

**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 CO2 into the atmosphere has led to serious global warming and climate change issues. Many physical, chemical, and biological processes have been tested for CO2 capture. Microalgae can convert sunlight and CO2 into organic carbon biomass with more advantages than terrestrial plants (e.g., fast growth rate, high carbon fixation rate of 1.83 kg CO2/kg of biomass, and accumulation of valuable components), and as such has been regarded as the most promising strategy for CO2 sequestration and utilization.
However, the low solubility and diffusivity of CO2 in water limits the microalgae growth and hence the carbon fixation capacity. Converting CO2 to highly water soluble and stable bicarbonates such as sodium bicarbonate, potassium bicarbonate, and ammonia bicarbonate, is a great way to capture CO2 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 CO2 capture mainly due to its low cost and the resultant ammonia bicarbonate (NH4HCO3) 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 CO2 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 CO2 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 CO2 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 CO2 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 CO2 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 CO2 capture and solar-drive microalgae-based CO2 utilization hybrid system will be developed and operational | December 31, 2024 |
| pH-stat feeding of CO2 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. Ineli gible** | **% Bene fits** | **# FTE** | **Class ified 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](https://lccmrprojectmgmt.leg.mn/media/map/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](https://lccmrprojectmgmt.leg.mn/media/attachments/866857dc-938.pdf) |
| Financial audit | [5cdf49ea-095.pdf](https://lccmrprojectmgmt.leg.mn/media/attachments/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