Environment and Natural Resources Trust Fund

2022 Request for Proposal

General Information

Proposal ID: 2022-051

Proposal Title: Nitrogen fixation from atmosphere for urban hydroponics

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: Develop a novel technology to produce nitrogen fertilizers from water and air using catalytic non-thermal plasma for urban food production.

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.

Humankind is faced with a significant challenge – to feed the world while sustaining the environment. Making and distributing enough fertilizers in the conventional manner will cause steep increases in energy consumption and greenhouse gas emissions. Minnesota imports roughly $400 to $800 million retail value of nitrogen fertilizer annually. Traditionally, ammonia, one of the predominant components in nitrogen fertilizers, has been produced with the Haber-Bosch process using hydrogen and nitrogen for over 100 years. This conventional process in centralized mega facilities works well but has many negative environmental impacts—using natural gas as reactant, emitting greenhouse gases, and relying on energy-intensive chemical plants and distribution networks, which may be difficult to sustain in centuries to come. The distribution networks also pose significant safety and liability concerns while transporting and storing large amounts of anhydrous ammonia across the nation. Therefore, a clean and renewable approach is highly sought after.

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

We propose a process to produce nitrogen fertilizer in-situ and on-demand for urban hydroponic production, essentially eliminating virtually all transportation and distribution safety and liability risks. If renewable electricity, e.g., from wind or solar energy, is used, it will eliminate the need for fossil resources and avoid pollutant emissions. In the proposed process, nitrogen is fixed from water and air using non-thermal plasma coupled with photocatalysis. The objectives of the project are to (1) develop several phototacalysts that can oxidize the nitrite to nitrate under UV or visible light; (2) develop and construct experimental catalytic NTP apparatuses in collaboration with industry partners; (3) improve the production of fertilizer nitrogen compounds via optimizing the key processing variables and conditions, i.e. nitrogen ionization catalysts, photocatalysts, feed gas, electric field, NTP reactor design, UV or visible light intensity, etc.; (4) investigate the energy consumption and environmental impacts of the technology, and (4) develop recommendations for technology transfer and further R & D efforts.

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 photocatalysts, optimal processing conditions for high yield of nitrogen fertilizers, and a pilot-scale nitrogen fixation system for systems analysis and demonstration. These outcomes will move the technology closer to commercial implementation, which will help produce renewable nitrogen fertilizers, reduce fossil energy demand, and reduce CO2 emission, and thus reduce environmental impacts of the nitrogen production industry and agricultural activities, and conserve natural resources.

Activities and Milestones

Activity 1: Develop an experimental catalytic NTP apparatus and optimize the synthesis process

Activity Budget: $100,000

Activity Description:
The concept of synthesizing nitrogen compounds using NPT has been proven in our preliminary studies. New and cost effective catalysts need to be developed and a NTP nitrogen fixation system coupled with photocalysis will be established. In this activity, we will first prepare several photocatalysts like TiO2 or modified TiO2, characterize their structure and properties, and test their performance on nitrogen and oxygen dissociation and nitrite oxidation under UV or visible light. After that, we will introduce the photocatalytic process into the non-thermal plasma and develop a bench scale synthesis system. The main parameters such as feeding gas rate or ratio, NTP reactor type, photocatalyst dosage, voltage and so on will be optimized. The related nitrogen fixation mechanism and catalytic mechanism will be studied. In addition, experiments will be conducted under different conditions to understand and optimize the process in terms of product yield and energy efficiency.

Activity Milestones:

Description	Completion Date
New and cost effective catalysts will be developed, characterized and evaluated.	December 31 2022
A bench scale synthesis system will be developed	June 30 2023
The synthesis and energy efficiency will be optimized.	December 31 2023

Activity 2: Test the experimental nitrogen fixation apparatus with a small hydroponic system

Activity Budget: $60,000

Activity Description:
Once the nitrogen fixation process is developed and optimized, we will test the experimental apparatus with a small hydroponic system. Our goal is to supply all the nitrogen fertilizer for the entire growth period of certain vegetables. The apparatus may be operated continuously or in intermittent mode. Solar power will be tested.

Activity Milestones:

Description	Completion Date
The experimental apparatus will be integrated with a small hydroponic system	June 30 2024
Operation of the nitrogen fixation apparatus and hydroponic system will be tested	December 31 2024
The operation is demonstrated to stakeholders	June 30 2025

Activity 3: Evaluate environmental impacts and economic performance

Activity Budget: $40,000

Activity Description:
The mass and energy balance data together with emission data will be used to evaluate the environmental and economic performance using mathematics models. This evaluation will provide good assessment of the environmental impact of the proposed technology. Further R&D efforts and commercialization strategy will be recommended.

Activity Milestones:

Description	Completion Date
The energy efficiency, cost, and emission will be evaluated	December 31 2024

Environmental impacts will be assessed	June 30 2025
Further R&D and commercialization strategy will be 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 be funded?

New scientific knowledge on plasma-based catalytic nitrogen fixation processes will be acquired through research, and the demonstration of the proposed technology will help raise significant interests from the relevant industries, the public, and government agencies. 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. 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 69, i10-index of 301, and over 19,000 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 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		PI - summer salary only			36.5%	0.12		$23,622
Professor/faculty		Co-PI - contract faculty			36.5%	0.24		$33,460
1 Graduate Research Assistant		Researcher			45%	2.25		$126,289
							Sub Total	**$183,371**
Contracts and Services								
University of Minnesota	Internal services or fees (uncommon)	Lab services				-		$5,000
							Sub Total	**$5,000**
Equipment, Tools, and Supplies								
	Tools and Supplies	Purchase of lab and miscellaneous supplies, including feedstock, catalysts, chemicals, fertilizers, vegetable sees, consumable supplies for analytical instruments	For setting up nitrogen fixation device and hydroponic system, and conducting proposed experiments in labs					$10,243
							Sub Total	**$10,243**
Capital Expenditures								
							Sub Total	**-**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								

	Miles/ Meals/ Lodging	9 one-day 2-person trips, 100 miles each round trip ($0.56/mile), meals @$49/person	Visit to industry collaborator sites and conduct on-site tests					$1,386
							Sub Total	**$1,386**
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

Optional Attachments

Support Letter or Other

Title	File
Letter of Submission Approval	01a41cf1-d60.pdf
Visual graphic	58c5dc1f-d25.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?

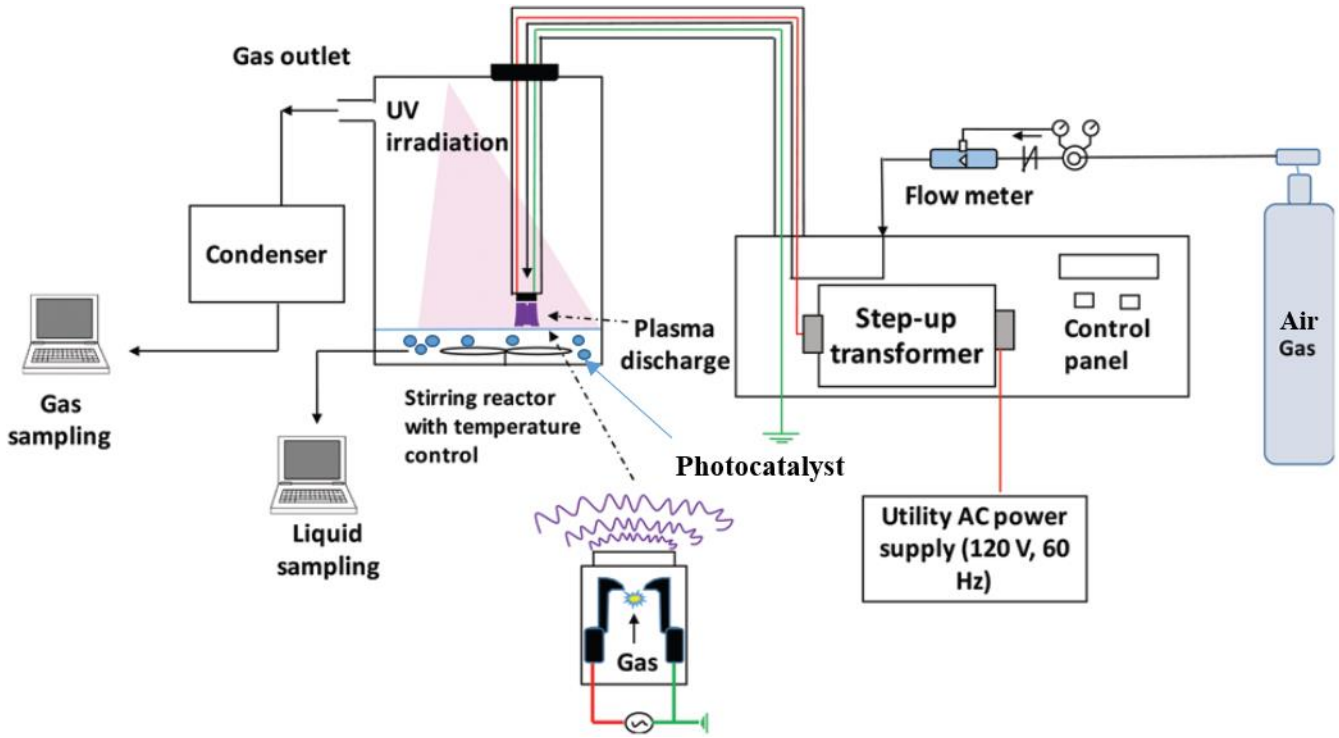
No

Does your project include original, hypothesis-driven research?

Yes

Does the organization have a fiscal agent for this project?

No



Schematic diagram of the catalytic non-thermal plasma system for nitrogen fertilizer production