Environment and Natural Resources Trust Fund (ENRTF) M.L. 2016 Work Plan

Date of Report: December 4, 2015

Date of Next Status Update Report: January 1, 2017

Date of Work Plan Approval:

Project Completion Date: June 30, 2019

Does this submission include an amendment request? No

PROJECT TITLE: Utilization of Dairy Farm Wastewater for Sustainable Production

Project Manager: Bradley Heins

Organization: University of Minnesota

Mailing Address: 46352 State Hwy 329

City/State/Zip Code: Morris, MN 56267

Telephone Number: (320) 589-1711

Email Address: hein0106@umn.edu

Web Address: http://wcroc.cfans.umn.edu/research-programs/dairy

---

Location: Statewide

Total ENRTF Project Budget:	**ENRTF Appropriation:**	**$500,000**
	Amount Spent:	**$0**
	Balance:	**$500,000**

Legal Citation: M.L. 2016, Chp. xx, Sec. xx, Subd. xx

Appropriation Language:

I. PROJECT TITLE: Utilization of Dairy Farm Wastewater for Sustainable Production

II. PROJECT STATEMENT:

The dairy industry in Minnesota generates over $3.2 billion dollars in economic activity. However, the 450,000+ dairy cows on over 4,000 dairy farms in Minnesota generate a significant amount of waste. Dairy producers from across the state have manure lagoons on their farms to store all of the waste generated. Nutrient removal, in particular nitrogen and phosphorus, from wastewater is a growing regulatory need and the use of algae may create a unique amalgamation between dairy wastewater treatment and livestock feed production. This project will benefit all size dairy operations in Minnesota ranging from 50 to 500 cows. We will clean the dairy waste stream through algae production before it moves to farm fields and streams instead of applying the dairy waste directly to the land. This will reduce the environmental impact of dairy waste from entering streams and watersheds. Dairy producers will learn about the remediation of dairy farm wastewater through research, demonstration, and outreach experiences.

This project will develop and demonstrate an integrated facility to utilize and recycle nutrients from dairy farm wastewater, as well as carbon dioxide emissions on-site to simultaneously produce “green” energy, clean water, food, and livestock feed. Nutrient laden wastes are a direct result of the dairy industry in Minnesota. Dairy wastewater is comparatively poor in organic matter but typically rich in nitrogen and phosphorus. This wastewater is used to irrigate agricultural cropland; however, runoff of excess nitrogen and phosphorus leads to anthropogenic eutrophication of Minnesota watersheds and rivers. Reduction of the nitrogen and phosphorus in dairy wastewater through engineered alga and hydroponics systems will allow for more control of the nutrient content in cropland irrigation water while supply feed for livestock. Other systems partly fix the problem by removing some nutrients, such as organic matter or sulfur. Overall, an integrated approach is needed and the proposed system represents a more intelligent nutrient recycling strategy that mitigates adverse environmental consequences such as eutrophication and pollution of Minnesota watersheds.

Specifically, we will develop and evaluate a novel, integrated facility consisting of a microalgae photobioreactor, and hydroponic system, which will be operated next to an existing underground dairy wastewater lagoon. This combination of systems will be utilized to interrupt waste streams, by cleaning dairy wastewater before it flows to fields and streams from land application. Briefly, wastewater discharged from the lagoon contains substantial amounts of nutrients that are well suited to serve as a water and nutrient source for the integrated system, yielding growth of microalgae. Excess clean water after from the systems may be utilized for other applications (e.g. washing the dairy barn or irrigation). The outcomes of the proposed system will be clean water and air, and microalgae as a livestock feed. This project would be scalable to dairy farms of all sizes in Minnesota.

In addition, we will utilize the microalgae biomass produced from the system to conduct demonstrations directed at the potential use of microalgae as livestock feed for cattle and swine. Livestock feed is an opportunity for additional source of income for farmers adopting a green technology that doesn’t add cost of livestock production, but generates income. This technology will enable dairy producers to meet greenhouse gas emission reductions and other current and future environmental regulatory requirements. The West Central Research and Outreach Center in Morris, is uniquely positioned as an excellent resource to use for conducting this research because of its national prominence in research and outreach involving renewable energy, environmental sustainability, and alternative livestock production systems.

III. OVERALL PROJECT STATUS UPDATES:

Project Status as of *January 1, 2017*:

Project Status as of *July 1, 2017*:

Project Status as of *January 1, 2018*:

Project Status as of *July 1, 2018*:

Project Status as of *January 1, 2019*:

Overall Project Outcomes and Results:

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Development of an integrated system to recycle and more effectively utilize nutrients in dairy wastewater to reduce agricultural runoff.
Description:

We will develop an integrated system to utilize and treat dairy waste water and simultaneously produce green energy and feeds. Specifically, the system will consist of a bioreactor to recover energy and ammonia through thermophilic anaerobic digestion (AD) of dairy wastewater with consistent methane production and a minor vacuum to recover ammonia and remove odor, a photo-bioreactor (PBR) for algae cultivation, and a hydroponic bioreactor. The system is designed to facilitate several processes intended to fully utilize dairy wastewater and at the same time produce clean water. Due to the scaling down of the project, a smaller scale of the complete system will be developed and tested on the St. Paul campus to demonstrate the feasibility of the proposed concept and respective processes, as well as testing of algal strains to clean dairy wastewater. However, a reasonably large PBR and algal cultivation system for cleaning dairy wastewater will be developed and demonstrated on the West Central Research and Outreach Center dairy site.

Dairy wastewater contains a large amount of nitrogen which is turned into ammonia during fermentation. Ammonia is an inhibitor in AD process as well as algae growth. Therefore, it is beneficial to remove ammonia during the AD process and prior to algae cultivation. Furthermore, if ammonia could be recovered and used as fertilizer, substantial value is captured and air pollution is reduced. There are several methods to remove ammonia from dairy manure, including crystallization/precipitation, acidic solution-sprayed scrubbers and bio-filters, and chemicals such as acidified clays and sodium hydrogen sulfate, gas-permeable membrane extraction, etc. Some of these methods are promising, but have limited use due to high cost, lack of ammonia recovery for beneficial uses, and the complexity of operation.

We propose to implement a thermophilic process in combination with vacuum volatilization and acid absorption to not only remove ammonia from the digestate but also capture ammonia in the form of ammonium sulfate. Recently, control over the point sources of N and P shifted from removal to recovery, with a particular emphasis on improving the sustainability of agricultural activities. Global demand for the nitrogenous fertilizer has been increasing steadily. Therefore, the current attempts are not only to clean and reuse the water resources, but also to extract the maximum amounts of N from dairy manure.

Thermophilic AD, which has been well documented in the literature, is usually operated at about 55°C (131°F). At these elevated temperatures, the reaction rates in thermophilic AD are significantly higher than those in normal AD, and ammonia is produced at higher rates as well. To help ammonia escape from the liquid manure, we propose to apply low vacuum to draw ammonia out of the liquid and the AD bioreactor and inject the air stream into dilute sulfuric acid solution where ammonium sulfate will be produced. The solution containing ammonium sulfate can be used directly as liquid fertilizer or made into ammonium sulfate granules for convenient transport and storage. The value from production of ammonium sulfate is expected to at least offset the cost associated with raising temperature for thermophilic AD process. In this project, the costs of the proposed system and process will be evaluated and compared with normal AD process.

Figure 1 is a schematic illustration of the thermophilic AD bioreactor combined with vacuum volatilization and acid absorption. We have prior experience in designing and operating an AD reactor. For this project, we will construct a 100 gallon bioreactor with a heating and temperature control apparatus to maintain the necessary thermophilic conditions for AD. A 20 gallon absorption column will be constructed and placed next to the AD bioreactor. A vacuum pump will connect the AD bioreactor and the absorption column. The key process parameters to be studied and optimized will include AD temperature, pH, low vacuum, feed depth, cycle length. The yield and composition of biogas (methane), yield of ammonium sulfate, energy consumption, and the overall productivity will be evaluated.

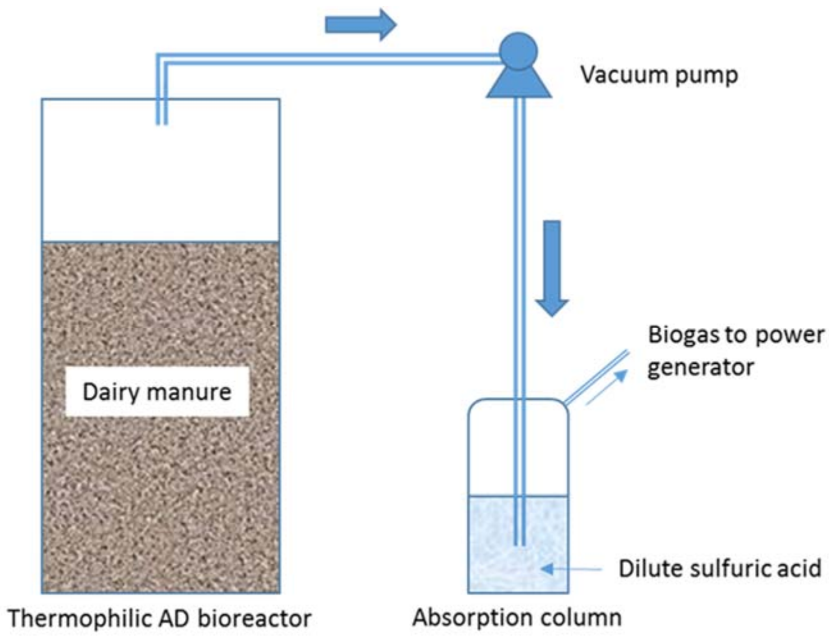

Figure 1. Thermophilic AD bioreactor with vacuum volatilization and acid absorption for ammonia removal and recovery.

Additionally, our previous research found that while algae utilize the carbon source in animal wastewaters quite effectively, one issue with these wastewaters is that there is insufficient carbon source to support complete utilization and removal of N and P, meaning that there will be 25-40% residual N and P in the culture broth after algae are removed. In order to fully utilize the resources in dairy wastewater, we proposed to incorporate a hydroponic bioreactor into the facility to grow vegetables and further utilize the residual N and P and clean the water for dairy housing wash, irrigation or discharged. We will source components and construct a hydroponic bioreactor in-house (Figure 2). We will evaluate this bioreactor's capacity of cleaning water through hydroponic production. The nutrient uptake will be monitored daily. The experience we obtained from another project involving an aquaponics system will guide us to maintain healthy growth of vegetables.

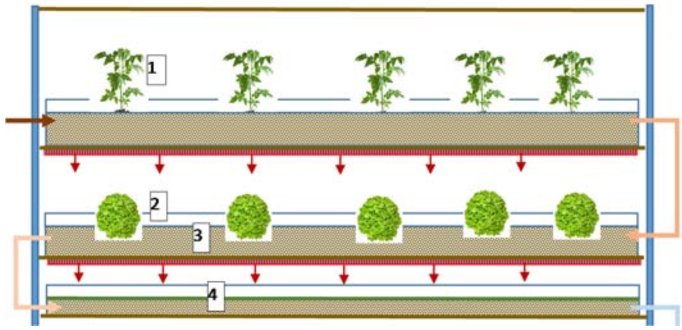

Figure 2. Hydroponic bioreactor for cultivating vegetables.

1. Tall plants, with 2-ft growth space.
2. Short plants with 1-ft growth space.
3. Gravel, fix the plant's root, bacteria, and filtration.
4. Sand filtration with algae attaching on the surface, 4-6 inch.

Summary Budget Information for Activity 1: **ENRTF Budget: $ 206,610**
Amount Spent: $ 0
Balance: $ 206,610

Outcome	Completion Date
1. Develop and optimize parameters and production of algae for the integrated facility to remove 25 to 40% of the residual nitrogen and phosphorus in dairy wastewater.	7/1/2017
2. Develop and test the microalgae photobioreactor and hydroponic systems to characterize the WCROC wastewater in terms of nitrogen, phosphorus, inorganic and organic carbon concentrations, and a complete micronutrient analysis.	7/1/2017
3. Integrate and test the facility to determine the efficacy and efficiency of the systems for screening of over 40 existing algal culture collections .	7/1/2017
4. Optimize nutrient removal rate of algae production system with dairy wastewater to clean 100% of dairy wastewater as it move from the algae production through the hydroponic system.	7/1/2017

Activity Status as of *January 1, 2017*:

Activity Status as of *July 1, 2017*:

Activity Status as of *January 1, 2018*:

Activity Status as of *July 1, 2018*:

Activity Status as of *January 1, 2019*:

Final Report Summary:

ACTIVITY 2: Evaluate the technical and environment impact of an integrated wastewater management facility at the research and outreach center in Morris and conduct algal feeding demonstrations with livestock.
Description:

A microalgae production system will be installed at the West Central Research and Outreach Center's dairy facility for the production of various microalgae strains for use in livestock feeds. Wastewater from the dairy will be utilized for the microalgae production system to produce quantities needed to conduct feeding trails and demonstrations of feeding diets containing microalgae to dairy and swine.

We will characterize the WCROC wastewater in terms of nitrogen, phosphorus, inorganic and organic carbon concentrations, and a complete micronutrient analysis. Additionally, we will isolate microalgae from WCROC wastewater capable of heterotrophic, mixotrophic, autotrophic growth using the nitrogen and phosphorus available from the wastewater. Care will be taken to monitor any strain for cyanotoxin production which could potential poison calves, pigs, and other livestock. Not any one strain is expected to perform all characteristics and community culturing or isolated culturing may be required; additionally, WCROC wastewater is different from other wastewater and strains will need to be optimized for production on it.

Screening of existing algal culture collections for known organisms capable of the properties discussed above will be conducted. We will scale growth of the top candidates to produce enough biomass to begin feeding studies. Outdoor cultivation is essential to ensure the feeding studies will represent algal strains that will actually be used in production. Optimization of the temporal and environmental influence on productive strains of algae will be implemented. We will implement a high productive system to optimize the selected strains for outdoor cultivation and treatment of WCROC wastewater. Selection of most suitable algae species will include their capacity for growth, biomass yield, and nutritional composition. Algae species will be sent for analysis of dry matter, crude protein, ether extract, starch, and neutral detergent fiber as well as calcium, phosphorus and heavy metals (i.e., Zn, Cu, Pb, Ni, Cd, As, Cr).

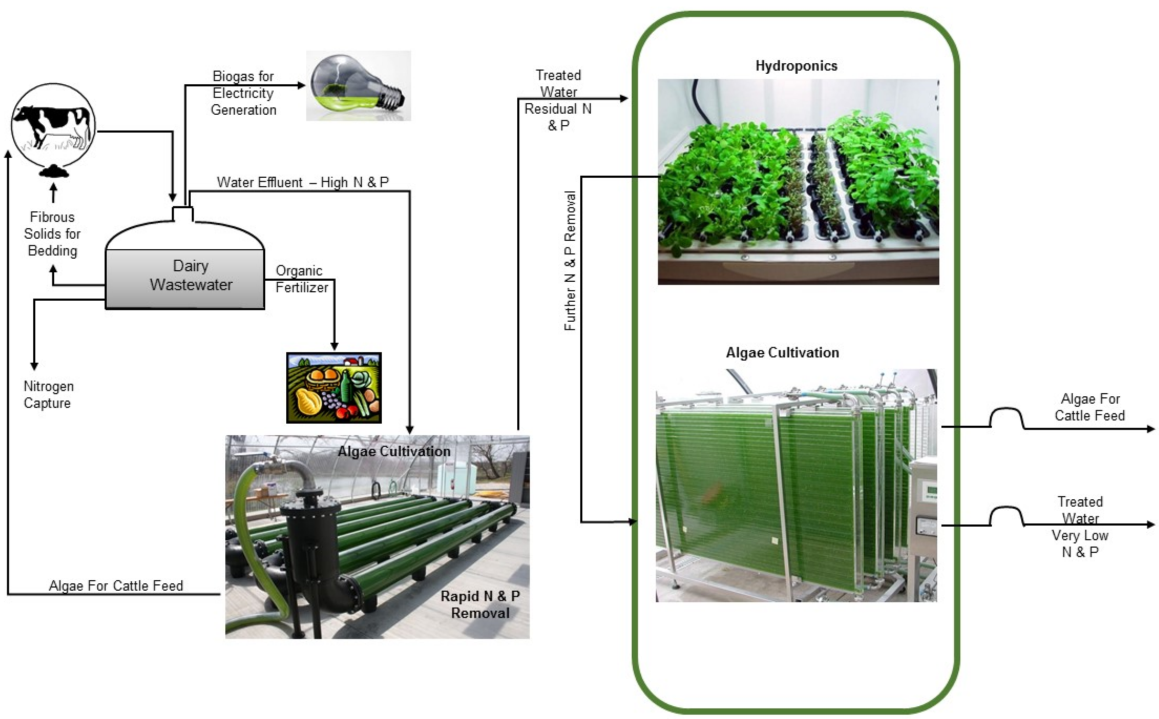

Figure 3. Fully scalable system to clean dairy wastewater, to recycle nutrients, and produce biomass algae for livestock feed.

Replicated feeding studies will be demonstrated and results verified using production strains from the outdoor WCROC wastewater system which has been optimized for high algal production and nitrogen/phosphorus removal. We will continue to demonstrate continual wastewater treatment and algal feed productivity.

For the algal feeding studies, the objective of this experiments will be to determine if calves prefer the taste of algae added to starter grain using the sequential elimination procedure. The algae will be added to calf starter grain and milk and mixed. The experiment will be conducted 1 calf at a time. A calf feeder will be used to determine the taste preference studies. The diets will be offered for 7 days, with the first 2 days used for adaptation to surroundings and day 3 to the end of day 7 used for data collection. After the third day of collection (day 5), the treatment with the overall greatest consumption will be removed and replaced by an empty container. During the last 2 day (day 6 and 7), the remaining treatments will be used to determine second preference.

Summary Budget Information for Activity 2: **ENRTF Budget: $ 280,890**
Amount Spent: $ 0
Balance: $ 280,980

Outcome	**Completion Date**
1. Install an algal production system to clean 20% of the dairy wastewater at the research center and produce biomass to feed at least 50 calves and 50 dairy cows.	7/1/2018
2. Graduate students will conduct three feeding trials with dairy calves on algae potential as a livestock feed at the research dairy.	7/1/2018
3. Evaluate the potential of feeding algae from the algal production system through an economic analysis to determine if feed costs can be reduced by 10% with algae.	7/1/2018
4. Evaluate the environmental impact of the dairy wastewater remediation system through measurement of the amount of dairy wastewater cleaned.	7/1/2018

Activity Status as of *January 1, 2017*:

Activity Status as of *July 1, 2017*:

Activity Status as of *January 1, 2018*:

Activity Status as of *July 1, 2018*:

Activity Status as of *January 1, 2019*:
Final Report Summary:

ACTIVITY 3: Educate producers and consumers about technology to recycle nutrients, prevent runoff and add value to nutrients in dairy wastewater.
Description:

We will develop a comprehensive extension program to educate producers, dairy professionals, and other stakeholders on the implementation of dairy wastewater efficiency, through the following activities: 1) Maintaining a web page within the University of Minnesota Dairy Extension websites throughout the project and beyond dedicated to dissemination of electronic information, 2) Disseminate results and educational information via social media (Facebook and YouTube, and 3) Present study results at extension and professional conferences in the state and region. For all outreach activities, we will solicit feedback using standard survey documents, and these surveys will determine the impacts of our activities on audience knowledge and farmers' behaviors related to adopting practices that reduce runoff of dairy wastewater to lakes and streams.

Summary Budget Information for Activity 3:	**ENRTF Budget:**	**$ 12,500**
	Amount Spent:	**$ 0**
	Balance:	**$ 12,500**

Outcome	**Completion Date**
1. Conduct workshops, webinars, and a WCROC field day each year of the integrated facility for producers.	6/30/2019
2. Prepare 5 Extension factsheets to inform stakeholders of the demonstration sites.	6/30/2019
3. Update the WCORC website every 6 months with an update on the dairy wastewater project	6/30/2019

Activity Status as of *January 1, 2017*:

Activity Status as of *July 1, 2017*:

Activity Status as of *January 1, 2018*:

Activity Status as of *July 1, 2018*:

Activity Status as of *January 1, 2019*:

Final Report Summary:

V. DISSEMINATION:
Description:

The most effective way to educate and motivate livestock producers to adopt new technologies is to demonstrate improved profitability and minimize the environmental impact of dairy wastewater. The results from Activity 1 and 2 will be used to demonstrate the potential of the microalgae system. The research and outreach center will be used as the demonstration site to showcase the opportunities to recycle nutrients and clean dairy wastewater, as well as generate new opportunities for the 5,000+ Minnesota dairy and pork producers to utilize a nutrient dense, alternative and sustainable feed ingredient. This activities are well within the capabilities of the WRCOC and the University of Minnesota.

Status as of *January 1, 2017*:

Status as of *July 1, 2017*:

Status as of *January 1, 2018*:

Status as of *July 1, 2018*:

Status as of *January 1, 2019*:

Final Report Summary:

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	$ Amount	Overview Explanation
Personnel:	$ 206,500	1 BBE research technician at 20% FTE for 3 years ($20,720); 1 ANSC research technician at 20% FTE for 3 years ($10,000); 2.25 graduate research assistants at 50% FTE each year for 3 years ($175,780)
Equipment/Tools/Supplies:	$261,500	Column, reagents, HPLC vial, chemical standards, biochemical kits for Chi Chen laboratory ($10,000); Supplies for scoping parameters for the photobioreactor system for Roger Ruan laboratory in Bioproducts and BioSystems Engineering; Supplies include bags, tubing, chemicals, racks, pumps, lights ($30,000); Small research facility and vacuum ammonia stripping for both ammonia sulfate production and enhancement of the wastewater process; supplies include piping and mechanisms for data collection for ammonia sulfate production for testing algae strains ($50,000); Algal cultivation system, centrifuge to harvest algae, pumps for moving water and wastewater throughout system at the WCROC Dairy; supplies for the system include Bags, pvc piping, compressor, heat sealer, filters, centrifuge, chemicals, metal racks, pumps, lights, electrical wiring, pH monitoring and control, CO2 sparging equipment and storage at the WCROC, Morris – The Morris system will be made from no parts costing more than $5,000 individually ($169,000); Costs include Extension programming, workshops, field days, factsheets, and dissemination of information at the WCROC ($2,500)
Capital Expenditures over $5,000:	$32,000	Automatic calf feeder and mixer for mixing algae with calf feed for feeding algae as a probiotic to pre-weaned dairy calves
TOTAL ENRTF BUDGET:	**$500,000**	

Explanation of Use of Classified Staff:

Explanation of Capital Expenditures Greater Than $5,000: One automatic calf feeder/mixer and supplies is being purchased and will continue to be used by the University of Minnesota WCROC for the life of the instrument for similar projects and purposes. If the instrument is sold prior to its useful life, proceeds from the sale will be paid back to the Environment and Natural Resources Trust Fund.

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 5.575

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: 3

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state			
University of Minnesota (In-kind support)	$260,000	$0	The 52% foregone federally negotiated ICR funding constitutes the University of Minnesota cost share to the project.
State	$0	$0	
TOTAL OTHER FUNDS:	**$260,000**	**$0**	

VII. PROJECT STRATEGY:

A. Project Partners:

Bradley Heins, U of MN Dairy Scientist, will serve as PI and project manager. He will be responsible for all reports and deliverables. He will also manage the activities of the dairy production system at the WCROC, conduct feeding trials, and manage the demonstration dairy site. Rob Gardner (U of MN Renewable Energy Scientist) will develop the microalgae system at the WCROC. Roger Ruan and Paul Chen (U of MN Bioproducts and Biosystems engineers) will design and develop integrated system for testing and demonstration. Gerald Shurson and Pedro Urriola (U of MN Swine Scientists) will be responsible for assisting with livestock feeding trials to demonstrate the nutritional value of microalgae. Chi Chen (U of MN Nutrition Scientist) will analyze the nutrient content of the products to characterize nutritional effects of algae from this system.

B. Project Impact and Long-term Strategy:

The overall goal of the project is to develop and demonstrate a technology that will recycle nutrients and add value to nutrients in wastewater from dairy farms in Minnesota to reduce environmental impact. This collaborative project will build on current algal and nutritional activities of the project investigators. The proposed project does not need additional investment other than funding requested from the ENRTF to be completed. Additional long-term funding will be sought to conduct research to integrate this facility within large livestock operations within Minnesota. It may be necessary to acquire federal funding before large scale demonstrations of the integrated facility may be commercialized.

C. Funding History:

N/A

VIII. FEE TITLE ACQUISITION/CONSERVATION EASEMENT/RESTORATION REQUIREMENTS:

N/A

A. Parcel List:

N/A

B. Acquisition/Restoration Information:

N/A

IX. VISUAL COMPONENT or MAP(S):

X. RESEARCH ADDENDUM: N/A

XI. REPORTING REQUIREMENTS:

Periodic work plan status update reports will be submitted no later than January 1, 2017; July 1, 2017; January 1, 2018; July 1, 2018 and January 1, 2019. A final report and associated products will be submitted between June 30 and August 15, 2019.

Environment and Natural Resources Trust Fund
M.L. 2016 Project Budget

Project Title: *Utilization of Dairy Farm Wastewater for Sustainable Production*
Legal Citation:
Project Manager: *Bradley Heins*
Organization: *University of Minnesota*
M.L. 2016 ENRTF Appropriation: $500,000
Project Length and Completion Date: *F: 3 Years, June 30, 2019*
Date of Report: *December 4, 2015*

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	***Develop and Test Integrated Dairy Wastewater System***			***Evaluate environmental impact and livestock algal feeding***			***Dissemination and Extension of Results***				
Personnel (Wages and Benefits)	$121,610		$121,610	$84,890		$84,890	$0		$0	$206,500	$206,500
Paul Chen, 6% FTE in year 1, 2, and 3; 33.7% fringe rate; estimated $20, 720											
Pedro Urriola, 2.7% FTE in year 1, 2, and 3; 33.7% fringe rate; estimated $10,000											
Bioproducts and Biosystems Engineering Graduate research assistant for 2 years; 17.60% fringe, plus tuition remission during the academic year and 17.60% fringe summer; estimated $85,910											
Animal Science Graduate Research Assistant for 2 years; 17.60% fringe, plus tuition remission during the academic year and 17.60% fringe summer; estimated $79,890											
Food Science partial graduate research assistant; 17.60% fringe, plus tuition remission during the academic year and 17.60% fringe summer; estimated $9,980											
Equipment/Tools/Supplies	$90,000		$90,000	$169,000		$169,000	$2,500		$2,500	$261,500	$261,500
Column, reagents, HPLC vial, chemical standards, biochemical kits for Chi Chen laboratory in Food Science	$10,000									$10,000	$10,000
Supplies for scoping parameters for the photobioreactor system for Roger Ruan laboratory in Bioproducts and BioSystems Engineering; Supplies include bags, tubing, chemicals, racks, pumps, lights	$30,000									$30,000	$30,000
Small research facility and vacuum ammonia stripping for both ammonia sulfate production and enhancement of the wastewater process; supplies include piping and mechanisms for data collection for ammonia sulfate production for testing algae strains	$50,000									$50,000	$50,000
Algal cultivation system, centrifuge to harvest algae, pumps for moving water and wastewater throughout system at the WCROC Dairy; supplies for the system include Bags, pvc piping, compressor, heat sealer, filters, centrifuge, chemicals, metal racks, pumps, lights, electrical wiring, pH monitoring and control, CO2 sparging equipment and storage.				$169,000						$169,000	$169,000
Costs include Extension programming, workshops, field days, factsheets, and dissemination of information at the WCROC							$2,500			$2,500	$2,500
Capital Expenditures Over $5,000				$32,000		$32,000				$32,000	$32,000
Automatic calf feeder and mixer for mixing algae with calf feed for feeding algae as a probiotic to pre-weaned dairy calves				$32,000						$32,000	$32,000
COLUMN TOTAL	**$211,610**	**$0**	**$211,610**	**$285,890**	**$0**	**$285,890**	**$2,500**	**$0**	**$2,500**	$500,000	**$500,000**