Environment and Natural Resources Trust Fund

2024 Request for Proposal

General Information

Proposal ID: 2024-229

Proposal Title: Electrify Nitrogen Fertilizer Production Using Solar Energy

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: Local and distributed production of liquid nitrogen fertilizer with high nitrate concentration and crop yield-boosting properties using renewable, low-cost resources.

Funds Requested: $552,000

Proposed Project Completion: June 30, 2027

LCCMR Funding 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.

US farming and other industries use large amounts of nitrogen fertilizers such as anhydrous ammonia and ammonia nitrate. The state of Minnesota alone imports $400 million to $800 million retail value per year of nitrogen fertilizer from other states and countries. Current industrial technology for nitrogen fertilizer production is non-renewable, expensive, dangerous, and environmentally unfriendly. Although the Haber-Bosch process provides over 130 million tons of ammonia annually to support approximately 40% of the world's population, it is also responsible for about 2% of global energy consumption and 1.5% of GHG emissions. The reaction conditions of the Haber Bosch process lie in the range of 200 to 400 atm and 400 to 600 °C, respectively. These intense temperature and pressure conditions are the main disadvantages of the Haber-Bosch process, as they prevent the possibility of lowering capital costs. Therefore, the drawback of the Haber-Bosch process provides the opportunity to develop new nitrogen fixation technology, which can produce nitrogen fertilizer more energy-efficient, cost-efficient, low GHG emission, and sustainable.

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 is to demonstrate a new process to fix nitrogen from water and air only via a novel non-thermal plasma (NTP) process. Yielding a nitrate-rich liquid fertilizer, which can be applied to cropland or hydroponics systems directly. Electrifying this fertilizer production by using solar energy eliminates the need for fossil resources and avoids pollutant emissions. A technique to generate nanobubbles in water will be adopted to significantly improve the efficiency of nitrogen fixation in plasma reaction. Thus, this proposal aims to develop a new type of liquid nitrogen fertilizer, which is characterized as a nitrogen nutrient and crop yield promoter. The works and objectives of the project are to 1) develop an experimental catalytic NTP apparatus with the incorporation of nanobubble water and nitrate concentration process; 2) develop effective and energy-efficient catalysts for the catalytic non-thermal plasma and improve the production of nitrogen fertilizer via optimizing the key processing variables and conditions; 3) integrate solar power component into the system and test the integrated system in outdoor operation with a reasonable length of time-on-stream; (4) evaluate the energy consumption and environmental impacts of the technology, and conduct techno-economic analysis to evaluate the financial viability of the technology.

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 specific project outcome will include the development of energy-efficient nitrogen fixation catalysts, electrifying production process, including nanobubble water as a plant growth promoter, optimal processing conditions for high nitrogen fixation efficiency, and a pilot-scale nitrogen fixation system for systems analysis and demonstration. These outcomes will move the technology closer to commercial implementation and provide following benefits: (1) circumvent fossil energy consumption by electrifying fertilizer production with solar energy, (2) protects the natural environment through accurate control of nitrogen concentration and avoiding nitrogen overdose in agricultural activities, long-term solution to a local nitrogen fertilizer production, eliminating the need for transportation.

Activities and Milestones

Activity 1: Develop an experimental catalytic NTP apparatus with the incorporation of nanobubble water and nitrate concentration process

Activity Budget: $150,000

Activity Description:
The concept of synthesizing nitrogen compounds using NTP has been proven in our preliminary studies. This project will focus on optimizing processing parameters including feedstock gas, catalysts, and electric field. A bench-scale synthesis system will be developed. Air nanobubble water is an emerging technology developed in recent years, which has been proven to promote plant growth and enhance crop yield due to it possesses a larger reaction surface area relative to normal water, which can provide more oxygen or nutrients to organisms. A nanobubble water generator will be developed and incorporated into the nitrogen fixation process. High-concentration nitrate is beneficial to storage and application of the fertilizer. An efficient nitrate concentration system based on electrodialysis will be developed and the processing parameters will be investigated. We will fabricate several ion exchange membranes, characterize their structure, and test their performance on the selective migration of nitrate ions in the concentration system. After that, we will introduce the ion exchange membrane in an electro-osmosis system, and optimize the main parameters (such as initial nitrate concentration, pH, voltage and temperature) and develop the control strategy of this system. Electrify this fertilizer production by connecting the electric power with solar panel energy.

Activity Milestones:

Description	Approximate Completion Date
A bench-scale synthesis system will be developed	December 31, 2024
A nanobubble water generator will be developed and incorporate it into system and evaluated	December 31, 2024
Ion exchange membranes will be fabricated and characterized	June 30, 2025
The control strategy of this system will be obtained	December 31, 2025
The main parameters for the nitrate concentration system will be optimized and energy efficiency evaluated	December 31, 2026

Activity 2: Develop effective and energy-efficient catalysts and optimize process conditions to improve the productivity and energy efficiency

Activity Budget: $150,000

Activity Description:
Catalysts play an important role in plasma-based catalytic nitrogen fixation, which involves three processes, namely N2/O2 dissociation, NO oxidation and nitrite oxidation. In this activity, we will first synthesize several N2/O2 dissociation catalysts, photo-catalysts, and some multi-functional catalysts, and characterize them to understand their structure and properties, i.e. morphology, crystal structure and chemical composition. After that, we will test their performance on N2/O2 dissociation, NO oxidation and nitrite oxidation, stability and recycling, and also evaluate the economic feasibility for future large-scale applications. Through a systematic review, important parameters which greatly impact nitrogen fixation efficiency will be studied, i.e. N2/O2 ratio, feeding gas flow rate, size of nanobubble in the liquid phase, power input, electric field, catalyst dosage, and intensity of UV or visible light. Experiments will be conducted under different conditions to understand and optimize the process in terms of nitrate yield and energy efficiency. Meanwhile, the nanobubble water(air bubble size <100nm) will be adopted as the feedstock directly. The main target is to enhance and maintain the nanobubble quantity in the final product of nitrogen-rich water.

Activity Milestones:

Description	Approximate Completion Date
Several catalysts will be prepared and characterized.	June 30, 2026
The working mechanisms and performance of the catalysts will be investigated.	June 30, 2026
Key parameters will be optimized and energy efficiency evaluated	December 31, 2026

Activity 3: Power the synthesis system with solar electricity and test the integrated system in outdoor operation

Activity Budget: $150,000

Activity Description:
Design a solar power system based on the systematic analysis of voltage, current, and power characteristics, which includes measuring the local solar radiation, optimizing the tilt of solar collectors, setting up the transformer and inverter, and establishing an energy storage system. Integrate the solar power components into the nitrogen fixation system, test the integrated system outdoors for a reasonable length of time, and demonstrate the entire system's functionality.

Activity Milestones:

Description	Approximate Completion Date
Design a solar power system based on the analysis of voltage and current characteristics	March 31, 2027
Integrate the solar power components into the nitrogen fixation system	March 31, 2027
Test the integrated system outdoors for a reasonable length of time and demonstrate the entire	March 31, 2027

Activity 4: Evaluate energy efficiency and economic and environmental impacts of the technology

Activity Budget: $102,000

Activity Description:
We will communicate our findings from Activity 1-4 to primary stakeholders such as fertilizer producers, farmers, and farm machine manufacturers. Based on their feedback, we will design and construct a small pilot-scale integrated system for comprehensive evaluation of the technology, including adopting a hydroponics system to assess the enhancement efficiency of crop yield. Rigorous tests will be conducted in the lab and then we will move the system to the field for testing and demonstration. With a small pilot system, the mass and energy balance data, together with emission data, will be used to evaluate the environmental and economic performance using a mathematical model. At this small pilot scale, the electrical energy needed to generate the non-thermal plasma, can be better evaluated, to confirm utility costs and economic analysis. This evaluation will also provide a good assessment of the environmental impact of the proposed technology. Further R&D efforts and commercialization strategies will be recommended.

Activity Milestones:

Description	Approximate Completion Date
The energy efficiency, cost, and emission will be evaluated	June 30, 2027
Economic and environmental impacts will be assessed	June 30, 2027
Further R&D and commercialization strategy will be recommended	June 30, 2027

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?

New scientific knowledge on feedstock breakdown and product synthesis during the plasma-based catalytic nitrogen fixation process will be acquired through this research, techno-economic analysis will be conducted to evaluate the financial viability of the technology, and the demonstration will help raise significant interests from the public. We will seek industry partners and private, state, and federal funding to further develop, and eventually commercialize the technology. Our lab work has already shown that 200 mg/Liter nitrate solution can be concentrated to over 2,000 mg/Liter, which is needed for practical application on corn crops.

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, Professor and Director of Graduate Studies, Department of Bioproducts and Biosystems Engineering, and Director of Center for Biorefining at University of Minnesota, is a Fellow of ASABE and a Fellow of IFT. Dr. Ruan's research focuses on renewable energy and environment technologies for sustainable development and circular economy. Specifically, he has conducted research and published his findings in the areas of municipal, agricultural, and industrial wastewater treatment and utilization through novel anaerobic digestion, microalgae cultivation, and hydroponic cultivation, biomass and solid wastes (including plastics) pyrolysis and gasification, airborne and other pathogen disinfection and pollutant control, catalysis, non-thermal plasma, and nitrogen fixation, etc. He is a top-cited author with an h-index of 88, i10-index of 443, and over 30,000 citations. He has supervised over 75 graduate students, 140 post-doctors, research fellows, and other engineers and scientists, and 21 of his Ph.D. students and post-doctors hold university faculty positions. He has also been invited to give over 300 keynote lectures, invited symposium presentations, company seminars, and short courses. Professor Ruan has received and managed over 200 projects totaling over $45 million in various funding for research, including major funding 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. His earlier LCCMR funded projects have resulted in several patented technologies which have been successfully licensed to the industry. Therefore, 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 helps 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		PI - 2.5 weeks summer salary - direct all research, analysis, admin and personnel			36.8%	0.15		$41,371
Professor/faculty		Co-PI - contract faculty - co-direct all aspects of project - supervise post doc and student			36.8%	0.48		$72,087
Graduate Research Assistant		One researcher to conduct experiments, analyis, education			47%	3		$162,682
Post Doc Researcher		Conduct research and analysis			25.7%	3		$215,166
							Sub Total	**$491,306**
Contracts and Services								
							Sub Total	**-**
Equipment, Tools, and Supplies								
	Tools and Supplies	Purchase of lab and miscellaneous supplies, including gases and catalysts for synthesis experiments, chemicals for analysis, consumable supplies for analytical instruments	For running experiments and operating synthesis reactors, chemical and physical analyses					$27,922
	Equipment	Components for fabrication of a small reactor system including power supply, NTP reactors, control system, concentration system, storage vessel.	To fabricate a small synthesis system for extensive testing, cost and emission analysis, and demonstration					$30,000
							Sub Total	**$57,922**
Capital Expenditures								
							Sub Total	**-**
Acquisitions and Stewardship								
							Sub Total	**-**

Travel In Minnesota								
	Miles/ Meals/ Lodging	12 one-day 2-person trips, 100 miles each round trip ($0.655/mile), meals @$50/person	Visits to farm lands, conduct experiments on site					$2,772
							Sub Total	**$2,772**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$552,000**

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: 7aed89d6-086.pdf

Alternate Text for Visual Component

a) Nitrogen Fixation Mechanism adopted in this proposal, b) schematic diagram of the plasma nitrogen fixation system using the concentrated high-intensity electric field, c) solar electricity powered nitrogen fertilizer production system...

Optional Attachments

Support Letter, Photos, Media, Other

Title	File
UMN Authorization	55eeb53b-361.pdf
2022 Audit	cef751f9-238.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

Does your project include the design, construction, or renovation of a building, trail, campground, or other capital asset costing $10,000 or more?

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?

No