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

**Project Title:** **ENRTF ID: 050-B**

Phosphorus/Nitrate Recapture through Biofilms for Agricultural Application

**Category:** B. Water Resources

**Total Project Budget: $** 773,000

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

**Summary:**

We propose to build, operate and demonstrate the effectiveness of modular algal biofilm reactor systems for on-site treatment of impaired waters, removing phosphorus and nitrates to restore these waters.

**Name:** Brett Barney

**Sponsoring Organization:** U of MN

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St. Paul MN 55108

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**Web Address**

**Location**

**Region:** Central, Metro

**County Name:** Hennepin, Ramsey, Stevens

**City / Township:** Morris, Minneapolis, Saint Paul

**Alternate Text for Visual:**

This graphic provides a conceptual drawing of the reactor systems and how these will be utilized in this project

| | | | |
|---|---|---|---|
| _____ Funding Priorities | _____ Multiple Benefits | _____ Outcomes | _____ Knowledge Base |
| _____ Extent of Impact | _____ Innovation | _____ Scientific/Tech Basis | _____ Urgency |
| _____ Capacity Readiness | _____ Leverage | _____ TOTAL | _____% |

**PROJECT TITLE: Phosphorus/Nitrate Recapture through Biofilms for Agricultural Application**

## I. PROJECT STATEMENT

**CONCEPT** – We propose to build, operate and demonstrate the effectiveness of modular algal biofilm reactor systems for on-site treatment of impaired waters. The biofilms will act as a nutrient sponge, drawing nitrate and phosphorus from contaminated water. The process will also sequester atmospheric carbon dioxide in the process. The final algal biomass will be applied back to agricultural fields as an alternative fertilizer to return these key nutrients to the soil in a state that is less prone to migration back into groundwater. The final outcome of this project will be the successful demonstration of this technology on several strategically selected bodies of water across the state. Key points that this project will address are provided below;

- Excessive application of fertilizers and other industrial chemicals results in an imbalance to the natural ecosystem and leads to eutrophication of our lakes and rivers, resulting in unsightly lakes and streams, odors and other public and ecological health problems.
- Agricultural nutrient runoff represents an economic loss to farmers who pay added costs to apply additional fertilizers to meet the needs of their crops.
- Algal biofilms offer a simple solution to capture key nutrients such as nitrates and phosphorus while also sequestering carbon dioxide and requiring only sunlight to drive this process.
- Biofilms can be easily and continually harvested and applied back to soils, where sequestered nitrogen, phosphorus and carbon will be released through the natural "slow release" process of biodegradation.
- Systems will be designed to be robust, resistant, autonomous, low cost and modular, so that they can be scaled to meet the requirements of each individual environment where they will be operated.

Our laboratories have worked with various algal growth systems for over a decade on projects that include bioreactor design and automation at both laboratory and commercial scales. A key facet of our work includes outdoor testing facilities and greenhouse systems where large-scale cultures can be managed for extended periods of time. The system includes a small solar panel system to provide the energy needed to operate the drum reactor system, and will be constructed in a manner that is easily adapted to operation within a standing water body or by diverting the flow of a small stream or runoff ditch through the bioreactor system.

## II. PROJECT ACTIVITIES AND OUTCOMES

**Activity 1: Design and Construction of Modular Prototype Bioreactors** **Budget: $390,000**

The aim of this first activity is to construct several working prototype inverted-drum-biofilm reactors (see graphical image for a simple conceptual schematic). The reactor will be constructed in a manner that is ideal for achieving maximum growth of nutrient accumulating algae. As part of this project, senior engineering students will assist in various design strategies as part of a Capstone Design course, encouraging competition to evaluate potential improvements and deliver multiple prototypes (tapping the resources of student interest from within the Bioproducts and Biosystems Engineering (BBE) Department. Later modifications will improve automation and allow the reactor to function autonomously based on system performance. Laboratory and greenhouse studies will allow us to optimize the system in a controlled environment to monitor performance while outdoor demonstration facilities at the West Central Research and Outreach Center (WCROC) will allow us to prepare the system for outdoor demonstration goals. All aspects of this activity will include educational opportunities for design improvement and concepts so that senior engineering students can engage in the project to construct prototypes and test feasibility in a range of environments.

| Outcome | Completion Date |
|---|---|
| 1. *Complete Initial Prototype Construction for Testing in a Greenhouse Space* | *Dec 1st, 2017* |
| 2. *Incorporate Enhancements and Modifications to Complete Modular Autonomous Prototype for Environmental Testing* | *June 1st, 2019* |

**Activity 2: Studies of Bioreactor Performance** **Budget: $383,000**

The goal of the second activity will be to determine optimal operational parameters to achieve the ultimate goal of the system; *rapid phosphorus and nitrate uptake and accumulation into biomass that can be easily collected for field application as a soil amendment*. The reactor prototypes (described in Activity 1) will be operated in a greenhouse setting at the University of Minnesota starting within 6 months of project initiation, and target water bodies will be selected. Continuous operation will allow testing of performance criteria, including the ability of the reactor to rapidly clear phosphorus and nitrates from solution and the composition of the resulting biofertilizer for soil amendment. Additionally, the collection of data will allow us to model the potential of individual systems which could then be either scaled up or replicated to meet the requirements for a specific application. The second component of this testing will be the outdoor performance criteria. Since this testing will be limited to certain times of the year, it will be done following the initial assessment in the greenhouse, which will allow us to establish benchmark parameters in a controlled environment.

| Outcome | Completion Date |
|---|---|
| 1. *Collect, Isolate and Identify Indigenous Strains of Rapid Growth Algae from Target Water Bodies in Minnesota and Collect Representative Water Samples from Impaired Water Sources Across the State to Optimize Strain Production in the Natural Environment* | *Jan 31st, 2019* |
| 2. *Complete Initial Laboratory (Greenhouse) Studies of Prototype 1 Performance* | *May 31st, 2020* |
| 3. *Test the Potential of Field Study Grown Algae Strains as a Suitable Soil Amendment and Fertilizer Alternative* | *Jan 1st, 2020* |

## III. PROJECT STRATEGY

### A. Project Team/Partners

The project will include Professors Brett Barney and Robert Gardner from the Department of Bioproducts and Biosystems Engineering (BBE) at the University of Minnesota (Twin Cities) and the West Central Research and Outreach Center (WCROC) in Morris, Minnesota. Additional participants include several full time students and scientists and an extensive number of senior engineering students from the BBE department who will be involved in the project as part of required coursework, taking advantage of shared interests and a need for interesting and challenging capstone design project ideas.

### B. Project Impact and Long-Term Strategy

Algae are often touted as a next-generation energy crop based on the potential to produce oils which can be converted to a product similar to what is obtained from soybean oil to make biodiesel. Algae have been used for many decades in a range of wastewater treatment systems. Algal wastewater systems have suffered in more recent years as it has been realized that unless the algae are harvested, their release to the environment following sewage treatment will result in the eventual loss of phosphorus and other nutrients back to the ecosystem. The requested funding would cover the expenses of prototype design and testing. We envision an final design that would utilize solar energy to maneuver autonomous floating reactors across targeted bodies of water, and then recall the reactors once biomass is maximized. The autonomous design would allow these to be operated with little effort or required energy inputs, while also having a minimal impact on the remaining ecosystem. Similar designs could operate within small streams or drainage ditches in the field by diverting water to a series of reactors.

### C. Timeline Requirements

This project has a proposed timeline of three years. The duration of the project has been carefully considered based on past experience developing and then testing numerous bioreactor prototypes and performing full characterizations of the performance of these systems.

## 2017 Detailed Project Budget

**Project Title: Phosphorus/Nitrate Recapture through Biofilms for Agricultural Application**

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

| BUDGET ITEM | AMOUNT | |
|---|---|---|
| **Personnel:** | $ | 568,000 |
| Brett Barney, Project Manager (75% salary, 25% benefits), Associate Professor, 9 Month Appointment, Summer Salary; 10% FTE for 3 years | $ 49,830 | |
| Rob Gardner, Co-PI (75% salary, 25% benefits), Assistant Professor, 9 month Appointment, Summer Salary; 10% FTE for 3 years | $ 44,818 | |
| Postdoctoral Microbiologist or Biological Engineer, Project Management (82% salary, 18% benefits); 50% FTE for 3 years | $ 83,475 | |
| Junior Scientist, Prototype Testing and Laboratory Experiment Data Analysis (78% Salary, 22% Benefits); 50% FTE for 3 years | $ 68,750 | |
| 2 Graduate Research Assistant, Laboratory Experiment Data Analysis (57% salary, 43% benefits); 50% FTE for 3 years each | $ 271,199 | |
| 3 Undergraduate Technicians, Laboratory and Field Data Collection (100% salary, 0% benefits); 10% FTE for 3 years (generally rotating 1 year appointments) | $ 49,928 | |
| **Professional/Technical/Service Contracts:** | $ | 35,000 |
| DNA sequencing analysis for identification of isolated strains and to monitor strain growth in bioreactors. Locally sourced through either the University of Minnesota Sequencing Center or Local Companies, or out for bid. | $ 10,000 | |
| Assistance by qualified individuals to make modifications and install prototype reactor systems to targeted bodies of water at the West Central Research and Outreach Center. | $ 25,000 | |
| **Equipment/Tools/Supplies:** | $ | 167,000 |
| Laboratory Supplies: General laboratory chemicals, media, kits and reagents for performing routine analytical procedures, including analysis of phosphorus and nitrate and for growing and maintaining strains within the laboratory for the duration of the project. (Based on historical costs of approximately $1500 a month) | $ 54,000 | |
| Protoype Materials and Supplies: Various components to construct prototype bioreactor systems, including various control elements, solar collection panels and motors and battery storage and communications equipment, and glassblowing services at the University of Minnesota. Based on previous project costs and proposed costs from initial design. It is anticipated that 5 or 6 prototype designs will be constructed at $15,000 per prototype. | $ 85,000 | |
| Ion Chromatography System: This piece of equipment is essential to perform routine monitoring of phosphorus and nitrogen compounds that accumulate in water. A similar system was utilized for many years at a previous institution, and would be instrumental to the success of this project. This piece of equipment will continue to be used through the duration of the project and through its useful lifetime. | $ 25,000 | |
| Publication Charges: Costs associated with the broad dissemination of research findings in journals that are largely accessible to the broader public (Estimated 3 at $1000) | $ 3,000 | |
| **Travel:** | $ | 3,000 |
| Travel by University of Minnesota (St. Paul) participants to West Central Research and Outreach Center (WCROC) for sample collection and to manage potential field studies at experiment stations at target water bodies throughout the state. | $ 3,000 | |
| **TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =** | $ | 773,000 |

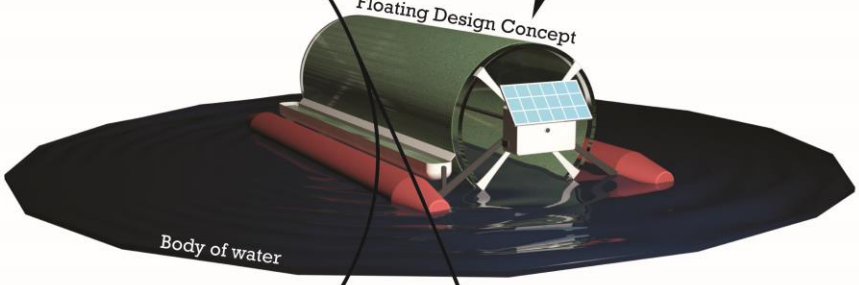
**V. OTHER FUNDS**

| 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:** *Unpaid Indirect Costs* | $ 362,003 | |
| **Funding History:** | $ - | |
| ~$500,000 - Defense Advanced Research Projects Agency (DARPA) as part of a subcontract through General Atomics. This project was aimed at large scale production of algae for biodiesel production and involved the construction and operation of various bioreactors and open raceway ponds. The PI | $ 500,000 | Completed |
| $150,000 - IREE Career Award: Microbial Communities for Enhanced Biofuel Feedstock Production; This proposal funded initial studies into beneficial nitrogen-fixing bacteria in combination with certain algae species. | $ 150,000 | Completed |
| **Remaining $ From Current ENRTF Appropriation:** | $ - | *Not Applicable* |

Phosphorous/Nitrate Recapture through Biofilms for Agricultural Application

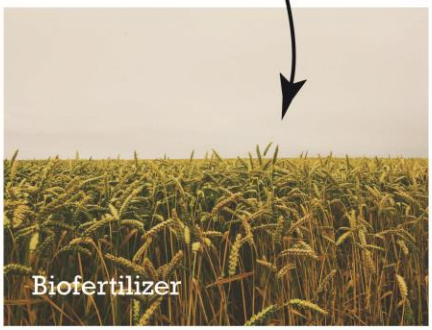

Eutrophied Water

Carbon Dioxide



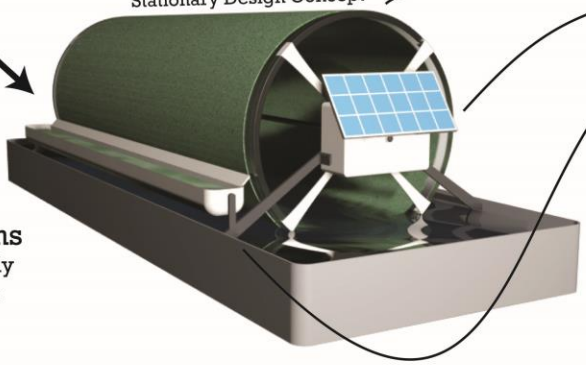

Clean Water

Farm Application




Ditch / Runoff Water

Stationary Design Concept



Reactor Components

Biomass

Solar Panel and Motor

Collection Trough and Scraper

Dimensions
Approximately
6 foot x 3 foot

Discharged to River

**Project Manager Qualifications**

**Brett Barney, Project Manager**

**Education:**

Ph.D. Biochemistry, Arizona State University, 2003
B.S. Professional Chemistry, Utah State University 1993

**Work and Research Experience:**

| | |
|---|---|
| 2015 – Present | Associate Professor, Bioproducts and Biosystems Engineering (UMN) |
| 2010 – Present | Faculty Member, BioTechnology Institute and Microbial and Plant Genomics Institute (UMN) |
| 2009 – 2015 | Assistant Professor, Bioproducts and Biosystems Engineering (UMN) |
| 2003 – 2009 | Research Assistant Professor and USDA Postdoctoral Fellow (USU) |
| 1999 – 2003 | Research Assistant and NSF Fellow, Department of Chemistry and Biochemistry (ASU) |
| 1993 – 1999 | Fiber Laboratory Manager, Research Chemist, Senior Laboratory Technician and Associate Chemist, Fresenius Medical Care, Ogden, Utah |
| 1991 – 1993 | Student Research Technician, Utah Water Research Laboratory (USU) |

**Robert Gardner, co-Project Manager, Assistant Professor, Bioproducts and Biosystems Engineering (UMN)**

Rob Gardner brings over 10 years of expertise in algae as a source of food, feed, biofertilizers, biofuels and specialty chemicals and is located at the West Central Research and Outreach Center at the University of Minnesota in Morris.

Dr. Barney's laboratory is focused on biological fertilizers (biofertilizers) for minimizing costs associated with biofuels and agriculture. Dr. Barney has more than 25 years of experience in both basic and applied research in both academia and industry, including experience managing projects and laboratories in a range of settings. Previous research funding has come from the National Science Foundation (NSF), the United States Department of Agriculture (USDA), the United States Department of Energy (DOE), the Defense Advanced Research Projects Agency (DARPA), Minnesota's Discover, Research and InnoVation Economy (MnDRIVE) and the Initiative for Renewable Energy and the Environment (IREE).

The Barney laboratory is housed in the Cargill building for Microbial and Plant Genomics at the University of Minnesota. The Cargill building was designed with the intention to promote interdisciplinary collaborations and provide a shared lab space for each floor, which facilitates flexible group sizes. This large laboratory space is designed around a shared communal format, with various rooms available for utilization for specific experiments. The laboratory contains the primary equipment to perform this research project, including facilities to cultivate various bacteria, autoclaves, analytical instrumentation for analysis (gas chromatography, spectrophotometers, and balances), thermocyclers for PCR reactions, centrifuges, electrophoresis equipment and various incubators. Additional facilities include the Biotechnology Resource Center, the Genomic Sequencing Center and a broad range of additional analytical laboratories which are available as pay services.

**Organization Description**

Dr. Brett Barney (PI) has been a professor with the Department of Bioproducts and Biosystems Engineering at the University of Minnesota since 2009. The Bioproducts and Biosystems Engineering Department serves as a core department combining Agricultural Engineering, Biological Engineering and Environmental and Ecological Engineering. The University of Minnesota provides a range of facilities and sufficient laboratory space to perform each of the activities described in this proposal. Additionally, controlled environments including greenhouse space sufficient for this work is conveniently located next door to Dr. Barney's laboratory space. UMN Sponsored Projects Administration (SPA) is the entity authorized by the Board of Regents to manage project agreements with the LCCMR program.