



Environment and Natural Resources Trust Fund

2023 Request for Proposal

General Information

Proposal ID: 2023-121

Proposal Title: Innovative High Temperature Anaerobic Digestion of Organic Wastes

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: Evaluate the effectiveness of high temperature acid hydrolysis as pretreatment for efficient anaerobic digestion of organic wastes and downstream acidophilic microalgae cultivation.

Funds Requested: \$200,000

Proposed Project Completion: June 30, 2025

LCCMR Funding Category: Small Projects (H)

Secondary 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 in the state of Minnesota including dairy and hog manures and food wastes, are an important source of environmental pollution. Anaerobic digestion and composting are currently the most common methods of processing organic wastes. Composting has a low capital cost, but requires forced aeration and produces a relatively low value product that can be compromised by plastic particles, heavy metals, and other contaminants. Mesophilic anaerobic digestion is slow and requires large vessels to allow for sufficient residence time. Thermal hydrolysis pretreatment in the range of 70 °C to 200 °C could enhance methane production in the AD process of organic wastes rich in proteins, carbohydrates and lipids, but it could not enhance the biodegradability of lignocellulosic material. Moreover, if the temperature is not properly controlled, it will lead to a huge consumption of thermal and electricity energy and cause the release of smaller soluble organics which may inhibit anaerobic digestion. In contrast, organic wastes can be regarded as resources for valuable bioproducts production by microalgae which will provide additional revenue to offset the cost of anaerobic digestion and make up for the above-mentioned shortcoming.

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 limitations mentioned above, a 20 Liter thermal hydrolysis vessel will be used to evaluate the ideal blending mixture of different organic waste sources and then test a variety of hydrolysis conditions (temperature and pH) to optimize the process for pretreating organic wastes into soluble organic compounds (e.g., sugars, amino acids, fatty acids, glycerol, etc) under high temperature conditions. The resulting refractory organic residual will further be treated by high temperature anaerobic digestion to maximize the treatment efficiency of organic wastes. Then the organic waste hydrolysate will be used for the cultivation of acidophilic microalgal species (e.g., *Chlamydomonas Eustigma*) to produce valuable components. This will be evaluated in laboratory and pilot scales, and the culture conditions as well as the feeding strategy of nutrients-rich hydrolysate and AD effluent will be optimized and applied to microalgae cultivation to efficiently improve microalgal cell growth and nutrient removal efficiency. This process would reduce the treatment time of organic wastes and improve utilization efficiency by more effectively hydrolyzing organic components and using microalgae to produce valuable biomass, realizing the simultaneous economic and environmental benefits.

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 is able to realize efficient high-temperature anaerobic digestion of different organic wastes. The second environmental benefit is that this process will increase biological treatment efficiency of organic wastes while reducing the required treatment time and energy consumption. This will allow for more organic waste to be treated with smaller and less capital intensive systems due to the lower hydraulic retention time. Another benefit is that organic wastes could be effectively hydrolyzed into nutrients for microalgae cultivation for producing valuable biomass as feedstocks for renewable fertilizers, fuels and materials, which will provide additional revenue for organic waste treatment.

Activities and Milestones

Activity 1: Design and build thermal acid hydrolysis vessel, conduct and optimize high temperature treatment of organic wastes assisted with acid hydrolysis

Activity Budget: \$80,000

Activity Description:

Obtain and identify a variety of the most common organic waste sources in Minnesota (dairy, swine, poultry, food waste). Blend these wastes appropriately into an integrated feedstock, and do proximate and ultimate analyses as well as experimentation to determine the ideal blending mixture that will result in the most efficient degradation of macromolecules (mainly proteins, carbohydrates, lipids) after high temperature treatment assisted with acid hydrolysis. Test and integrate pretreatment methods and conditions (e.g., temperature, pH, organic loading rates, etc.) of the feedstock mixture to maximize the release of nutrients (e.g., sugars, amino acids, fatty acids, glycerol, etc) into the liquid hydrolysate of organic wastes to produce a nutrient solution for acidophilic microalgae cultivation while minimizing acid and energy requirements during the acid-assisted high temperature treatment. The recalcitrant organic residuals will be centrifuged and transferred to the anaerobic digester to maximize the hydrolysis of organic wastes. Determine experimentally the best conditions for thermal and acid hydrolysis for the full utilization of organic wastes in high temperature anaerobic digestion and as nutrients for microalgae cultivation while minimizing acid and energy requirements and producing recycling biosolids for unlimited land application.

Activity Milestones:

Description	Completion Date
Different organic wastes will be obtained and their components analyzed	September 30, 2023
Proximate and ultimate analyses and experimentation. Determine the ideal blending mixture for hydrolysis treatment	September 30, 2023
Bench scale acid-assisted high temperature hydrolysis system for organic waste treatment is developed and operational	December 31, 2023
Pretreatment conditions for acid-assisted high temperature AD of organic wastes is evaluated and optimized	March 31, 2024
AD process of recalcitrant organic residual is conducted and the obtained effluent is analyzed	June 30, 2024

Activity 2: Identify or adapt suitable microalgae species, integrate pretreatment with downstream microalgae cultivation

Activity Budget: \$70,000

Activity Description:

As Activity 1 proceeds to optimize hydrolysis conditions during the acid-assisted high temperature treatment of organic wastes, Activity 2 will address the microalgae-based utilization of the obtained nutrient-rich hydrolysates. The acidophilic green microalga *Chlamydomonas eustigma* will be selected and, if necessary, undergo adaptive laboratory evolution (ALE) to improve its growth rate under acidic conditions. The ALE strategy involves a repeating process of growth and selection under increasingly extreme conditions until a suitably acidophilic microalgae is produced, which will result in the highest growth rate of microalgae and maximum nutrient removal efficiency during the microalgal cultivation using the pretreated organic waste hydrolysate as nutrients.

Then the feedstock blending ratios and different culture conditions (e.g., light intensity, initial pH and initial nutrient concentration) will be evaluated and optimized for microalgal cultivation in the laboratory-scale system for the enhancement of microalgal cell growth and the efficient nutrient utilization.

Activity Milestones:

Description	Completion Date
Growth performance of acidophilic green alga <i>C. eustigma</i> is primarily investigated and compared	March 31, 2024
Microalgal strain improvement under acidic conditions by ALE strategy is developed and evaluated	June 30, 2024
Microalgae cultivation using nutrient-rich hydrolysate of organic wastes and culture conditions are evaluated	September 30, 2024
Biomass accumulation and composition and nutrient removal rates are determined and progressively optimized	October 31, 2024

Activity 3: Design, construct, and operate the microalgae cultivation systems; scale up the process, and demonstrate the system to the stakeholders.

Activity Budget: \$50,000

Activity Description:

The strategy of using the nutrient-rich liquid hydrolysate and AD effluent from Activity 1 for the cultivation of selected acidophilic microalgal strains in pilot-scale bioreactors under optimal culture conditions (Activity 2) will be systematically investigated in this section. The culture conditions as well as the feeding strategy of nutrient-rich hydrolysate and AD effluent will be optimized and applied to microalgae cultivation to improve microalgal cell growth and nutrient removal efficiency. After the cultivation, the acidic supernatant will be harvested and analyzed to determine composition and then recycled for the hydrolysis of organic wastes; thus reducing chemical requirements and preventing acidic discharge into the environment.

The mass and energy balance data will be used to evaluate the economic feasibility and environmental impact of the proposed technology in a hypothetical commercial scale model. Further research will be proposed with a focus on commercialization and the results of the proposed and future projects will be published in academic and industrial journals.

Activity Milestones:

Description	Completion Date
Microalgae-based nutrient removal of organic waste hydrolysate will be developed and operational	October 31, 2024
Feeding strategy of acid hydrolysate and organic wastes for acidophilic algae is evaluated and optimized	March 31, 2025
Commercial scaled-up mass and energy balances, economic analysis, capital costs are estimated	June 30, 2025
Further R&D and commercialization strategy will be recommended in the final project report	June 30, 2025

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 improved pretreatment process of thermal hydrolysis and acid hydrolysis combined with acidophilic microalgae cultivation will improve the utilization of organic wastes and reduce the time and energy required to treat such organic wastes. Successful development and optimization of this process will reduce the organic waste accumulation in waterways and groundwater by increasing the volume of waste that can be treated in existing systems. Successful implementation and demonstration of the proposed process would be of interest to industries including renewable energy, wastewater treatment, and agriculture.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Demonstrating Innovative Technologies to Fully Utilize Wastewater Resources	M.L. 2014, Chp. 226, Sec. 2, Subd. 08c	\$1,000,000
Development of Innovative Sensor Technologies for Water Monitoring	M.L. 2016, Chp. 186, Sec. 2, Subd. 04j	\$509,000

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. Ruan, Professor and Director of Graduate Studies of Bioproducts and Biosystems Engineering Department, and Director of Center for Biorefining at University of Minnesota, is a Fellow of ASABE, IFT, Vebleo, and IAAM, and has received many other awards, including CAFS Professional Achievement and Scientist of IAAM, etc. He is a top cited author in engineering and technology with an h-index of 80, i10-index of 392, and has over 25,000 citations. Dr. Ruan's research include renewable energy and environment technologies for sustainable development. He has published over 500 referred journal articles, two books, 24 book chapters, and holds 20 US patents in the areas of municipal, agricultural, and industrial liquid and solid waste including biomass and waste plastics treatment and utilization through novel anaerobic digestion, microalgae and hydroponic cultivation, pyrolysis and gasification, airborne and other pathogen disinfection and pollutant control, catalysis, non-thermal plasma, and nitrogen fixation, etc. He has received over 200 grants totaling over \$45 million in various funding for research, including major grants 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. He has supervised over 75 graduate students, 140 post-doctors, research fellows, and other engineers and scientists. He has given over 300 keynote lectures, invited symposium presentations, and short courses. His earlier LCCMR funded projects have resulted in several patented technologies which have been successfully licensed

to the industry. 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 help 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		Primary Investigator - project lead, advises researchers, plans and directs research, oversees budget, monitors and reports progress			33.5%	0.08		\$26,302
Professor/faculty		Co-Primary Investigator - advises researchers, designs and directs experiments, conducts data analysis, writes reports and publications			33.5%	0.16		\$28,490
1 Graduate Research Assistant		Researcher - carries out experiments, collects and analyzes data, prepares reports and manuscripts			45%	1		\$105,699
1 Technician		Researcher - sets up equipment and apparatuses, carries out experiments and collects data.			7.5%	0.7		\$23,650
							Sub Total	\$184,141
Contracts and Services								
							Sub Total	-
Equipment, Tools, and Supplies								
	Tools and Supplies	Purchase of lab and miscellaneous supplies, including samples, inoculants, micronutrients, chemicals, consumable supplies for analytical instruments, and parts and components for reactor fabrication and modification	For running experiments and operating systems					\$14,859
							Sub Total	\$14,859
Capital Expenditures								
							Sub Total	-
Acquisitions and Stewardship								
							Sub Total	-

Travel In Minnesota								
	Miles/ Meals/ Lodging	4 one-day 3-person trips, ~100 miles each round trip (\$0.585/mile), meals @\$49/person	Visits to farms, conduct experiments on farms and industry collaborators sites					\$1,000
							Sub Total	\$1,000
Travel Outside Minnesota								
							Sub Total	-
Printing and Publication								
							Sub Total	-
Other Expenses								
							Sub Total	-
							Grand Total	\$200,000

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: [f3f86f12-5f8.pdf](#)

Alternate Text for Visual Component

It shows the process from anaerobic digestion of organic wastes to acidophilic microalgae cultivation for valuable bioproducts. Organic wastes including dairy manure and food waste can be hydrolyzed into soluble organic compounds using dilute acid and high temperature anaerobic digestion for efficient utilization of waste....

Optional Attachments

Support Letter or Other

Title	File
Financial audit	5cdf49ea-095.pdf
Institutional Approval to Submit	f550cca5-c24.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

