

**Environment and Natural Resources Trust Fund**

# 2023 Request for Proposal

## **General Information**

**Proposal ID:** 2023-196

**Proposal Title:** Produce Green Nitrogen Fertilizer from Air and Water

## **Project Manager Information**

**Name:** Roger Ruan

**Organization:** U of MN - College of Food, Agricultural and Natural Resource Sciences

**Office Telephone:** (612) 804-2270

**Email:** RUANX001@UMN.EDU

## **Project Basic Information**

**Project Summary:** Locally produced high-concentration nitrogen fertilizers from renewable and extremely low cost natural resources.

**Funds Requested:** $499,000

**Proposed Project Completion:** June 30, 2026

**LCCMR Funding Category:** Water Resources (B)

## **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 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 the global energy consumption and 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. Additionally, the high pressure required for the traditional Haber-Bosch Process is also a limiting factor in reducing the economies of scale of localized production facilities due to the high energy (and cost) requirements of compression. Producing fertilizers locally eliminates the need for transportation and thus reduces costs and GHG emission. Nitrogen fertilizers to be produced with the proposed technology are non-volatile.

**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 intended to demonstrate a new process to fix nitrogen from water and air only to produce nitrogen-rich water using renewable electricity, e.g., from wind or solar energy, potentially eliminating the need for fossil resources and avoiding pollutant emissions all together. The nitrogen-rich water (mainly nitrate and ammonia) can be used as fertilizer directly on cropland or hydroponics systems to reduce nitrogen runoff and water needs. In the proposed process, nitrate fertilizer is produced from water and air using catalysts (N2 dissociation catalysts and photocatalysts) in the non-thermal plasma (NTP) discharge reactor and has been effectively concentrated with an electrodialysis concentration system. The objectives of the project are to (1) develop and evaluate effective and energy efficient catalysts, i.e. N2 dissociation catalysts and photocatalysts; (2) develop and construct an experimental catalytic NTP apparatus, and improve the production of nitrate fertilizer via optimizing the key processing variables and conditions, i.e. catalysts dosage, feed gas rate and ratio, electric field, NTP reactor design, increase nitrate concentration, UV intensity, wavelength; (3) evaluate the energy consumption and environmental impacts of the technology, and (4) 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 N2 dissociation catalysts and photocatalysts, optimal processing conditions for high nitrogen fixation efficiency, efficient production of high-concentration nitrate solution in water, 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, reduce CO2 emissions, and thus reduce environmental impacts of the nitrogen production industry and agricultural activities, and conserve natural resources.

## **Activities and Milestones**

### **Activity 1: Develop and evaluate effective and energy efficient catalysts for the catalytic non-thermal plasma**

**Activity Budget:** $150,000

**Activity Description:**Catalysts play an important role during the plasma-based catalytic nitrogen fixation process, which involves three processes, N2/O2 dissociation process, NO oxidation and nitrite oxidation process. The catalysts not only can greatly lower the activation energy of the feedstock gas, but also oxidize the NO or nitrite into nitrate, thus improving the nitrogen fixation efficiency and reducing the energy consumption. 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 application.

**Activity Milestones:**

|  |  |
| --- | --- |
| **Description** | **Completion Date** |
| Several catalysts will be prepared and characterized. | December 31, 2023 |
| The performance of catalysts will be investigated. | June 30, 2024 |
| New knowledge of catalytic mechanisms will be explored. | June 30, 2024 |
| The economic feasibility will be evaluated. | June 30, 2024 |

### **Activity 2: Develop an experimental catalytic NTP apparatus and optimize the synthesis process**

**Activity Budget:** $89,000

**Activity Description:**The concept of synthesizing nitrogen compounds using cNTP has been proven in our preliminary studies. A new and cost effective nitrogen fixation system will be developed, and we will study processing parameters, such as the feedstock gas, catalysts, and electric field. In this activity, we will first develop a bench scale synthesis system that can house different types of NTP reactors, and allow inclusion of catalysts. Then, important parameters which greatly impact nitrogen fixation efficiency will be studied, i.e. N2/O2 ratio, feeding gas flow rate, 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.

**Activity Milestones:**

|  |  |
| --- | --- |
| **Description** | **Completion Date** |
| A bench scale synthesis system will be developed. | December 31, 2023 |
| Important parameters will be optimized. | December 31, 2024 |
| New knowledge of the process works will be obtained | December 31, 2024 |
| Energy efficiency will be evaluated. | December 31, 2024 |

### **Activity 3: Develop concentration process to produce high-concentration nitrate**

**Activity Budget:** $100,000

**Activity Description:**High-concentration nitrate is beneficial to storing and using the fertilizer. An efficient nitrate concentration system based on electrodialysis will be developed and the processing parameters will be investigated. In this activity, 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. To confirm the level of nitrate concentration needed for practical application of nitrate solution on a typical corn crop.

**Activity Milestones:**

|  |  |
| --- | --- |
| **Description** | **Completion Date** |
| Ion exchange membranes will be fabricated and characterized | June 30, 2025 |
| The main parameters for the nitrate concentration system will be optimized | June 30, 2025 |
| The control strategy of this system will be obtained | June 30, 2025 |

### **Activity 4: Develop an integrated catalytic high-concentration nitrate production system and evaluate environmental impacts and economic performance**

**Activity Budget:** $160,000

**Activity Description:**We will communicate our findings from Activity 1-3 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. 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** | **Completion Date** |
| An integrated catalytic high-concentration nitrate production system will be developed. | June 30, 2026 |
| The energy efficiency, cost, and emission will be evaluated | June 30, 2026 |
| Environmental impacts will be assessed | June 30, 2026 |
| Further R&D and commercialization strategy will be recommended | June 30, 2026 |

## **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** |
| 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% | 0.06 |  | $15,940 |
| Professor/faculty |  | Co-Primary Investigator - advises researchers, designs and directs experiments, conducts data analysis, writes reports and publications |  |  | 33.5% | 0.15 |  | $69,062 |
| 1 Graduate Research Assistant |  | carries out experiments, collects and analyzes data, prepares reports and manuscripts |  |  | 45% | 1.5 |  | $160,139 |
| Post Doctoral Reseracher |  | designs and carries out experiments, collects and analyzes data, prepares reports and manuscripts |  |  | 20.9% | 3 |  | $185,001 |
|  |  |  |  |  |  |  | **Sub Total** | **$430,142** |
| **Contracts and Services** |  |  |  |  |  |  |  |  |
| equipment manufacturer | Professional or Technical Service Contract | Maintenance and repair, including callibration |  |  |  | 0 |  | $9,000 |
|  |  |  |  |  |  |  | **Sub Total** | **$9,000** |
| **Equipment, Tools, and Supplies** |  |  |  |  |  |  |  |  |
|  | Equipment | Components for fabrication of a small pilot system including reactor vessel, high voltage power supply, catalysts, pumps, membrane separator | To fabricate a small pilot system for extensive testing, cost analysis, and demonstration |  |  |  |  | $25,000 |
|  | Tools and Supplies | Purchase of lab and miscellaneous supplies, including feed gases, catalysts, chemicals, consumable supplies for analytical instruments | For running experiments and operating conversion systems |  |  |  |  | $31,858 |
|  |  |  |  |  |  |  | **Sub Total** | **$56,858** |
| **Capital Expenditures** |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | **Sub Total** | **-** |
| **Acquisitions and Stewardship** |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | **Sub Total** | **-** |
| **Travel In Minnesota** |  |  |  |  |  |  |  |  |
|  | Miles/ Meals/ Lodging | 12 one-day 3-person trips, ~100 miles each round trip ($0.585/mile), meals @$49/person | Visits to farms, conduct experiments on farms and industry collaborators sites |  |  |  |  | $3,000 |
|  |  |  |  |  |  |  | **Sub Total** | **$3,000** |
| **Travel Outside Minnesota** |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | **Sub Total** | **-** |
| **Printing and Publication** |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | **Sub Total** | **-** |
| **Other Expenses** |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | **Sub Total** | **-** |
|  |  |  |  |  |  |  | **Grand Total** | **$499,000** |

### **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: [f0156bdb-a15.pdf](https://lccmrprojectmgmt.leg.mn/media/map/f0156bdb-a15.pdf)

#### ***Alternate Text for Visual Component***

Figure 1 and 2 show how nitrate fertilizer generates and concentrates and the preliminary results. Catalytic non-thermal plasma (cNTP) provides an alternative way to ensure green synthesis of nitrate fertilizers efficiently. Nitrate is produced from water and air in an NTP reactor and then concentrated by an effective electrodialysis system....

### **Optional Attachments**

#### ***Support Letter or Other***

|  |  |
| --- | --- |
| **Title** | **File** |
| Financial audit | [c0bec3bb-235.pdf](https://lccmrprojectmgmt.leg.mn/media/attachments/c0bec3bb-235.pdf) |
| Institutional Approval to Submit | [bb17e55d-c1f.pdf](https://lccmrprojectmgmt.leg.mn/media/attachments/bb17e55d-c1f.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