Environment and Natural Resources Trust Fund

2021 Request for Proposal

General Information

Proposal ID: 2021-115

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: This proposal requests funding for a new integrated process with potential to promote nutrient removal/recovery and renewable energy production at rural municipal and industrial wastewater treatment plants (WWTP).

Funds Requested: $200,000

Proposed Project Completion: 2023-06-30

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?

In the Future

Narrative

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

Many WWTPs typically have biological phosphorus (P) removal and anaerobic digestion (AD) to reduce sludge volume. These two processes affect each other, causing issues that impact performance and increase operating costs. The bio-P removal impacts AD by mineral precipitation and decreasing solids dewaterability. P mineral precipitation clogs piping and accumulates on mixers and in reactors, requiring costly maintenance. Dewatering performance can be reduced by 3 – 6% after bio-P is initiated, significantly increasing solids management costs. The cause of dewatering issues has been linked to the ratio of mono/divalent cations, ortho-P concentration and extracellular polymeric substances, however, the complete mechanism has not been defined. AD impacts bio-P removal by converting P bound in cell mass to a soluble form. The recycled P load may be greater than 50% of the total plant load, often requiring addition of expensive reduced organics such as methanol or metal salts to achieve the required treatment. Also, with existing processes, P recovery is more difficult by its mixture with a high concentration of biological solids. This requires use of expensive separation equipment such as fluidized bed reactors for P recovery, limiting its application only to a few large metro WWTPs; disproportionally affecting rural plants.

What is your proposed solution to the problem or opportunity discussed above? i.e. What are you seeking funding to do? You will be asked to expand on this in Activities and Milestones.

We are proposing a new integrated process, including thermophilic acid AD (TAAD) followed by dewatering, P recovery and high rate AD (HRAD) that address above issues (see attached process flow diagrams of conventional/new systems). The first step is the TAAD operated at 55°C for 2–4 days hydraulic retention time (HRT) in order to hydrolyze organics to volatile fatty acids (VFA), and P to soluble phosphate. The second step is dewatering and P recovery. TAAD effluent contains higher concentration phosphate than conventional AD, exceeding 500 mg-P/L. Dewatering of this effluent has been tested by Centrysis, documenting high cake solids concentrations and P recovery (up to 84%). Via lime/magnesium hydroxide dosing, valuable P minerals including brushite ($CaHPO_4$) and struvite ($MgNH_4PO_4$) can be recovered from the liquid effluent. These P minerals can be used as P fertilizer, readily available for crop uptake. Finally, the effluent after P recovery contains high concentration of VFAs that can be recycled as a source of reduced organics for bio-P treatment, or sent to HRAD for conversion to renewable biogas energy. HRAD is able to operate at short HRTs of below 2 days as compared to over 20 days in conventional AD.

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 new, integrated process has potential to improve the efficiency and effectiveness and reduce the operation costs of bio-P and AD in rural WWTPs, thus promoting their use. Specific advantages include:

- Higher P recovery than current systems, better integrated at lower costs.
- Recovery of more valuable P minerals, increasing the application and protecting rivers and lakes.
- Reducing maintenance costs at WWTPs, improving dewaterability, allowing land application of biosolids in areas with P load limitations, and reducing transportation costs.
- More stable AD, less potential for foaming, significant reduction in time/tank volume and promoting AD as means of generating renewable bioenergy.

Activities and Milestones

Activity 1: Set-up and test of lab-scale experimental system

Activity Budget: $101,305

Activity Description:
A lab-scale experimental system will be set up to study this new process. Thickened primary sludge (TPS) and thickened waste activated sludge (TWAS) will be collected from local WWTPs as the test substrates. TPS and TWAS will be characterized and fed into the first-stage TAAD at 55°C and an HRT of 2-4 days. The P solubilization and VFA production in the effluent will be analyzed to evaluate the substrate hydrolysis and degradation in TAAD, and the fecal coliform destruction will also be monitored. Subsequently, solid-liquid separation will be applied to assess the dewaterability of the effluent after TAAD. The dewatered cake solids will be processed as biosolids for land application, whilst lime or magnesium hydroxide will be dosed into the liquid phase to capture and recover P in the form of brushite and struvite. The effects of varied reagent dosage on P recovery will be recorded. After P recovery, the liquid effluent rich in VFA will be fed into the third-stage HRAD for biogas generation. The correlation between the VFA loading and biogas production will be graphed. The optimum operation parameters of this three-stage system will be obtained finally.

Activity Milestones:

Description	Completion Date
Lab-scale three-stage experimental system set-up.	2021-08-31
TPS/TWAS characterization and first-stage TAAD optimization.	2021-11-30
Maximum P recovery with minimum reagent dosage in the second stage.	2022-03-31
Interim report on the lab-scale system performance.	2022-06-30
Correlation between VFA loading and biogas production in the third-stage HRAD.	2022-06-30

Activity 2: On-site demonstration of a pilot-scale system

Activity Budget: $98,695

Activity Description:
With the establishment of lab-scale three-stage system and the optimization of operation parameters obtained in Activity 1, a pilot-scale system will be built and installed at or near a local WWTP. This pilot-scale three-stage system confirm the lab-scale experimental results (i.e., P solubilization and organic hydrolysis in TAAD, P recovery through lime/magnesium hydroxide dosage, and biogas production of VFA-rich liquid effluent in HRAD) with a much larger working volume of TPS/TWAS. The full and continuous operation of this pilot-scale system will provide a new insight of this novel integrated process on future actual deployment in WWTPs. After a successful demonstration, a techno-economic assessment of the proposed system will be conducted, thus addressing the economic feasibility of the implementation of this integrated three-stage system for improved bio-P recovery and biofuel production. The expenses resulting from the on-site pilot-scale demonstration will be used for the cost analysis, including equipment purchase and construction, reagents, electricity and fuel usage, and labors in the installation and operation/maintenance. The corresponding value increase due to biosolids sale, P recovery for further utilization, biogas production, and eased discharging of effluents with lower P and organics will be monetarized in the benefit analysis.

Activity Milestones:

Description	Completion Date
On-site pilot-scale system construction and installation.	2022-09-30
Continuous operation and optimization of pilot-scale system treating TPS/TWAS.	2023-03-31

Techno-economic assessment of this three-stage system including expenses and monetarized benefits.	2023-06-30
Final report on both the lab-scale system and pilot-scale demonstration performances.	2023-06-30

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
James Postiglione	HR Green, Inc	Mr. James Postiglione currently is a process engineer at HR Green, a local engineering consulting firm. He initiated this research and will be employed at the University of Minnesota as a post graduate researcher (50%). Role to collaborate on study design and assist in lab and pilot operation and monitoring.	Yes

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 be funded?

The proposed research can be used by design engineers soon after the work is completed for application at new or existing WWTPs, especially those small ones at Greater Minnesota. 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 and USDA Rural Development program.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Extracting Deicing Salt from Roadside Soils with Plants	M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 04i	$360,000
Next Generation Large-Scale Septic Tank Systems	M.L. 2014, Chp. 226, Sec. 2, Subd. 08g	$258,000

Project Manager and Organization Qualifications

Project Manager Name: Bo Hu

Job Title: Associate professor

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

Dr. Bo Hu is an associate professor at Department of Bioproducts and Biosystems Engineering, University of Minnesota. With more than 18 years of active research experience specifically in bioprocessing development, nutrient removal, and waste management, he is leading projects to remove phosphorus from manure and from wastewater in the septic tank systems, projects to reveal the myth of recent swine manure foaming in Midwestern states, 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 set up several standard procedures such as 16s rDNA based microbial analysis by using high-throughput pyrosequencing methods to study the microbial species in the waste treatment processes, ITS sequences to identify fungal species, etc. His team is also developing several conversion platforms, such as lichen biofilm co-cultivation of fungi and microalgae, pelletized fungal fermentation, and solid and hemi-solid state fermentation of filamentous fungi, to produce bioproducts and biofuel from agricultural waste and residue, and to remove nutrients and pollutant from contaminated water. Dr. Hu will design and coordinate the research; and his postdoc researcher Dr. Ding will assist in design and experimentation as well as data collection and dissertation.

Dr. Hu's laboratory has all the necessary equipment and facilities for this project, including: 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/fermenter, Agilent 7820 A GC-FID-TCD, Agilent Micro-GC, Agilent 1260, and Dionex ICS 2100/ ICS 1100 bundle ThermoFisher Scientific. 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, Agriculture 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. As a participating faculty of Biotechnology Institute of UMN, Dr. Hu has the access to the Biotechnology Resource Center, which is a 4000 square-foot laboratory/pilot plant facility with state-of-the-art equipment for research and development in fermentation, animal cell culture technology, molecular biology, protein expression, and separation of a wide range of biological molecules. The facility has a wide range of bench-scale to pilot-scale fermenters available, ranging in size from 6 L to 300 L. The university also has the following facility that can be accessed with payment: Center for Mass Spectrometry and Proteomics. This facility is house in the basement of the Gortner / Snyder complex and provides support, equipment and expertise for analyzing complex protein mixtures. This facility has several full-time staff trained to run and troubleshoot experiments. It is home to the UMN Mass Spectrometry and Proteomics Initiative.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Associate Professor		Principal Investigator, coordinate the research efforts, design experiments and write project reports			36.5%	0.08		$13,855
Researcher		scientific staff, working on experimental design and data collection			36.5%	2		$144,089
							Sub Total	**$157,944**
Contracts and Services								
							Sub Total	-
Equipment, Tools, and Supplies								
	Tools and Supplies	Chemicals, analysis kits, and personal protection supplies	materials for lab experiments					$11,662
	Equipment	A pilot scale bioreactor for phosphorus removal will be built in the first year and operated at a local wastewater treatment in the second project year to scale up the lab developed process. The components of this pilot scale reactor includes carboy, pumps, air compressor, insulation, filter device etc	This pilot scale reactor will enable us to test our proposed process in the real wastewater treatment plant					$25,000
							Sub Total	**$36,662**
Capital Expenditures								
							Sub Total	-
Acquisitions and Stewardship								
							Sub Total	-
Travel In Minnesota								

	Miles/ Meals/ Lodging	Within-state travel using university vehicles, standard rate applies	Trips to go to site for collection of waste samples					$2,040
							Sub Total	**$2,040**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
	Publication	Publication cost for two journal articles	To disseminate our research in scientific journals					$3,354
							Sub Total	**$3,354**
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				
In-Kind	Since this project does not charge any indirect cost, therefore University of Minnesota matches the in kind service F&A. The current indirect cost rate is 54% of the direct total project cost without capital equipment.	UM F&A	Secured	$95,112
			State Sub Total	**$95,112**
Non-State				
			Non State Sub Total	**-**
			Funds Total	**$95,112**

Attachments

Required Attachments

Visual Component

File: 4a7a9870-3f9.pdf

Alternate Text for Visual Component

This visual shows the differences between the current process and what we propose to develop.

Optional Attachments

Support Letter or Other

Title	File
SPA approval to submit	20db0704-3ad.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Does your project have patent, royalties, or revenue potential?

No

Does your project include research?

Yes

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

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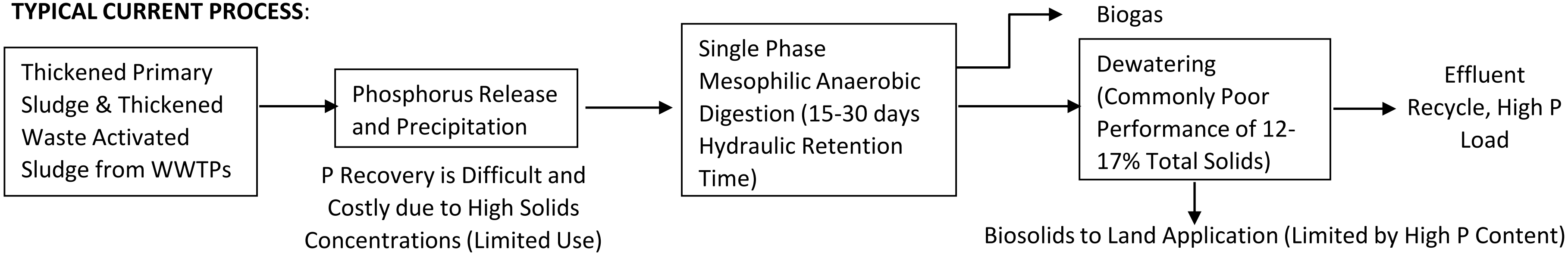
Bo Hu, University of Minnesota, 612-625-4215, bhu@umn.edu

Project Summary: This proposal requests funding for a new integrated process with potential to promote nutrient removal/recovery and renewable energy production at rural municipal and industrial wastewater treatment plants (WWTP).

TYPICAL CURRENT PROCESS:



EXISTING PROBLEMS:

Rural and smaller wastewater treatment plants typically have difficulties in recovering phosphorus, primarily because their anaerobic digestion and biological P removal steps are negatively affecting each other, causing costly maintenance, poor dewaterability, and additional equipment requirements

BENEFITS FROM THE NEW PROCESS:

- Higher P recovery, better integration at lower costs.
- Recovery of more valuable P minerals, increasing the application and protecting rivers and lakes.
- Reducing maintenance costs at WWTPs, improving sludge dewaterability, allowing land application of biosolids in areas with P load limitations, and reducing transportation costs.
- More stable AD, less potential for foaming, significant reduction in time/tank volume, and promoting renewable bioenergy production by means of high-rate anaerobic digestion.

EXPERIMENTAL PLAN:

- Lab scale experimental system
- On-site demonstration of a pilot-scale system

NEW INTEGRATED PROCESS: