

# The Role of Quantum Dots in Solar Greenhouses for Sustainable Food-Energy Generation Systems

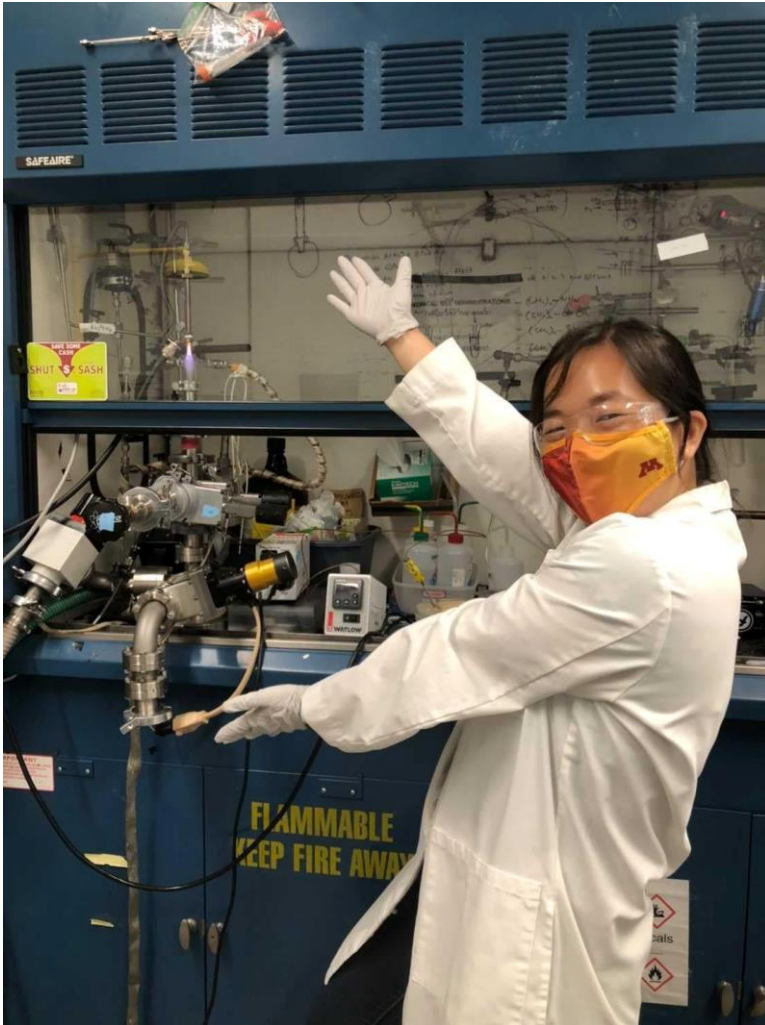
Kristine Loh,  
Professors Vivian Ferry and Uwe Kortshagen  
October 7, 2024



UNIVERSITY OF MINNESOTA  
Driven to Discover®

**Mechanical Engineering**

# About Me



- Kristine Loh (she/her)
- 5<sup>th</sup> year PhD Candidate in Chemical Engineering
- Research focus: nontoxic nanomaterials for solar energy tech.
- Co-advised by Profs. Uwe Kortshagen and Vivian Ferry
- BS/MS from Drexel University
- Hometown of Miami, FL



# Agrivoltaics: *Agriculture + Photovoltaics*



Agostini, A., et al., *Applied Energy*, (2021)



<https://www.agweek.com/livestock/umn-morris-mixes-cows-and-solar-on-midwests-largest-agrivoltaic-pasture>



Corrado, C., et al., *J. Renewable Sustainable Energy*, (2016)



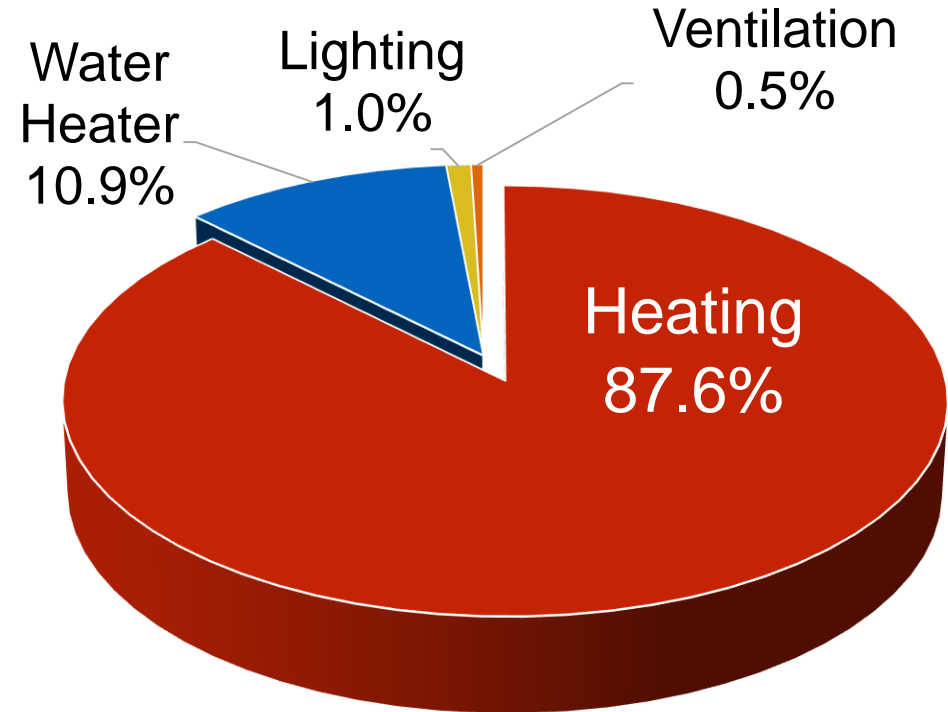
<https://www.wri.org/insights/agrivoltaics-energy-food-production-asia>

# Agrivoltaic Greenhouses: Concomitant Food and Energy Production in a Controlled Environment



<https://projects.research-and-innovation.ec.europa.eu/en/horizon-magazine/feed-growing-population-farmers-look-sun>

## Breakdown of Energy Use in Greenhouses

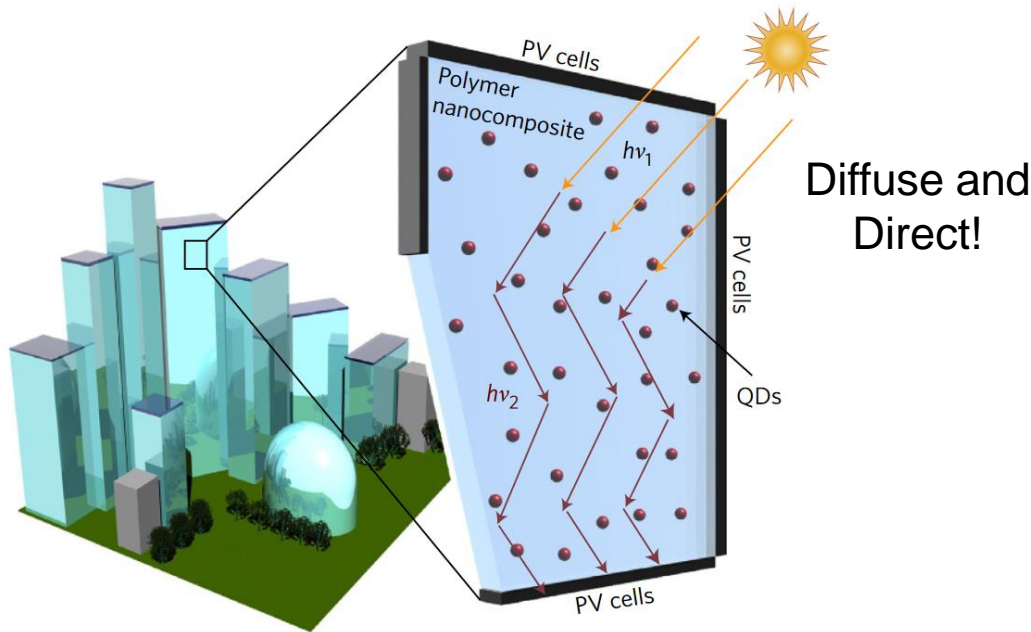


Michigan Farm Program, 2021

How can agrivoltaic greenhouses offset or meet large energy demands?



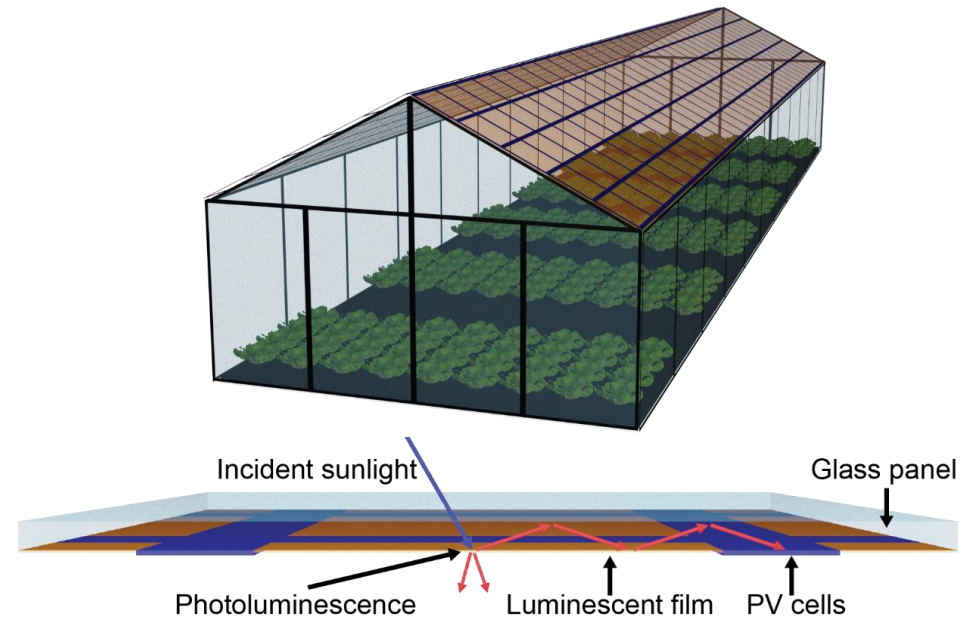
# Luminescent Solar Concentrators (LSCs) for Building Integrated Photovoltaics (BIPV)



Meinardi, F., et al. *Nature Photon.*, **11**, pp. 177-185 (2017)

## Design requirements:

Broad absorption, color rendering, semi-transparency, low reabsorption, high quantum yield, PV-matched emission



Liu, Y., et al, *Adv. Sustain. Syst.*, **7**, 8, 2300107 (2023)

## Design requirements:

Plant-specific color (absorption and emission), semi?-transparency, low reabsorption, high quantum yield?

Given different design goals, what is an ideal LSC for agrivoltaic greenhouses?

# Commercial LSC Greenhouses and Opportunities for Exploration



<https://lleaf.com/shop/p/style-01-ej5na-8akeb>



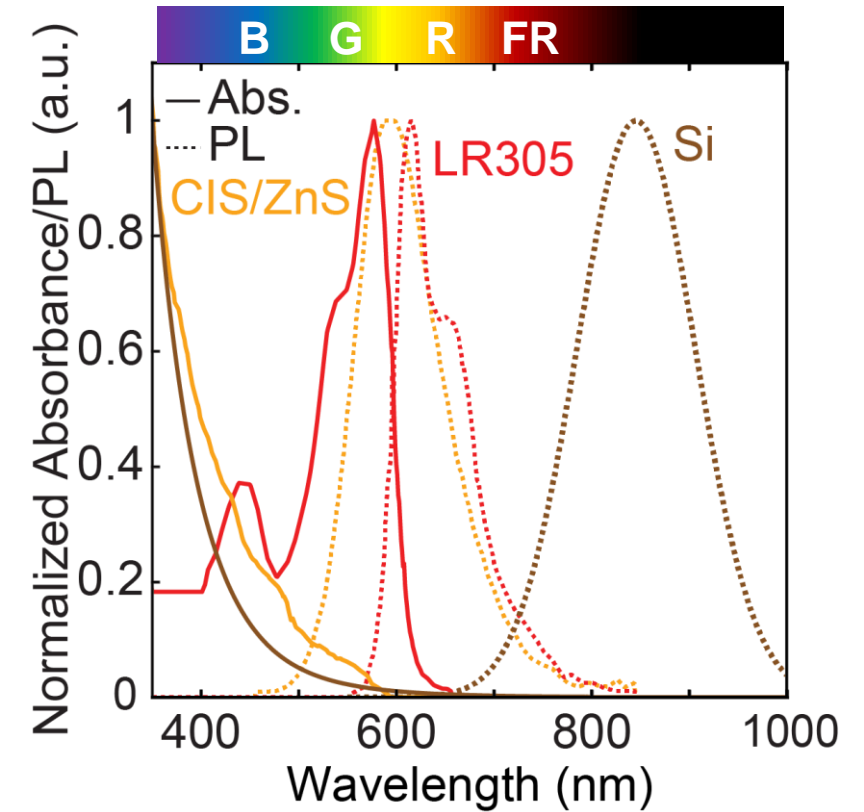
<https://ubigro.com/>



<https://heliene.com/gipv-solar-glass/>



<http://www.soliculture.com/projects/>

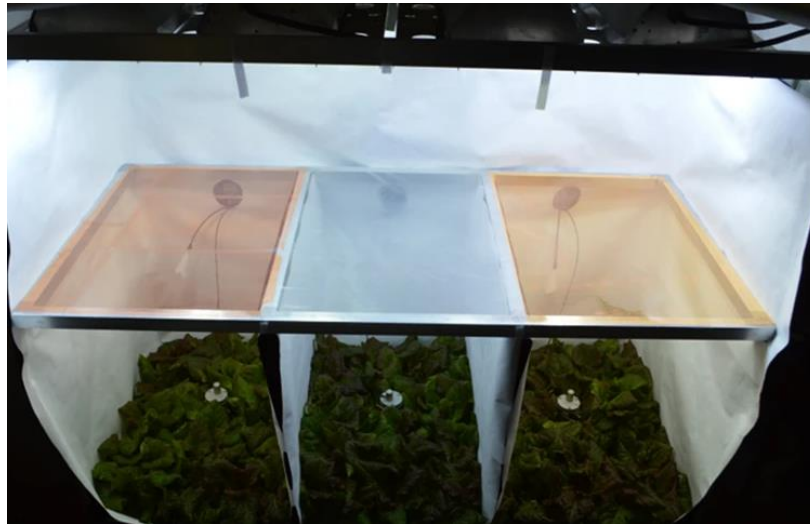


How does LSC design impact greenhouse operation?



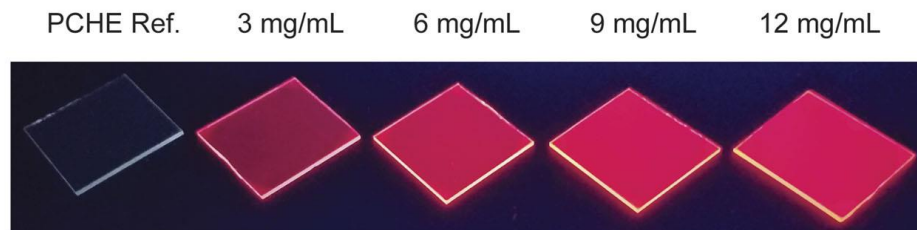
# Large, Complex LSC Design Space for Agrivoltaics

## Luminophore (Color)



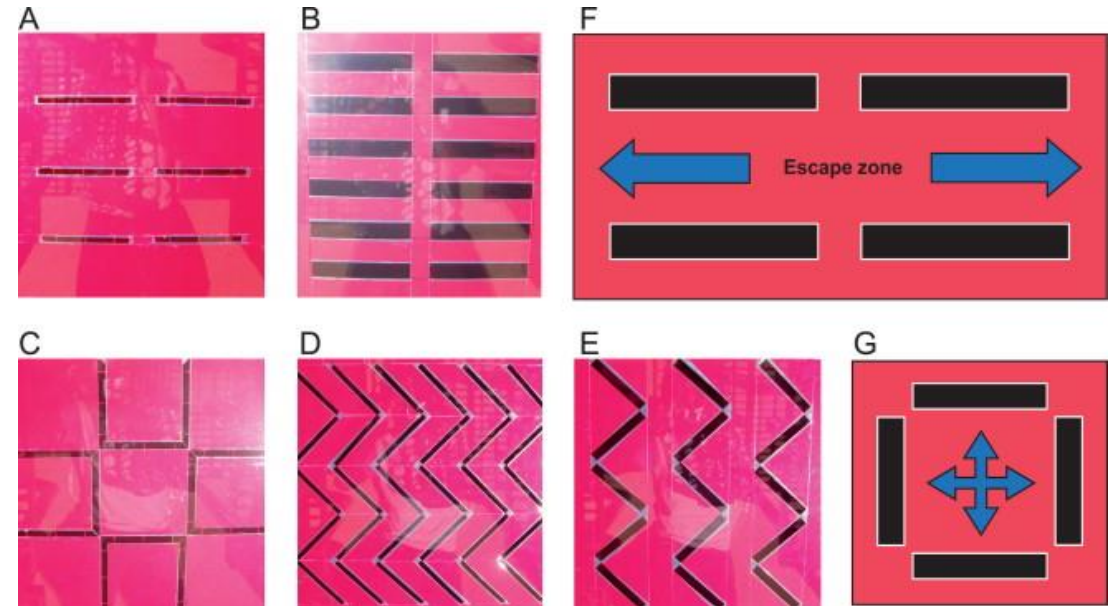
Parrish, C., et al, *Communications Biology*, **4**, 124 (2021)

## Concentration



Connell, R., et al, *APL Mater.*, **7**, 101123 (2019)

## Shape and/or Size



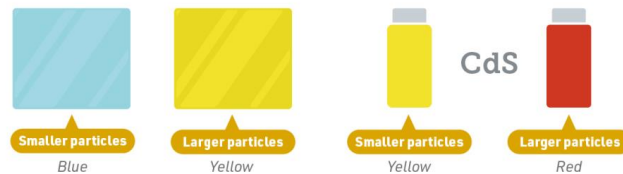
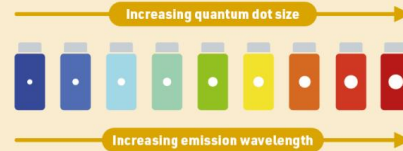
Corrado, C., et al, *Sol. Energy Mater. Sol. Cells.*, **111**, pp. 74-81 (2013)

# Quantum Dots as Promising Material Candidates

## The 2023 Nobel Prize in Chemistry

The 2023 Nobel Prize in Chemistry was awarded jointly to **Moungi G. Bawendi**, **Louis E. Brus** and **Alexei I. Ekimov** for the discovery and synthesis of quantum dots.

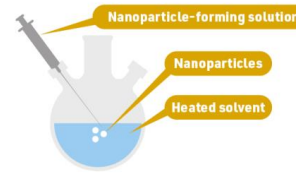
Quantum dots are nanoparticles of semiconducting materials. Their very small size gives them properties that differ from those of larger particles of the same material. For example, their absorption and emission of light varies with size. This is due to quantum effects arising from electrons in the particles being squeezed together.



In 1981, **Alexei Ekimov** made glass tinted with copper chloride. He noticed that the size of the copper chloride nanoparticles that formed in the glass affected the glass colour. This was the first time someone deliberately produced quantum dots.

In 1983, **Louis Brus** created solutions of cadmium sulfide nanoparticles, and noticed that the properties of freshly made and older solutions differed. He also discovered that the smaller the nanoparticles, the bluer the light they absorbed and emitted.

In 1993, **Moungi Bawendi** grew nanocrystals of cadmium selenide of a specific size in a solvent which produced smooth and even particles. This effective method for producing quantum dots paved the way for their use in wider applications.



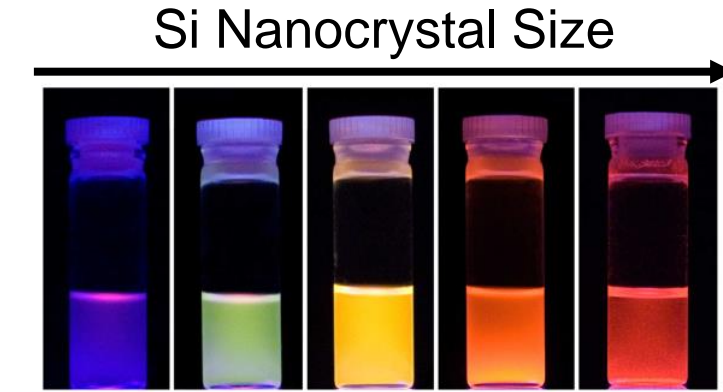
### WHY DOES THIS RESEARCH MATTER?

QLED televisions use quantum dots to enhance the colours displayed on screen. They are also used in some LED lamps. Future applications could include flexible electronics, tiny sensors, and thinner solar cells.

Nobel Prize in Chemistry press release: <https://www.nobelprize.org/prizes/chemistry/2023/press-release/>

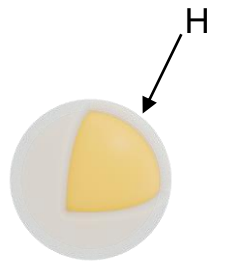
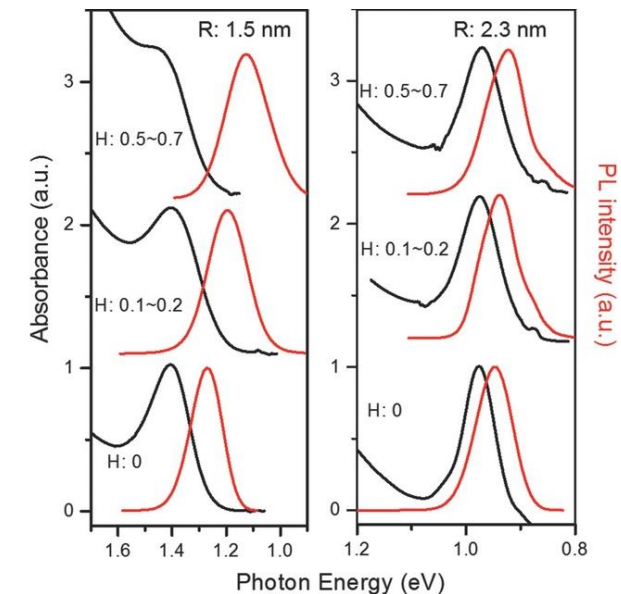


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Pi, X.D., et al., *Nanotechnology*, 19, 245603, (2008)

## Stokes Shift Engineering

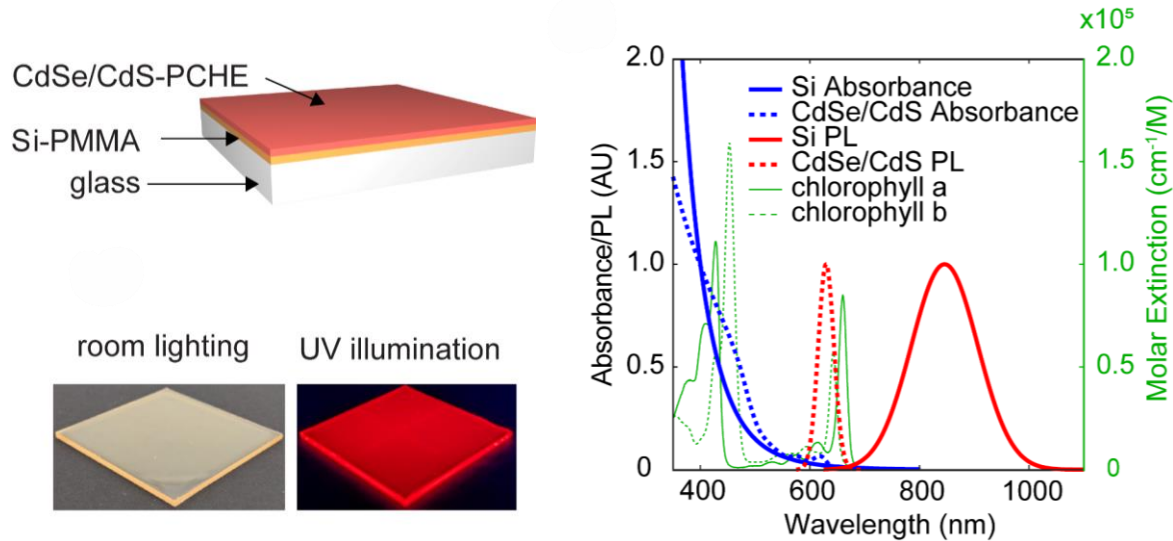


<https://www.compoundchem.com/2023/10/04/2023nobelchemistry/>

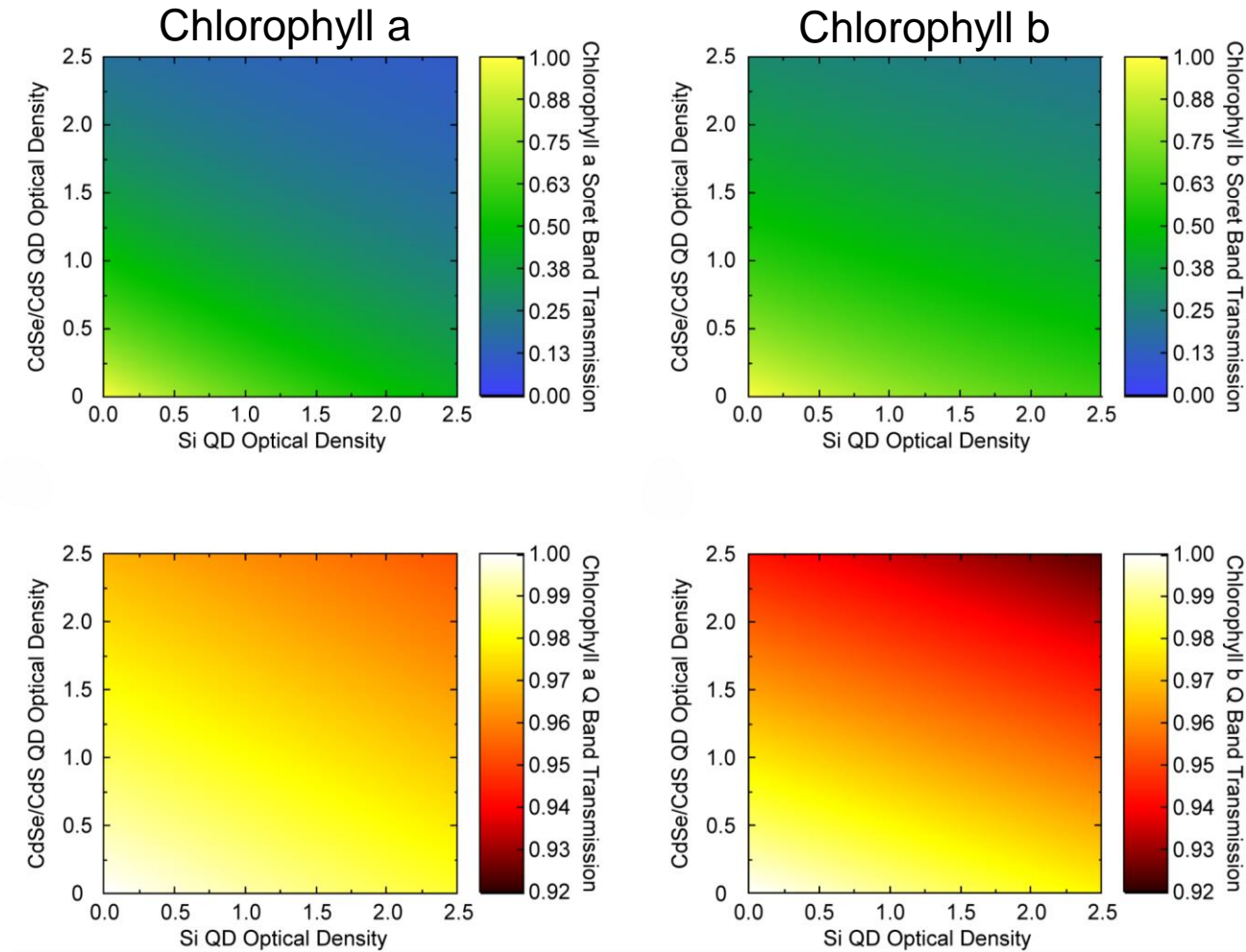
Zhou, Y., et al., *Adv. Energy Mater.*, 6(11), 1501913, (2016)



# Bilayer LSC Films with Transmission Spectrum Tunability

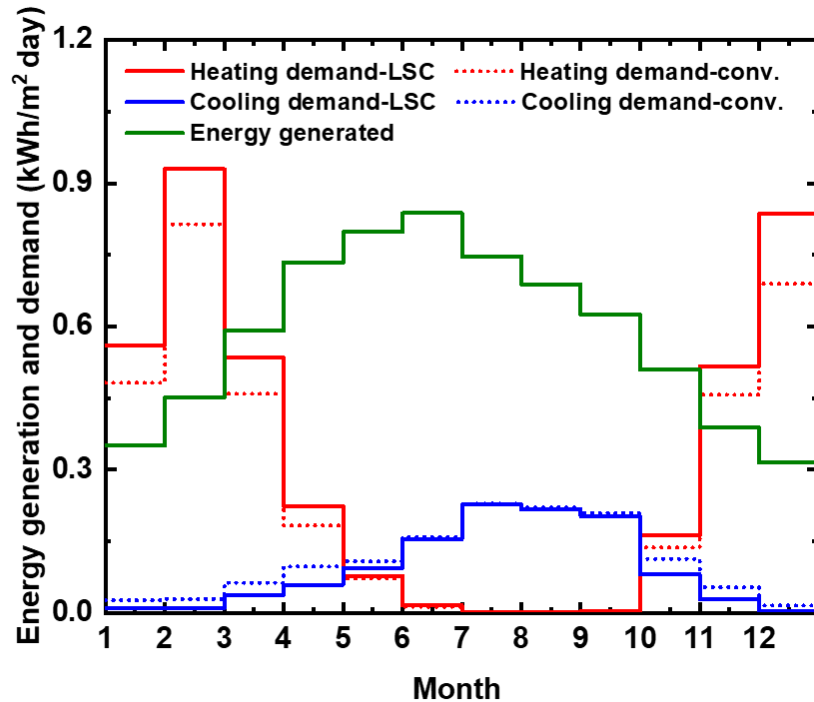


- LSC design parameters: luminophore, film structure, and concentration
- Fabricated and simulated bilayer film
- Bilayer films enhance optical efficiency (power generation) with potential spectral modification



Keil, J., et al, *ACS Appl. Energy Mater.* 4, 12, 14102–14110 (2021)

# Simulated Si LSC Greenhouses: Net Zero Energy in Arizona



Liu, Y., et al, *Adv. Sustain. Syst.*, **7**, 8, 2300107 (2023)

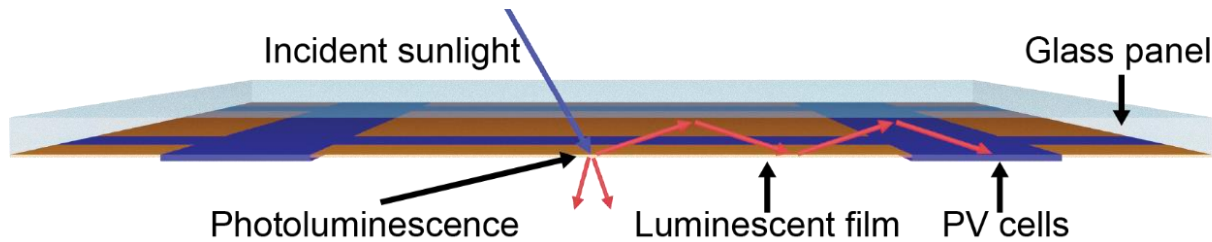
Location	Period	Greenhouse	Heating demand (kWh/m <sup>2</sup> )	Cooling demand (kWh/m <sup>2</sup> )	Total demand (kWh/m <sup>2</sup> )	Energy generation (kWh/m <sup>2</sup> )
AZ	Annual	Conv.	99.5	40.4	139.9	-
		LSC	116.2	34.3	<b>150.5</b>	<b>214.1</b>
MN	Annual	Conv.	839.8	12.8	852.5	-
		LSC	997.2	8.1	1005.3	<b>143.9</b>
	May-Sep	Conv.	69.0	12.4	81.5	-
		LSC	89.6	8.1	<b>97.6</b>	84.2

- LSC design parameters: luminophore and concentration
- 5 wt% Si QD LSC greenhouses can generate enough annual energy to power greenhouses in AZ
- MN greenhouses have high heating demands

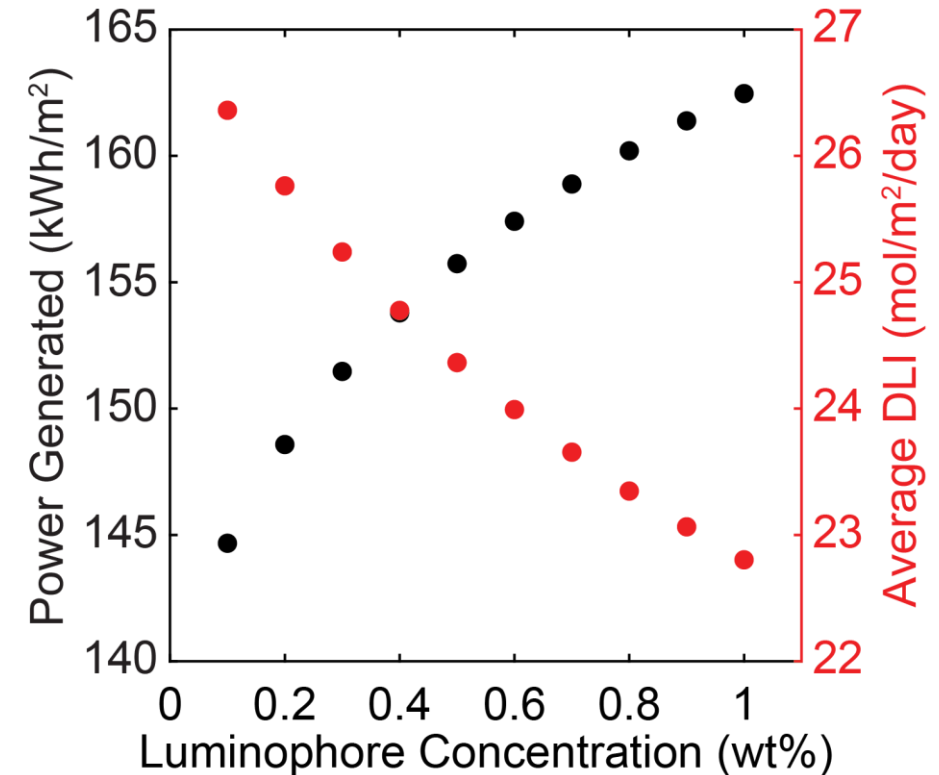


# Competing Priorities in LSC Greenhouse Design

Low concentration range to minimize reabsorption:



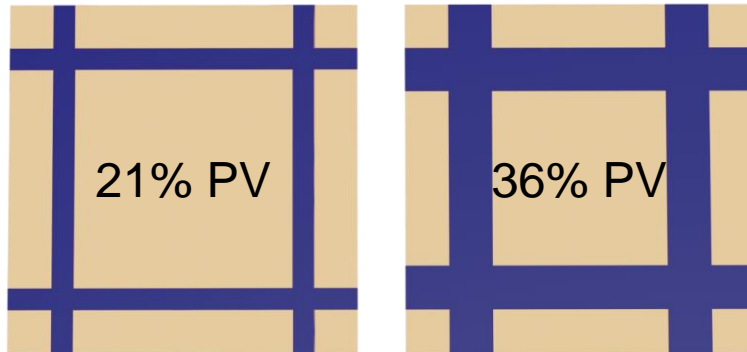
Liu, Y., et al, *Adv. Sustain. Syst.*, **7**, 8, 2300107 (2023)



How can we design LSCs to balance the tradeoff between light transmission and energy generation?

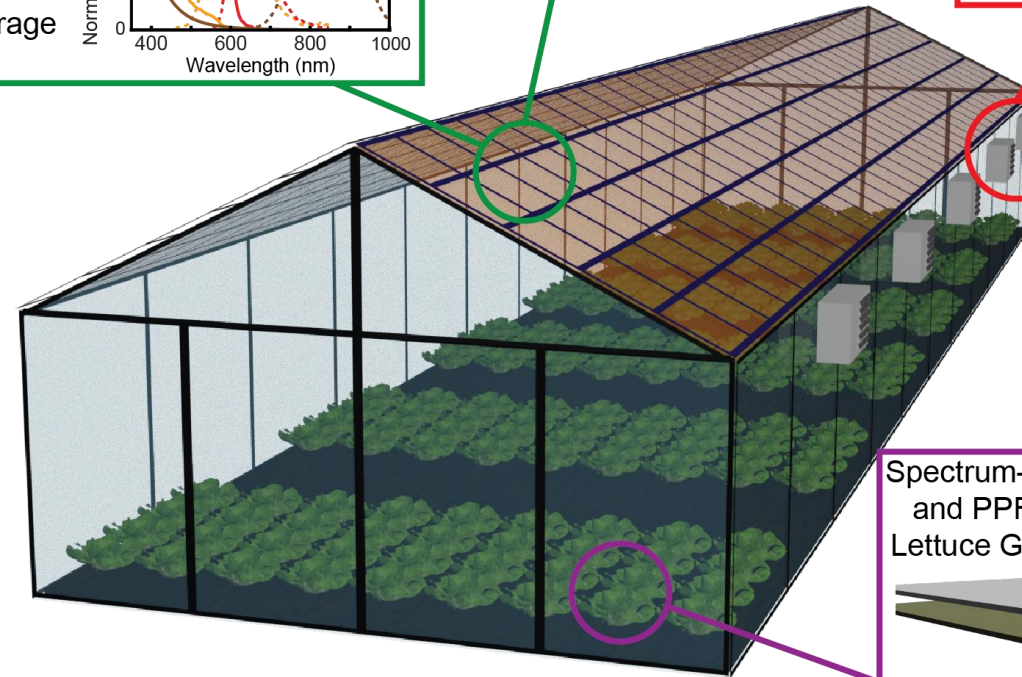
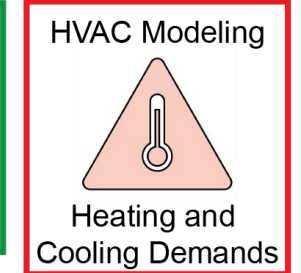
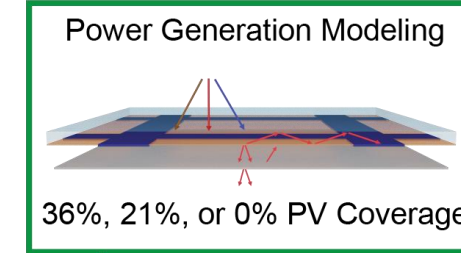
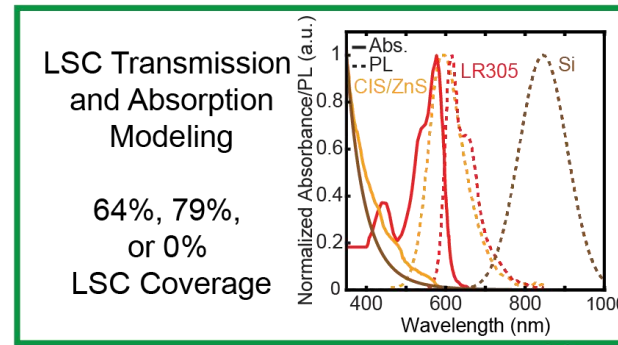
# LSC Greenhouse Modeling Framework

- Varying three nontoxic luminophores' concentrations
- Varying LSC sizes

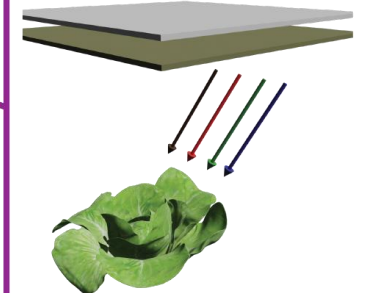


16 x 16 cm LSC      8 x 8 cm LSC

- Compared to conventional glass greenhouse

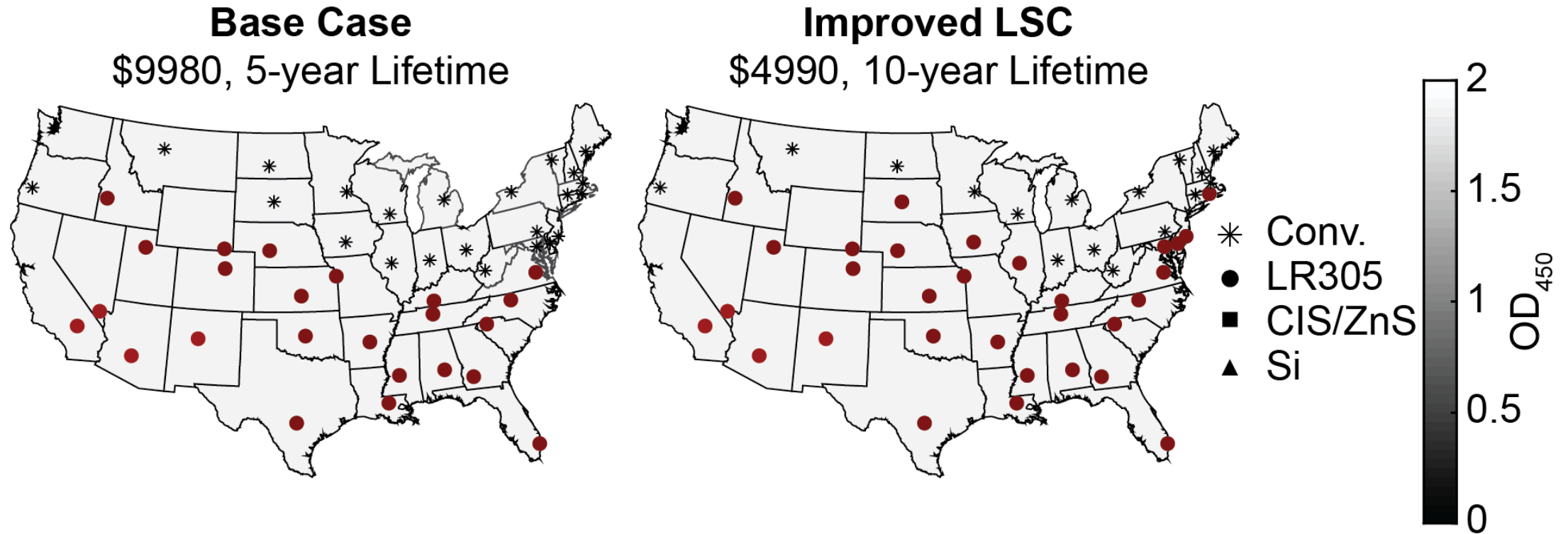


Spectrum-, temperature-, and PPFD-dependent Lettuce Growth Modeling





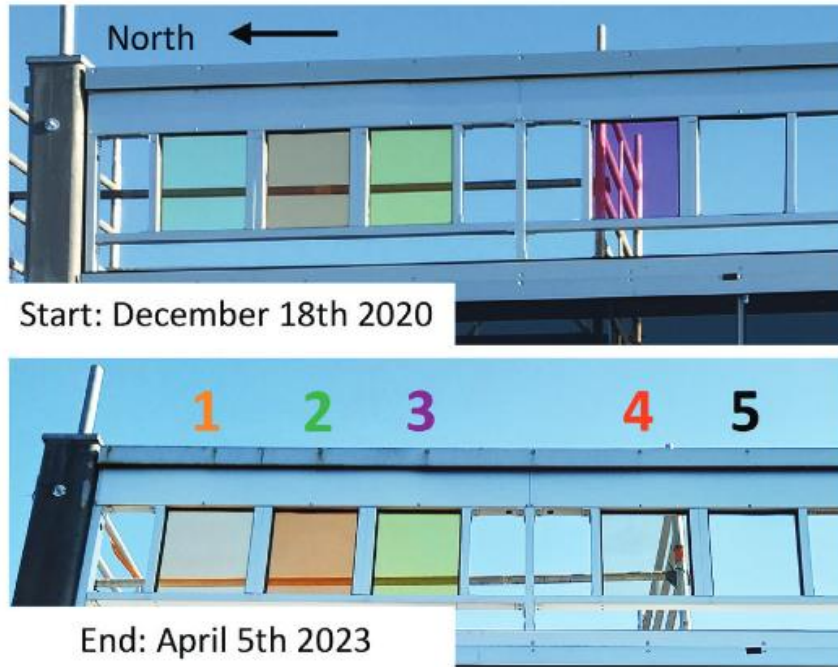
# LSC Greenhouses in the Continental United States



LSC design that maximizes red light transmission enhances profit!  
Improving LSC lifetimes and cost can help make LSC greenhouses more economically viable, even in cold climates.

# Opportunities for Exploration

## Outdoor Tests for BIPV



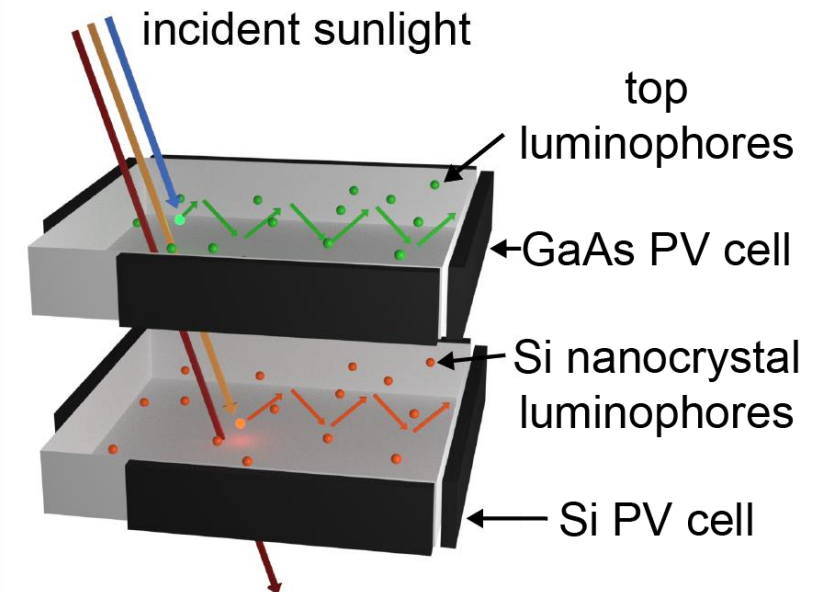
Terricabres-Polo, R., et al, *Adv. Energy Mater.*, 2402375 (2024)

## More Crop Types (like broccoli!)



Mälardalen University

## Tandem LSCs (my current project!)



Keil, J. et al, *2021 IEEE 48th Photovoltaic Specialists Conference (PVSC)*, pp. 1680-1684

14



## Advisors

Prof. Vivian Ferry

Prof. Uwe Kortshagen

## Ferry Group Members

Rohan Chakraborty

Dr. Yidenekachew Donie

Clare Froehlich

Aquarina Hoanca

Dr. Emily McGuinness

Ayaka Moriyama

Maya Ramamurthy

Hagmar Tinoco

## Kortshagen Group Members

Masoumeh Amirifard

Thomas Cameron Jr.

Mohammad Kazemi

Bailey Klause

Sachin Kumar

*Dr. Yaling Liu*

Yue Zhao

## Collaborators

Dr. Kale Harbick (USDA)

Prof. Nate Eylands (UMN Horticultural Sciences)

# Acknowledgements



**Thank you! Questions?**



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