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

Date of Report: May 16, 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: Clean Water and Renewable Energy from Beet Processing Wastewater and Manure

Project Manager: Xiao Wu

Organization: University of Minnesota Southern Research and Outreach Center

Mailing Address: 35838 120th Street

City/State/Zip Code: Waseca, MN 56093

Telephone Number: (507)837-5625

Email Address: wuxxx199@umn.edu

Web Address: sroc.cfans.umn.edu

Location: Waseca, Statewide

Total ENRTF Project Budget:		
	ENRTF Appropriation:	**$400,000**
	Amount Spent:	**$0**
	Balance:	**$400,000**

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

Appropriation Language:
$400,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for the Southern Research and Outreach Center in Waseca to research the co-fermentation of sugar beet processing wastewater and swine manure for hydrogen and methane production and to install and evaluate a pilot-scale 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: Clean Water and Renewable Energy from Beet Processing Wastewater and Manure

II. PROJECT STATEMENT:

Minnesota is ranked #2 in hog production and #1 in sugar beet production in the nation, which generate about 11 million tons of pig manure and over 1 million tons of sugar processing wastes annually. Up to this date, there are no cost-effective methods available to deal with these waste streams environmentally and resourcefully other than land application, which, over the years, is linked to environmental issues in many places in the state due to the buildup of nutrients (nitrogen and phosphorus) in the soil receiving these two wastes, increasing the potential of surface and ground water pollution caused by nutrients runoff and/or leaching from overloaded soils. In early 2012, Minnesota became the nation's first test site for a novel federal program designed to stem the flow of agricultural pollution to water resources (http://phys.org/news/2012-01-strategy-farm-runoff-minnesota.html). Needless to say, this sounds an alarm that immediate actions must be taken to treat these wastes. However, treatment alone is not only expensive but fails to recover the resource values of both waste streams. In fact, the two wastes, i.e., sugar beet processing wastewater (containing molasses) and pig manure, have complementary nutrients, one having residual sugar which is an ideal carbon source highly needed in biological processes such as fermentation and anaerobic digestion, while the other having all the other nutrients but sugar for biological activities. Therefore, this proposal is aimed at using these two waste streams with complementary nutrients to produce bioenergy and reduce their negative impact on water resources. There are two sugar beet processing companies in MN (American Crystal Sugar Company and Southern Minnesota Sugar Cooperative) that produce all the sugars (the former has three facilities located in East Grand Forks, Moorhead, and Crookston, while the latter has one facility located in Renville, MN). There are also a total of around 4700 hog farms across the state but concentrated in the southern counties in Minnesota (see the attached concentration map). The proposed research project will address the environmental issues and produce bioenergy as indicated below.

- Land application of over 1 million tons of sugar processing wastewater threatens water resource
- Land application of over 11 million tons of pig manure increases surface and groundwater pollution
- $10 million can otherwise be saved for sugar beet processers annually for wastewater treatment
- Bio-electricity of 143 million kWh ($9.72 million) can be produced yearly from the two waste materials (at a ratio of 5 (pig manure) to 1 (sugarbeet wastewater))
- An alternative use of the produced hydrogen and methane is to produce “biohythane”, which is a better combustion engine fuel that can cut down on greenhouse gas emission by 57% when used in combustion engines (equivalent to 27 million gallons of diesel that can be produced annually); biohythane is a mixture of 10% hydrogen, 60% methane, and 30% carbon dioxide, which can be used for combustion engines on the farm, such as tractors, etc.
- 15,560 tons of ammonia/phosphate fertilizer (struvite) will also be produced annually ($5 mil value)

The proposed system flow chart is shown in figure 1 in the appendix. The specific objectives of this proposal will include 1) determining the optimal operating values of swine manure to molasses ratio, hydraulic retention time (HRT), and pH for a biohydrogen fermenter to maximize biohydrogen production; 2) determining the optimal operating values of organic loading rate, pH and HRT for an anaerobic sequencing batch reactor (ASBR) biomethane digester receiving the effluent from the biohydrogen fermenter to maximize biomethane generation and for the effectiveness in chemical oxygen demand (COD) reduction; 3) developing an absorption reactor to remove CO_2 from the biogases from either the biohydrogen fermenter or biomethane digester using alkaline chemicals as an absorbent; 4) developing a process to recover nitrogen and phosphorus in the digestate by forming struvite; and 5) based on the results of 1)-4), building and evaluating an integrated system consisting of a biohydrogen fermenter, a ASBR biomethane digester, a CO_2 removal reactor, and a struvite precipitator to co-treat swine manure and sugar waste molasses and harvest the biogases and fertilizer.

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: Biohydrogen and biomethane production processes development
Description: Anaerobic sequencing batch reactor (ASBR) systems for biohydrogen and biomethane production from the two waste streams will be built at the University of Minnesota Southern Research and Outreach Center (SROC) at Waseca. The reactor size for hydrogen generation will be 4 L with a working volume of 2 L, which will be completely mixed with pH controlled. The influent and effluent flows will be regulated in order to adjust the hydraulic retention time (HRT, h). Mixing, pH controller and pumps will be controlled by a programmable control module with its software capable of repeating a programed cycle operation in a time sequence. The ASBR will be run on 4-h cycles with 2.5 min each for feeding and discharging, 30 min for settling, and 205 min for reaction. The ASBR setup for biomethane production will be similar to that of the hydrogen-producing reactor, only with larger reactor size of 10L with a working volume of 5L. The effluent from biohydrogen reactor will be used as influent for biomethane reactor. Reactor systems will be startup and operated for stable and continuous operation.

The reactors will be seeded with biohydrogen/methane-producing sludge obtained from a local wastewater treatment plant/anaerobic digester. Gas and liquid samples will be collected at respective sampling ports. The amount of gas produced will be recorded using a wet gas meter. Gas sampling will be conducted every day and gas analysis will include biohydrogen, biomethane, and CO_2 using a gas chromatography. The liquid samples will be taken at the same time intervals as in gas sampling for analysis of chemical oxygen demand (COD), total solids (TS), total volatile solids (TVS), total suspended solids (TSS), volatile suspended solids (VSS), volatile fatty acids (VFAs), sugar content, and total Kjeldahl nitrogen (TKN) following the Standard Methods.

Key operational parameters for hydrogen production (pH, HRT, substrate TS level) and methane production (pH, HRT), each with 5 levels will be tested to determine the optimal combination conditions for a particular substrate. Optimum values of pH, HRT and TS level for the ASBR system in terms of biogas production rate (L/d/L), hydrogen/methane production rate (L/d/L), hydrogen/methane content (%) and hydrogen/methane yield (L/g major substrate) will be obtained using a central composite design (CCD) coupled with response surface methodology. Second order (quadratic) models for each response variable will be established for predicting the response value for different operational conditions.

Summary Budget Information for Activity 1: **ENRTF Budget: $ 175,735**
Amount Spent: $ 0
Balance: $ 175,735

Activity Completion Date: Dec. 31, 2015

Outcome	**Completion Date**	**Budget**
1. ASBR reactor setup for biohydrogen production finished	Oct. 1, 2014	$30,013
2. Optimal condition for continuous biohydrogen production reported	June 30, 2015	$50,242
3. ASBR reactor setup for biomethane production finished	June 30, 2015	$50,001
4. Optimal condition for continuous biomethane production reported	Dec. 31, 2015	$45,479

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: Gas cleaning and struvite recovery processes development

Description: The chemical scrubber (gas cleaning reactor) will be fabricated from an acrylic column (10 cm in diameter, 122 cm in height) equipped with pumps and gauges to move the absorbent and biogas through the system at desired flow rates. The absorption column will be packed with a packing material (named "plastic bioball") to a height of 100 cm to facilitate gas/liquid interaction, which is ideal for applications where efficient gas/liquid interaction is needed. The gas will be continuously fed from the bottom while the absorbent will be sprayed from the top of the reactor, creating a counter current flow to improve the gas/liquid contact for the biogas purification process. The absorbent will be circulated between the reactor and a reservoir (20 L liquid volume) by means of a pump. The flow rate of both liquid and biogas will be controlled to achieve effective CO_2 removal. The pH of the absorbent reservoir will be monitored and recorded to determine the time elapsed between absorbent replacements when the pollutants approach saturation. NaOH (0.1 M) solution will be used as the absorbent for this study, due to relatively low cost and availability in bulk volumes.

The experiment will be carried out in two phases, starting with a batch phase to investigate the effect of different gas/liquid flow rate ratios, followed by a continuous phase to evaluate CO_2 removal. The best liquid flow rate will be obtained by slowly adjusting the flow rate to a level when a smooth liquid film coming out of the absorbent spaying nozzle is observed (a few more nozzles of different size may be tested to accommodate potential different gas flow rates). With the liquid flow rate determined, five ratios of gas to liquid flow rate (e.g., 0.6, 0.8, 1.0, 1.2, and 1.4) will then be examined with respect to its performance in removing CO_2 and H_2S from the biogas to determine the optimal ratio. In continuous operation, percentages of the total volume in the NaOH reservoir and replacing time intervals (e.g., % saturation time) will be determined and examined via a 4x4 factorial experimental design to find the best combination of these two variables in achieving a good removal efficiency for the treated biogas, while keeping the replacement of absorbent at a reasonable frequency.

The struvite precipitator will be built in cone shape, 25.4 cm in diameter and 106.7 cm in height (working height: 90 cm), with a bottom to collect settled struvite. It will consist of a center section (5 in. in diameter, working as draft-tube type) and a peripheral section. The effluent from biomethane reactor will be continuously added into the draft tube. The pH in the reaction section will be controlled automatically by a pH controller. The generated struvite will be separated from the effluent in the peripheral section outside the draft tube by gravity separation and settle to the bottom of the precipitator for removal. The recovered struvite will then be dewatered from the small amount of solution, which is lost when the crystals are removed, by natural drying. An influent flow rate of 2 L/min (may be adjusted if needed) will be employed to feed the struvite precipitator, leading to an HRT of 23 min.

Several airflow rates such as 5, 10, 15, and 20 L/min will be tried first to determine an appropriate aeration rate to be used in the experimental runs, and once started, aeration will be provided continuously. pH and the molar ratio of $Mg^{2+}/PO_4^{3-}/NH_4^+$ in the liquid play a decisive role in struvite precipitation, a 4x4 factorial experimental design will be adopted to examine their interacting effect on the process performance and optimal combination of ion ratio and pH will be determined.

Summary Budget Information for Activity 2: **ENRTF Budget: $ 148,924**
Amount Spent: $ 0
Balance: $ 148,924

Activity Completion Date: Dec. 31, 2016

Outcome	Completion Date	Budget
1. Biogas cleaning reactor setup finished	Dec. 31, 2015	$45,479
2. Optimal condition for CO_2/H_2S removal reported	June 30, 2016	$32,158
3. Struvite precipitator setup finished	June 30, 2016	$45,479
4. Optimal condition for struvite production reported	Dec. 31, 2016	$25,808

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: System integration and evaluation
Description: With all the component units of the proposed system for co-treating swine manure and sugar waste molasses developed and tested with their respective optimum operating conditions determined, the entire treatment system according to Figure 1 will be assembled for evaluation. The resize of each component will be considered based on their throughput capacities. A centralized and integrated computer control system with software will be constructed to coordinately operate the treatment system in terms of controlling pH, temperature, influent and effluent flow rates, gas flow rates, pumps, mixers, and data logging according to the design for each individual unit.

The evaluation of the integrated system will be carried out in three aspects. First, the performance of the system in treating two wastewaters in reducing organic pollutants will be examined in terms of removals of COD, TN, TP, and solids and the throughput capacity. Second, the net energy recovery of the system will be evaluated according to energy produced less consumed. The energy consumed will include electricity used for heating and running all the component units, including the chemicals used (equivalent). The energy gained will include the energy contained in the final products such as the cleaned biohydrogen, biomethane, and struvite (equivalent). Also, the GHG (CO_2) removed through the treatment process will be considered a gain as opposed to the same amount of energy needed to remove it (1.36 kg CO_2 equiv./kWh). Third, the costs of constructing and operating the full-scale treatment system will be calculated based on which the potential revenues (values of different products) and the initial capital investment can be estimated.

Summary Budget Information for Activity 3: **ENRTF Budget: $ 75,341**
Amount Spent: $ 0
Balance: $ 75,341

Activity Completion Date: June 30, 2017

Outcome	Completion Date	Budget
1. Integrated system construction and assembling finished	Dec. 31, 2016	$32,158
2. Productivity of the integrated system evaluated and reported	June 30, 2017	$43,183

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: Successful publication and dissemination of project findings will be a key component of this proposal to maximize its impact, which will be achieved by sharing information with not only the scientific community but also the general public on a timely basis. In order for this to happen, the research outcomes will be presented in both technical and non-technical formats, including refereed journal publications for pundits and other outlets for lay people, aiming at distributing the information of this project not just in Minnesota but across the nation, and the world as well. Quantitatively, starting from the end of first year of the project, at least one manuscript will be generated and submitted for possible publication in refereed journals annually on the findings gained from the project. Concomitantly, two to three non-refereed publications will also be generated and published in trade magazines such as *The National Hog Farmer*, *Pork,* and *The Sugarbeet Grower Magazine*, or presented at technical symposia and professional conferences. In addition, a project *Newsletter* will be developed providing up-to-date information on the status of the project and made available to LCCMR commission members as well as all other concerned parties. The target audience of the outcome of this project includes, but not limited to, hog and sugar beet processors, agricultural engineers and consultants, state regulatory agencies, renewable energy industries, and the general public, within the state and across the country. A special field day for people in the concerned industries and the stakeholders will be organized at the end of the project to demonstrate the complete system for co-treating swine manure and sugar processing waste molasses. In the meantime, talks will be initiated to those interested in adopting the newly developed technology on their farms or plants to benefit their production and protect the environment. Finally, under the same token, the obtained information will potentially be included in the teaching materials for Biological Process Engineering and Renewable Energy Technologies courses, to educate our future scientists/engineers in a long run.

Status as of January 1, 2015:

Status as of July 1, 2015:

Status as of January 1, 2016**:**

Status as of July 1, 2016**:**

Status as of January 1, 2017:

Final Report Summary:

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	$ Amount	Explanation
Personnel:	$ 310,000	One 100% research associate for three years: salary: $166,916; fringe: $56,084; The research associate will be the PM of this project overseeing the entire project with responsibility in all aspects including developing test protocols, conducting experiments, and preparing materials for publications and information dissemination. One 100%-time postdoc associate for two years: salary: $71,079; fringe: $15,921; The postdoc will be responsible for the execution of the project by preparing and running experiments; setting up experimental apparatuses; sampling and data analysis; preparing manuscripts and other publications; and collecting and analyzing samples and data; helping the research associate with reporting as well.
Equipment/Tools/Supplies:	$84,000	$30,000 - supplies for constructing all the reactors including hydrogen fermenter, methane digester, biogas cleaning scrubber, struvite reactor and the size-adjusted integration system with all the control systems including reactor bodies, pumps, mixers, temperature and pH controllers, etc.; $54,000 - sample analysis and data processing costs including 400 gas samples for hydrogen, methane and carbon dioxide content analysis ($60 each) and 500 liquid samples for COD, BOD, nitrogen, phosphorus, solids level and VFA tests ($60 each).
Travel Expenses in MN:	$6,000	$6,000 - in-state travel from Waseca to Moorhead area to collect samples and run experiments for two people including meals and lodging during the three year period (estimated $500/trip x 12 trips).
TOTAL ENRTF BUDGET:	**$400,000**	

Explanation of Use of Classified Staff: N/A

Explanation of Capital Expenditures Greater Than $5,000: No capital requests are made for this proposal.

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 5 FTEs

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: None

B. Other Funds: N/A

VII. PROJECT STRATEGY:

A. Project Partners:

Project Partners Not Receiving Funds:

- Kevin Hennessy, MDA, providing assistance in information dissemination activities such as workshops, seminars, field days/tours, etc.
- Minnesota Sugar Beet Processors, American Crystal Sugar and MN Southern Sugar Beet Co-op, providing sugar beet processing wastewater for the experiment and participating in demonstration of the project outcome.

B. Project Impact and Long-term Strategy:

Whether future agriculture is able to meet the demand for quality food of the ever-growing global population hinges largely on its capability of minimizing the environmental footprint of food production by maximizing the recycling of the production wastes. As stated early on, Minnesota has two major waste streams (sugar beet processing wastewater and swine manure) that are deemed infeasible to be handled by conventional treatment systems because some of them require a large land space while others incur high capital and operational costs. In addition, most conventional treatments fail to recover the values of the wastes, thus providing little benefit in building a sustainable agriculture, especially when today's agriculture is facing the quandary of finite resources with a growing consumer base. As a result, these wastes must be recycled into value-added products to the extent possible, period. This is exactly what this project will achieve. The new treatment system proposed herein will use the nutrients contained in both waste streams in a complementary way to maximize their values and benefits by producing biohydrogen, biomethane, and fertilizer. In doing so, the pollutants in both waste streams can be reduced and, at the same time, with their values recovered. Therefore, the long-term impact of this project is to promote and establish sustainable agriculture in Minnesota by developing a novel treatment system to recycle the wastes generated from two major agricultural industries in the State into renewable products, thus conserving natural resources and maintaining environmental sustainability. This strategy presented by the proposed system will change the current swine manure management infrastructure by introducing an advanced manure treatment system that not only reduces the environmental impact of swine production but also offers the producers additional revenues. The proposed system also will provide the sugar beet processing industry with an environmentally friendly, better alternative in disposing of processing wastewater. Furthermore, the new paradigm stemming from this project will educate the vast majority of swine producers and sugar beet processors and turn them into environmental stewards and advocates for environmental sustainability, which is essential for the continued economic growth in Minnesota over the long haul.

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
		N/A			

VIII. ACQUISITION/RESTORATION LIST: N/A

IX. VISUAL ELEMENT or MAP(S): See attached maps.

X. ACQUISITION/RESTORATION REQUIREMENTS WORKSHEET: N/A

XI. RESEARCH ADDENDUM: N/A

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.

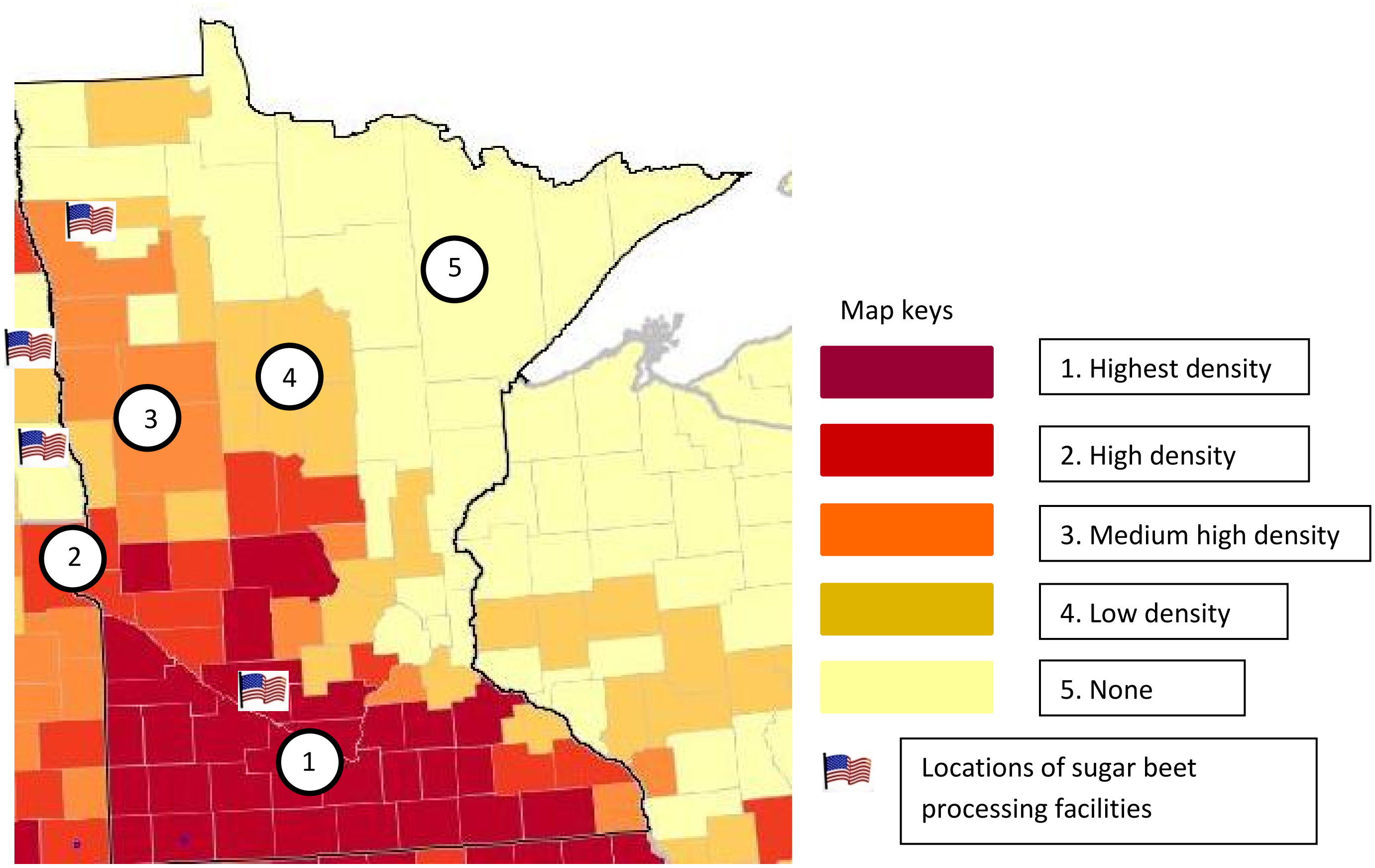
Environment and Natural Resources Trust Fund
M.L. 2014 Project Budget

Project Title: Clean Water and Renewable Energy from Beet Processing Wastewater and Manure
Legal Citation: M.L. 2014, Chp. 226, Sec. 2, Subd. 08f
Project Manager: Xiao Wu
Organization: University of Minnesota
M.L. 2014 ENRTF Appropriation: $400,000
Project Length and Completion Date: 3 Years, June 30, 2017
Date of Report: May 16, 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	***Lab-scale biohydrogen fermenter develop***			***Fill in your activity title here.***			***Fill in your activity title here.***				
Personnel (Wages and Benefits)	$130,735	$0	$130,735	$118,924	$0	$118,924	$60,341	$0	$60,341	$310,000	$310,000
Dr. Xiao Wu, Research Associate, Project Manager: $223,000 (75% salary, 25% benefits); one FTE for three years; The research associate will be the PM of this project overseeing the entire project with responsibility in all aspects including developing test protocols, conducting experiments, and preparing materials for publications and information dissemination.											
One 100%-time postdoc associate: $87,000 (81.7% salary, 18.3% benefits); one FTE for two years; The postdoc will be responsible for the execution of the project by preparing and running experiments; setting up experimental apparatuses; sampling and data analysis; preparing manuscripts and other publications; and collecting and analyzing samples and data; helping the research associate with reporting as well.											
Equipment/Tools/Supplies											
Purchasing parts and component for constructing all the reactors and systems including hydrogen fermenter, methane digester, biogas cleaning scrubber, struvite reactor and the size-adjusted integration system with all the control systems including reactor bodies, pumps, mixers, temperature and pH controllers, etc.: $20,000	$10,000	$0	$10,000	$6,700	$0	$6,700	$3,300	$0	$3,300	$20,000	$20,000
lab supplies: chemicals, tools, glasswares, gloves: $10,000	$5,000	$0	$5,000	$3,300	$0	$3,300	$1,700	$0	$1,700	$10,000	$10,000

sample analysis and data processing costs including 400 gas samples for hydrogen, methane and carbon dioxide content analysis ($60 each) and 500 liquid samples for COD, BOD, nitrogen, phosphorus, solids level and VFA tests ($60 each): $54,000	$27,000	$0	$27,000	$18,000	$0	$18,000	$9,000	$0	$9,000	$54,000	$54,000
Travel expenses in Minnesota	$3,000	$0	$3,000	$2,000	$0	$2,000	$1,000	$0	$1,000	$6,000	$6,000
mileage, lodging, meals for travel to and from sugar processing facilities and swine farms for substrates collection and data gathering											
COLUMN TOTAL	**$175,735**	**$0**	**$175,735**	**$148,924**	**$0**	**$148,924**	**$75,341**	**$0**	**$75,341**	**$400,000**	**$400,000**

Minnesota hog production distribution map



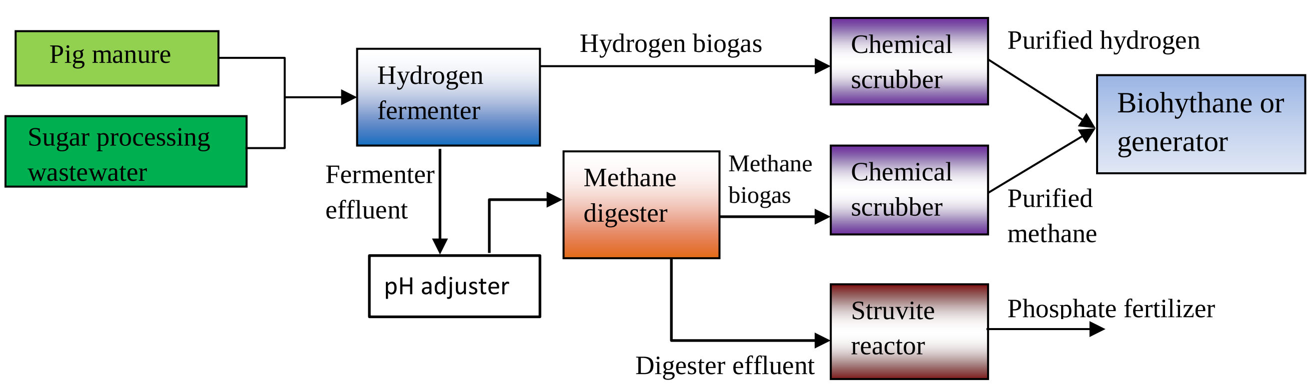


Figure 1. The schematic of the flowchart of the proposed treatment system