Environment and Natural Resources Trust Fund
2019 Request for Proposals (RFP)

Project Title: **ENRTF ID: 183-E**

Instant On-Demand Nitrogen Fixation (iONF) from Air

Category: E. Air Quality, Climate Change, and Renewable Energy

Sub-Category:

Total Project Budget: $ 1,352,000

Proposed Project Time Period for the Funding Requested: June 30, 2022 (3 yrs)

Summary:

To develop and demonstrate innovative instant on-demand nitrogen fixation (iONF) process and system to convert air nitrogen and water to nitrogen fertilizer rich water for direct cropland applications.

Name: Roger Ruan

Sponsoring Organization: U of MN

Title: Professor and Director

Department: Bioproducts and Biosystems Engineering

Address: 1390 Eckles Ave.

St. Paul MN 55108

Telephone Number: (612) 625-1710

Email ruanx001@umn.edu

Web Address biorefining.cfans.umn.edu

Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

Showing iONF systems using tractor power in-field or wind/solar electricity on-site to instantly produce n-fertilizer from water and air for on-demand cropland application or hydroponic and drip fertilizer applications.

_____ Funding Priorities	_____ Multiple Benefits	_____ Outcomes	_____ Knowledge Base
_____ Extent of Impact	_____ Innovation	_____ Scientific/Tech Basis	_____ Urgency
_____ Capacity Readiness	_____ Leverage	_____ TOTAL	_____%
____ If under $200,000, waive presentation?			

PROJECT TITLE: Instant On-demand Nitrogen Fixation (iONF) from Air

I. PROJECT STATEMENT

The US farming and other industries use a large amount 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. This project addresses **Priority E** titled "*Air Quality, Climate Change, and Renewable Energy*" through demonstrating a new process to fix nitrogen from air and generate nitrogen-rich water on site or in field for direct cropland applications on demand. This instant on-demand nitrogen fixation (iONF) process is based on state of the art non-thermal plasma (NTP) technology that has been investigated and developed by the U of MN researchers for over two decades.

The iONF process ***using only water and air as inputs*** and the application strategy will be much cleaner and of lower cost than the conventional methods which use natural gas as reactant, emitting greenhouse gases, 662500highly portable distributed production and application methods will provide ***benefits*** including (1) reduction in environmental impacts through clean production technology and land application of low concentration of nitrogen fertilizers, (2) capturing of the value of nitrogen industry and products locally without the use of hydrogen, and (3) therefore generating significant tax revenue and jobs in the regions by reducing imports.

The proposed project is aimed at developing and demonstrating a novel process in which nitrogen plasma generated through electrical discharge is injected into water where a series of reactions take place, resulting in an aqueous solution containing nitrite, nitrate, and ammonium, which can be used as fertilizers with or without dilution. The resource inputs are nitrogen from air (air contains about 80% nitrogen), water (hydrogen and oxygen source), and electricity which can be renewable (e.g. solar panels for mobile systems or wind electricity for stationary systems).

The process can be made highly portable so that it can be implemented on a ***farm truck*** to generate instantly and apply the nitrogen rich solution to soil on demand. Alternatively, the process can be integrated with ***crop irrigation systems*** (e.g., drip irrigation) and ***hydroponic cultivation***. Currently, nitrogen fertilizers are applied to fields in high concentration, which is the main source of nitrogen contamination of ground water. The new features of the proposed nitrogen fixation and application methods will help overcome many environmental and technical disadvantages of conventional production and application methods and offer the benefits of sustainable distributed production of nitrogen fertilizers from renewable resources via clean process that circumvents (1) the use of expensive hydrogen gas and (2) the need for fertilizer storage and transportation.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: *Improve and optimize the non-thermal plasma based iONF process*

The concept of producing aqueous solution of nitrate, nitrite, and ammonia has been proven in our preliminary studies. In order to move the technology to commercial stage, we need to expand our knowledge base and make scientific breakthroughs in related areas including understanding of the reaction mechanisms, improving conversion efficiency, increasing concentration, reducing energy consumption, and developing optimized process flow diagram.

ENRTF BUDGET: $466,500

Outcome	Completion Date
1. Key processing variables will be identified and quantified and basic reaction mechanisms will be delineated	*06/30/2020*

2. Conversion efficiency, concentration of nitrogen derived compounds, and energy efficiency will be increased by 30-50% over the current performance	*12/31/2020*
3. An optimized process flow diagram will be delivered	*12/31/2021*

Activity 2: *Develop and demonstrate a prototype instant on-demand nitrogen fixation (iONF) system*

With the knowledge, experience, and optimized instant on-demand nitrogen fixation (iONF) process flow diagram obtained from Activity 1, we will develop a skid mount unit for comprehensive evaluation of the process and demonstration of the technology to general public for education and outreach purpose.

ENRTF BUDGET: $662,500

Outcome	Completion Date
1. Scale-up parameters will be determined for the optimized process flow	*03/31/2021*
2. System design for the prototype iONF unit will be completed	*06/30/2021*
3. The skid mount prototype iONF unit will be fabricated and tested in lab and on fields	*12/31/2021*
4. The skid mount iONF unit will be demonstrated on a farm setting to the stakeholders	*06/30/2022*

Activity 3: *Evaluate the environmental impacts and economic performance of the instant on-demand nitrogen fixation (iONF) process and system*

The data obtained from lab and field tests will be used to establish models for evaluation of environmental impacts and techno-economic performance.

ENRTF BUDGET: $223,000

Outcome	Completion Date
1. Data obtained from lab and field tests of the prototype system will be generated	*12/31/2021*
2. Models will be established for analysis of environmental impacts and technoeconomic performance	*06/30/2022*
3. Formulate a development and commercialization strategic plan	*06/30/2022*

III. PROJECT PARTNERS:

A. Project team:

Roger Ruan (BBE, UMN), Paul Chen (BBE, UMN), Mike Reese (UMN West Central Research & Outreach Ctr), Alon McCormick (ChemE, UMN), Prodromos Daoutidis (ChemE, UMN)

B. Partners not receiving ENRTF funding

Name	Title	Affiliation	Role
John Snyder	President/owner	Minnesga Inc.	System development and testing

IV. LONG-TERM- IMPLEMENTATION AND FUNDING:

New scientific knowledge on plasma based nitrogen fixation process will be acquired through research, 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.

V. TIME LINE REQUIREMENTS:

This 3 years project will begin on 07/01/19 and end on 06/30/22. The first 18 months will be focused on process improvement and parameter optimization, and full understanding of the proposed process, and the second 18 months will be focused on development, evaluation, and demonstration of the prototype instant on-demand nitrogen fixation (iONF) system.

2019 Proposal Budget Spreadsheet

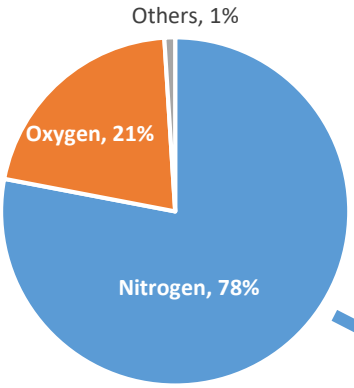
Project Title: Instant On-demand Nitrogen Fixation (iONF) from Air

IV. TOTAL ENRTF REQUEST BUDGET *[3]* **years**

BUDGET ITEM	AMOUNT
Personnel: other personnel categories may be used as needed	**$ 1,070,000**
Roger Ruan, PI/PD, 1 month/year, 3 years, including 33.5% benefits, leading and managing project, overlooking R&D, leading demonstration, supervising postdocs and RA	$ 65,000
Paul Chen, co-PI, 25%, 3yrs, including 31.8% benefits, project coordination, conducting R&D, project evaluation, progress report	$ 98,000
Alon McCormick, .5 mos/year, 3 years, including 33.5% benefits, conducting research on reaction kinetics	$ 37,000
Mike Reese, co-PI, 2 months/year, 3 years, including 33.5% benefits, responsible for field application and extension and outreach	$ 51,000
Prodromos Daoutidis, 1 month/year, co-PI, including 33.5% benefits, conducting research on modeling and economic analysis	$ 88,000
1.5 research professional (post-doctor, research associate, or research faculty) 100%, 3yrs, including 33.5% benefits, conducting R&D, operations, demonstration, data analysis	$ 313,000
2 Graduate Research Assistants (BBE Dept), 50%, 3yrs, including 15% benefits plus tuitions, conducting R&D, operationg, demonstration	$ 334,000
0.5 Graduate Research Assistant (ChemE Dept), 50%, 3 years, conduct research on modeling and economic analysis	$ 84,000
Equipment/Tools/Supplies:	**$196,000**
High voltage power supply	$15,000
Plasma monitor and analyzer	$24,000
Plasma jet systems	$32,000
Components for fabrication of lab scale experimental reactors	$14,000
Equipment for catalyst preparation	$8,000
Components for farbication of small scale nitrogen fixation systems	$47,000
Lab supplies, catalysts, instrument and equipment consumables, minor equipment	$56,000
Travel:	**$38,000**
For researchers to travel to collect samples in fields and between campus and demonstration site over the 3yrs project period	$38,000
Additional Budget Items:	**$48,000**
Outside analysis service (labs outside BBE Dept or labs outside the university with MN Company preferred)	$16,000
Instrument and equipment maintanance and repair (Processing equipments and analytic instruments)	$32,000
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	**$1,352,000**

V. OTHER FUNDS *(This entire section must be filled out. Do not delete rows. Indicate "N/A" if row is not applicable.)*

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period:	$ -	
Other State $ To Be Applied To Project During Project Period:	$ -	
In-kind Services To Be Applied To Project During Project Period: Unrecovered F&A	$ 591,000	
SOURCE OF FUNDS	**AMOUNT**	**Status**
Demonstrating innovative technologies to fully utilize wastewater resources (ML 2014 Sec. 2), US petent has been issued for the technology developed from this project.	$ 1,000,000	spent
Pyrolysis pilot project (ML 2007, Sec. 2), The technology developed from this project has been licensed by Resynergi Inc	$ 900,000	spent
Algae for Fuels Pilot Project (ML 2010, Sec. 2)	$ 500,000	spent
Other Funding History:	$ -	



iONF instant On-demand Nitrogen Fixation

Simple and Clean Production Technology based on **Non-Thermal Plasma (NTP)**

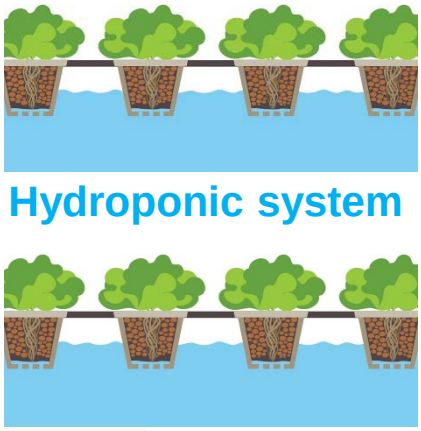
Air

Water
(hydrogen & oxygen)

NTP Reactor

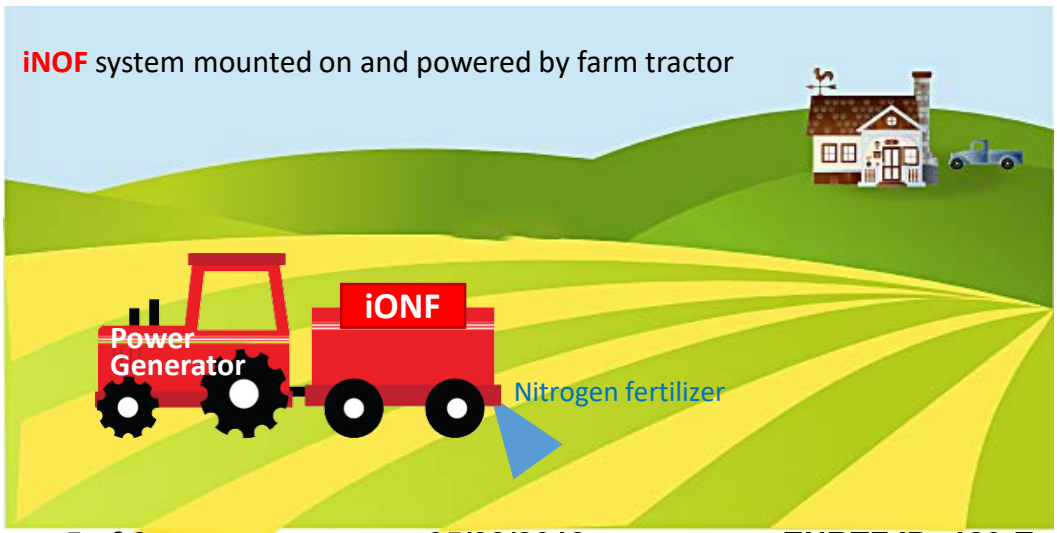
Wind/solar electricity

Nitrate (NO_3^-), nitrite (NO_2^-) & ammonia (NH_3)



Hydroponic system

Case #1: On-site Generation and Application



Case #2: Direct Field Generation and Application

Project Manager Qualifications and Organization Description

Dr. Roger Ruan, Professor and Director, Center for Biorefining and Department of Bioproducts and Biosystems Engineering, University of Minnesota, is the project manager of the proposed project. Dr. Ruan's research focuses on renewable energy and the environment as well as food safety and quality. Professor Ruan has published over 400 papers in refereed journals, has co-authored two books, and many book chapters, over 300 meeting papers and reports, and holds 18 US patents. He is also a top cited author in the area of agricultural and biological sciences. He has supervised over 65 graduate students, 110 post-doctors, research fellows, and other engineers and scientists, and 12 of his Ph.D. students and 8 other post-doctors hold university faculty positions. He has received over 160 projects totaling over $40 million in various funding for research, including major funding from USDA, DOE, DOT, DOD, LCCMR, and industries. Professor Ruan has given over 250 keynote lectures, invited symposium presentations, company seminars, and short courses, and has been a consultant for government agencies, and many local, national, and international companies and agencies in bioprocess engineering, food engineering, and renewable energy and environment areas. He has taught many undergraduate and graduate courses, including *Renewable energy technologies*, *Biological process engineering*, *Managing water in food and biological systems*, *Instrumentation and control for biological systems*, Food process engineering, and *Engineering principles and applications*, *etc*.

Dr. Ruan has extensive experience with non-thermal plasma (NTP) technology and use of NTP for ammonia and nitrogen fertilizer synthesis. They developed many non-thermal plasma devices and investigated NTP assisted catalytic synthesis of ammonia, deodoring of animal house air using NTP and ozone technologies. In addition, they conducted research on using non-thermal plasma technology for disinfection of pathogens in animal blood, liquid foods, and solid foods, and on food process equipment/plant environment. Three to five logs reduction in total bacteria counts have been demonstrated in their studies. He is one of the inventors of a number of US patents involving the non-thermal plasma technology particularly for ammonia synthesis. This experience will provide a good basis for them to develop and test non-thermal plasma reactors for cost effective synthesis and use of nitrate, nitrite, and ammonia.

The Center for Biorefining is a University of Minnesota research center and help coordinate the University efforts and resources to conduct exploratory fundamental and applied research; provide education on bioenergy, biochemicals and biomaterials; 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. In particular, they have the capability to develop NTP reactors and catalysts for different applications.