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

Project Title: **ENRTF ID: 144-E**

Developing Bank-Protection Energy-Converter Systems for Minnesota Rivers

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

Total Project Budget: $ 622,000

Proposed Project Time Period for the Funding Requested: 3.5 years, July 2017 - September 2020

Summary:

A new device able to prevent side-bank erosion while extracting energy will be designed, tested and deployed in Minnesota rivers. The material included is being evaluated for a provisional patent.

Name: Michele Guala

Sponsoring Organization: U of MN - St. Anthony Falls Laboratory

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Minneapolis MN 55455

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Email mguala@umn.edu

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Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

The visual presents key design components and potential deployment locations in Minnesota rivers

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

_____ Extent of Impact _____ Innovation _____ Scientific/Tech Basis _____ Urgency

_____ Capacity Readiness _____ Leverage _______ TOTAL ______%

DEVELOPING BANK-PROTECTION ENERGY-CONVERTER SYSTEMS FOR MINNESOTA RIVERS

I. PROJECT STATEMENT

The proposed research project focuses on the design and development of a new device, called ***W²***, able to operate in Minnesota rivers of variable size and flow rate, preventing side bank erosion while extracting energy. The ***W²*** technology is based on a horizontal baffled wheel partially embedded in a bank protection system, placed where the stream flow is more energetic, i.e. at the outer bank of meandering channels. While the flow sustains the wheel rotation and continuously produces electric energy, the stream velocity near the bank in the device's wake is reduced, along with the sidewall erosional rate.

During this project, the ***W²*** design will be finalized, a small scale model and a full scale prototype will be built and tested in the experimental facilities of the St. Anthony Falls Laboratory and deployed in a Minnesota river.

The ***W²*** technology targets straight and single-thread meandering river channels common to the upper Midwest. It is envisioned to operate at river mid-depth, and thus accommodates the ability to work with floating ice and debris (e.g. large wood branches, logs) or canoes, as well as under high sediment transport and migrating bedforms. Several units can be staggered along the outer bank achieving both goals of stabilizing the river channel under high discharge conditions, and contributing to renewable energy production for nearby houses or street illumination. Because of the design dual purpose, we anticipate deployments in natural parks, small riverfront communities or at the riverside of state, county or cycling roads (for free illumination).

Key elements of the ***W²*** design have been reviewed by the Office of Technology and Commercialization of the University of Minnesota, and are currently listed in a patent procedure.

The facilities of the St. Anthony Falls Laboratory, including full-scale water channels and a high performance computing cluster, will be utilized during design and prototype testing. The main tasks are 1) design development using small scale physical models and computational methods, 2) prototype deployment and performance assessment in a field-scale channel under controlled flow conditions.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: *<u>Developing and testing **W²** models via numerical and laboratory experiments</u>* **Budget: $260,000**

A laboratory scale ***W²*** baffled turbine model will be built and tested in the SAFL tilting bed flume (0.9m-3ft wide, 25m-82ft long), varying bed slope, flow rate, bed material grain size, and sediment transport rate.

The goal is to improve the design by simultaneously working on physical small scale models in laboratory experiments and computational models. Because of the ability to prevent bank erosion, experiments will be conducted in laboratory flumes with erodible sediment bed and banks, which make the SAFL facilities perfect for this purpose. There are several elements of novelty that are guiding our design and our patent application:

The partial exposure of the ***W²*** to the flow guarantees high performance while keeping the rotating shaft of the wheel, the connected gearbox, and the generator enclosed with the river bank protection. This way, the major electrical components will not be submerged but located above the water level on the river side and connected to the main shaft, reducing deployment and maintenance costs, and failure risks. This will also provide easy access to any utility connection. The ***W²*** turbine will be built using a water-tight aluminum or composite frame (with air inside) ensuring neutral buoyancy when deployed in water, thus minimizing bearing friction, as well as weight and fatigue loads. Torque is generated mostly by momentum transfer (as e.g. a Pelton turbine) which is an improvement over technologies relying on complex lift producing blade elements that are susceptible to underperforming because of biofouling from leaves and algae build-up. Finally, this technology will provide stability and protection of natural river banks by reducing near bank velocities and diverting the outer stream core towards the channel center, preventing erosion.

Outcome: *W²* Lab. testing	**Completion Date**
1. Build a small scale model with exchangeable blade designs (allowing multiple tests)	*March. 2018*
2. Quantify device performance in clear water (performance curve at different flow rates)	*Sept. 2018*
3. Validate the available numerical simulation algorithm	*March 2019*
4. Finalize the design using computational tests to systematically vary the baffle geometry	*Sept 2019*

The agreement between observed and computed performances over an acceptable power coefficient (C_p >0.3) will mark the end of reduced scale testing and the start of prototyping

Activity 2: *Building and field-testing a full scale **W²** prototype* **Budget: $362,000**

The design of the ***W²*** energy converter will be scaled-up using numerical simulations as a guideline tool for prototype fabrication. The device will be built and tested in the SAFL Main Channel under active sediment transport conditions. The flume is 85m (278ft) long, 2.75m (9ft) wide, and able to operate with a mean flow velocity ~ 1m/s (~3ft/s), at depth up to 1.6 m (~5ft), thus representative of a small-medium scale river in Minnesota. Flow rate and levels are controlled by upstream and downstream gates. Sediment can be recirculated guaranteeing equilibrium conditions during tests. The ***W²*** power performance and shielding effects on the channel erodible topography will be quantified until an optimum design is reached. The expected power output of each device, which can be staggered along the meandering curve to achieve larger power capacity, is in the 1-2KW range per unit (enough for a small house, or more than 20 LED-based street light systems).

Outcome: *W²* Field testing	**Completion Date**
1. Build a prototype able to operate in a 0.5-2m depth river and quantify the mechanical power harnessed from the flow (performance curves at varying river discharges)	*February2020*
*2. Quantify **W²** induced scour in the bed and side banks at optimal performance conditions*	*May 2020*
3. Deploy the prototype in a Minnesota river and measure performance.	*September 2020*

III. PROJECT STRATEGY

A. Project Team/Partners

The project team includes: Principal Investigator (PI) prof. Michele Guala, who will be responsible for the design, laboratory and field testing of the **W²** models (SAFL, Civil Environmental and Geo- Eng., UMN); co-PIs (Lian Shen professor Mechanical Eng., UMN and SAFL associate director) will supervise the design and supervise the numerical simulation work; Jeff Marr (Associate Director for Engineering at SAFL) will contribute to the prototype fabrication and field testing. The PIs have expertise in renewable energy production (wind and hydro), river geomorphology and sediment transport, river engineering, physical and numerical modeling, mechanical engineering and structural design.

B. Project Impact and Long-Term Strategy

The overarching goal is to expand renewable energy installations to small scale communities and water bodies, creating a technology for local energy production at the lowest environmental costs (invisible, inaudible) embedded into bank protection systems, which are already in place at the river bank.

Marine and Hydrokinetic (MHK) energy technologies represent an extremely viable opportunity to access clean and renewable energy from rivers, waves and tidal currents. Utility scale technologies such as those by Verdant Power and OpenHydro are capable of generating hundreds of kilowatts of energy but also require deep channels and high flow discharges (pilot projects in the East River in New York, the Juan de Fuca Strait Channel near Seattle, Washington and the Chankoo Channel near Conception, Chile). These massive hydrokinetic devices have substantial technological and environmental barriers to overcome before measurable penetration of the technologies are realized. We believe there is opportunity and need for small to medium sized energy converters, which can be deployed in smaller rivers, streams and even ditches, suited for pristine natural areas in Minnesota as well as remote communities in under-developed countries with limited access to electric grid; given that ~900 million people in the tropics did not have access to electricity in 2010, harnessing energy from local streams and irrigation channels has applicability on a global scale. In more pragmatic terms, the ***W²*** device is being patented, and a local start-up company will be created to develop and commercialize the technology.

C. Timeline Requirements

The project activities will be performed between June 2017 and September 2020. The milestones include a reduced scale model development (year 1-2) and a utility-scale prototype (year 2-3). The design will be optimized using validated numerical simulations and laboratory experiments in flumes of different sizes.

2017 Detailed Project Budget

Project Title: **DEVELOPING BANK-PROTECTION ENERGY-CONVERTER SYSTEMS FOR MINNESOTA RIVERS**

INSTRUCTIONS AND TEMPLATE (1 PAGE LIMIT)

Attach budget, in MS-EXCEL format, to your "2016 LCCMR Proposal Submission Form".

(1-page limit, single-sided, 10 pt. font minimum. Retain bold text and DELETE all instructions typed in italics. ADD OR DELETE ROWS AS NECESSARY. If budget item row is not applicable put "N/A" or delete it. All of "Other Funds" section must be filled out.)

IV. TOTAL ENRTF REQUEST BUDGET: $622,000.00 for 3 years

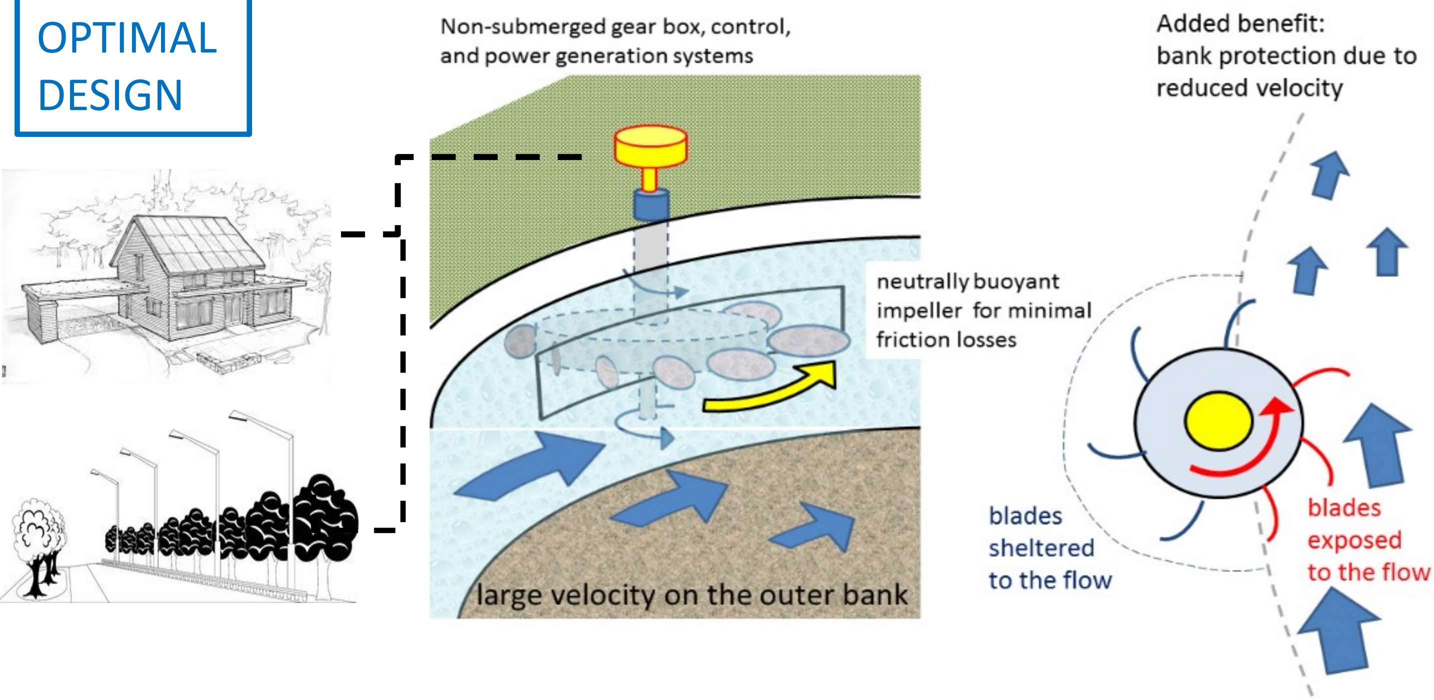
BUDGET ITEM *(See "Guidance on Allowable Expenses", p. 13)*	AMOUNT
Personnel: *In this column, list who is getting paid to do what and what is the % of full-time employment for each position. List out by position or position type - one row per position/position type. For each, provide details in this column on the inputs: i.e., % dollars toward salary, % dollars toward benefits, time period for position/position type, and number of people in the position/position type.*	
Michele Guala, PI (75% salary, 25% benefits); 11% FTE , 1 month per year for 3 years.: Guala brings critically important expertise in experimental fluid dynamics and renewable energy a. He is the inventor of the device being patented and he will supervise all the tasks listed in the project activities with specific focus on laboratory and field sclae testing at SAFL.	$ 41,622
Jeff Marr, CO-PI (75% salary, 25% benefits); 7% FTE, 3 weeks per year for 3 years. J Marr is the associate director for applied research at SAFL. He has expertise in river dynamics, sediment transport , renewable energy, and project management. J Marr will supervise the prototype building and deployment and all field-scale operations.	$ 29,906
Lian Shen, CO-PI (75% salary, 25% benefits); 7% FTE , 3 weeks per year for 3 years: Prof. Shen is an expert in computational fluid dynamics and renewable energy. He will supervise the postoctoral researcher in computational research	$ 31,101
Staff Engineer (78% salary, 22% fringe): 22% FTE (8 weeks per year) . He will help the PhD student to build small scale models and the prototype and obtain the performance curves. He will also be the main operator during field deployments (year 3).	$ 50,004
Graduate student (59% salary, 41% fringe): Michael Heisel, receipient of the Summerfeld felloship in Civi Engineering (UMN) will be funded during the three of the project, bringing him to PhD completion. He will be responsible for building the experimental model, collect data, and collaborate with the numerical researcher to achieve the best perfornig design under reasonable flow hydrographs	$ 137,306
Postdoctoralscholar 100% salary): The postdoctoral scholar will be devoted to the computational design and optimization of the blade geometry and field siting. He will be supervised by prof. Shen.	$ 185,964
Professional/Technical/Service Contracts: *In this column, list out proposed contracts. Be clear about whom the contract is to be made with and what services will be provided. If a specific contractor is not yet determined, specify the type of contractor sought. List out by contract types/categories - one row per type/category. If an RFP will be issued, state that.*	$ -
Equipment/Tools/Supplies: *In this column, list out general descriptions of item(s) or item type(s) and their purpose - one row per item/item type.*	$ -
Supplies: General supplies for laboratory and field setups are quantified based on previous experience. Year 1 & 2 ($12,000), Year 3 ($10,000). The amounts will include 1) data acquisitionsystem (board and computer) for the laboratory and field experiment testing, SAFL main channel and tilting bed operating and maintenance costs (include updates on the laser scanner for bed topography measurements)	$ 34,000
Supplies: sand of different grain size covering the SAFL Main channel section 85m x 3m x 0.3m. Expected amount is 20 tonns, at a cost of 15,000$ including removal from the channel. Addition of a fine or coarse sediment fraction that will change bed material composition to match that of a MN river (5,000$)	$ 20,000
Equipment: turbine components. A variable speed motor and drive and a torque sensor will be purchased for the laboratory scale turbine model ($5000). Blade and torque producing elements will be rapid prototyped or 3D printed ($10,000, for various shapes)For the prototype we expect total component cost of approximately 45,000$	$ 60,000
Equipment : A laboratory Acoustic Dopppler Velocimeter (Nortek) will be used for measuring incoming flow conditions. The components of the turbine model and prototype are listed above	$ 25,000
Acquisition (Fee Title or Permanent Easements): *In this column, indicate proposed number of acres and and name of organization or entity who will hold title.*	$ -
Travel: *Be specific. Generally, only in-state travel essential to completing project activities can be included.*	
The field deployment will require extensive traveling to a in-state locations (to be defined) where the prototype will be deployed. We expect 5-8 trips in the last year at 500$ each	$ 4,000
During year 2 and 3 the graduate student will present research data and progress at the AGU, APS or ASCE conference. Based on previous experience we are requesting 1500$ per conference (1) per person(1), per year (2). For a total of 3000$. This is the minimum for the educational enrichment of the graduate student.	$ 3,000
Additional Budget Items: *In this column, list any additional budget items that do not fit above categories. List by item(s) or item type(s) and explain how number was determined One row per type/category.*	$ -
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	**$ 621,903**

V. OTHER FUNDS *(This entire section must be filled out. Do not delete rows. Indicate "N/A" if row is not applicable.)*

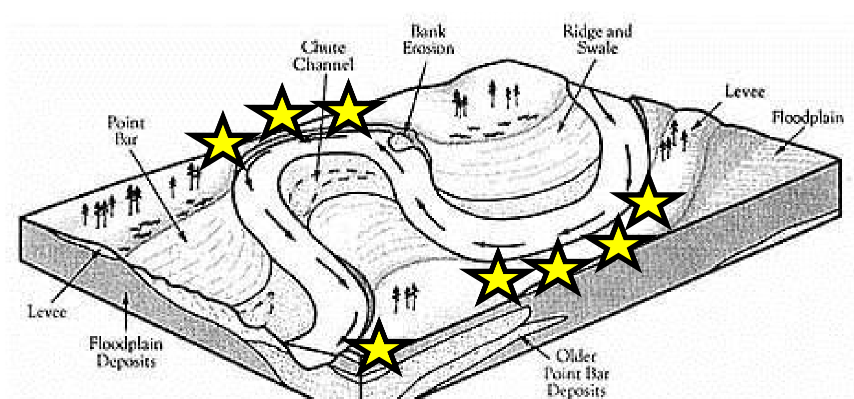
SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period: *NSF career project funding will be used for some of the supplies and equipment that will be shared in those project. In additio, the PhD student supported by the NSF grant will be involved in the current research activities for at least 2 years.*	$ 410,000	*secured*
Other State $ To Be Applied To Project During Project Period: *A proposal to IONE research funding is focused on SAFL Main channel experiments. If granted it will provide additional resources for sand and equipment maintenance (about 30,000$) could be saved.*	$ 500,000	*pending*
In-kind Services To Be Applied To Project During Project Period: *Indicate any additional in-kind service(s) secured or applied for to be spent on the project during the funding period. For each type of service, list type of service(s), estimated value, and indicate whether it is secured or pending. In-kind services listed must be specific to the project.*	$ -	*Indicate: Secured or Pending*
Funding History: *Indicate funding secured but to be expended prior to July 1, 2016, for activities directly relevant to this specific funding request, including past and current ENRTF funds. State specific source(s) of fund and dollar amount.*	$ -	
Remaining $ From Current ENRTF Appropriation: *Specify dollar amount and year of appropriation from any current ENRTF appropriation for any directly related project of the project manager or organization that remains unspent or not yet legally obligated at the time of proposal submission. Be as specific as possible. Indicate the status of the funds.*	$ -	*Indicate: Unspent? Legally Obligated*

GOAL 1: Expand renewable energy deployment in rivers	GOAL 2: mitigate side bank erosion

W^2 OPTIMAL DESIGN



★ Potential deployment location of single- or multi- unit systems



PROJECT MANAGER QUALIFICATIONS

Michele Guala, assistant professor St. Anthony Falls Laboratory (SAFL), Department of Civil Environmental and Geo- Engineering CEGE, University of Minnesota, Minneapolis, 55414, MN, USA

Education

Ph.D. Hydraulic Engineering, 2003, University of Padova, Italy

Laurea (BS+MS) Civil and Environmental Engineering, 1998, University of Genova, Italy

Professional experience

UMN , SAFL & Department of Civil, Environmental, and Geo- Engineering, assistant professor 2011-present
Caltech Postdoctoral GALCIT, Caltech, Pasadena , 2008-2010, SLF, Davos Research scientist 2007,
ETH Zurich, CH Postdoctoral fellow at the Institute of Hydromechanics 2003-2006

Awards/Recognitions

Recipient of the **NSF CAREER award** "Geophysical Flow Control" (2014-2019)

Recipient of the **IREE Early Career Award** (UMN) "*Evaluating wind farm performance under realistic thermal and complex terrain conditions: the first path towards optimization*

Publications

(Relevant to this LCCMR proposal; out of a total of 57 publications→1004 citations)

1) Hill C., Musa M. and Guala M. "Interaction between axial flow hydrokinetic turbines and uni-directional flow bedforms. " **Renewable Energy** 86, 409-421 (**2016**)

2) Howard K., Guala M. "Upwind preview to a horizontal axis wind turbine: a wind tunnel and field-scale study", **Wind Energy** (**2016**).

Chowdary S.† Hill C. † , Guala M. and Sotiropoulos F.* "Wake characteristics of a tri-frame of axial flow hydrokinetic turbines. " **Renewable Energy** (**2016** submitted).

3) Hill C, Kozarek J. Sotiropoulos F., Guala M. "Hydrodynamics and sediment transport in a meandering channel with a model axial flow hydrokinetic turbine" **Water Resources Research** (**2016**)

4) Hill C. , M Musa , LP Chamorro, C Ellis, M Guala , "Local Scour around a Model Hydrokinetic Turbine in an Erodible Channel**" Journal of Hydraulic Engineering**, 140(8) 04014036, **(2014**).

5) Guala M., Singh A., BadHeartBull N., Foufoula–Georgiou E.. Spectral description of migrating bed forms and sediment transport. **Journal of Geophysical Research: Earth Surface** 119 (2), 123-137 (**2014**)

6) Hong J., Toloui M., Chamorro L.P., Guala M., Howard K., Riley S., Tucker J., Sotiropoulos F. Natural snowfall reveals large-scale flow structures in the wake of a 2.5-MW wind turbine. **Nature communications** 5 (**2014**)

ORGANIZATION DESCRIPTION: St. Anthony Falls Laboratory, University of Minnesota

The proposed research will be performed at the St. Anthony Falls Laboratory, University of Minnesota. SAFL faculty, staff and researchers have an excellent scientific reputation and experience in conducting and analyzing laboratory and field measurements for renewable energy converter installations in wind tunnel and river flows, as well as deploying utility-scale device (EOLOS 2.5MW wind turbine). SAFL hosted the Workshop on "Research at the Interface of Marine Hydrokinetic Energy and the Environment" sponsored by NSF, Oct 5-7th 2011. The SAFL Main Channel s has been equipped with a laser scan device by Dr. Guala, allowing researchers to study the interaction of sediment bed with in-stream turbine models under controlled depth and discharge conditions. The PI has collaborated with Verdant Power and Sandia Nat Lab. on renewable energy devices.

TEAM DESCRIPTION

Michele Guala will supervise the turbine design, the performance quantification, and the sheltering effects on side bank erosion. He will be coordinating all the research activities, including documentation and reporting.

Lian Shen (professor in Mechanical Eng. UMN, and SAFL associate director) is an expert in computation fluid mechanics and fluid structure interaction with several ongoing projects on renewable energy and offshore wind turbine. He will supervise the computational work and design optimization.

Jeff Marr is the SAFL director of applied research. He has expertise in laboratory experiments and testing, river mechanics, sediment transport and field scale models. He will supervise prototype fabrication, field testing and deployment.