Environment and Natural Resources Trust Fund
2020 Request for Proposals (RFP)

Project Title: **ENRTF ID: 182-E**

Nitrogen Fixation for Fertilizers and Hydrogen Fuels Production

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

Sub-Category:

Total Project Budget: $ 487,000

Proposed Project Time Period for the Funding Requested: June 30, 2023 (3 yrs)

Summary:

To demonstrate a new process to fix nitrogen from water and air to produce ammonia and nitrogen-rich water using renewable electricity from wind or solar energy, eliminating the need for fossil resources and pollutant emissions.

Name: Roger Ruan

Sponsoring Organization: U of MN

Job Title: Professor

Department: College of Food, Agricultural and Natural Resource Sciences

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Location:

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

Taking air, water, and renewable electricity as input to fix nitrogen as fertilizer for land and hydroponic crop production and as fuel for ammonia fuel cells.

_____ Funding Priorities	_____ Multiple Benefits	_____ Outcomes	_____ Knowledge Base
_____ Extent of Impact	_____ Innovation	_____ Scientific/Tech Basis	_____ Urgency
_____ Capacity Readiness	_____ Leverage	_____ TOTAL	_____%

PROJECT TITLE: Nitrogen Fixation for Fertilizers and Hydrogen Fuels Production

I. PROJECT STATEMENT

The US agriculture and other industries use a large amount of nitrogen fertilizers such as anhydrous ammonia and ammonia nitrate. Minnesota alone imports $400 million to $800 million retail value of nitrogen fertilizer annually. Current industrial technology for nitrogen fertilizer production is non-renewable, expensive, dangerous, and environmentally unfriendly. Application of ammonia to land causes pollution of surface and ground water and air due to runoff and evaporation because it takes a long time for crops to utilize ammonia. This project is intended to demonstrate a new process to ***fix nitrogen from water and air*** to produce nitrogen-rich water using **renewable electricity from wind or solar energy**, eliminating the need for fossil resources and avoiding pollutant emissions. The nitrogen-rich water can be used as fertilizer directly on cropland or hydroponics system to reduce nitrogen runoff and water needs. The ammonia produced alongside may be used as fertilizer and a source of clean, zero-carbon emission energy for direct combustion and hydrogen fuel cells that provides a vehicle to store wind and solar electric energy through the ammonia-to-hydrogen-fuel-cell route, a potentially more energy efficient alternative to hydrogen production through direct water electrolysis. And better yet, storage of ammonia is much easier, safer, and cheaper than storage of hydrogen gas.

This proposed nitrogen fixation technology is built on ***state of the art non-thermal plasma (NTP) process*** that has been investigated and developed by the U of MN researchers for over two decades. An LCCMR funded project proved the feasibility of synthesizing ammonia, nitrite, and nitrate using NTP process. The ***objectives of the project*** are to (1) further develop and optimize the NTP based ammonia and nitrogen-rich water processes through conducting objective-oriented laboratory work, (2) team up with scientists and engineers at West Central Research and Outreach Center (WCROC) to develop a small pilot system integrated with a wind or solar energy system, (3) test and demonstrate the pilot system to stakeholders, (4) evaluate the techno-economic feasibility and environmental impacts of the technology, and (5) develop recommendations for further R&D and technology transfer efforts.

To achieve these intended objectives, we assemble a team of engineers and scientists with background and experience in NTP physics and engineering, nitrogen fixation chemistry, renewable energy production and adaptation, systems engineering and assessment. Both the BBE and WCROC have access to most of the necessary equipment and facilities to execute the planned work.

Application of nitrogen-rich water to cropland or hydroponics system also has many ***benefits***, including:

- Reducing environmental impacts through clean production technology and use of low concentration nitrogen fertilizers to avoid runoff of excessive nitrogen;
- Capturing the value of nitrogen industry and products locally without the use of hydrogen; and
- Disinfecting the microorganisms and oxidize contaminants that will hinder plants growth and pose threat to consumer safety, and
- Therefore generating significant tax revenue and jobs in the regions by reducing imports of much needed nitrogen fertilizers and in turn reducing most transportation related greenhouse gas emission and air pollutions.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: *Improve and optimize the non-thermal plasma based ammonia and nitrogen fertilizer processes*

Synthesis of ammonia via catalytic processes assisted by dielectric barrier discharge (DBD) in gaseous state at atmospheric pressure has been studied and demonstrated in labs; the concept of generating nitrogen-rich water containing ammonia (NH_3), ammonium (NH_4+), nitrate (NO_3-), and nitrite (NO_2-) using an NTP jet or concentrated high intensity electric field (CHIEF) discharge in water directly at atmospheric pressure has also been proven in lab. In this Activity, researchers in UMN Center for Biorefining (CB) and Department of Bioproducts and Biosystems Engineering (BBE) will carry out objective-oriented laboratory work to expand our knowledge base on some important process parameters and more importantly improve conversion efficiency, increase concentration, reduce energy consumption, and develop optimized process.

ENRTF BUDGET: 150,000

Outcome	Completion Date
1. Key processing variables will be identified and quantified and basic reaction mechanisms will be delineated	*06/30/2021*
2. Conversion efficiency, concentration of nitrogen derived compounds, and energy efficiency will be increased by 30-50% over the current performance	*12/31/2021*
3. An optimized process flow diagram will be delivered	*12/31/2022*

Activity 2: *Develop and demonstrate an integrated nitrogen fixation system*

With the knowledge, experience, and optimized process flow diagrams obtained from Activity 1, researchers in CB and BBE will work closely with researchers at WCROC to design an integrated system and construct a skid mount pilot system for comprehensive evaluation of the process and demonstration of the technology to general public for education and outreach purpose. The system is powered by wind or solar energy. The system will be demonstrated to stakeholders in the Morris Research and Outreach Center.

ENRTF BUDGET: 170,000

Outcome	Completion Date
1. Scale-up parameters will be determined for the optimized process flow	*03/31/2022*
2. System design will be completed	*06/30/2022*
3. The skid mount system will be fabricated and tested in lab and on fields	*12/31/2022*
4. The skid mount system will be demonstrated in WCROC *to the stakeholders*	*06/30/2023*

Activity 3: *Evaluate the environmental impacts and economic performance of the NTP based nitrogen fixation 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. An assessment report will be written, which will also include recommendations for further development and technology transfer.

ENRTF BUDGET: 167,000

Outcome	Completion Date
1. Data obtained from lab and field tests of the pilot system will be generated	*12/31/2022*
2. Models will be established for analysis of environmental impacts and techno-economic performance	*06/30/2023*
3. Formulate a development and commercialization strategic plan	*06/30/2023*

III. PROJECT PARTNERS:

A. Project team:

Roger Ruan (BBE, UMN), Cory Marquart (UMN West Central Research & Outreach Ctr), Paul Chen (BBE, UMN)

B. Partners not receiving ENRTF funding

Name	Title	Affiliation	Role
John Snyder	President	Minnesga	Pilot system development & demonstration
Michael Reese	Renewable Energy Director	UMN WCROC	Field testing and demonstration

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:

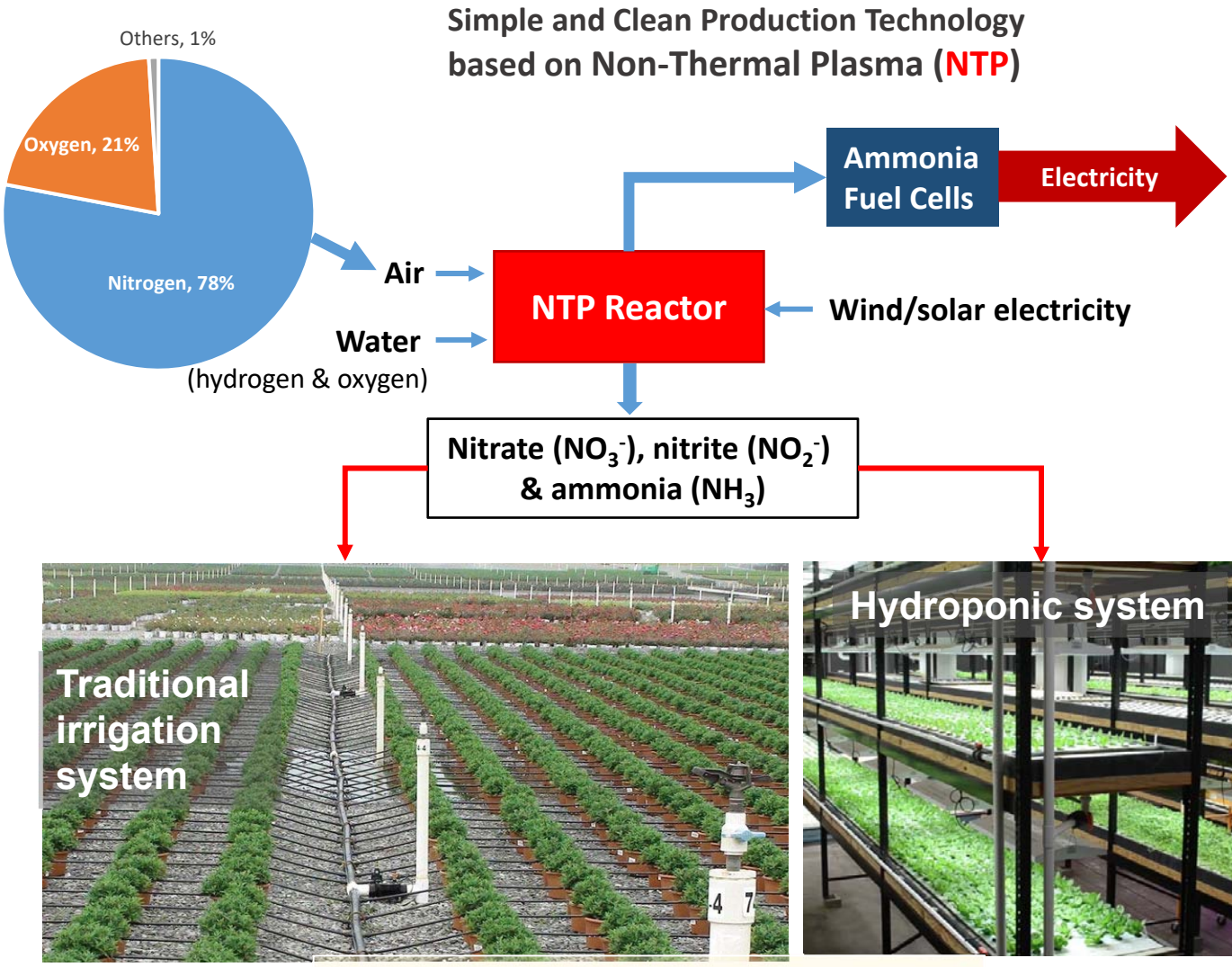
This 3 years project will begin on 07/01/20 and end on 06/30/23. The first 18 months will be focused on process improvement and parameter optimization, and full understanding of the proposed process, and the second 18 months will be focused on development, evaluation, and demonstration of the small pilot scale integrated system.

Attachment A: Project Budget Spreadsheet
Environment and Natural Resources Trust Fund
M.L. 2020 Budget Spreadsheet
Legal Citation:
Project Manager: Roger Ruan
Project Title: Nitrogen Fixation for Fertilizers and Hydrogen Fuels from Renewable Resources
Organization: University of Minnesota
Project Budget: $487,000
Project Length and Completion Date: 3 years - June 30, 2023
Today's Date: 4/11/19

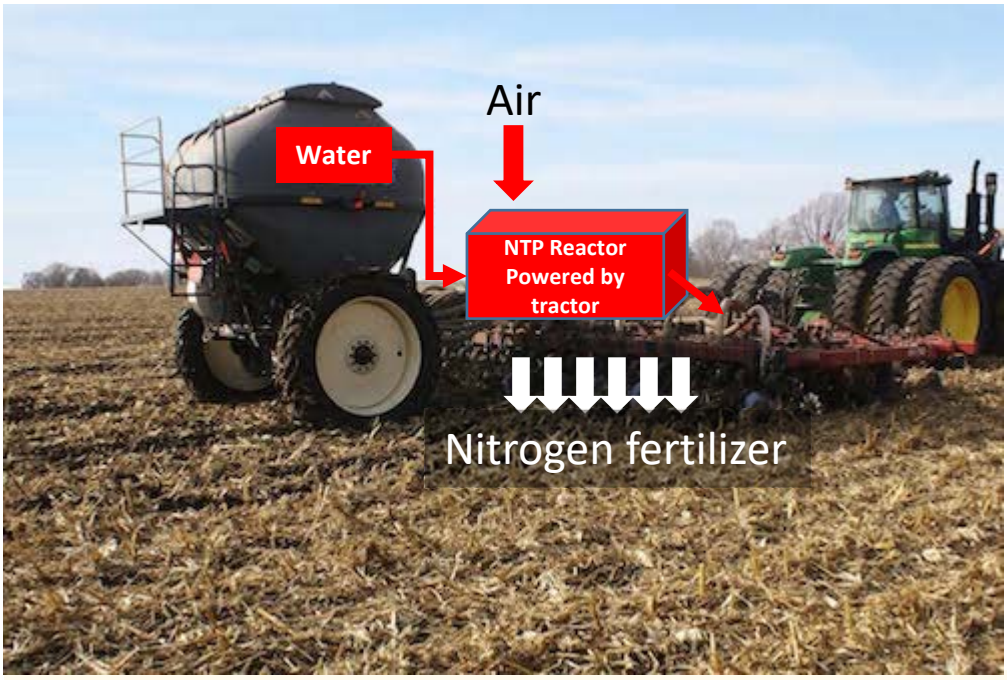
ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Budget	Amount Spent	Balance
BUDGET ITEM			
Personnel (Wages and Benefits)	$ 327,000	$ -	$ 327,000
Roger Ruan, PI, 0.08 FTE, $67,000, 73.5% salary/26,5% fringe, lead and manage lab and field testing project, leading demonstration, supervising post-doc associate			
Cory Marquart, key personnel, 0.08 FTE/yr, last 2 yrs, $40,000, 73.5% salary/26.5% fringe, project coordination, conducting R&D, project evaluaiton, progress report			
Paul Chen, co-PI, 0.16 FTE, 3 yrs, $64,000, 73,5% salary/26,5% fringe; project coordination, conducting R&D, project evaluation, progress report.			
Post-doc associate, 1 FTE, 3 yrs; $156,000, 80.5% salary/19.5% fringe, conducdct R&D, operations, demonstration, data analysis			
Professional/Technical/Service Contracts			
	$ -	$ -	$ -
Equipment/Tools/Supplies			
Lab supplies, instruments, non-capital equipment for setting up lab and field experiments	$ 145,000	$ -	$ 145,000
Capital Expenditures Over $5,000			
	$ -	$ -	$ -
Fee Title Acquisition			
	$ -	$ -	$ -
Easement Acquisition			
	$ -	$ -	$ -
Professional Services for Acquisition			
	$ -	$ -	$ -
Printing			
	$ -	$ -	$ -
Travel expenses in Minnesota			
Travel to collect samples in fields and demonstration site over the project period	$ 5,000	$ -	$ 5,000
Other			
Outside analysis services, equipment repair and calibration	$ 10,000	$ -	$ 10,000
COLUMN TOTAL	$ 487,000	$ -	$ 487,000

SOURCE AND USE OF OTHER FUNDS CONTRIBUTED TO THE PROJECT	Status (secured or pending)	Budget	Spent	Balance
Non-State:		$ -	$ -	$ -
State:		$ -	$ -	$ -
In kind: Unrecovered F&A	Secured	$ 262,000	$ -	$ 262,000

Other ENRTF APPROPRIATIONS AWARDED IN THE LAST SIX YEARS	Amount legally obligated but not yet spent	Budget	Spent	Balance
M.L. 2014, Chp. 226, Sec. 2, Subd. 08c		$ 1,000,000	$ 1,000,000	$ -



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, Fellow of ASABE and Fellow of IFT, 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 450 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 13 of his Ph.D. students and 8 other post-doctors hold university faculty positions. He has received over 170 projects totaling over $40 million in various funding for research, including major funding from USDA, DOE, DOT, DOD, LCCMR, and industries. ***He was the project manager of earlier LCCMR funded projects which resulted in issuance of a US patent and licensing of a technology.***

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.