Environment and Natural Resources Trust Fund

2025 Request for Proposal

General Information

Proposal ID: 2025-162

Proposal Title: Bioelectrochemical Utilization of Waste CO2 from Ethanol Plants

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 combines CO2 capture from ethanol plants with wastewater treatment. It utilizes microbial electrosynthesis system with optimized bioelectrodes to convert the CO2 to valuable fuels and bioproducts.

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.

Minnesota holds a prominent position in the national ethanol industry, ranking fifth in production with 1.4 billion gallons annually from 19 ethanol plants. However, the emission of CO2 from ethanol plants poses a significant threat to global warming and climate change, necessitating urgent investigation and effective measures to address this issue. CO2 emitted from ethanol plants holds an advantage as it is produced through yeast fermentation, resulting in fewer impurities and harmful chemicals. Consequently, the valorization and reutilization of CO2 from ethanol plants have attracted international research attention. Among various approaches to CO2 capture and sequestration, microbial electrosynthesis system (MES), which integrates CO2 sequestration with the production of low-carbon fuels and bioproducts, emerges as the most promising technology to address these challenges and limitations. However, numerous obstacles remain to be overcome, including the slow formation of biofilms on electrodes, the selection of economical electrode materials for efficient electron transfer, and appropriate system configurations and crucial parameters. This project aims to address these technical challenges and address the feasibility and sustainability of MES for commercial CO2 fixation and conversion, thereby contributing to the sustainable development of ethanol production in Minnesota.

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.

This project aims to explore the bioelectrochemical conversion of waste CO2 from ethanol plants, integrated with wastewater treatment, utilizing an optimized microbial electrosynthesis system integrated with anaerobic digestion (AD) for sustainable production of low-carbon fuels and bioproducts. Initially, we will investigate economically viable biochar-based electrode materials and the formation of mixed biofilms on the electrodes for MES performance improvement. Subsequently, we will establish the microbial electrosynthesis system with optimized configuration and operation parameters to efficiently convert CO2 alongside wastewater treatment. Simulation and modeling of MES will be used to investigate the interdependence of essential parameters and the interactions within the bioelectrode community, thereby improving the efficiency of CO2 conversion and wastewater oxidation. Lastly, we will scale up the optimized microbial electrosynthesis system to validate its integrated treatment capability for waste CO2 and wastewater generated by ethanol plants. Dynamic models, combined with techno-economic analysis and life cycle assessment, will be developed and applied to evaluate the overall feasibility and sustainability of MES-based CO2 sequestration and wastewater treatment, aiming for sustainable ethanol production with minimum environmental impact in the long term.

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?

This project aims to establish an optimal microbial electrosynthesis to reutilize and valorize waste CO2 alongside wastewater treatment for sustainable production of fuels and bioproducts. The anticipated outcomes hold potential for advancing the scaled-up utilization of MES-based CO2 conversion, thereby contributing to the sustainable development of corn ethanol production. Furthermore, the commercial application of this technology will lead to the establishment of several companies in Minnesota, focusing on MES-based carbon biosequestration and carbon-neutral fuel and bioproduct production. This initiative will generate employment opportunities for local residents and promote the sustainable economic advancement of energy industries and bioproduct manufacturing in Minnesota.

Activities and Milestones

Activity 1: Investigate economically viable biochar-based electrode materials and the formation of mixed biofilms on the electrodes for MES performance improvement

Activity Budget: $100,000

Activity Description:

The selection of economical electrode materials and the formation of optimal microbial biofilms on electrodes have significant roles in enhancing MES performance and CO2 conversion efficiency. Initially, the low-cost and sustainable biochar, derived from plastics and microalgal biomass as explored in our previous research, will be selected and then doped with metal particles and/or coated with functional groups to enhance electron transport and biofilm formation. Subsequently, cathodic biofilms enriched with a consortium of microalgae (for cellular compound production), bacteria (for acetate/butyrate production), and archaea (for methane production) will be developed and examined to ensure the current density exceeding 50-100 mA cm-2 and thus enhance the electricity-driven microbial conversion of CO2. The microalgal Chlorella species preserved in our lab exhibit high CO2 fixation rate and possess a variety of membrane-bound and soluble cytochromes conductive to extracellular electron transport, while Methanospirillum species possess nanowires to gain the electrons directly for methane production. These microorganisms will be inoculated solely or collectively, and they will rapidly enrich within the biofilms by adjusting the polarity or potential of the electrodes during the start-up period. Similarly, the optimal bioanode for organic oxidation will be investigated and optimized for subsequent MES fabrication.

Activity Milestones:

Description	Approximate Completion Date
Biochar-based electrodes will be evaluated and compared	August 31, 2025
The formation of mixed biofilms on the cathode will be investigated for enhanced CO2 conversion	October 31, 2025
The optimal bioanode will be investigated and optimized for wastewater treatment	December 31, 2025

Activity 2: Establish the lab-scale microbial electrosynthesis system with optimized configuration and operation parameters for the efficient CO2 conversion alongside wastewater treatment

Activity Budget: $100,000

Activity Description:

The microbial electrosynthesis system will be developed with optimized bioelectrodes and photovoltaic (PV) cells alongside wastewater treatment. Initially, we will investigate the formation of optimized mixed biofilms on the electrodes, which will then be connected to PV cells to enhance electricity-driven CO2 conversion. To achieve maximum conversion efficiency based on CO2 fixation rate, an on-line control of currency , CO2 inflow rate, and wastewater feeding rate will be established and optimized to withstand electrical power fluctuations and balance different operating potential requirements in bioelectrodes.

Additionally, MES will be integrated with anaerobic digestion of wastes for biogas upgrading through CO2 absorption in cathodic chamber. The nanobubble technique, recirculation systems, and gas diffusion electrodes will be used to improve mass transfer and enhance CO2 conversion. In the anodic chamber, liquid digestates will be tested as anolytes and catalyzed by anode biofilms.

Furthermore, computational modeling of MES via thermodynamic and kinetic models will be used to explore the independence of essential parameters and bioelectrode community interactions. We previously employed multi-scale modeling and simulation techniques for the pilot concentrated high intensity electric field system. They will be employed to optimize MES parameters and bioelectode communities for enhancing CO2 conversion efficiency and wastewater oxidation.

Activity Milestones:

Description	Approximate Completion Date
The lab-scale microbial electrosynthesis system will be developed	March 31, 2026
The on-line control of the currency, CO2 inflow rate, and wastewater feeding rate	June 30, 2026
Employ the integration of MES and AD process for biogas upgrading and organic oxidation	August 31, 2026
Computational modeling of MES to investigate bioelectrode community interactions and optimize crucial parameters	October 31, 2026

Activity 3: To scale up the microbial electrosynthesis system for validating its integrated treatment capability and conduct the sustainability analysis for commercialization

Activity Budget: $50,000

Activity Description:

The pilot-scale microbial electrosynthesis systems will be developed to integrate the treatment of waste CO2 and wastewater generated in ethanol plants. The scaling-up of microbial electrosynthesis system and operating conditions, aimed at producing specific products, will be estimated and compared using machine learning-based novel dynamic models. Additionally, the requirements of energy and resources, production costs, and financial benefits of converting CO2 into specific fuels and bioproducts will be determined and compared for commercial applications. Furthermore, results and data obtained from experiments and models will be identified and applied to the analysis of dynamic models integrated with techno-economic analysis and life cycle assessment. These approaches are used to achieve optimal MES performance and estimate the overall sustainability of MES-based CO2 sequestration and wastewater treatment.

Activity Milestones:

Description	Approximate Completion Date
Pilot-scale MES system for CO2 sequestration will be established	December 31, 2026
Dynamic models will be developed to validate and optimize MES-based CO2 conversion and wastewater treatment	March 31, 2027
Experimental data will be incorporated into both TEA and LCA analysis for sustainability assessment	June 30, 2027
Commercial scaled-up analysis, economic analysis, capital costs, further R&D and commercialization strategy	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?

This project will develop an efficient biohybrid electrosynthesis system capable of significantly enhancing electrochemical CO2 conversion for commercial applications. The results will help guide the transition of corn ethanol production to a bio-based carbon-neutral economy, and attract more public funding for further research. We believe that this project will create opportunities for using this technology in full-scale installations. We will collaborate with commercial partners to support further investigation and efforts to mitigate CO2 emissions in Minnesota and statewide. This work will provide valuable opportunities and needed investments to better reconcile environmental protection and the socio-economic development of energy industries.

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	Purchase of lab and miscellaneous supplies, including microalgae feedstocks, chemicals, 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: 3ab31c07-053.pdf

Alternate Text for Visual Component

This figure illustrates a schematic representation of an integrated microbial electrosynthesis system designed to address the treatment of waste CO2 and wastewater from ethanol plants. Specifically, the biohybrid system comprises photovoltaic cells and microbial electrosynthesis cells with optimized bioelectrodes and operating conditions to high-efficiency CO2 biosequestration and wastewater oxidation....

Supplemental Attachments

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

Title	File
SPA Cover Letter - Waste CO2	173cf157-0b1.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, and Wendy Moylan, University of Minnesota