Environment and Natural Resources Trust Fund (ENRTF) M.L. 2017 LCCMR Work Plan

Date of Submission: August 4, 2016

Date of Next Status Update Report: January 31, 2018

Date of Work Plan Approval:

Project Completion Date: June 30, 2020

Does this submission include an amendment request? __

PROJECT TITLE: Innovative Nitrogen Removal Technology to Protect Water Quality

Project Manager: Paige J. Novak

Organization: University of Minnesota

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City/State/Zip Code: 55455

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Location: Minneapolis, Minnesota 55455

Total ENRTF Project Budget:		
	ENRTF Appropriation:	**$450,000**
	Amount Spent:	**$0**
	Balance:	**$450,000**

Legal Citation: M.L. 2017, Chp. xx, Sec. xx, Subd. xx

Appropriation Language:

I. PROJECT TITLE:
Innovative Nitrogen Removal Technology to Protect Water Quality

II. PROJECT STATEMENT:
As we exceed planetary boundaries on nutrients, regulatory directives to remove total nitrogen from wastewater are increasing. Traditionally, bacteria are used to remove total nitrogen from wastewater in a two-step process. Although reliable, this process is energy- and in some cases, material-intensive and also requires significant land as a result of its large footprint. Fortunately, viable new processes that facilitate the transformation of influent ammonium (NH_4^+) to harmless nitrogen gas (N_2) while minimizing energy use and/or addition of other chemicals, and in some cases plant footprint, are increasing in number. Anaerobic ammonia oxidation (anammox) is one of the most promising emerging nitrogen removal technologies. Anammox microorganisms anaerobically convert 1-to-1 ratios of NH_4^+ and nitrite (NO_2^-) to N_2 in a single step without excessive oxygen input. Some oxygen is required to generate NO_2^-, but the aeration, and therefore energy requirements are much lower than that of traditional treatment.

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 retain anammox bacteria where they are needed while easily controlling air addition. This will make nitrogen removal from wastewater faster and cheaper. The specific goals of the project are to:

- Develop a material that concentrates the food source of anammox bacteria, enabling selective colonization of these bacteria on the material,
- Develop a material that easily controls the air addition to the system via the material properties,
- Optimize the design of technology (spacing, amount of material, etc.), and
- Test the system with municipal wastewater.

The envisioned system will operate for long time periods and provide improved nitrogen removal from wastewater with much lower energy usage. Patent protection will be sought by the University of Minnesota for the technology.

III. OVERALL PROJECT STATUS UPDATES:

Project Status as of January 31, 2018:

Project Status as of July 31, 2018:

Project Status as of January 31, 2019:

Project Status as of July 31, 2019:

Project Status as of January 31, 2020:

Overall Project Outcomes and Results:

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Develop materials that promote selective colonization of anammox bacteria at their surface

Description:
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 inorganic 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.

Summary Budget Information for Activity 1:

ENRTF Budget:	**$ 181,000**
Amount Spent:	**$ 0**
Balance:	**$ 181,000**

Outcome	**Completion Date**
1. *Modify commercially available materials with charged particles for ammonia concentration at the surface*	12/31/17
2. *Incorporate charged particles into novel materials for ammonia concentration at the surface*	12/31/18
3. *Develop novel materials containing charged chemical groups for ammonia concentration at the surface*	2/28/19
4. *Demonstrate anammox bacteria proliferation and retention on the various material surfaces*	6/30/19

Activity Status as of January 31, 2018:

Activity Status as of July 31, 2018:

Activity Status as of January 31, 2019:

Activity Status as of July 31, 2019:

Activity Status as of January 31, 2020:

Final Report Summary:

ACTIVITY 2: Optimization of materials for easily controlled air addition/delivery to support the anammox process

Description:
The anammox process requires that very small quantities of air be delivered to the organisms present. To accomplish this, materials will be incorporated into a hollow tube configuration, using 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. Eventually, the material used will combine the attributes of those materials developed in Activity 1

to attract and retain the anammox bacteria with those developed in Activity 2 to easily modulate oxygen addition to the system. This will facilitate the anammox process without the need for complex external (i.e., operator) process control.

Summary Budget Information for Activity 2: **ENRTF Budget: $ 269,000**
Amount Spent: $ 0
Balance: $ 269,000

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*	6/30/19
2. *Optimize the bundle configuration for predictable and controlled air delivery*	1/31/20
3. *Demonstrate robust anammox activity in the absence of complex process control*	6/30/20

Activity Status as of January 31, 2018:

Activity Status as of July 31, 2018:

Activity Status as of January 31, 2019:

Activity Status as of July 31, 2019:

Activity Status as of January 31, 2020:

Final Report Summary:

V. DISSEMINATION:

Description:
The target audience for results from this research will be professionals in the area of wastewater treatment and industry. Specific targets will be industries such as Dow Chemical/Filmtec and GE Water, environmental engineers and scientists in academia, industry, state/local government and agencies such as the MDA and MPCA, and environmental consultants. Results will be disseminated through scholarly publications in peer-reviewed journals such as *Environmental Science and Technology* and the *Journal of Membrane Science.* Results from the research project will also be presented at regional conferences such as the *Conference on the Environment*. Results will be used to further scale up this technology and implement it for the treatment of wastewater.

We plan to file an Intellectual Property Disclosure with the Office of Technology Commercialization at the University of Minnesota on the proposed technology. If the University of Minnesota pursues patent protection, this could lead to potential income for the state. Therefore, information contained in the Research Addendum is confidential.

Status as of January 31, 2018:

Status as of July 31, 2018:

Status as of January 31, 2019:

Status as of July 31, 2019:

Status as of January 31, 2020:

Final Report Summary:

VI. PROJECT BUDGET SUMMARY:

A. Preliminary ENRTF Budget Overview:

Budget Category	$ Amount	Overview Explanation
Personnel:	$385,000	Novak (PI) ($31,900), Romero-Vargas Castrillon (co-PI) ($27,800), and Tsapatsis (co-PI) ($22,200) budgeted for 4, 6, and 2% time per year for three years, for Novak, Romero-Vargas Castrillon, and Tsapatsis, respectively, salary 75% of cost, fringe benefits 25% of cost. Co-PI Hillmyer will not take salary on the project. PI and co-PIs will provide project supervision, guidance on the experimental aspects of the project along with guidance on data analysis. A graduate student researcher ($132,000), postdoctoral researcher ($162,100), and undergraduate researcher ($9,000) are also budgeted for three years (72% salary, 14% tuition (for graduate student only), 14% fringe benefits). The students and postdoctoral researcher will perform laboratory experiments.
Equipment/Tools/Supplies:	$63,000	Laboratory supplies include, but not limited to: chemicals for membrane construction, chemicals for bacterial culture, gas tanks for the air supply to the membrane flow, analysis needs such as standards, gas tanks, needles, and septa, supplies for bacterial enumeration and identification, and consumables such as gloves and solvents ($17,000/yr, for a total of $51,000). Additional funds are budgeted for equipment repair and maintenance ($6,000) and laboratory services for microbial quantification and identification ($6,000).
Travel Expenses in MN:	$2,000	Mileage charges to Metropolitan Council wastewater facilities for wastewater collection to feed reactors. Mileage will be reimbursed $0.55 per mile or current U of M compensation plan.
TOTAL ENRTF BUDGET:	**$450,000**	

Explanation of Use of Classified Staff: N/A

Explanation of Capital Expenditures Greater Than $5,000: N/A

Total Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation:
Novak, Romero-Vargas Castrillon, and Tsapatsis will represent 0.04, 0.06, and 0.02 FTE per year, respectively (for 0.12, 0.18, and 0.06 FTE each over the entire 3-year project period). Half of a graduate student researcher (for 1.5 FTE over the entire 3-year project period), one postdoctoral researcher (for 3 FTE over the entire 3-year project period), and a 14% of an undergraduate researcher (for 0.42 FTE over the entire 3-year project period) will be employed with this appropriation per year. This results in a total of 5.28 FTE for the total project.

Total Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation:
None.

B. Other Funds: N/A

VII. PROJECT STRATEGY:

A. Project Partners:
Partners receiving ENRTF funding

- *Paige Novak, Professor, University of Minnesota, $31,900, Role: Principal Investigator. Novak will oversee the project and direct the testing of microbial colonization and determination of anammox activity.*
- *Santiago Romero-Vargas Castrillon, Assistant Professor, University of Minnesota, $27,800, Role: Co-principal Investigator. Romero-Vargas Castrillon is an expert in material development and will focus on Activity 1.*
- *Michael Tsapatsis, Professor, University of Minnesota, $22,000, Role: Co-principal Investigator. Tsapatsis is also an expert in material development and will work on both Activity 1 and 2.*

Partners NOT receiving ENRTF funding

- *Marc Hillmyer, Professor, University of Minnesota, Role: Co-principal Investigator. Hillmyer is an expert in material chemistry and will focus on Activity 2.*
- *The Metropolitan Wastewater Treatment Plant in St. Paul, MN will provide wastewater for the project.*

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. Funding History: N/A

VIII. REPORTING REQUIREMENTS:

- **The project is for 3 years, will begin on 07/01/17, and end on 06/30/20.**
- **Periodic project status update reports will be submitted January 31 and July 31 of each year.**
- **A final report and associated products will be submitted between June 30 and August 15, 2020**.

IX. VISUAL COMPONENT or MAP(S): N/A

X. FEE TITLE ACQUISITION/CONSERVATION EASEMENT/RESTORATION REQUIREMENTS: N/A

Environment and Natural Resources Trust Fund
M.L. 2017 Project Budget

Project Title: Innovative Nitrogen Removal Technology to Protect Water Quality
Legal Citation:
Project Manager: Paige Novak
Organization: University of Minnesota
M.L. 2017 ENRTF Appropriation: $450,000
Project Length and Completion Date: 3 Years, June 30, 2020
Date of Report: 10/10/16

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget	Amount Spent	Activity 1 Balance	Activity 2 Budget	Amount Spent	Activity 2 Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	Develop materials that promote selective colonization of anammox bacteria at their surface			Optimization of materials for easily controlled air addition/delivery to support the anammox process				
Personnel (Wages and Benefits) Overall	$153,400	$0	$153,400	$231,600	$0	$231,600	$385,000	$385,000
Paige Novak (PI, 4% time per year for three years, salary 75% of cost, fringe benefits 25% of cost) Est. $31,900								
Santiago Romero-Vargas Castrillon (co-PI, 6% time per year for three years, salary 75% of cost, fringe benefits 25% of cost)Est. $27,800								
Michael Tsapatsis (co-PI, 2% time per year for three years, salary 75% of cost, fringe benefits 25% of cost) Est. $22,200								
Graduate Research Assistant (50% time per year for three years, 57% salary, 33% tuition, 10% fringe benefits) Est. $132,000								
Undergraduate Research Assistant (approximately 300 hours per year for three years)Est. $9,000								
Postdoctoral Researcher (100% time per year for three years, 82% salary, 18% fringe benefits)Est. $162,100								
Equipment/Tools/Supplies	$31,500	$0	$31,500	$31,500	$0	$31,500	$63,000	$63,000

Laboratory supplies include, but not limited to: chemicals for membrane construction, chemicals for bacterial culture, gas tanks for the air supply to the membrane flow, analysis needs such as standards, gas tanks, needles, and septa, supplies for bacterial enumeration and identification, and consumables such as gloves and solvents ($17,000/yr, for a total of $51,000). Additional funds are budgeted for equipment repair and maintenance ($6,000) and laboratory services for microbial quantification and identification ($6,000).								
Travel expenses in Minnesota	$1,000	$0	$1,000	$1,000	$0	$1,000	$2,000	$2,000
Mileage charges to Metropolitan Council wastewater facilities for wastewater collection to feed reactors. Mileage will be reimbursed $0.55 per mile or current U of M compensation plan.								
COLUMN TOTAL	**$185,900**	**$0**	**$185,900**	**$264,100**	**$0**	**$264,100**	**$450,000**	**$450,000**

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