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

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Professors Vivian Ferry and Uwe Kortshagen

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About Me

- Kristine Loh (she/her)
- 5th 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: *Agri*culture + Photo*voltaics*

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

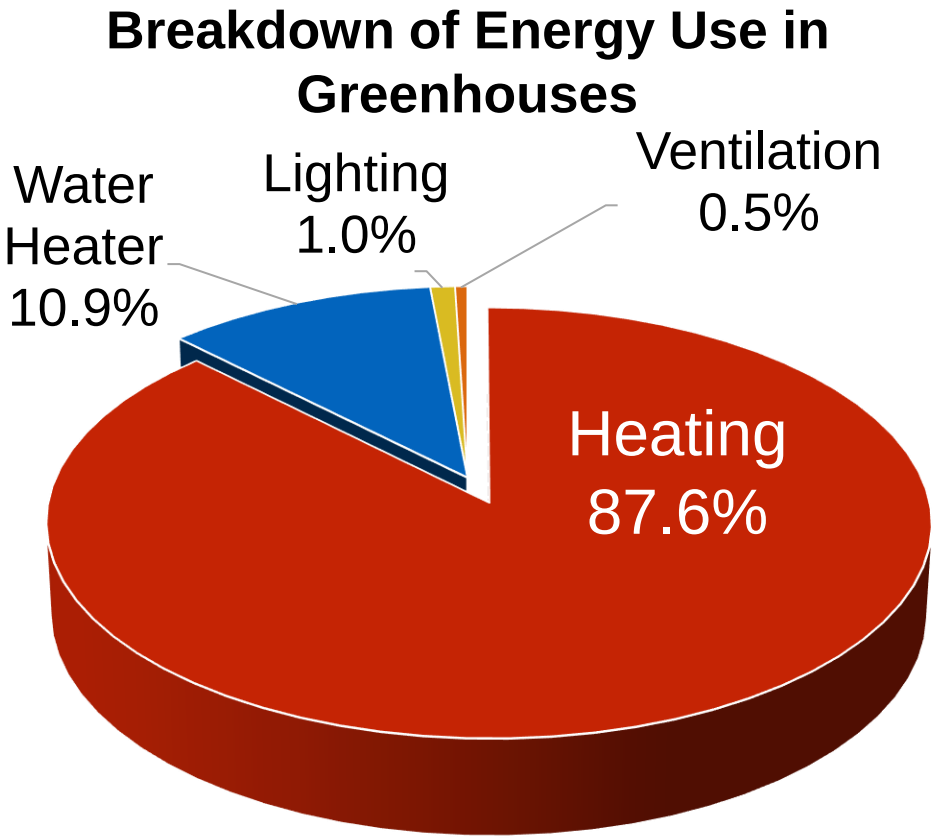
https://www.agweek.com/livestock/umn-morris-mixes-cows-and-solar-on-midwests-largest-agrivoltaic-pasture

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

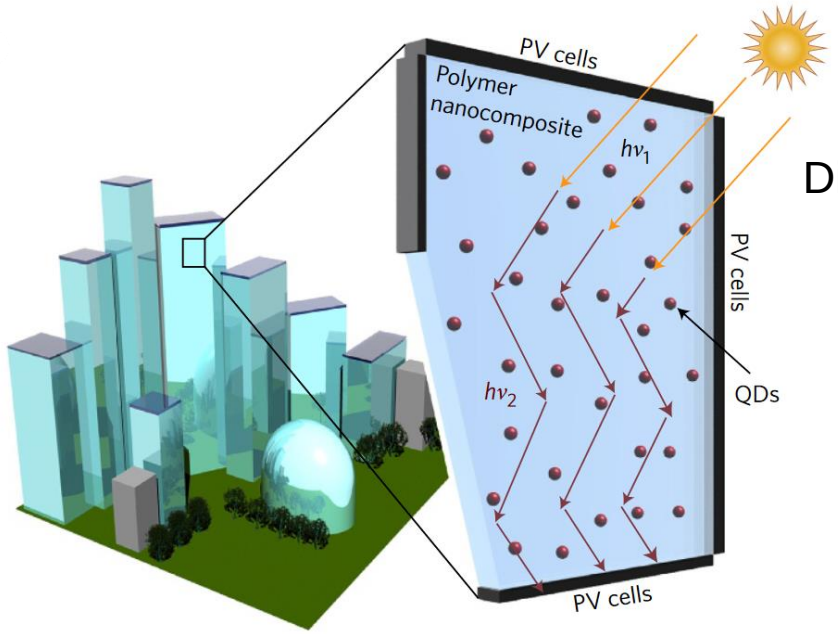
https://projects.research-and-innovation.ec.europa.eu/en/horizon-magazine/feed-growing-population-farmers-look-sun



Michigan Farm Program, 2021

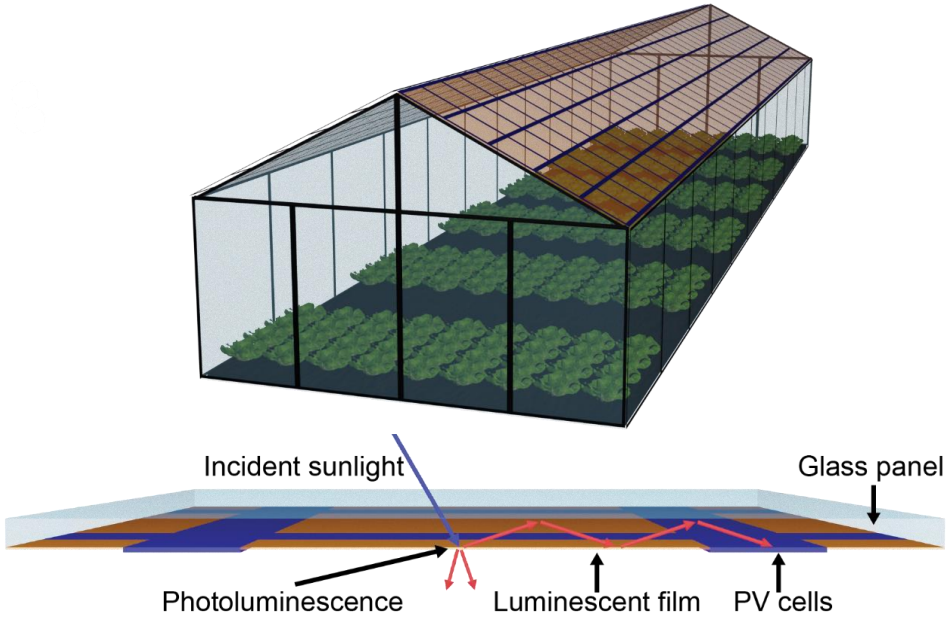
How can agrivoltaic greenhouses offset or meet large energy demands?

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



Diffuse and Direct!

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



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

<u>Design requirements:</u>
Broad absorption, color rendering, semi-transparency, low reabsorption, high quantum yield, PV-matched emission

<u>Design requirements:</u>
Plant-specific color (absorption and emission), semi?-transparency, low reabsorption, high quantum yield?

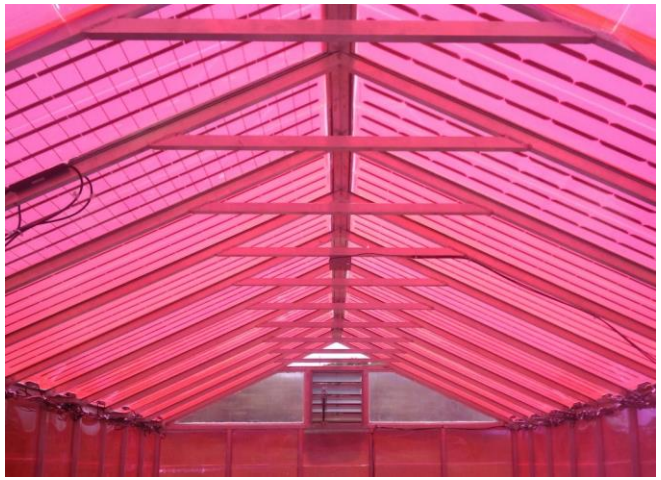
Given different design goals, what is an ideal LSC for agrivoltaic greenhouses?

Commercial LSC Greenhouses and Opportunities for Exploration

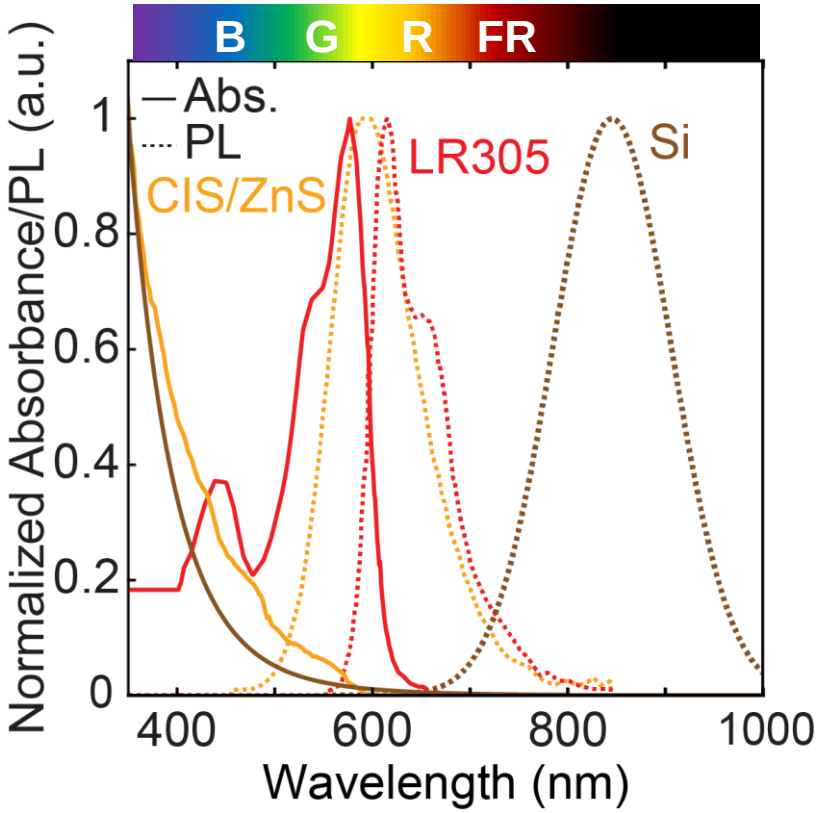
https://lleaf.com/shop/p/style-01-ej5na-8akeb

https://ubigro.com/

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



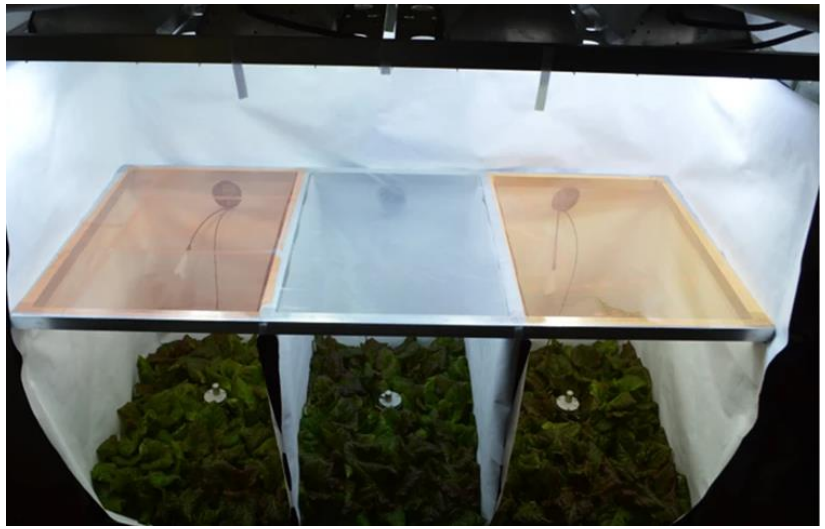
http://www.soliculture.com/projects/



How does LSC design impact greenhouse operation?

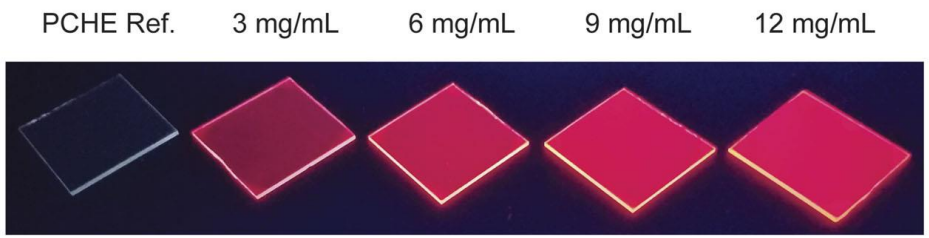
Large, Complex LSC Design Space for Agrivoltaics

Luminophore (Color)



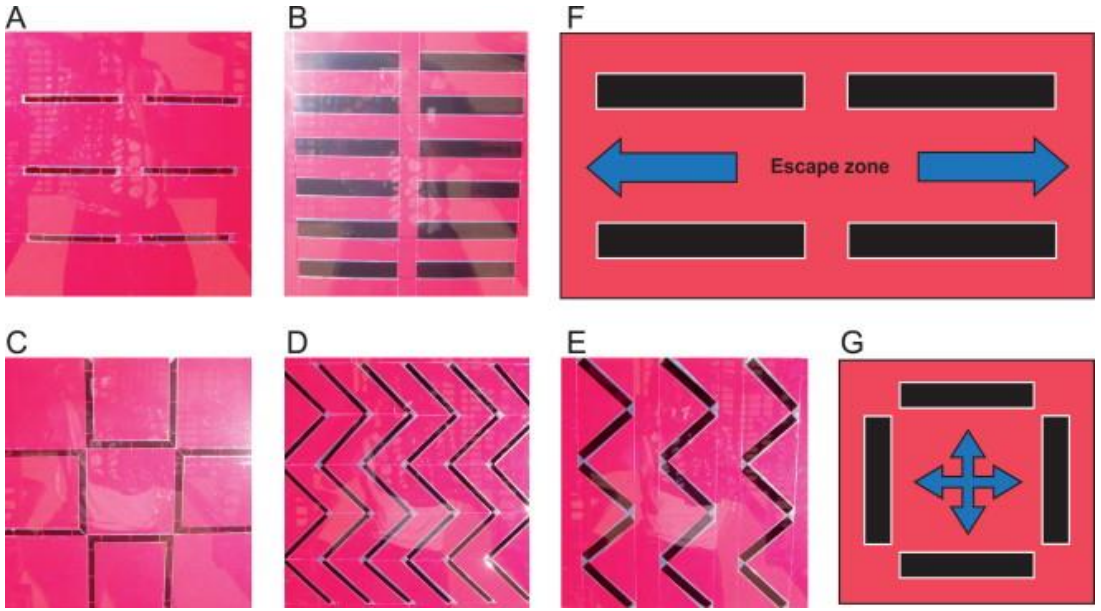
Parrish, C., et al, *Communications Biology*, **4**, 124 (2021)

Concentration



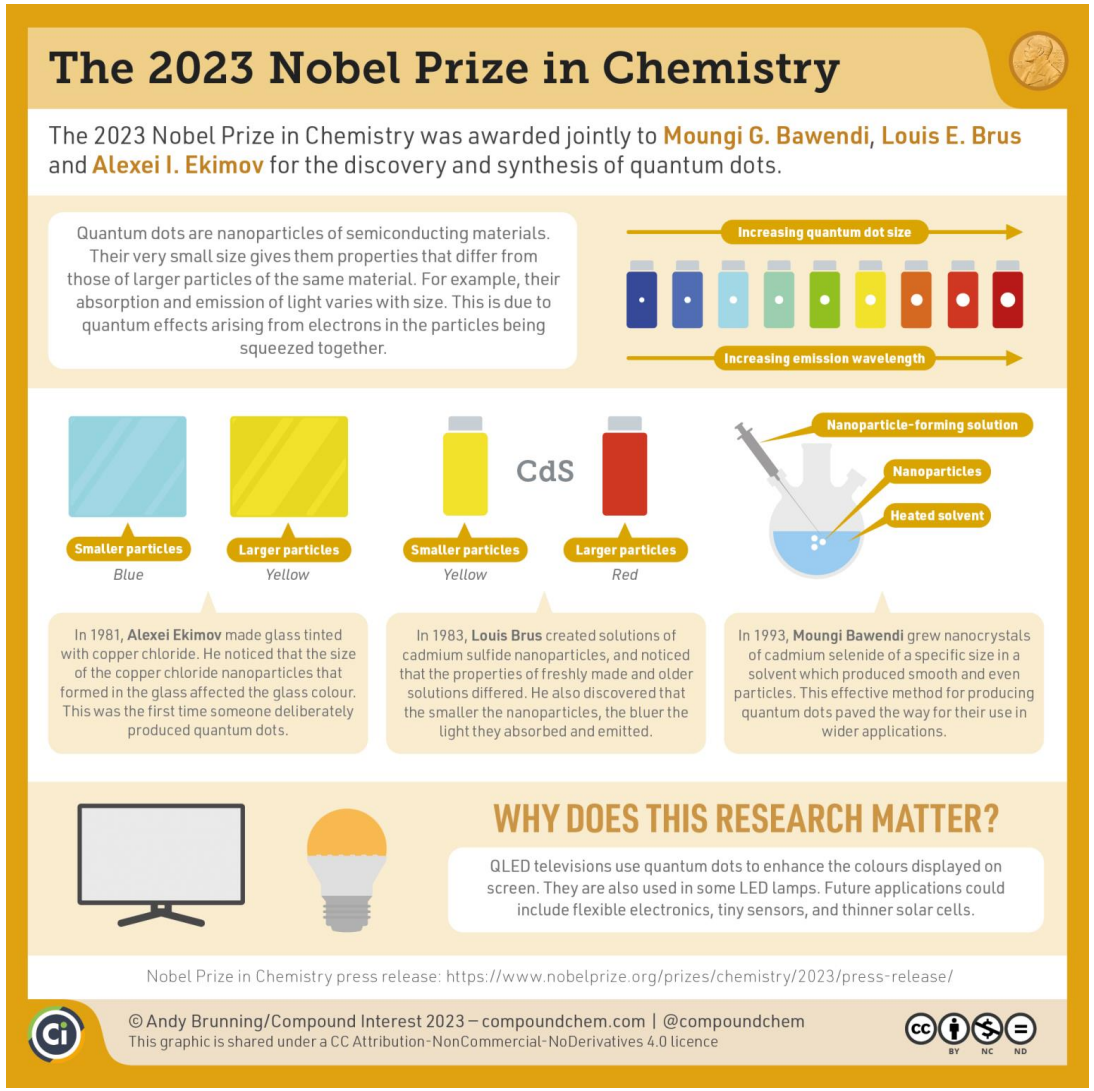
Connell, R., et al, *APL Mater.,* 7, 101123 (2019)

Shape and/or Size



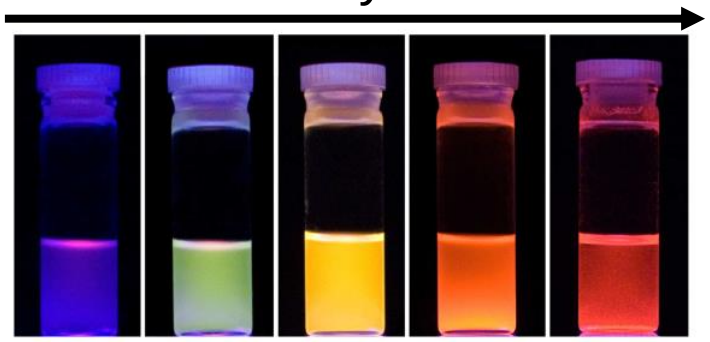
Corrado, C., et al, *Sol. Energy Mater. Sol. Cells.*, **111**, pp. 74-81 (2013)

Quantum Dots as Promising Material Candidates



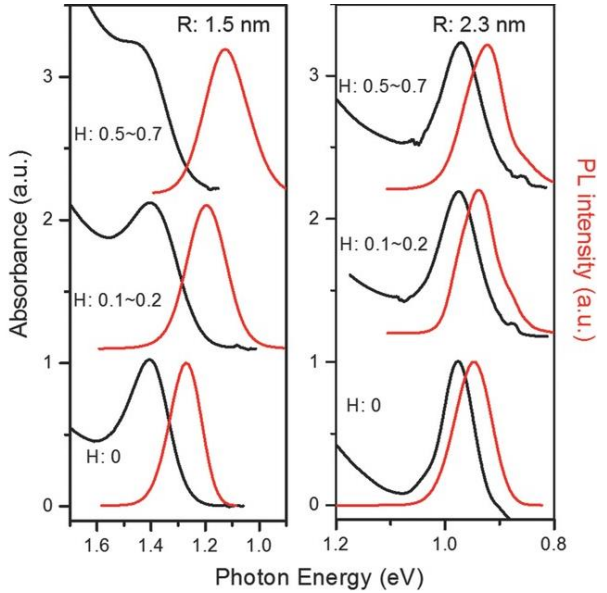
https://www.compoundchem.com/2023/10/04/2023nobelchemistry/

Si Nanocrystal Size



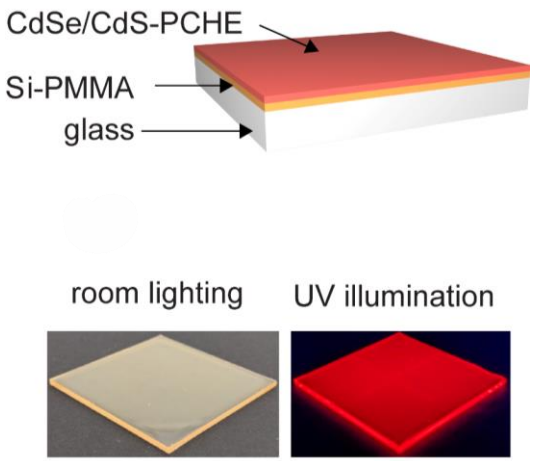
Pi, X.D., et al., *Nanotechnology*, 19, 245603, (2008)

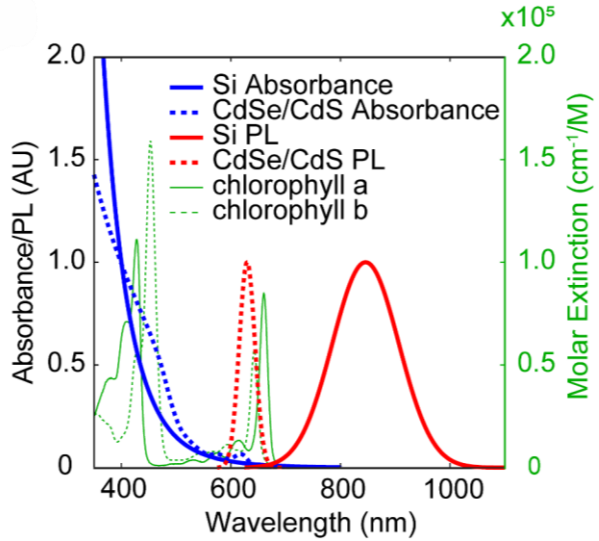
Stokes Shift Engineering

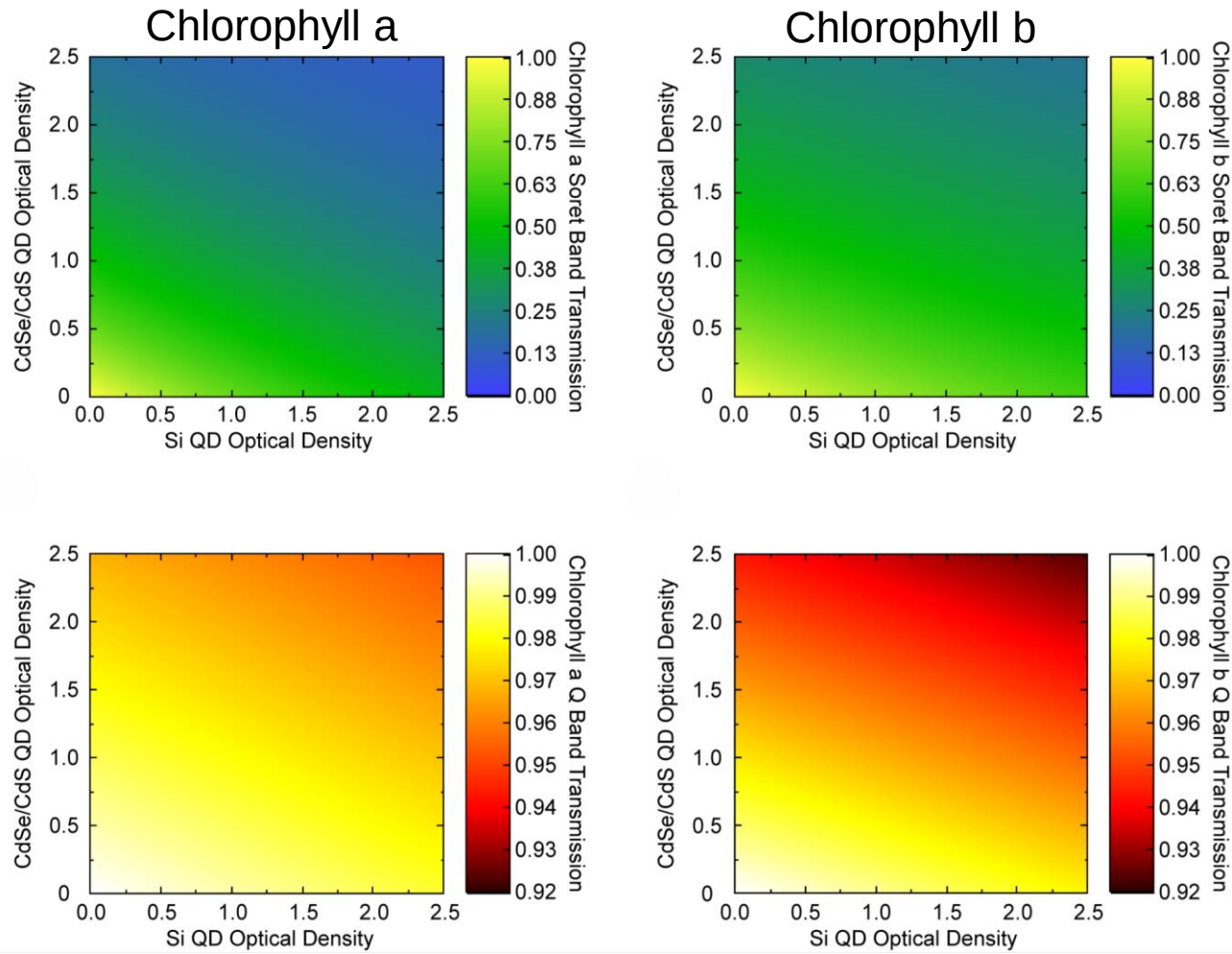


Zhou, Y., et al., *Adv. Energy Mater.*, 6(11), 1501913, (2016)

Bilayer LSC Films with Transmission Spectrum Tunability



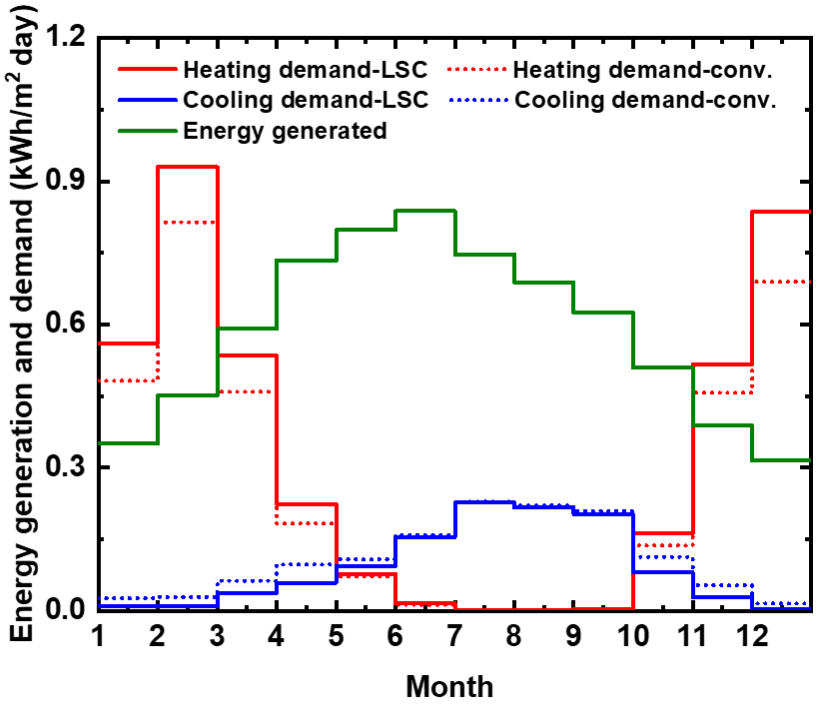




- LSC design parameters: luminophore, film structure, and concentration
- Fabricated and simulated bilayer film
- Bilayer films enhance optical efficiency (power generation) with potential spectral modification

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

Simulated Si LSC Greenhouses: Net Zero Energy in Arizona

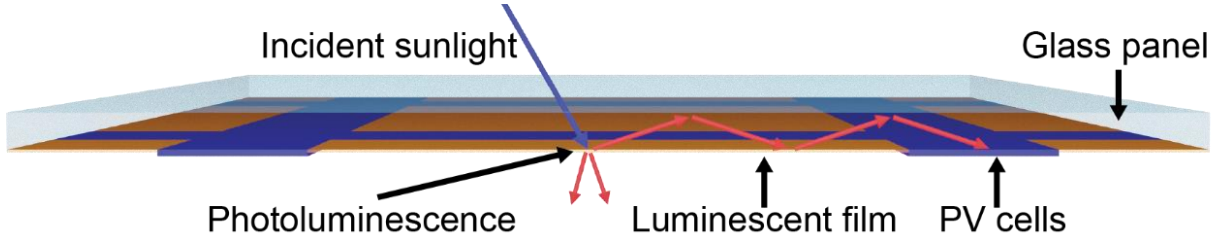


Location	Period	Greenhouse	Heating demand (kWh/m^2)	Cooling demand (kWh/m^2)	**Total demand (kWh/m^2)**	**Energy generation (kWh/m^2)**
AZ	Annual	Conv.	99.5	40.4	139.9	-
		LSC	116.2	34.3	**150.5**	**214.1**
MN	Annual	Conv.	839.8	12.8	852.5	-
		LSC	997.2	8.1	1005.3	**143.9**
	May-Sep	Conv.	69.0	12.4	81.5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

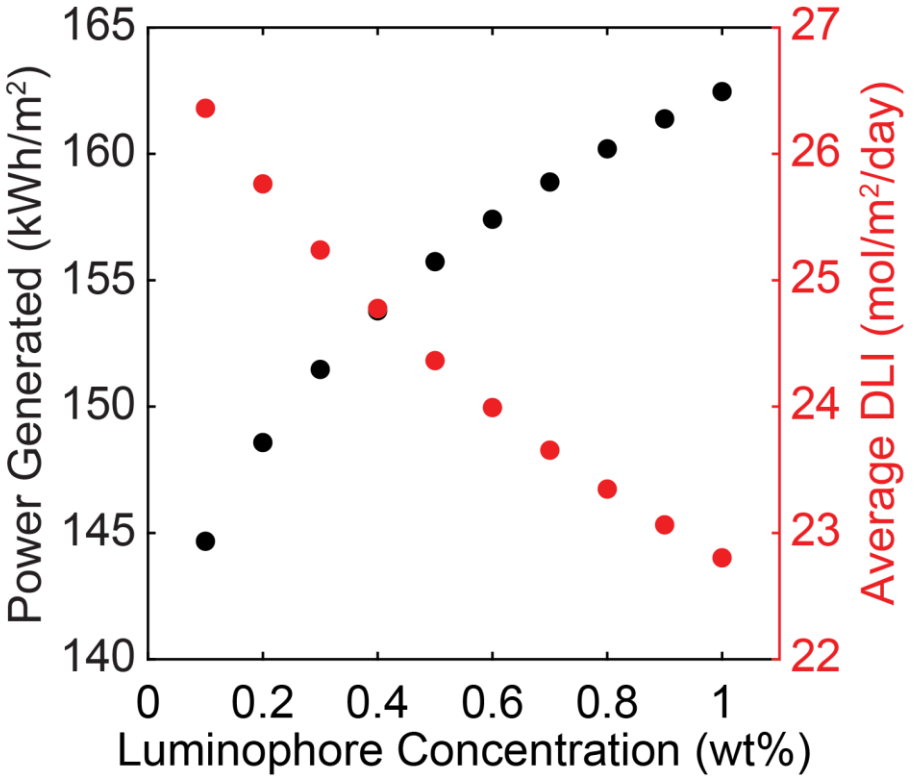
Liu, Y., et al, *Adv. Sustain. Syst.*, **7**, 8, 2300107 (2023)

Competing Priorities in LSC Greenhouse Design



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

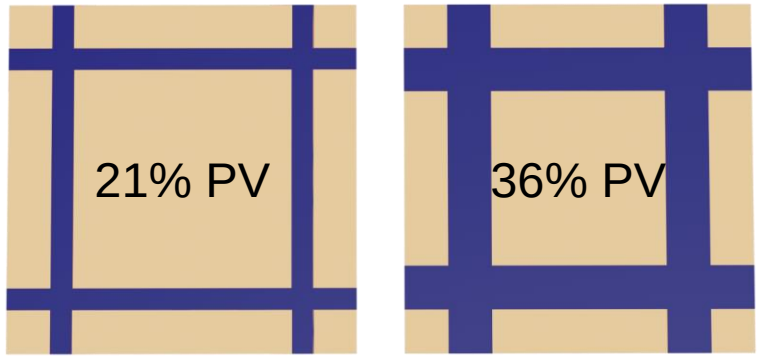
Low concentration range to minimize reabsorption:



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

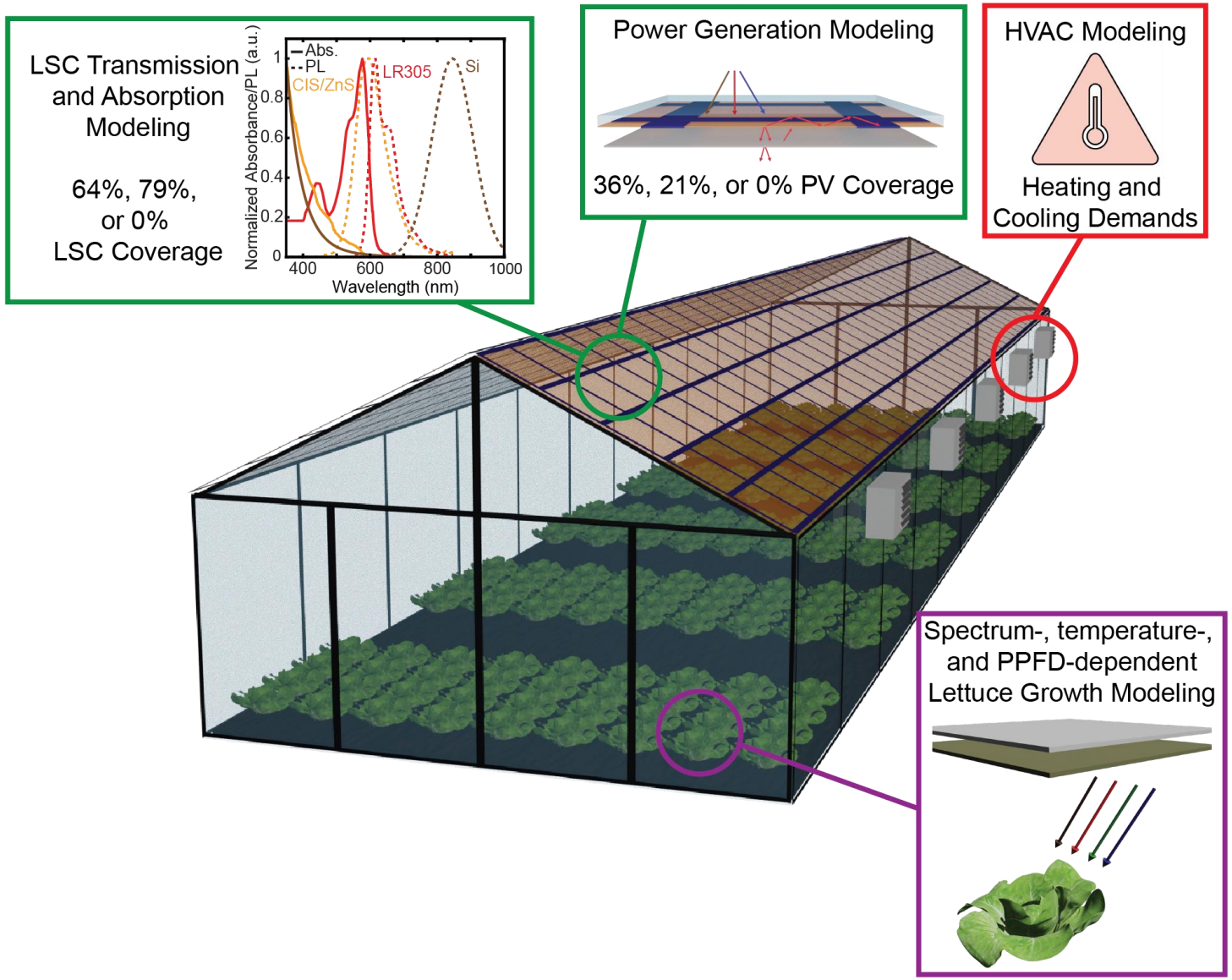
LSC Greenhouse Modeling Framework

- Varying three nontoxic luminophores' concentrations
- Varying LSC sizes

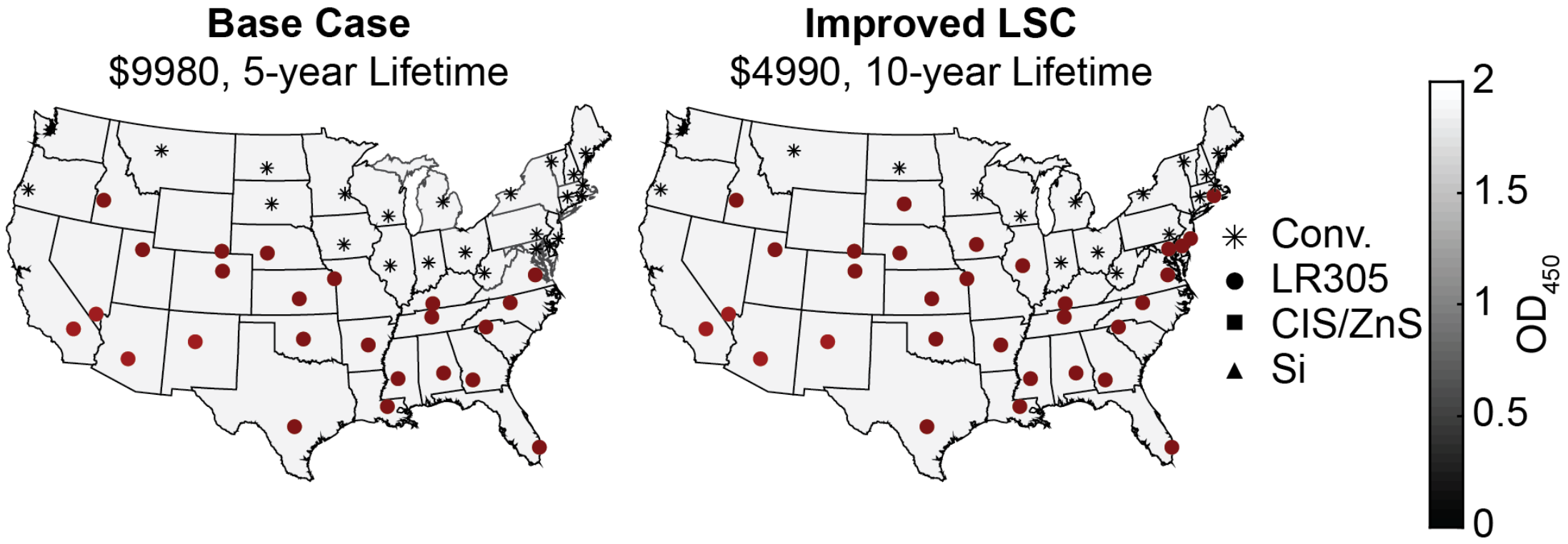


16 x 16 cm LSC 8 x 8 cm LSC

- Compared to conventional glass greenhouse



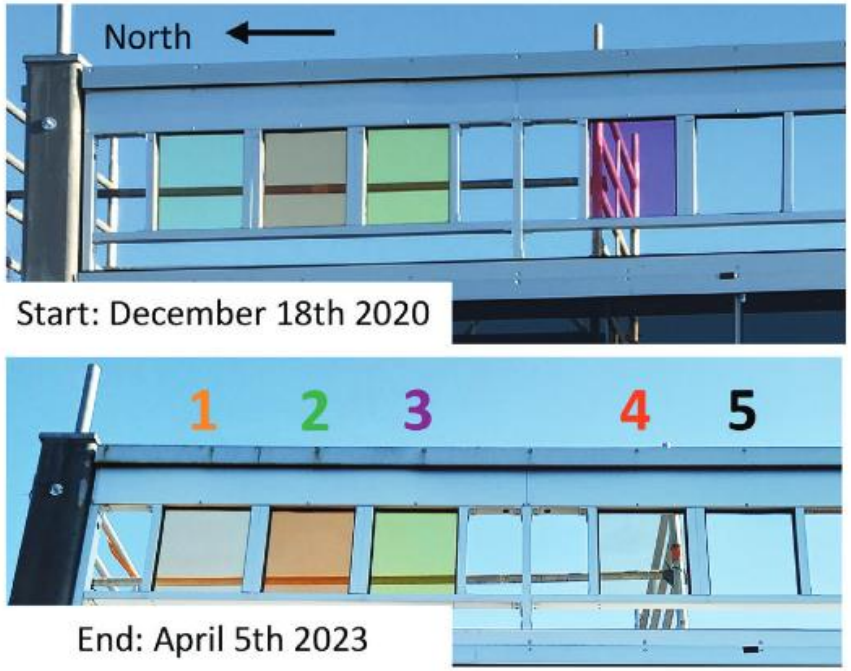
LSC Greenhouses in the Continental United States



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

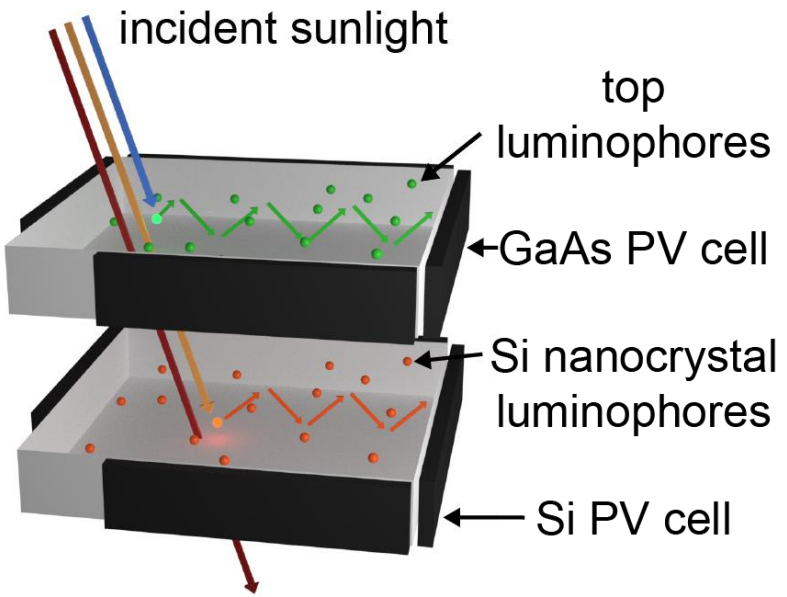


Terricabres-Polo, R., et al, *Adv. Energy Mater.*, 2402375 (2024)

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

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Thank you! Questions?