Environment and Natural Resources Trust Fund

2025 Request for Proposal

General Information

Proposal ID: 2025-290

Proposal Title: Renewable Energy Conversion for Farm Diesel and Ammonia

Project Manager Information

Name: Paul Dauenhauer

Organization: U of MN - College of Science and Engineering

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Project Basic Information

Project Summary: To develop a novel charge-swing reactor that can convert water to hydrogen at lower cost (<$1 / kg-H2) for on-the-farm energy storage or as reductant for diesel or ammonia fertilizer.

ENRTF Funds Requested: $836,000

Proposed Project Completion: June 30, 2028

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?

Region(s): Metro

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.

Rural Minnesota has the opportunity for extensive renewable energy from wind and solar power at low cost (<3¢/kWhr) with limited utility other than sale to the existing electrical grid. However, substantial economic potential only exists for individual farmers or large agricultural collectives to install wind and solar power generation if they can find alternative uses for power. The largest barrier to storing distributed electrical power remains its conversion to chemical energy; electrical power once converted to a reductant such as H_2 gas can be stored or transported within a global energy market or be used onsite for the manufacturing of fuels such as conventional (diesel) or alternative (dimethyl ether) liquids. Additionally, conversion of wind or solar power to H_2 is the largest economic barrier to on-site manufacturing of fertilizers such as ammonia that are critical to agriculture. H_2 production via electrolysis has remained costly, at prices in excess of \$6/kg-H_2, primarily due to the conventional manufacturing process utilized, which employs expensive membrane materials and precious metals (e.g., Pt and Ir). We are pursuing entirely new H_2-generation technology that uses low-cost materials and operates at high efficiency, to enable the on-site production of H_2 from renewable power in

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.

We propose the development of a catalytic device called a 'charge-swing catalytic condenser' that will enable the low-cost production of hydrogen from water using rural electricity for renewable diesel and ammonia fertilizer. While the conventional method of electrolysis uses exotic membrane materials combined with precious metals to continuously separate and diffuse protons, the new charge-swing condenser will be designed and fabricated with low-cost Earth-abundant materials. The condenser will operate in two modes in simple operation to first produce H_2 from water, followed by a second function to regenerate and release oxygen. The condenser is designed as a series of layers that have independent functions to control the distribution of electrons, to split water to form hydrogen, and to store oxygen during operation. These condenser devices can be fabricated with large surface areas and integrated into simple form factors that allow for use in existing wind and solar facilities, generating H_2 onsite that can store electrical power. The simple construction and operational modes allow for mass production of these devices that will drive down capital costs required to achieve costs below \$1/kg-H_2, which will enable rural cost-competitive diesel and ammonia fertilizer production.

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?

A charge-swing catalytic condenser device will be designed that demonstrates carbon-free sustainable H_2 generation from water to offset CO_2 in small devices with a projected production cost below conventional electrolysis. Performance of the device will be experimentally evaluated and used for three specific outcomes: (1) The economic potential of condensers for rural sustainable power generation in agricultural settings will be estimated. (2) The device design and operation will initiate a commercialization effort that includes intellectual property and a stage-gate commercial development cycle. (3) Device performance technical specifications will be identified to project further improvements in economic potential for commercial development.

Activities and Milestones

Activity 1: Synthesize charge-swing condenser films

Activity Budget: $269,142

Activity Description:
Charge-swing condenser films will be prepared from layered metal and metal-oxide films on conductive silicon wafers with a top surface that can undergo reduction-oxidation in the presence of water or steam. Wafers will be prepared with varying thicknesses of dielectric and/or oxygen-accumulating films varying in thickness from 1 to 100 nanometer thickness, with varying degrees of crystallinity and grain size. Composition, crystallinity, and thickness of the composite films will be varied to optimize overall performance of the device. Task #1: Silicon-based devices are synthesized with a combined high-k dielectric oxide film and a redox active top layer of metal/metal-oxide film in sizes at or above 1 cm^2. Task #2: A secondary, alternative design device with oxygen-sorbent base layer is fabricated with a water-splitting O2-conductive film capable of stabilizing a charge above 1 V on surfaces at or above 1 cm^2. Task #3: Both device concepts from milestones 1 and 2 are varied in film thickness over three possible length scales to reduce charge leakage through the films.

Activity Milestones:

Description	Approximate Completion Date
Silicon-based devices are synthesized with a combined high-k dielectric oxide film and redox top layer	June 30, 2026
A device designed with an oxygen-sorbent base layer is fabricated capable of 1 V stabilization	June 30, 2027
Film thicknesses are varied over three possible lengthscales to assess electronic leakage	June 30, 2028

Activity 2: Evaluate and characterize charge-swing condenser films

Activity Budget: $278,563

Activity Description:
Accumulation of oxygen with applied potential will promote the initial release of H2 gas in phase 1, while a second phase will reverse the applied potential and evolve O2 gas to complete the entire regeneration cycle. The electronic device will be designed and optimized to control the flow and distribution of electrons throughout the device to accelerate the rate of water splitting to evolve H2 and O2 gas separately and to maximize the total amount of evolved gas. Task 1: Electronic characterization of fabricated devices identifies a design that exceeds 100 nF/cm2 in total device capacitance. Task 2: Device electronic switching between applied potential phases occurs at speeds as fast as 10 Hz without a loss in device capacitance. Task 3: Three different redox active metals are evaluated as the top active layer exposed to water or steam for the water splitting mechanism to determine their ability to split and/or accumulate oxygen. Evolved gases are measured with a mass spectrometer above the detection limit.

Activity Milestones:

Description	Approximate Completion Date
Electronic characterization of devices exceeds 100 nF/cm^2	June 30, 2026
Device electronic switching exhibits speeds as fast or faster than 10 Hz	June 30, 2027
Three different redox active metals are evaluated for water splitting	June 30, 2028

Activity 3: Fabricate charge-swing condenser devices for applications

Activity Budget: $288,295

Activity Description:
The fabricated films designed in activities 1 and 2 will be developed in parallel for application as a device that could function with higher productivity per unit volume with incorporated electrical connections and spacing for gas flow. This film design will utilize a flexible substrate that can be rolled into dense pellets that maximize the film surface area per unit volume while also permitting macropores for gas flow into and out of the reacting pellet. Task 1: Charge-swing condensers are fabricated on flexible conductive substrate films such as metal on Kapton. Task 2: Charge-swing condensers are fabricated with an oxide-based electrical contact that enables application of potential to soft substrates. Task 3: The performance of charge-swing condensers for electronic charge separation and for water splitting (i.e., measurable H2 evolution) is evaluated for flexible devices with curvature in excess of 1 cm^-1.

Activity Milestones:

Description	Approximate Completion Date
Charge-swing condensers are fabricated on flexible conductive films	January 31, 2028
Charge-swing condensers are fabricated with oxide electrical contacts	March 31, 2028
Charge swing condenser performance is evaluated with curvative above 1 cm^-1	June 30, 2028

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
C. Daniel Frisbie	University of Minnesota, Twin Cities	Leads the effort to fabricate devices and characterize their electronic properties	Yes
Professor Chris Leighton	University of Minnesota, Twin Cities	Synthesizes functional films and evaluates their properties and storage capacity	Yes
Professor Chris Bartel	University of Minnesota, Twin Cities	Computes the energy of reaction and diffusion films for water splitting and storage	Yes

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 goal of the project is to advance the rural processing technology to make H2 for ammonia and diesel such that it can be developed commercially via a startup company independent of the university. The PI has already communicated with a venture capital firm, and formation of a future startup company will use private equity combined with a license to the technology developed in this project to form a company in Minnesota to manufacture these devices. The results and findings developed during this project will serve to generate patents and to identify the required manufacturing stages required for device commercialization.

Project Manager and Organization Qualifications

Project Manager Name: Paul Dauenhauer

Job Title: Co-Founder of Sironix Renewables, Lakril Technologies, and Carba, Professor, Distinguished McKnight Professor, MacArthur Fellow

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

Paul Dauenhauer is a co-founder of the startup companies Sironix Renewables (www.sironixrenewables.com), Carba (www.carba.com), Lakril Technologies (www.lakril.com), and Activated Research Company (www.activatedresearch.com), as well as the McKnight Distinguished Professor, Zsolt Rumy Innovation Chair, and MacArthur Fellow at the University of Minnesota in the Department of Chemical Engineering and Materials Science. In these roles, he has managed the invention, development, and commercialization of multiple energy and chemical technologies including advanced detergent products from soybean oil, a commercial process to manufacture acrylate materials from corn, a chemical reactor technology to quantify complex chemical and fuel mixtures, and a novel reactor design to convert agricultural residues to carbon for economic credits. He has led multiple large-scale teams including two Department of Energy research centers, the Catalysis Center for Energy Innovation (2012 – 2022), and the University of Minnesota Center for Programmable Energy Catalysis (2022 – Present), a $10.6 million fundamental research team of ~40 researchers studying advanced catalytic devices.

Organization: U of MN - College of Science and Engineering

Organization Description:

The University of Minnesota is a world-class research institution with over 50,000 students, more than 5,000 research active faculty, and over one billion dollars in annual research expenditures, ranked 10th in the nation among public research institutions. Within the university, the College of Science and Engineering provides premiere research facilities to conduct materials, chemical, and energy research, spanning state-of-the-art research laboratories and world-class user facilities, including the Minnesota Supercomputing Institute, the Minnesota Characterization Facility for, e.g., electron microscopy, and the Minnesota Nano Center for fabrication of catalytic nanomaterials. Research contracts are managed through the Office of the Vice President for Research via the Sponsored Projects Administration (https://research.umn.edu/units/spa/about-us/overview)

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Post-doctoral scholar		Fabricates, characterizes, and evaluates the performance of charge-swing condensers			21%	3		$222,999
Graduate Student 1		Evaluates charge-swing condenser electronic characteristics			25%	3		$149,667
Graduate Student 2		Operates the charge-swing reactor to evaluate the rate of water splitting			25%	3		$149,667
Graduate Student 3		Optimizes the sputtering of condenser oxide films			25%	3		$149,667
Principal Invesigator		Paul Dauenhauer, Principal Investigator			27%	0.03		$9,434
Co-Investigator 1		Chris Bartel, Co-Investigator			27%	0.03		$6,448
Co-Investigator 2		Chris Leighton, Co-Investigator 2			27%	0.03		$11,052
Co-Investigator 3		C. Daniel Frisbie, Co-Investigator 3			27%	0.03		$12,834
							Sub Total	**$711,768**
Contracts and Services								
							Sub Total	-
Equipment, Tools, and Supplies								
	Tools and Supplies	Laboratory supplies	Purchase of standard lab materials and supplies (chemicals, gases, glassware, etc.)					$124,232
							Sub Total	**$124,232**
Capital Expenditures								

							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	**$836,000**

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: $836,000

This amount accurately reflects total project cost?

Yes

Attachments

Required Attachments

Visual Component

File: 8a83c303-e96.pdf

Alternate Text for Visual Component

Figure 1. Charge-swing condenser for H_2O splitting to H_2 and O_2 gases. A charge-swing reactor converts water, carbon dioxide and air to H_2, ammonia, and chemicals such as methanol. The price of H_2 can be manufactured below $1/kg-$H_2$ for low electrical prices below $0.03/kWhr....

Supplemental Attachments

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

Title	File
Letter of Approval, U of Minnesota Sponsored Projects Administration	5346a3db-e5a.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

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?

Yes, Sponsored Projects Administration

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:

None