

**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. Ineli gible** | **% Bene fits** | **# FTE** | **Class ified 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](https://lccmrprojectmgmt.leg.mn/media/attachments/01a41cf1-d60.pdf) |
| Visual graphic | [58c5dc1f-d25.pdf](https://lccmrprojectmgmt.leg.mn/media/attachments/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