Environment and Natural Resources Trust Fund

2025 Request for Proposal

General Information

Proposal ID: 2025-207

Proposal Title: Sustainable Manipulation to Reduce Dairy Methane Emissions

Project Manager Information

Name: Roger Ruan

Organization: U of MN - College of Food, Agricultural and Natural Resource Sciences

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Project Basic Information

Project Summary: This project will utilize in vitro simulation systems and prediction models to assess the potential of live microalgae as feed additives for regulating and mitigating dairy methane emissions.

ENRTF Funds Requested: $250,000

Proposed Project Completion: June 30, 2027

LCCMR Funding Category: Small Projects (H)

Secondary Category: Air Quality, Climate Change, and Renewable Energy (E)

Project Location

What is the best scale for describing where your work will take place?

Statewide

What is the best scale to describe the area impacted by your work?

Statewide

When will the work impact occur?

During the Project and In the Future

Narrative

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

Biogenic methane is a severely underestimated greenhouse gas which causes at least 25 % of current global warming, with a global warming potential over 28 times that of CO2. Minnesota ranks the top dairy producers in the United States, boasting nearly 500,000 dairy cows. Methane and odor emissions from dairy cow farming poses a significant threat to local habits and livelihoods in Minnesota. Therefore, effectively reducing methane emissions from livestock farms at no net cost becomes a crucial research priority and an urgent necessity for long-term sustainable development. Microalgae have gained interests as potential feed additives in livestock diets, primarily serving as prebiotics to mitigate methane emissions. However, this approach is hindered by its high harvesting costs and limited efficiency in large-scale applications. Utilizing live microalgae as probiotics and metabiotics, in addition to prebiotics, presents an effective and sustainable strategy for reducing methane emissions and ruminant odors through dietary and rumen manipulation. Despite the potential benefits, research in this area remains sparse. This research project aims to fill the gap and facilitate the large-scale, cost-effective reduction of methane emissions from livestock farms, thereby fostering long-term sustainable development.

What is your proposed solution to the problem or opportunity discussed above? Introduce us to the work you are seeking funding to do. You will be asked to expand on this proposed solution in Activities & Milestones.

Our proposed solution aims to explore the potential of live microalgae as probiotics and/or metabiotics, in addition to as prebiotics, for the regulation and inhibition of methanogens to reduce methane and odor emissions. The solution includes: (1) Microalgal performance improvement: We have an adaptive microalgal Chlorella species preserved in our lab, capable of utilizing anaerobic digestion effluent with high concentrations of volatile fatty acids (VFAs, above 25 g/L) for cell growth. We will employ tolerance engineering-based approaches coupled with culture optimization to improve VFA utilization performance. Additionally, we will profile and qualify biochemical and bioactive compounds accordingly. Furthermore, we will conduct experiments involving sole and/or co-cultures of microalgae and methanogens under anaerobic conditions to assess the impacts of live microalgae on microbial growth and methane emissions. (2) In vitro simulation and prediction: A lab-scale biological system based on the rumen simulation technique will be used to simulate enteric fermentation. Diets containing different ratios of live microalgae and microalgal powder and will be digested in this system to evaluate methane and odor reduction in vitro. Furthermore, we will develop methane prediction models to assess and compare the effects of live microalgae as feed additives on the reduction.

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state's natural resources?

The long-term outcomes aim to utilize live microalgae as prebiotics, probiotics, and metabiotics in large-scale livestock farming to significantly mitigate methane emissions, as well as alleviate nitrogen and sulfur odors. Specific outcomes contain: (1) Enhancing the performance of microalgal species identified in our previous research to grow on VFAs and accumulate various compounds with potential for rumen manipulation; (2) Developing and optimizing in vitro rumen simulation systems along with predictive models to investigate and compare the effects of live microalgae as additives in cow feed. This aims to regulate and inhibit methanogenic archaea, reducing odor and methane emissions.

Activities and Milestones

Activity 1: Enhancing microalgal performance to improve VFAs utilization and accumulation of antimethanogenic compounds

Activity Budget: $100,000

Activity Description:
Identify and collect organic wastes from local farms (dairies, hogs, turkeys, chickens) and local restaurants, groceries, and institutional food facilities. Blend these wastes appropriately into a mixed feedstock, and carry out proximate and ultimate analyses to assure a proper mixture of ingredients to support healthy anaerobic bacteria culture; this is not a one-time activity, but an ongoing process to continuously supply the fermenter for the life of the project. We will include challenging feedstocks that need special attention, to assure they do not continue to be discarded in landfills, or simply added to WWTP influent. Test and integrate pretreatment methods of the feedstock mixture to maximize the utilization of the organic wastes during AD processing, and minimize the remaining COD in the effluent stream.

Activity Milestones:

Description	Approximate Completion Date
Utilize multiple approaches to enhance microalgae to utilize VFAs	August 31, 2025
Analysis of microalgal biomass composition and antimethanogenic compounds	October 31, 2025
Sole and co-cultures of microalgae and methanogens and to investigate their interactions	December 31, 2025

Activity 2: In vitro simulation of enteric fermentation to assess the potential of live microalgae in mitigating methane emissions

Activity Budget: $140,000

Activity Description:
As Activity 1 continues to document the productivity of the biogas and bio-methane, Activity 2 will begin to address the effluent stream from the digester. The volume, COD, proximate and ultimate analyses, will be measured for the effluent. Its suitability for supplying nutrients for aerobic and hydroponic/algae processing will be evaluated. After being used in these downstream processes, the final effluent analyses such as COD, volatile solids, and dissolved solids, will be evaluated. Biochar filtration will be used to further remove pollutants if necessary. The goal of Activity 2 is to demonstrate that the final effluent, after AD and additional downstream processing, can be discharged into a WWTP with minimal COD, or even discharged to a local river within standard environmental WWTP discharge limits.

Activity Milestones:

Description	Approximate Completion Date
Develop lab-scale rumen simulation systems	March 31, 2026
In vitro comparisons of live microalgae and microalgal powder in simulated rumen apparatuses	June 30, 2026
Correlation analysis to investigate and compare live microalgae as feed additives for methane reduction	October 31, 2026

Activity 3: Development of prediction models for comparisons and enhancement of methane reduction

Activity Budget: $10,000

Activity Description:
Methane prediction models will be developed to characterize enteric fermentation and assess the impact of live

microalgae and microalgal powder on the emissions of methane and odors. We previously employed modeling and simulation techniques for the pilot Concentrated high-intensity electric field (CHIEF) system, estimating intrinsic liquid flow behavior, electric field strength, and heat transfer within the system. In this study, newly developed models will be employed to find the feed additives with the best performance and explore the potential functions of live microalgae as prebiotics, probiotics, and metabiotics in influencing rumen microbiota without compromising animal health and production. They will also be utilized to predict enteric emissions of methane and odors through inhibiting methanogenic archaea through competition for substrates and antimethanogenic chemical inhibition. Furthermore, these models will be compared with existing empirical models to compare prediction performance and enhance their predictive accuracy. All the experimental data will be analyzed and used to provide valuable information for mitigating methane and odor emissions from livestock farms for long-term sustainable development.

Activity Milestones:

Description	Approximate Completion Date
Develop methane prediction models	December 31, 2026
Comparisons of prediction models with existing empirical models	March 31, 2027
Data analysis to estimate the strategy for commercialization and provide further R&D recommendations	June 30, 2027

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this work be funded?

Following the project completion, microalgae-based dietary management and rumen manipulation will be established for future implementation in livestock farming, aiming at mitigating global warming effects. Furthermore, advanced simulation and prediction models will be developed to monitor rumen digestion and forecast methane emissions from dairy cows. We will seek additional funding options and conduct long-term research to facilitate the implementation and demonstration of our approach at the field scale, targeting the reduction of methane and odors emissions from livestock farms in Minnesota. This project will significantly contribute to sustainable livestock farming practices with less environmental impacts in a long term.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Methods to Destroy PFAS in Landfill Leachates	M.L. 2022, , Chp. 94, Art. , Sec. 2, Subd. 04a	$200,000

Project Manager and Organization Qualifications

Project Manager Name: Roger Ruan

Job Title: Professor and Director

Provide description of the project manager's qualifications to manage the proposed project.

Dr. Roger Ruan is a Fellow of the National Academy of Inventors, the American Society of Agricultural and Biological Engineers, the Institute of Food Technologists, the International Association of Advanced Materials, and Vebleo, and have received many other awards, including International Bioprocessing Association's Pandey Award, CAFS Professional Achievement, Scientist of IAAM, etc. Dr. Ruan's research areas include renewable energy and environment technologies for sustainable development and circular economy. His research has focused on biomass and solid wastes such as plastic wastes pyrolysis and gasification for chemicals, materials, fuels, and energy production; wastewater treatment and utilization through novel anaerobic digestion, microalgae cultivation; airborne and other pathogen disinfection and pollutant control; innovative catalytic non-thermal plasma, low temperature microwave and pulse microwave, photocatalytic intensive pulse light, and NMR/MRI technologies development and applications in nitrogen fixation, food safety assurance, and food quality improvement; and food engineering and various value-added processing. Dr. Ruan has published over 600 papers in refereed journals, two books, and 28 book chapters, and holds 19 US patents. He is also a top-cited author in engineering and technologies, with an h-index of 96, i10-index of 480, and over 37,000 citations. He has received over 200 projects totaling over $45 million in various funding for research, including major funding from USDA, DOE, DOT, DOD, LCCMR, and industries. He was the project manager of several earlier LCCMR funded projects which resulted in the issuance of US patents and licensing of technologies. He has the technical expertise and project management experience to ensure the execution of proposed project.

Organization: U of MN - College of Food, Agricultural and Natural Resource Sciences

Organization Description:

The Center for Biorefining is a University of Minnesota research center and help coordinate University efforts and resources to conduct exploratory fundamental and applied research; provide education on bioenergy, biochemicals and biomaterials; stimulate collaboration among the University researchers, other public sector investigators, and private investigators in biobased production technology development; promote technology transfer to industries; and foster

economic development in rural areas. The Center's research programs have been founded by DOE, USDA, DOT, DOD, LCCMR, IREE, Xcel Energy, and other federal and state agencies, NGOs, and private companies. The Center is equipped with state of the arts analytical instruments, and processing facilities ranging from bench to pilot scale.

The Department of Bioproducts and Biosystems Engineering, in CFANS, discovers and teaches solutions for the sustainable use of renewable resources and the enhancement of the environment. We discover innovative solutions to address challenges in the sustainable production and consumption of food, feed, fiber, materials, and chemicals by integrating engineering, science, technology, and management into all degree programs.

https://bbe.umn.edu/biobrief

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Professor/Faculty		PI - summer salary			37.1%	0.1		$27,831
Professional Researcher		Manage lab, develop methodology, conduct research and analysis			37.1%	1		$83,494
Post doctoral researcher		research			27.1%	1.5		$129,007
							Sub Total	**$240,332**
Contracts and Services								
							Sub Total	**-**
Equipment, Tools, and Supplies								
	Tools and Supplies	L50 Purchase of lab and miscellaneous supplies, including microalgae feedstocks, chemicals reagents for in vitro simulate fermentation, consumable supplies for analytical instruments, PPEs, etc.	For running experiments and operating the systems.					$9,668
							Sub Total	**$9,668**
Capital Expenditures								
							Sub Total	**-**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
							Sub Total	**-**
Travel Outside Minnesota								

							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$250,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	**-**
Non-State				
			Non State Sub Total	**-**
			Funds Total	**-**

Total Project Cost: $250,000

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: eddc075f-671.pdf

Alternate Text for Visual Component

The figure illustrates the utilization of microalgae-based dietary and rumen manipulation for reducing methane and odor emission from dairy cows for sustainable development....

Supplemental Attachments

Capital Project Questionnaire, Budget Supplements, Support Letter, Photos, Media, Other

Title	File
SPA Cover Letter - Methane	d3b515bd-ba5.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Does your project have potential for royalties, copyrights, patents, sale of products and assets, or revenue generation?

No

Do you understand and acknowledge IP and revenue-return and sharing requirements in 116P.10?

N/A

Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF?

N/A

Does your project include original, hypothesis-driven research?

Yes

Does the organization have a fiscal agent for this project?

No

Does your project include the pre-design, design, construction, or renovation of a building, trail, campground, or other fixed capital asset costing $10,000 or more or large-scale stream or wetland restoration?

No

Do you propose using an appropriation from the Environment and Natural Resources Trust Fund to conduct a project that provides children's services (as defined in Minnesota Statutes section 299C.61 Subd.7 as "the provision of care, treatment, education, training, instruction, or recreation to children")?

No

Provide the name(s) and organization(s) of additional individuals assisting in the completion of this proposal:

Paul Chen, Juer Liu, Wendy Moylan, University of Minnesota