment conditions	June 30, 2025
Biogas residues will be used as biofertilisers for mushroom and plant cultivation for resource recovery	September 30, 2025

Activity 3: Develop two microalgal strains mediated stepwise cultivation on AD effluent to produce protein and oil-rich microalgal biomass

Activity Budget: $160,000

Activity Description:
This activity aims to investigate the use of anaerobic digester (AD) effluent with high concentrations of ammonia and chemical oxygen demand (COD) for stepwise cultivation of two microalgal strains in air-lift photobioreactors. Ammonia toxicity alleviation will be achieved in the first heterotrophic Chlorella vulgaris cultivation to remove ammonia from the AD effluent. These strategies include short-term acclimation of algal cells to enhance ammonia tolerance and addition of carbon sources to promote ammonia assimilation. In the second process, the supernatant with high COD levels will be used for stress cultivation of C. zofingiensis under high blue light irradiation, enabling COD removal and lipid/carotenoid-rich microalgal biomass production. Finally, advanced oxidation processes (AOPs) will be employed for effective removal of residual materials and water reclamation. Different AOPs and process times will be optimized for efficient wastewater treatment.

Activity Milestones:

Description	Approximate Completion Date
Heterotrophic cultivation of C. vulgaris for ammonia removal will be developed and operational	October 31, 2025
Stress cultivation of mixotrophic C. zofingiensis under blue light for COD removal will be evaluated	March 31, 2026
Advanced oxidation processes for remaining residual removal and water reclamation will be estimated and optimized	June 30, 2026

Activity 4: Integrate the three bioprocesses into a small pilot system for testing and demonstration

Activity Budget: $152,000

Activity Description:
Based on the studies described in Activities 1-3, we will develop a small pilot system that integrates the three main biological processes. Additional treatments will be employed to clean the water at the end of integrated process to ensure the water is clean enough for discharge to the environment or for uses in the treatments. The mass and energy balance data will be used in Life cycle analysis and Techno-economic analysis to evaluate the economic feasibility and environmental impact of the proposed technology in a hypothetical commercial scale model. Further research will be recommended to focus on commercializing the proposed bioprocessing.

Activity Milestones:

Description	Approximate Completion Date
Streamline the processes and develop an integrated system	September 30, 2026
Test and evaluate the integrated system's performance and economic and environmental impacts	June 30, 2027
Demonstrates the system to the stakeholders	June 30, 2027
Further R&D and commercialization strategy will be recommended in the final project report	June 30, 2027

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Paul Chen	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?

The project aims to develop an integrated bioprocessing approach for organic waste, which combines insect-mediated processes, upgraded anaerobic digestion, and stepwise microalgae cultivation. Successful implementation and demonstration of the proposed process would be of interest to various industries in Minnesota, including renewable energy, wastewater treatment, and agriculture in Minnesota. To further promote large-scale utilization of this technology for organic waste, we plan to seek additional future funding opportunities, with the ultimate goal of achieving environmental sustainability and carbon-neutral bio-manufacturing in the pursuit of resource circularity 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, Professor and Director of Graduate Studies, Department of Bioproducts and Biosystems Engineering, and Director of Center for Biorefining at University of Minnesota, is a Fellow of ASABE and a Fellow of IFT. Dr. Ruan's research focuses on renewable energy and environment technologies for sustainable development and circular economy. Specifically, he has conducted research and published his findings in the areas of municipal, agricultural, and industrial wastewater treatment and utilization through novel anaerobic digestion, microalgae cultivation, and hydroponic cultivation, biomass and solid wastes (including plastics) pyrolysis and gasification, airborne and other pathogen disinfection and pollutant control, catalysis, non-thermal plasma, and nitrogen fixation, etc. He is a top-cited author with an h-index of 88, i10-index of 443, and over 30,000 citations. He has supervised over 75 graduate students, 140 post-doctors, research fellows, and other engineers and scientists, and 21 of his Ph.D. students and post-doctors hold university faculty positions. He has also been invited to give over 300 keynote lectures, invited symposium presentations, company seminars, and short courses. Professor Ruan has received and managed over 200 projects totaling over $45 million in various funding for research, including major funding from USDA, DOE, DOT, DOD, LCCMR, and industries. He has served as guest editor or editorial board member of Bioresource Technology, Renewable Energy, Engineering, Applied Catalysis and Chemical Engineering, Journal of Food Process Engineering, The Open Plasma Physics Journal, and Associate Editor of Transactions of ASABE, Engineering Applications in Agriculture, and Transactions of CSAE, and Chairman of Editorial Board and Editor-in-Chief of International Journal of Agricultural and Biological Engineering, etc. His earlier LCCMR funded projects have resulted in several patented technologies which have been

successfully licensed to the industry. Therefore, he has the technical expertise and project management experience to ensure the 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								
Professor/faculty		PI - 2.5 weeks summer salary - direct all research, analysis, admin and personnel			36.8%	0.15		$41,371
Professor/faculty		Co-PI - contract faculty - co-direct all aspects of project - supervise post doc and student			36.8%	0.48		$72,087
Graduate Research Assistant		One researcher to conduct experiments, analysis, education			47%	3		$162,682
Post Doc Researcher		Conduct research and analysis			25.7%	3		$215,166
							Sub Total	**$491,306**
Contracts and Services								
							Sub Total	**-**
Equipment, Tools, and Supplies								
	Tools and Supplies	Purchase of lab and miscellaneous supplies, including feedstocks, chemical reagents, culture media, chemicals for analysis, consumable supplies for analytical instruments	For running experiments and operating synthesis reactors, chemical and physical analyses					$27,922
	Equipment	Purchase of components such as AD reactor, microalgae reactor, and black soldier fly and waxworm vessels, mixers, pumps, control devices, for fabrication of a small pilot testing and demonstration system	To fabricate a small pilot testing and demonstration system					$60,000
							Sub Total	**$87,922**
Capital Expenditures								
							Sub Total	**-**
Acquisitions and Stewardship								

							Sub Total	**-**
Travel In Minnesota								
	Miles/ Meals/ Lodging	12 one-day 2-person trips, 100 miles each round trip ($0.655/mile), meals @$50/person	Visits to waste management sites, feedstock collection and transport					$2,772
							Sub Total	**$2,772**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$582,000**

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	**-**

Attachments

Required Attachments

Visual Component

File: 6535362e-269.pdf

Alternate Text for Visual Component

Figure 1 depicts the integrated bioprocessing of organic waste into valuable biomass, with the aim of achieving resource circularity through multiple processing steps including insect-mediated bioconversion, high-temperature anaerobic digestion to generate biogas and fertilizers, stepwise microalgae cultivation to achieve complete nutrient removal and produce valuable microalgal biomass and clean water....

Optional Attachments

Support Letter, Photos, Media, Other

Title	File
Letter of Authorization	72811447-b9b.pdf
2022 Audit	f31dcca8-9c1.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

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

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 design, construction, or renovation of a building, trail, campground, or other capital asset costing $10,000 or more?

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?

No