Environment and Natural Resources Trust Fund (ENRTF)
M.L. 2014 Work Plan

Date of Report: January 15, 2014

Date of Next Status Update Report: January 1, 2015

Date of Work Plan Approval:

Project Completion Date: June 30, 2017

Does this submission include an amendment request? No

PROJECT TITLE: Next Generation Large-Scale Septic Tank Systems

Project Manager: Bo Hu

Organization: University of Minnesota

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Location: The experiment will be primarily done at Biological Agricultural Engineering Building (BAE) 320, 1390 Eckles Ave, St Paul, MN, 55108. The impact of the project will be statewide

Total ENRTF Project Budget:		
	ENRTF Appropriation:	**$258,000**
	Amount Spent:	**$0**
	Balance:	**$258,000**

Legal Citation: M.L. 2014, Chp. 226, Sec. 2, Subd. 08g

Appropriation Language:
$258,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to develop a dual utility large-scale septic tank system designed for nutrient recuperation, bioenergy generation, and environmental protection using a bio-electrochemical system. This appropriation is subject to Minnesota Statutes, section 116P.10. This appropriation is available until June 30, 2017, by which time the project must be completed and final products delivered.

I. PROJECT TITLE: Next Generation Large-Scale Septic Tank Systems

II. PROJECT STATEMENT:

Subsurface Sewage Treatment Systems, commonly known as septic tank systems, aim to treat sewage generated from homes and mid-sized facilities that do not have access to centralized wastewater treatment plants. Nearly 25% of the US population is served by an onsite wastewater treatment system as their primary means of wastewater treatment. The primary wastewater treatment of conventional septic tanks is limited since the system relies on the capacity of retaining suspended solids by accumulation and sedimentation. Furthermore, most of the dissolved organics (soluble organic matter) and nutrients (nitrogen and phosphorous) need further soil treatment and can cause environmental problems such as eutrophication in water bodies if not properly treated. The waste stream in the septic tanks is a great potential source to recover phosphorus. Septic tanks also emit instead of collect powerful GHGs, such as methane (CH_4) and nitrous oxide (N_2O) to the atmosphere, as well as hydrogen sulfide (H_2S), which causes obnoxious odors and concrete corrosion. The role of anaerobic digestion (AD) for closing the water and the nutrient cycle has been considered of importance during onsite wastewater treatment. AD has the capability of generating energy from organic matter as biogas while decreasing the amount of pathogens. However, AD has only a limited capability to remove other pollutants such as nitrogen (N) and phosphorus (P).

Electrochemical assisted AD has been recently introduced as a new alternative to improve the AD process and to allow nutrient recuperation. The implementation of a bio-electrochemical system such as a microbial electrolysis cell (MEC) coupled with a digester can allow *in situ* production of hydrogen (H_2), oxygen (O_2) and precipitation of phosphorus salts such as struvite ($MgNH_4PO_4 \cdot 6H_2O$) by applying an electric field. Therefore, an increase of the energy content of the biogas can be expected due to a higher H_2 concentration or direct methanogenesis by converting electrons, protons and CO_2 into CH_4. A decreased H_2S concentration in the biogas can be achieved by the micro-aeration effect. Meanwhile, phosphorous concentration in effluent can also be lowered by salt precipitation at electrodes.

This project aims to develop next generation septic systems focusing on nutrient recuperation, bioenergy generation and environmental protection by the implementation of a bio-electrochemical system. This project proposes to plug a microbial electrolysis cell (MEC) into current septic tank systems in order to improve the water quality of septic tanks effluents, to recuperate phosphorus that can be used as fertilizer, to increase the production and collection of biogas for the bioenergy application and to decrease the greenhouse gas (GHGs) emissions. The experimentation will be carried out at the lab and at the field, and the results obtained will be applied to modify current design of the septic tank systems. The project will evaluate the capital and operational costs of the implementation of such a system and assess the potential benefits. The technology developed during this project could be useful to thousands of rural communities, especially those that do not have access to centralized wastewater treatment facilities. When communities effectively manage their wastewater treatment systems, public health and the environment are adequately protected while the community has the management structure in place to sustainably treat their wastewater over the long-term.

III. PROJECT STATUS UPDATES:

Project Status as of January 1, 2015:

Project Status as of July 1, 2015:

Project Status as of January 1, 2016:

Project Status as of July 1, 2016:

Project Status as of January 1, 2017:

Overall Project Outcomes and Results:

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Reactor optimization at lab-scale level

Description: The aim of this activity is to find the most efficient reactor design and operation in terms of quality of the effluent, nutrient recuperation and biogas production. To achieve this, laboratory scale continuously stirred tank reactors will be designed and built with working volumes of approximately 2 liters (Outcome 1). The CSTRs will be used as the septic tank part of a coupled system.

Lab-scale prototype systems will be studied, primarily focusing on evaluating different electrode materials and understanding mechanisms for the increased biogas production and phosphorus crystallization in order to finalize the best reactor design (Outcome 2). Electrochemical analysis will be conducted to screen suitable cathode materials of the smallest onset potential and internal resistance, the largest exchange current density, and the least inhibition induced by the real domestic sewage. Different approaches will be followed based on the coupled system to understand mechanisms for the biogas production. Possible promoting factors for increased biogas production will be screened out, including the increased hydrogen partial pressure induced by MEC cathode, the increased attached biomass, and the improved electro-activity of anaerobic granules. The phenomenon and mechanism for phosphorous (or phosphate) crystallization on cathode surface will be evaluated through designed experiments and appropriate characterization methods.

Optimization for the coupled system will be carried out in order to achieve better quality effluent, nutrient recuperation and biogas production (Outcome 3). Major operational variables include the MEC applied voltage, hydraulic retention time, and medium temperature. These variables will be evaluated by experimental design and analyzed by response surface methodology for their effects on reactor performance of biogas production rate, methane production rate, hydrogen sulfide concentration, COD removal, total phosphorus removal, and total nitrogen removal. Chemical and physicochemical characteristics of the influent and effluents will be analyzed by recommended methods or APHA-AWWA Standard Methods, and compared with statewide standards.

Summary Budget Information for Activity 1:

ENRTF Budget: $ 124,106
Amount Spent: $ 0
Balance: $ 124,106

Activity Completion Date: *Jan1th, 2016*

Outcome	Completion Date	Budget
1. Lab scale septic tank design and construction	*Oct 1st, 2014*	$24,851
2. The best reactor design has been chosen	*June 1st, 2015*	$52,936
3. The operational parameters have been optimized.	*Jan 1st, 2016*	$46,319

Activity Status as of January 1, 2015:

Activity Status as of July 1, 2015:

Activity Status as of January 1, 2016:

Activity Status as of July 1, 2016:

Activity Status as of January 1, 2017:

Final Report Summary:

ACTIVITY 2: Prototype construction and evaluation
Description: The main objective is to design and construct an MEC prototype that can be installed on a typical traditional septic tank. A MNDOT community septic tank system will be chosen to test the prototype. The manhole of the septic tank system will be retrofit to accommodate the MEC and the prototype will be primarily built on this existing system to test different operation conditions on the biogas production and nutrient recuperation (Outcome 4). Design considerations and operational parameters will be based on the knowledge acquired from activity 1. Influent flow rates, organic loading rates and hydraulic retention times will be similar to the values of current systems. Chemical and physicochemical characteristics of the influent and effluents as well as crystal properties will be determined according to recommended methods or APHA-AWWA Standard Methods. The operation of the reactors will be carried out in long operational periods to simulate real systems (4-6 months) and parameters such as electric voltage will be adjusted to reach the optimized operation (Outcome 5).

Summary Budget Information for Activity 2:

ENRTF Budget: $ 92,191
Amount Spent: $ 0
Balance: $ 92,191

Activity Completion Date: *June 30th, 2017*

Outcome	Completion Date	Budget
4. Prototype construction.	*June 1st, 2016*	$ 53,595
5. Prototype optimization.	*Jan 1st, 2017*	$ 38,596

Activity Status as of January 1, 2015:

Activity Status as of July 1, 2015:

Activity Status as of January 1, 2016:

Activity Status as of July 1, 2016:

Activity Status as of January 1, 2017:

Final Report Summary:

ACTIVITY 3: Economic analysis
An economic assessment will be carried out by considering the cost of the system, the cost related with the operation of the system and the valorization of the outputs such as biogas and nutrients (Outcome 6). Nutrients, recuperated in the form of struvite, have potential as a slow release fertilizer. A comprehensive evaluation of the inputs and outputs of the whole process will be carried out in terms of mass balances, energy balances, and the suitability of outputs as fertilizers. A detailed technological and economic analysis of the proposed system using input data from literature and from the prototype operation will be carried out. The economic analysis will address issues involved in commercial implementation of the system, including the size of facility required for commercial application; the realistic estimates of biogas production rates achievable under commercial conditions; the expected costs to construct a commercial-scale facility; the opportunity cost of capital required; the useful life of the system; the operations and maintenance costs, including labor requirements, repairs, and downtime; and the utilization of the biogas and the value derived from it. These considerations will be incorporated into a discounted cash-flow capital-budgeting analysis that generates results for investment

criteria such as net present value, internal rate of return, return on investment, and cash flow surpluses and deficits over time.

Summary Budget Information for Activity 3:

ENRTF Budget: $ 41,703
Amount Spent: $ 0
Balance: $ 41,703

Activity Completion Date: *June 30th, 2017*

Outcome	Completion Date	Budget
6. Evaluation of capital and operational costs	*June 30th, 2017*	$ 41,703

Activity Status as of January 1, 2015:

Activity Status as of July 1, 2015:

Activity Status as of January 1, 2016:

Activity Status as of July 1, 2016:

Activity Status as of January 1, 2017:

Final Report Summary:

V. DISSEMINATION:

Description: Part of the reactor design in the lab scale, if proved to be innovative, will be applied to the University Office for Technology Commercialization for filling the patent protection. We will publish two to three peer-reviewed manuscripts in the related journals to disseminate our results to the general public. We will also use the Onsite Sewage Treatment Program website http://septic.umn.edu/ as one-dissemination mechanism to our targeted audience. The program seeks to protect public health and the environment by improving wastewater treatment through research-based education and outreach for homeowners, small communities, professionals and policy-makers. The technology developed during this project will be posted on the website and it could be useful to thousands of rural communities, especially those that do not have access to centralized wastewater treatment facilities. The primary target to disseminate our research results will be the community based septic tank systems installed in the rural area where multiple family and business are connected to generate relatively large amount of the wastewater. When communities effectively manage their wastewater treatment systems, public health and the environment are adequately protected while the community has the management structure in place to sustainably treat their wastewater over the long-term. The small scale septic tank systems can also be re-designed based on our results to better manage the waste, so the producers of these small scale septic tank systems will also the audience of the technology. Any royalty, copyright, patent, and sales of products and assets resulting from this project will be subject to revenue sharing requirements with ENRTF according to Minnesota Statutes, section 116P.10.

Activity Status as of January 1, 2015:

Activity Status as of July 1, 2015:

Activity Status as of January 1, 2016:

Activity Status as of July 1, 2016:

Activity Status as of January 1, 2017:

Final Report Summary:

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	$ Amount	Explanation
Personnel:	$ 222,800	1 project manager at 8% FTE for 3 years; 1 extension specialist at 16.7% FTE for 3 years; 1 postdoc researcher at 85% FTE for 3 years.
Equipment/Tools/Supplies:	$20,455	Chemical, supplies, analysis and lab septic tank systems
Capital Expenditures over $5,000:	$10,000	MEC plug-in prototype for the pilot test
Printing:	$1,035	Publication cost for the manuscripts
Travel Expenses in MN:	$3,710	Mileage, lodging, meals for travels to the community septic tank test site for taking samples as well as testing the prototype. U of M plan for travel expense will be used to process the travel cost
TOTAL ENRTF BUDGET:	**$258,000**	

Explanation of Use of Classified Staff: N/A

Explanation of Capital Expenditures Greater Than $5,000:
$10,000 is requested to build the MEC plug-in prototype to be set up on the existing septic tank system to test its long term operation. The prototype will be built on the manhole of the septic tank system, and the cover of the manhole will be retrofit to accommodate the pilot sized of MEC, including two electrodes, electric wiring and a hand hole for sampling.

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 3

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: 0

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state			
	$134,160	$0	In-kind services during project period: Unrecovered F&A at 52% MTDC
TOTAL OTHER FUNDS:	**$**	**$**	

VII. PROJECT STRATEGY:

A. Project Partners:

B. Project Impact and Long-term Strategy:
The outcome of the project is to build a supplementary MEC unit that can be plugged into current septic tank systems in order to improve the water quality of septic tanks effluents, recuperate phosphorus nutrient that can be harvested as fertilizer, increase the production and collection of biogas for the bioenergy application and decrease the emissions of GHGs. The project will test the technical feasibility of this new system. In addition,

capital and operational costs of the implementation of such a system will be projected and the benefits will be assessed. The research specifically focuses on the modification of large scale septic systems, where collecting the nutrients and biogas is economically possible. It will also provide valuable information to re-design the household septic system with better wastewater treatment. The technology developed during this project could be useful to thousands of rural communities, especially those that do not have access to centralized wastewater treatment facilities. Since half of the MN septic tank systems are actually located in the metro areas, these urban population can also benefit from better wastewater treatment that protects ground and surface waters along with protecting human health. This new information will be reported to existing and new wastewater professionals throughout Minnesota and beyond by our educational program; and it will open the opportunities to promote the applications of the next generation septic system.

C. Spending History:

Funding Source	M.L. 2008 or FY09	M.L. 2009 or FY10	M.L. 2010 or FY11	M.L. 2011 or FY12-13	M.L. 2013 or FY14
No funds have been spent	0	0	0	0	0

VIII. ACQUISITION/RESTORATION LIST:
N/A

IX. VISUAL ELEMENT or MAP(S):

X. ACQUISITION/RESTORATION REQUIREMENTS WORKSHEET:
N/A

XI. RESEARCH ADDENDUM:
A separate research addendum has been completed and submitted.

XII. REPORTING REQUIREMENTS:
Periodic work plan status update reports will be submitted no later than January 1, 2015; July 1, 2015; January 1, 2016; July 1, 2016; and January 1, 2017. A final report and associated products will be submitted between June 30 and August 15, 2017.

Environment and Natural Resources Trust Fund
M.L. 2014 Project Budget

Project Title: Next Generation Large-Scale Septic Tank Systems
Legal Citation: M.L. 2014, Chp. 226, Sec. 2, Subd. 08g
Project Manager: Bo Hu
Organization: University of Minnesota
M.L. 2014 ENRTF Appropriation: $258,000
Project Length and Completion Date: *3 Years, June 30, 2017*
Date of Report: *1/15/2014*

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget	Amount Spent	Activity 1 Balance	Activity 2 Budget	Amount Spent	Activity 2 Balance	Activity 3 Budget	Amount Spent	Activity 3 Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	***Reactor optimization at lab-scale level***			***Prototype construction and evaluation***			***Economic analysis***				
Personnel (Wages and Benefits)	$109,205	$0	$109,205	$75,359	$0	$75,359	$38,237	$0	$38,237	$222,800	$222,800
Bo Hu, Project Manager: $34,534 (74.85% salary, 25.15% benefits); 8% FTE for 3 years											
Sara Heger, Septic system extension specialist: $45,376 (74.85% salary, 25.15% benefits); 16.7% FTE for 3 years											
PostDoc Researcher: $142,890 (83.28% salary, 16.72% benefits); 85% FTE for 3 years											
Equipment/Tools/Supplies											
Two lab scale CSTR Septic tank systems ($2,500 each)	$5,000	$0	$5,000		$0			$0		$5,000	$5,000
Lab supplies: chemicals, tools, bottles, gloves	$7,575	$0	$7,575	$5,227	$0	$5,227	$2,653	$0	$2,653	$15,455	$15,455
Capital Expenditures Over $5,000											
A MEC plug-in prototype will be constructed and installed on a typical traditional septic tank, for instance, the MNDOT community septic tank system. The cover of the manhole of the septic tank system will be retrofit to accommodate the pilot sized MEC, including two electrodes, electric wiring and a hand hole for sampling.				$10,000	$0	$10,000				$10,000	$10,000
Printing											
Publication cost for manuscripts	$508	$0	$508	$350	$0	$350	$177	$0	$177	$1,035	$1,035
Travel expenses in Minnesota											
Mileage, lodging, meals for travels to the community septic tank test site for taking samples as well as testing the prototype. U of M plan for travel expense will be used to process the travel cost	$1,818	$0	$1,818	$1,255	$0	$1,255	$636	$0	$636	$3,710	$3,710
Others											
COLUMN TOTAL	**$124,106**	**$0**	**$124,106**	**$92,191**	**$0**	**$92,191**	**$41,703**	**$0**	**$41,703**	**$258,000**	**$258,000**

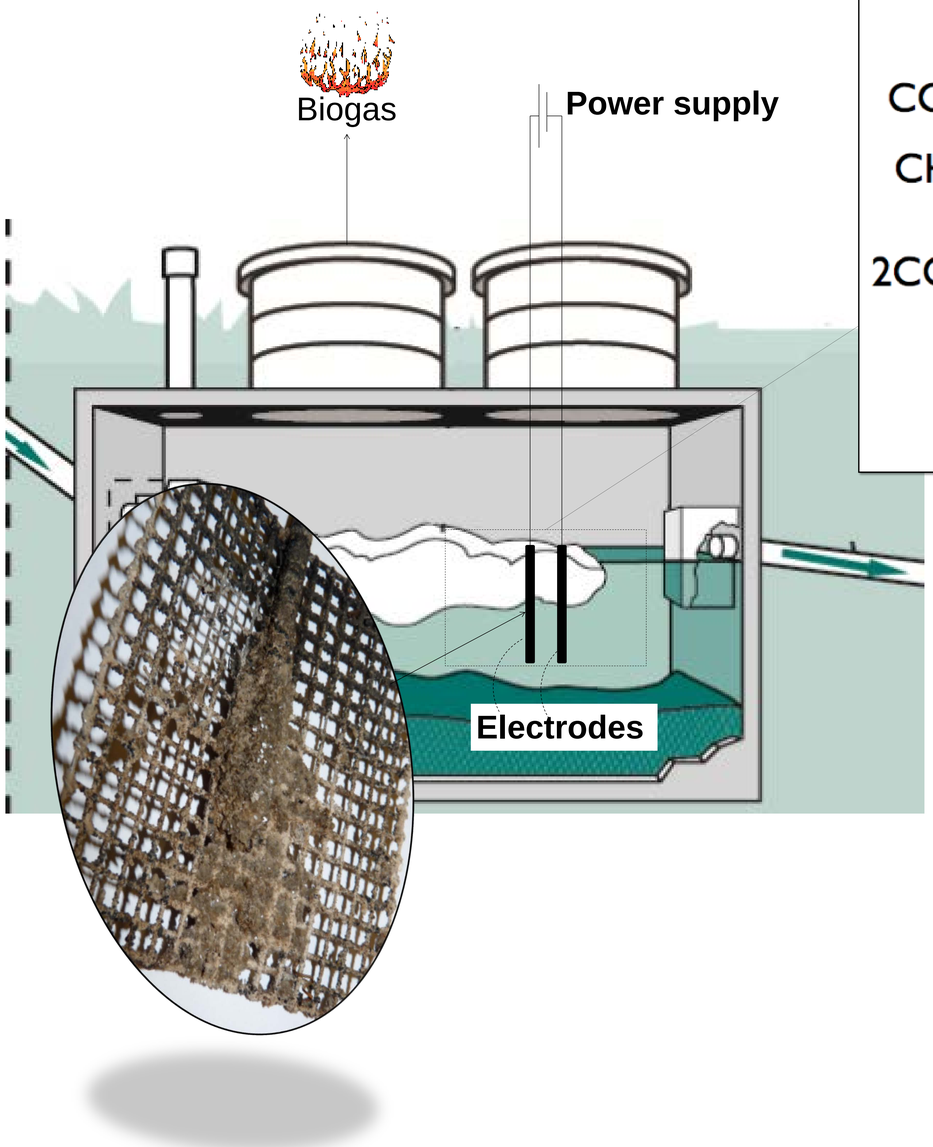
Next Generation Large-Scale Septic Tank Systems

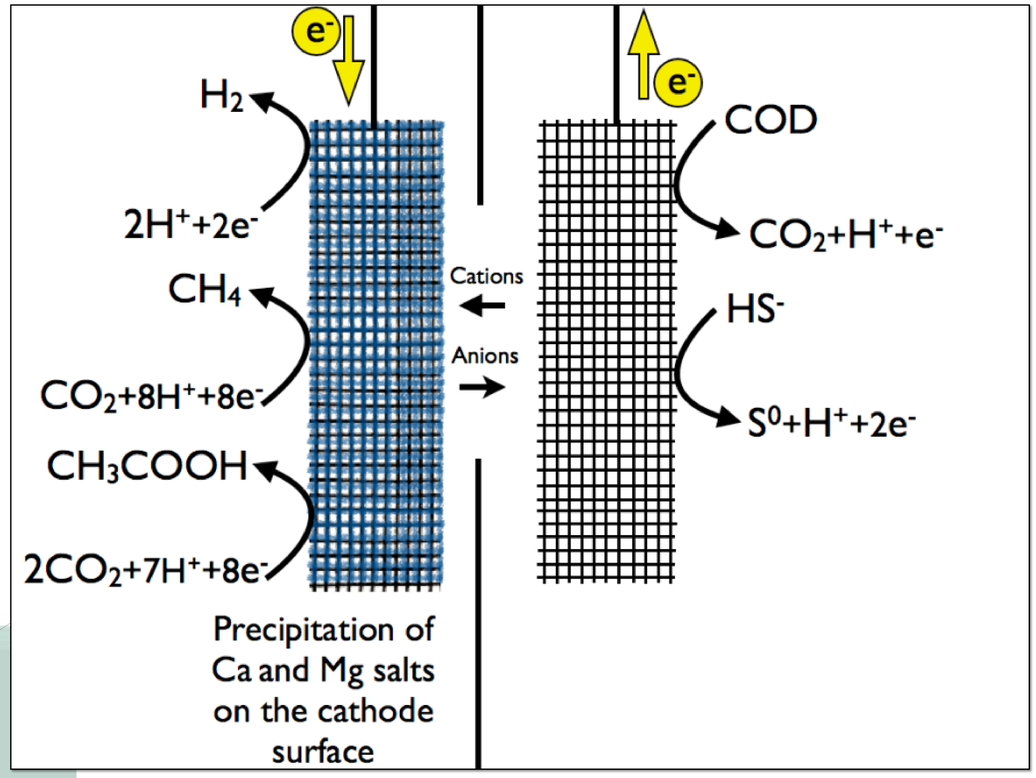
Bo Hu
University of Minnesota

Environment and Natural Resources Trust Fund

Project 133-E
Jan 15th, 2014

This project proposes to develop next generation septic tank systems by plugging a microbial electrolysis cell (MEC) into current septic tank systems for the purpose of nutrient recuperation, bioenergy generation and environmental protection.





- *In situ* implementation.
- Biogas collection (heat generation).
- Sludge reduction.
- Decrease on GHG's emissions.
- Phosphorus nutrient recuperation (bio-fertilizer).