Project Title: **ENRTF ID:** 135-E

Clean Electricity from Cheap Luminescent Solar Concentrators

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

Total Project Budget: $ 627,149

Proposed Project Time Period for the Funding Requested: 3 years, July 2017 - June 2020

Summary:

Cheap luminescent solar concentrators 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 St SE
Minneapolis MN 55455

Telephone Number: (612) 625-4028

Email kortshagen@umn.edu

Web Address

Location

Region: Metro

County Name: Statewide

City / Township:

Alternate Text for Visual:

The chart describes the function of 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 Cheap Luminescent Solar Concentrators

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 luminescent solar concentrators** using highly luminescent nanometer-sized silicon crystals, a technology developed at the University of Minnesota. These concentrators consist of luminescent silicon crystals embedded within a plastic sheet or film. The silicon crystals 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, luminescent 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.

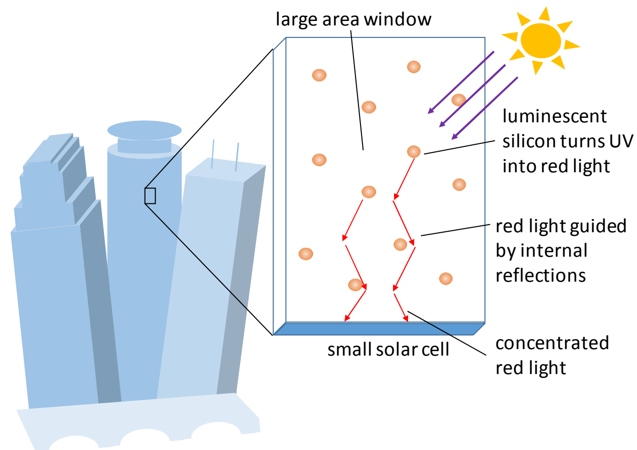


Figure 1: Schematic of a solar concentrator window

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 efficiencies of ~3% with a clear path to more than 5%, considered to be the threshold for commercial viability of transparent concentrator windows. 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. This technology offers our team a competitive advantage and may lend itself to large scale commercialization. The project will focus on producing large-area concentrators based on efficient luminescent silicon crystals paired with inexpensive coating techniques.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: *Demonstrate Efficient Silicon-Based Window Luminescent Concentrators* **Budget: $231,570**

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. Professor Francis' coatings lab will enable quick turnaround on lab scale silicon crystal/plastic films coated onto glass sheets to experimentally test concentrator designs.

Outcome	**Completion Date**
1. Produce silicon-based test concentrator windows of least 100 cm^2 in area	*Dec 31, 2017*
2. Characterize device efficiency as function of concentration & film roughness	*June 30, 2018*
3. Evaluate visible transparency for suitability for window applications	*June 30, 2018*

Activity 2: *Explore Maximum Silicon-Based Concentrator Efficiency* **Budget: $195,220**

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 or stand-alone solar concentrators. The interplay between silicon crystal properties, concentration, and concentrator size must be examined in order to determine the upper efficiency limit of these devices. Additionally, the concentrator efficiency may change for curved devices, which needs to be studied.

Outcome	Completion Date
1. Explore optimum efficiency on devices of at least 100 cm^2	*Dec 31, 2018*
2. Evaluate transparency / color for applications as windows or opaque building panels	*Jun 30, 2019*

Activity 3: *Characterize Efficiency of a Large Concentrator Window* **Budget: $200,359**

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 device scale must increase in order to prove the silicon-based concentrator technology and encourage commercialization. Demonstrating a concentrator as large as standard size windows will also 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, 2018*
2. Scale luminescent concentrator devices up to at least 2,000 cm^2	*Jun 30, 2019*
3. Evaluate performance & stability over time	*Jun 30, 2020*

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. The co-director, Professor Lorraine Francis, is an expert in the area of coating microstructures and processing, with research spanning from flexible electronic coatings and solar cells to polymer/ceramic composites. Jointly, they will supervise one post-doctoral researcher, responsible for concentrator manufacture, characterization, and optimization, and two graduate research assistants, one responsible for the luminescent silicon crystal synthesis and one responsible for the coating technology. 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 great prospect for commercialization. Based on the team's comprehensive expertise in luminescent silicon crystals and coating technologies, the aim is to develop these silicon solar concentrators 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.

2017 Detailed Project Budget

Project Title: Clean Electricity from Cheap Luminescent Solar Concentrators

IV. TOTAL ENRTF REQUEST BUDGET: 3 Years

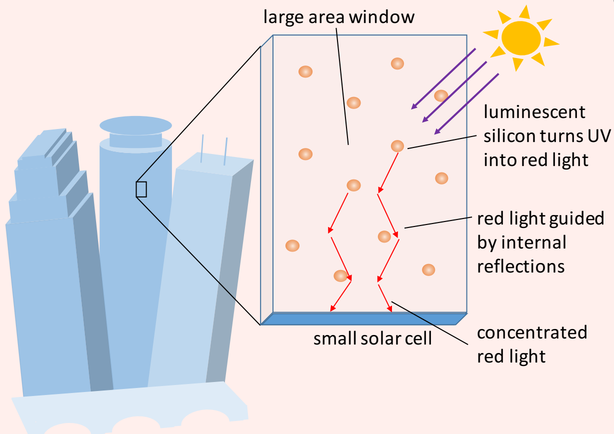
BUDGET ITEM	AMOUNT
Personnel:	**$ 542,149.00**
Uwe Korthagen Project Manager (2 weeks (.04FTE) + fringe 33.7% fringe) for 3 years	$ 37,817.00
Lorraine Francis, co-PI, (2 weeks (.04 FTE) + fringe 33.7% fringe) for 3 years	$ 33,166.00
1 post-doctoral research associate (1.0 FTE + 22.4% fringe) for 3 years	$ 170,247.00
2-Graduate Research Assistant 50% FTE (fall & spring include fringe plus tuition, summer fringe only) for 3 years	$ 300,919.00
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	**$ 45,000.00**
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, $10,000 per year) for 3 years	$ 30,000.00
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 627,149

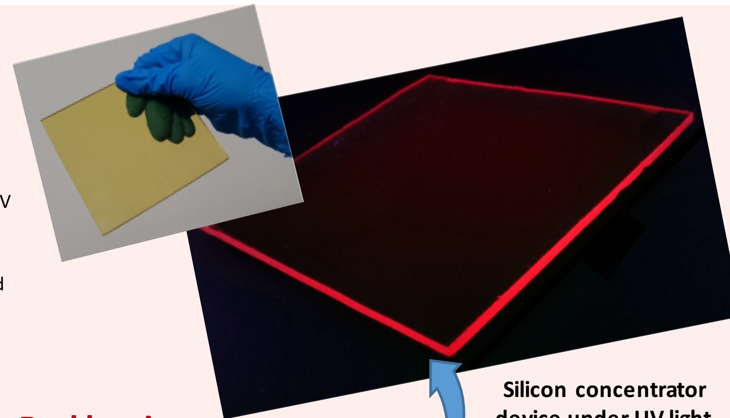
V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period:	$ -	*N/A*
Other State $ To Be Applied To Project During Project Period: *waived F&A rate: $627,149*0.53, contingent on granting of this proposal*	$332,389	*pending*
In-kind Services To Be Applied To Project During Project Period: *Academic year faculty effort on this project, contingent on granting of this proposal*	$70,983.00	*pending*
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 Cheap Luminescent Solar Concentrators

WHAT it is:



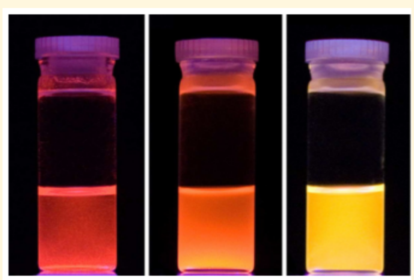


Red luminescence is concentrated at the edges

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

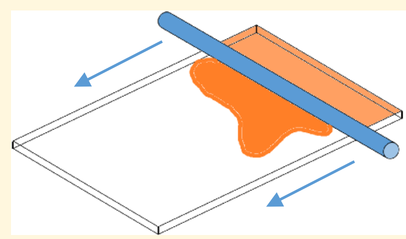
HOW it will be made:

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



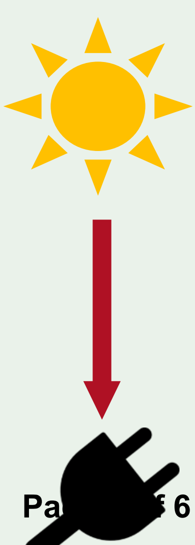
Luminescent silicon crystals under UV light
(Kortshagen group)

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)

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 m^2 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. He served as President of the International Plasma Chemistry Society and is a Fellow of the American Society of Mechanical Engineers, the Institute of Physics, and the International Plasma Chemistry Society. He won the 2015 Plasma Prize of the American Vacuum Society. 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 is the co-leader of the Coating Process Fundamentals Program, an industry-sponsored research group of the University's Industrial Partnership for Interfacial and Materials Engineering (IPRIME). Professor Francis has received several honors, including the John A. Tallmadge Award for Contributions to Coating Technology (2014) and UMN Alumni Association Award for Outstanding Contributions to Undergraduate Education (2014). She has published over 130 journal publications and one textbook.

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** is the co-PI for the project with the responsibility of tailoring the nanocrystal-polymer dispersions, and developing coating processes to create the concentrator films. The two PIs will coordinate with each other to develop new luminescent concentrators and assess and optimize their performance.

The **University of Minnesota** offers world-class infrastruture 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.