



Environment and Natural Resources Trust Fund

2023 Request for Proposal

General Information

Proposal ID: 2023-244

Proposal Title: Energy and Water Reduction in Greenhouse Production Systems

Project Manager Information

Name: Vivian Ferry

Organization: U of MN - College of Science and Engineering

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Project Basic Information

Project Summary: The team will develop a comprehensive model for MN-based greenhouses that uses photovoltaics for more efficient energy and water utilization.

Funds Requested: \$363,000

Proposed Project Completion: June 30, 2025

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?

Statewide

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

Statewide

When will the work impact occur?

During the Project and In the Future

Narrative

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

Minnesota ranks fifth among U.S. states in agricultural production. Commensurate with its enormous contribution to the state economy, agriculture also has a large environmental footprint: agricultural production accounts for about a quarter of the state's greenhouse gas emissions, requires significant water resources, and fertilizers impact water quality. With growing demand for locally grown foods year-round and more frequent occurrence of droughts and severe weather events, greenhouse production is quickly gaining increased popularity in Minnesota. Modern greenhouses, such as the one operated by Revol Greens in Owatonna, reduce the use of water by up to 90%, largely operate on collected precipitation, reduce the use of fertilizer, and produce crops even during droughts or in the winter. Although greenhouse operation is energy intensive, there is significant opportunity to reduce energy use by integrating photovoltaic (PV) technologies. In addition to supplying electricity on-site, photovoltaic module integration strategies can be designed to also address light and thermal management, increasing crop yield without increasing energy demand. There are currently no comprehensive simulation tools for photovoltaic greenhouses that enable predictive design of photovoltaic energy generation, greenhouse thermal loads, carbon budget, and techno-economic analysis that allow for the optimization of food and electricity production.

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

Globally, researchers are investigating a wide range of strategies to integrate PV devices with greenhouses, including partly covering greenhouse roofs with statically mounted, opaque solar cells, using semi-transparent organic PV cells or luminescent solar concentrators (solar windows), or using dynamically positionable solar cells that can act of "PV blinds" to block excessive solar radiation and produce electricity. In preliminary work, members of our team have developed a simulation model that, with the additional extensions proposed here, will be capable of examining all of these PV implementation strategies using location specific historical weather data. The model will simultaneously predict PV electricity generation, greenhouse heating and cooling loads, and operational (non-irrigation) water consumption. We propose here to validate its predictive capabilities against experimental data from University of Minnesota research greenhouses, and extend its capabilities to assess a wide array of PV technologies. We then propose to connect our greenhouse model to environmental life cycle analysis to compare the carbon budget of greenhouse production to other modalities that provide food to communities, such as shipping produce across the country, as well as economic analysis. Ultimately, this model will allow us to determine the optimal strategies for photovoltaic integration into greenhouses for the state

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?

- Development of a simulation tool for photovoltaic greenhouses that reduces energy consumption, water, and fertilizer use compared to conventional greenhouses and open-field farming while increasing crop yields
- Compare energy demand (renewable and fossil), water and carbon footprints of PV optimized greenhouse grown produce with other methods of providing produce to Minnesota communities
- Development of economic analyses that assess the costs-benefits of photovoltaic greenhouses vs. conventional greenhouses vs. open-field farming

Activities and Milestones

Activity 1: Development of Model for Energy Generation in Photovoltaic Greenhouses

Activity Budget: \$218,000

Activity Description:

In preliminary work, our team has developed a PV-thermal model for a greenhouse equipped with solar luminescent concentrator roofs, experimental devices that are semi-transparent and produce electricity with inexpensive, small-area solar cells. The model predicts PV electricity generation using location specific data from NASA's Surface meteorology and Solar Energy (SSE) Data Archive, and computes energy and water usage by modeling greenhouse cooling and heating loads. The model also predicts the photosynthetically active radiation (PAR) available for plant growth. To date, the model has been validated against available data in the literature. This activity will initially focus on more thoroughly validating the model against data available for research greenhouses at the University of Minnesota Plant Growth Facilities-West in St. Paul. In further research, the model will be extended to include additional PV strategies, such as statically mounted, opaque solar cells modules, semi-transparent organic PV cells, and dynamically controlled solar “PV blinds” systems. The model will be benchmarked against available data in the literature.

Activity Milestones:

Description	Completion Date
Model validation for conventional greenhouses on UMN St. Paul campus	December 31, 2023
Model extension and validation for statically mounted PV modules	June 30, 2024
Model extension and validation for semi-transparent organic modules	December 31, 2024
Model extension and validation for dynamically positioned PV panels	June 30, 2025

Activity 2: Life Cycle Assessment on Photovoltaic Greenhouses

Activity Budget: \$68,000

Activity Description:

The renewable energy, fossil energy, water footprint, and carbon footprints for the PV greenhouses being considered will be analyzed using life cycle assessment (LCA). LCA is an accounting technique that examines the inputs and outputs of a system in order to evaluate its environmental performance. The LCA performed for this studied will use data from the PV thermal model in activity 1, Minnesota greenhouse performance data, Minnesota electrical generation data, and national LCA data sets. A key step in evaluating the technologies' performance is developing a background inventory of the additional infrastructure and equipment that is needed to integrate solar into current greenhouse designs. Combining all of this data, the energy resources, water and carbon emissions needed to grow a unit of produce can be calculated. The analysis will include a baseline current technology greenhouse and numerous alternative scenarios for examining the PV design and operation enhancements compared in the PV model for activity 1. The option of transporting produce from other regions of the country or from international markets will also be compared.

Activity Milestones:

Description	Completion Date
Collect data on optimized PV systems and greenhouses	December 31, 2023
Build LCA models of optimized PV systems	June 30, 2024
Incorporate PV model output data from activity 1 into LCA models	December 31, 2024
Compare production from baseline, PV optimized, and non-local greenhouses	June 30, 2025

Activity 3: Economic Assessment of Photovoltaic Greenhouses

Activity Budget: \$77,000

Activity Description:

The economics of PV greenhouses is multi-dimensional with principal dimensions being: (i) PV electricity generation, (ii) thermal management cost for greenhouse operation, (iii) agricultural crop yield, (iv) greenhouse gas emissions, (v) project installation costs, and, (vi) operation and maintenance costs. This intricate dependency will be studied by cost-benefit analysis based on data from the PV-thermal greenhouse model using the projected costs and benefits of the system. PV electricity generation will be valued based on its retail economic value to the greenhouse owner and its modeled future economic and environmental value to the utility system using the National Renewable Energy Laboratory's Cambium Model. Thermal management costs, project installation costs, and operation and maintenance costs will be based on observations collected from UMN research greenhouses and the literature. Agricultural crop yields, estimated from the literature, will be valued at market rates. Over the course of the project, different PV strategies will be implemented, which will allow for assessment of the optimal control strategies to maximize the net benefits of the system under different decision criteria and pricing assumptions.

Activity Milestones:

Description	Completion Date
Solar output model development and calibration for solar greenhouses	December 31, 2023
Development of cost model of solar greenhouses	June 30, 2024
Analysis of design alternatives and cost-benefit analysis of solar greenhouses	June 30, 2025

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 – Twin Cities. 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. He and PI Ferry will co-advise a student to work on Activity 1.	Yes
Gabriel Chan	University of Minnesota	Gabriel Chan is an Associate Professor in the Humphrey School of Public Affairs in Science, Technology, and Environmental Policy at the University of Minnesota – Twin Cities. He is an expert in the economic impact of photovoltaics, and will lead efforts in Activity 3.	Yes
Joel Tallaksen	University of Minnesota - WCROC	Joel Tallaksen is a renewable energy scientist at the University of Minnesota – West Central Research and Outreach Center (Morris, MN) . He is an expert on using renewable energy to solve environmental challenges facing rural communities. He will lead efforts in Activity 2.	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 work be funded?

Our team plans to submit additional proposals to agencies such as the Department of Energy and the US Department of Agriculture for ongoing support, which will be expanded to include additional collaborators in horticulture for additional experimental work. The support from this project will allow us to develop this comprehensive model and best direct our efforts toward impactful implementations in future work. The project will ultimately determine the best strategies for photovoltaic-integrated greenhouses in Minnesota.

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. Prof. Ferry and Prof. Kortshagen can utilize

the Minnesota Supercomputing Institute, the University of Minnesota's principle center for computational research. To validate the greenhouse model proposed here, we will access data from the University of Minnesota plant growth facilities. MSI operates several data center on campus, and staff are available for expert consulting in software development and algorithm optimization.

The plant growth facilities, located on the St. Paul campus, consist of several state-of-the-art, computer-controlled greenhouses with modern temperature, humidity, and lighting controls.

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	\$ Amount
Personnel								
Project manager - faculty		Direct research progress and project reporting.			25%	0.04		\$9,000
Two co-investigators		Oversee research			25%	0.08		\$27,000
Research manager		Perform research			25%	0.5		\$47,000
2 research assistants		Perform calculations on model validation, implementations, and economic impact			44%	1.5		\$169,000
							Sub Total	\$252,000
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								
		Indirect Costs	Indirect expenses from University					\$111,000
							Sub Total	\$111,000
							Grand Total	\$363,000

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request
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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: [a6c2b42b-e14.pdf](#)

Alternate Text for Visual Component

Drawing of greenhouse with integrated photovoltaic panels...

Optional Attachments

Support Letter or Other

Title	File
Letter of authorization	1cf61b73-98b.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

