Environment and Natural Resources Trust Fund
2015 Request for Proposals (RFP)

Project Title: **ENRTF ID: 097-E**

Electrochemical Micro-Aeration for Hydrogen Sulfide Removal from Biogas

Category: E. Air Quality, Climate Change, and Renewable Energy

Total Project Budget: $ 316,754

Proposed Project Time Period for the Funding Requested: 3 years, July 2015 - June 2018

Summary:

The project will develop a novel electrochemical micro-aeration process for removal of hydrogen sulfide from biogas to decrease its environmental impact and increase the techno-economic feasibility of anaerobic digestions

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Sponsoring Organization: U of MN

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Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

An illustration on how this electrochemical system works to remove hydrogen sulfide from biogas

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

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

_____ Capacity Readiness _____ Leverage _______ TOTAL

PROJECT TITLE: Electrochemical micro-aeration for hydrogen sulfide removal from biogas

I. PROJECT STATEMENT

MN has 67 operating anaerobic digesters treating organic wastes; wastes which may alternatively end up in landfills if not digested. We propose to develop an electrochemical micro-aeration system to remove hydrogen sulfide from biogas. Use of this technology will benefit all anaerobic digestion operations by minimizing the environmental impact of hydrogen sulfide and upgrading the biogas produced for better utilization.

Anaerobic digestion (AD) is a commercially available process that generates biogas from a wide range of organic-rich wastes, including livestock manure, food wastes, organic fraction of municipal solids, and activated sludge from wastewater treatment plants. AD is traditionally linked to agricultural manure management with 6-7 anaerobic digesters operating in the dairy farms in MN. The economic feasibility of these farm digesters relies heavily on the price paid for electricity produced. However, most anaerobic digesters are not located on farms and their operation is primarily driven by environmental causes because landfill space for organic wastes is becoming limited. The non-farm digesters rely on tipping fees for accepting food wastes, municipal solids and sludge to finance them. Interest in new anaerobic digesters has grown because many regions have banned the landfill of food wastes, including New York City, Northeastern states Massachusetts, Connecticut and Vermont, as well as West Coast cities such as Seattle, San Francisco and Portland.

Multiple techno-economic barriers prevent the further adoption of the anaerobic digestion. One of the most concerned issues is impurities in the biogas, mainly hydrogen sulfide (H_2S), which significantly decreases the value of the biogas and poses an environmental challenge. Organic wastes contain sulfate (SO_4^{2-}), which is reduced in the AD process by sulfate-reducing bacteria (SBR), e.g., *Desulfovibrio desulfuricans*, to either stay in liquid effluent as dissolved species including hydrogen sulfide, bisulfide (HS^-), and sulfide (S^{2-}), or emit into biogas as gaseous hydrogen sulfide. The accumulated hydrogen sulfide content in biogas generally lies in the range of 1,000 and 6,000 parts per million by volume (ppm). Hydrogen sulfide is odorous and toxic to exposed humans and animals, and corrosive to metal pipe, heating boilers, internal combustion engines, and some thermo-catalytic metals. Hydrogen sulfide must be completely or partially removed prior to use in most equipment, e.g., most engine warranties limit the concentrations of hydrogen sulfide up to 800 ppm. If it is not removed, sulfur oxides will be generated and emitted during combustion of biogas, and limits of these emissions are mandated by the MN Pollution Control Agency.

Current available technologies for hydrogen sulfide removal are mostly based on physico-chemical processes, such as adsorption and absorption of the hydrogen sulfide after digestion. These processes unavoidably associate with frequent sorbent/chemical addition and regeneration, resulting in high chemical and operation costs. In this study, we propose to eliminate hydrogen sulfide in biogas through the application of an electrochemical reactor. Electrochemical micro-aeration increases oxidation-reduction potential (ORP) in AD medium, so the activity of SRB is inhibited and hydrogen sulfide generation is reduced. Meanwhile, existing sulfides donate electrons to oxygen gas or anodes and eventually deposits elemental sulfur ready for removal from the digester. Compared to other physiochemical methods, this method is energetically effective, environmentally benign, and easy to operate.

II. DESCRIPTION OF PROJECT ACTIVITIES

Activity 1: H_2S removal: construction and optimization of lab-scale reactors. Budget: $137,634

The objective of this activity is to develop and implement an electrochemical reactor for hydrogen sulfide removal. This first activity will involve construction of lab scale reactors to test the operation and optimization of the hydrogen sulfide removal system. Electrode materials will be screened for high oxygen evolution reaction and sulfur deposition rate. Operational parameters, such as electrode surface area, applied voltage or current, medium oxidation-reduction potential, electrode cleaning cycle, will be optimized for sulfide removal. This first step is both challenging and time consuming because any changes to the system for optimization require time for system stabilization before results can be assessed.

Outcome	Completion Date
1. Effective electrode materials have been chosen at potentiostatic mode.	*Nov 1st, 2015*
2. Lab-scale reactor has been built and tested, and mechanisms elucidated.	*June 1st, 2016*
3. The operational parameters have been optimized.	*Dec 1st, 2016*

Activity 2: On site implementation and evaluation of sulfide removal. Budget: $110,497

The objective of this activity is to construct and evaluate a prototype reactor at a 5-10 liter scale on a dairy farm at Princeton, MN. Design and operational parameters acquired from activity 1 will be used for prototype implementation. The anaerobic digester at Princeton MN has a biogas utilization facility, originally constructed with the anaerobic digester to test biogas cleaning and utilization with a catalytic fuel cell. The facility is ideal to test the concept of this proposal as it has the plumbing, piping, and building already installed to do pilot scale testing. An agreement has been negotiated with the facility owner. The rental fees including utility costs have been included in the budget.

Outcome	Completion Date
1. Prototype has been designed and constructed.	*March 1st, 2017*
2. Prototype has been optimization and operated.	*Feb 1st, 2018*

Activity 3: Techno-economic analysis Budget: $48,409

A detailed technological and economic analysis of the proposed system using input data from literature and from the on-site evaluation will be carried out. The economic analysis will address commercial implementation of the system, including the size of facility required for commercial applications; the removal ratio of the hydrogen sulfide; expected construction costs for a commercial-scale facility; system useful life; and operating and maintenance costs. Long-term benefits will also be explored in the techno-economic analysis. With cleaned biogas, a possible business model will be suggested.

Outcome	Completion Date
1. Evaluation of capital and operational costs	*June 30th, 2018*

III. PROJECT STRATEGY

A. Project Team/Partners

The project team will include Dr. Hongjian Lin, David Schmidt, Dr. Kevin Janni and Dr. Bo Hu from Department of Bioproducts and Biosystems Engineering at University of Minnesota. Dr. Lin is a Postdoctoral Associate with expertise on the application of electrochemical systems for environmental protection and biogas cleaning. Schmidt is a research associate working on the anaerobic digestion and on-farm application. Janni is a professor, expert on the animal housing and livestock systems and Hu is the PI of the project, an assistant professor and expert on the bioprocess development.

B. Timeline Requirements

The project will be finished within 3 years, one and half years for lab-scale study and the remaining years for on-site implementation and evaluation as well as economic analysis.

C. Long-Term Strategy and Future Funding Needs

Minnesota has at least 67 operating anaerobic digesters and more are under construction to process organic wastes. The technology developed in this project will provide methods for those ADs to upgrade biogas quality by reducing hydrogen sulfide concentrations and generating a cleaner renewable energy. Once the process is proved to be feasible, large scale tests will be requested to demonstrate this technology to the industry.

2015 Detailed Project Budget

Project Title: [Electrochemical micro-aeration for hydrogen sulfide removal in biogas]

IV. 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. 75.32% of payment will be the salary and 24.68% will be the fringe benefits.	$ 37,067
Postdoc researcher, Dr. Hongjian Lin will be paid to execute the activities and provide technical expertise. 100% of time enployment will be covered for this position by the project, including 82.30% for the salary and 17.70% for the fringe benefits.	$ 150,219
Anaerobic digestion extension specialist , Mr. David Schmidt will be paid to provide practical field research experience relating to anaerobic digestion systems in MN, facilitate the onsite design and provide extension on the application of the research. Two month appointment will be paid with the project, including 74.68% for the salary and 25.32% for the fringe.	$ 58,802
Contracts:	$ -
Equipment/Tools/Supplies:	$ -
Lab scale reactors: Build two lab scale anaerobic digesters, one with electrochemical system and one without electrochemical system, in order to evaluate and test the ananerobic digestion under the effects of micro-aeration	$ 5,000
Onsite prototype at Princeton farm digestor: build a pilot scale anaerobic digestor with electrochemical micro-aeration system to test the hydrogen sulfide concentration and compare with the biogas generation at the digesters at Princeton MN	$ 28,000
Facility rental, including utility, for testing the prototype system at Princeton Farm for ten month	$ 9,000
Supply and chemicals to work in the lab and field for experiments and analysis	$ 21,636
Acquisition (Fee Title or Permanent Easements):	$ -
Travel: Travel to the digester at Princeton MN to take samples, build a onsite imprelimentation and evaluation system. 5 travels are planned per each project year and $200 per travel is budgeted. For the final year, one travel per week for 10 month are requested.	$ 7,030
Additional Budget Items:	$ -
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 316,754

V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period:	$ -	
Other State $ To Be Applied To Project During Project Period:	$ -	
In-kind Services During Project Period: *Unrecovered F&A at 52% MTDC*	$ 150,151	*Secured*
Funding History:	$ -	
Remaining $ From Current ENRTF Appropriation:	$ -	

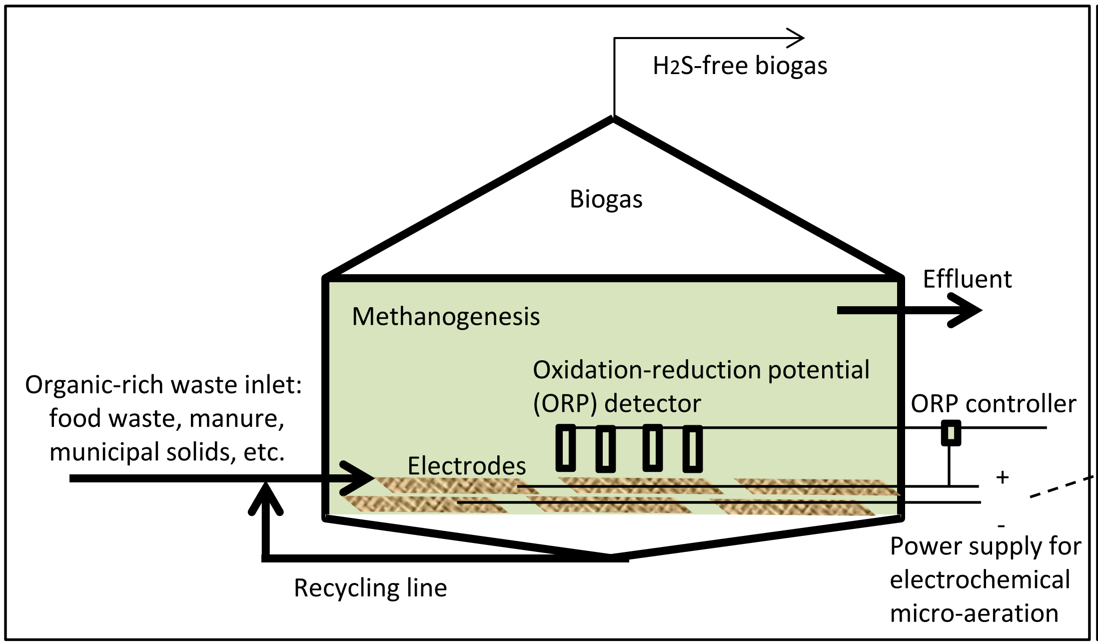
Electrochemical micro-aeration for hydrogen sulfide removal from biogas

Hongjian Lin, David Schmidt, Kevin Janni and Bo Hu
University of Minnesota

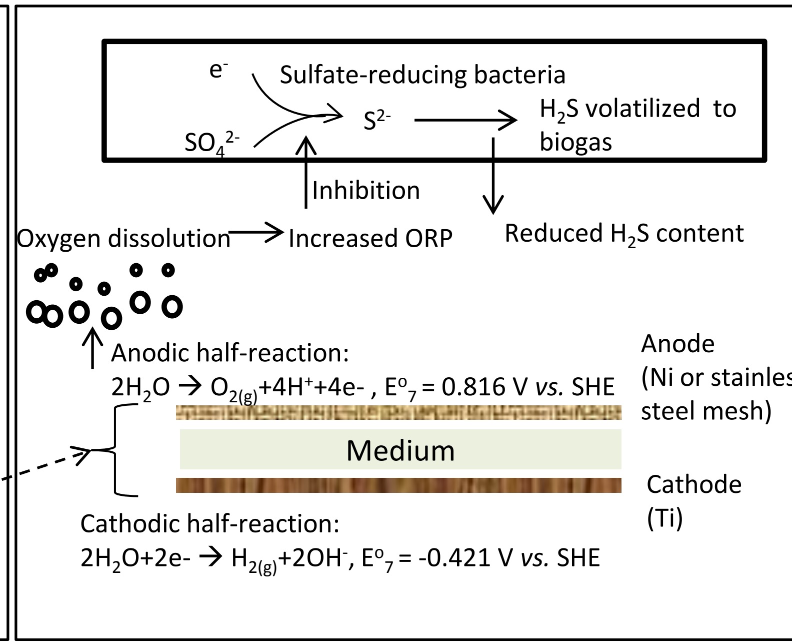
Environment and Natural Resources Trust Fund

No Landfill for Food Waste? Anaerobic Digestion is the solution, but its application is limited by the hydrogen sulfide in the biogas.

Key issue: Sulfate reducing bacteria, the hydrogen sulfide producers, are more sensitive to oxygen than methanogens, the methane producers. Providing small dose of oxygen will completely inhibit the hydrogen sulfide production, but will not affect the methane generation. How to precisely deliver oxygen to the anaerobic digestion is the key the proposed project wants to solve.



Electrochemical micro-aerated anaerobic digester



Electrochemical micro-aeration mechanism

Research goal: This project proposes to implement electrochemical micro-aeration reactors inside anaerobic digesters, for the purpose of hydrogen sulfide removal from biogas. The operation of the micro-aerator is automatically controlled by monitoring the oxidation-reduction potential of the anaerobic digestion medium, so the electrochemical reactor can be easily and precisely controlled. Successful application of this technology will benefit anaerobic digestion by minimizing the environmental impact from hydrogen sulfide and generating cleaner biogas for use in internal combustion engines, heating boilers, and fuel cells.

Project Manager Qualifications

The research team will include Dr. Hongjian Lin, David Schmidt, Dr. Kevin Janni and Dr. Bo Hu from Department of Bioproducts and Biosystems Engineering at University of Minnesota. Dr. Lin is a Postdoctoral Associate with expertise on the application of electrochemical systems for environmental protection and biogas cleaning. Schmidt is a research associate working on the anaerobic digestion and on-farm application. Janni is a professor, expert on the animal housing and livestock systems and Hu is the PI of the project.

With regard to technical expertise, **Dr. Bo Hu** is an Assistant Professor at the Department of Bioproducts and Biosystems Engineering of UMN. He is also a joint faculty member of Biotechnology Institute of UMN. With over 10 years of active research experience specifically in biomass utilization, fermentative conversion, and molecular biology, he has led projects on microbial oil production from waste materials via mixotrophic microalgae and oleaginous fungal fermentation, and projects to develop the modified anaerobic digestion system for biohydrogen production and its microbial community change by using 16s rDNA based microbial analysis. Hu's team at UMN has set up several standard procedures such as 16s rDNA fingerprint screening for microbial species in the wastewater treatment facilities, ITS sequences to identify oleaginous fungal species; and several conversion platforms such as pelletized fungal fermentation, solid and hemi- SolidSF to accumulate oil from lignocellulosic materials. His research ideas have been funded by many programs, especially local funding agencies such as MN Pork Board, IOWA Pork Board, MN Rapid Agricultural Response Program, etc. to tackle regional issues.

Dr. Hu's lab is located at BAE 320B, adjacent to Dr. Hu's office. The lab space is around 1000 sqft and it is equipped with two laminar flow hoods and one clean bench. The lab has all the necessary equipment and facilities for this project, including a refrigerated shaker, two open air shakers, one incubation shaker, two incubators, one fermentation bioreactor, GC-FID-TCD, PCR thermal cycler, several electrophoresis, centrifuge, and ovens. The research group can also utilize facilities and equipment at the **Biotechnology Resource Center** (BRC), on a pay-per-sample base. BRC is a 4,000 square-foot laboratory/pilot plant facility with state-of-the-art equipment for research and development in fermentation, animal cell culture technology, molecular biology, protein expression, and separation of a wide range of biological molecules.

Organization Description

Dr. Bo Hu joined the faculty at Department of Bioproducts and Biosystems Engineering of UMN in August 2009. As the core department of UMN to tackle Agricultural engineering and environmental engineering issues, Bioproducts and Biosystems Engineering Department has very dynamic research activities and numerous excellent scientific researchers have received grant supports from LCCMR program. The collaborative partner Sara Heger works with the Onsite Sewage Treatment Program at the Water Resource Center of UMN. 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. UMN Sponsored Projects Administration (SPA) will be the entity authorized by the Board of Regents to manage the project agreements with LCCMR program.