Environment and Natural Resources Trust Fund
2019 Request for Proposals (RFP)

Project Title: **ENRTF ID: 079-B**

Converting Concentrated Wastewaters to Fertilizers and Clean Water

Category: B. Water Resources

Sub-Category:

Total Project Budget: $ 842,000

Proposed Project Time Period for the Funding Requested: June 30, 2022 (3 yrs)

Summary:

To develop and demonstrate innovative and sustainable technologies to convert concentrated animal wastewaters to clean water and at the same time produce methane energy, fertilizers, and valuable biomass.

Name: Roger Ruan

Sponsoring Organization: U of MN

Title: Professor and Director

Department: Bioproducts and Biosystems Engineering

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Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

Showing different processes including vacuum-assisted thermophilic anaerobic digestion, minimum oxygen sludge process, bacteria and algae and hydroponic plants production, etc. for truly complete utilization and therefore treatment of concentrated wastewater.

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

_____ Extent of Impact _____ Innovation _____ Scientific/Tech Basis _____ Urgency

_____ Capacity Readiness _____ Leverage _______ TOTAL ______%

____ If under $200,000, waive presentation?

PROJECT TITLE: Converting concentrated wastewaters to fertilizers and clean water

I. PROJECT STATEMENT

Each year, Minnesota agricultural activities generate a huge amount of wastewaters, especially in the animal production sector. Direct discharges of waste from large concentrated animal feeding operations into the water way are regulated under the Clean Water Act and must obtain a National Pollutant Discharge Elimination System permit. Small to mid-size animal producers, for example, are struggling to find economically acceptable technologies to treat their wastewater to meet the discharge requirements. There are increasing interests and efforts in treatment through complete utilization approaches but not without challenges. This project addresses ***Priority B*** *titled "Water Resources, 2II. Preventing or reducing levels of contaminants in ground and surface waters"* through developing and demonstrating innovative and practical technologies that (1) enable the truly complete use of animal wastewater for (a) methane, fertilizer, and biomass production, and (b) hydroponic cultivation without diluting with fresh water, and (2) at the same time allow us to treat the water and thus reduce contaminants (including antibiotics) in ground and surface waters.

In the past we have demonstrated that after anaerobic digestion (AD), the treated animal wastewater could be used for microalgae cultivation after ***diluted with >5 times fresh water***. Dilution effectively lowers the chemical oxygen demand (COD) and major nutrients especially ammonia and hydrogen sulfide to levels that do not inhibit bacteria and microalgae growth. However, ***adding 5 times fresh water to a wastewater treatment process does not seem intuitive and sustainably sound***. In this proposed project, we aim to develop a series of efficient processes to lower the chemical oxygen demand and nutrient to such levels that ***dilution with fresh water for algae and hydroponic vegetable production or crop application is no longer necessary***. The key research components in this project include:

1) <u>Vacuum and/or nitrogen bubbling assisted thermophilic anaerobic digestion</u>: Conventional ADs are faced with issues arising from high ammonia and hydrogen sulfide levels that hinder methane production reactions. The vacuum and/or nitrogen bubbling assisted thermophilic anaerobic digestion being developed is aimed to address these issues and quickly and efficiently produce methane (as energy), reduce chemical oxygen demand, and recover ammonia and hydrogen sulfide (as fertilizers).
2) <u>Bio-film anaerobic digestion and minimal oxygen sludge process</u>: Since the chemical oxygen demand remains infinitively high, further treatments are necessary, which may take one of the two routes to be investigated in the project. In Route I, aerobic bacteria strains selected in our lab are allowed to grow and form a bio-film, which is used to facilitate bio-film aerobic digestion of the effluent from anaerobic digestion. Our preliminary data show that through bio-film aerobic digestion, chemical oxygen demand and ammonia were further reduced by 94% and 88%, respectively, so that chemical oxygen demand and ammonia levels are then suitable for photosynthetic algae and bacteria growth. In Route II, a minimal oxygen sludge process utilizing both anaerobic and aerobic bacteria will be investigated. Minimal oxygen sludge process has shown strong ability to reduce chemical oxygen demand rapidly.
3) Next, <u>photocatalytic materials coupled with above processes</u> will be used to treat the broth after bacteria and algae cultivation to reduce antibiotics. The harvested bacteria and algal biomass from these processes can be used to produce value-added products including feeds and bioenergy. Finally, <u>biochar filtration</u> is used to remove solid particles, etc., resulting in an effluent containing mainly nutrients suitable for <u>hydroponic or aquaponic systems</u>. After that, water may be discharge to wet land or used for animal facility cleaning.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: *Develop and optimize processes to reduce chemical oxygen demand and ammonia to desirable levels*

Vacuum assisted thermophilic anaerobic digestion, bio-film aerobic digestion, and minimal oxygen sludge process are the three major processes to be developed and optimized in the project. The feasibility of these processes have been demonstrated in previous studies. The effects of key process conditions such as vacuum, nitrogen bubbling, oxygen level, temperature, time, addition of pretreated cellulosic biomass to adjust carbon/nitrogen ratio, and bacteria strains will be studied, and level of chemical oxygen demand, ammonia, total nitrogen, hydrogen sulfide, and total phosphorus removal and recovery will be evaluated and the results will be used to optimized the processes. How well bacteria and microalgae grow on the treated water will also be evaluated. For animal wastewaters that contain high level of antibiotics, the effect of photocatalytic materials coupled with aerobic bacteria on antibiotics removal will be studied. The effectiveness of biochar from biomass pyrolysis for particle and nutrient removal will be investigated.

ENRTF BUDGET: $442,000

Outcome	**Completion Date**
1. Develop and optimize vacuum assisted thermophilic anaerobic digestion and bio-film aerobic digestion processes	*06/30/2020*
2. Evaluate microalgae growth on vacuum assisted thermophilic anaerobic digestion and bio-film aerobic digestion treated water	*12/31/2020*
3. Develop and optimize photocatalytic materials coupled with aerobic bacteria *for antibiotics removal and biochar filtration for particle removal*	*12/31/2021*
4. Study hydroponic cultivation on the treated water	*12/31/2022*

Activity 2: *Develop a demonstration system*

With the knowledge, experience, and optimized processes obtained from Activity 1, we will develop a small pilot scale system consisting of *vacuum assisted thermophilic anaerobic digestion, bio-film aerobic digestion*, photocatalytic materials coupled with aerobic bacteria, biochar filtration and hydroponic tray for comprehensive evaluation of the processes and demonstration of the technology to general public for education and outreach purpose.

ENRTF BUDGET: $400,000

Outcome	**Completion Date**
1. Scale-up parameters will be determined for the optimized process flow	*03/31/2021*
2. System design will be completed	*06/30/2021*
3. Individual units will be fabricated and assembled, and tested	*12/31/2021*
4. The system will be demonstrated on UMN outreach center or a farm setting to the stakeholders	*06/30/2022*

III. PROJECT PARTNERS:

A. Project team:

Roger Ruan (BBE, UMN), Paul Chen (BBE, UMN)

B. Partners NOT receiving ENRTF funding

Name	**Title**	**Affiliation**	**Role**
Peter Forsman	President/owner	Forsman Farms	System development and testing

IV. LONG-TERM- IMPLEMENTATION AND FUNDING:

New scientific knowledge and experience on complete wastewater utilization process will be acquired through research, and the demonstration will raise significant interests from the public. We will seek industry partners and private, state, and federal funding to further develop and eventually commercialize the technology.

V. TIME LINE REQUIREMENTS:

This project is planned for 3 years beginning July 1, 2019 and ending June 30, 2022. Most of the first 24 months will be focused on process improvement and parameter optimization, and full understanding of the proposed process, and much of the second 12 months will be focused on development, evaluation, and demonstration of the proposed demonstration system.

2019 Proposal Budget Spreadsheet

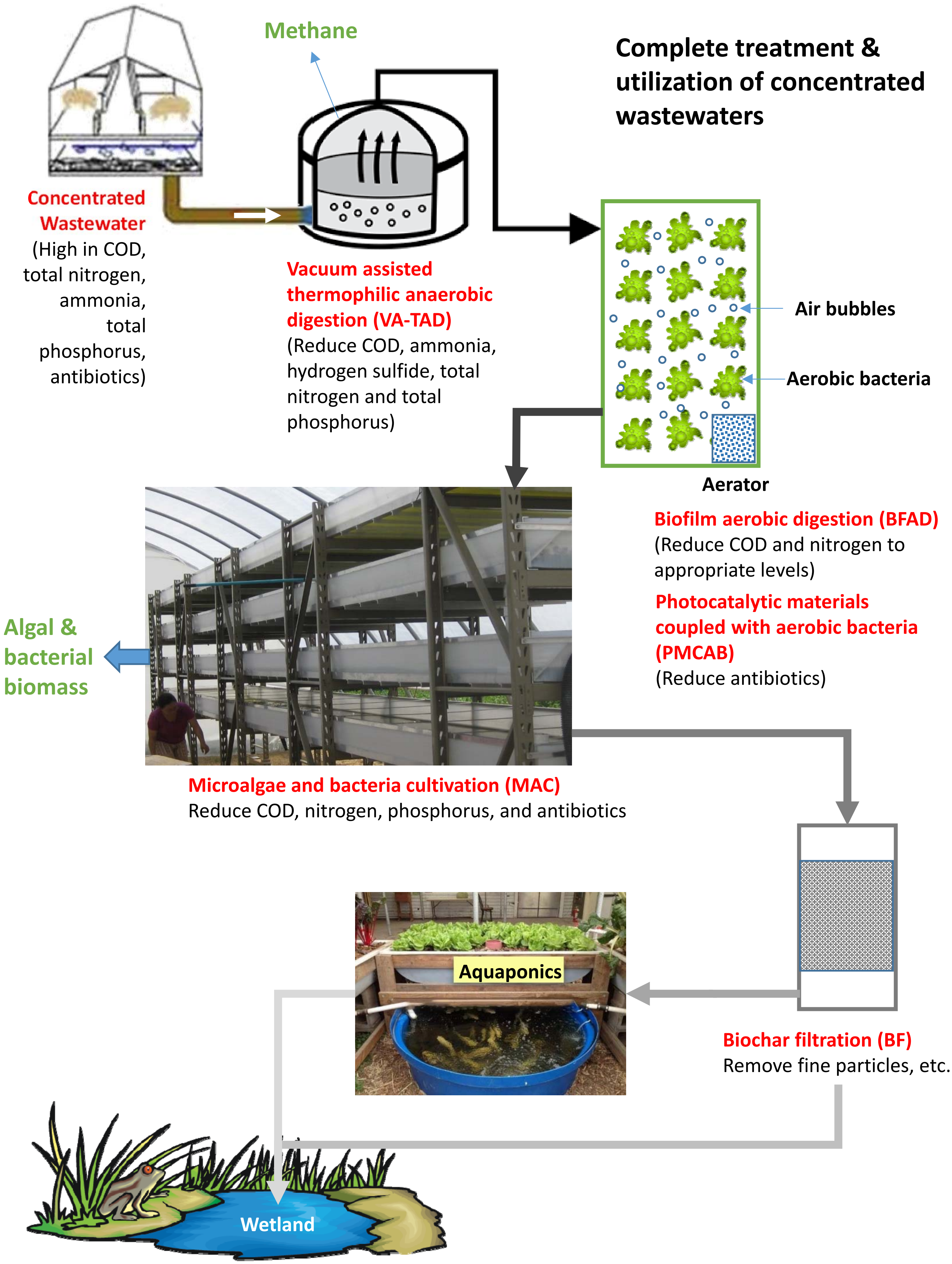
Project Title: Converting concentrated wastewaters to fertilizers and clean water

IV. TOTAL ENRTF REQUEST BUDGET *[3]* **years**

BUDGET ITEM	**AMOUNT**	
Personnel: other personnel categories may be used as needed		**$ 654,000**
Roger Ruan, PI/PD, 1 month/year, 3 years, including 33.5% benefits, leading and managing project, overlooking R&D, leading demonstration, supervising postdocs and RA	$ 65,000	
Paul Chen, co-PI, 25%, 3yrs, including 33.5% benefits, project coordination, conducting R&D, project evaluation, progress report	$ 98,000	
1 Research Professional (post-doc, research associate, or research faculty) 100%, 3yrs, including 33.5% benefits, conducting R&D, operations, demonstration, data analysis	$ 208,000	
2 Graduate Research Assistants (BBE Dept), 50%, 3yrs, including 15% benefits plus tuitions, conducting R&D, operationg, demonstration	$ 283,000	
Equipment/Tools/Supplies:		**$134,000**
Components for farbication of small scale demonstration facility including: vacuum assisted anaerobic digestion reactor, biofilm aeriobic digestion reactor, microalgae and bacteria cultivation reactor, biochar filtration unit, methane, ammonia and hydrogen sulfide collectors, hydroponic reactor	$90,000	
Lab supplies, catalysts, instrument and equipment consumables, minor equipments for settting up lab experimental reaction systems	$44,000	
Travel:		**$8,000**
For researchers to travel to collect samples in fields and between campus and demonstration site over the 3yrs project period	$8,000	
Additional Budget Items:		**$46,000**
Outside analysis service (labs outside BBE Dept and labs outside the university with MN Company preferred)	$15,000	
Instrument and equipment maintanance and repair (wastewater retreatment and analytic equipment)	$31,000	
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =		**$842,000**

V. OTHER FUNDS *(This entire section must be filled out. Do not delete rows. Indicate "N/A" if row is not applicable.)*

SOURCE OF FUNDS	**AMOUNT**	**Status**
Other Non-State $ To Be Applied To Project During Project Period:	$ -	
Other State $ To Be Applied To Project During Project Period:	$ -	
In-kind Services To Be Applied To Project During Project Period: Unrecovered F&A	$ 356,000	
Past and Current ENRTF Appropriation:	$ -	
Demonstrating innovative technologies to fully utilize wastewater resources (ML 2014 Sec. 2), US petent has been issued.	$ 1,000,000	spent
Pyrolysis pilot project (ML 2007, Sec. 2), The technology has been licensed by Resynergi Inc	$ 500,000	spent
Algae for Fuels Pilot Project (ML 2010, Sec. 2)	$ 900,000	spent
Other Funding History:	$ -	



Methane
Complete treatment & utilization of concentrated wastewaters
Concentrated Wastewater
(High in COD, total nitrogen, ammonia, total phosphorus, antibiotics)
Vacuum assisted thermophilic anaerobic digestion (VA-TAD)
(Reduce COD, ammonia, hydrogen sulfide, total nitrogen and total phosphorus)
Air bubbles
Aerobic bacteria
Aerator
Biofilm aerobic digestion (BFAD)
(Reduce COD and nitrogen to appropriate levels)
Photocatalytic materials coupled with aerobic bacteria (PMCAB)
(Reduce antibiotics)
Algal & bacterial biomass
Microalgae and bacteria cultivation (MAC)
Reduce COD, nitrogen, phosphorus, and antibiotics
Aquaponics
Biochar filtration (BF)
Remove fine particles, etc.
Wetland

Project Manager Qualifications and Organization Description

Dr. Roger Ruan, Professor and Director, Center for Biorefining and Department of Bioproducts and Biosystems Engineering, University of Minnesota, is the project manager of the proposed project. Dr. Ruan's research focuses on renewable energy and the environment as well as food safety and quality. Professor Ruan has published over 400 papers in refereed journals, has co-authored two books, and many book chapters, over 300 meeting papers and reports, and holds 18 US patents. He is also a top cited author in the area of agricultural and biological sciences. He has supervised over 65 graduate students, 110 post-doctors, research fellows, and other engineers and scientists, and 12 of his Ph.D. students and 8 other post-doctors hold university faculty positions. He has received over 160 projects totaling over $40 million in various funding for research, including major funding from USDA, DOE, DOT, DOD, LCCMR, and industries. Professor Ruan has given over 250 keynote lectures, invited symposium presentations, company seminars, and short courses, and has been a consultant for government agencies, and many local, national, and international companies and agencies in bioprocess engineering, food engineering, and renewable energy and environment areas. He has taught many undergraduate and graduate courses, including *Renewable energy technologies*, *Biological process engineering*, *Managing water in food and biological systems*, *Instrumentation and control for biological systems*, Food process engineering, and *Engineering principles and applications, etc*.

Dr. Ruan has very active ongoing research programs in the areas of environmental and renewable energy engineering. Specifically, his research group has been investigating processes for wastewater treatment and utilization including thermophilic anaerobic digestion, microalgae cultivation, and aquaponics systems. They have accumulated good collections of wastewater sludge, aerobic bacteria, and microalgae strains. His team has experience in building bench and small pilot systems for testing and systems analysis. They are well published in these areas.

The Center for Biorefining is a University of Minnesota research center and help coordinate the 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 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. In particular, they have the capability to develop various bioreactors for different purpose and the means to evaluate related processes.