Environment and Natural Resources Trust Fund

2022 Request for Proposal

General Information

Proposal ID: 2022-191

Proposal Title: Solar Powered Sensor for Monitoring Pesticide in Water

Project Manager Information

Name: Tianhong Cui

Organization: U of MN - College of Science and Engineering

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Project Basic Information

Project Summary: The project aims to develop a small, cheap, solar-powered sensor with data storage to continuously monitor pesticide pollutants in very large areas of lakes and rivers in Minnesota.

Funds Requested: $300,000

Proposed Project Completion: June 30 2025

LCCMR Funding Category: Water Resources (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.

Chlorpyrifos is one of the most frequently used organophosphate pesticides in agriculture. It can disrupt cholinesterase, leading to cholinergic dysfunction and death. This endangers the health of both humans and animals, and especially children and seniors are more vulnerable. People can be exposed to chlorpyrifos when breathing dust that drifts from nearby fields or drinking water from impaired water bodies. According to the reports of Minnesota Department of Agriculture, detections of chlorpyrifos in water appear to an increase since 2010, and nine water bodies have found to be impaired by chlorpyrifos. In concerns over health and environment, large-area and long-term chlorpyrifos monitoring in water to prevent and predict its pollution to the water bodies is the prerequisite for efficient pollution control in water from agriculture. Conventional chlorpyrifos analysis methods in laboratory, for example, mass spectrometry and atomic absorption spectroscopy, involve massive laboratory testing work and intensive labor effort. These limitations make the above technologies impossible for on-site water monitoring and high-cost for continuously monitoring. To reduce the above limitations, we propose a new technology of a small cheap sensor with data storage self-powered by solar energy for chlorpyrifos concentration detection, which is capable of continuous monitoring without external energy.

What is your proposed solution to the problem or opportunity discussed above? i.e. What are you seeking funding to do? You will be asked to expand on this in Activities and Milestones.

We propose a distributed photoelectrochemical (PEC) sensor based on an integrated solar cell for self power. This technique seeks to 1) design a self-powered, autonomous, on-site chlorpyrifos sensor suitable for diverse water conditions of Minnesota at low cost, and 2) build internal data storage that provides continuous data in large-area open water. The sensor exploits light and photocurrent as the excitation source and the recognition signal, respectively, which leads to lower background noise and higher sensitivity than conventional electrochemical sensors. Moreover, the heterojunction structure of the PEC and the photovoltaic (PV) solar cell in this technology can contribute to higher optoelectronic conversion efficiencies and power the detection circuit at the same time. For long-term and large-area water pollutant monitoring, it is favorable to have low power sensing and data storage components. Given such requirements, a solar cell powered data recording component will be exploited. Distributed sensor data can be read by a mobile device on site, or can be exported after retrieving the used sensors. Here the solar cell will power the whole device to achieve long-time and large-area monitoring of pesticides.

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?

There are three deliverables proposed in this project, including (1) a prototype of PEC/PV pesticide sensors suitable for self-powered, long-term, and on-site testing, (2) a data storage component integrated with pesticide sensor that stores data from the sensor, and (3) a software on a mobile device that contains the data processing functions of multiple sensors suitable for on-site testing applications. Furthermore, the sensing platform built in this project will help the end users including clear water agencies, researchers, and advocacy groups for continuous detection and analyses of waters and prevention of ecological contaminations in Minnesota.

Activities and Milestones

Activity 1: Development of a small, cheap, sensitive photoelectrochemical sensor self-powered by a solar cell for pesticide monitoring in water

Activity Budget: $198,612

Activity Description:
The objective of this activity is to develop a self-powered photoelectrochemical sensor based on a perovskite solar cell. Perovskite is a cheap material used for low-cost but high-performance solar cells. Graphene, Bi2O3 and BiOCl nanoparticles are modified directly on the gold electrode of a perovskite solar cell. With light illumination, the photoactive heterojunction BiOCl/graphene/Bi2O3 nanomaterial induces electron-hole pairs inside the sensor. The spatial separation of the electron-hole pairs in the BiOCl/graphene and graphene/Bi2O3 interfaces retards their recombination, while photo-electrons being smoothly transferred. Meanwhile, the photon-excited holes from the device migrate to the gold electrode, and combine with photon-electrons, facilitating the transfer of electrons from Bi2O3 to the gold electrode interface. Furthermore, the inner potential drop from the solar cell applied to the photoelectrochemical sensor improves electron-hole separation inside Bi2O3. Such an integrated structure leads to the generation of an enhanced photocurrent signal with a very high sensitivity. When adding pesticides, the BiOCl nanoparticles forming the Bi-chlorpyrifos complex on BiPO4 surface achieve a good selectivity, which inhibits the separation electron, yielding to return electron transfer on surface due to steric effect as the formation of C=N and P=S bonds. Increasing pesticides leads to decreasing photocurrent.

Activity Milestones:

Description	Completion Date
Develop a tiny, cheap, sensitive, selective and stable photoelectrochemical sensor to detect pesticides in water	June 30 2023
Integrate the pesticide photoelectrochemical sensor with a perovskite solar cell for self-powered monitoring of pesticides	June 30 2023
Self-powered pesticide photoelectrochemical sensors are improved and tested, in comparison with conventional lab testing results	June 30 2024

Activity 2: Development of self-powered data storage component with corresponding mobile device software, and field tests in lakes and rivers in Minnesota

Activity Budget: $101,388

Activity Description:
To achieve long-term and large-area pesticides monitoring, we propose to develop a data storage component to record signals obtained from the pesticides sensors. The data storage chip will also be powered by the solar cell integrated with the pesticide sensor. The sensors working in the water can record data for a long period of time, and the data can be obtained through a mobile device on site (with physical interface integrated on the chip). The pesticide sensor can be retrieved after a certain working time to prevent from additional pollution. We will deploy the distributed sensor nodes at Buffalo River Watershed in Minnesota for instance, root river that several water bodies have reported near or above alarming pesticides concentration by Minnesota Pollutants Control Agency (MPCA). We will closely work with MPCA to compare the results from our pesticide sensors with respect to their lab testing ones.

Activity Milestones:

Description	Completion Date
A solar cell powered data recording chip will be developed	June 30 2025
A software system on a mobile device will be developed	June 30 2025

The prototype will be built on three water sites, and data acquisition will be tested	June 30 2025

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 be funded?

The pesticide sensor will be developed and tested with a portable instrument for lab tests and field detections in rivers and lakes in Minnesota. Next, we will build up and test a distributed sensor array in natural water (lakes and rivers) in high contamination environments. We need funding from LCCMR to support this effort. We plan to file patents on the proposed sensors for future commercialization in Minnesota. In addition, we can also use the sensors for monitoring and detection of soil in Minnesota. We will also apply for funding from USDA, NSF, and EPA for long-term research and development.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Development of Innovative Sensor Technologies for Water Monitoring	M.L. 2016, Chp. 186, Sec. 2, Subd. 04j	$509,000
Develop Small and Inexpensive Purification System for Community Drinking Water	M.L. 2018, Chp. 214, Art. 4, Sec. 2, Subd. 04e	$425,000
Develop Inexpensive Energy from Simple Roll-to-Roll Manufacturing	M.L. 2018, Chp. 214, Art. 4, Sec. 2, Subd. 07c	$300,000

Project Manager and Organization Qualifications

Project Manager Name: Tianhong Cui

Job Title: Professor

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

Dr. Tianhong Cui is the Distinguished McKnight University Professor at the University of Minnesota. He is a Professor in Mechanical Engineering and an Affiliate Senior Member of the graduate faculty in Department of Electrical and Computer Engineering. He joined the faculty of the University of Minnesota in 2003. From 1995 to 2003, he held research or faculty positions at Tsinghua University, University of Minnesota, National Laboratory of Metrology in Japan, and Louisiana Tech University. He is a Distinguished Visiting Fellow at the University of Cambridge in UK, and a Distinguished Visiting Professor at the University of Paris East in France. He is a Fellow of American Society of Mechanical Engineering.

Dr. Cui is an international leading expert on micro devices and advanced manufacturing. He has more than 350 archived publications in scientific journals and prestigious conferences. He received awards including the STA & NEDO Fellowships in Japan, the Alexander von Humboldt Fellowship in Germany, the Richard & Barbara Endowed Chair and the Distinguished McKnight University Professorship from the University of Minnesota, the Distinguished Visiting Professorship from University of Paris East, the Distinguished Visiting Fellowship from the Royal Academy of Engineering in UK, the Outstanding Editor Award from Nature Publishing Group, and numerous best paper awards. He is the founding Executive Editor-in-Chief for a Nature journal, Microsystems & Nanoengineering. He is also serving as the founding Editor-in-Chief for the first AAAS/Science Partner Journal titled Research.

Dr. Cui will serve as the PI and the project manager, responsible for overseeing the project, all reports, and deliverables. He will supervise one graduate research assistant to work on design, fabrication, and characterization of solar-powered

pesticide sensors. He will hold weekly meetings with his graduate assistant to ensure good progress of this proposed work, in addition to some daily technical discussion with his research assistant.

Organization: U of MN - College of Science and Engineering

Organization Description:
This work will be performed at the University of Minnesota in the Technology Integration & Advanced Nano/Microsystems Laboratory (TIAN Lab), located in the Mechanical Engineering Building. Professor Cui is the director of TIAN Lab equipped with the state-of-the-art instruments and facilities to conduct the proposed research, with a variety of fabrication and characterization equipment and tools, sufficient for Professor Cui and his graduate research assistant to design, fabricate, characterize and analyze the proposed sensors.

Some fabrication work will be partially done in Minnesota Nano Center (www.nfc.umn.edu), a state-of-the-art facility for research in nanoscience and applied nanotechnology. It is located at the University of Minnesota in a 7000 square foot facility, including 3000 square feet of class 10 clean room. The Lab contains all of the major pieces of processing equipment. Minnesota Nano Center well maintains these systems, keeps safe operating procedures, and trains students. State support, support from NSF through the NNCI network, and industry usage allows Minnesota Nano Center to offer academic rates that are normally less than half of the actual cost of operation. In addition to clean room tools available, the center will also operate two new non-cleanroom labs on nanomaterials and nanotechnology.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
PI and Project Manager		manage the overall project, lead the design, fabrication, and testing of pesticide sensor, supervising graduate assistant			36.5%	0.24		$99,818
Graduate Research Assistant		Conduct R&D including design, fabrication, and testing of pesticide sensors			47.8%	1.5		$159,225
							Sub Total	**$259,043**
Contracts and Services								
Minnesota Nano Center and Characterization Facility	Internal services or fees (uncommon)	Fabrication and testing of solar powers pesticide sensors				-		$15,000
							Sub Total	**$15,000**
Equipment, Tools, and Supplies								
	Tools and Supplies	Lab Materials & Supplies for instrument and equipment consumables and set-ups of lab and field experimental and testing systems. Scientific Services (i.e. MN Nano Center & Characterization Facility).	Design, fabrication, and testing of solar powered pesticide sensors					$16,957
							Sub Total	**$16,957**
Capital Expenditures								
							Sub Total	**-**
Acquisitions and Stewardship								

							Sub Total	**-**
Travel In Minnesota								
	Miles/ Meals/ Lodging	Per University of Minnesota travel policy, this is for researchers to travel to collect samples in fields and between campus and demonstration sites over the 3yrs project period.	For field tests					$9,000
							Sub Total	**$9,000**
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				
In-Kind	Overhead match at the University of Minnesota	Office supplies, computers, etc.	Potential	$137,896
			State Sub Total	**$137,896**
Non-State				
			Non State Sub Total	**-**
			Funds Total	**$137,896**

Attachments

Required Attachments

Visual Component

File: 37141bea-4e8.pdf

Alternate Text for Visual Component

Comparison of old technologies and new solar-powered sensors to monitor pesticides in Water...

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

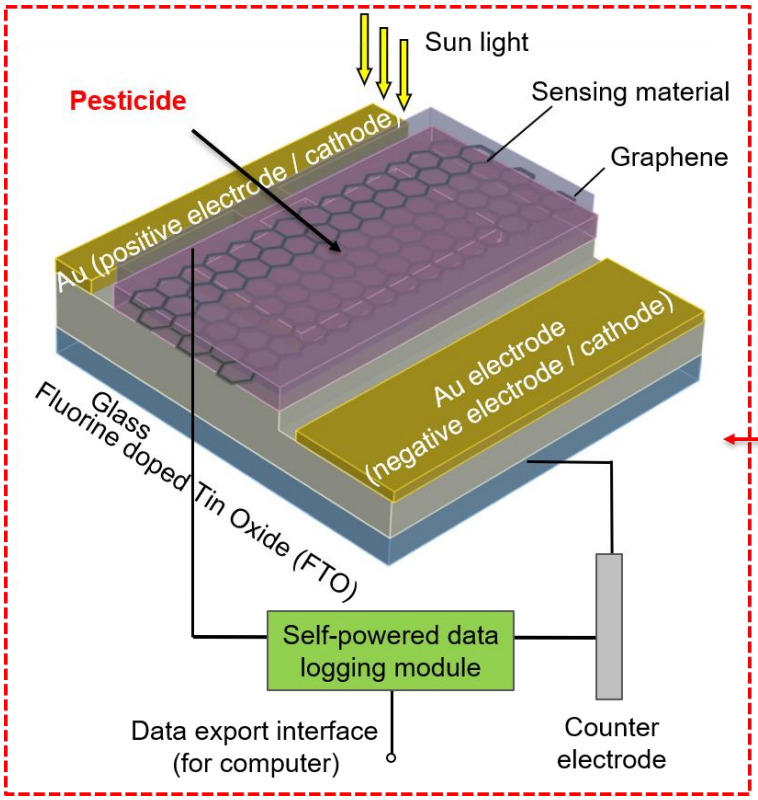
Does the organization have a fiscal agent for this project?

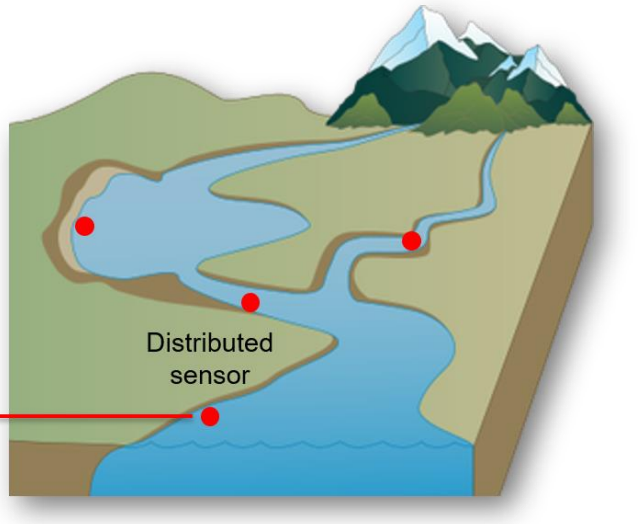
Yes, Sponsored Projects Administration

PI/PD: Tianhong Cui, University of Minnesota

Project Title: Solar-Powered Sensor for Monitoring Pesticide in Water

Current technology for lab (left), portable (middle), and station (right) methods
(Problems: large, complex, expensive)





Proposed new technology: solar-powered pesticide sensor

Features of new technology

- **Small, cheap, fast**
- **No power supply**
- **Continuous data storage**
- **Easy to install and use**