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

Project Title: ENRTF ID: 142-E

Making Solar Energy Cheaper than Carbon-Based Energy

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

Total Project Budget: $ 664,180

Proposed Project Time Period for the Funding Requested: 3 years, July 2016 to June 2019

Summary:

We will demonstrate inexpensive thin-film devices that can bring the cost of solar energy in Minnesota below carbon. The device operates by capturing different parts of sunlight in different layers.

Name: Stephen Campbell

Sponsoring Organization: U of MN

Address: 200 Union Street
Minneapolis MN 55455

Telephone Number: (612) 625-6608

Email campb001@umn.edu

Web Address

Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

Current solar cell approaches will never be cost-competitive with carbon-generated power in Minnesota. The proposed devices will overcome this obstacle.

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

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

_____ Capacity Readiness _____ Leverage _______ TOTAL ______%

PROJECT TITLE: Making Solar Energy Cheaper Than Carbon-Based Energy

I. PROJECT STATEMENT

This project will demonstrate very high-efficiency, inexpensive thin-film solar devices. We focus on this goal because the cost of solar energy is the primary obstacle to expanding its use. However, it is not enough to just make the cells cheaply, the installation cost alone can price solar out of many markets. This is particularly true in Minnesota where conventional power is relatively inexpensive and the solar irradiance is not as high as in the desert southwest. To be cost competitive, solar cells must be both cheap and highly efficient. Since fewer high-efficiency cells are needed to get the desired amount of energy, the *installed* cost of solar drops as efficiency rises. When that happens, solar usage rises sharply and pollution falls. However, the power conversion efficiency of regular solar cells is nearing its limit. Manufacturing improvements have led to more efficient cells, but commercial cells are rapidly approaching the performance of world-record devices. The world record for the market-leading material (silicon) has not changed much in 20+ years and so represents a practical limit for solar.

For the past four years the proposer has been partially supported by the Department of Energy to develop the materials needed for a new type of solar cell. The basic idea is to use different layers of the device to convert the energy from low-energy (red) sunlight and from the high energy (blue) sunlight. This is called a multi-junction cell. It is similar to having a transmission in a car, switching gears to obtain the best efficiency of the engine for a given speed. Current generation solar cells only have a single gear and so more than 80% of the energy in sunlight is lost. The planned device uses mostly industry-standard materials and processes, but is capable of much higher efficiency. The work done to date has been extremely successful. Not only have we developed the new materials that are needed, we also found out how to put them together and have demonstrated pieces of the multijunction cell. Furthermore, the underlying idea is well-proven as it has been used for years in very expensive satellite-based solar cells. We discovered of how such devices could be built using far less expensive materials and processes, making their cost similar to those of conventional solar cells. Efficiency is particularly critical in Minnesota where the solar irradiance is about 30% less than Arizona.

We plan to assemble these materials and processes and actually demonstrate the high efficiency multi-junction solar cells. Steve Campbell will direct the work. Steve is a native Minnesotan and a chaired professor in the University's Electrical and Computer Engineering Department. Two graduate students will also be involved. One will deposit the materials and make the devices. The multi-junction device requires one last material that we have not deposited already: zinc sulfide. However, this is a simple material to work with. We are asking for funds to modify our thin-film deposition system to accommodate this new material. The second graduate student will expose the devices to light and measure the electrical response. By varying the color of the light, the intensity, and the temperature of the solar cell, we can get the information needed to optimize the device. To get the best performance, we also have to balance the output of the different layers of the cell. To guide the experiments we will model the device, using the model to determine what parameters to change.

Ultimately, we plan to commercialize this technology. The Minnesota Solar Energy Industries Association (MnSEIA) projects that Minnesota's solar industry will expand from about $150 million of current solar investment to $1 billion by 2020. Minnesota is home to Silicon Solar and tenKsolar, companies that assemble solar modules using Chinese solar cells. Globally, solar cell production is growing at 40% per year, but there is no production in Minnesota despite the fact that the technology underlying solar cell fabrication is used widely here. Companies such as 3M, Cypress, Goodrich, Honeywell, Imation, Seagate, and Sage provide a large pool of people with suitable skills. Sage is a good example of a market-leading company in outstate Minnesota that produces world-class products that are highly relevant to solar cells. We will develop a new company or work with existing manufacturers to ensure production of the multi-junction device.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: *Prototyping multi-junction thin-film devices* **Budget: $199,189**

The PI, working with world-class experts at the Department of Energy, the National Renewable Energy Lab, and multiple universities, has developed new and highly effective processes for making the materials needed for the breakthrough multi-junction thin-film solar cell. We have built a materials deposition system to make the most difficult side of the solar cell. The early device results are very positive. We will add a few minor components to make the much simpler side of the device which is made using zinc sulfide. We will then build the devices for the red sunlight and blue sunlight separately. The former is already done. The latter needs the zinc sulfide layer. During the third year we will put the two device stacks together to demonstrate high performance multi-junction thin film solar cells.

Outcome	Completion Date
1. *Demonstrate an in-situ zinc sulfide deposition capability on the existing reactor*	*3/30/17*
2. *Demonstrate high efficiency wide bandgap (blue sunlight) devices*	*6/30/18*
3. *Demonstrate a high efficiency multi-junction device*	*6/30/19*

Activity 2: *Model and characterize multi-junction thin-film devices* **Budget: $140,717**

Building a complex device such as this must be done in steps. In this activity the requestor will work with a graduate student to characterize the materials and the devices made is activity one. This information is fed into a device model to speed the development process. Ultimately this activity will demonstrate the complete device.

Outcome	Completion Date
1. *Determine the behavior of wide bandgap (blue sunlight) devices with zinc sulfide*	*9/30/17*
2. *Develop a model of these wide bandgap (blue sunlight) devices*	*6/30/18*
3. *Model the full multi-junction structure and compare with experiment*	*6/30/19*

III. PROJECT STRATEGY

A. Project Team/Partners

The work will be directed by Stephen Campbell at the University of Minnesota. A Minnesota native, Steve is a Professor in Electrical and Computer Engineering where he holds the Bordeau Chair. He also directs the Minnesota Nano Center where he has a long history of working with local and national companies on high technology problems. He is the author of more than 250 publications and a widely used textbook. Most recently he has worked on solar energy with Dow, the Department of Energy (DOE), and the National Renewable Energy Lab (NREL). Almost all of the infrastructure needed to make and characterize the proposed multi-junction devices already exists in his labs at the University.

B. Project Impact and Long-Term Strategy

The thin-film multi-junction device demonstration will certainly be adopted by industry. Steve will work with the University's Office of Technology Commercialization to protect the intellectual property that is developed. The ENRTF will receive a pro-rata share of the proceeds. We also plan to publicize the results at conferences and archival journal publications. This will lead to additional proposals to the Department of Energy, the National Science Foundation, and other federal agencies where the PI has a strong track record.

C. Timeline Requirements

The described technical work will require three years to complete. Interim milestones are provided in a prior section. Basically, we will build and optimize the device designed to convert blue light efficiently. We will characterize and model that device, and we will integrate it into the multi-junction device. Once we start making that device we will characterize and model it, using that information to optimize the full multi-junction device.

2016 Detailed Project Budget

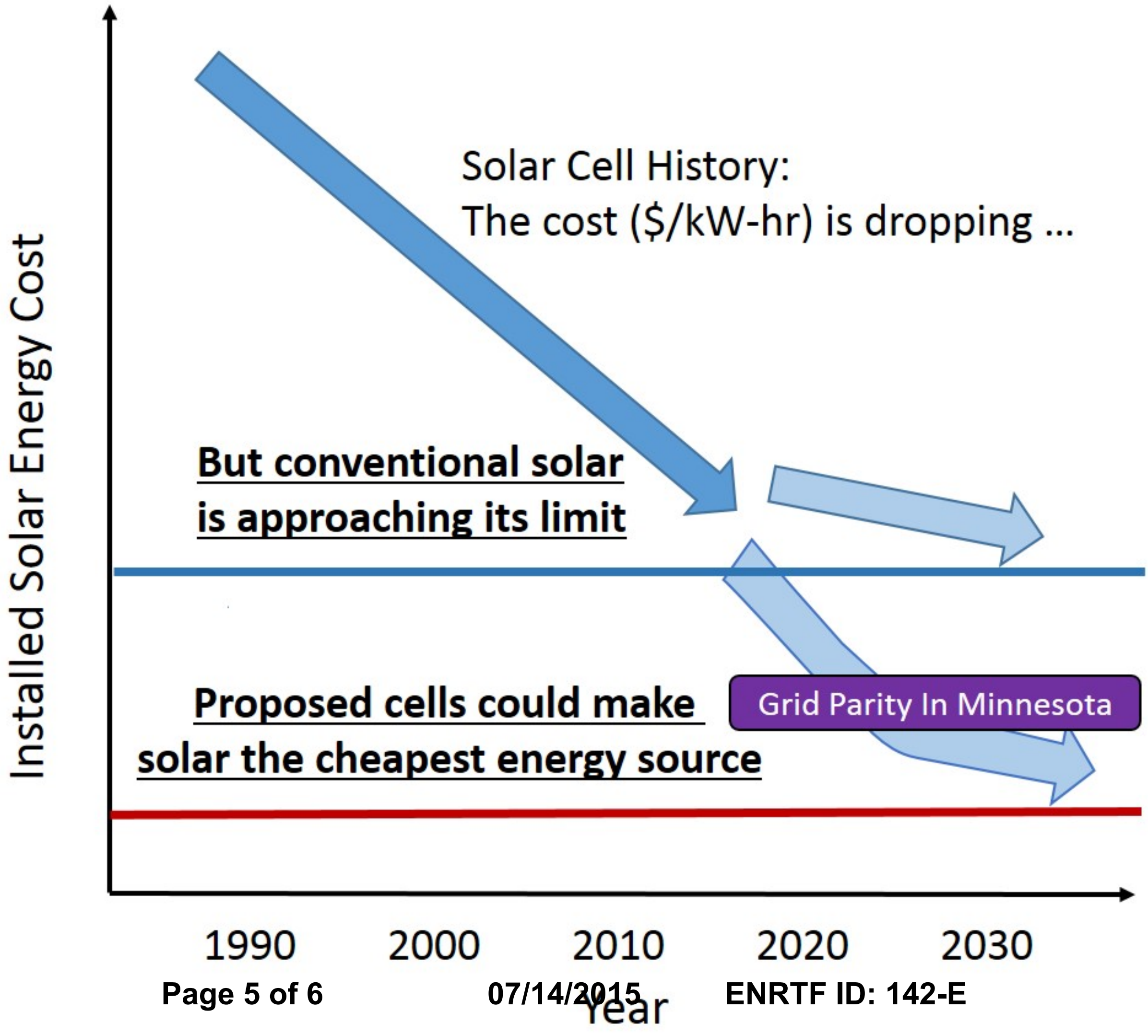
Project Title: ***Making Solar Energy Cheaper Than Carbon-Based Energy***

IV. TOTAL ENRTF REQUEST BUDGET Three Years

BUDGET ITEM	AMOUNT
Personnel:	
Stephen Campbell will act as the project manager and will lead the development of the advanced solar device. The requested salary represents two weeks of his summer salary (75% salary, 25% benefits) for three years. One week will be devoted to each of the two tasks. The remainder of his effort will be covered by his nine-month University salary.	$ 40,711
Two Research Associates: The first will fabricate the proposed high efficiency thin-film solar device. The second will model and charcterize the devices made by the first. Two 50% appointments. Salary: 60%, Fringe and Tuition: 40%	$ 276,469
Equipment/Tools/Supplies:	
The equipment needed to make the desired device is nearly complete after an investment of approximately $400,000. Here we request $60,000 to buy the components to allow the deposition of zinc suflide, the final layer needed for making full multi-junction devices.	$ 60,000
Materials and supplies: We estimate $12000 per year. This will be used to buy substrates ($2000/year), chemicals ($2500/year), materials ($1500 per year), electronic test components (($1000 per year), and provide for upkeep on the thin film deposition system ($5000).	$ 36,000
Additional Budget Items:	
Lab access fees - In order to build the proposed devices the graduate students must use the equipment in the University's Nano Center. To characterize the materials, the graduate students must use the equipment in the University's Characterization Facility. Both charge projects on a "per-minute" basis to be able to recover the costs needed to maintain these systems. The amount requested, $10,000 per year, is typical for a project of this type.	$ 30,000
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 443,180

V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period: *Professor Campbell holds the Bordeau Chair of Electrical and Computer Engineering. For this he receives a stipend of $30,000 per year to spend on research. He will use these funds to support an additional student working on this project.*	$ 90,000	*Secured*
Other State $ To Be Applied To Project During Project Period:	$ -	
In-kind Services To Be Applied To Project During Project Period: *Professor Campbell will spend about 8 weeks of his time during the school year managing the project. This time will be covered by his University salary.*	$ 162,844	*Secured*
Funding History: Department of Energy Award DE-EE0005319 (New Materials for Implementing Tandem CIGS): from 10/11 to 10/15 to develop the materials needed to make the multi-junction thin film device.	$ 1,500,000	*Completed*


Solar Cell History:
The cost ($/kW-hr) is dropping ...
But conventional solar
is approaching its limit
Proposed cells could make
solar the cheapest energy source
Grid Parity In Minnesota
Installed Solar Energy Cost
1990
2000
2010
2020
2030
Year

Stephen A. Campbell was born in St. Paul. He holds a BA from St. Thomas and a PhD from Northwestern University, both in physics. After a brief stint at Unisys he joined the University of Minnesota. He is a fellow of the Institute of Electrical and Electronics Engineers (IEEE), holds the Sanford P. and Lenore Edgerton Bordeau Chair in Electrical and Computer Engineering and is a Distinguished Professor in the University's College of Science and Engineering. He also directs the Minnesota Nano Center. He has written about 240 refereed publications and a widely used text on micro fabrication. His current research areas include thin film solar cells, BioMEMS, and 2D materials.

The Electrical and Computer Engineering (ECE) Department, founded in 1891, is one of the leading international programs in electrical and computer engineering education and research. Attracting nearly $20M in research annually, it consistently ranked among the top 20 programs in the United States. ECE faculty and students serve as key sources of scientific and engineering talent, expertise, and innovative ideas for communication, software, electronics, controls, defense, and biotechnology companies worldwide. ECE graduates dominate the more than 4,000 College of Science and Engineering alumni-founded companies that are active today. These companies employ more than half a million people worldwide and generate $90 billion in annual revenue.