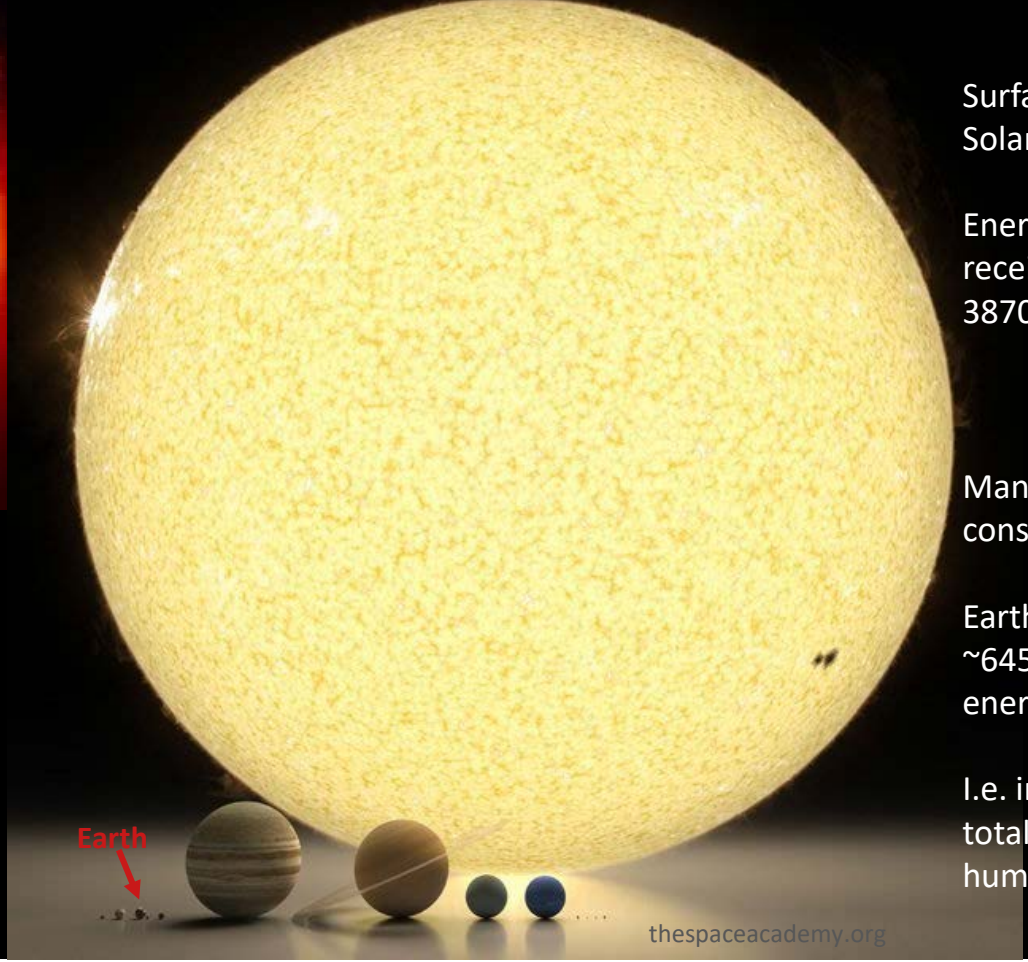


Surface temperature: ~5800 K
Solar radiation: ~3.9 x 10^{26} W

Energy (extraterrestrially) received by Earth:
3870 ZJ/yr

Mankind's energy consumption: ~600 EJ/yr

Earth receives every year ~6450 times its human energy use from the Sun.

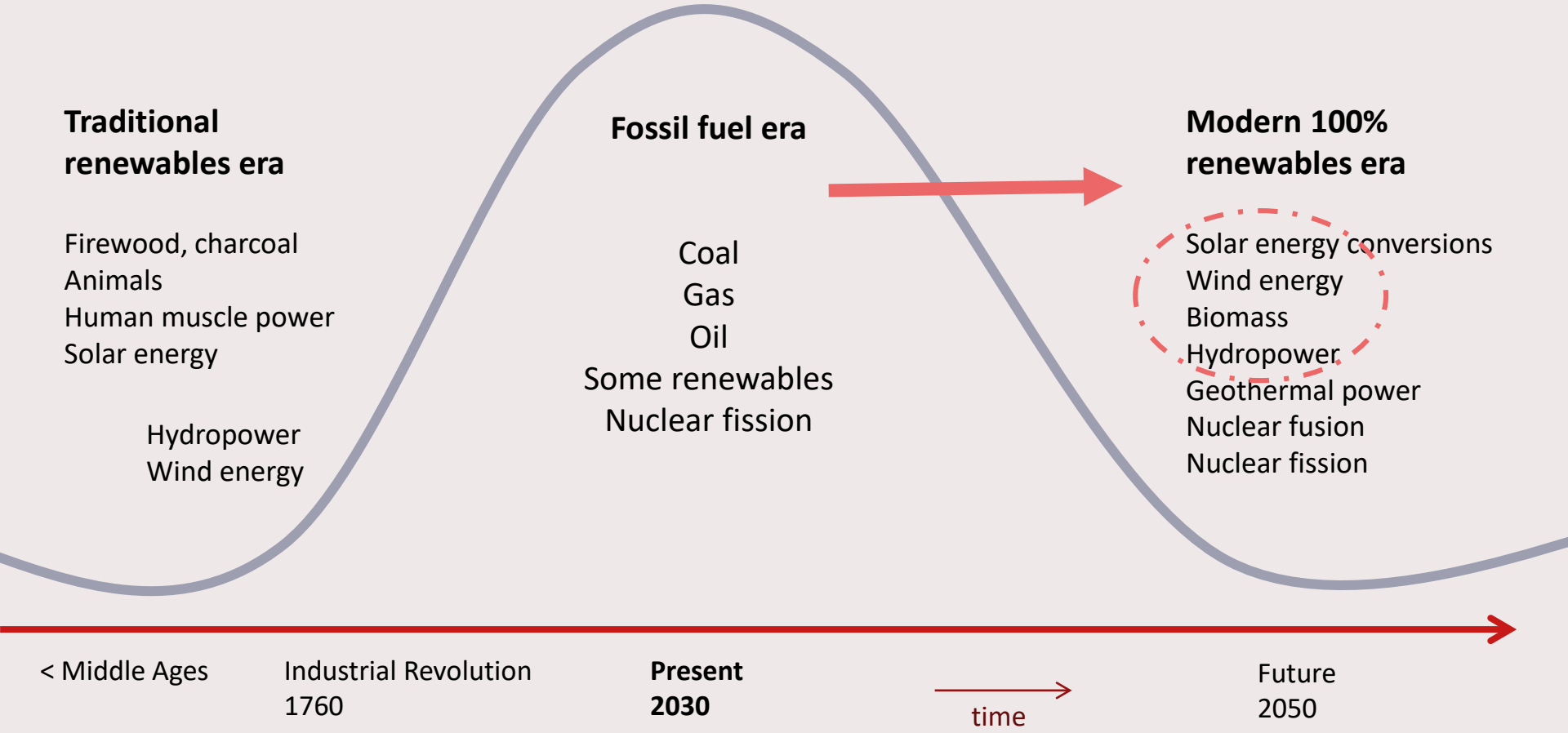
I.e. in approx. 1,5 hour the total amount of yearly human energy use!

Physics answer to the question

Can we achieve 100% solar energy supply?

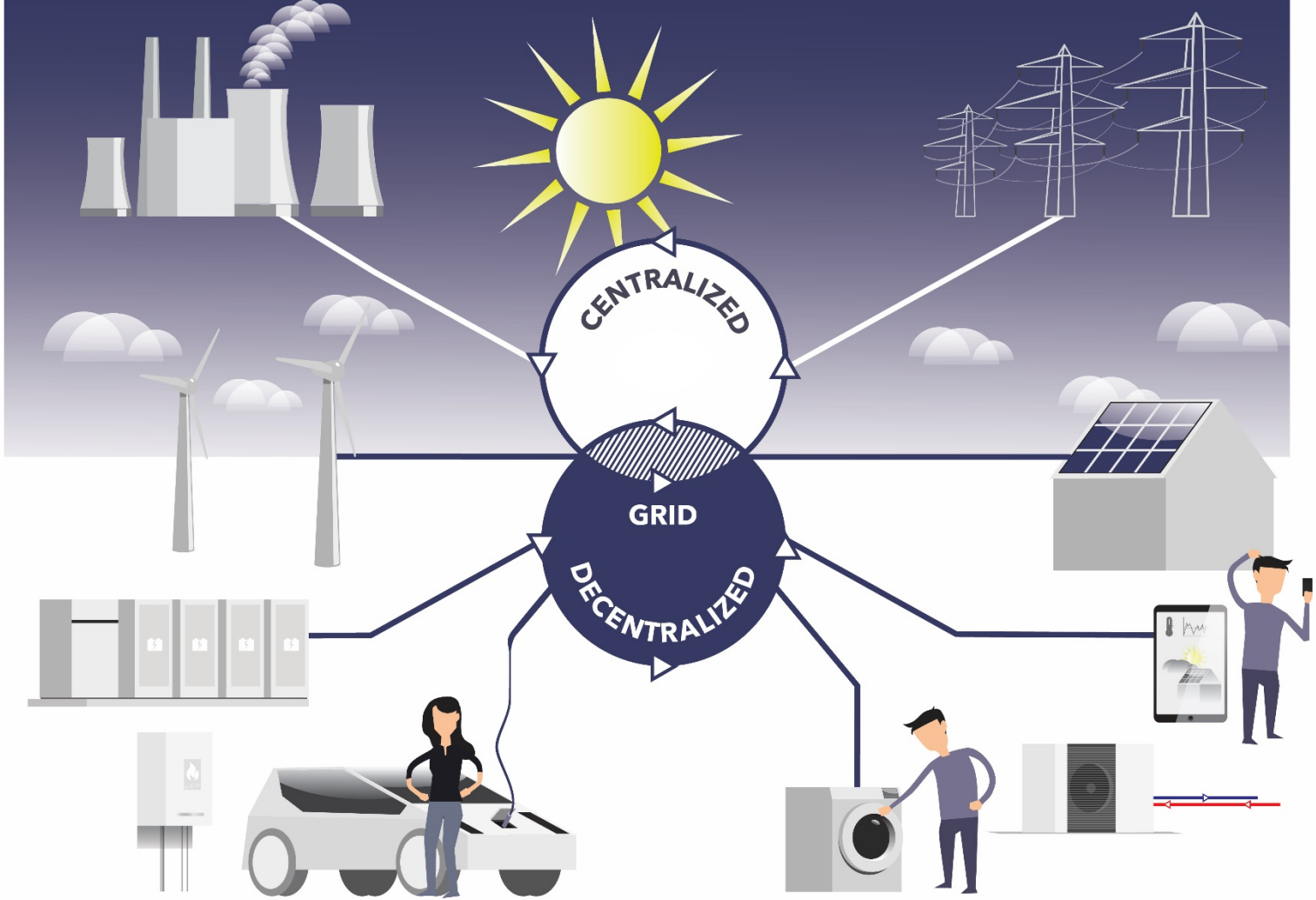
Yes, we can!

Energy transitions



Solar energy, technologies and their application contexts

Electricity	•Photovoltaic (PV) effect in semiconductor materials: silicon, III-V compounds, chalcogenides etc. Concentration irradiance. •PV systems: intermittency can be partially handled by grid, and demand management, otherwise additional storage is required	Infrastructures Buildings Transport	Challenge for large-scale use: daily and seasonal storage
Thermal energy	•Heat transfer through various (fluid) media by absorption, conduction, convection and radiation. Short term storage in system. • Eventually combined with PV technologies (PVT) and/or heat engine (CSP).	Infrastructures Buildings	Challenge: seasonal storage
Fuels	•Solar fuels: hydrogen, methane and ammonium, etc. Produced by: Electrolysis using PV electricity or photochemical processes using solar heat as an input •Fuel itself is the storage means	Infrastructures Transport	Challenges: cost compared to fossil fuels, TRL of technologies


CENTRALIZED
GRID
DECENTRALIZED

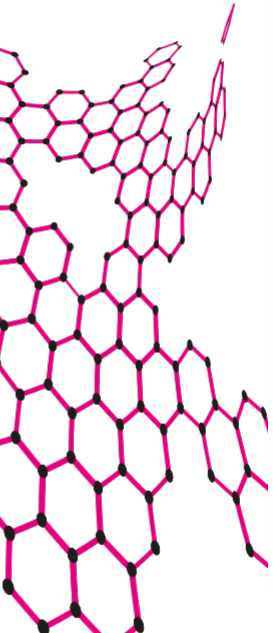
A possible route to achieve 100% solar energy supply

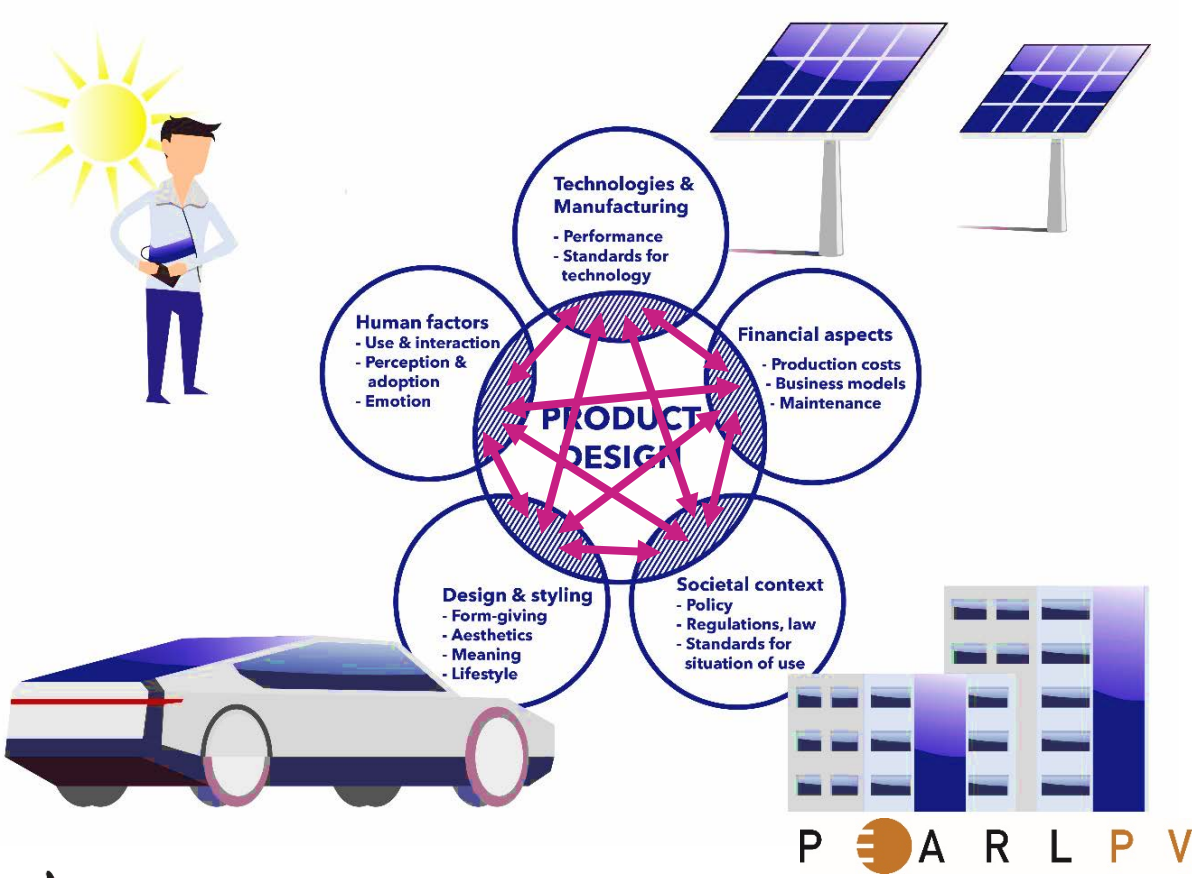
producing and using energy in a way that "meets the needs of the present without compromising the ability of future generations to meet their own needs"

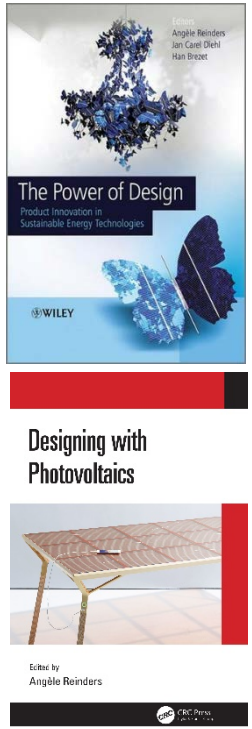
"the human capacity to shape and make our environment in ways without precedent in nature, to serve our needs and give meaning to our lives"

the long-term, structural transformation of a society which is mainly based on fossil fuel conversions to a decarbonized one with a high share of sustainable energy

DESIGN-DRIVEN RESEARCH







P A R L P V

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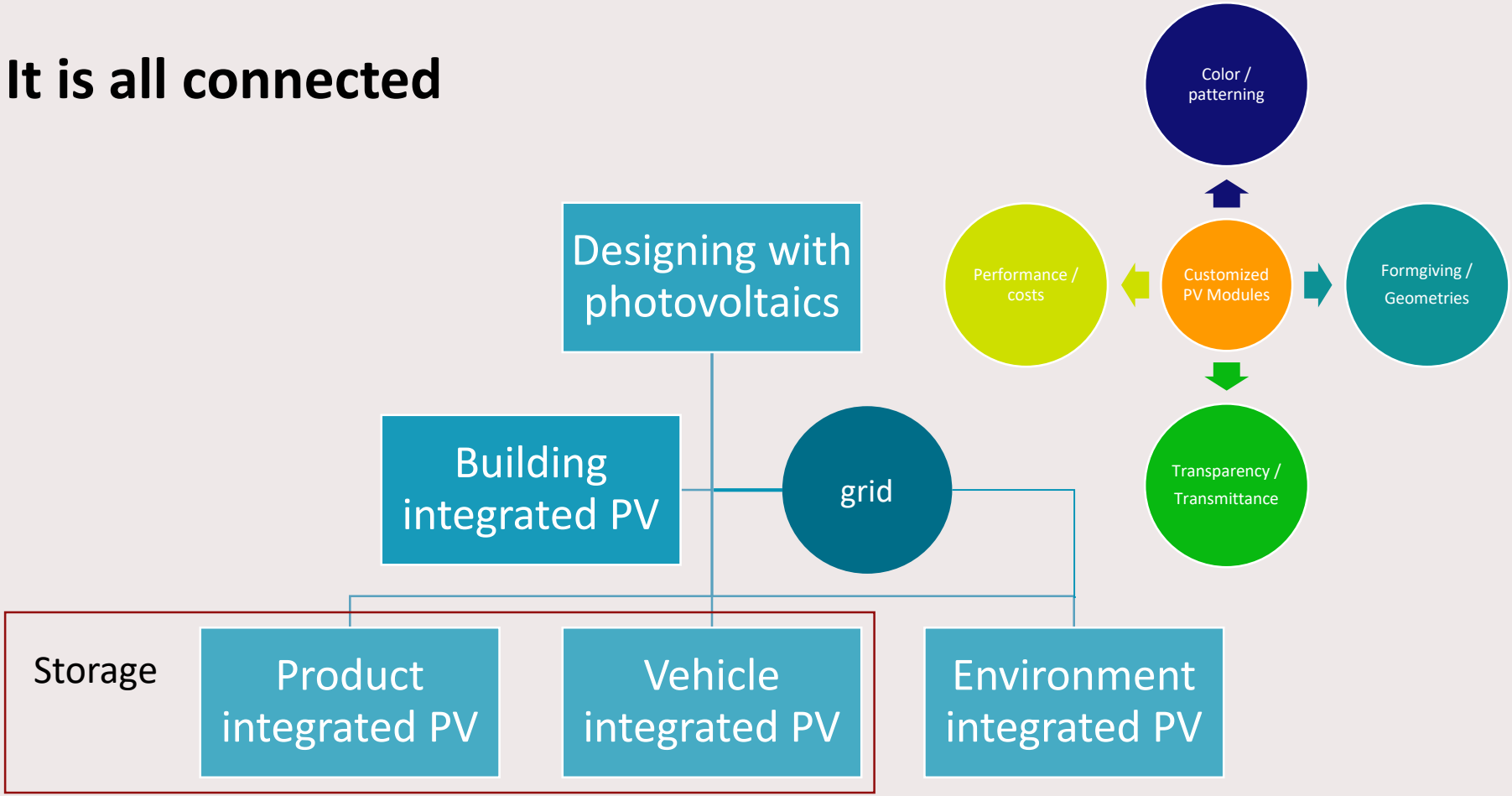
It is all connected



Solar integration: unique appearance will be possible

Backpack by Solid Grey, Kiwitz, 2016

Virtue of Blue by Jeroen Verhoeven, 2009-2010

PV plant in the shape of pandas

Solar powered PV art work resembling vegetation, Compaz Art, 2019

La Seine Musicale, by Shigeru Ban Architects, Paris.

PV applications in transport: electric vehicles

asom Association for Solar Mobility

Vehicles with integrated PV developed by LightYear (left), IM Efficiency (middle) and Trens Solar (right)

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Design features of commercially available PV

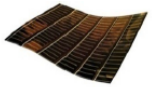
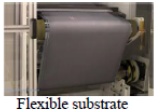
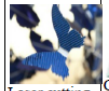
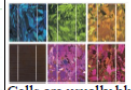
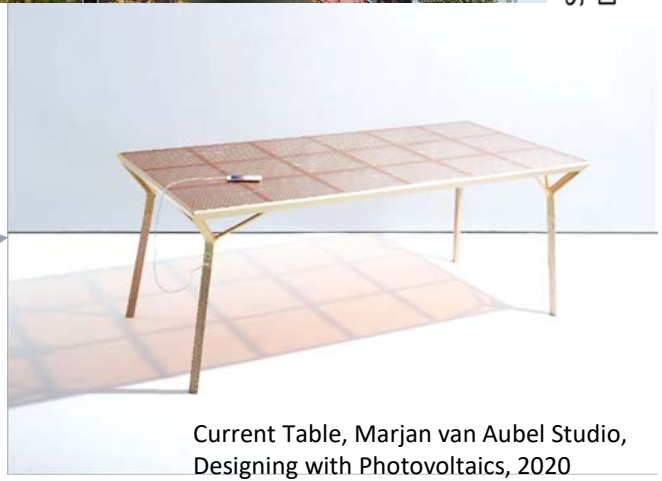
PV technologies	Typical size Substrate (mm × mm)	Patterning	Shaping of edges	Bending andcurvature	Color	Transparency
CdTe	Customizable from 10 × 10 to 1,000 × 2,000, rigid and flexible	 Screen printing front glass	n.a.	 Flexible substrate	Cells are brownish or black. Color by colored front glass	Semi-transparency by wider space between cells and laser scribing
CIGS	Customizable from 10 × 10 to 1,000 × 2,000, rigid and flexible	 Screen printing front glass	n.a.	 Flexible substrate	 Colored front glass	Semi-transparency by wider space between cells and laser scribing
a-Si	Customizable from 10 × 10 to 1,000 × 2,000, rigid and flexible	Screen printing front glass	n.a.	 Flexible substrate	 Cells are usually brownish or black, other colors can be produced	Semi-transparency by wider space between cells and laser scribing
 x-Si/p-Si	156 × 156 (cells), rigid only due to the fragility of the cells	 Cells can be used as pixels	 Laser cutting	 Curvature by rigid carrier substrate	 Cells are usually blue, other colors can be produced	Semi-transparency by wider space between cells and punching holes in cells
DSSC	Customizable from 10 × 10 to 1,000 × 2,000, rigid and flexible	Cells can be used as pixels	Defined by cell geometry, i.e., shaping of cell	Flexible substrate	Orange, reddish, purple, depending on the dye applied	Always transparent

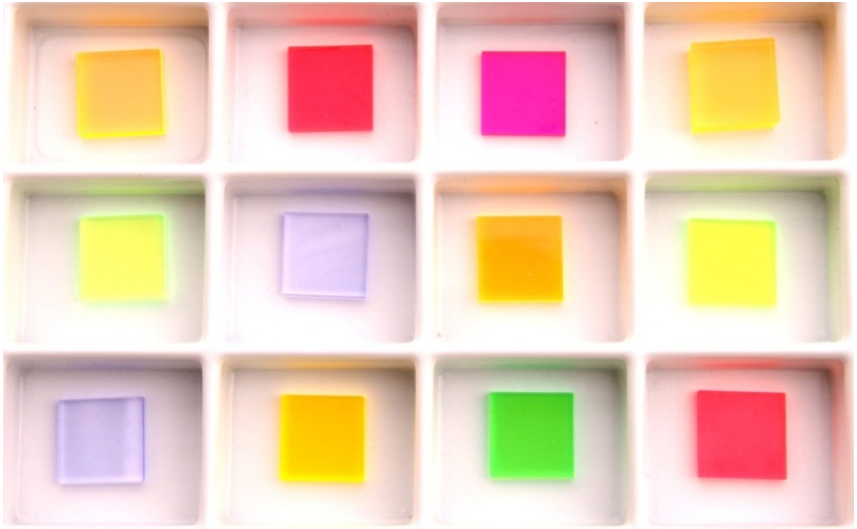
Figure from Chapter 3, Designing with Photovoltaics, 2020

Solaris Building, Alessandra Scognamiglio, Designing with Photovoltaics, 2020

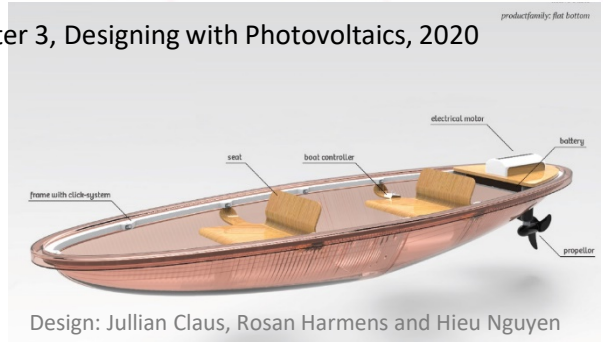


Current Table, Marjan van Aubel Studio, Designing with Photovoltaics, 2020

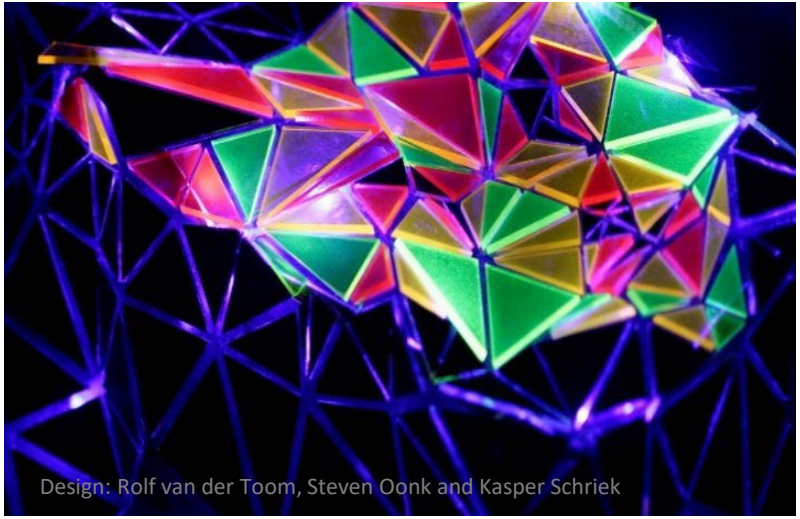
Design features of luminescent solar concentrators



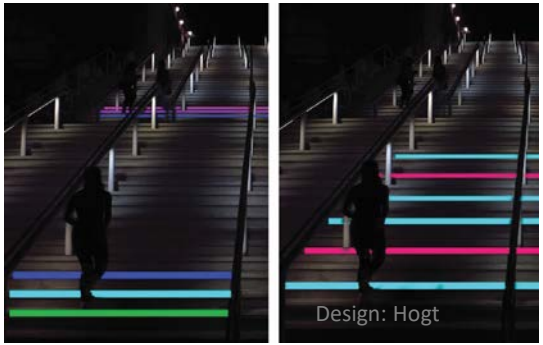
Colors of LSCs, Chapter 3, Designing with Photovoltaics, 2020
& Shaping of LSCs:



Design: Jullian Claus, Rosan Harmens and Hieu Nguyen

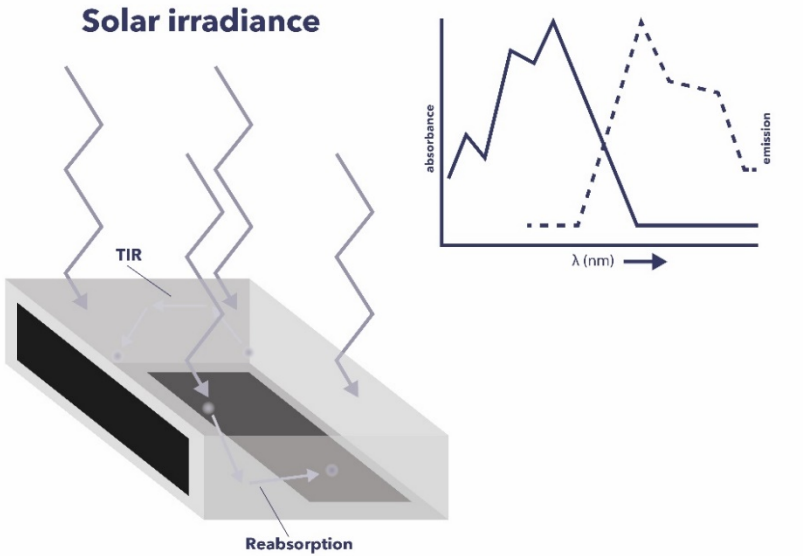


Design: Rolf van der Toom, Steven Oonk and Kasper Schriek

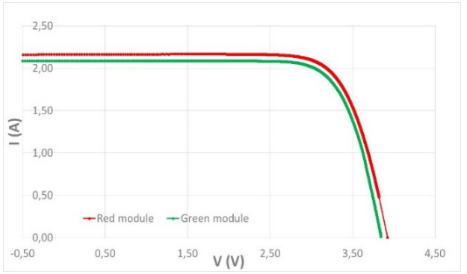


Design: Hogt

LUMINESCENT SOLAR CONCENTRATOR PHOTOVOLTAICS (LSC PV)



Reinders, A.H.M.E., Debije, M.G. and Rosemann, A.L.P., Measured efficiency of a luminescent solar concentrator PV module called Leaf Roof, Journal of Photovoltaics, Vol. 7, No. 6, 1663 – 1666, 2017

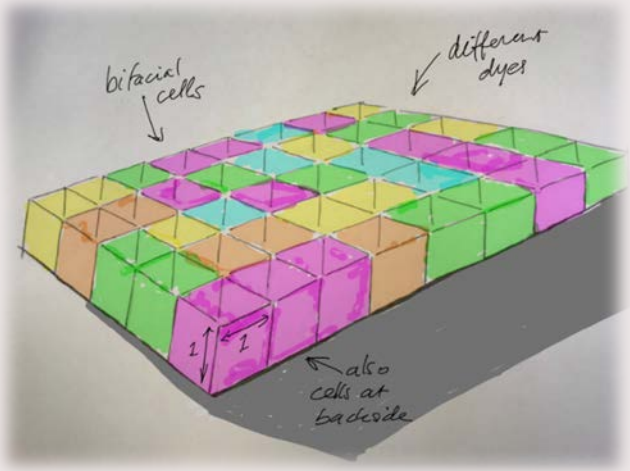


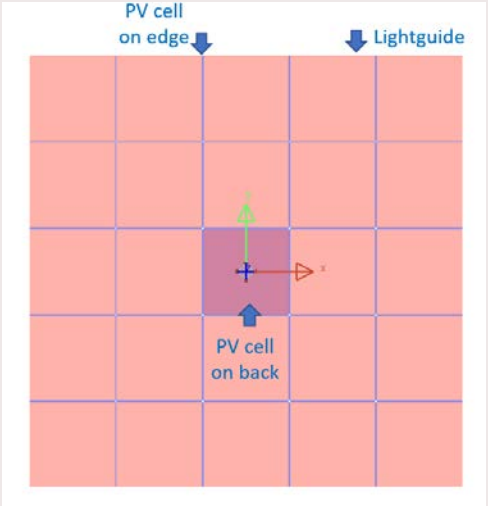
LSC PV modules from the LeafRoof project and their I-V curves under Standard Test Conditions (Reinders, Debije et al. 2017).

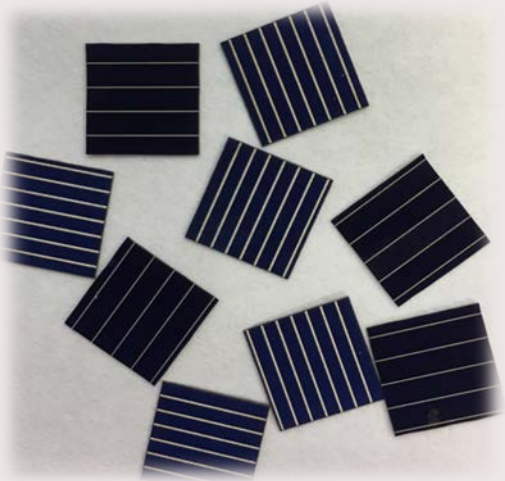
Impression of a dwelling with customizable, integrated LeafRoof modules (2016).

Developing highly-efficient LSC PV devices

Bifacial LSC PV devices with an array of cubical lightguides







Angele Reinders, Ned Ekins-Daukes, Timothy Schmidt, Hanbo Yang, Monika Michalska, Rosina Pelosi, Marcello Nitti, Lara Gillan, Dane McCamey, Elham M. Gholizadeh, Parisa Hosseinabadi, Blair Welsh, Scott Kable, ***Designing with luminescent solar concentrator photovoltaics***, IEEE 46th Photovoltaic Specialists Conference, Chicago, **2019**

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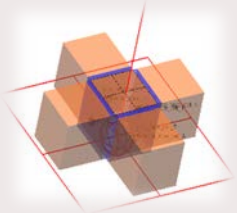
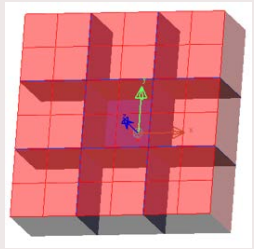
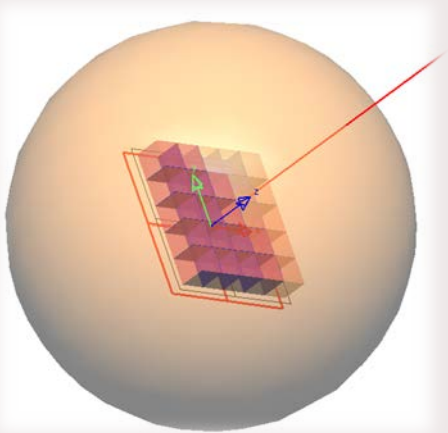
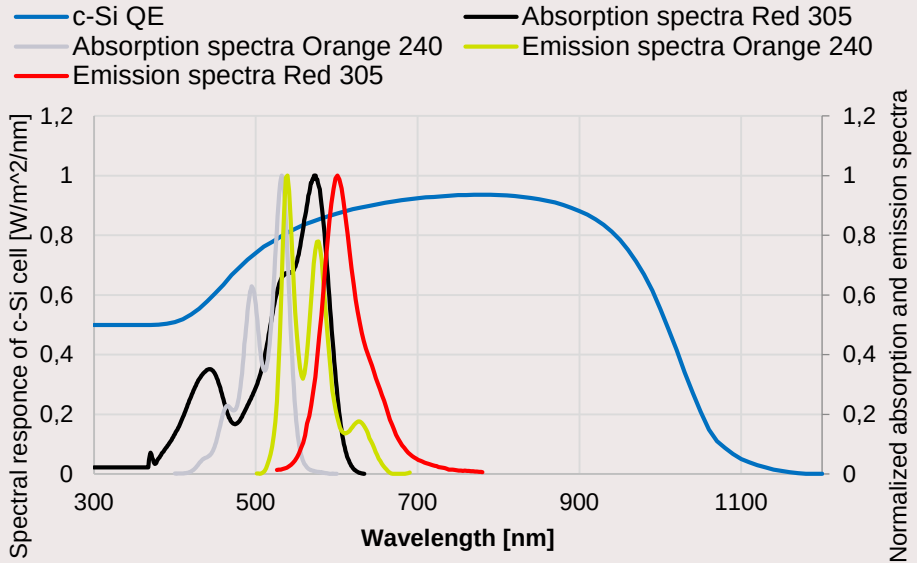
Ray-tracing simulations of bifacial LSC PV devices







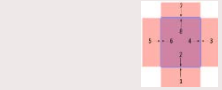
LSC cubes: 1 x 1 x 1 cm3, PMMA doped with Lumogen dye (Orange 240 or Red 305)
Silicon solar cells, refractive index is wavelength dependent
Irradiance: 700 W/m^2 direct (AM1.5 spectrum) and 300 W/m^2 diffuse irradiance

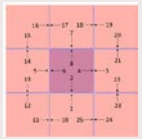


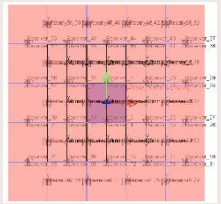
Aghaei, M.; Nitti, M.; Ekins-Daukes, N.J.; Reinders, A.H. **Simulation of a Novel Configuration for Luminescent Solar Concentrator Photovoltaic Devices Using Bifacial Silicon Solar Cells**. *Appl. Sci.* **2020**, *10*, 871.

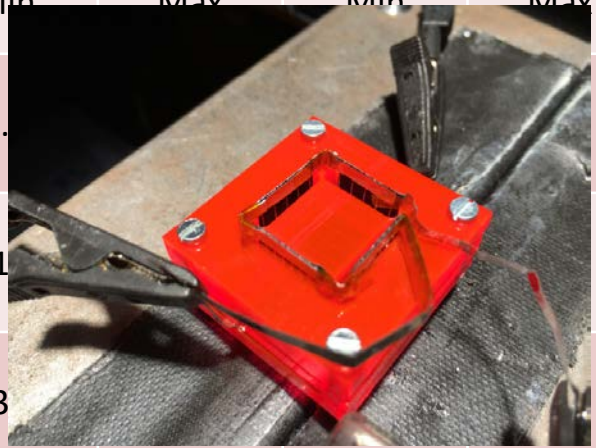
Power conversion efficiency (%)

	Orange Dye				Red Dye			
	Whole device		Device with only side cells		Whole device		Device with only side cells	
Number of PV cells	Min	Max	Min	Max	Min	Max	Min	Max
4 on the sides + 5 on the back	6.7	9.2	0.3	0.9	5.			
12 on the sides + 9 on the back	13.0	**16.9**	0.9	2.5	11			
40 on the sides + 25 on the back	14.5	15.5	1.8	2.3	13			





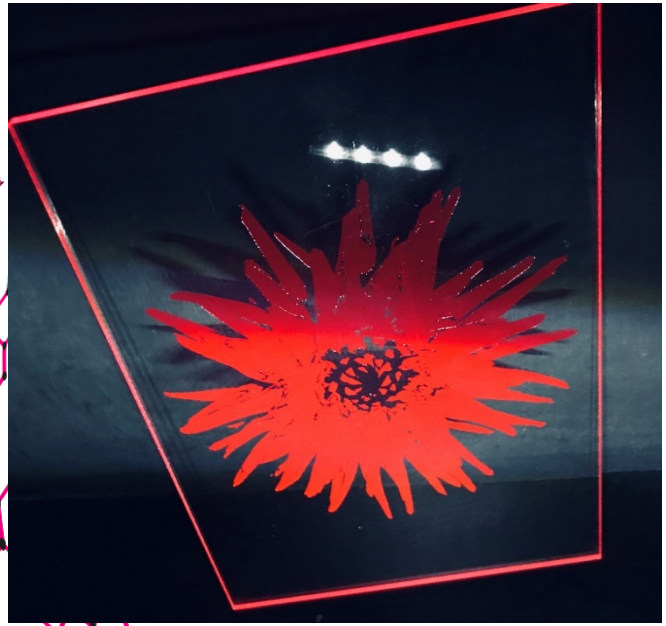




Aghaei, M.; Nitti, M.; Ekins-Daukes, N.J.; Reinders, A.H. **Simulation of a Novel Configuration for Luminescent Solar Concentrator Photovoltaic Devices Using Bifacial Silicon Solar Cells**. *Appl. Sci.* **2020**, *10*, 871.

PRINTABLE LSC PV MODULES

Prints with luminescent dyes on glass or PMMA can be graphically tailored



Example shown left at 1 A4 size print

Collaboration with

PARLPV

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Integration of printed luminescent solar PV technology in windows, design by Reinders, 2020

Acknowledgements

My group members: Dr. Reza Aghaei, Alonzo Sierra Rodriguez Dr. Cihan Gercek, Kunaifi, Xitong Zhu, Amrita Raghoebarsing Neel Patel, Olga Kanz, Martin Huijzer, Wouter Eggink and Arjan Frijns.

As well as master students: Tiago Santana, Marcello Nitti, Vincent Nieuwenhuizen, Nikhita Desai, Varildo Vaseur, and others, and all students that have attended the design course Sources of Innovations in Fall 2019