Environment and Natural Resources Trust Fund (ENRTF)
M.L. 2013 Work Plan

Date of Status Update Report: September 27, 2012

Date of Next Status Update Report: January 31, 2014

Date of Work Plan Approval: June 11, 2013

Project Completion Date: June 30, 2016 **Is this an amendment request?** _No_

PROJECT TITLE: Membranes for Wastewater-Generated Hydrogen and Clean Water

Project Manager: Paige Novak

Affiliation: University of Minnesota

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Location: Minneapolis, Minnesota 55455; Pilot studies will likely take place at the Metropolitan Wastewater Treatment Plant, Saint Paul, Minnesota, in the last year of the project.

Total ENRTF Project Budget:		
	ENRTF Appropriation:	**$246,000**
	Amount Spent:	**$0**
	Balance:	**$246,000**

Legal Citation: M.L. 2013, Chp. 52, Sec. 2, Subd. 05g

Appropriation Language:
$246,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to develop, optimize, and test membranes made of thin film polymers embedded with selected bacteria to generate clean water and energy in the form of hydrogen from wastewater. This appropriation is available until June 30, 2016, by which time the project must be completed and final products delivered.

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

II. 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. Patent protection is being sought by the University of Minnesota for the technology, which could lead to potential income for the state.

Please note that, as part of the patent protection process, an Intellectual Property Disclosure has been filed with the Office of Technology Commercialization at the University of Minnesota on the technology proposed to be developed through this project. As a result, some information pertaining to this project is confidential at this time. This work plan omits confidential information and provides lesser detail than it otherwise might.

III. PROJECT STATUS UPDATES:

Project Status as of January 31, 2014:

Project Status as of July 31, 2014:

Project Status as of January 31, 2015:

Project Status as of July 31, 2015:

Project Status as of January 31, 2016:

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Protoype development, laboratory testing, and design optimization

Description:

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 the membrane material, the 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.

We anticipate testing at least 15 different systems, each in replicate. In general, experiments will be set up similarly. 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 composite fermentative membrane module. In initial experiments, the composite membrane module will be placed into a continuously-stirred tank reactor fed with synthetic wastewater. Hydrogen concentrations in the inlet and exit gas streams will be measured as a function of time using gas chromatography. We will also explore the practicality of automatically and continuously measuring hydrogen as it is produced using a flow-through hydrogen gas analyzer. The hydrogen analyzer can be connected to a computer to enable automated data collection. If the detector appears to be sensitive enough to monitor hydrogen production in this small-scale system, a gas flow meter will also be connected to the manifold exit to automatically and continuously monitor gas flow rate (and hence, the mass of hydrogen generated with time).

Summary Budget Information for Activity 1:

ENRTF Budget: $162,000
Amount Spent: $ 0
Balance: $162,000

Activity Completion Date: December 31, 2015

Outcome	Completion Date	Budget
1. *Initial membranes constructed and tested*	1/31/14	$81,000
2. *Membranes containing a variety of hollow fiber materials constructed and tested*	6/30/14	$27,000
3. *Membranes containing a variety of bacteria species constructed and tested*	1/31/15	$27,000
4. *Membranes optimized with respect to fiber spacing, sandwich layers, and gas flow*	6/30/15	$27,000

Activity Status as of January 31, 2014:

Activity Status as of July 31, 2014:

Activity Status as of January 31, 2015:

Activity Status as of July 31, 2015:

Activity Status as of January 31, 2016:

Final Report Summary:

ACTIVITY 2: Pilot-scale testing

Description:
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 provide information regarding the longer-term operation of the system.

Summary Budget Information for Activity 2:

ENRTF Budget: $84,000
Amount Spent: $ 0
Balance: $84,000

Activity Completion Date: June 30, 2016

Outcome	Completion Date	Budget
1. *Testing of membranes in the laboratory with real (non-sterile) wastewater completed*	1/31/16	$4,000
2. *Testing of the scaled-up membranes and gas manifold system at the Metropolitan Wastewater Treatment Plant*	6/30/16	$80,000

Activity Status as of January 31, 2014:

Activity Status as of July 31, 2014:

Activity Status as of January 31, 2015:

Activity Status as of July 31, 2015:

Activity Status as of January 31, 2016:

Final Report Summary June 30, 2016:

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 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 *Minnesota Water* conference. Results will be used to further scale up this technology and implement it for the treatment of a variety of waste streams.

An Intellectual Property Disclosure has been filed with the Office of Technology Commercialization at the University of Minnesota on the proposed technology. The University of Minnesota will pursue patent protection, which could lead to potential income for the state. Therefore, information contained in the Research Addendum is confidential.

Status as of January 31, 2014:

Status as of July 31, 2014:

Status as of January 31, 2015:

Status as of July 31, 2015:

Status as of January 31, 2016:

Final Report Summary June 30, 2016:

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget:

Budget Category	$ Amount	Explanation
Personnel:	$211,000	Novak (PI) ($39,800) and Arnold (co-PI) ($42,900) budgeted for 6% time per year for three years, salary 73.5% of cost, fringe benefits 26.5% of cost. PI and co-PI will provide project supervision, guidance on the experimental aspects of the project along with guidance on modeling and data analysis. A graduate student researcher ($128,300) is also budgeted (50% time per year for three years, 56% salary, 33% tuition, 11% fringe benefits). The student will perform laboratory experiments and prototype testing.
Equipment/Tools/Supplies:	$34,000	Laboratory supplies include, 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, and septa, supplies for bacterial enumeration and identification, and consumables such as gloves and solvents ($7,300/yr, for a total of $21,900). Additional funds are budgeted for equipment repair and maintenance ($6,000) and the automated data acquisition system (Qubit hydrogen analyzer, computer, flow meters) and software for data acquisition ($6,100).
Travel Expenses in MN:	$1,000	Mileage charges to Metropolitan Council wastewater 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.
TOTAL ENRTF BUDGET:	**$246,000**	

Explanation of Use of Classified Staff: N/A
Explanation of Capital Expenditures Greater Than $3,500: N/A

Number of Full-time Equivalent (FTE) funded with this ENRTF appropriation:
Novak and Arnold will each represent 0.06 FTE per year (for 0.18 FTE each over the entire 3-year project period). Half of a graduate student researcher will be employed with this appropriation per year (for 1.5 FTE over the entire 3-year project period). This results in a total of 1.86 FTE for the total project.

Number of Full-time Equivalent (FTE) estimated to be funded through contracts with this ENRTF appropriation: None.

B. Other Funds: N/A

VII. PROJECT STRATEGY:
A. Project 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. Project Impact and Long-term Strategy:
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.

C. Spending History:

Funding Source	**M.L. 2007 or FY08**	**M.L. 2008 or FY09**	**M.L. 2009 or FY10**	**M.L. 2010 or FY11**	**M.L. 2011 or FY12-13**
National Science Foundation via the University of Minnesota's Materials Research Science and Engineering Center (a 1-year seed grant)					$50,000

VIII. ACQUISITION/RESTORATION LIST: N/A

IX. MAP(S): N/A

X. RESEARCH ADDENDUM:
Due to the patent protection being sought for the technology being developed with this project, in consultation with LCCMR staff it was determined that ENRTF research project requirements for a research addendum and peer review could be satisfied through an internal University of Minnesota peer review process that meets standard University of Minnesota protocols for a patent seeking situation. As a result the research addendum produced for the project and potentially revised through the peer review process will remain confidential while patent protection is pending.

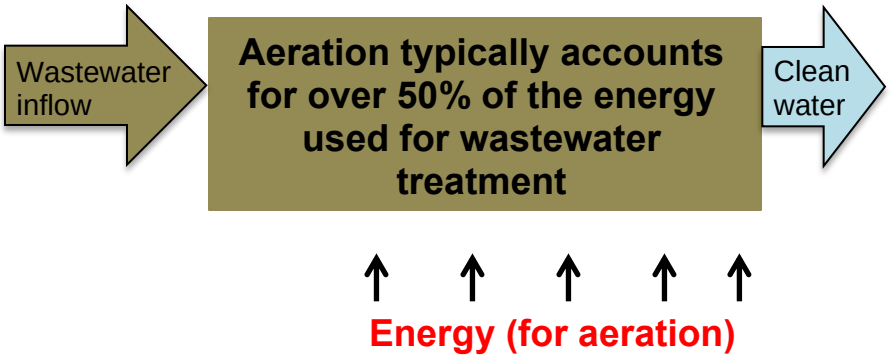
XI. REPORTING REQUIREMENTS:
Periodic work plan status update reports will be submitted not later than January 31, 2014, July 31, 2014, January 31, 2015, July 31, 2015, and January 31, 2016. A final report and associated products will be submitted between June 30 and August 15, 2016 as requested by the LCCMR.

Attachment A: Budget Detail for M.L. 2013 Environment and Natural Resources Trust Fund Projects

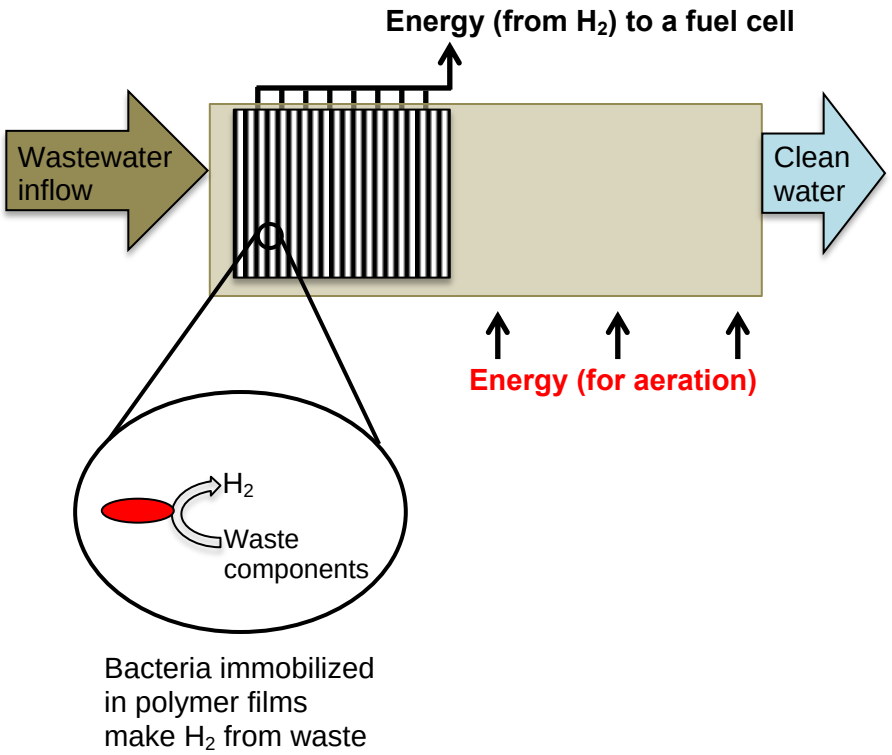
Project Title: *Membranes for wastewater-generated hydrogen and clean water*
Legal Citation: M.L. 2013, Chp. 52, Sec. 2, Subd. 05g
Project Manager: *Paige Novak*
M.L. 2013 ENRTF Appropriation: $ *246,000*
Project Length and Completion Date: *6/30/2016*
Date of Update:

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget	Amount Spent	Balance	Activity 2 Budget	Amount Spent	Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	***Protoype development, laboratory testing, and design optimization***			***Pilot-scale testing***				
Personnel Overall (Wages and Benefits)	141,500	0	141,500	69,500	0	69,500	211,000	211,000
Paige Novak (PI, 6% time per year for three years, salary 73.5% of cost, fringe benefits 26.5% of cost)								
William Arnold (co-PI, 6% time per year for three years, salary 73.5% of cost, fringe benefits 26.5% of cost)								
Graduate Research Assistant (50% time per year for three years, 56% salary, 33% tuition, 11% fringe benefits)								
Equipment/Tools/Supplies (Laboratory supplies include, 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, and septa, supplies for bacterial enumeration and identification, and consumables such as gloves and solvents ($7,300/yr, for a total of $21,900). Additional funds are budgeted for equipment repair and maintenance ($6,000) and the automated data acquisition system (Qubit hydrogen analyzer, computer, flow meters) and software for data acquisition ($6,100).)	20,500	0	20,500	13,500	0	13,500	34,000	34,000
Travel expenses in Minnesota.) (Mileage charges to Metropolitan Council wastewater 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.		0	0	1,000	0	1,000	1,000	1,000
COLUMN TOTAL	**$20,500**	**$0**	**$20,500**	**$14,500**	**$0**	**$14,500**	**$35,000**	**$35,000**

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