Environment and Natural Resources Trust Fund

2026 Request for Proposal

General Information

Proposal ID: 2026-421

Proposal Title: Electrified Nitrogen Fixation for Localized, On-Demand Fertilization

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 develops a novel non-thermal plasma technology to replace the Haber-Bosch process with renewable electricity and nitrogen dissociation for greener production of liquid nitrogen fertilizers.

ENRTF Funds Requested: $850,000

Proposed Project Completion: June 30, 2029

LCCMR Funding Category: Resiliency (A)

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 Haber-Bosch (HB) process produces over 130 million tons of ammonia annually and supports nearly 40% of the global food supply, but its reliance on fossil fuels makes it highly vulnerable to energy price fluctuations, supply chain disruptions, and geopolitical instability. Over 90% of the process's energy demand comes from hydrogen production via steam reforming, requiring a steady methane supply, contributing to 2% of global energy use and 1.5% of greenhouse gas (GHG) emissions. Extreme operational conditions, 400-600°C and 200-400 atm pressure, drive high costs and infrastructure challenges, limiting the adaptability of fertilizer production to environmental and economic changes.

Minnesota alone, imports between $400 million and $800 million in nitrogen fertilizers annually, making it particularly vulnerable to global supply chain disruptions. As climate change intensifies extreme weather events and disrupts traditional agricultural inputs, a more resilient, decentralized, and renewable approach to nitrogen fertilizer production is urgently needed.

This project seeks to develop a plasma-based nitrogen fixation process powered entirely by electricity, preferably from renewable sources, eliminating fossil fuel dependency, reducing GHG emissions, and enabling on-site fertilizer production. By decentralizing nitrogen supply and strengthening local production capacity, this solution enhances Minnesota's agricultural resilience against environmental and economic uncertainties.

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 research project aims to revolutionize nitrogen fixation by developing a non-thermal plasma (NTP) reactor for one-step synthesis of nitrogen compounds (ammonia, nitrate, and nitrite). Focused on resilience, our approach enhances agricultural stability against climate change, supply chain disruptions, and extreme weather. The proposed Concentrated High-Intensity Electric Fields (CHIEF) reactor generates plasma in situ within a liquid medium, increasing nitrogen compound production while reducing dependence on the centralized, energy-intensive Haber-Bosch process.

Key advantages include being exclusively powered by electricity, in-situ reactive species generation (e.g., H, N), improved energy efficiency, and minimal or zero CO_2 emissions. This on-demand, locally adaptable process strengthens agricultural resilience by reducing reliance on fossil-fuel-based fertilizer supply chains. Project objectives include optimizing the CHIEF reactor, integrating water electrolysis for hydrogen generation, employing nano- or micro-bubble technology, advancing catalyst development, and incorporating ion exchange membranes for product concentration.

The ultimate goal is to produce liquid nitrogen fertilizer sustainably and reliably, ensuring a local, adaptable supply. A comprehensive techno-economic analysis will assess scalability and feasibility, paving the way for a resilient nitrogen fixation system that supports sustainable agriculture and enhances regional food security.

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 revolutionize production of ammonia and nitrogen oxides for a next-generation liquid nitrogen fertilizer by developing an innovative non-thermal plasma technology as a sustainable alternative to the Haber-Bosch process. Key outcomes include: 1) Zero carbon emissions, reducing environmental impact; 2) Electrification with renewable energy (solar, wind, etc.), decreasing fossil fuel reliance; 3) A long-term electrosynthesis strategy to reduce dependence on Haber-Bosch; 4) A cost-effective, scalable production process; 5) Small-scale on-site models for localized fertilizer and water treatment; 6) Large-scale industrial adoption, promoting sustainable nitrogen fixation for industry and agriculture.

Activities and Milestones

Activity 1: Develop and optimize non-thermal plasma reactor for ammonia and nitrogen oxides synthesis

Activity Budget: $260,000

Activity Description:
In this activity, we will first develop a bench-scale synthesis system capable of accommodating various NTP reactors and metallic catalysts. Different CHIEF reactor variations will be customized for specific nitrogen fixation functions and integrated with the power supply, substrate feeding, and measurement equipment.
In the next step, preliminary tests will be conducted under diverse conditions, guided by theoretical data from the literature. We will systematically investigate and model the relationship between nitrogen species yield and key test conditions, including applied voltage, discharge dimensions, electrical conductivity, electrode configurations, power frequency, and flow rates. This analysis will establish correlations and determine the significance of various parameters. Using the collected data, we will gain insights into the plasma discharge mechanism in CHIEF, including the breakdown voltage required for plasma initiation, liquid-gas interactions, and reactive species generation under high-voltage applications. This understanding will mark a significant milestone, distinguishing our process from the conventional Haber-Bosch method. Unlike the energy-intensive, multi-step Haber-Bosch process, our approach aims to reduce complexity while enhancing sustainability—achieving comparable nitrogen compound yields through a more efficient and environmentally friendly pathway.

Activity Milestones:

Description	Approximate Completion Date
Develop a bench-scale synthesis system	October 31, 2026
Conduct literature based preliminary tests under various test conditions	December 31, 2026
Establish a mathematical model for plasma discharge conditions and nitrogen fixation yield	February 28, 2027
Investigate the plasma discharge mechanism based on the results and model	April 30, 2027
Optimize the reactor configuration and working conditions	June 30, 2027

Activity 2: Develop effective and energy-efficient catalysts and utilize nano-bubble technology in the ammonia and nitrogen oxides production system

Activity Budget: $320,000

Activity Description:
First, we will integrate nano-bubble technology—an emerging innovation—into ammonia and nitrogen oxides production. This approach will encompass three key aspects: a) investigating the underlying mechanism of nano-bubble plasma discharge in the liquid phase, b) exploring the relationship between externally applied voltage, bubble size, and plasma discharge occurrence within nano-bubbles, using regression analysis to develop a predictive model, c) determining the optimal bubble size and quantifying improvements in nitrogen fixation yield when using nano-bubble water as the liquid feedstock.
Meanwhile, catalysts play a crucial role in plasma-based catalytic nitrogen fixation by promoting N_2/H_2 dissociation and nitrogen reduction to NH_3, thereby lowering activation energy, enhancing efficiency, and reducing energy consumption. In this part, we will screen various catalyst candidates, including metals (Fe, Ru, Ni, Co), oxides (TiO_2, ZrO_2), and carbon-based catalysts. Initially, we aim to establish the relationship between catalyst structure and nitrogen dissociation efficiency in a non-thermal plasma system, accelerating catalyst development. Once an effective catalyst material is identified, we will assess its longevity and thoroughly investigate the mechanisms behind its deactivation.

Activity Milestones:

Description	Approximate Completion Date
Investigate the underlying mechanism of nano-bubble plasma discharge in the liquid phase	August 31, 2027
Determine the optimal bubble size and quantify the improvement in nitrogen fixation yield	September 30, 2027
Prepare, characterize, and investigate the performance of catalysts	December 31, 2027
Explore catalytic mechanisms and optimize processing parameters	February 28, 2028
Evaluate catalyst energy efficiency and economic feasibility	April 30, 2028

Activity 3: Integrate solar power, assess energy consumption and environmental impacts of the technology, and conduct a techno-economic analysis

Activity Budget: $270,000

Activity Description:
We will design a solar power system through a systematic analysis of voltage, current, and power characteristics. This includes measuring local solar radiation, optimizing solar collector tilt, setting up transformers and inverters, and establishing an energy storage system. The solar power components will then be integrated into the nitrogen fixation system and tested outdoors for an extended period.

Additionally, we will communicate findings from Activities 1-3 to key stakeholders, including fertilizer producers and ammonia manufacturers. Based on their feedback, we will design and construct a small pilot-scale integrated system for comprehensive evaluation. Rigorous lab tests will be conducted before deploying the system to relevant sites for real-world testing and demonstration.

Mass and energy balance data, along with emission measurements, will be analyzed using a mathematical model to assess environmental and economic performance. At this scale, we will better evaluate the electrical energy required for non-thermal plasma generation, confirming utility costs and economic feasibility. This assessment will also provide a clear understanding of the environmental impact of the technology. Based on the results, we will propose further R&D efforts and develop commercialization strategies to advance the implementation of this sustainable nitrogen fixation system.

Activity Milestones:

Description	Approximate Completion Date
Design and integrate a solar power system	July 31, 2028
Test the integrate system outdoors and demonstrate functionality	November 30, 2028
Evaluate energy efficiency, cost, and emissions	January 31, 2029
Assess environmental impacts of the system	April 30, 2029
Recommend further R&D and commercialization strategies	June 30, 2029

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Juer Liu	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?

The project will transition to pilot-scale demonstrations to validate real-world performance. We will collaborate with agricultural cooperatives, fertilizer producers, and renewable energy developers to integrate plasma-based nitrogen fixation into Minnesota's infrastructure. Federal funding sources, including USDA and DOE ARPA-E, along with state partnerships, will support ongoing efforts. The University of Minnesota will assist with intellectual property management and commercialization. Outreach through workshops and industry conferences will promote adoption. This decentralized, renewable nitrogen production technology will strengthen Minnesota's agricultural resilience, reduce fossil fuel reliance, and support sustainable fertilizer production for regional food security.

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
Preventing PFAS and Microplastics Contaminants across Minnesota	M.L. 2024, , Chp. 83, Art. , Sec. 2, Subd. 08k	$656,000

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 has been elected to the National Academy of Engineering (NAE, Class 2025), and inducted as a Fellow of the National Academy of Inventors (NAI, Class 2023) and a Fellow of multiple other esteemed organizations, including ASABE, IFT, IAAM, and Vebleo. He has received numerous awards, including the International Bioprocessing Association's Pandey Award, the CAFS Professional Achievement Award, and the Scientist of IAAM Award. Dr. Ruan's research focuses on renewable energy and environmental technologies for sustainable development and the circular economy. His work spans biomass and solid waste pyrolysis and gasification, including plastic waste, to produce chemicals, materials, fuels, and energy. He has also developed novel wastewater treatment technologies using anaerobic digestion, microalgae cultivation, and hydroponics. Additionally, he specializes in pathogen disinfection and pollutant control using catalytic non-thermal plasma, low-temperature and pulse microwave, photocatalytic intensive pulse light, and NMR/MRI applications for nitrogen fixation, food safety, and food quality enhancement. Dr. Ruan has published over 600 peer-reviewed journal articles, authored two books and 30 book chapters, and holds 21 U.S. patents. He ranks 83rd nationally and 190th globally in Engineering and Technology according to research.com and holds the Number One global ranking in microwave pyrolysis and microalgae and wastewater treatment research per Web of Science. His work has an h-index of 105, an i10-index of 527, and over 43,000 citations on Google Scholar. He has secured over $45 million in research funding from agencies such as USDA, DOE, DOT, and DOD. As a project manager on several LCCMR-funded projects, his work has led to U.S. patents and technology licensing. His technical expertise and project management experience ensure the successful 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								
Lead PI - summer salary only		Direct all research and personnel			36.6%	0.15		$45,341
Co-PI- position .9 FTE funding dependent on grants		Direct work in the lab			36.6%	0.9		$81,706
Post doctoral student		Conduct experiments, analysis			25.9%	3		$251,866
Graduate student		Help post doc with conducting experiment and analysis, education			83.6%	3		$179,501
							Sub Total	**$558,414**
Contracts and Services								
							Sub Total	-
Equipment, Tools, and Supplies								
	Equipment	computer hardware to interface with analytical instruments	to conduct analysis	X				$3,000
	Equipment	components of lab testing system	for lab testing system development and testing					$44,558
	Tools and Supplies	Purchase of lab and miscellaneous supplies, including gas, catalysts, chemicals, consumable supplies for analytical instruments, PPEs, etc.	for personnel to conduct research accurately and safely					$30,028
							Sub Total	**$77,586**
Capital Expenditures								
		components - including various plasma reactor vessel, powder supplies with high voltage, control, motors, mixer, feeder, valves, etc.	for building demonstration system for ammonia production	X				$210,000

							Sub Total	**$210,000**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
	Miles/ Meals/ Lodging	tbd	Local outreach and community engagement					$4,000
							Sub Total	**$4,000**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$850,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request
Equipment, Tools, and Supplies		computer hardware to interface with analytical instruments	this is necessary for the equipment to work, could be considered equipment
Capital Expenditures		components - including various plasma reactor vessel, powder supplies with high voltage, control, motors, mixer, feeder, valves, etc.	integral to conduct research for project **Additional Explanation :** The capital equipment purchased with this appropriation will continue to be used for the same program throughout its useful life by supporting ongoing research, development, and demonstration of plasma-based nitrogen fixation technology. After project completion, the equipment will remain at the University of Minnesota's Center for Biorefining, where it will facilitate future advancements in electrified nitrogen fixation, process optimization, and scale-up efforts. It will also be used for student training, industry collaboration, and additional grant-funded projects aimed at improving sustainable fertilizer production and agricultural resilience. This long-term utilization ensures the technology's continued development and integration into Minnesota's agricultural infrastructure.

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	-
Non-State				
			Non State Sub Total	-
			Funds Total	-

Total Project Cost: $850,000

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: 40a4c210-fe9.pdf

Alternate Text for Visual Component

The visual shows our CHIEF system setup and preliminary nitrogen fixation results. It includes data from a high-voltage plasma generator (input voltage: 150 V, liquid conductivity: 130 µS, nitrogen feeding rate: 150 ml/min, treatment time: 20 min). Results show reduced power consumption and a linear increase in ammonia concentration....

Supplemental Attachments

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

Title	File
Letter of Authorization to Submit	905e9cc4-8f7.pdf
Audit	21aacfcf-b71.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Do you understand that travel expenses are only approved if they follow the "Commissioner's Plan" promulgated by the Commissioner of Management of Budget or, for University of Minnesota projects, the University of Minnesota plan?

Yes, I understand the UMN Policy on travel applies.

Does your project have potential for royalties, copyrights, patents, sale of products and assets, or revenue generation?

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 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:

Wendy Moylan, Juer Liu, University of Minnesota

Do you understand that a named service contract does not constitute a funder-designated subrecipient or approval of a sole-source contract? In other words, a service contract entity is only approved if it has been selected according to the contracting rules identified in state law and policy for organizations that receive ENRTF funds through direct appropriations, or in the DNR's reimbursement manual for non-state organizations. These rules may include competitive bidding and prevailing wage requirements

N/A