Environment and Natural Resources Trust Fund
2017 Request for Proposals (RFP)

Project Title: **ENRTF ID: 062-B**

Environment-Friendly Nanosensors to Detect Nutrients in Water

Category: B. Water Resources

Total Project Budget: $ 455,026

Proposed Project Time Period for the Funding Requested: 3 years, July 2017 - June 2020

Summary:

Excessive nutrients in water can trigger harmful algal blooms and cause serious environmental problems. We propose to develop environment-friendly nanosensor arrays for simultaneous detection of multiple nutrients in lakes/rivers.

Name: Rusen Yang

Sponsoring Organization: U of MN

Address: 111 Church St SE

Minneapolis MN 55455

Telephone Number: (612) 232-1020

Email yangr@umn.edu

Web Address

Location

Region: Metro

County Name: Statewide

City / Township:

Alternate Text for Visual:

Environment-friendly Nanosensors to Detect Nutrients in Water

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

PROJECT TITLE: Environment-friendly Nanosensors to Detect Nutrients in Water

I. PROJECT STATEMENT

This object of this project is to develop first-of-the-kind, environment-friendly nanosensor arrays for the simultaneous detection of excessive nutrients, such as nitrate and phosphate, in Minnesota lakes and rivers.

- Why need to monitor nutrients in water?

Water requires some nutrients to be healthy. However, fertilizer and wastewater introduce excess nitrate and phosphate into lakes and rivers, which may trigger harmful algal blooms, cause severe illness to human being and animals, and kill fish and other organisms. Continuous monitoring is critical for water quality control.

- What is new in proposed technology?

This project substantially differs from other efforts (e.g., the LCCMR project "Tiny Cheap Sensors for Pollutants Monitoring in Waters" of last year) in that: 1) This project **focuses on nutrients detection**, while the others focus on pollutants. 2) This project will enable **simultaneous detection of multiple species**, while the others detect one specie at a time. 3) Our technology is **more environment-friendly** with the use of zinc oxide nanowires with confirmed biocompatibility, while the effect of nanomaterials previously used by others on the environment and human health is still a subject of research.

- What will be delivered at the end of this project?

We will develop very safe nanosensors of low cost for the detection of nitrate and phosphate in lakes and rivers. A small solar panel will drive the device to monitor the water quality continuously. The sensing system will be tested outdoor in natural waters. We suggest to deploy one sensing system every mile along Mississippi River, near shore of Lake Superior, and other river and lakes. Demonstration units will be developed to disseminate scientific findings and raise environmental awareness.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: *Fabricate zinc oxide-based nanosensors detecting nitrate and phosphate* **Budget: $136,952**

The objective of this activity is to develop safe, selective, and sensitive nanosensors with zinc oxide nanowires. The surface water contains a variety of ions like phosphate, nitrate, sodium, carbonate, etc. The sensor may response to different ions at the same time, such that it only provides accurate measurements when just one specie presents in water. The interference from different ions has been an issue in existing technologies. We will achieve the selective sensing with novel surface treatment with enzyme. Enzymes are exquisitely selective catalysts, *capable of choosing a single substance from a sea of similar compounds*. The sensitivity of nanosensors will be further increased by the unique piezoelectricity found in zinc oxide nanowires.

Outcome	Completion Date
1. Zinc oxide-based nanosensors selectively detecting nitrate and phosphate in water	*June 30, 2018*
2. Enhanced sensitivity by introducing strain in piezoelectric nanowires	*Dec. 31, 2018*

Activity 2: *Develop nanosensor arrays for simultaneous detection of multiple nutrients* **Budget: $ 134,097**

The objective of this activity is to integrate nanowires treated with different enzymes into nanosensor arrays, so that multiple nutrients, e.g., phosphate and nitrate, can be detected simultaneously and accurately. We have recently developed a technology to achieve nanowire arrays that are lined up like soldiers. These nanowire arrays facilitate the fabrication of sensor arrays. In addition, a software will be developed so that the measurement data can be easily collected, analyzed, and displayed.

Outcome	Completion Date
1. Nanosensor arrays detecting multiple nutrients simultaneously	*March 31, 2019*
2. A software for fast analysis and display of nutrient concentrations	*June 30, 2019*

Activity 3: *Develop self-powered nanosensor system and field testing* **Budget: $183,975**

The object of this activity is to develop an autonomous sensing system suitable for surface water quality monitoring. An off-the-shelf solar panel will be sufficient to power the tiny sensor arrays. The entire unit will be designed and packaged for long-term out-door usage. The self-powered nanosensor system will be tested in water from the Mississippi River in the Outdoor StreamLab (OSL) of the University of Minnesota. The OSL offers laboratory-quality measurements within a field-scale experimental channel. Examination of the prototype unit in OSL will prepare the technology to be applied in Mississippi River, Laker Superior, and other water bodies.

Outcome	Completion Date
1. Integrate a solar panel and package the sensing unit for outdoor deployment	*Dec. 31, 2019*
2. Test prototype unit with the water from the Mississippi River in Outdoor StreamLab	*April 30, 2020*
3. Demonstrate the autonomous sensing system in lakes	*June 30, 2020*

III. PROJECT STRATEGY

A. Project Team/Partners

Professor Rusen Yang will serve as Project Manager. He is a faculty member in the Department of Mechanical Engineering at the University of Minnesota. He has over 10 years' experience with the growth and application of nanomaterials and published over 60 journal articles. His rich experience in developing ultra-sensitive nanosensors prepared him well for this project. Yang will be responsible for overseeing the project, all reports, and deliverables. Professor Lian Shen will be a collaborator responsible for characterizing water flows around devices and setting up field tests. He is Associate Director of St. Anthony Falls Laboratory. He is a world expert in the study of environmental air and water flows. He will bring in expertise in the field test of nanosensors. The project will be assisted by one postdoctoral associate and one graduate student.

B. Project Impact and Long-Term Strategy

The long term goal for this project is to develop self-powered autonomous system for continuous water quality monitoring. In addition to contributing to the knowledge base of nanoscience and nanotechnology, this project will have broad and long-term impact on the water quality in Minnesota. The state is required by the federal Clean Water Act to assess the condition of all their waters and list the waters failing to meet standards as "impaired" every two years. More than $25 million are invested each year for monitoring/assessment activities and water quality study. Minnesota Pollution Control Agency (MPCA) relies on volunteers to collect water samples and send them for laboratory analysis. The entire process is very time-consuming and expensive, and it heavily depends on the availability of volunteers. As of year 2010, less than one third of water bodies in Minnesota have been tested, and 40% or them failed to meet water quality standards established to protect these uses. Excess nutrients are the second largest source of water quality impairment in Minnesota. With the generous support from LCCMR, the success of this project will produce a cheap and powerful platform for continuous monitoring of nutrients in water bodies in Minnesota. The project will ultimately help MPCA realizing the 10-year plan of Minnesota's Water Quality Monitoring Strategy.

In addition, we will share our results with the MPCA and environment protection advocacy groups. We will be engaged in public presentation to Minnesota's natural resource management professionals and other citizens. We will disseminate our finding at professional conferences frequented by state and federal natural resource management officials, and report our work in prestigious scientific journal. We will demonstrate our prototype self-powered nutrients sensing system in our on-going outreach activities, including summer camps for high school students. Our outreach program will promote and enhance education and communication on the significance of water quality monitoring and state-of-the-art research results on this topic.

C. Timeline Requirements

The project will be conducted over a 3-year period from July 1, 2017 to June 30, 2020.

2017 Detailed Project Budget

Project Title: *Environment-friendly Nanosensors to Detect Nutrients in Water*

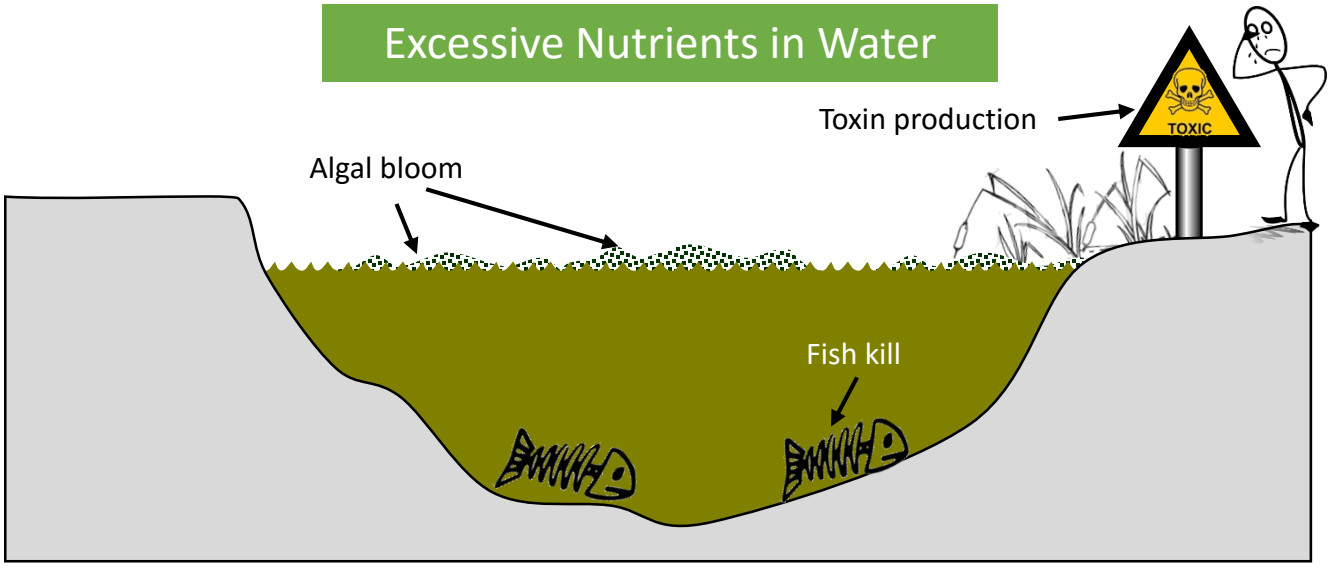
IV. TOTAL ENRTF REQUEST BUDGET: 3 years

BUDGET ITEM	AMOUNT
Personnel: Professor Rusen Yang, Project Manager, (75% salary, 25% benefit); 11% FTE summer salary for each of 3 years. He will supervise the project and be in charge of progress report.	$ 45,176
Professor Lian Shen, Co-investigator, (75% salary, 25% benefit); 5.5% FTE summer salary for each of 3 years. He will be responsible for the field test and characterization of water flows around nanosensors.	$ 24,212
1 Postdoctoral Associate, Device fabrication and field test (82% salary, 18% benefit); 100% FTE for each of 3 years	$ 168,856
1 Graduate Research Assistant, Nanomaterial growth, sofeware development, and data analysis (59% salary, 41% benefit (including tuition)); 50% FTE for each of 3 years	$ 140,262
Equipment/Tools/Supplies: *Lab Materials & Supplies: fabrication materials & supplies including silicon and glass substrate ($2,000), polymer substrates ($6,000), Zinc oxide, zinc nitrate, zinc carbonate, ammonia, hexamethylenetetramine, carbon black, and specimen mounts for electron micnroscopy ($12,000), manufacturing set-up items ($9,000), glasswares, quatz tubes, gloves, other electronics for testing, etc. ($8,000)*	$ 37,000
Sceintific Services: User fees at Minnesota Nano Center (MNC) and Characterization Facility (CharFac) at the University of Minnesota. The access fee for MNC is $245 per month per user. The equipment usage is at about $50/hour on average. The cost for using MNC is about $898/month for 12 month each year. No monthly fee is charged by CharFac, and the equipment usage is charged at $36/hour on average. The cost for using CharFac is about $200/month for 12 month each year. Evening and weekend usage is prioritized due to the lower rate.	$ 39,520
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 455,026

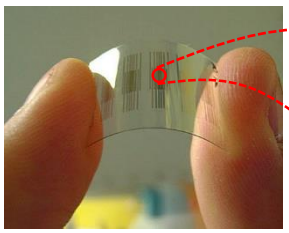
V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period: *3M Company* *Professor Yang received the 3M Non-Tenured Facult Award. 3M compnay is giving $15,000 each year to support his research activity. The 3M project is listed as other funding that for projects related to the proposed work, for informational purposes only, and not intended as a cost share commitment for the proposed project.*	$ 15,000	*Secured*
Other State $ To Be Applied To Project During Project Period: *N/A*	$ -	
In-kind Services To Be Applied To Project During Project Period: *University of Minnesota* *The University of Minnesota's Facilities and Administrative rate will be 53% of modified total direct cost (total direct less graduate fringe, equipment, and on-site facilities rental). The amount, if F&A expenses would have been allowed on the project, would be $206,064. The University will provide office space, IT services, and administrative/financial services in support of the project.*	$ 206,064	*Secured*
Funding History: 3M Company Professor Yang received the 3M Non-Tenured Facult Award. 3M compnay was giving $15,000 each year in past two years to support his research activity. The 3M project is listed as other funding that for projects related to the proposed work, for informational purposes only, and not intended as a cost share commitment for the proposed project.	$ 30,000	Secured
Remaining $ From Current ENRTF Appropriation: *N/A*	$ -	

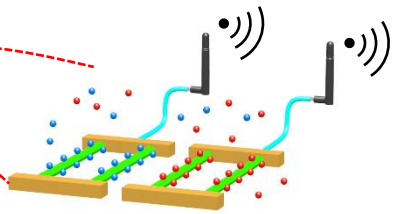
Excessive Nutrients in Water



Nutrients Monitoring with Nanosensor Arrays



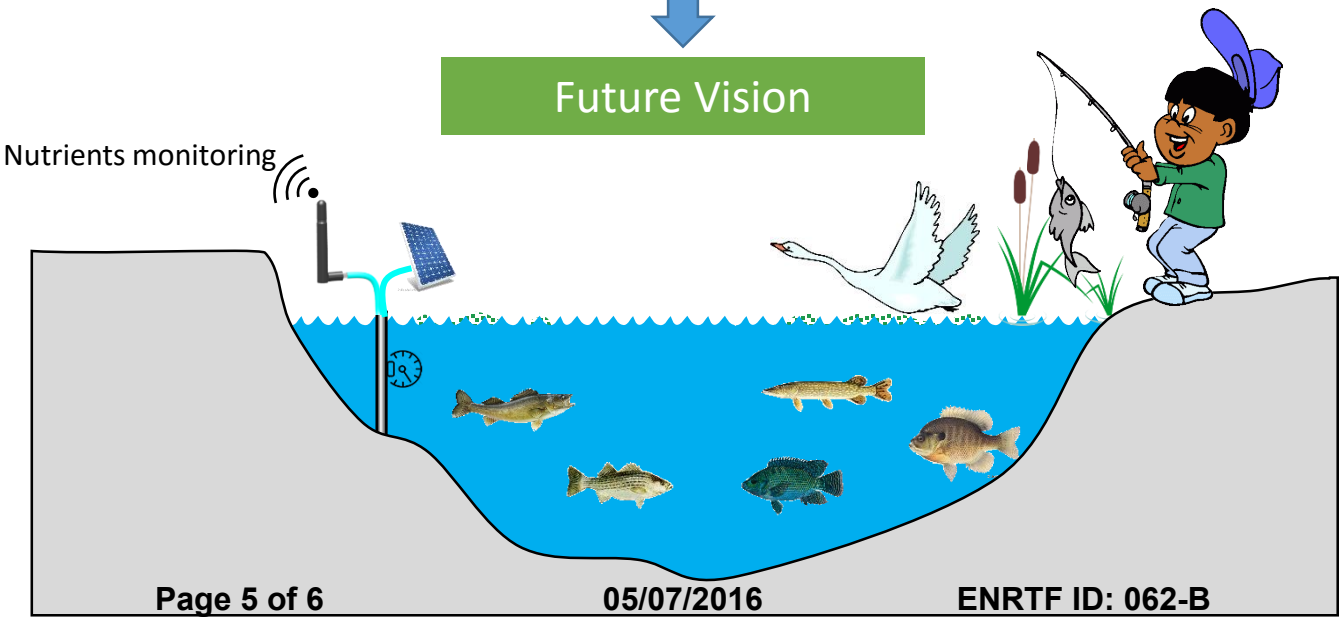
nanosensor arrays



Simultaneous detection of nitrate (N) and phosphate (P)

Real-time nutrients monitoring

Future Vision



PROJECT TITLE: Environment-friendly Nanosensors to Detect Nutrients in Water

I. PROJECT MANAGER QUALIFICATIONS

This project will be led by Rusen Yang as Project Manager. Yang is an Assistant Professor in the Department of Mechanical Engineering at the University of Minnesota since 2010. He is a leading scientist in the field of nanotechnology with over 60 papers published in prestigious scientific journals. He was featured in the *Star Tribune* and his innovative work has been reported by *Technology Review*, *Discovery News*, *CNN*, etc. He has successfully discovered new nanomaterials with exotic properties and applied them in advanced sensors. In 2014, his group manufactured the most sensitive sensors in the world using zinc oxide nanowires. His work has been cited in more than 5,300 scientific papers. He has an established history of innovation and cross-cutting interdisciplinary research, with successful outcomes. He has been recognized with the National Science Foundation CAREER award in 2012. He was one of six people awarded the McKnight Land-Grant Professorship for 2013-2015 at the University of Minnesota.

Lian Shen will be co-investigator in this project. Shen currently holds the position of Benjamin Mayhugh Associate Professor and Associate Director of the St. Anthony Falls Laboratory (SAFL) at the University of Minnesota. He is a world expert in the study of environmental air and water flows. He is on the editorial boards of the International Journal of Computational Methods and the Ocean Systems Engineering Journal. Shen has been active in professional societies, including American Society of Civil Engineering (ASCE) and American Geophysical Union (AGU), and is a member of the ASCE Environmental & Water Resources Institute (EWRI) task committee on CFD Application in Water and Wastewater Treatment.

II. Organization Description

Fabrication of nanomaterials for the environment-friendly nanosensors will be conducted in the Nanomaterials and Sustainable Technology Laboratory (NSTL) at the University of Minnesota. Professor Yang is the head of NSTL with all necessary equipment for the nanomaterial fabrication and device characterization. The sophisticated Atomic Force Microscopy in NSTL substantially cuts the cost of the proposed activities. It enables the Yang group to design and conduct customized experiments to improve sensitivity with nanostructures on the film. Professor Yang has invested in establishing versatile nanofabrication capabilities through different processes. He has set up a comprehensive and versatile platform for testing the performance of nanosensors.

Nanomaterial characterization and device fabrication will be partly performed in the Characterization Facility (CharFac, http://www.charfac.umn.edu/) and the Minnesota Nano Center (MNC, http://www.nfc.umn.edu/). The CharFac is a multi-user, shared instrumentation facility for measuring properties of nanomaterials. MNC is a state-of-the-art facility for interdisciplinary research in nanoscience and applied nanotechnology. It is one of 16 centers in the nation supported by the National Science Foundation. The state support, federal funds, and industrial usage allows MNC to offer academic rates that are normally less than half of the actual cost of operation.

Field test of nanosensors will be performed in natural water in the Outdoor StreamLab (OSL) of SAFL at the University of Minnesota (http://www.safl.umn.edu/facilities/OSL.html). SAFL is a world-renowned research laboratory specialized in environmental fluid flows. SAFL researchers have been performing many innovative environmental studies for the state. Some projects were/are funded by the Minnesota Environment and Natural Resources Trust Fund. The OSL is an experimental stream channel system designed to host experiments on the interactions between physical, chemical, and biological processes with water diverted from the Mississippi River. Studies of nanosensors in the OSL represents a vital step between controlled laboratory conditions and field variability. Located across the Mississippi River from downtown Minneapolis, OSL is frequently visited by public. The proposed project will provide an excellent opportunity for public education and outreach.