Environment and Natural Resources Trust Fund
2017 Request for Proposals (RFP)

Project Title: **ENRTF ID:** **034-B**

Innovative Nitrogen Removal Technology to Protect Water Quality

Category: B. Water Resources

Total Project Budget: $ 476,100

Proposed Project Time Period for the Funding Requested: 3 years, July 2017 - June 2020

Summary:

Ammonia and nitrate in wastewater cause fish toxicity and harmful algal blooms, but removal is expensive and energy intensive. We will develop a technology for inexpensive, low-energy wastewater nitrogen removal.

Name: Paige Novak

Sponsoring Organization: U of MN

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Minneapolis MN 55455

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Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

The visual shows a schematic of our proposed technology, which will use advanced materials to encourage selective growth and retention of specialized bacteria to promote low-energy inexpensive wastewater nitrogen removal.

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

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

_____ Capacity Readiness _____ Leverage _______ TOTAL ______%

PROJECT TITLE: INNOVATIVE NITROGEN REMOVAL TECHNOLOGY TO PROTECT WATER QUALITY

I. PROJECT STATEMENT

We will develop a new wastewater treatment technology to facilitate inexpensive, low-energy, and robust total nitrogen removal for enhanced surface water quality.

Background

Urine and feces contribute ammonia to wastewater. Wastewater treatment plants are required to treat ammonia, typically converting it to nitrate, because ammonia causes oxygen depletion and fish toxicity when released to surface water. Unfortunately, the nitrate present in treated wastewater can also cause water quality problems, much like the nitrate in agricultural runoff can. **As a result, the state is moving towards requiring ammonia *and* nitrate removal from wastewater.**

Bacteria are currently used to remove ammonia and nitrate from wastewater, turning it into harmless nitrogen gas (N_2) in a two-step process (ammonia to nitrate with air addition, then nitrate to N_2 with "food" addition). Though less expensive than chemical treatment technologies, **this biological process is expensive, energy intensive, and requires a great deal of space and careful process control.**

Approximately 20 years ago a **novel type of bacteria was discovered that performed a process called anaerobic ammonia oxidation (or "anammox")**. In this process, "anammox" bacteria are able to **degrade ammonia directly to N_2 with only a small amount of air addition in smaller reactors for a much lower cost**. This process has the potential to greatly reduce the cost and energy intensity of ammonia removal at wastewater treatment plants while simultaneously improving surface water quality. Despite its significant promise, however, there are several problems with the anammox process: (1) anammox bacteria are notoriously slow growing and **a method of retaining them in the treatment reactor is needed**; and (2) **controlling air addition to optimize the anammox process is difficult**. As a result, the anammox process has yet to be implemented in the United States for municipal wastewater treatment. Given that each year 19 trillion gallons of wastewater are generated in North America (approximately 130 billion gallons in Minnesota alone), and approximately 3% of the total US electricity use is for wastewater treatment, **if the anammox process could be reliably used for nitrogen removal in municipal wastewater treatment plants, it would have an enormous impact on the cost and energy intensity of wastewater treatment in Minnesota, the US, and the world.**

We propose to develop a material that can preferentially attract and hold anammox bacteria where they are needed while easily controlling air addition. This will make nitrogen removal from wastewater **faster and cheaper.**

We will produce a plastic-like material that, through carefully designed surface properties, creates an ideal niche for anammox bacteria—concentrating their food sources (namely, ammonia) directly on the material surface to enable selective colonization. This material would be configured much like a jellyfish, containing strings of material in a bundle that could be deployed in existing wastewater treatment reactors. The anammox bacteria would grow on these strings and be held in the reactor. In addition, these strings of material would be constructed of hollow tubes with one end closed ("dead end"). The hollow space could be filled with air. The material would be engineered such that a highly controlled rate of air delivery would be achieved naturally through the material properties, without the need for an operator of the system to control the air addition externally.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: Develop materials that promote selective colonization of anammox bacteria on the material surface — Budget: $194,100

An essential component of material development entails achieving high surface concentrations of ammonia to create an environment naturally selective for the proliferation and retention of anammox bacteria. Materials with different degrees of "stickiness" will also be tested to determine how to best retain anammox bacteria on the surface without simultaneously retaining unwanted bacteria. Our investigations will initially be conducted with commercially available materials, the surface of which will be modified with charged particles (so called "zeolites"). Additional efforts will focus on ways to incorporate charged particles or other charged chemical groups into novel, but inexpensive materials. The goal will be to develop materials that are inexpensive and scalable while also maintaining a surface that is highly selective for anammox bacteria.

Outcome	Completion Date
1. *Modify commercially available materials with charged particles for ammonia concentration at the surface.*	*12/31/2017*
2. *Incorporate charged particles into novel materials for ammonia concentration at the surface.*	*12/31/2018*
3. *Develop novel materials containing charged chemical groups for ammonia concentration at the surface.*	*2/28/2019*
4. *Demonstrate anammox bacteria proliferation and retention on the various material surfaces.*	*6/30/2019*

Activity 2: Optimization of materials for easily controlled air addition/delivery to support the anammox process. **Budget: $282,000**

The anammox process requires that very small quantities of air be delivered to the organisms present. To accomplish this the materials developed in Activity 1 will be incorporated into a hollow tube configuration that will use the material properties themselves to control the air addition to the surrounding wastewater/microbial culture. We will explore the development of materials (*i.e*., material thickness, permeability to gas) and configurations (*i.e*., "jellyfish" bundle packing, spacing, number of hollow tubes present) that facilitate simple controlled air addition to the wastewater. This will facilitate the anammox process without the need for complex external (i.e., operator) process control.

Outcome	Completion Date
1. *Determine how material characteristics (thickness, diameter, material permeability to gas, material choice) control the diffusion of air across the tube wall to the wastewater.*	*6/30/2019*
2. *Optimize the bundle configuration for predictable and controlled air delivery.*	*1/31/2020*
3. *Demonstrate robust anammox activity in the absence of complex process control.*	*6/30/2020*

III. PROJECT STRATEGY

A. Project Team/Partners

The project team consists of the Principal Investigator (PI) Paige Novak (University of Minnesota) and co-PIs Santiago Romero-Vargas Castrillon (UMN), Marc Hillmyer (UMN), and Michael Tsapatsis (UMN). Novak will oversee the project and direct the testing of microbial colonization and determination of anammox activity; Tsapatsis and Romero-Vargas Castrillon, experts in material development, will focus on Activity 1; Hillmyer, an expert in material chemistry, will focus on Activity 2. The Metropolitan Wastewater Treatment Plant in St. Paul, MN will provide wastewater for the project. The results from this work will be directly applicable to wastewater treatment plants throughout the state. Novak has performed preliminary method development in her laboratory on the quantification of anammox bacteria and is currently growing anammox bacteria in her laboratory.

B. Project Impact and Long-Term Strategy

The proposed work fits into a larger research agenda centered at UMN focused on the development of new treatment technologies for water and wastewater. The proposed research complements current and prior research in this area. There are likely to be additional nitrogen removal requirements for wastewater treatment plants in the future. Current technology for the removal of nitrogen is energy and resource intensive. The proposed effort is focused on enabling inexpensive, low-energy nitrogen removal in the absence of complex process control.

C. Timeline Requirements

The proposed project will be completed in the allotted three-year period.

2017 Detailed Project Budget

Project Title: INNOVATIVE NITROGEN REMOVAL TECHNOLOGY TO PROTECT WATER QUALITY

IV. TOTAL ENRTF REQUEST BUDGET: 3 years

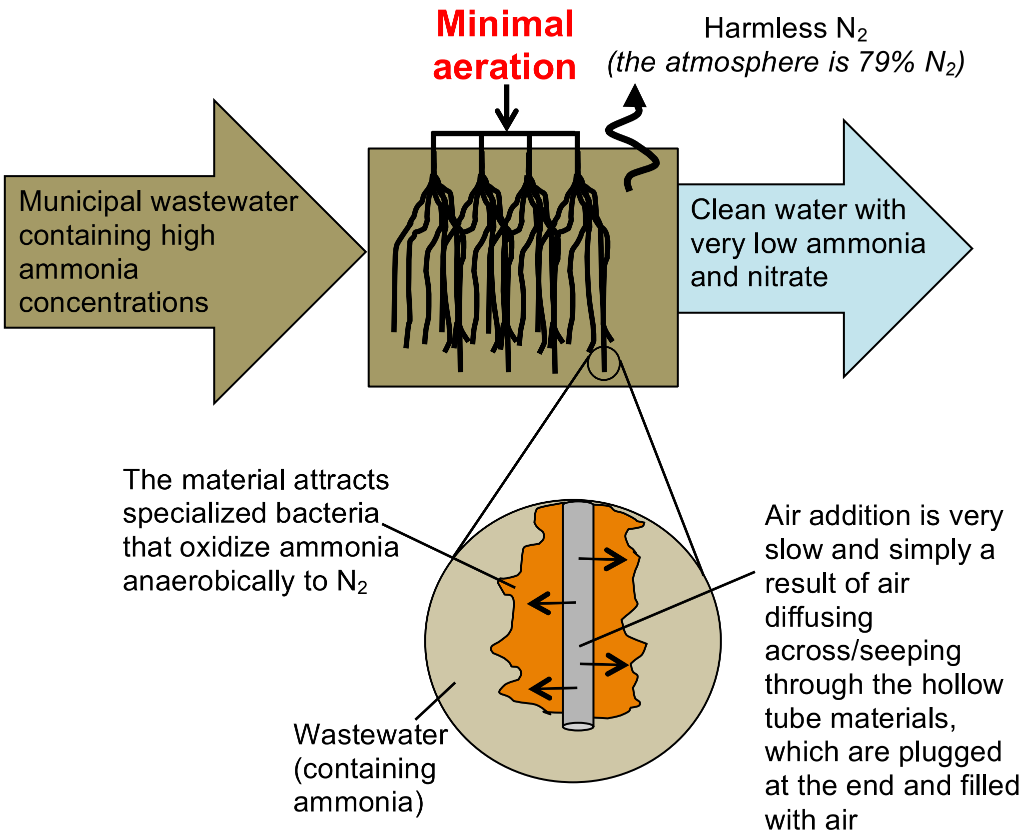
BUDGET ITEM	AMOUNT
Personnel:	
Novak (PI, 4% time per year for three years, salary 75% of cost, fringe benefits 25% of cost). Project supervision, provide guidance on the microbial aspects of the project (culturing, quantifying the organisms present on the materials produced, analysis of chemicals in wastewater).	$ 31,900
Romero Vargas Castrillon (PI, 6% time per year for three years, salary 75% of cost, fringe benefits 25% of cost). Project supervision, guidance on materials/chemical aspects of the project (polymer materials, modification of commercially available materials, construction of new materials containing charged particles).	$ 27,800
Tsapatsis (PI, 2% time per year for three years, salary 75% of cost, fringe benefits 25% of cost). Guidance on materials/chemical aspects of the project (polymer materials, modification of commercially available materials, construction of new materials containing charged particles).	$ 22,100
Note: Hillmyer will also provide guidance on the materials/chemical aspects of the project but does not need summer financial support. He will cost-share 4% effort to the project. See also "In-kind Services" below.	$ -
Graduate student (50% time per year for three years, 57% salary, 32% tuition, 11% fringe benefits). Conducting laboratory experiments and prototype testing.	$ 132,000
Postdoctoral researcher (100% time per year for three years, 83% salary, 17% fringe benefits). Developing novel materials for testing.	$ 181,600
Undergraduate student (13 weeks (i.e., summer), full time per year for three years). Assisting with routine wastewater analyses (nitrogen measurements) and laboratory experiments.	$ 15,600
Equipment/Tools/Supplies: Laboratory supplies including, but not limited to: chemicals for material synthesis; analysis needs such as standards, sample vials, columns and guard columns, supplies for culture-independent bacterial enumeration and identification; consumables such as gloves and solvents ($16,900/yr). Additional funds budgeted for equipment repair and maintenance ($6,000), shipping specialized anammox cultures if needed ($300); and laboratory services (sequencing for confirmation of organism identity, $6,000).	$ 63,000
Travel: Mileage charges to Metropolitan Council wastwater facilities and possibly outstate wastewater treatment plants for wastewater collection. Mileage will be reimbursed $0.55 per mile or current U of M compensation plan.	$ 2,100
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 476,100

V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period:	N/A	
Other State $ To Be Applied To Project During Project Period:	N/A	
In-kind Services To Be Applied To Project During Project Period: Novak, Hillmyer, and Tsapatsis will provide unpaid time to the project (including 2% cost-share for Novak and Tsapatsis and a total of 4% cost-share for Hillmyer). Because the project is overhead-free, laboratory space, electricity, and other overhead costs are provided in kind. The University of Minnesota overhead rate is 52%.	$ -	
Funding History:	N/A	
Remaining $ From Current ENRTF Appropriation:	N/A	

Innovative nitrogen removal technology to protect water quality

With the proposed technology, anaerobic ammonia oxidation is used, making ammonia degradation to N_2 faster and cheaper



Project Manager Qualifications and Organization Description

Dr. Paige Novak
Professor, Environmental Engineering, Department of Civil Engineering and Resident Fellow of the Institute on the Environment, University of Minnesota

B.S., Chemical Engineering, 1992, The University of Virginia, Charlottesville, VA.
M.S., Environmental Engineering, 1994, The University of Iowa, Iowa City, IA.
Ph.D., Environmental Engineering, 1997, The University of Iowa, Iowa City, IA.

Dr. Novak will be responsible for overall project coordination. She is an expert in applied environmental microbiology and has been studying biological nitrogen removal and anaerobic biological processes for over 20 years, wastewater treatment for over 10 years, and the use of hollow fibers for gas delivery for about 15 years. She has also performed recent research on anaerobic ammonia oxidation through a collaborative LCCMR-funded effort.

Dr. Santiago Romero Vargas Castrillon (University of Minnesota) is an expert in the development, characterization, and testing of advanced materials, including membrane materials and membrane-based processes for water purification and treatment.

Dr. Marc Hillmyer (University of Minnesota) is an expert on the synthesis of polymers and novel materials and has led a research group in this area for nearly 20 years. He also has expertise in using new and advanced membrane technologies and materials for resource recovery.

Dr. Michael Tsapatsis (University of Minnesota) is an expert on materials for separation and purification processes and the synthesis of charged particles as required for the proposed work.

Organization Description
The University of Minnesota is one of the largest, most comprehensive, and most prestigious public universities in the United States (http://www1.umn.edu/twincities/01_about.php). The laboratories and offices of the PI and co-PIs contain all of the necessary fixed and moveable equipment and facilities needed for the proposed studies.