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

Project Title: **ENRTF ID: 146-E**

Cheap and Clean Energy from Friction-Induced Static Charges

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

Total Project Budget: $ 422,874

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

Summary:

We will develop nanogenerators to harness energy from road vibration, wind, and waves. The device will power a state-wide sensor network and improve the air, water, and safety in Minnesota.

Name: Rusen Yang

Sponsoring Organization: U of MN

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Web Address

Location

Region: Metro

County Name: Statewide

City / Township:

Alternate Text for Visual:

Cheap and Clean Energy from Friction-induced Static Charges

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

PROJECT TITLE: Inexpensive and Clean Energy from Friction-induced Static Charges

I. PROJECT STATEMENT

The objective of this project is to harness the energy from road vibration, wind, and waves by generating useful electricity from friction-induced static charges. **The significance of this work** is that the technology can provide clean, renewable energy to homes, an inexpensive sensor network along roads and in the Mississippi River and lakes, and can raise community awareness about the environment, renewable energy, and the concept of sustainability. **The approach** is to further develop a triboelectric nanogenerator which creates static charges from the movement of roads, air, and water and produces electricity for air and water quality sensors. Field tests of prototype will be carried out by the end of the project.

Understanding Minnesota's environment and natural resources requires hundreds of thousands of air and water quality sensors for the state's over 12,000 lakes, 92,000 miles of rivers, and 140,000 miles of road. The challenge is how to power these low-power but widely distributed devices. Batteries are not a viable solution due to the prohibitive cost of replacing them regularly. Solar panels do not work at night or during a cloudy day. We address this challenge with an efficient, cheap, and powerful triboelectric generator that is a result of recent research breakthroughs in our lab. *This project will create a roll-to-roll process for producing energy generation materials, and a process for assembling them into generators that can produce from vibration and waves electricity for sensors*. The process is based on a spray coating method which simplifies the current complex and expensive process. It paves the way to low-cost continuous production. The roll-to-roll process of optimized energy harvesters will be ready for the stage of commercialization and provide a new green energy resource. It will lower the energy cost to Minnesotan and reduce carbon emissions. The locally-produced renewable energy will enable a state-wide environment monitoring system and improve the air, water, and safety in Minnesota.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: *Develop roll-to-roll processing to fabricate spray-coated films for generators* **Budget: $135,226**

The objective of this activity is to fabricate energy generation film with a roll-to-roll manufacturing based on a simple spray-coating process. Carbon nanotube films will be sprayed to form electrodes. The superior mechanical properties and conductivity of carbon nanotubes promise long life time and minimal energy loss. Polytetrafluoroethylene (PTFE) will be sprayed onto a wavy Kapton sheet for the energy conversion. The wavy structure provides restoring force so that devices can continuously generate electricity on the road or in the lake. PTFE is selected because it can collect more negative charges than any other materials. More static charges will result in more energy generation and higher device efficiency.

Outcome	Completion Date
1. A working simple spray-coating process to fabricate films for generators	*June 30, 2018*
2. Films produced through a roll-to-roll manufacturing process	*Dec. 31, 2018*

Activity 2: *Improve the energy generation and reliability of triboelectric nanogenerators* **Budget: $143,768**

The objective of this activity is to improve the energy generation and reliability with nanostructures formed on the surface of films. The electricity from a generator is proportional to the surface area that contains static charges. Nanostructures have one million times more surface area than the same amount of bulk materials. Thus, we will fabricate nanostructures on the surface of the film to increase the energy generation from the device. In addition, a PTFE film with nanostructured surface will completely repel water and oils on its surface. This unique property enables the generator to function in various environment without deterioration over time.

Outcome	Completion Date
1. Increased electricity generation with nanostructures formed on the film surface	*Dec. 31, 2018*
2. Dry, clean, and reliable generators with PTFE films that repel water and oils	*June 30, 2019*

Activity 3: *Design, fabricate and test triboelectric nanogenerators* **Budget: $ 143,880**

The objective of this activity is to use the results from Activities 1 and 2 to develop high efficient, high power, reliable triboelectric nanogenerators. Generators will be tested and their performance optimized under road excitation. The area power density of a generator can reach 500 $watt \cdot m^{-2}$ and the efficiency can exceed 50%. In addition to the controlled measurement in laboratory, prototype unites will be set up on an outdoor site and the real time performance will be measured.

Outcome	Completion Date
1. Enhanced performance of triboelectric nanogenerators under controlled excitation	*Dec. 31, 2019*
2. Field tests of optimized triboelectric nanogenerators driven by road excitation/waves	*June 30, 2020*

III. PROJECT STRATEGY

A. Project Team/Partners

Professor Rusen Yang of Mechanical Engineering at U of MN will be the project's principal investigator and U of MN will be the recipient of all funding. Yang will be responsible for all reports and deliverable. He will lead a team of research staff at U of MN Nanomaterials and Sustainable Technology Laboratory to accomplish the stated project goals. Yang's research is at the frontier of renewable energy, and he was frequently invited to present his work at international conferences. He created the world's first flexible mechanical energy harvester using nanomaterials in 2009, and now he focuses on massive production and commercialization. He will be involved in designing the roll-to-roll manufacturing, coupled with a simple spray-coating process. Under Yang's supervision, a Ph.D. student will be responsible for the fabrication and characterization of spray-coated films, and a post-doc will be in charge of the manufacturing facility, prototype development, and field tests.

B. Project Impact and Long-Term Strategy

The long term goal for this project is implementation of the new generator that provides inexpensive green energy for Minnesota. Yang is currently supported by the 3M Company to study the energy conversion in triboelectric nanogenerators. The large scale triboelectric nanogenerator from this project holds promise as a new and efficient approach to harvest energy from road vibration, wind, and waves that would be otherwise wasted. The generated power can be used locally for air and water quality monitoring and illuminated safety warning signs which often lack suitable power sources in remote areas. The technology also has potential for generating large amounts of electricity from wind and waves. In addition to the rich wind energy in Minnesota, wave energy is another renewable energy source that has been overlooked so far. The wave energy from Lake Superior is about $1.55 \times 10^{16}\ J/year$. Harvesting only 1% of the wave energy with our generator will generate about 5 megawatt electricity that would power over 4,000 homes. A new power plant can also reduce the shoreline erosion caused by the wave action as the power plant absorbs wave energy from the lake.

By the end of the project, we will have a prototype device that can demonstrate the feasibility of the technology. We will closely collaborate with state agencies, energy and environment researchers, and industry to develop an implementation plan for self-powered water and air monitor sensor network in Minnesota. The prototype will also be used in outreach activities, such as summer camps for high school students, to raise community awareness about the environment, renewable energy, and the concept of sustainability. Renewable energy is the best solution to the current energy crisis, and our novel triboelectric nanogenerator has great potential for commercialization. Consequently, this project can contribute to both the environment and economics of Minnesota.

C. Timeline Requirements

The project is planned for 3 years beginning on July 1, 2017 and ending on June 31, 2020.

2017 Detailed Project Budget

Project Title: Cheap and *Clean Energy from the Friction-induced Static Charges*

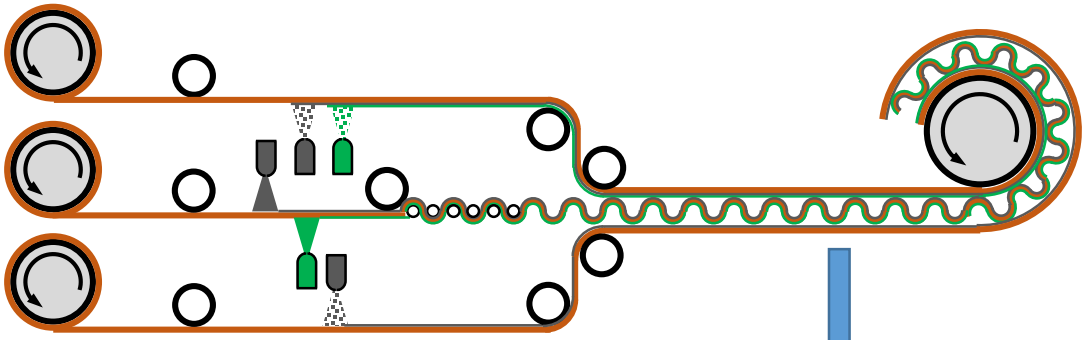
IV. TOTAL ENRTF REQUEST BUDGET: 3 years

BUDGET ITEM	AMOUNT
Personnel: Professor Rusen Yang, PI, (75% salary, 25% benefit); 11% FTE summer salary for each of 3 years	$ 45,176
Post-Doc,12 months (100% FET) plus 21.4% fringe for 3 years	$ 168,856
Graduate Research Assistant, 50% FTE (fall & spring semesters include 16.6% fringe plus $17.84/hour tuition, summer 16.6% fringe only) for 3 years	$ 140,262
Equipment/Tools/Supplies: *Lab Materials & Supplies: fabrication materials & supplies including polymer substrates ($3,000), photoresist and specimen mounts for electron micnroscopy ($2,000), carbon nanotubes and spray solution for teflon ($7,000), roll-to-roll manufacturing set-up items ($14,000), bottles, gloves, other electronic test components, etc. ($5,000)*	$ 31,000
Sceintific Services: User fees at Minnesota Nano Center (MNC) and Characterization Facility (CharFac) at the University of Minnesota. The cost for using MNC is about $884/month for 12 month each year. It incldues the access fee of $245/month and the equipment usage of $639/month at $50/hour on average. The cost for using CharFac is about $160/month for 12 month each year. No monthly fee is charged by CharFac, and the equipment usage is charged at $36/hour on average. Evening and weekend usage is prioritized due to the lower rate.	$ 37,580
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 422,874

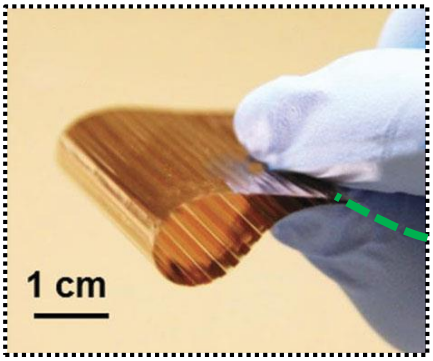
V. OTHER FUNDS

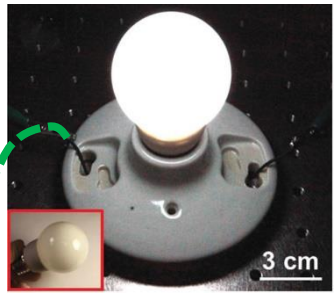
SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period: *3M Company* *Professor Yang received the 3M Non-Tenured Facult Award. 3M compnay is giving $15,000 each year to support his research activity. The 3M project is listed as other funding that for projects related 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 $186,109. The University will provide office space, IT services, and administrative/financial services in support of the project.*	$ 186,109	*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*	$ -	

Manufacture of Triboelectric Nanogenerators that Harness Energy from Road, Wind, Waves, …



Electricity is created from friction-inducted static charges as a nanogenerator is shaken on roads or swung by wind/waves



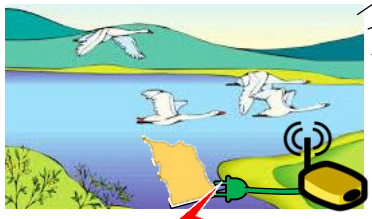


G16 globle light (120 V) powered by a nanogenerator

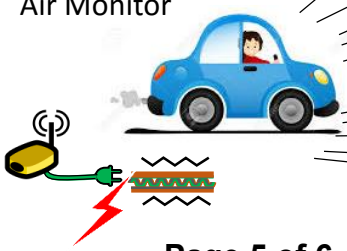
State-wide Power Plants

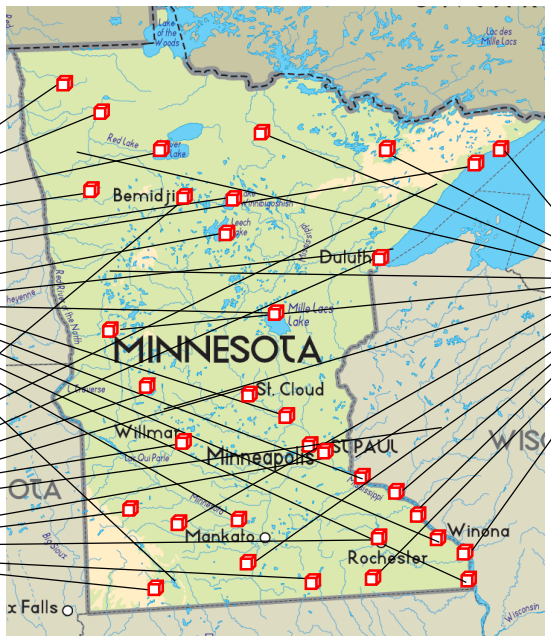
Self-powered Sensors

Water Monitor



Air Monitor

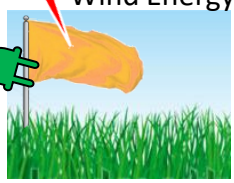




Clean Energy for Homes

Wave Energy

Wind Energy



PROJECT TITLE: Cheap and Clean Energy from Friction-induced Static Charges

I. PROJECT MANAGER QUALIFICATIONS

Rusen 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. His innovative work of energy harvesting was reported by *Technology Review*, *Discovery News*, *CNN*, etc. He was featured in the *Star Tribune* for his research as "energy scavengers." He serves as an editor for 2 journals and frequently reviews manuscript for over 50 journals. He has been frequently invited to present his work at international conferences. He fabricated the world's first flexible energy harvester with piezoelectric nanomaterials in 2009 and he has improved dramatically the performance of nanogenerators since then. His research on nanogenerators made significant contribution in the field of energy harvesting. His work has been cited in more than 5,300 scientific journal papers reported by scientists worldwide. *His recent research interests focus on large scale fabrication of nanogenerators and explore their commercialization potentials*. 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 6 people awarded a McKnight Land-Grant Professorship for 2013-2015 at the University of Minnesota.

II. Organization Description

Investigation of the triboelectric nanogenerator 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 (AFM) in NSTL substantially cuts the cost of the proposed activities. It enables the Yang group to design and conduct customized experiments to improve the energy generation with desired nanostructures from controlled process parameters. Professor Yang has invested in establishing versatile fabrication capabilities through different processes. He has set up a comprehensive and versatile platform for testing the performance of triboelectric nanogenerators.

The proposed research involves nanomaterials and nanofabrication. Thus, it is necessary to employ the electron microscope in the Characterization Facility (CharFac, http://www.charfac.umn.edu/) and to use the lithography, etching, and metallization instruments in the Minnesota Nano Center (MNC, http://www.nfc.umn.edu/). The CharFac is a multi-user, shared instrumentation facility at the University of Minnesota. It has analytical capabilities to measure properties of nanomaterials. MNC is a state-of-the-art facility for interdisciplinary research in nanoscience and applied nanotechnology. It is one of 16 similar centers in the nation supported by the National Science Foundation. MNC offers a comprehensive set of tools to help researchers develop new micro- and nanoscale devices. 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.