Environment and Natural Resources Trust Fund
2016 Request for Proposals (RFP)

Project Title: **ENRTF ID: 051-B**

Tiny Cheap Sensors for Pollutants Monitoring in Waters

Category: B. Water Resources

Total Project Budget: $ 508,878

Proposed Project Time Period for the Funding Requested: 3.5 years, July 2016 to August 2019

Summary:

This project is to develop very tiny, cheap, fast, sensitive sensors and wireless sensor networks, a new approach for pollutants continuous monitoring in lakes and rivers in Minnesota.

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Sponsoring Organization: U of MN

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Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

Comparison of current and new technologies of pollutants monitoring

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

PROJECT TITLE: Tiny Cheap Sensors for Pollutants Monitoring in Waters

I. PROJECT STATEMENT

The objective of this project is to develop very tiny, cheap, fast, accurate sensors to continuously monitor the pollutants including phosphate, nitrate, mercury, and chlorine in Minnesota's waters. This is a new testing and monitoring technique, which can provide wireless sensing capability to accurately assess the conditions of Minnesota's waters at very low cost. The proposed new technology is to make graphene micro sensors using the micro-manufacturing techniques available in Minnesota, and to build wireless sensor networks based on the sensors. Graphene is a monolayer of carbon atoms with outstanding material properties, a newly developed material very sensitive to molecules in liquids. This will enable the tiny sensors to detect pollutants in lakes and rivers with very high sensitivity and super short response time to pollutants in waters. In contrast, current agencies have to rely on bulky and expensive equipment to do off-line detections and analyses. The advanced manufacturing techniques at the University of Minnesota allow us to develop the sensors in a very high quantity at a super low cost, while surmounting the performance of pollutants detection using large equipment or devices. In addition, the sensors can be further developed into sensor networks so that we can form wireless detection for continuous monitoring of water quality in Minnesota. This will help the end-users including clear water agencies, researchers, and advocacy groups for continuous detection and analyses of Minnesota waters and prevent from ecological contaminations. This project is intended to develop the tiny cheap sensors, to prove its feasibility, and to provide foundational knowledge of the technique. In the next phase of the research, we will closely collaborate with state agencies, water researchers, and industry to develop an implementation plan for pollutants monitoring in broader water regions in Minnesota.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: *Development of tiny cheap sensors and sensor arrays* **Budget: $332,882**

The objective of this activity is to develop tiny sensors using graphene, which is very tiny, cheap, fast, accurate, and sensitive for pollutants monitoring in lakes and rivers in Minnesota. Multi-array sensors will be designed and fabricated for continuous monitoring of phosphate, nitrate, mercury, and chlorine in waters. The size of a single sensor or a sensor array will be as small as a rice grain. The sensor network system together with the sensors will be at least 10,000 times smaller than the current existing equipment, while the cost is at least 1,000 times lower than the bulky machine currently used for water quality detection, while overrunning performance of the bulky equipment being used.

Outcomes	Completion Date
1. Single and multi-array sensors hardware will be developed for testing and continuous monitoring of water quality indicators including phosphate, nitrate, mercury, and chlorine; Initial testing results of tiny sensors in response to pollutants in lab	*6/30/2017*
2. Software for signal process and data display will be developed	*6/30/2017*
3. Tiny sensors will be tested in comparison with conventional results in lab; Improved sensors with optimized design, fabrication, and testing; Sensors testing of pollutants monitoring of waters sampled from lakes and rivers in Minnesota	*6/30/2018*
4. Comprehensive assessment of the techniques will be completed	*6/30/2018*

Activity 2: *Development of wireless sensor networks and field testing* **Budget: $175,996**

A prototype unit will be designed and constructed to demonstrate the feasibility. Data networking protocol and hardware will be developed and tested. Field testing will include setting up a test site and three data relay stations. Upon completion of the project, we will demonstrate the integrated system to the stakeholders and LCCMR committee members and officials.

Outcomes	Completion Date
1. A prototype of sensing network with tiny sensors unit will be developed	*6/30/2019*
2. Data networking protocol and hardware will be developed	*6/30/2019*
3. The prototype unit will be set up on a water site and data transmission through relay will be tested	*6/30/2019*

III. PROJECT STRATEGY

A. Project Team/Partners: Tianhong Cui, professor in Mechanical Engineering, will serve as PI and project manager. He will be responsible for overseeing the project, all reports, and deliverables. He will also develop the tiny sensors, portable sensor network units, and data transfer protocols. Roger Ruan, professor in Bioproducts and Biosystems, will be a collaborator responsible for setting up field testing of the proposed techniques. Paul Chen, associate professor in Bioproducts and Biosystems, will be another collaborator responsible for lab analysis of water quality using conventional and the proposed techniques.

B. Project Impact and Long-Term Strategy

Minnesota Pollution Control Agency (MPCA) works together with other agencies and advocacy groups in developing strategy to prevent, control, and abate discharges that cause water pollution and violate water quality standards. The first task in the strategy is testing and assessment to provide information on the conditions of the waters. Currently, many of our water bodies are unmonitored despite the requirement of the federal 1972 Clean Water Act. As of year 2010, the MPCA and its partners had assessed just 17% of Minnesota's rivers, and about 28% of lakes over 10 acres in size. Minnesota State currently provides approximately $85 million per year for the Clean Water Fund. More than 30% of the fund is for monitoring/ assessment activities and water quality study. There is a push for increased resources for water monitoring as the information on the conditions of water quality is vital to all restoration and protection actions. However, technologies and resources are limited for real-time water monitoring. The proposed tiny sensors will provide low-cost, but high-performance techniques and infrastructure, i.e. unique sensors and sensing networks, for assessment of Minnesota's waters in much greater geographic area. Upon completion this project will realize economical and high-performance tiny sensing technique for continuous monitoring of water conditions. The knowledge learned throughout the project will provide a solid foundation for further research and development efforts that would lead to eventual implementation of the novel technique practically enabling broader monitoring of Minnesota's waters with remote sensing and data transmission via wireless capability. This will provide a solution to current resources strapped monitoring programs in Minnesota, ultimately help implement the MPCA's clear water strategy, and thus enhance the ecological benefits of Minnesota waters.

In addition, we will plan to file patents on the proposed sensors and sensor networks for commercialization in the future. We can also use the sensors or sensor networks for monitoring and detection of drinking water, juice, liquid food, etc. As a result, the innovative technology can also benefit the local industry by developing new products in Minnesota including new graphene sensors and sensor networks for broader applications.

C. Timeline Requirements

This project is planned for 3 years beginning on July 1, 2016 and ending on June 30, 2019. The first two years will be focused on the tiny sensor development, and Year 3 will be focused on development of a prototype unit, data transmission protocol and hardware, and field test. The results of this study will be disseminated through oral and poster presentations by faculty and students involved in the project, briefings to the LCCMR as requested, and peer-reviewed publications. We also intend to present progress on this project periodically to relevant personnel who have been aware of this project and may be interested in the results, specifically at the Minnesota Pollution Control Agency and environment protection advocacy groups.

2016 Detailed Project Budget

Project Title: Tiny Cheap Sensors for Pollutants Monitoring in Waters

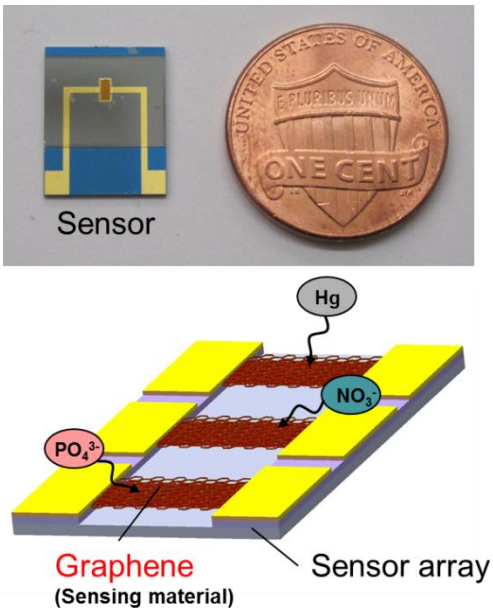
IV. TOTAL ENRTF REQUEST BUDGET: 3 Years

BUDGET ITEM	AMOUNT
Personnel:	
Dr. Tianhong Cui PI (4.3 weeks (.11FTE) + fringe 33.8% fringe) for 3 years. 9 months appointment	$ 66,376.00
Dr. Roger Ruan (3.12 weeks (.08FTE) + fringe 33.8% fringe) for 3 years. 9 months appointment	$ 31,688.00
Dr. Paul Chen (14.5 weeks (.28FTE) + fringe 33.8% fringe) for 3 years. 12 months appointment	$ 99,474.00
Post-Doc (Ruan and Chen) (6 months + 21.4% fringe) for 3 years	$ 84,427.00
Graduate Research Assistant 50% FTE (fall & spring include 16.6% fringe plus $17.84/hour tuition, summer 16.6% fringe only) for 3 years	$ 139,458.00
Equipment/Tools/Supplies:	
Lab Supplies (Cui): fabrication materials & supplies including silicon wafers ($5,000), polymer substrates ($4,000), chemicals ($6,000), graphene substrate and solutions ($5,000), carbon based gases ($3,000), bottles, gloves, other electronics for testing, etc. ($2,500)	$ 25,500.00
Scientific Services (Cui): User fees at Minnesota Nano Center and Characterization Facility at the University of Minnesota. The cost is about $541 per month for the Post-Doc, and $500 per month for the graduate research assistant for 3 years.	$ 37,500.00
Lab Materials & Supplies (Ruan & Chen): Purchase of chemical reagents ($3,000), analytical kits ($2,500), compressed gases ($500), glassware ($855), consumable supplies (standards and columns) for analytical instruments ($5,000), instrument maintenance and repair ($3,600)	$ 15,455.00
Travel:	
Ruan & Chen domestic travel (year 2 &3): Mileage, lodging, and meals for travel between the sensor testing sites and the university; Cui, Ruan, and Chen need work together on the testing. This cost is based on the university compensation policy.	$ 9,000
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 508,878

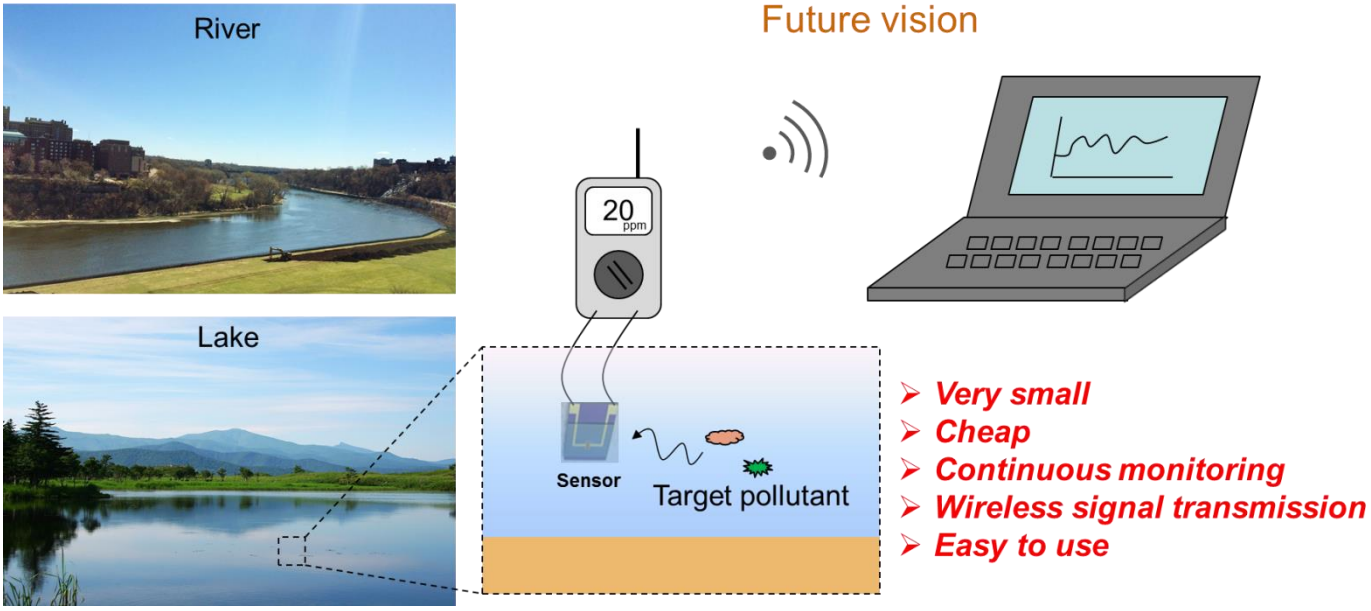
V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period: *N/A*		
Other State $ To Be Applied To Project During Project Period: *the University overhead*	$ 237,500	*Secured*
In-kind Services To Be Applied To Project During Project Period: *N/A*		
Funding History: *Minnesota private company funds for development of graphene sensors*	$ 98,000	Secured
Remaining $ From Current ENRTF Appropriation: *N/A*		

Current Technology



New Technology Proposed



Future applications to continuous pollutants monitoring in Minnesota waters

Project Manager Qualifications and Organization Description

Tianhong Cui is currently a Professor of Mechanical Engineering and an Affiliate Senior Member of the graduate faculty in Department of Electrical and Computer Engineering at the University of Minnesota. He joined the faculty of the University of Minnesota in 2003. He was also a visiting professor at University of Freiburg in Germany in 2006. He is an international leading expert on micro devices, especially on graphene sensors. He has more than 260 publications and 5 US patents in the relevant area. His research has been sponsored for more than 5 million dollars for the last few years by NSF, DARPA, NASA, DOE, and companies. As an editor-in-chief, he founded the first engineering journal of Nature Publishing Group titled *Microsystems & Nanoengineering*, and he is also responsible for another Nature Journal, *Light: Science & Applications*. In the meantime, he is serving as an associate editor for *Journal of Nanoscience and Nanotechnology* and *Journal of Nano Research*, and he was a past editor for *IEEE Sensors Journal*.

The proposed fabrication work will be done in Minnesota Nano Center (www.nfc.umn.edu) 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 NNIN, and industry usage allows Minnesota Nano Center to offer academic rates that are normally less than half of the actual cost of operation. In 2014, NFC took possession of a second clean room as part of a new Physics and Nanotechnology Building. The new building is across the street from the ECE Building which houses the existing clean room. At 5000 square feet under filter and almost 10,000 square feet gross, it is more than double the existing space. In addition to expanding the suite of clean room tools available, the lab will also operate two new non-clean core labs that support research in nanomaterials and nanotechnology.

The design and characterization of the tiny sensors proposed here will be performed in the Technology Integration & Advanced Nano/Microsystems Laboratory (TIAN Lab), located in room ME4128 of the Mechanical Engineering Building, on the Minneapolis campus of the University of Minnesota. The lab is equipped with the state-of-the-art instrument and facilities to conduct the proposed research. TIAN Laboratory resources include a variety of fabrication and characterization equipment and tools, sufficient for Professor Cui and his Ph.D. student to design, fabricate, characterize and analyse the proposed graphene sensors for pollutant monitoring.

The Center for Biorefining directed by Professors Roger Ruan and Paul Chen is a University of Minnesota research center and helps coordinate the University efforts and resources to conduct exploratory fundamental and applied research on renewable energy, materials, and environmental mitigation. 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-art analytical instruments, and processing facilities ranging from bench to pilot scale for characterization and field testing of this project.

Professor Tianhong Cui in Mechanical Engineering will serve as the PI and project manager. He will be responsible for overseeing the project, all reports, and deliverables. He will also develop the tiny sensors, portable units, and data transfer protocols. Professor Roger Ruan in Bioproducts and Biosystems will be a collaborator responsible for setting up field testing of the proposed techniques. Paul Chen, associate professor in Bioproducts and Biosystems, will be another collaborator responsible for lab analysis of water quality using conventional and the proposed techniques.