Environment and Natural Resources Trust Fund

2021 Request for Proposal

General Information

Proposal ID: 2021-167

Proposal Title: Solar Windows: Combining Agriculture and Photovoltaics

Project Manager Information

Name: Uwe Kortshagen

Organization: U of MN - College of Science and Engineering

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Project Basic Information

Project Summary: Semitransparent “solar windows” absorb some solar light to create clean electricity while letting pass light for agricultural crop growth. This project will optimize both functions of solar windows.

Funds Requested: $280,000

Proposed Project Completion: 2023-06-30

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.

Agrivoltaics is a relatively recent trend of combining agriculture with photovoltaics. Research has shown that, on a per area basis, the combined use of agricultural land for crop growth and photovoltaics can increase the overall efficiency of land use compared to dedicating land separately for these purposes. 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 instance, for crops which grow well in partial shade or for providing shelter for 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, the use of traditional solar panels in agrivoltaics is akin to a binary "on-off" approach. Solar panels will either provide sun exposure during part of the day, or shade at other times, but nothing in between. This approach may work for some crops, but not for others. Moreover, traditional solar arrays are still expensive and, as some may argue, do not visually integrate well with landscapes.

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.

The idea is to create semitransparent solar windows that optimally utilize sunlight to both generate photovoltaic electricity and grow crops underneath them. Solar windows absorb the blue and green components of sunlight to create photovoltaic electricity, but let yellow and red light pass for crops to grow. Nanometer-sized "quantum dots" in the solar window turn the absorbed light into guided light, similar to a fiber optic cable, and concentrate it onto very small solar cells at the device edges to reduce cost.

Being largely transparent, solar windows are visually pleasing and may be ideally matched to agricultural crop growth. Plants utilize blue and red light for photosynthesis, while green light is unused and reflected. Energetic blue light, which can lead to cell damage and inhibits cell elongation, is absorbed by solar windows. Red light, which is required for germination and plant growth, passes through solar windows. Especially the broad-leaf crops perform well under the red light. This project will study how the light absorption by solar windows affects the growth of common agricultural crops and how the optical properties of solar windows can be tailored to optimize both the production of solar electricity and of crop growth.

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 windows that will combine the generation of clean, renewable solar electricity with 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 through the simultaneous growing of crops that thrive under red light and production of renewable electricity.

Activities and Milestones

Activity 1: Testing crop growth under solar windows

Activity Budget: $140,000

Activity Description:
Essential elements embedded in solar windows are light absorbing “quantum dots”, nanometer-sized inorganic crystals. These quantum dots absorb part of the solar light and reemit it at a different color such that the reemitted light can be guided in a fashion similar to an optical fiber to the small solar cells at the device edges. Our team will evaluate quantum dots of copper indium sulfide, which strongly absorb blue light, and silicon, which also utilize green light. The optical light absorption and photovoltaic performance of solar windows with different amounts of silicon and copper indium sulfide will be explored in experiments and designed using models. Important agricultural crops, including soy beans, potatoes, tomatoes, and alfalfa will be tested with research scale devices by comparing to the conventional glasses as a reference. We will select the dwarf/miniature cultivars for testing under the research scale devices. For each crop species, cell structure, including chloroplast number and structure, cell size, and plant dry weight will be measured to evaluate plant health, development, and yield.

Activity Milestones:

Description	Completion Date
Development of a testing protocol including controls (conventional glass panels)	2021-10-31
Selection and assessment of plant species for testing including important crop species for Minnesota agriculture	2021-10-31
Fabrication of small enclosures with a solar window for plant growth	2021-10-31
Evaluation of plant germination and growth under solar windows with different transmission characteristics	2022-06-30

Activity 2: Testing scaled up solar windows

Activity Budget: $140,000

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 windows, 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. Two approaches will be pursued: (i) direct application on glass and (ii) coating onto flexible plastic sheets. The first approach will utilize a batch coating apparatus onto glass sheets and the second, which may be more versatile, will involve roll-to-roll deposition of onto a plastic film. Then the coated plastic film could 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. With the scaled-up devices, we will test major crops including maize, soybeans, potatoes, tomatoes, and alfalfa. For these larger scale devices, conditions will be determined that optimize both plant growth and photovoltaic electricity generation.

Activity Milestones:

Description	Completion Date
Optimize quantum dot/polymer solutions for large scale coating processing	2022-08-31
Testing of coating methods for uniform deposition and curing over large areas	2022-09-30
Optimization of the coating process for rigid glass and plastic sheets	2022-10-31
Testing and comparison of plant growth using scaled-up solar windows	2022-12-31
Optimization of plant growth and photovoltaic electricity generation	2023-06-30

Project Partners and Collaborators

Name	Organization	Role	Receiving Funds
Lorraine Francis	University of MinnesotaTwin Cities Campus	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 has published over 160 journal publications and one textbook.	Yes
Vivian Ferry	University of MinnesotaTwin Cities Campus	Vivian Ferry is an Assistant Professor in the Department of Chemical Engineering and Materials Science at the University of Minnesota. She is an expert in innovative photonic con-cepts. She has experience in the theoretical modeling of luminescent solar concentrators, their design to optimize performance, and the manufacture of actual devices.	Yes
Changbin Chen	University of MinnesotaTwin Cities Campus	Changbin Chen is an Associate Professor in the Department of Horticultural Science at the University of Minnesota. Chen studies the mechanisms of DNA damage response and LED based lighting systems for indoor farming. Chen has served as a PI/co-PI on grants of ~$9.5M and published 45 peer-reviewed articles.	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?

Under current LCCMR support, the team has developed solar windows that can be produced with inexpensive coating technologies on glass and that have tunable absorption of blue and green light. This project will advance this technology for use in agriculture. This topic has newly attracted the attention of the US Department of Energy (DOE). Our team plans to compete for additional DOE funding, and hopefully commercialize the technology by forming a start-up company or licensing the technology to interested commercial partners. An initial "beach head" application of solar windows may be in energy producing greenhouses.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Waste Heat Recovery with Efficient Thermoelectric Energy Generators	M.L. 2016, Chp. 186, Sec. 2, Subd. 07b	$400,000
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: Uwe Kortshagen

Job Title: Professor

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

Uwe Kortshagen is a Professor of Mechanical Engineering at the University of Minnesota. He holds the Ronald L. and Janet A. Christenson Chair in Renewable Energy. Professor Kortshagen has extensive experience as manager of research projects. Throughout his career, he has directed research on 46 research projects with a combined funding exceeding $40M, of which he served as director (project manager) for projects totaling $23M. His work has been published in more than 200 scientific articles in peer-reviewed journals. He was issued 4 patents that generated royalty income exceeding $1M and led to 2 start-up companies.

Professor Kortshagen is an expert in the synthesis of silicon quantum dots with nonthermal plasmas, a technology which has been patented by the University of Minnesota and licensed to various industrial partners. His role on the project will be the quantum dot synthesis and fabrication of solar windows.

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. The synthesis of copper indium sulfide quantum dots and solar window device fabrication will be performed in Professor Ferry's laboratory. 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 Chen laboratory is well equipped to study plant germination and growth under solar windows.

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 the University of Minnesota.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount
Personnel								
Project Manger - faculty director		Direct research progress and project reporting. (approved fringe rate 36.5% rate)			26.7%	0.04		$16,342
3 faculty investigators		Direct research efforts. (approved fringe rate 36.5% rate)			26.7%	0.12		$25,890
2 Research Assistants		Perform research on solar window 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.)			41.7%	4		$218,231
							Sub Total	**$260,463**
Contracts and Services								
							Sub Total	**-**
Equipment, Tools, and Supplies								
							Sub Total	**-**
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								
		Materials and supplies	Materials for solar window manufacturing, plant growth experiments, including, chemicals, gases, coating supplies, seeds, light sources					$10,212
		Characterization facility services	Services to characterize materials such as user fees for electron microscopes, etc.					$9,325
							Sub Total	**$19,537**
							Grand Total	**$280,000**

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: 7af68bea-3ff.pdf

Alternate Text for Visual Component

The top panel of attached slide shows the working principle of solar windows and how they enable crops to grow under them. The middle panel describes the fabrication scheme, and the bottom panel summarizes the scientific merit, understanding crop growth under solar windows, and the broader impact.

Optional Attachments

Support Letter or Other

Title	File
Institutional endorsement letter	76d7623d-24d.pdf

Administrative Use

Does your project include restoration or acquisition of land rights?

No

Does your project have patent, royalties, or revenue potential?

Yes,

- Patent, Copyright, or Royalty Potential

Does your project include research?

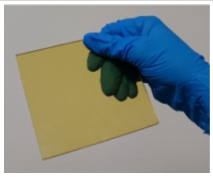
Yes

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

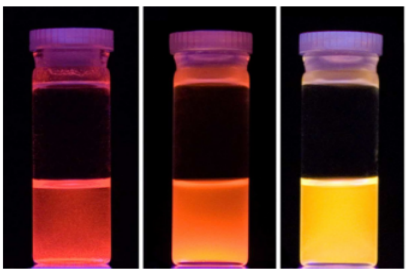
Solar Windows: Combining Agriculture and Photovoltaics

Solar Windows: How they work



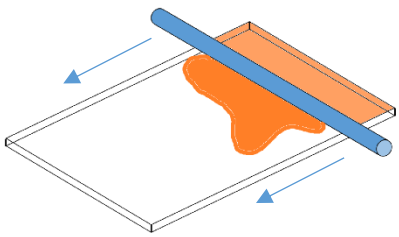
How they will be produced

Silicon and copper indium selenide quantum dots will be synthesized (Kortshagen & Ferry)



Silicon quantum dots under blue light
(Patented UMN technology)

Quantum dots will be coated onto LARGE AREA glass sheets with simple & easy coating processes like bar coating



Schematic of bar coating process
(Francis group)

What is the expected outcome?

Scientific Merit:
Plant growth will be assessed and optimized (Chen group)

Broader Impact:
A new approach of combining agriculture and generation of clean solar electricity