Environment and Natural Resources Trust Fund

2027 Request for Proposal

General Information

Proposal ID: 2027-355

Proposal Title: Bio-Based Slow-Release Fertilizer to Reduce Agricultural Nitrate Runoff

Project Manager Information

Name: Xiaowen Chen

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

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Project Basic Information

Project Summary: Advance a nonthermal plasma-enabled lignin-based slow-release nitrogen fertilizer to improve nutrient retention and quantify nitrate transport in Minnesota soils, strengthening groundwater and surface-water protection.

ENRTF Funds Requested: $300,000

Proposed Project Completion: June 30, 2030

LCCMR Funding Category: Small Projects (G)
Secondary Category: Water (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.

Nitrogen fertilizer is essential for crop production, yet nitrate, the dominant plant-available form is highly mobile in soil and can move rapidly to groundwater and surface waters when not taken up by plants. Approximately 70% of Minnesotans rely on groundwater for drinking water, including over one million private well users. U.S. EPA drinking water standard for nitrate is 10 mg/L due to infant health risks and contamination can require costly treatment. State monitoring confirms nitrate is present in vulnerable areas. The MDH reports that about 4% of new wells exceed 3 mg/L nitrate-nitrogen, and some townships have more than 10% of private wells exceeding 10 mg/L. The MDA identifies nitrogen leaching past the crop root zone as a primary contributor in rural regions and has adopted statewide fertilizer management strategies to reduce this risk. Increasing frequency of intense rainfall events further elevates leaching potential in permeable and tile-drained soils. Most conventional nitrogen fertilizers are produced through centralized, energy-intensive processes and are formulated for rapid solubility, characteristics that increase vulnerability to nitrate loss under variable precipitation. There is opportunity to develop a fertilizer system that releases nitrogen gradually under Minnesota conditions to protect groundwater and surface waters.

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 will develop and evaluate a lignin-based slow-release nitrogen fertilizer designed to reduce Minnesota's nitrate contamination in groundwater. The approach uses a gas-liquid nonthermal plasma process to activate atmospheric nitrogen under ambient conditions, generating reactive nitrogen species that chemically fixed onto lignin, a naturally occurring biomass polymer and precursor to soil organic matter. Through this process, nitrogen becomes incorporated within the lignin matrix rather than remaining fully soluble in mineral salt form. Because nitrogen is associated with a carbon-rich structure, its release to soil solution may differ from conventional fertilizers formulated for immediate dissolution. Funding will support laboratory-scale nitrogen fixation, structural characterization to verify nitrogen bonding and content, and controlled soil incubation and leaching experiments. Nitrogen release kinetics will be quantified under defined moisture conditions, and leachate will be analyzed for nitrate, ammonium, and total nitrogen to compare transport behavior with conventional fertilizer controls. Process parameters affecting nitrogen incorporation efficiency and energy input will be screened to establish mass balance and assess feasibility at lab scales. A preliminaryTEA and LCA will identify key cost, energy, and environmental drivers. This study will determine whether measurable differences in nitrogen release and transport justify further field-scale investigation for groundwater protection in Minnesota.

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 successful completion of this project will enable the development of a lignin-based, slow-release nitrogen fertilizer designed to minimize nitrogen losses associated with intensive agricultural practices. Excessive application of conventional nitrogen fertilizers often results in nitrate leaching into groundwater, contributing to drinking water contamination in Minnesota. By chemically stabilizing reactive nitrogen within a biomass-derived lignin matrix, the proposed fertilizer can release nutrients in a controlled manner that better matches crop uptake. This approach has the potential to reduce overall nitrogen input requirements, decrease groundwater contamination, mitigate nutrient runoff into lakes and rivers, and protect aquatic ecosystems while improving long-term soil.

Activities and Milestones

Activity 1: CHIEF-Based Nitrogen Fixation and Material Characterization

Activity Budget: $135,000

Activity Description:
This activity will establish the nitrogen incorporation mechanism, efficiency, and energy basis of nitrogen-enriched lignin fertilizer (NELF) production using the CHIEF gas-liquid NTP system operating under ambient temperature and atmospheric pressure. The CHIEF reactor will be used to activate atmospheric nitrogen, generating reactive nitrogen species in the liquid phase that interact with lignin's phenolic and aromatic functional groups. A structured parameter screen will evaluate applied voltage/power setting, duty cycle, gas composition (N_2/O_2 ratio), gas flow rate, and liquid conductivity to define a bounded operating window that maximizes nitrogen incorporation while minimizing specific energy consumption (kWh/per unit N incorporated). Two to three representative technical lignins (e.g., alkali lignin from agricultural residue and an industrial kraft or organosolv lignin) will be evaluated to assess structural sensitivity of nitrogen uptake. A constrained catalyst will also be evaluated for heterogeneous catalytic surfaces-enhanced nitrogen incorporation or shift nitrogen-bonding pathways. Nitrogen incorporation will be quantified via elemental analysis (CHN), aqueous nitrogen species (NO_3^-, NO_2^-, NH_4^+) will be quantified for full nitrogen mass balance, and spectroscopic analysis (e.g. FTIR) will verify structural changes consistent with nitrogen association. Electrical energy input will also be continuously monitored to establish specific energy consumption.

Activity Milestones:

Description	Approximate Completion Date
CHIEF reactor operational with baseline nitrogen fixation experiments completed.	March 31, 2028
Process parameter screening and bounded operating window identified for nitrogen incorporation efficiency and energy input	September 30, 2028
Nitrogen incorporation verified through CHN analysis and spectroscopic characterization across selected lignin feedstocks.	December 31, 2028

Activity 2: Nitrogen Release Dynamics and Nitrate Transport Under Minnesota Soil Conditions

Activity Budget: $115,000

Activity Description:
This activity will quantify nitrogen release kinetics and nitrate transport behavior of NELF relative to conventional soluble nitrogen fertilizer under representative Minnesota soil conditions. Two contrasting agricultural soils will be selected to capture variability in hydraulic conductivity and leaching vulnerability (e.g., coarse-textured sandy loam and finer-textured loam or clay loam). Soils will be characterized for texture, organic matter content, pH, and baseline inorganic nitrogen prior to experimentation. Controlled incubation experiments will determine time-resolved mineral nitrogen generation from NELF under defined moisture regimes and controlled temperature conditions, enabling construction of nitrogen release profiles and estimation of mineralization kinetics. Parallel leaching column experiments will simulate rainfall events under standardized hydraulic loading to quantify cumulative transport of nitrate, ammonium, and total nitrogen in leachate. Nitrogen application rates will be normalized across treatments to ensure direct comparability. Analytical methods will include ion chromatography or equivalent for NO_3^- and NO_2^-, colorimetric or ion-selective methods for NH_4^+, and total nitrogen analysis where appropriate. Replication and QA/QC procedures will be applied to support statistical comparison of cumulative nitrate export and release dynamics. This activity evaluates whether nitrogen association within lignin alters nitrogen mobility under conditions representative of leaching-vulnerable Minnesota soils.

Activity Milestones:

Description	Approximate Completion Date
Selection and full characterization of representative Minnesota soils	March 31, 2029
Time-resolved soil incubation dataset for NELF and conventional fertilizer controls	September 30, 2029
Leaching column experiments with quantified cumulative nitrate, ammonium, and total nitrogen export	December 31, 2029

Activity 3: Integrated Mass Balance, Energy Analysis, and Preliminary Systems Assessment

Activity Budget: $50,000

Activity Description:

This activity will integrate nitrogen incorporation efficiency, energy consumption, and soil transport performance into a structured feasibility assessment. Nitrogen mass balance data generated in Activity 1 will be combined with electrical energy measurements to calculate specific energy input per unit nitrogen incorporated and evaluate production efficiency within the defined CHIEF operating window. Environmental performance metrics from Activity 2, including nitrogen release kinetics and cumulative nitrate export, will be incorporated into a comparative framework evaluating how nitrogen association within lignin influences nitrogen mobility under representative soil conditions. A preliminary techno-economic assessment (TEA) will be developed using measured nitrogen incorporation efficiency, energy intensity, lignin feedstock assumptions, and material handling considerations to estimate production cost drivers at laboratory scale. In parallel, a streamlined life-cycle assessment (LCA) will evaluate potential environmental performance indicators, including energy use and nutrient loss implications relative to conventional nitrogen fertilizer pathways. Sensitivity analysis will identify dominant feasibility drivers and define quantitative advancement thresholds for nitrogen incorporation efficiency, specific energy consumption, and comparative nitrate transport. The final output will be an integrated technical assessment providing decision-ready criteria for staged advancement, continuation, or modification of the technology pathway in alignment with Minnesota groundwater protection priorities.

Activity Milestones:

Description	Approximate Completion Date
Integrated nitrogen mass balance and process energy analysis completed.	February 28, 2030
Preliminary techno-economic assessment and streamlined life-cycle assessment completed.	April 30, 2030
Final feasibility framework and technical report completed defining advancement criteria for field-scale investigation.	June 30, 2030

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Roger Ruan	UMN	Co-PI	Yes

Dissemination

Describe your plans for dissemination, presentation, documentation, or sharing of data, results, samples, physical collections, and other products and how they will follow ENRTF Acknowledgement Requirements and Guidelines.
Project findings will be disseminated to scientific, regulatory, agricultural, and public audiences to ensure results are accessible to entities responsible for protecting Minnesota's groundwater and surface waters. Technical results including nitrogen incorporation efficiency, nitrogen release kinetics, and nitrate transport behavior will be compiled in a final technical report and shared with the MDA Fertilizer Management Unit, MDH Drinking Water Protection Section, and MDNR Groundwater Monitoring and Assessment Program. These agencies oversee programs addressing nitrate contamination, fertilizer practices, and drinking water protection and will receive technical summaries describing the experimental results and data interpretation.

Results relevant to agricultural nutrient management will be communicated through UMN Extension nutrient management and water quality programs, which engage farmers, crop advisors, watershed districts, and SWCDs across Minnesota. Short technical summaries will translate research findings into accessible information describing the potential of slow-release fertilizers to reduce nitrate leaching and protect groundwater resources. Findings will also be shared with fertilizer manufacturers and agricultural industry partners interested in emerging controlled-release nutrient technologies that could support improved nitrogen management in Minnesota cropping systems.

Scientific dissemination will occur through peer-reviewed journal publications and presentations at conferences (e.g. ASABE, SSSA). Research datasets including nitrogen release profiles and nitrate leaching measurements will be archived through the UMN Data Repository to ensure long-term accessibility for researchers and natural resource professionals.

Public-facing summaries describing project goals and key findings will be posted on UMN CFANS and BBE program webpages, helping Minnesotans understand how ENRTF-supported research contributes to protecting groundwater and drinking water resources. All reports, presentations, publications, and electronic outreach materials will acknowledge support from the ENRTF using the required attribution language and logo in accordance with ENRTF Acknowledgment Guidelines.

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?
Project results will establish the technical and environmental feasibility of nitrogen-enriched lignin fertilizers for reducing nitrate transport in Minnesota soils. Findings will inform future field validation and agronomic evaluation in collaboration with agricultural stakeholders. Early discussions with the MDA Fertilizer Management Unit highlighted interest in continued dialogue as the technology progresses toward field-scale evaluation and regulatory consideration. Outcomes from this project will guide subsequent applied agronomic trials and system-scale assessment. Follow-on work will be pursued through federal funding programs (e.g., USDA-NIFA, NSF) and partnerships with agricultural and biomass processing stakeholders to advance field validation and potential deployment pathways.

Project Manager and Organization Qualifications

Project Manager Name: Xiaowen Chen

Job Title: Assistant Professor

Provide description of the project manager's qualifications to manage the proposed project.
Dr. Xiaowen Chen, Project Manager, is an Assistant Professor in the Department of Bioproducts and Biosystems Engineering (BBE) at the University of Minnesota. Dr. Chen leads the overall technical vision, project integration, and execution of this effort. Building on prior LCCMR funding, the University of Minnesota has developed a patented, non-thermal plasma (NTP) - based, pilot-scale mobile PFAS treatment trailer that has demonstrated high efficiency in degrading long-chain PFAS in contaminated water. Leveraging this established platform, Dr. Chen developed the consolidated PFAS treatment concept and assembled and coordinated a multidisciplinary team to further optimize, extend, and scale the technology. Dr. Chen has led more than10 DOE–funded projects with a cumulative funding total exceeding $10 million, demonstrating a strong track record in managing complex, multi-institutional research programs and translating laboratory innovations toward pilot- and field-scale deployment.

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

Organization Description:
In the College of Food, Agricultural and Natural Resources Sciences (CFANS) at the University of Minnesota, we look at the bigger picture. When we envision a better tomorrow, it includes disease-resistant crops, products that protect our health, lakes free from invasive species, and so much more. We use science to find answers to Minnesota and the world's grand challenges and solve tomorrow's problems. Almost 93 percent of students who earn CFANS undergraduate degrees find jobs in their career field or enter graduate school within six months of graduation.

The Department of Bioproducts and Biosystems Engineering, in CFANS, discovers and teaches solutions for the sustainable use of renewable resources and the enhancement of the environment. We discover innovative solutions to address challenges in the sustainable production and consumption of food, feed, fiber, materials, and chemicals by integrating engineering, science, technology, and management into all degree programs.

We have a public impact through community engagement and extension efforts. We develop and deliver high quality, regionally and nationally-recognized research-based programs to meet current and emerging needs of industry and communities. We also have a long-standing tradition of close partnerships with alumni, industry professionals, organizations, government agencies, donors, and community members.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Professor/Faculty		PI - 9 month appointment (2 weeks summer salary) - direct the overall project, supervise CHIEF-based nitrogen fixation experiments, coordinate data integration across activities, oversee student and postdoctoral research personnel, and lead project reporting and dissemination.			36.6%	0.15		$29,090
Professor/Faculty		Co-PI - 9 month appointment (2 weeks summer salary) - co-lead project design, oversee fertilizer and soil-related experimental planning, supervise interpretation of nitrogen release and nitrate transport results, and contribute to reporting and translation of results toward future agronomic validation.			36.6%	0.15		$37,533
Postdoctoral Researcher		Conduct day-to-day experimental work across Activities 1–3, including CHIEF reactor operation, nitrogen incorporation experiments, material characterization, soil incubation and leaching studies, data analysis, and preparation of reports and manuscripts.			26.1%	1.5		$124,917
Graduate Research Assistant		Assist with experimental setup, sample preparation, analytical measurements, data collection, and data processing for nitrogen release, nitrate transport, and preliminary systems assessment tasks.			24.2%	0.75		$47,082
							Sub Total	**$238,622**
Contracts and Services								
Lab and Medical Services	Internal services or fees (uncommon)	Internal analytical service charges and instrument use fees with internal rates needed to characterize materials and quantify nitrogen species. Services may include CHN elemental analysis, ion chromatography or equivalent nitrate/nitrite analysis, ammonium analysis, and other fee-based shared instrumentation needed to support Activities 1 and 2.				-		$6,000

							Sub Total	**$6,000**
Equipment, Tools, and Supplies								
	Tools and Supplies	Lignin feedstocks, catalyst materials, compressed gases, salts and reagents for nitrogen fixation and analytical testing, nitrate/ammonium calibration standards, pH and conductivity buffers, filters, tubing, vials, pipette tips, centrifuge tubes, sample bottles, gloves, masks, and other routine laboratory consumables.	Produce and evaluate nitrogen-enriched lignin fertilizer materials and perform soil testing					$28,378
	Equipment	High-voltage power supply upgrade for CHIEF reactor operation — $4,800; Mass flow controllers for N_2/O_2 gas delivery (2 units) — $4,200; Soil column assemblies, fittings, and support manifolds — $2,900; Peristaltic pump with tubing sets for controlled flow/leachate collection — $1,600; Gas regulators, pressure control, and safety shutoff components — $1,450; Data acquisition modules and process sensors — $2,050	To support construction and refinement of the CHIEF testing platform, controlled gas delivery, monitoring of reactor conditions, and standardized soil column testing for nitrate transport experiments.					$17,000
	Equipment	Replacement reactor electrodes, dielectric tubes, and fittings — $2,400; Leachate collection and filtration manifold components — $1,850; Soil moisture and temperature monitoring sensors — $1,750; Sample preparation equipment for soil/leachate processing — $2,950; Data logging and interface hardware — $1,050	To support continued reactor operation, replicate soil incubation and leaching experiments, sample handling, and environmental monitoring.					$10,000
							Sub Total	**$55,378**
Capital Equipment								
							Sub Total	**-**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
							Sub Total	**-**

Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$300,000**

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	**-**

Total Project Cost: $300,000

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: d593533b-518.pdf

Alternate Text for Visual Component

This illustration discusses the rational of slow releasing fertilizer. It also shows the activities related to nitrogen fixation onto lignin using nonthermal plasma to produce a slow-release fertilizer....

Supplemental Attachments

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

Title	File
Letter of Authorization to Submit	2451084f-617.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?

N/A

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:

Juer Liu

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