Environment and Natural Resources Trust Fund

2023 Request for Proposal

General Information

Proposal ID: 2023-151

Proposal Title: Carbon-Free Green Ammonia to Power Minnesota Farms

Project Manager Information

Name: Sayan Biswas

Organization: U of MN - College of Science and Engineering

Office Telephone: (612) 625-6012

Email: biswas@umn.edu

Project Basic Information

Project Summary: This proposal aims to demonstrate a heavy-duty agricultural equipment engine fueled solely by green ammonia, employing a novel and inexpensive plasma-based ignition technology that minimizes nitrous oxide production.

Funds Requested: $250,000

Proposed Project Completion: June 30, 2025

LCCMR Funding 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?

In the Future

Narrative

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

Minnesota agriculture uses anhydrous, i.e., 'without water' ammonia, to supply nitrogen to crops, an essential nutrient for plant growth. According to the Minnesota Department of Agriculture, Minnesota farms consume nearly 600,000 metric tons of ammonia every year, part of which is produced in-state using wind energy. Carbon-free green ammonia produced electrolyzing water and atmospheric nitrogen powered by renewable wind or solar energy offers a significant decarbonization opportunity. With rapidly growing wind power capacity, Minnesota possesses a unique opportunity to utilize ammonia both as a fertilizer as well as fuel. Utilizing a novel plasma-assisted ammonia combustion technology, agricultural engines, and farm machinery can be powered solely by ammonia. A $10 plasma igniter retrofitted to the agricultural ammonia engines eliminates the necessity of a second/dual-fuel like diesel or hydrogen to ignite ammonia. This permits Minnesota farmers to cut down their reliance on fossil fuels reducing greenhouse emissions. Minnesota farms are already equipped with ammonia storage and handling; hence, ammonia can easily be dropped into the existing agricultural equipment and power systems. The rise of the 'Ammonia Economy' will make Minnesota a leader in sustainability, a self-sufficient circular economy, and the fight against climate change.

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.

Ammonia — a renewable fuel made from wind, air, and water — could power Minnesota farms without emitting greenhouse gases. However, running an agricultural engine solely on ammonia is challenging due to poor reactivity and difficulty in ammonia ignition. To overcome this challenge, existing ammonia combustion technologies add a second fuel — hydrogen, diesel, or dimethyl-ether. Always using two fuels to power agriculture and farming equipment brings strain and complexity in logistics and, at times, is impractical. Ammonia – NH_3 contains 1-part nitrogen and 3-parts hydrogen. We are proposing a plasma-based innovative and novel approach to break the NH-H_2 bond to release hydrogen that works like a second fuel. Plasma reforming dramatically improves ammonia reactivity and ignites ammonia without a second fuel. A $10 low-temperature plasma igniter can reform ammonia in-cylinder to produce enough hydrogen to burn it like gasoline. Besides improving reactivity, plasma can simultaneously extend the lower ignition limit of ammonia and reduce nitrous oxide emission. Our project will demonstrate the plasma technology in a heavy-duty tractor engine running solely on ammonia. The ultimate objective of our project is to enable the Minnesota farms to find a cost-effective, carbon-free future fuel that will power agriculture and farming for decades to come.

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?

'Green ammonia' produces zero carbon emissions while maintaining energy security for the state of Minnesota. By switching from fossil fuels to ammonia, Minnesota could save over 40 metric tons of carbon dioxide emissions each year. Proposed plasma technology solves one of the biggest challenges of ammonia combustion by reducing nitrous oxide emissions to the floor. This significantly improves air quality in rural Minnesota and helps maintain the natural resources. Green ammonia produced from Minnesota's wind power benefits the environment by eliminating greenhouse gases like carbon dioxide and nitrous oxide, improving energy efficiency, and strengthening energy security for Minnesota farms.

Activities and Milestones

Activity 1: Employ plasma-based ammonia reforming and plasma-assisted ammonia combustion

Activity Budget: $50,000

Activity Description:
In this activity, a novel, robust, and inexpensive low-temperature plasma-assisted fuel reforming, ignition, and flame stabilization system will be used for ammonia combustion to achieve combustion efficiency ≥ 95%, leading to near-zero nitrous oxide emissions. Low-temperature non-equilibrium plasmas generate electrons of extremely high temperatures, with energies in excess of 5 – 10 eV capable of dissociating even the most stable chemical bonds. However, the plasma and the surrounding bulk gas temperatures remain fairly low ~ 300 K. That saves energy and eliminates potential electrode erosion issues. Plasma-assisted in-situ ammonia reforming substantially improves the chemical reactivity of ammonia, leading to faster, efficient, and complete combustion of ammonia.

We will perform a series of well-controlled rigorous scientific experiments discharging low-temperature plasma in pure ammonia and measuring the discharge products using gas chromatography and mass spectrometry (GC-MS). We will vary the plasma input energy, pulse delay, and other parameters targeting various engine operating conditions. We will add engine residual EGR gases, such as air, water, etc., and examine their effect on ammonia reforming. The short-lived intermediate chemical species and radicals will also be measured for detailed chemical kinetics studies.

Activity Milestones:

Description	Completion Date
Set up the optical vessel to study ammonia reforming by low-temperature plasmas	December 31, 2023
Complete testing of plasma-assisted ammonia reforming in a laboratory setting	February 28, 2024
Investigate the role of various plasma parameters on ammonia reforming	April 30, 2024
Activity 1 summary report	May 31, 2024

Activity 2: Optimize plasma igniter performance suitable for ammonia engine applications

Activity Budget: $50,000

Activity Description:
In this activity, we will build a transient plasma fuel reforming module to be used for all planned ammonia tests. The ignition system will include a nanosecond pulsed power generator capable of high repetition rate bursts (10 – 100 kHz). The pulse voltage and repetition rate will be optimized for ammonia reforming for given operating conditions. The system will also include the capability to 'sense' discharge mode (no breakdown, high impedance corona/glow discharge, or low impedance spark discharge) and then adjust subsequent ignition pulses in response.

We will design and build plasma electrodes in-house that function by using nanosecond duration transient plasma pulses to achieve fuel reforming of ammonia across the entire range of planned testing. Two custom electrode designs will be explored: 1) A pin-to-pin opposed electrode configuration, 2) Multi-prong corona-like discharge configuration: Multi-prong electrode featuring 4-8 sharpened prong electrodes that generate elongated and very repeatable corona-like plasma streamers that emanate into ammonia.

Activity Milestones:

Description	Completion Date
Test different plasma igniter performance on ammonia reforming	June 30, 2024
Complete a series of plasma-assisted ammonia reformed combustion	October 31, 2024
Optimize plasma parameters to enhance ammonia combustion	December 31, 2024

Activity 2 summary report	December 31, 2024

Activity 3: Perform field demonstration of heavy-duty agricultural equipment running solely on ammonia

Activity Budget: $120,000

Activity Description:
In this activity, we will retrofit the plasma-assisted in-situ ammonia reforming hardware in a heavy-duty agricultural equipment engine, such as a tractor, backhoe, or farm machinery running solely on ammonia. We will use a suitable real-time plasma control for optimum performance and energy usage. The energy required for plasma generation is critical for the proposed technology. We will measure ammonia engine performance and emissions with and without the proposed technology for baseline conditions and compare it with diesel operation. Field testing of our plasma system will be instrumental in demonstrating the proposed system's capabilities and exposing potential concerns and roadblocks that need to be addressed before commercialization efforts.

PI Biswas is currently involved in field testing this plasma technology in partnership with several local Minnesota farms. Once developed, the plasma technology will bring enthusiastic participation from Minnesota farmers.

Activity Milestones:

Description	Completion Date
Integration and demonstration of plasma-assisted in-situ ammonia reforming technology completed	March 31, 2025
Complete preliminary field testing of the proposed technology in a local Minnesota farm	April 30, 2025
Provide detailed insights based on learnings from engine testing	May 31, 2025
Activity 3 summary report	May 31, 2025

Activity 4: Reporting, results dissemination, and journal paper writing

Activity Budget: $30,000

Activity Description:
This phase of the project will focus on the final data analysis and report writing. In addition to meeting the deliverable requirements of the LCCMR Fund, the project team will prepare manuscripts for submission to peer-reviewed journals and will communicate the results of the project with the energy companies and waste management entities. Our final goal is to demonstrate ammonia as a cost-effective, carbon-free alternative fuel that will power the off-road agricultural machinery, farms, and energy sector of Minnesota for decades to come.

Activity Milestones:

Description	Completion Date
Finished drafting the first version of the journal/conference article	March 31, 2025
Complete analysis of ammonia engine testing data	March 31, 2025
Activity 4 summary report	April 30, 2025
Final project report	June 30, 2025

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Will Northrop	Mechanical Engineering, University of Minnesota	Prof. Will Northrop is a senior researcher and expert in the handling and utilization of ammonia. He will serve as a technical advisor to this project.	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?

Results of the project will be communicated with the Minnesota farms/agriculture, off-road engine manufacturers, and other stakeholders via conferences, journal articles, reports, and direct communication with the engine companies. The impact of this project will influence strategic planning activities of primary agricultural machinery and engine OEM stakeholders as they develop the next generation of environment-friendly technologies. The US Department of Energy and the Minnesota Department of Agriculture is committed to reducing the environmental impacts of agriculture and farming. Proposals for funding additional work can be submitted to these sources, as well as by establishing partnerships with private energy companies.

Project Manager and Organization Qualifications

Project Manager Name: Sayan Biswas

Job Title: Assistant Professor

Provide description of the project manager's qualifications to manage the proposed project.

Prof. Sayan Biswas, Benjamin Mayhugh Assistant Professor of Mechanical Engineering, is an expert in clean energy, LiDAR sensing, and novel laser-based sensing and diagnostics, will lead this project. PI Biswas has utilized LiDAR to solve challenging problems including the detection of bald eagles and snow particles for self-driving cars. Besides LiDAR sensing, PI Biswas has extensive experience developing optical sensors for energy applications. His research has received support from the Department of Energy (DOE), Advanced Projects Research Agency-Energy (ARPA-E), National Science Foundation (NSF), and several clean energy companies. He manages an annual research portfolio of $1.6M. Before joining the University of Minnesota in 2020, Dr. Biswas spent 3+ years at the Sandia National Laboratories and 5+ years at Purdue University, working on clean energy and developing advanced light/laser sensing systems. To date, PI Biswas has published 20+ journal articles, 40+ conference articles, 1 single-authored book, 6 book chapters, and holds 1 US patent. PI Biswas leads a highly diverse research group consisting of 6 PhD, 3 MS, and 8 UG students. His lab actively participates in educating the community about our energy future and in K-12 outreach activities, inspiring the next generation of scientists and engineers, and providing an open and equitable learning atmosphere for women, minorities, and indigenous students. Prof. Biswas serves on several technical and advisory committees, volunteering for his professional societies and local Minnesota-based organizations.

Organization: U of MN - College of Science and Engineering

Organization Description:

The University of Minnesota, Twin Cities is a public land-grant research university in the Twin Cities of Minneapolis and Saint Paul, Minnesota, and one of the most comprehensive research universities in the nation. The University leadership acknowledges that the University of Minnesota Twin Cities is built within the traditional homelands of the Dakota people. It is the flagship institution of the University of Minnesota System and is organized into 19 colleges, schools, and other major academic units. The University advances Minnesota state and US society through new ideas, technologies,

treatments, and cures, and continues to create and transfer technology to companies for the development of new products and services that benefit the public good and foster economic growth. The University's College of Science and Engineering received $141.9 million in research funding in FY2015. The University of Minnesota College of Science and Engineering (CSE) ranks #4 in the country for the best bachelor's degree in engineering. In other rankings, CSE majors traditionally rank among the top 20.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Sayan Biswas		Principal Investigator			25%	0.16		$29,059
Research Assistant		Graduate Student			43%	2		$109,507
							Sub Total	**$138,566**
Contracts and Services								
							Sub Total	**-**
Equipment, Tools, and Supplies								
	Tools and Supplies	Ammonia fuel supply system, plasma electrodes, wiring, fastening	Conducting ammonia reforming reactions in a field heavy-duty engine					$9,434
							Sub Total	**$9,434**
Capital Expenditures								
		Ammonia catalytic converter, plasma generator	Converting ammonia into hydrogen using plasma discharges	X				$84,000
							Sub Total	**$84,000**
Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
	Miles/ Meals/ Lodging	One trip per year for one PI and one graduate student	Attend conference for knowledge dissemination and attract potential customers/end-users					$6,000
							Sub Total	**$6,000**

Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
	Publication	Publication cost in open source journals	Open source journal let everyone access the research results at free of cost					$2,000
							Sub Total	**$2,000**
Other Expenses								
		Facilities	Fees for characterization facilities to study plasma electrode surface behavior to study longevity and robustness of these plasma electrodes. $5k/year budget is allocated for characterization facility.					$10,000
							Sub Total	**$10,000**
							Grand Total	**$250,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request
Capital Expenditures		Ammonia catalytic converter, plasma generator	We plan to demonstrate the plasma-assisted ammonia combustion technology in an agricultural engine that requires us to build a prototype system. Several components of this technology have already been developed by PI Biswas. The rest need to put purchased and put together. The $84k consists of a prototype plasma ignition technology to retrofit in an engine. **Additional Explanation :** Plasma-assisted reforming of ammonia enhancing reactivity is the crucial step in this project and must be done to achieve the final goal.

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	**-**
Non-State				
In-Kind	unrecovered F&A calculated at 55% MTDC	Support of ME facilities where research will be conducted.	Secured	$75,250
			Non State Sub Total	**$75,250**
			Funds Total	**$75,250**

Attachments

Required Attachments

Visual Component

File: cdf76faa-447.pdf

Alternate Text for Visual Component

The visual illustrates the challenge and opportunity of using ammonia as a fertilizer and fuel. The plasma-based proposed technology to reform and ignite ammonia to power engines solely using ammonia is shown pictorially. The vision of the 'ammonia economy' is explained....

Optional Attachments

Support Letter or Other

Title	File
UMN SPA Support Letter	060ac61f-96b.pdf
Plasma ignition technology	0cd9c8d5-1e8.pdf
Plasma Ignition Innovation Impact Award 2022	c91d6394-dc1.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?

Yes, Sponsored Projects Administration

Carbon-Free "Green Ammonia" to Power Minnesota Farms

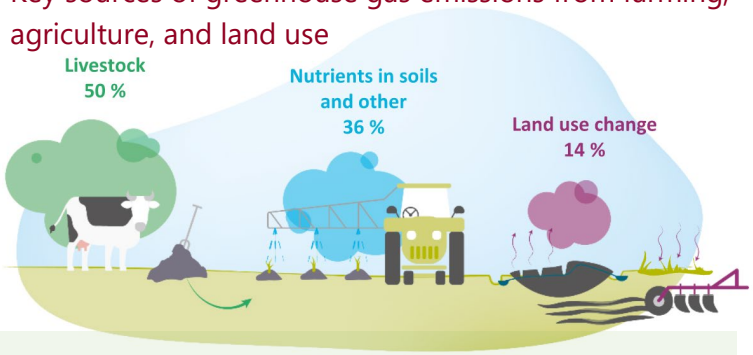
Principal Investigator Sayan Biswas, Mechanical Engineering

University of Minnesota Twin Cities

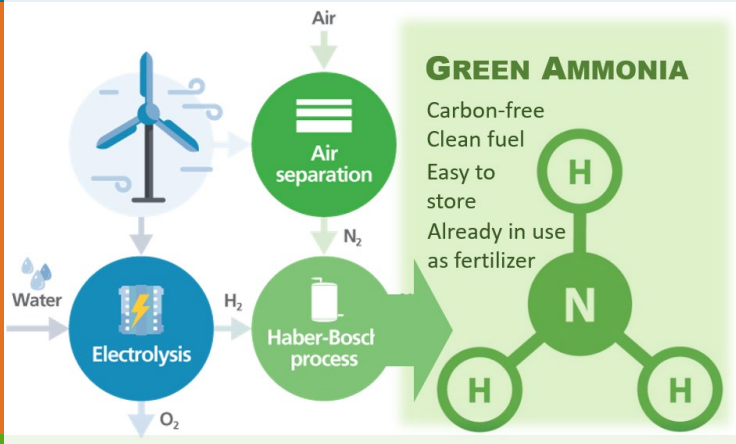
The Problem

Farming and agriculture generate nearly 60% of Minnesota's emissions of nitrous oxide and methane – two potent greenhouse gases

Key sources of greenhouse gas emissions from farming, agriculture, and land use



The Opportunity



"Green Ammonia" offers a practical solution to decarbonize farming

Green Ammonia

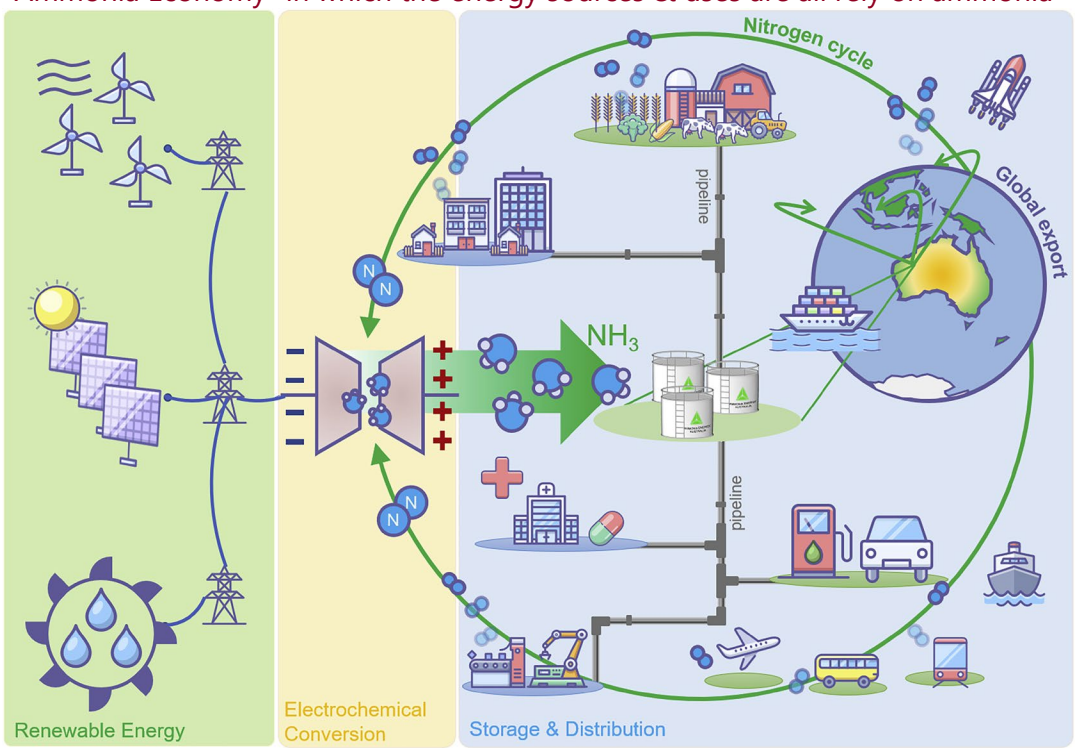
- A clean fuel made from wind, air, & water
- Has zero-carbon footprint, easy to store
- Could be used both as a *fertilizer* as well as *fuel*
- Powers Minnesota farms eliminating fossil fuels
- Create sustainable & self-sufficient economy

Proposed Solution

Provide the local Minnesota farms with a cost-effective, carbon-free clean fuel that will power the agriculture and farming sector for decades to come

We are proposing a *plasma-based* novel, inexpensive, & innovative approach to break the NH-H_2 bond in NH_3 to release H_2 that can dramatically improve ammonia reactivity; Enabling agricultural engines & farm machinery powered ***solely*** by ammonia

"Ammonia Economy" in which the energy sources & uses are all rely on ammonia



Plasma technology