Environment and Natural Resources Trust Fund

2023 Request for Proposal

General Information

Proposal ID: 2023-138

Proposal Title: Novel Nutrient Recovery Process from Wastewater Treatment Plants

Project Manager Information

Name: Bo Hu

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

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Project Basic Information

Project Summary: We request funding to extend an existing grant project, phosphorus recovery and anaerobic digestion at wastewater treatment plants, and include recovery of other nutrients as well as reduce sludge odor.

Funds Requested: $482,000

Proposed Project Completion: June 30, 2026

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?

In the Future

Narrative

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

Our current LCCMR seed project addresses issues at wastewater treatment plants (WWTPs) with both biological phosphorus (bio-P) removal and anaerobic digestion (AD). With bio-P, phosphorus is accumulated in the sludge, but sludge AD will dissolve the phosphorus and cause nutrient pollutions. We are developing a two-stage AD process, where phosphorus release can be facilitated in the 2-3 days first-stage thermophilic acid AD for easier precipitation and high-rate biogas generation can be secured in the second-stage AD. Our results show that release of soluble P from the thermophilic acid AD of mixed sludge increased from approx. 100-300mg P/L (in conventional AD effluent) to over 600mg P/L, suitable to an efficient P recovery in the form of high-purity P-bearing minerals through chemical dosing and precipitation. Other nutrient pollutants such as ammonia and hydrogen sulfide (H2S) are also quickly generated at the first stage. WWTPs are required to remove nitrogen, but conventional nitrogen removal requires significant chemical addition and energy use. H2S is a toxic gas present in the biogas generated through AD, and its removal is often an expensive component of biogas cleansing needed for beneficial use. Therefore, this development provides a great opportunity to recover all these other nutrients.

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.

The new process involves thermophilic acid AD followed by solids separation, nutrient recovery, and AD for biogas (renewable energy) generation. Our attachment shows the process flow diagrams of the current research on P recovery and the proposed improvement to include removal/recovery of ammonia and H2S. The proposed research will add an ammonia removal step after acid hydrolysis and solids separation. Our current research has shown we can achieve high ammonia concentrations, 1200-1800 mg-N/L. Several technologies can be tested to remove ammonia at these concentrations including gas permeable membranes (GPMs). GPMs can be configured in a vacuum mode that can also remove carbon dioxide (CO2) with the added benefit of raising the pH, which is required for phosphorus removal/recovery. As a result, this combined removal/recovery approach may be achieved with reduced chemical costs. Concentrated ammonia can be recovered as ammonium sulfate or ammonium hydroxide. We will also add a step for sulfur removal/recovery in the first-stage thermophilic acid AD. Our team studies methods of sulfur management in farm AD treatment to reduce cost of biogas utilization. Our work will study several H2S treatment options with the goal to reduce costs, thereby promoting use of renewable energy.

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?

We will develop an integrated process with following specific project outcomes:

- Effective P removal without metal salts, protecting rivers and lakes.
- Lower cost and higher capture for P recovery systems, increasing their use and generating a valuable P mineral.
- Reducing maintenance costs at WWTPs and allowing land application of biosolids in areas with P load limitations.
- Reducing N recycle from AD process, resulting in lower energy use, increased applicability of bio-P process and reduced chemical use.
- Ability to recover ammonia as a useful product.
- Reducing the cost of H2S management with AD biogas utilization as a renewable bioenergy fuel.

Activities and Milestones

Activity 1: Lab-scale study to remove nitrogen from first stage AD effluent

Activity Budget: $148,000

Activity Description:
The lab-scale system used in our current work will be modified to include nitrogen removal/recovery. Thickened primary sludge (TPS) and thickened waste activated sludge (TWAS) from a local WWTP will be used as the feeding substrate for the first-stage thermophilic acid AD with a hydraulic retention time (HRT) of 2-3 days. The properties of the liquid effluent (e.g., phosphorus release, volatile fatty acids (VFAs) production, and ammonia generation) will be monitored under different operation conditions (e.g., HRT, pH, etc.). Subsequently, the liquid effluent will go through dynamic membranes for solid/liquid separation, and the liquid portion will go through the nutrient recovery process: the ammonia removal/recovery will be conducted using GPMs, and phosphorus will be precipitated with chemical dosing. The ammonia removal/recovery will be studied under various operational conditions. Furthermore, the optimum sequencing of ammonia and phosphorus removal/recovery will be determined to minimize chemical use and prevent scaling issues. After nutrient recovery, the liquid stream will be recombined with the solid portion and sent to the second-stage AD for biogas production, and the changes of biogas volume, composition and total HRT will be monitored and compared with conventional one-stage AD.

Activity Milestones:

Description	Completion Date
Complete lab setup modification to study dynamic membrane solids separation and ammonia treatment	September 30, 2023
Measure performance and operating parameters of gas permeable membranes	November 30, 2023
Study sequence of ammonia and P treatment to minimize chemical use and scaling	June 30, 2024

Activity 2: Lab-scale study to remove sulfide from first stage AD effluent

Activity Budget: $154,000

Activity Description:
During the first-stage thermophilic acid AD in Activity 1, the biogas generated will also be collected and measured to determine the volume and composition, especially the H2S content. The effects of different operation conditions of thermophilic acid AD (e.g., HRT and pH) on the H2S release will be monitored, and the H2S release pattern will be summarized. Different sulfur treatment methods, typically including adsorption onto carbon-based sorbents, micro-aeration, metal ions (e.g., iron and copper) dosing, and electrochemical sulfide remediation using sacrificial metal anodes, will then be applied to the thermophilic acid AD and independently studied. The sulfur removal efficiencies between different methods will be compared under each identical operation condition, and the one with the highest efficiency and relatively low costs (i.e., chemical/material consumption and operational cost) will be selected as the appropriate sulfur removal method. Subsequently, the selected sulfur removal method will be incorporated into the first-stage thermophilic acid AD, and its influences on the following P and ammonia treatment will be assessed, based on which the further fine-tuning of such a multi-nutrient remediation process will be conducted.

Activity Milestones:

Description	Completion Date
Summarize H2S release pattern in first-stage thermophilic acid AD	November 30, 2024
Study the efficiencies of different sulfur removal methods on first-stage thermophilic acid AD	February 28, 2025
Incorporate sulfur treatment with phosphorus and ammonia recovery process and further conduct process optimization	June 30, 2025

Activity 3: Pilot-scale process research and techno-economic assessment

Activity Budget: $180,000

Activity Description:

Activity 3 involves modification of current research pilot-scale system to include dynamic membrane solids separation, ammonia recovery, and sulfur removal. This pilot-scale system will be installed and performed at a local WWTP with easy access to the raw sludge materials, and the data obtained will confirm the lab-scale work in Activities 1 and 2 (i.e., thermophilic acid AD for nutrient release, dynamic membrane solids separation, P recovery through chemical dosing, ammonia recovery using GPMs, and sulfur treatment using the appropriate method selected) with a much larger working volume of the feeding materials (i.e., TPS and TWAS). A fine-tuning strategy considering the reactor size changes will be established to maintain the optimum operation performance of such a pilot-scale system. In addition, the full and continuous operation of this pilot-scale system will provide reasonable data for a techno-economic assessment. The expenses include equipment purchase and construction, chemical reagents, electricity usage, and labor in system installation and operation/maintenance; the monetized benefits include phosphorus and nitrogen recovery for further utilization such as fertilizer, upgraded biogas production with less H2S, and eased discharging of effluents with less nutrients. Finally, the economic feasibility of the system deployment in WWTPs will be addressed.

Activity Milestones:

Description	Completion Date
Complete pilot setup	September 30, 2025
Stabilize and monitor acid AD process and solids separation	February 28, 2026
Optimize the overall process	April 30, 2026
Techno-economic analysis	June 30, 2026

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
George Sprouse	Environmental Services - Metropolitan Council (MCES)	George Sprouse is our contact to facilitate our on-site pilot research and demonstration. We are working with him on a detailed description of the proposed system and on-site work plan to be reviewed and approved by the MCES Safety, Operations, and Maintenance staff.	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 proposed research can be used by design engineers soon after the work is completed for application at new or existing WWTPs. Our team intends to present the results as they are compiled via LCCMR reporting, publishing in scientific and engineering journals and conference presentations. Our team will also present the process and research results to wastewater treatment system vendors/manufacturers. Potential vendors include Suez, Centrysis and Ovivo. If additional study is needed, funding may be pursued through the EPA Small business innovation research program.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Novel Nutrient Recovery Process from Wastewater Treatment Plants	M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 04b	$200,000

Project Manager and Organization Qualifications

Project Manager Name: Bo Hu

Job Title: Professor

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

Dr. Bo Hu is a Professor at Department of Bioproducts and Biosystems Engineering, University of Minnesota. With more than 20 years of active research experience specifically in bioprocessing development, nutrient removal, and waste management, he is leading projects to remove phosphorus from wastewater and assist plants for better uptake, projects on bioconversion of agricultural residue to value-added bioproducts, and projects on synthetic ecology in lichen biofilm formation by co-culturing mixotrophic microalgae and filamentous fungi. He has finished projects to develop a community microbial electrochemical septic system and a fungal biofilm system for water treatment. Dr. Hu's team at UMN has developed several bioconversion platforms, such as lichen biofilm co-cultivation of fungi and microalgae, pelletized fungal fermentation, and solid and hemi-SolidSF of filamentous fungi, to produce bioprducts and biofuel from agricultural waste and residue, and to remove nutrients and pollutant from contaminated water.

Dr. Hu's laboratory has all the necessary equipment and facilities for this project, including: greenhouse space, Bio-Rod MJ Mini 48-Well Personal Thermal Cycler, Bio-Rod electrophoresis, New Brunswick refrigerated incubation shaker INNOVA 42R, New Brunswick shaker Excella E-24, Beckman Allegra X-15R Refrigerated Centrifuge, VWR refrigerated water heater circulator, Bioreactor/fermentor, Agilent 7820 A GC-FID-TCD [gas-chromatography analysis–flame-ionization detector–thermal conductivity detector] , Agilent Micro-GC, Agilent 1260 HPLC (Diode Array detector, Refractive Index Detector and autosampler), and Dionex ICS 2100/ ICS 1100 bundle ThermoFisher Scientific. Other basic equipment within the lab includes Biosafety cabinet, Autoclave, -20 freezer and 4 degree refrigerator, balances, pH

meter, etc.. The lab is also equipped with two incubation rooms with full range of temperature control, a walk-in refrigeration room and a walk-in cold room.

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

Organization Description:
As the core department of UMN to tackle agricultural engineering and environmental engineering issues, Bioproducts and Biosystems Engineering Department has very dynamic research activities and numerous excellent scientific researchers have received grant supports from LCCMR program. UMN Sponsored Projects Administration (SPA) will be the entity authorized by the Board of Regents to manage the project agreements with LCCMR program.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
PI		Lead project, research, supervise, analyze - summer salary only			33.5%	0.3		$54,175
Two research professional		research, 75% appointment			33.5%	4.5		$375,060
							Sub Total	**$429,235**
Contracts and Services								
							Sub Total	-
Equipment, Tools, and Supplies								
	Tools and Supplies	Lab supplies	regular lab supplies					$31,204
	Equipment	Gas permeable membrane contactors, electrochemical systems to be added on the pilot scale	These are testing components that we want to add to the two stage anaerobic digestion ssytem					$20,000
							Sub Total	**$51,204**
Capital Expenditures								
							Sub Total	-
Acquisitions and Stewardship								
							Sub Total	-
Travel In Minnesota								
	Miles/ Meals/ Lodging	Trips to go to the Blue Lake or Empire wastewater treatment plants	To take samples or work on the pilot study					$1,561
							Sub Total	**$1,561**

Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$482,000**

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: 2ca02b19-97d.docx

Alternate Text for Visual Component

Flow diagram of the typical current process for sludge handling with anaerobic digestion, current research process supported by the LCCMR seed grant program, and the proposed extended research process that can remove sulfur, nitrogen, phosphorus from sludge handling...

Optional Attachments

Support Letter or Other

Title	File
U Mn approval to submit	1d57406e-f38.pdf
Supporting letter from Metro Council Wastewater Treatment Plant	16e88787-d2e.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?

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?

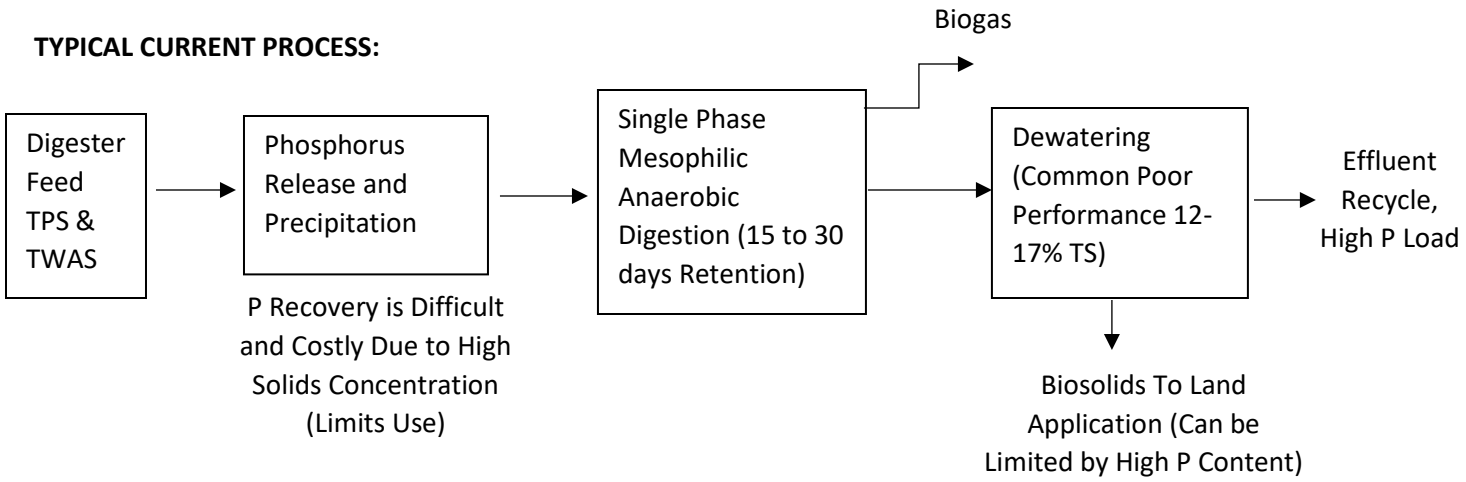
No

Does the organization have a fiscal agent for this project?

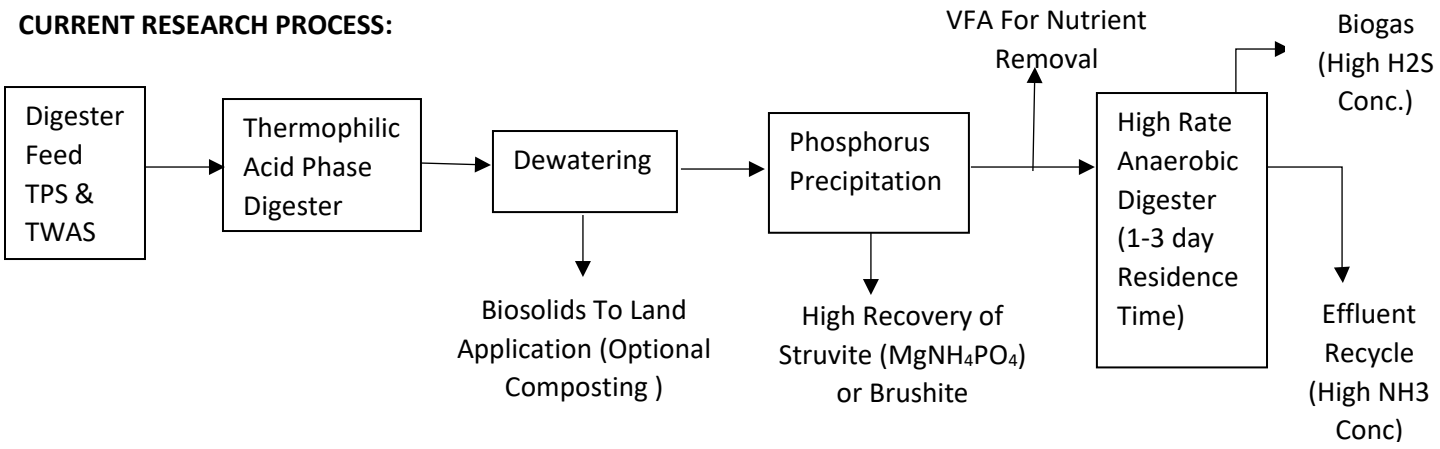
Yes, Sponsored Projects Administration

Visual Component Attachment

TYPICAL CURRENT PROCESS:



CURRENT RESEARCH PROCESS:



PROPOSED EXTENDED RESEARC PROCESS: