Environment and Natural Resources Trust Fund
2018 Request for Proposals (RFP)

Project Title: **ENRTF ID:** **158-E**

Clean Electricity from Solar Windows

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

Total Project Budget: $ 458,494

Proposed Project Time Period for the Funding Requested: 3 years, July 2018 to June 2021

Summary:

Solar windows are a disruptive photovoltaic technology that virtually invisibly integrates with buildings. This renewable energy technology will increase photovoltaics adoption, reduce air pollution, and ameliorate climate change.

Name: Uwe Kortshagen

Sponsoring Organization: U of MN

Address: 111 Church Street SE
Minneapolis MN 55455

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Email kortshagen@umn.edu

Web Address www.umn.edu

Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

The chart describes the function of solar windows based on luminescent solar concentrators, how they will be manufactured, and their impact on leap-frogging solar energy utilization.

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

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

_____ Capacity Readiness _____ Leverage _______ TOTAL ______%

PROJECT TITLE: Clean Electricity from Solar Windows

I. PROJECT STATEMENT

Imagine every outdoor wall and window collecting solar light and cheaply converting it into clean electricity. The objective of this project is to make this idea a reality with inexpensive "solar windows," an idea that, while still preliminary, has already captured interest by Minnesota-based window manufacturers. Solar windows are based on concentrators using highly luminescent nanometer-sized silicon crystals, a technology developed at the University of Minnesota. The silicon crystals, embedded in or coated onto the window pane, absorb harmful-to-humans ultraviolet and blue light and turn it into red light, which is guided by internal reflection to the sheet edge, where it is concentrated onto a small area solar cell, Figure 1. The concentrator sheet can be made largely transparent such that it can serve as a window. As light is collected by the large area of the window but only a small and thus cheap solar cell is required, the cost of solar electricity is reduced. Moreover, these luminescent solar concentrators collect light from any direction and virtually invisibly integrate with buildings, thus eliminating aesthetic objections and the *cost of land* for solar installations. This cheap renewable energy technology may widely expand the adoption of clean solar electricity, reduce air pollution, and ameliorate climate change.

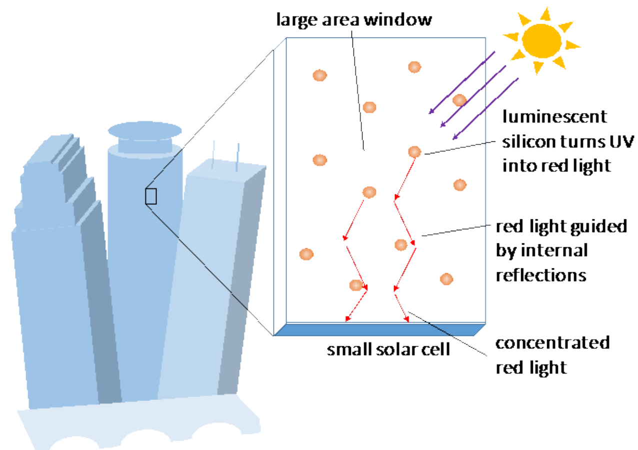


Figure 1: Schematic of a solar concentrator window

The progress of luminescent concentrators has long been hampered by the lack of suitable luminescent species. Recently, Professor Kortshagen and collaborators demonstrated that luminescent silicon crystals have virtually ideal properties for this application. First silicon-based window concentrators have shown promising efficiencies. The development of this technology was covered in local news media, including KARE11, and has already led to preliminary interest by the Minnesota-based window manufacturer Viracon. The silicon crystals were produced using University of Minnesota technology, which is covered by three US patents and was licensed to two major corporations for a combined royalty income of $1.1M. The project will focus on solving the remaining bottleneck science and engineering problems on the way to producing large-area solar windows.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: *Demonstrate Efficient Silicon-Based Window Luminescent Concentrators* **Budget: $176,431**

Largely transparent window solar concentrators will be produced by coating thin films of luminescent silicon crystals dispersed in common plastics onto inexpensive sheets of glass. Luminescent silicon crystals are ideal for this application, as they strongly absorb invisible ultraviolet light with limited loss of visible light. They are also compatible with common, sturdy plastics like poly(methyl methacrylate), also known as Plexiglas®. By carefully selecting the silicon crystal concentration in the plastic coating, the optical properties of the luminescent concentrators can be tuned to produce transparent to semi-transparent devices, ideal for window applications.

Outcome	Completion Date
1. *Produce silicon-based test concentrator windows of least 100 cm^2 in area*	*Dec 31, 2018*
2. *Characterize device efficiency as function of concentration & film roughness*	*June 30, 2019*
3. *Evaluate visible transparency for suitability for window applications*	*June 30, 2019*

Activity 2: *Explore Maximum Silicon-Based Concentrator Efficiency* **Budget: $139,272**

While transparent concentrators have great potential for window applications, the efficiency may be improved by absorbing and concentrating more solar light with semi-transparent to opaque devices. Such designs may find applications as colored architectural façades, siding panels, or stand-alone solar concentrators. The interplay between silicon crystal properties, concentration, and concentrator size will be examined in order to determine the upper efficiency limit of these devices. Additionally, the concentrator efficiency may change for curved devices, which will be studied.

Outcome	Completion Date
1. Explore optimum efficiency on devices of at least 100 cm^2	*Dec 31, 2019*
2. Evaluate transparency / color for applications as windows or opaque building panels	*Jun 30, 2020*

Activity 3: *Characterize Efficiency of a Large Concentrator Window* **Budget: $142,791**

Published research on luminescent concentrators is largely limited to devices on the scale of 100 cm^2 or less, primarily due to optical losses encountered by the luminescent materials studied thus far. The team will develop large area devices to prove the silicon-based concentrator technology on a realistic scale and encourage commercialization. They will demonstrate a concentrator as large as standard size windows to enable study of the device in its real-world environment, provide an educational tool for visitors to the University, and break records on luminescent concentrator size. Prolonged assessment of the device performance will establish expected lifetime estimates.

Outcome	Completion Date
1. Develop large-area thin film coating technology	*Dec 31, 2019*
2. Scale luminescent concentrator devices up to at least 2,000 cm^2	*Jun 30, 2021*
3. Evaluate performance & stability over time	*Jun 30, 2021*

III. PROJECT STRATEGY

A. Project Team/Partners

The project director, Professor Kortshagen, the inventor of the luminescent silicon crystal technology, brings unique expertise in materials synthesis and optical characterization. Professor Lorraine Francis, is an expert in the area of coating microstructures and processing, with research spanning from flexible electronic coatings to polymer/ceramic composites. Professor Ferry is an expert in the design of luminescent solar concentrators. Jointly, they will supervise the graduate research assistants, responsible for the luminescent silicon crystal synthesis, coating technology, and solar window numerical design. The project can leverage upon research which is performed by the "Sustainable Nanocrystal Materials" group of the National Science Foundation-funded Materials Research Science and Engineering Center, a $17.8M federal grant, and the Department of Energy-funded Center for Advanced Solar Photophysics.

B. Project Impact and Long-Term Strategy

This project will contribute to the development of a novel renewable energy technology, and subsequently reduce the usage of fossil fuels to ameliorate air pollution and the emission of greenhouse gases. If successful, the outcomes of this work will contribute to the scientific knowledge base, but also hold prospect for commercialization. Based on the team's unique expertise and the interest shown by Minnesota-based window manufacturers, the aim is to develop these silicon solar windows into a uniquely Minnesota technology.

C. Timeline Requirements

The project will require 36 months to complete with the milestones explained above. The first two years will be dedicated to the design and testing of both transparent and semitransparent to opaque luminescent concentrators, with the final year dedicated to a truly large scale device fabrication and full characterization.

2018 Detailed Project Budget

Project Title: Clean Electricity from Cheap Luminescent Solar Concentrators

IV. TOTAL ENRTF REQUEST BUDGET: 3 Years

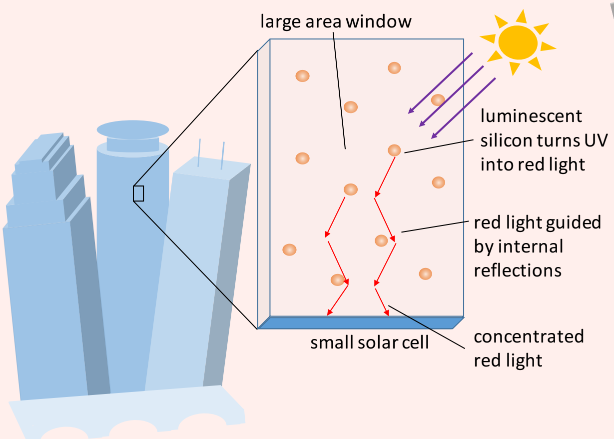
BUDGET ITEM	AMOUNT
Personnel:	**$ 388,494.00**
Uwe Korthagen Project Manager (2 weeks (.04FTE) + fringe 33.5% fringe) for 3 years	$ 38,796.00
Lorraine Francis, co-PI, (2 weeks (.04 FTE) + fringe 33.5% fringe) for 3 years	$ 33,988.00
Vivian Ferry, co-PI, (2 weeks (.04 FTE) + fringe 33.5% fringe) for 3 years	$ 19,248.00
2.0-Graduate Research Assistant 50% FTE (fall & spring include fringe plus tuition, summer fringe only) for 3 years	$ 296,462.00
Equipment/Tools	**$ 40,000.00**
Custom built equipment to characterize solar concentrators: 1) Solar simulator: This includes high intensity Xeon arc lamp, fiters to simulate solar light, lenses, silicon photodetectors, 2) Large integrating sphere to analyze concentrator efficiency.	$ 20,000.00
Custom built equipment for large area coating in dry nitrogen atmosphere: Bar coating apparatus with controlled temperature hot plate and gas flow for making wide format (18") coatings on glass.	$ 20,000.00
Lab Supplies/User Fees	**$ 30,000.00**
Cost for purchasing precursor gases ($500/year), chemicals ($3000/yr), sample substrates ($500/year), general laboratory supplies ($1000/year) for 3 years	$ 15,000.00
User fees for rental and usage of facilities at the campus CharFac center for nanoparticle structural/property characterization (X-ray diffraction, secondary electron microscopy, Raman spectroscopy, tunneling electron microscopy, and ellipsometry, $5,000 per year) for 3 years	$ 15,000.00
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 458,494

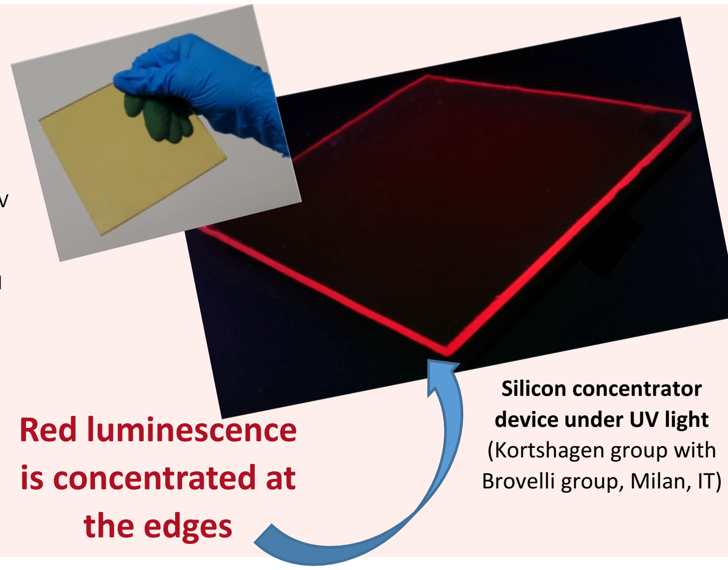
V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period:	$ -	*N/A*
Funding History: *past federal funding (National Science Foundation, Department of Energy, Army Office of Research) to Professors Kortshagen for developing luminescent silicon technology and Prof. Francis for developing coating technologies*	~$9M	*completed*
Remaining $ From Current ENRTF Appropriation: *N/A*	N/A	*N/A*

Clean Electricity from Solar Windows

WHAT it is:



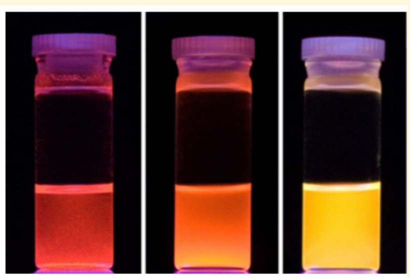


Red luminescence is concentrated at the edges

Silicon concentrator device under UV light
(Kortshagen group with Brovelli group, Milan, IT)

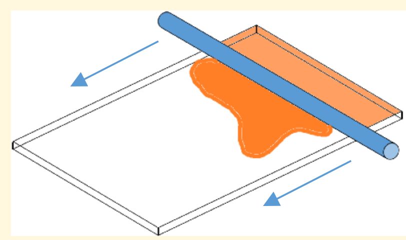
HOW it will be produced:

Arguably the highest quality luminescent silicon crystals are produced with a patented University of Minnesota synthesis method



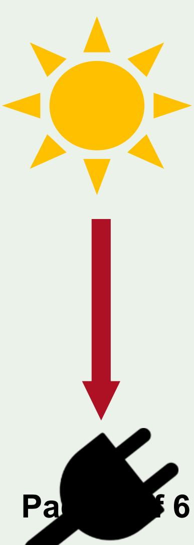
Luminescent silicon crystals under UV light
(Kortshagen group)

Silicon crystals/plastic films will be coated onto LARGE AREA glass sheets with simple & easy coating processes like bar coating



Schematic of bar coating process
(Francis group, Verry group)

What is the impact?



Building integrated solar electricity through windows and walls:

- ✓ reduced cost
- ✓ no *cost of land*
- ✓ aesthetic integration with buildings

Windows and architectural panels could create electricity

IDS tower: 50,000 m² of windows that could generate electricity
(Image from ids-center.com)

Project Manager Qualifications & Organization Description

Uwe Kortshagen is James J. Ryan and Distinguished McKnight University Professor and Head of the Department of Mechanical Engineering at the University of Minnesota. He earned all his degrees in Physics (Diploma degree 1988, Ph.D. in 1991, Habilitation 1995) from the Ruhr University Bochum. He came to the U.S. in 1995 and spent a year at the University of Wisconsin-Madison. In 1996, he joined the Department of Mechanical Engineering at the University of Minnesota as Assistant Professor, where he was promoted to Associate Professor in 1999, and to Professor in 2003. His work is in the area in the plasma synthesis of nanomaterials. His work has been published in more than 160 articles in peer-reviewed journals.

Lorraine Francis is Professor of Chemical Engineering and Materials Science at the University of Minnesota. She received a B.S. in Ceramic Engineering from Alfred University in 1985, and M.S. and Ph.D. in Ceramic Engineering from the University of Illinois in 1987 and 1990, respectively. She then joined the University of Minnesota, where she has been ever since. 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 130 journal publications and one textbook.

Vivian Ferry is an Assistant Professor in the Department of Chemical Engineering and Materials Science at the University of Minnesota. She received her Ph.D. in Chemistry from the California Institute of Technology in 2011. She was a Postdoctoral Fellow, Materials Science Division, Lawrence Berkeley National Laboratory from 2011 – 2014, and joined the University of Minnesota in 2014. She is an expert in innovative photonic concepts. She has experience in the theoretical modeling of luminescent solar concentrators, their design to optimize performance, and the manufacture of actual devices.

Uwe Kortshagen is the principal investigator (PI) of this proposed work, and he will be responsible for the overall management of this project and the status reports of project update. He has directed research on grants exceeding $25M. He is responsible for the synthesis of luminescent silicon nanocrystals. **Lorraine Francis** will be responsible for the of tailoring the nanocrystal-polymer dispersions, and developing coating processes to create the concentrator films. **Vivian Ferry** will perform numerical modeling design to guide the optimization of the solar windows. The PIs will coordinate with each other to develop new luminescent concentrators and assess and optimize their performance.

The **University of Minnesota** offers world-class infrastructure for this project. The luminescent silicon crystal synthesis will be performed in Kortshagen's laboratory, which is part of the **High Temperature and Plasma Laboratory** in the Department of Mechanical Engineering. This lab is one of the best equipped plasma technology laboratories in the world. His laboratory includes ten custom-built plasma reactors and facilities for nanocrystal processing that will be available to this project. 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 facility houses custom coating dies and rolls for the study of all major coating processes, including slot coating, tensioned web-over slot coating, curtain coating and slide coating, and multilayer versions of these. 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 and glass shops are also available at the University of Minnesota.