Environment and Natural Resources Trust Fund

Research Addendum for Peer Review

Project Manager Name: **Bo Hu**
Project Manager Email address: **bhu@umn.edu**
Project Title: **Next generation large-scale septic tank systems**
Project number: **133-E**

1. Abstract

This project aims to develop a 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 large-scale 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 community septic tank systems. The project will evaluate the capital and operational costs of the implementation of such a system and assess the potential benefits.

2. Background

Subsurface Sewage Treatment Systems, also referred to as septic 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 [1]. Large-scale septic tanks are utilized across Minnesota, such as for local communities, resorts, camp grounds, and restaurants, treating wastewater with flow rates varying from 1,000 to 40,000 gpd (gallon per day). There are currently thousands of community septic tank systems across the state. 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. Phosphorus is currently produced from non-renewable resources (mined from phosphate rocks) and is increasingly needed in order to sustain the rising food and biomass energy demand. Therefore, 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 [2]. 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). After the digestion, total N and P contents remain constant although AD mineralizes organic N and P to mainly ammonia and phosphate. Therefore, additional treatment steps are needed to remove the remaining Chemical Oxidation Demand (COD), ammonia and phosphate from the AD liquid effluent.

Electrochemical assisted AD has been recently introduced as a new alternative to improve the AD process and to allow nutrient recuperation [3-7]. 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, for instance, hydroxylapatite ($Ca_{10}(PO4)_6(OH)_2$) and 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 in the biogas and/or a higher production of CH_4 through hydrogenotrophic or homoacetogenic pathways [8, 9]. Moreover, it has been shown that direct methanogenesis can occur at electrodes where methanogenic archaea are able to convert electrons, protons and CO_2 into CH_4 [5]. Alternatively, the production of micro-aerobic conditions at the anode can increase hydrolysis rates and decrease the concentration of H_2S in the biogas [10-13]. Phosphorous crystallization occurs at the cathode due to the local increase of pH in the close vicinity of the electrode [5]. A recent lab scale preliminary study by one of the team members coupled a microbial electrolysis cell (MEC) with a digester achieved a biogas production of a factor of 5 higher, phosphorus recuperation of about 40% from the influent wastewater accumulated on the surface of the cathode electrode and a hydrogen sulfide (H_2S) concentration in the biogas a factor of 2.5 lower than in a standard septic tank.

Despite the very recent efforts to implement electrochemical assisted AD, there is a need for more in-depth understanding, implementing and improving of the process. Consequently, the development of next generation septic tanks with higher treatment efficiencies is of importance in order to effectively utilize waste resources and protect the environment, especially for those large-scale community septic tank systems.

3. Hypothesis

There is a significant improvement regarding biogas production and nutrient recuperation in a microbial electrolysis cell (MEC) coupled with a septic tank.

4. Methodology

The project will be divided in two work packages: Reactor optimization at lab-scale level (WP1); and Reactor prototype construction and evaluation at pilot level (WP2) (Fig.1). In addition, an economic analysis will be carried out in order to evaluate the techno-economic feasibility of the proposed system.

ACTIVITY 1: Reactor optimization at lab-scale level

WP1 includes two main tasks in which laboratory scale reactors will be prepared with working volumes of approximately 1-2 liters. The cathode material will be stainless steel mesh, nickel foam or carbon cloth with a projected surface area of 50 to 200 cm^2, which will be large enough to capture fertilizer from wastewater at a precipitation rate of 10 g-solid/m^2/d. Anode materials will be plain carbon cloth or graphite brush. A typical municipal wastewater contains a total COD of 500 mg/L, total nitrogen of 40 mg/L, and total phosphorus of 8 mg/L. The lab-scale lab study will focus on the ideal situations with a hydraulic retention time of 0.5 to 2 d and an organic loading rate of 250 to 1,000 mg-COD/L/d. The reactor will be inoculated with a sufficient amount of a mixture of activated sludge and anaerobic sludge. Mixing will be provided in the small-scale study so that the wastewater solution can be homogenous and this wastewater will be taken from Metropolitan Wastewater Treatment Plant in St Paul, MN, in order to maintain its consistency of chemical components with the influent in pilot-scale study. Standard continuous stirred tank reactors (CSTR) will be used as control reactors and CSTR reactors with a membrane-less MEC system installed will be the reactors to be studied (tasks 1.1).

Lab-scale prototype systems will be studied, primarily focusing on evaluating different electrode materials and necessary surface area, and understanding mechanisms for the increased biogas production and phosphorus crystallization in order to finalize the best reactor design. Electrochemical analysis will be conducted in phosphate buffer solution (PBS) to screen suitable cathode materials for the smallest onset potential and internal resistance, the largest exchange current density, and the least inhibition induced by the real sewage (Table 1). Appropriate cathode surface area will be determined by kinetic study on solid precipitation rate on the surface. 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 amount of attached biomass, and the improved electro-activity of anaerobic granules. The coupled system will be operated in batch mode with cathode poised to different potential levels (e.g., from -0.8 to 0 V vs SHE) for hydrogen evolution, and correlating the cathode potential with methane production will elucidate the effect of hydrogen partial pressure induced by MEC. At the similar mode, monitoring biogas production after removing anode from MEC will show the effect of the anode-attached biomass on methane generation. After long time operation, the electro-activity of the anaerobic granules in the coupled and the controlled reactor will be evaluated by cyclic voltammetry to compare the capability of extracellular electron transfer, and these granules will be used as inocula for anaerobic digestion to evaluate their methanogenic activity.

The phenomenon and mechanism for phosphorous (or phosphate) crystallization on cathode surface will be evaluated through designed experiments and appropriate characterization methods. The locally increased pH value due to hydrogen evolution reaction at cathode will reduce solubility of various phosphate salts, e.g., hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$) and struvite ($MgNH_4PO_4•6H_2O$). So the inclusion of MEC may accelerate crystallization and yield more phosphate-containing solids. Solids on cathode surface and in the reactor will be imaged and characterized using scanning electron microscopy (SEM) and crystals will be analyzed with energy dispersive spectrographs (EDS) for their elemental constituents. The local pH gradient in the vicinity of cathode will be characterized by quantitative confocal scanning laser microscopy (CSLM) with the presence of pH-sensitive molecular fluoroprobe.

Table 1. Experiment for screening suitable cathode materials for microbial electrolysis cells

	Cathode and catalyst material	Testing medium	Electrochemical responses		
			Onset potential (mV vs SHE)	Exchange current density (mA/cm^2)	Internal resistance (Ω)
1	Stainless steel	PBS buffer			
2	Stainless steel	Sewage			
3	Nickel foam	PBS buffer			
4	Nickel foam	Sewage			
5	Carbon cloth/Pt	PBS buffer			

6	Carbon cloth/Pt	Sewage			
7	Carbon cloth	PBS buffer			
8	Carbon cloth	Sewage			

Subsequently, lab-scale prototype will be prepared and optimized as well (task 1.2). Optimization for the coupled system will be carried out in order to achieve better quality effluent, nutrient recuperation and biogas production. 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. Biogas production will be measured by means of a liquid displacement in acid water columns. 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.

ACTIVITY 2: Prototype construction and evaluation

During WP2, the pilot test in the field will mimic the real septic system. A current MNDOT community septic tank system of 3,000 gallon will be chosen to test the prototype. A reactor prototype will be constructed and operated based on the information collected during WP1. 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. Similarly to task 1.1 and 1.2, the process will be evaluated in order to demostrate the feasability of the proposed system. The small scale household septic system may receive different waste materials at different time with different loads; however, the wastewater generated from a large community will be fairly consistent over the time, similar to the wastewater received at municipal wastewater treatment plant. The electrode material will be the most effective one identified in Activity 1, with the appropriate ratio of electrode surface area to reactor volume. The power input for the MEC will be less than 10 W. Organic loading rates and hydraulic retention times will be similar to the optimal values of the lab-scale reactors. Biogas flow rate will be continuously monitored by a gas flow meter and biogas will be sampled every other week for gas component analysis. The cathode will be unplugged from the septic tank every three months to scrape off the solid fertilizer and then put back for reuse.

The pH, the temperature, the COD volatile fatty acids (VFA) and the biogas production will be monitored on a continual basis. The VFA and biogas composition will be analyzed using gas chromatography equipment. Total solids (TS), volatile solids (VS), suspended solids (SS), total ammonia nitrogen (TAN), total Kjeldahl nitrogen (TKN), chemical oxygen demand (COD), total phosphorus (TP) and pH will be determined according to Standard Methods [14]. Crystals will be imaged and characterized using scanning electron microscopy (SEM) and crystals will be analyzed with energy dispersive spectrographs (EDS) from cathode accumulated crystals. The operation of the reactors will be carried out in long operational periods to simulate real systems (4-6 months).

For a 3,000 gallon septic tank serving a community with about 60 people (assuming 100 gallon wastewater per person per day), the inclusion of an MEC has the potential to generate 336 m^3 of biomethane, 62 kg-P, and 11 kg-N in phosphorus- or nitrogen-containing cathode precipitates based on 50% recovery every year.

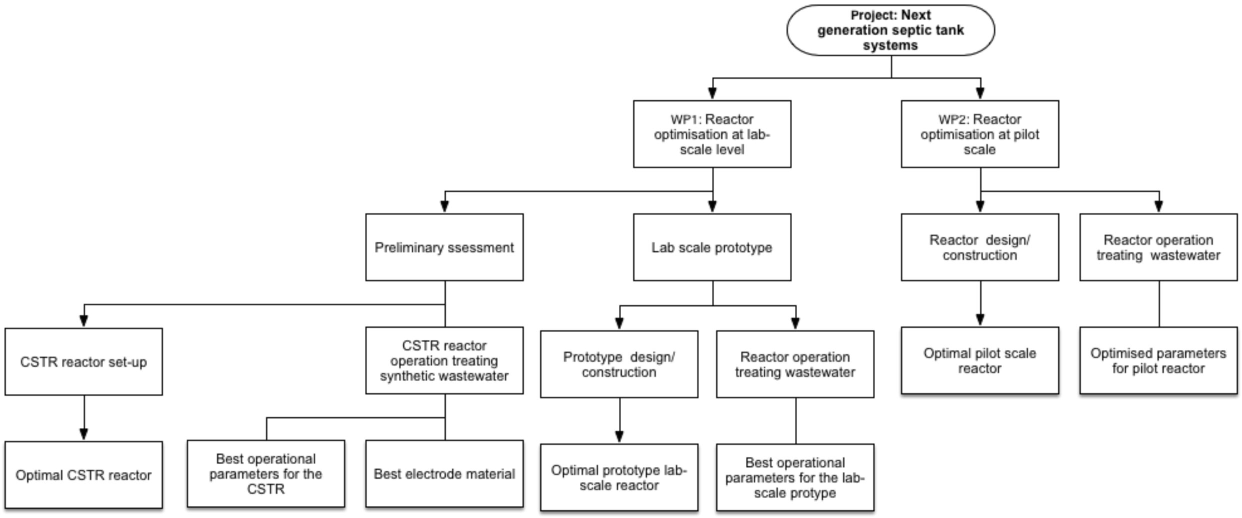

Figure 1. Project summary of work breakdown structure (WBS).

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). Although biogas will not be collected and utilized in this study, biogas productivity data will be obtained in prototype study for economic analysis. Nutrients, recuperated in the form of hydroxyapatite and 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.

Applied voltage (E_{ap}) for MEC directly consumes electrical power with a value of $W = I^* E_{ap}$; since the applied voltage is maintained small (< 1.5 V), the power consumption is small as well. Energy efficiency, a term quantifying the ratio of the energy in biomethane to the applied electrical energy, will be included in the study to demonstrate the net energy yield. Even though we will only utilize the electricity from the rest center directly, inclusion of solar panel for powering MEC may create a more sustainable system, as parasitic load is further eliminated and energy efficiency is raised. The techno-economic analysis will explore the possibility to include the solar panel as the power source to operate the MEC.

The long-term benefits of the new septic system will also be explored in the techno-economic analysis. Even though the small scale household septic tank contains too little organic matters to collect the biogas and nutrients, it may be well economically feasibility for the large-scale community septic systems to be benefited from this project. We will calculate how much additional biogas and nutrients can be generated and collected and explore their value as heating fuel and fertilizer individually. A possible business model will be suggested.

5. Results and Deliverables

The following milestones and deliverables have been established across this project:

Milestones

End of year 1:
M1: Set-up of CSTR for a preliminary assessment.
M2: CSTR is operational and best operational parameters have been found.
M3: Best electrode material has been chosen.

End of year 2:
M4: Lab-scale reactor prototype has been constructed.
M5: Lab-scale reactor prototype is operational and best operational parameters have been found.

End of year 3:
M6: Pilot scale has been constructed.
M7: Pilot scale reactor is operational and best operational parameters have been found

Deliverables

End of year 1:
D1: Understanding critical parameters for the implementation of MEC with a digester.

End of year 1:
D2: Implementing a complete process to improve anaerobic digestion and recuperation of nutrients at lab-scale level.

End of year 3:
D3: A complete process to improve anaerobic digestion and recuperation of nutrients from wastewater in a septic tank kind of reactor.
D4: Guidelines to implement and control this process.

6. Timetable - The schedule as outlined in Fig. 2 defines the two work packages and four tasks to be completed starting on 1st July 2014. The proposed time for completing the proposed research is 144 weeks (about 3 years).

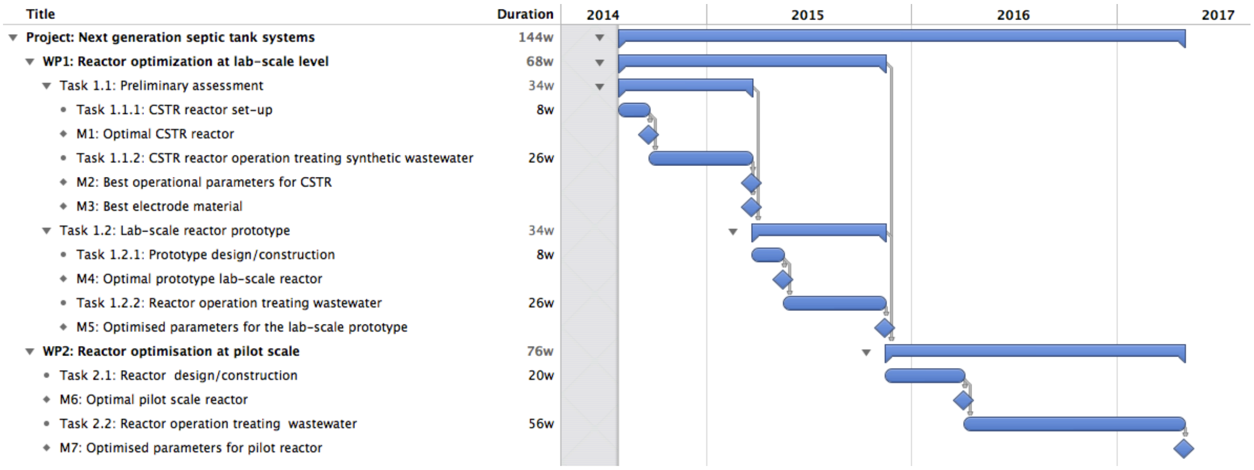

Figure 2. Gantt chart of the project timetable

In the above chart, it is indicated the time frame including proposed dates for individual results and deliverables.

7. Budget

Detailed Project Budget

Project Title: *[Next generation septic tank systems]*

TOTAL ENRTF REQUEST BUDGET *[3]* **years**

BUDGET ITEM	**AMOUNT**
Personnel:	
Project director, Bo Hu will be paid to manage the project, design the experiments and write the project report. The payment will cover his one month summer salary and fringe benefits. 74.85% of payment will be the salary and 25.15% will be the fringe benefits.	$ 34,534
Postdoc researcher, Dr. Carlos Zamalloa will be paid to execute the activities and provide technical expertise. His time employment will be covered for this position by the project, including 83.28% for the salary and 16.72% for the fringe benefits.	$ 142,890
Septic system extension specialist, Ms. Sara Heger will be paid to provide practical field research experience relating to septic systems in MN, locate a demonstration site, facilitate the onsite design and provide extension on the application of the research. Two month appointment will be paid with the project, including 74.84% for the salary and 25.16% for the fringe.	$ 45,376
Equipment/Tools/Supplies:	$ -
Lab scale septic tanks with MEC	$ 5,000
MEC plug-in prototype for the pilot test	$ 10,000
Lab supply and chemicals	$ 15,455
Printing and page charges	$ $1,035
Travel: *Travel to the Metropolitan Wastewater Plant and MNDOT community septic tank site to take samples, measure chemical compositions of waste streams, and build an improved septic tank system. 4 travels are planned per each project year and $300 per travel is budgeted.*	$3,710
Additional Budget Items: *In this column, list any additional budget items that do not fit above categories. List by item(s) or item type(s) and explain how number was reached. One row per type/category.*	$ -

TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 258,000

V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
In-kind Services During Project Period: *Unrecovered F&A at 52% MTDC*	$ 134,160	*Secured*

Budget Justification

Personnel:

One month of salary will be charged to the project for Dr. Bo Hu's summer time on managing the grant. His one month salary is $8,363 in the first academic year and FTE with 3% salary increase for the following project years. The fringe benefit for Nine-Month B-term faculty is 33.6% based on the University regulation.

One postdoc will be hired for this project for three years. The postdoc researcher will be paid with $38,500 for the first year and FTE with 3% salary increase for the following project years. The rate of fringe benefits the postdoc researcher is 20.08% based on the University regulation. The postdoc researcher will work with Dr. Hu to design experiments and collect the research data on the lab scale study as well as pilot demonstration.

Septic system extension specialist, Ms. Sara Heger will be paid to provide practical field research experience relating to septic systems in MN, locate a demonstration site, facilitate the onsite design and provide extension on the application of the research. Her monthly salary is projected at $5,494 on 2014 and two month appointment will be paid with the project with 3% salary increase for the following project years.

Permanent Equipment:

$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.

Expendable Supplies and Minor Equipment:

Regular chemical supply to measure COD, phosphorus etc. is budgeted for $5,000 for the first project year and FTE with 3% increase for the following project year. Additional $5,000 is budgeted for the first year to pay for the small reactors we will set up in the lab.

Travel:

Travel to the Metropolitan Wastewater Treatment Plant in St Paul as well as MNDOT Roadside septic system to take samples, measure chemical compositions of waste streams, and build an improved septic tank system. Four travels are planned per each project year and $300 per travel is budgeted.

Publication:

We budgeted $335 for the publication costs with 3% increase for each project year.

Total cost to LCCMR:

The total cost for the first year is $83,617, the second year $80,972, and the third year $93,406. The total project cost to LCCMR is $258,000.

Other funds:
In-kind services during the project period will be provided even though UMN did not charge the indirect cost for this project. The total estimate fund $134,160 is calculated based on the University F&A rate (52% of modified base).

8. Credentials

The research team will include Professor Bo Hu, Dr. Carlos Zamalloa from the Department of Bioproducts and Biosystems Engineering, and Ms. Sara Heger, the extension specialist at Water Resource Center, University of Minnesota.

Hu, Bo is an expert on the anaerobic digestion and will serve as the project director to manage the project, design the experiments and write the project reports. Here are his recent grants and publications:

Funded Projects

1. Bo Hu, Carlos Zamalloa, Sara Heger, 07/01/2014-06/30/2017. Next generation septic tank system, LCCMR, $258,000
2. Bo Hu, 07/01/2013-06/30/2015. Nutrient recovery in anaerobic digestion coupled with a bio-electrochemical system for the treatment of agricultural manure, MnDRIVE Postdoc Fellow program, $100,000
3. Bo Hu, AURI, BMP analysis of corn syrup, $4,065
4. Bo Hu, Jose Hernandez, Larry Jacobson, Chuck Clanton, Jun Zhu, 07/01/2013-06/30/2015, Phosphorus recovery from digested manure via filamentous fungi, MAES State Reserve Funds, $146,835
5. Bo Hu, 07/01/2013-01/15/2015, *Phosphorus removal and recovery via filamentous fungi,* UMN Grant-in-Aid program, $33,378
6. Bo Hu, Steven Severtson, 01/08/2013-01/07/2015, *Develop pelletized microalgae cultivation via attraction between microalgae and fungal cells*, UMN-BTI Synthetic Ecology Program, $90,000
7. Yan Yang, Bo Hu, 08/26/2012-01/15/2013, Graduate student assistantship, UMN-CFANS-RFP, $15,500.
8. Chuck Clanton, Bo Hu, Larry Jacobson, 09/01/2012-09/01/2014, *Identifying the cause and subsequent remediation of foaming in swine manure management systems*, Iowa Pork Board, $391,810. Bo Hu's group share: $117,974.
9. Jerry Jennissen, Jer-Lindy Farms, Bo Hu, David Schmidt, 09/01/2012-06/30/2014, *Making small anaerobic digesters work*, Minnesota Department of Agriculture, $137,000. Bo Hu's group share: $20,000
10. Bo Hu, 07/01/2011-01/15/2013, *Oil accumulation from lignocellulosic biomass via oleaginous fungi* , UMN Grant-in-Aid program,, $31,915
11. Bo Hu, Larry Jacobson, Chuck Clanton, Wei Wei, 07/01/2011-06/30/2013, *Microbial analysis of foaming swine manure to improve deep-pitted swine barn safety,* Minnesota Rapid Agricultural Response Fund, $136,611.
12. Bo Hu, Larry Jacobson, Chuck Clanton, 05/01/2011-12/01/2012, *Microbial analysis to identify risk factors of swine manure foaming,* Minnesota Pork Board, $30,000.
13. Bo Hu, Patricia Ortiz, Yang Deng, USDA-Rural Development, $50,000, 2009
14. Bo Hu, Yang Li, Paul Singh, INDUNIV Research Consortium, $30,000, 2009

15. Bo Hu, Patricia Ortiz, Ernesto Riquelme, Yang Deng, $81,700, UPRM-BIOSEI 2008
16. Bo Hu, NIH-MBRS SORE Program, University of Puerto Rico, Seed Fund Program, $7,000, 2008.

Recent Publications

1. Sarman Gultom, Bo Hu, 2013, Invited Review: Fungal pelletization and its application in algae harvest, Energies (In press)
2. Yan Yang, Mi Yan, Bo Hu, 2013, Endophytic Fungal Strains of Soybean for Lipid Production (In press)
3. Jianguo Zhang, Bo Hu, 2012, Effects of External Enzymes on the Fermentation of Soybean Hull to Lipid by *Mortierella isabellina*, Applied Biochemistry and Biotechnology, 168(7): 1896-1906
4. Jianguo Zhang, Bo Hu, 2012, A Novel Method to Harvest Microalgae Via Co-Culture of Filamentous Fungi to Form Cell Pellets, Bioresource Technology, 114:529-535
5. Jianguo Zhang, Bo Hu, 2012, Solid-State Fermentation of *Mortierella isabellina* for Lipid Production from Soybean Hull, Applied Biochemistry and Biotechnology, 166(4):1034-46
6. Chunjie Xia, Jianguo Zhang, Weidong Zhang, Bo Hu, 2011, A New Cultivation Method for Bioenergy Production --- Cell Pelletization and Lipid Accumulation by *Mucor circinelloides*, Biotechnology for Biofuels, 4:15.
7. Tamarys Heredia-Arroyo, Wei Wei, Roger Ruan, Bo Hu, 2011, Mixotrophic Cultivation of *Chlorella vulgaris* and its Potential Application for the Oil Accumulation from Non-sugar Materials, Biomass and Bioenergy, 35(5): 2245-2253
8. Tamarys Heredia-Arroyo, Wei Wei, Bo Hu, 2010, Oil accumulation from waste via heterotrophic/mixotrophic *Chlorella protothecoides,* Applied Biochemistry and Biotechnology, 162 (7): 1978-1995
9. Yan Yang, Bo Hu, April 2014, Bio-based chemicals: lipid and wax conversion and utilization, Book chapter for *Advances in biorefineries, Biomass and waste supply chain exploitation*, 978-0857095213
10. Woodhead Publishing Limited, Cambridge, UK
11. Jianguo Zhang, Bo Hu, March 2013, Liquid-Liquid extraction in biorefineries, *Separations and Purification Technologies in Biorefineries*, ISBN: 978-0-470-97796-5, Wiley, UK
12. Mi Yan, Jianguo Zhang, Bo Hu, December 2012, Integration of microalgae cultivation with anaerobic digestion, Book chapter for *Microbial Biotechnology: Energy and Environment*, ISBN 978-184-593-956-4, CABI, Page 190-206.
13. Jianguo Zhang, Bo Hu, Microbial Biodiesel Production --- Oil Feedstocks Produced from Microbial Cell Cultivations. Book chapter for *Biodiesel - Feedstocks and Processing Technologies*, ISBN 978-953-307-713-0, InTech, November 2011, Page 93-110.
14. Bo Hu, Yan Yang, Mi Yan, Production of lipids in Fusarium strains, UMN invention disclosure case #20130178
15. Bo Hu, Jianguo Zhang, New method to harvest microaglae via cell pelletizatioin assisted with filamentous fungi, US Patent Application No. 61/547,177.

Zamalloa, Carlos is a postdoc researcher at Hu's group, will execute the activities and provide technical expertise. Here are his recent publication records:

Recent Publications:

1. López Barreiro D., Zamalloa C., Boon N., Vyverman W., Ronsse F., Brilman W., Prins W. (2013), Influence of strain-specific parameters on hydrothermal liquefaction of microalgae, Bioresource Technol., **146**, 463-471.
2. Zamalloa, C., Boon, N., Verstraete, W. (2013) Performance of a lab-scale bio-electrochemical assisted septic tank for the anaerobic treatment of black water. New Biotechnology, **30** (5), 573-580.
3. Zamalloa, C., Boon, N., Verstraete, W. (2012) Decentralized two-stage sewage treatment by chemical-biological flocculation combined with microalgae biofilm for nutrient immobilization in a roof installed parallel plate reactor. Bioresource Technology, **130** (0), 152-160.
4. Zamalloa, C., De Vrieze, J., Boon, N., Verstraete, W. (2012) Anaerobic digestibility of marine microalgae *Phaeodactylum tricornutum* in a lab-scale anaerobic membrane bioreactor. Appl. Microbiol. Biotechnol., **93**, 859-869.
5. Zamalloa, C., Boon, N., Verstraete, W. (2012) Anaerobic digestibility of *Scenedesmus obliquus* and *Phaeodactylum tricornutum* under mesophilic and thermophilic conditions. Appl. Energy, **92**, 733-738.
6. Zamalloa, C., Vulsteke E, Albrecht J, Verstraete W (2011) The techno-economic potential of renewable energy through the anaerobic digestion of microalgae. Bioresource Technol. **102** (2), 1149-1158.

Heger, Sara will provide practical field research experience relating to septic systems in MN, locate a demonstration site, facilitate the onsite design and provide extension on the applications. Here is her recent resume:

Funded Grants

1. On-Site Sewage Treatment Alternatives: Performance, Outreach & Demonstration 1995-2002.
2. 319 milkhouse waste treatment project: Milkhouse Wastewater Treatment Research and Demonstration 2001-2007.
3. Minnesota Pollution Control Agency Grant to Update Professional Training Manual, 2005-2008
4. Infiltrator Field Evaluation Gift, 2005-2006
5. Colorado School of Mines Residential Water Use Survey Grant, 2007-2008
6. USEPA and Texas A&M Installation Training Manual Development Grant, 2007 – 2009.
7. LCCMR BWSR Septic System and Milkhouse Wastewater Estimator Development 2012-2014
8. USDA NIFA Community Septic System Owner's Guide Grant 2013-2016
9. MnDOT Rest Stop Septic System Evaluation 2013-2014

Recent Publications

1. Heger, S.F., D.R. Schmidt and K.A. Janni. 2010. Aerobic and media filter treatment systems for milk house wastewater on small dairy operations. Applied Engineering in Agriculture.
2. Onsite Sewage Treatment Program. 2009. Manual for Septic System Professionals in Minnesota. University of Minnesota, Water Resource Center. St. Paul, MN.
3. CIDWT: S. Christopherson, N. Deal, D. Kalen, B. Lesikar, D. Lindbo, G. Loomis and R. Melton. 2009. Installation of Wastewater Treatment Systems. Midwest Plan Service. Iowa State University of Science and Technology.

4. Christopherson, S., Wheeler, D., Wittwer, J and T. Haeg. *2008.* Field Evaluation of Rock versus Chamber Trench Systems. *In Press Journal of Hydrologic Engineering*.
5. Christopherson, S. and D. Gustafson. 2006. Preliminary Evaluation of Cluster Septic Tank Performance. *In Proceedings of the 2006 National Onsite Wastewater Recycling Association (NOWRA) Conferenc*e, Denver, CO.
6. Christopherson, S. and J. Anderson. 2004. Twenty Years of Successful Onsite Wastewater Management – The Otter Tail, Minnesota Water Management District*. In Proceedings of the 2004 National Onsite Wastewater Recycling Association (NOWRA) Conferenc*e, Albuquerque, NM.
7. Christopherson, Sara, D. Schmidt, and K. Janni. 2004. Evaluation of Aerobic Treatment Units in Treating High Strength Waste From Dairy Milk Houses. Pp. 172 – 177. In proceedings of the *Tenth National Symposium on Individual and Small Community Sewage Systems*, (Sacramento, California USA), ed. Kyle R. Mankin.
8. Christopherson, S., David Schmidt and Kevin Janni. 2003. Evaluation and Demonstration of Treatment Options for Dairy Parlor and Milk House Wastewater. *Annual ASAE Proceedings, Las Vegas, NE*. Amer. Society of Agricultural Engineers, St. Joseph, Michigan. 49085-9659 USA.
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9. **Dissemination and Use** –

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 website www.septic.umn.edu for dissemination of the research along with over 40 workshops offered annually across Minnesota and the US. We will also work with the Minnesota Oniste Wastewater Association and the National Onsite Wastewater Recycling Association to provide this information at their annual onsite conferences and newsletters. 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 manufacturers of these small scale septic tank systems will also the audience of the technology.

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