Environment and Natural Resources Trust Fund

2023 Request for Proposal

General Information

Proposal ID: 2023-199

Proposal Title: Innovative Utilization of Waste CO2

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: Ammonia-based CO2 capture and utilization for valuable bioproducts production by ammonia-tolerant microalgae integrated with two-stage cultivation and pH-stat feeding strategy

Funds Requested: $200,000

Proposed Project Completion: June 30, 2025

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.

The global emission of large amounts of anthropogenic CO_2 into the atmosphere has led to serious global warming and climate change issues. Many physical, chemical, and biological processes have been tested for CO_2 capture. Microalgae can convert sunlight and CO_2 into organic carbon biomass with more advantages than terrestrial plants (e.g., fast growth rate, high carbon fixation rate of 1.83 kg CO_2/kg of biomass, and accumulation of valuable components), and as such has been regarded as the most promising strategy for CO_2 sequestration and utilization.
However, the low solubility and diffusivity of CO_2 in water limits the microalgae growth and hence the carbon fixation capacity. Converting CO_2 to highly water soluble and stable bicarbonates such as sodium bicarbonate, potassium bicarbonate, and ammonia bicarbonate, is a great way to capture CO_2 as well as to provide a carbon source for microalgae cultivation. The ammonia-based carbon capture technology has been recognized as an efficient strategy for CO_2 capture mainly due to its low cost and the resultant ammonia bicarbonate (NH_4HCO_3) which supplies both carbon and nitrogen for microalgae growth. However, using ammonia from fossil sources is unsustainable.

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.

We propose to use the ammonia recovered through stripping from anaerobic digestion (AD) of nitrogen-rich organic wastes to capture waste CO_2 during biogas upgrading to renewable natural gas (RNG), and then use the ammonia bicarbonate synthesized as carbon and nitrogen sources for microalgae cultivation. The microalgae harvested can be used as feedstock for production of renewable fuels, feeds, and materials.
Food and animal wastes are suitable substrates for AD. Research is necessary to improve ammonia recovery for the purpose of generating ammonia bicarbonate. Furthermore, ammonia bicarbonate will increase the pH of the culture media and be toxic to microalgal cells and therefore we need to identify and develop ammonia-tolerant microalgae strains for this application. The adaptive laboratory evolution strategy can be used to improve and select microalgal strains with high tolerance to ammonia and salinity. Certain active chemicals such as phytohormones, inorganic ions and osmoregulatory solutes would also be evaluated and applied to improve the antioxidant activities and osmoregulation capabilities of microalgae cells to resist adverse environments and grow at a high rate. Novel bioreactors for microalgae cultivation with less light attenuation will be designed and constructed for microalgae cultivation.

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 direct environmental benefit offered by the project is the efficient capture of waste CO_2 from biological and industrial activities such as biogas purification, fermentation, landfills, power plants, etc. A secondary environmental benefit is the ammonia bicarbonate approach to microalgae cultivation provides a tool for AD operators to utilize the ammonia which is otherwise wasted and pollutes the air. Another environmental benefit is that the microalgae biomass can be used to produce renewable energy and valued added bioproducts that replace fossil-based energy and products.

Activities and Milestones

Activity 1: Design and build efficient stripping reactor to recover ammonia from the anaerobic digestion, and use ammonia for cost-efficient CO2 capture.

Activity Budget: $80,000

Activity Description:
Identify and evaluate key factors governing ammonia production in anaerobic digestion process of different organic wastes for low-cost ammonia synthesis, and then design and construct novel stripping reactors for ammonia recovery. Additionally, different kinds of promoters such as amines and amino acid salts will be compared and evaluated to improve the capability of aqueous ammonia solution for CO2 capture and absorption. Finally, integrate all these methods to maximize the ammonia-based CO2 capture with the advantages of low cost and the synthesized NH4HCO3 with application potentials for microalgae cultivation.

Activity Milestones:

Description	Completion Date
A bench scale ammonia stripping system will be developed and operational	September 30, 2023
Key factors affecting ammonia stripping are identified and optimized for the recovery of ammonia for AD process at low cost and high efficiency	December 31, 2023
Crucial promoters favoring the absorption of CO2 by ammonia are evaluated, and high efficient ammonia-based CO2 capture technologies are developed and evaluated	March 31, 2024

Activity 2: Select microalgae strains tolerant to high concentrations of ammonia and salinity, evaluate active chemicals to improve strains' tolerance salinity-ammonia.

Activity Budget: $70,000

Activity Description:
As Activity 1 focuses on the low-cost production of ammonia and its utilization for CO2 capture, Activity 2 will begin to select salinity and ammonia tolerant microalgal strains (e.g., Chlorella vulgaris) suitable for the utilization of ammonia bicarbonate for cell growth. The adaptive laboratory evolution strategy will be used to enhance microalgal tolerance to high concentrations of ammonia bicarbonate and eventually obtain maximally tolerant strains. Then the optimal cultural conditions (e.g., initial pH and nutrient concentrations) and positive chemicals favoring the increase in antioxidant activity and osmoregulation of microalgal cells will be evaluated and used to improve microalgal cell growth on ammonia bicarbonate. Moreover, different bicarbonate sources including sodium and potassium bicarbonates will also be compared and applied to microalgal cultivation to highlight the effectiveness and advantages of ammonia bicarbonate-based cultivation in terms of microalgal cell growth and carbon utilization efficiency.

Activity Milestones:

Description	Completion Date
The tolerance of selected strains to high concentrations of salinity and ammonia is compared	December 31, 2023
The selected strains are improved through adaptive laboratory evolution process	June 30, 2024
The effect of added active chemicals on strains' tolerance to pH and salinity stresses evaluated	September 30, 2024
Microalgal cell growth and CO2 utilization are optimized	December 31, 2024

Activity 3: Evaluate two-stage mixo-photoautotrophic cultivation with pH-stat feeding strategy and different bicarbonates, demonstrate the system

Activity Budget: $50,000

Activity Description:

The strategy of using ammonia-based CO_2 capture solution (from Activity 1) as the nutrient source for the cultivation of salinity-ammonia tolerant microalgal strain (from Activity 2) will be investigated and used in this section. The two-stage microalgae cultivation systems for enhanced carbon fixation will be constructed at the laboratory and pilot scale, and meanwhile, the strategy of pH-stat feeding of CO_2 and ammonia bicarbonate will be applied to enhance microalgal growth and carbon fixation. Different bicarbonate species will be evaluated using the same strategy and compared with ammonia bicarbonate to realize the maximum carbon utilization. Additionally, considering CA and RuBisCo are crucial enzymes in carbon concentration mechanism and photosynthesis, different factors and culture conditions will be optimized to induce the activities of these two enzymes and eventually improve CO_2 fixation and utilization by microalgal cells. The mass and energy balance data, together with analytical data, will be used to evaluate the environmental and economic performance, in a hypothetical scaled-up commercial model. This evaluation will provide a good assessment of the environmental impact of the proposed technology. Further R&D efforts and commercialization strategy will be recommended. The results will be published in academic journals, and in industrial journals for commercial consideration.

Activity Milestones:

Description	Completion Date
Ammonia-based CO_2 capture and solar-drive microalgae-based CO_2 utilization hybrid system will be developed and operational	December 31, 2024
pH-stat feeding of CO_2 and ammonia bicarbonate to enhance algae growth and carbon fixation evaluated	March 31, 2025
Mass, energy balance data documented, preliminary techno-economic performance of scaled-up system estimated	June 30, 2025
Further R&D and commercialization strategy recommended	June 30, 2025

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Paul Chen	University of Minnesota	Co-PI	No

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?

The proposed innovative utilization of waste CO2 will promote solar-driven microalgae-based CO2 capture, utilization and storage (CCUS) and address many of the issues contributing to global warming and climate change. Successful development and implementation of the proposed technology will make full utilization of ammonia from the AD process and anthropogenic CO2 within a waste-to-resource circular economy to replace the use of natural resources and reduce current pollution and contamination. We will seek industry partners and private, state, and federal funding to further develop and eventually commercialize the technology.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Demonstrating Innovative Technologies to Fully Utilize Wastewater Resources	M.L. 2014, Chp. 226, Sec. 2, Subd. 08c	$1,000,000
Development of Innovative Sensor Technologies for Water Monitoring	M.L. 2016, Chp. 186, Sec. 2, Subd. 04j	$509,000

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. Ruan, Professor and Director of Graduate Studies of Bioproducts and Biosystems Engineering Department, and Director of Center for Biorefining at University of Minnesota, is a Fellow of ASABE, IFT, Vebleo, and IAAM, and has received many other awards, including CAFS Professional Achievement and Scientist of IAAM, etc. He is a top cited author in engineering and technology with an h-index of 80, i10-index of 392, and has over 25,000 citations. Dr. Ruan's research include renewable energy and environment technologies for sustainable development. He has published over 500 referred journal articles, two books, 24 book chapters, and holds 20 US patents in the areas of municipal, agricultural, and industrial liquid and solid waste including biomass and waste plastics treatment and utilization through novel anaerobic digestion, microalgae and hydroponic cultivation, pyrolysis and gasification, airborne and other pathogen disinfection and pollutant control, catalysis, non-thermal plasma, and nitrogen fixation, etc. He has received over 200 grants totaling over $45 million in various funding for research, including major grants from USDA, DOE, DOT, DOD, LCCMR, and industries. He has served as guest editor or editorial board member of Bioresource Technology, Renewable Energy, Engineering, Applied Catalysis and Chemical Engineering, Journal of Food Process Engineering, The Open Plasma Physics Journal, and Associate Editor of Transactions of ASABE, Engineering Applications in Agriculture, and Transactions of CSAE, and Chairman of Editorial Board and Editor-in-Chief of International Journal of Agricultural and Biological Engineering, etc. He has supervised over 75 graduate students, 140 post-doctors, research fellows, and other engineers and scientists. He has given over 300 keynote lectures, invited symposium presentations, and short courses. His earlier LCCMR funded projects have resulted in several patented technologies which have been successfully licensed to the industry. He has the technical expertise and project management experience to ensure the execution of proposed projects.

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 affiliated with the College of Food, Agricultural and Natural Sciences and help coordinate the University efforts and resources to conduct exploratory fundamental and applied research and provide education on science and technology for environment protection and circular economy; stimulate collaboration among the University researchers, other public sector investigators, and private investigators involved in biobased production technology development; promote technology transfer to industries; and foster economic development in rural areas. The Center's research programs are 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.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Professor/faculty		Primary Investigator - project lead, advises researchers, plans and directs research, oversees budget, monitors and reports progress			33.5%	0.08		$26,302
Professor/faculty		Co-Primary Investigator - advises researchers, designs and directs experiments, conducts data analysis, writes reports and publications			33.5%	0.16		$28,490
1 Graduate Research Assistant		Researcher - carries out experiments, collects and analyzes data, prepares reports and manuscripts			45%	1		$105,699
1 Technician		Researcher - sets up equipment and apparatuses, carries out experiments and collects data.			7.5%	0.7		$23,650
							Sub Total	**$184,141**
Contracts and Services								
							Sub Total	-
Equipment, Tools, and Supplies								
	Tools and Supplies	Purchase of lab and miscellaneous supplies, including algae strains, chemicals, consumable supplies for analytical instruments, parts and components for fabricating experimental apparatuses	For running experiments and operating systems					$14,859
							Sub Total	**$14,859**
Capital Expenditures								
							Sub Total	-
Acquisitions and Stewardship								
							Sub Total	-

Travel In Minnesota								
	Miles/ Meals/ Lodging	4 one-day 3-person trips, ~100 miles each round trip ($0.585/mile), meals @$49/person	Visits to CO2 emission sites, collect samples, conduct experiments on site.					$1,000
							Sub Total	**$1,000**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$200,000**

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	**-**

Attachments

Required Attachments

Visual Component

File: 3596f034-dc3.pdf

Alternate Text for Visual Component

Shows process from waste CO2 and ammonia recovered from anaerobic digestion to the production of microalgal biomass for use as fuels, feeds, and materials. Low-cost ammonia will be recovered from anaerobic digestion of organic wastes and be utilized to capture waste CO2 generated during biogas upgrading to renewable natural gas....

Optional Attachments

Support Letter or Other

Title	File
Institutional Approval to Submit	866857dc-938.pdf
Financial audit	5cdf49ea-095.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

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

Yes

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

Yes

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

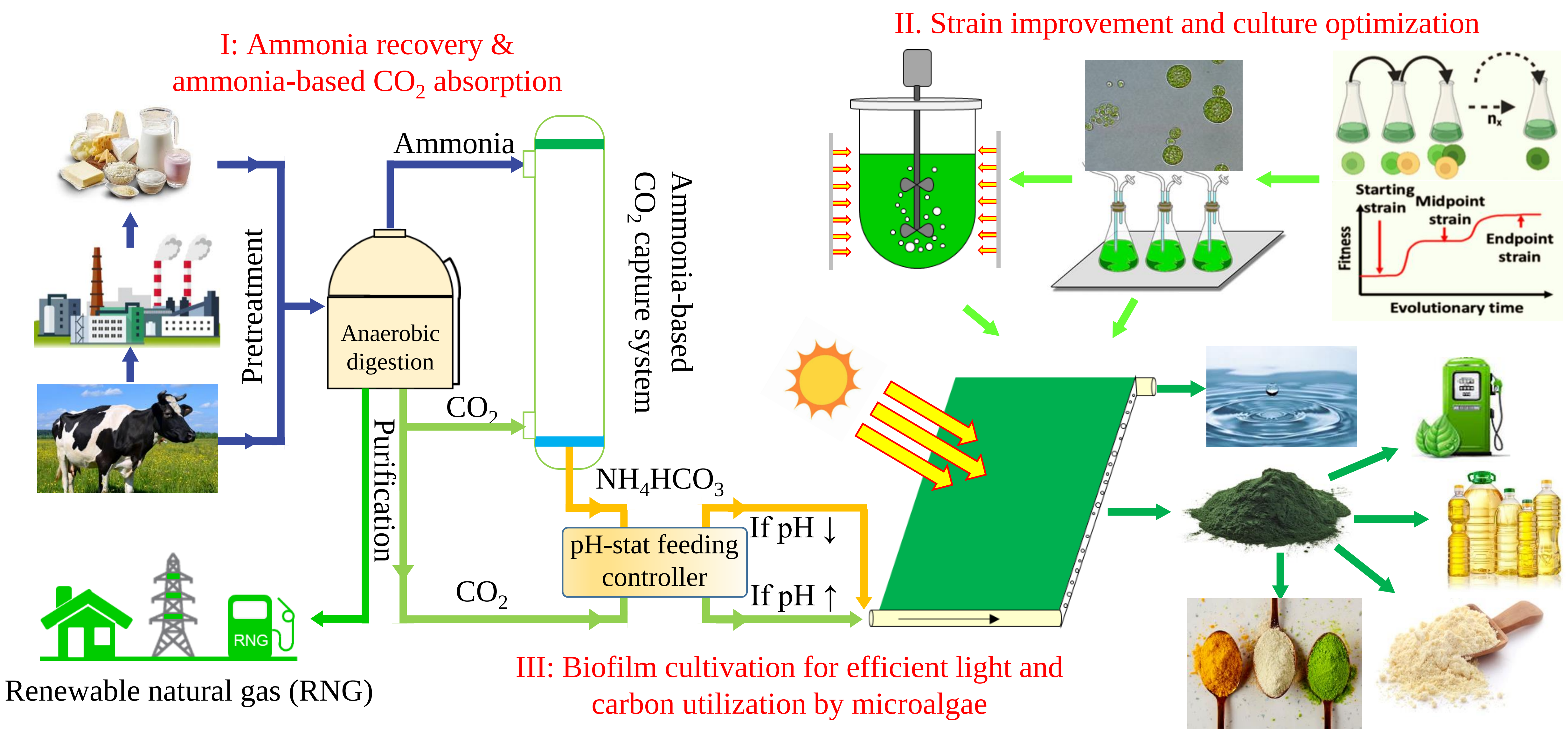
No

Does your project include original, hypothesis-driven research?

Yes

Does the organization have a fiscal agent for this project?

No



I: Ammonia recovery &
ammonia-based CO_2 absorption
II. Strain improvement and culture optimization
Pretreatment
Ammonia
Anaerobic digestion
Ammonia-based
CO_2 capture system
CO_2
Purification
NH_4HCO_3
pH-stat feeding controller
If pH ↓
If pH ↑
CO_2
RNG
Renewable natural gas (RNG)
Starting strain
Midpoint strain
Endpoint strain
Fitness
Evolutionary time
n_x
III: Biofilm cultivation for efficient light and
carbon utilization by microalgae