Environment and Natural Resources Trust Fund

2022 Request for Proposal

General Information

Proposal ID: 2022-239

Proposal Title: Transparent Solar Panes for Agrivoltaics

Project Manager Information

Name: Vivian Ferry

Organization: U of MN - College of Science and Engineering

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Project Basic Information

Project Summary: This project will create solar panes for greenhouses that simultaneously generate electricity from sunlight and promote plant growth.

Funds Requested: $404,000

Proposed Project Completion: June 30 2024

LCCMR Funding Category: Air Quality, Climate Change, and Renewable Energy (E)

Project Location

What is the best scale for describing where your work will take place?

Region(s): Metro

What is the best scale to describe the area impacted by your work?

Statewide

When will the work impact occur?

During the Project

Narrative

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

Agrivoltaic systems are installations that co-use agricultural land for crop growth and electricity generation. Research has shown that, on a per area basis, this increases the overall efficiency of land use compared to separate installations on dedicated land. However, careful design is required to maximize the use of sunlight for both applications simultaneously.

Common approaches rely on installing traditional solar cell arrays along field boundaries or over land that does not require a full day's worth of solar radiation for crops which grow well in partial shade or to shelter farm animals on pastures. The solar arrays can also have a positive impact on the fields' micro-climate, including improving water retention in soil.

However, these approaches do not use sunlight simultaneously for both applications. The solar panel is either used to generate electricity, or to provide shade, limiting both the locations for installation and the types of crops that may be grown. Moreover, traditional solar arrays are still expensive and do not visually integrate well with landscapes. Inexpensive structures are needed that simultaneously transmit sunlight for crop growth and produce electricity on-site, blend into the rural environment, and can be installed on a variety of types of land.

What is your proposed solution to the problem or opportunity discussed above? i.e. What are you seeking funding to do? You will be asked to expand on this in Activities and Milestones.

We propose semitransparent solar panes that collect some colors of sunlight for electricity generation, but transmit others for agricultural use, allowing for true simultaneous land utilization. Photovoltaic panels do not convert all colors of sunlight to electricity at the same efficiency. Similarly, crop germination and growth can be enhanced by illumination with specific colors. Greenhouse glazing is commonly used to tailor lighting and thermal conditions.

Our solar pane consists of a transparent, plastic sheet with nanoscale "quantum dots" embedded in the plastic, and photovoltaic devices placed at the edges. These quantum dots absorb specific colors of sunlight, transform it into colors that are efficiently converted to electricity by a photovoltaic device, and concentrate this more ideal spectrum onto the edge-mounted solar cells. This reduces the cost of electricity generation by using only a small area solar cell and eliminating the need for an expensive tracking system.

The spectrum of the incident sunlight is also tailored for crop growth as it transmits through the solar pane. Energetic blue light, which can lead to cell damage and inhibits cell elongation, is absorbed by the solar pane. Red light, which is required for germination and plant growth of some species, is transmitted.

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state's natural resources?

This project will develop solar panes that simultaneously generate clean, renewable solar electricity and promote the growth of agricultural crops. This renewable energy technology will lead to a reduction of greenhouse gas emissions, while simultaneously allowing farmers in the State of Minnesota to diversify their land use by simultaneously growing crops that thrive under red light and producing renewable electricity. This project may also lead to reduced water demands for agriculture.

Activities and Milestones

Activity 1: Testing crop growth under transparent solar panes

Activity Budget: $202,000

Activity Description:
The solar panes contain nanometer-sized inorganic crystals called “quantum dots” that absorb sunlight and reemit it at a different color. This reemitted light is concentrated onto a small solar cell mounted at the edge of the device. Simultaneously, sunlight is transmitted through the solar pane. The efficiency of the solar cell and the radiation that reaches the crops depend on factors such as the type and quantity of quantum dots and window design. Our team will evaluate solar panes in greenhouses with silicon and copper indium sulfide quantum dots using experiments and computational models. We will create research-scale devices, test the light transmission and other optical properties, design nanostructures that direct specific colors toward the solar cell or crops, and develop models that predict the thermal impact of these solar panes on both the land underneath and the solar cell performance. Important agricultural crops, including lettuce, basil, and other bedding and potted plants will be tested with research scale devices by comparing to conventional double strength float glass. For each crop species, % seed germination, cell structure, including chloroplast number and configuration, cell size, internode length, and plant fresh/dry weights will be measured to evaluate plant growth, development, and yield.

Activity Milestones:

Description	Completion Date
Development of a testing protocol including controls (conventional glass panels)	October 31 2022
Selection and assessment of plant species for testing including important crop species for Minnesota agriculture	October 31 2022
Fabrication of small enclosures with a solar panes for plant growth	October 31 2022
Evaluation of seed germination and plant growth parameters under solar panes with different transmission characteristics	June 30 2023

Activity 2: Testing scaled up solar panes

Activity Budget: $202,000

Activity Description:
As with many devices or processes, problems are encountered in scale up that are not apparent in small laboratory scale devices. In solar panes, these can be related to coating non-uniformities, agglomeration of quantum dots, etc. Building on the results of activity 1, scaled-up devices as large as 25cm x 50cm will be fabricated on a variety of substrates, including rigid substrates such as glass, Exolite, and polycarbonate, and flexible plastic sheets. The first approach will utilize a batch coating apparatus onto glass panes and the second, which may be more versatile, will involve roll-to-roll deposition onto a plastic film. The coated plastic film could then be integrated onto an existing structure. For both options, a dispersion of quantum dots in a polymer solution will be prepared and deposited onto a substrate. These scaled-up devices can be used for major crops. For these larger scale devices, conditions will be determined that optimize both plant growth and photovoltaic electricity generation. Optimal plant growth for each crop will be determined, based on growth parameters such as the number of leaves, plant height, plant width, leaf length/width, number of leaves to flowering, visible bud date, and anthesis.

Activity Milestones:

Description	Completion Date
Optimize quantum dot/polymer solutions for large scale coating processing	August 31 2023
Testing of coating methods for uniform deposition and curing over large areas	September 30 2023

Optimization of the coating process for rigid glass and plastic sheets	October 31 2023
Testing and comparison of plant growth using scaled-up solar panes	December 31 2023
Optimization of plant growth and photovoltaic electricity generation	June 30 2024

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Uwe Kortshagen	University of Minnesota	Uwe Kortshagen is Professor of Mechanical Engineering at the University of Minnesota, and holds the Ronald L. and Janet A. Christenson Chair in Renewable Energy. Professor Kortshagen is an expert in the synthesis of silicon quantum dots with nonthermal plasmas. His group wil synthesize quantum dots and fabricated solar panes.	Yes
Lorraine Francis	University of Minnesota	Lorraine Francis is Professor of Chemical Engineering and Materials Science at the University of Minnesota. Professor Francis' research interests include coating processing, microstructure and stress development in coatings, and development of processes and materials for printed electronics. She will develop large scale coating processes for the solar panes.	Yes
Neil Anderson	University of Minnesota	Neil Anderson is a Professor of Flower Breeding/Genetics in the Department of Horticultural Science. He is a recognized expert in greenhouses and sustainable greenhouse production systems. His role in the project will be plant production using the solar panes to determine whether plant growth is optimized.	Yes

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this be funded?

The panes will be tested in greenhouses for their effects on plant growth. At the conclusion of the project, the investigators will seek industrial partners who are interested in commercializing these coatings for greenhouse applications, as either replacements for glass/plastic panes or as retrofit coatings. The investigators will also apply to other federal funding agencies such as the Department of Energy at the completion of this project for additional research support.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Develop Solar Window Concentrators for Electricity	M.L. 2018, Chp. 214, Art. 4, Sec. 2, Subd. 07a	$350,000

Project Manager and Organization Qualifications

Project Manager Name: Vivian Ferry

Job Title: Associate Professor

Provide description of the project manager's qualifications to manage the proposed project.

Vivian Ferry is an Associate Professor of Chemical Engineering & Materials Science at the University of Minnesota. She has published more than 50 research papers and given over 70 invited talks. Professor Ferry has directed research on over $2M worth of funding, and has received numerous awards recognizing her contributions to renewable energy, including the National Science Foundation CAREER award, the American Physical Society Ovshinsky Sustainable Energy Fellowship, and the SPIE Early Career Achievement Award. In 2016 she was named one of Technology Review's 35 Innovators under 35 for her work on photovoltaics. She leads a research group with expertise in the optical properties of nanoscale materials, and performs both experimental and computational research.

Organization: U of MN - College of Science and Engineering

Organization Description:

The University of Minnesota offers world-class infrastructure for this project. The luminescent silicon crystal synthesis will be performed in Kortshagen's laboratory. This lab is one of the best equipped plasma technology laboratories in the world. Solar pane device fabrication will be performed in Professor Ferry's laboratory. Professor Ferry's laboratory also has numerous unique modeling techniques to predict the performance of the solar panes in outdoor installations, and access to the Minnesota Supercomputing Institute, the University of Minnesota's principle center for computational research. The Coating Process and Visualization (CPV) Lab is a unique academic facility with equipment for coating and printing, visualization and characterization. The CPV Lab is the primary lab of the Coating Process Fundamentals Program, a research program of the Industrial Partnership for Research in Interfacial and Materials Engineering (IPRIME). The Plant Growth Facilities has state-of-the-art, computer-controlled greenhouses for testing the material types generated in this grant.

In addition, the team has access to a large number of shared materials characterization instruments at the University of Minnesota Materials Characterization Facility ("CharFac," http://www.charfac.umn.edu/), including a small angle X-ray scattering facility, and an electron microscopy center. Several machine shops are also available at

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Project Manager - Faculty Director		Direct research progress and project reporting. (approved fringe rate 36.5% rate)			26.7%	0.04		$7,830
3 Faculty Investigators		Direct research efforts. (approved fringe rate 36.5% rate)			26.7%	0.12		$36,929
3 Research Assistants		Perform research on solar pane fabrication and characterization and plant growth experiments. (approved fringe rate: 19.90% for health insurance and 21.06/hour for tuition. Students will not take summer classes.)			42.1%	6		$318,531
							Sub Total	**$363,290**
Contracts and Services								
							Sub Total	**-**
Equipment, Tools, and Supplies								
	Tools and Supplies	Materials and supplies	Materials for solar pane manufacturing, plant growth experiments, including, chemicals, gases, coating supplies, seeds, light sources					$20,710
	Tools and Supplies	Characterization facility	Fees to characterize materials such as user fees for electron microscopes, etc.					$20,000
							Sub Total	**$40,710**
Capital Expenditures								
							Sub Total	**-**

Acquisitions and Stewardship								
							Sub Total	**-**
Travel In Minnesota								
							Sub Total	**-**
Travel Outside Minnesota								
							Sub Total	**-**
Printing and Publication								
							Sub Total	**-**
Other Expenses								
							Sub Total	**-**
							Grand Total	**$404,000**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request

Non ENRTF Funds

Category	Specific Source	Use	Status	Amount
State				
			State Sub Total	**-**
Non-State				
			Non State Sub Total	**-**
			Funds Total	**-**

Attachments

Required Attachments

Visual Component

File: 87623ce1-17d.pdf

Alternate Text for Visual Component

The attached figure shows the general concept, where transparent panes containing quantum dots are embedded in a greenhouse. Incident sunlight is both captured and converted to electricity and transmitted to promote plant growth....

Optional Attachments

Support Letter or Other

Title	File
SPA	40848429-efb.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Does your project have potential for royalties, copyrights, patents, or sale of products and assets?

Yes

Do you understand and acknowledge IP and revenue-return and sharing requirements in 116P.10?

Yes

Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF?

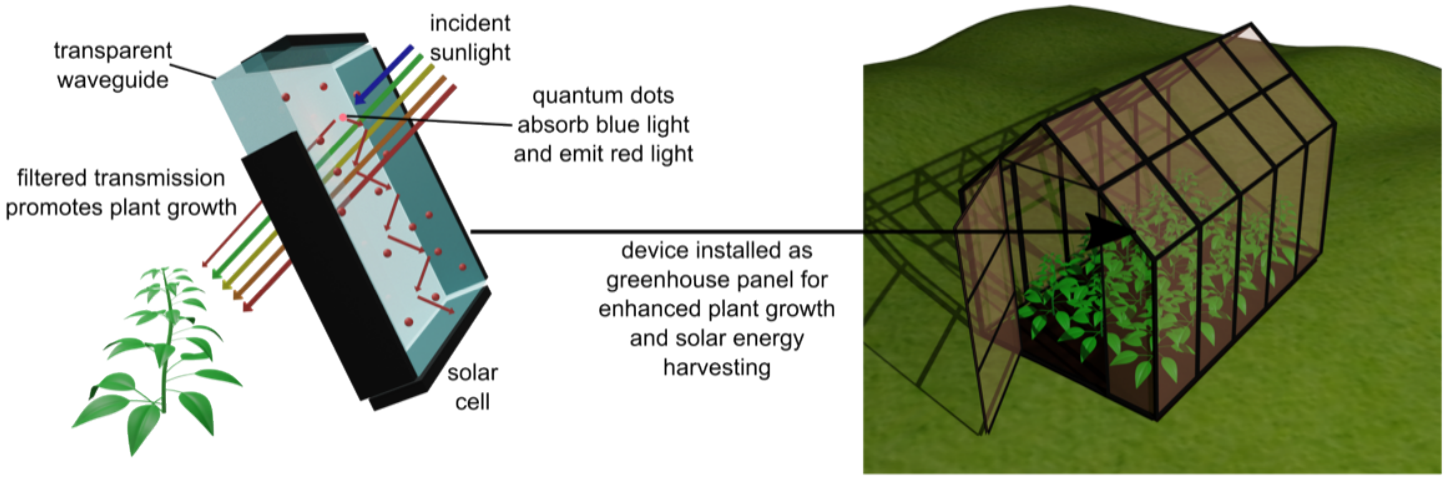
No

Does your project include original, hypothesis-driven research?

Yes

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration


transparent waveguide
incident sunlight
quantum dots absorb blue light and emit red light
filtered transmission promotes plant growth
solar cell
device installed as greenhouse panel for enhanced plant growth and solar energy harvesting