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

Project Title: **ENRTF ID:** **131-E**

Enabling Extraction of Solar Thermal Energy in Minnesota

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

Total Project Budget: $ 351,040

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

Summary:

This project will develop new Solar Particle Receivers, a low-cost, high-efficiency and clean technology to absorb, store, and utilize solar thermal energy, and show its viability at Minnesotas latitudes.

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Sponsoring Organization: U of MN

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Web Address

Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

We illustrate the central role of the solar receiver in renewable power plants, and show our design strategy that leverages unique facilities.

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

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

_____ Capacity Readiness _____ Leverage _______ TOTAL ______%

PROJECT TITLE: ENABLING EXTRACTION OF SOLAR THERMAL ENERGY IN MINNESOTA

I. PROJECT STATEMENT

The **objective** of this proposal is to develop a novel **Solar Particle Receiver** (**SPR**), a low-cost, high-efficiency technology to absorb, store, and utilize **solar thermal energy**.

Traditional concentrated solar thermal systems use mirrors to concentrate solar radiation on the surface of a pipe, which then transfers heat to a fluid running in it. For the hot fluid to be useful (for example to power a turbine generator), its temperature needs to be at least 500°C (almost 1000°F). At **Minnesota's latitudes** the sun radiation is not sufficiently strong to achieve this goal with the standard type of solar thermal systems. In fact almost all solar energy installations in the state are photovoltaic (PV), which convert radiation directly into electricity. However PV systems require sophisticated materials for energy conversion, leading to high upfront costs. Also, because electricity is difficult to store, **PV solar systems are only usable when the sun is shining**.

The SPR technology is a step change solar thermal energy. In these systems fine particles suspended within the fluid (typically a gas) **directly absorb the sunlight** and transfer the heat evenly throughout the fluid. This means higher energy absorption and heat transfer rates, higher efficiency of the system, and **much less sun radiation needed** to reach the required fluid temperatures. Importantly, the hot particles also serve as chemically benign, low-cost heat storage medium, which is crucial to **utilize the solar energy around the clock**: energy can be stored during daytime and used to extend power generation during cloud passages or at night.

The concept of SPR has been demonstrated in pilot sites, using curtains of free falling particles and slow gas-particle streams. For this technology to move **from the experimentation to the energy market**, the SPR performance needs to be tested in realistic situations where the fluid flow rate is higher. In this condition the gas motion becomes turbulent and the particles rapidly change their distribution, potentially altering the heat transfer rates. We propose to **design, build, test, and optimize an SPR prototype**, to demonstrate viability for the Minnesota energy needs. We will determine the optimal set of design parameters that **maximizes thermal efficiency in realistic regimes**. To this end, we will leverage the **existing facilities** available to our team, including: (i) a flow facility in which air flow laden with microscopic particles is metered and analyzed; (ii) a solar simulator facility that reproduces concentrated sun radiation in the laboratory; (iii) a performance prediction tool that uses the power of super-computing. Finally we will use our results to assess the **economical and environmental benefits** of implementing this novel and optimized SPR design in large-scale solar thermal fields.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: Build, design, and test a prototype of Solar Particle Receiver **Budget: $132,042**

In this activity we will leverage an existing laboratory apparatus that our team built to investigate the flow of gas-particle mixtures. This consists of a 2.5 meter tall duct in which air flows at up to 300 liters/min, carrying microscopic solid particles injected at precise concentrations. We will use silica carbide particles, a low-cost material that absorbs 80% of the incoming thermal radiation, and will irradiate them using our solar simulator: an array of 6.5 kW xenon lamps that produces a radiation flux up to 8.5 MW/m^2 (the most powerful in the country). We will vary the design parameters (air flow rate, particle size and concentration) and monitor the device performance in terms of thermal efficiency.

Outcome	Completion Date
1. Design and build a prototype of Solar Particle Receiver	June 2018
2. Measure thermal efficiency of the receiver in different air-particle mixture regimes.	January 2019

Activity 2: Optimize the performance of the Solar Particle Receiver **Budget: $120,956**

In this activity we will incorporate the findings of Activity #1 into an advanced predictive tool to calculate the SPR thermal efficiency. We will leverage a state-of-the-art framework that our team has developed and used extensively to simulate flows of fluid and particles in environmental and renewable energy settings. The extension of the framework to include thermal radiation will be straightforward, and the results will be validated against the laboratory experiments. We will then exploit the super-computer capabilities available at St. Anthony Falls Laboratory to evaluate the performance of numerous sets of design parameters, which would take an excessive amount of time to be tested experimentally. This will greatly speed up the design cycle.

Outcome	Completion Date
1. Extend the existing predictive tool to include thermal radiation	January 2018
2. Validate the model against laboratory results	January 2019
3. Vary systematically the simulation parameters until the optimal efficiency is obtained	December 2020

Activity 3: Validate the optimized design of Solar Particle Receiver and evaluate benefits **Budget: $112,042**
We will perform new tests on the SPR prototype: we will compare the data with the predicted performance, using the optimal set of parameters estimated in Activity #2, verifying the predicted improvement in thermal efficiency. Using information on solar irradiation, cost of fossil fuel and efficiencies of existing power plants, we will quantify the positive impact of the new SPR design in terms of energy saving and reduction of pollution.

Outcome	Completion Date
1. Carry out performance measurements at predicted optimal regimes	January 2020
2. Demonstrate competitive thermal performance at radiation levels typical of Minnesota	June 2020
3. Quantitatively assess environmental benefit of optimized solar receiver design	June 2020

III. PROJECT STRATEGY

A. Project Team/Partners

The team consists of Filippo Coletti (Assistant Professor of Aerospace Engineering & Mechanics and member of the St. Anthony Falls Laboratory) as the Project Manager, Jane Davidson (Professor of Mechanical Engineering, Chair in Renewable Energy and Director of the Solar Energy Laboratory), and Lian Shen (Associate Professor of Mechanical Engineering and St. Anthony Falls Laboratory Associate Director), all at the University of Minnesota.

B. Project Impact and Long-Term Strategy

Although solar energy production in Minnesota has been growing, a substantial leap forward is urgently needed to comply with the **2013 Solar Energy Jobs Act**, which requires investor-owned utilities in the state to produce 1.5% of their electricity from solar power by 2020. Current solar energy systems produce electricity at a cost **3 to 6 times higher** than fossil fuels. This project will help impose a **clean and low-cost** renewable energy technology, demonstrating that solar thermal energy extraction is economically viable at our latitudes.

According to the National Renewable Energy Laboratory, Minnesota's annual potential of concentrated solar thermal energy in Minnesota exceeds 16 megawatt hours per acre of land, so that **each acre of solar thermal field could offset 11 tons of annual CO_2 emissions**. This project will be critical to exploit this largely **untapped potential**, helping to reduce carbon emissions to prevent further **climate change**, facilitating local power generation critical in **rural areas**, and improving **energy affordability** for everyone. By making solar thermal energy possible in Minnesota, this technology will generate numerous **green job** opportunities.

This project will lay the groundwork for collaborations with companies members of the Minnesota Solar Energy Industries Association (**MnSEIA**), several of which have already partnered with St. Anthony Falls Lab, for the technology commercialization and the installation of **the first solar thermal field** in the state. The design and test results will be made available to the public via a **web portal**, where the public can contribute ideas for further improvements. In the long term we aim at creating an **open-source solar thermal project** that can leverage the creativity of the people in Minnesota and beyond, and inspire future **renewable energy start-ups**.

C. Timeline Requirements

This project is planned for 3 years beginning on July 1 2017 and ending on June 30 2020.

2017 Detailed Project Budget

Project Title: Enabling extraction of solar thermal energy in Minnesota

IV. TOTAL ENRTF REQUEST BUDGET: 3 years

BUDGET ITEM	AMOUNT
Personnel:	$ 351,040
Graduate Research Assistant (Activity #1 and #3, Aerospace Engineering & Mechanics Dept.) 50% FTE & 17.6% fringe plus tuition for 3 years ($141,086)	
Graduate Research Assistant (Activity #2 and #3, Mechanical Engineering Dept.) 50% FTE & 17.6% fringe plus tuition for 3 years ($141,086)	
Research Associate (Activity #1 and #3, Mechanicale Engineering Dept.) 33% FTE & 22.4% fringe for 3 years ($68,868)	
Equipment/Tools/Supplies:	$ 14,000
Quartz windows for solar simulator experiment ($9,000)	
Calorimeter fabrication for solar receiver prototype ($5,000)	
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST	$ 365,040

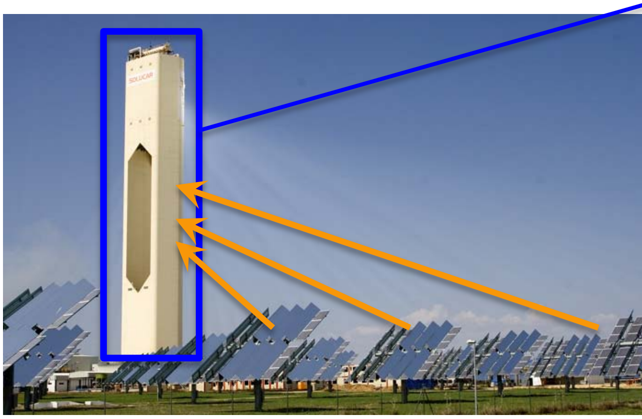
V. OTHER FUNDS

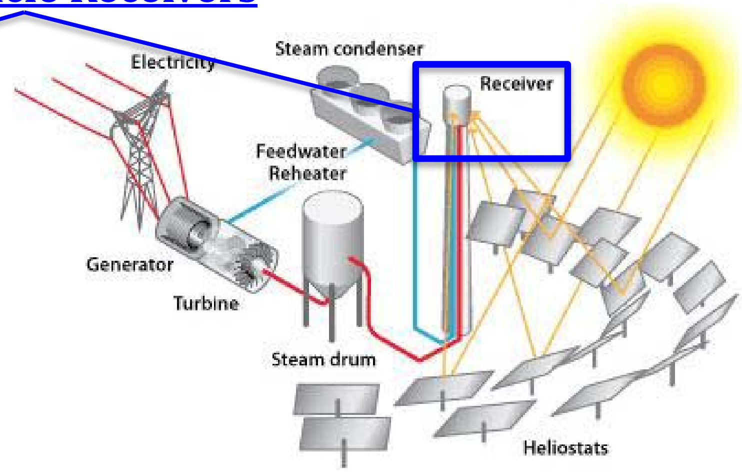
SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period:	N/A	
Other State $ To Be Applied To Project During Project Period:	N/A	
In-kind Services To Be Applied To Project During Project Period: The University of Minnesota does not charge the State of Minnesota its typical overhead rate of 52% of the total modified direct costs (graduate tuition and academic fringe are excluded). Professor Filippo Coletti, Lian Shen, and Jane Davidson will provide time and effort as in-kind service.	$ 126,557	*Secured*
Funding History:	N/A	
Remaining $ From Current ENRTF Appropriation:	N/A	

Filippo Coletti, Jane Davidson & Lian Shen, University of Minnesota

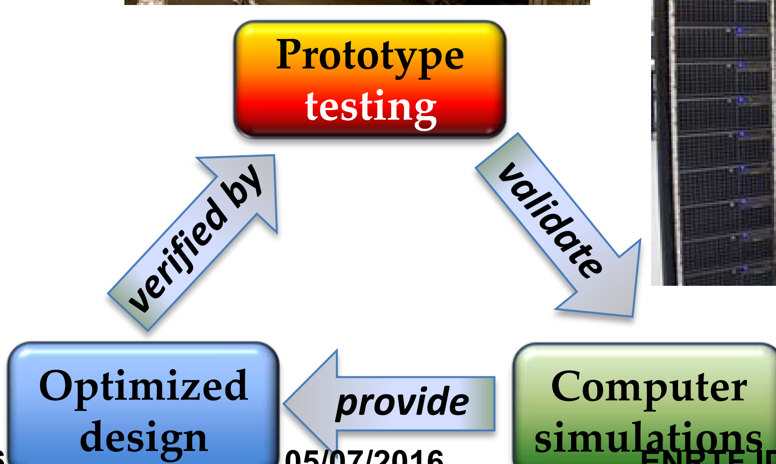
Enabling extraction of solar thermal energy in Minnesota

Solar Thermal Energy can be extracted efficiently using Solar Particle Receivers





OBJECTIVE: build and optimize a new **Solar Particle Receiver**
STRATEGY: couple **laboratory** and **computer** simulation
GOAL: enable **solar thermal power** in Minnesota



PROJECT MANAGER QUALIFICATIONS

Filippo Coletti is Assistant Professor of Aerospace Engineering and Mechanics at the University of Minnesota. Coletti obtained his bachelor's and master's degrees in Mechanical Engineering at the University of Perugia (Italy) in 2005, and a research master in Fluid Dynamics at the von Karman Institute (Belgium) in 2006. He performed his doctoral studies at the von Karman Institute and at the University of Stuttgart (Germany), where he obtained his Ph.D. in Aerospace Engineering in 2010. From 2011 to 2013 he was postdoctoral fellow at Stanford University in the Center for Turbulence Research. At Stanford he was in charge of the design of a prototype of solid particle receiver (SPR), and collaborated to a proposal to characterize SPR performance which was awarded a $16 million grant by the US Dept. of Energy. Coletti joined the U of M in 2014 and shortly after became member of the St. Anthony Falls Laboratory (SAFL). He conducts research in experimental fluid mechanics and heat transfer, focusing on the transport of solid particles in turbulent air which he studies with advanced imaging and thermal measurement techniques. His research is funded by federal agencies including the National Science Foundation (NSF) and the National Institute of Health (NIH), as well as by major companies including 3M and Boston Scientific. Coletti has published 50 refereed journal articles and conference papers on heat transfer, and experimental fluid mechanics. A list of his recent honors include the CAREER Award from the National Science Foundation (2015-2019), the Non-Tenured Faculty Award from The 3M Company (2015-2017).

Jane Davidson is Professor of Mechanical Engineering, Ronald L. and Janet A. Christenson Chair in Renewable Energy, and Director of the Solar Energy Laboratory at the University of Minnesota. Davidson is a national and international leader in the field of solar energy harvesting and storage. She is the Editor of the ASME (American Society of Mechanical Engineer) Journal of Solar Energy Engineering, Chair of the ASME Solar Energy Division, and on the Boards of the American Solar Energy Society (ASES) and the Solar Rating and Certification Corporation. She has received the American Solar Energy Society Charles Greeley Abbot Award, the ASME John I. Yellott and Frank Kreith Energy Awards, and the University of Minnesota Distinguished Women Scholar Award in Science and Engineering. She is a Fellow of the American Society of Mechanical Engineers and of the American Solar Energy Society.

Lian Shen is Associate Director for Research of St. Anthony Falls Laboratory (SAFL) and the Benjamin Mayhugh Associate Professor of Mechanical Engineering at the University of Minnesota. Shen leads SAFL's computational fluid dynamics (CFD) group, which has developed high-fidelity simulation algorithms for turbulent transport, particle transport, and propagation of radiation in renewable energy settings. He earned his bachelor's degree in mechanics from University of Science and Technology of China in 1993 and his doctoral degree in fluid mechanics from Massachusetts Institute of Technology in 2001. Prior to coming to the University of Minnesota, he was at the faculty in Department of Civil Engineering at the Johns Hopkins University (2004-2012). Being a world-expert on CFD, Shen has been active in professional societies, including American Society of Mechanical Engineers, and he is on the editorial board of the International Journal of Computational Methods.

ORGANIZATION DESCRIPTION

The proposed research will be using facilities and equipment available through the Departments of Aerospace Engineering & Mechanics (AEM) and Mechanical Engineering (ME) at the University of Minnesota. These include high-resolution cameras for advanced imaging, as well as temperature sensors for heat transfer measurements, as well as a world unique solar simulator capable of radiation fluxes comparable to concentrated solar power plants. The College of Science and Engineering of the University of Minnesota provides a wide array of machine shop services for research, including fabrication, machining, welding, on-site inspection, and consulting, which will be essential for designing and building the solar receiver prototype. For the performance optimization, top-notch computer capabilities available at the St. Anthony Falls Laboratory will be used.