Environment and Natural Resources Trust Fund
2012-2013 Request for Proposals (RFP)

Project Title: **ENRTF ID:** **140-I**

Membranes for Wastewater-Generated Hydrogen and Clean Water

Topic Area: I. Water Resources

Total Project Budget: $ 246000

Proposed Project Time Period for the Funding Requested: 3 yrs, July 2013 - June 2016

Other Non-State Funds: $ 0

Summary:

Develop, optimize and test membranes (thin film polymers embedded with selected bacteria) to generate clean water and valuable energy in the form of hydrogen from wastewater.

Name: Paige Novak

Sponsoring Organization: U of MN

Address: 122 Civil Engineering Bldg, 500 Pillsbury Dr SE
Minneapolis MN 55455

Telephone Number: (612) 626-9846

Email novak010@umn.edu

Web Address http://personal.ce.umn.edu/~novak/

Location

Region: Statewide

County Name: Statewide

City / Township:

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

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

_____ Capacity Readiness _____ Leverage _____ Employment _______ TOTAL ______%

PROJECT TITLE: Membranes for wastewater-generated hydrogen and clean water

I. PROJECT STATEMENT

In our current energy climate, we can no longer afford to think of anything as merely a waste stream. As a result, researchers have been working to develop technologies to extract energy in usable forms from wastewater, including microbial fuel cells and algal-based biofuel production. **We propose to develop another technology that can be used to extract energy from wastewater:** a polymer membrane (a plastic film typically used for gas or liquid separations) containing bacteria that generate hydrogen while cleaning the wastewater. By putting the bacteria in the membrane, we can make sure that they are present in the numbers necessary to generate hydrogen, they are protected, and their growth is encouraged. The system will also contain a mesh of small, permeable tubes ("fibers") for efficient hydrogen collection. This should lead to sustained maximal hydrogen production from wastewater for use on site (e.g., in a fuel cell). After the hydrogen production step, it will also be possible to add a methane production step, providing a second source of high energy per mass fuel from the waste stream. The modular design envisioned for such a system—composite membrane racks fitted with gas collection manifolds—should enable use of the system at any scale and for any liquid waste stream containing biodegradable substrates (primarily for municipal sanitary waste, but also agricultural and industrial wastes). **This project adapts proven technologies for a new application, and we therefore feel it is positioned to succeed.** The goals of the project are to:

- Test the proposed system at the laboratory scale (about 1 liter),
- Optimize the design of the bacteria-embedded membranes, and
- Build and test a pilot-scale module at a municipal wastewater treatment plant.

The envisioned system will operate for long time periods and provide improved wastewater treatment coupled with fuel generation. The system will also reduce the need for aeration during wastewater treatment. Because aeration typically accounts for over 50% of the energy used for wastewater treatment, any technology that decreases aeration needs could also save significant energy.

II. DESCRIPTION OF PROJECT ACTIVITIES

Activity 1: Protoype development, laboratory testing, and design optimization Budget: $162,000

Experiments will be performed with prototype membranes developed in the laboratory. Films containing the selected bacteria will be cast. We have successfully used this technique for the long-term (>10 months) immobilization of an aerobic pollutant-degrading bacterium and have experience modeling the diffusion of chemicals through these systems. The bacteria-containing film will be coupled with the gas collection fibers. We have previously used such fibers for hydrogen delivery, and they should function similarly for hydrogen collection. Parameters to be optimized in the prototype development include choice of bacterial species, gas collection fiber material and spacing, and wastewater contact time with the membrane system. Different configurations (including multiple hydrogen generation and collection layers, called "sandwich layers") will be tested.

The open ends of the gas collection fibers will be connected into a gas flow-through system containing nitrogen. The flowing nitrogen gas is used to collect the hydrogen gas. The gas line will be equipped with ports for collecting samples at the gas inlet and exit of the membrane module to measure hydrogen, thereby quantifying hydrogen production. The nitrogen gas flow will be optimized to ensure that flow rates are high enough to draw hydrogen out (which is critical to maintaining hydrogen production) but low enough to minimize eventual gas use in scale-up. Initial lab experiments will be use synthetic (sterile) wastewater. Hydrogen concentrations in the inlet and exit gas will be measured as a function of time.

Outcome	Completion Date
1. Initial membranes constructed and tested	1/31/14
2. Membranes containing a variety of hollow fiber materials constructed and tested	6/30/14
3. Membranes containing a variety of bacteria species constructed and tested	1/31/15
4. Membranes optimized with respect to fiber spacing, sandwich layers, and gas flow	6/30/15

Activity 2: Pilot scale testing **Budget: $84,000**

Optimized prototypes will first be tested in the laboratory (Phase I) using wastewater collected from the secondary influent stream at the Metropolitan Wastewater Treatment Plant (Metro, St. Paul, MN). Pilot scale systems (0.5 m×1 m) will be produced at the University of Minnesota for deployment at the Metro Plant (and other sites as time permits) for Phase II testing. The system will be fed nitrogen gas from a cylinder and an on-line hydrogen gas analyzer will be used to monitor hydrogen production. The hydrogen analyzer will be connected to an automated data acquisition system to enable continuous data collection regarding hydrogen production. A gas flow meter will also be used to monitor gas flow rate (and hence, the mass of hydrogen generated with time). The system will run for a period of at least 2 months at the Metro Plant, with automated collection of hydrogen concentration and flow rate data. After the pilot test is complete, the module will be tested for leaks and other problems. The membrane will be broken down and the microbial community will be evaluated using techniques to measure the bacterial DNA present to evaluate the numbers/survival of the encapsulated bacteria after the pilot deployment period. This will verify that the system is sustainable for long-term operation.

Outcome	Completion Date
1. Testing of membranes in the laboratory with real (non-sterile) wastewater completed	1/31/16
2. Testing of the scaled-up membranes and gas manifold system at the Metro Wastewater Treatment Plant	6/30/16

III. PROJECT STRATEGY

A. Project Team/Partners

The project team consists of the Principal Investigator (PI) Paige Novak (University of Minnesota) and the co-PI William Arnold (UMN). Novak (PI) will provide guidance on the microbial aspects of the project (culturing, immobilization, and analysis of the organisms, analysis of wastewater) and also has substantial experience using hollow fibers for gas delivery. Arnold will provide guidance on the abiotic aspects of the project (polymer materials, hydrogen detection, modeling). MCES General Manger Bill Moore has offered support in providing plant access for the scaled up system.

B. Timeline Requirements

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

C. Long-Term Strategy and Future Funding Needs

Arnold has substantial experience in the development and modeling of membranes for chemical containment. Novak has substantial experience with anaerobic bacteria and wastewater treatment. Novak and Arnold have collaborated on the development of membranes containing immobilized bacteria for the containment and treatment of sediment contaminants. The proposed hydrogen-producing membrane concept is a logical extension of this exciting field, and our team is well equipped to perform this research. We plan to move the technology from the laboratory and proof-of-concept stage to the field. In the short term, optimizing hydrogen recovery from the fermentation of wastewater will be achieved. We believe this scalable technology will be able to recover hydrogen from any biodegradable, liquid waste stream. We expect the research to lead to a patentable technology. The long-term potential of this technology may reach well beyond the application targeted in this work.

2012-2013 Detailed Project Budget

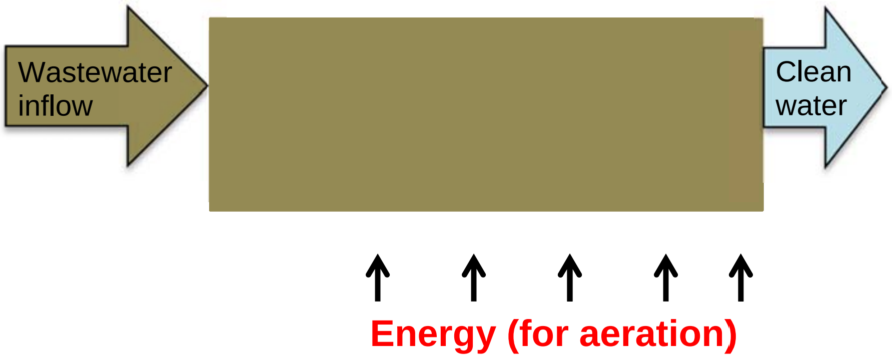
IV. TOTAL ENRTF REQUEST BUDGET: 3 years

11	AMOUNT
Personnel: Novak (PI, 6% time per year for three years, salary 73.5% of cost, fringe benefits 26.5% of cost). Project supervision, provide guidance on the microbial aspects of the project (culturing, immobilizing, and enumerating the organisms, analysis of wastewater), and module design.	$ 39,800
Personnel: Arnold (PI, 6% time per year for three years, salary 73.5% of cost, fringe benefits 26.5% of cost). Project supervision, guidance on the abiotic aspects of the project (polymer materials, hydrogen detection, modeling) and module/prototype design.	$ 42,900
Personnel: Graduate student (50% time per year for three years, 56% salary, 33% tuition, 11% fringe benefits). Conducting laboratory experiments and prototype testing	$ 128,300
Equipment/Tools/Supplies: Laboratory supplies including, but not limited to: chemicals for membrane construction, bacterial cultures, gas tanks for the membrane flow, hollow fibers; analysis needs such as standards, gas tanks, needles, septa, supplies for bacterial enumeration and identification; consumables such as gloves and solvents ($7,300/yr). Additional funds budgeted for equipment repair and maintenance ($6,000), automated data aquisistion system and software for data acquisition ($6,100)	$ 34,000
Travel: Mileage charges to Metropolitan Council wastwater facilities and outstate wastewater treatment plants for sample collection and monitoring of Phase II pilot system. Mileage will be reimbursed $0.55 per mile or current U of M compensation plan.	$ 1,000
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 246,000

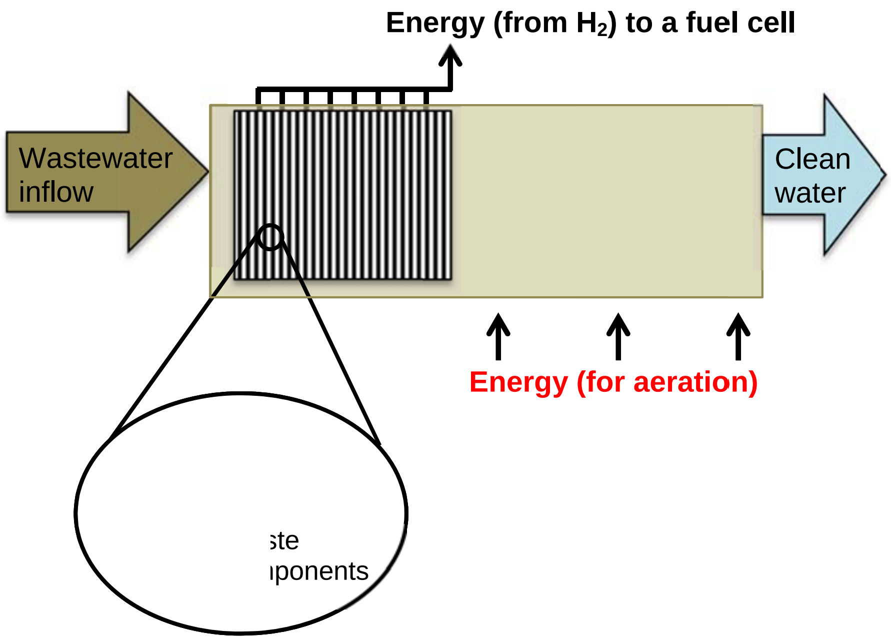
V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ Being Applied to Project During Project Period: none	$ -	
Other State $ Being Applied to Project During Project Period: none	$ -	
In-kind Services During Project Period: Novak and Arnold will provide unpaid time to the project (including 1% cost-share each). 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%.	$ -	
Remaining $ from Current ENRTF Appropriation (if applicable): no prior projects directly related to proposed project	$ -	
Funding History: none	$ -	

Wastewater and energy use/potential production



In traditional wastewater treatment, energy is *used* to aerate (and therefore treat) the wastewater



Bacteria immobilized in polymer films make H_2 from waste

With the proposed technology, aeration requirements are reduced (*saving energy*) and *energy (H_2) is produced* within specialized polymer films during an anaerobic (no aeration) phase of treatment

Project Manager Qualifications and Organization Description

Paige J. 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. Paige Novak will be responsible for overall project coordination. She has been studying anaerobic bacteria (the kind of bacteria that generate hydrogen and methane) for almost 20 years, wastewater treatment for about 10 years, and the use of hollow fibers for gas delivery for about 14 years. Recent collaborative work with Arnold has investigated the use of bacteria encapsulated in a polymer film for the degradation of sediment contaminants.

Dr. William Arnold (University of Minnesota) is an expert on the abiotic transformation of organic chemicals in aquatic systems. For the past 10 years he has been a pioneer in the development and modeling of polymer films for chemical containment.

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.