Integrated combination of concentrating solar thermal technologies and photovoltaics - the bifacial PV-Mirror

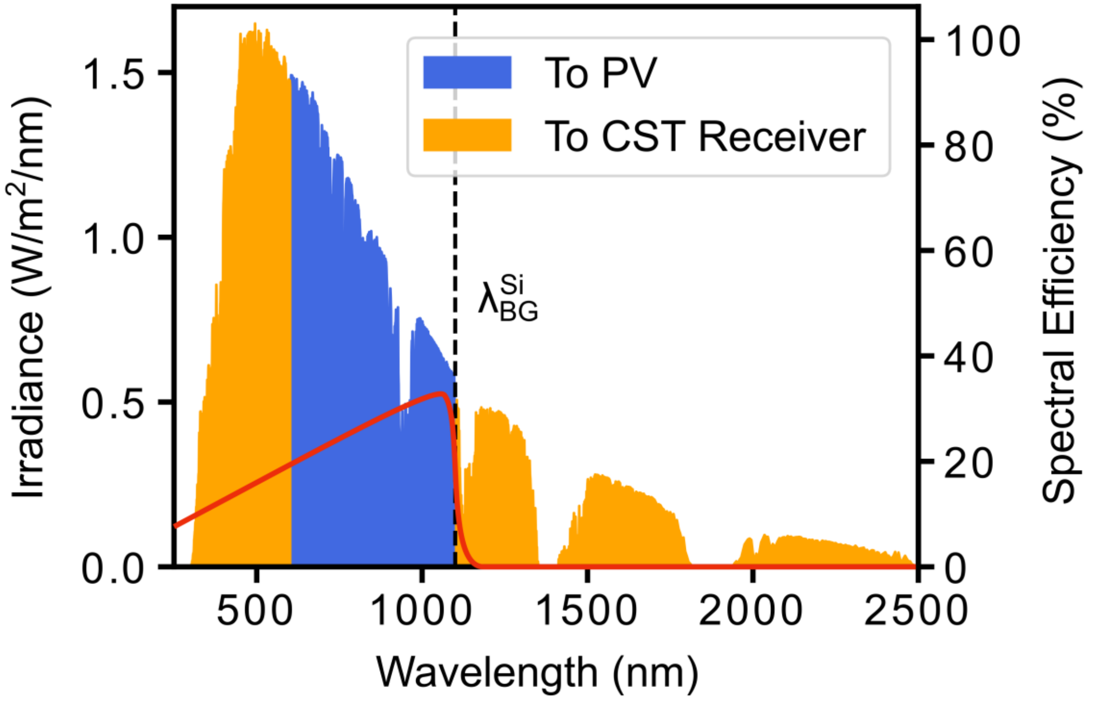
Moritz Ruhwedel[1,2], Florian Sutter[1], Stephan Heise[3], Kai Gehrke[3], Eckhard Lüpfert[1], Antoine Grosjean[4], Peter Heller[1], Robert Pitz-Paal[1,2]

[1] Deutsches Zentrum für Luft- und Raumfahrt e. V. , Institute of Solar Research
[2] RWTH Aachen University, Chair of Solar Technology
[3] Deutsches Zentrum für Luft- und Raumfahrt e. V. , Institute of Networked Energy Systems
[4] EPF Ecole d'ingénieurs

DLR

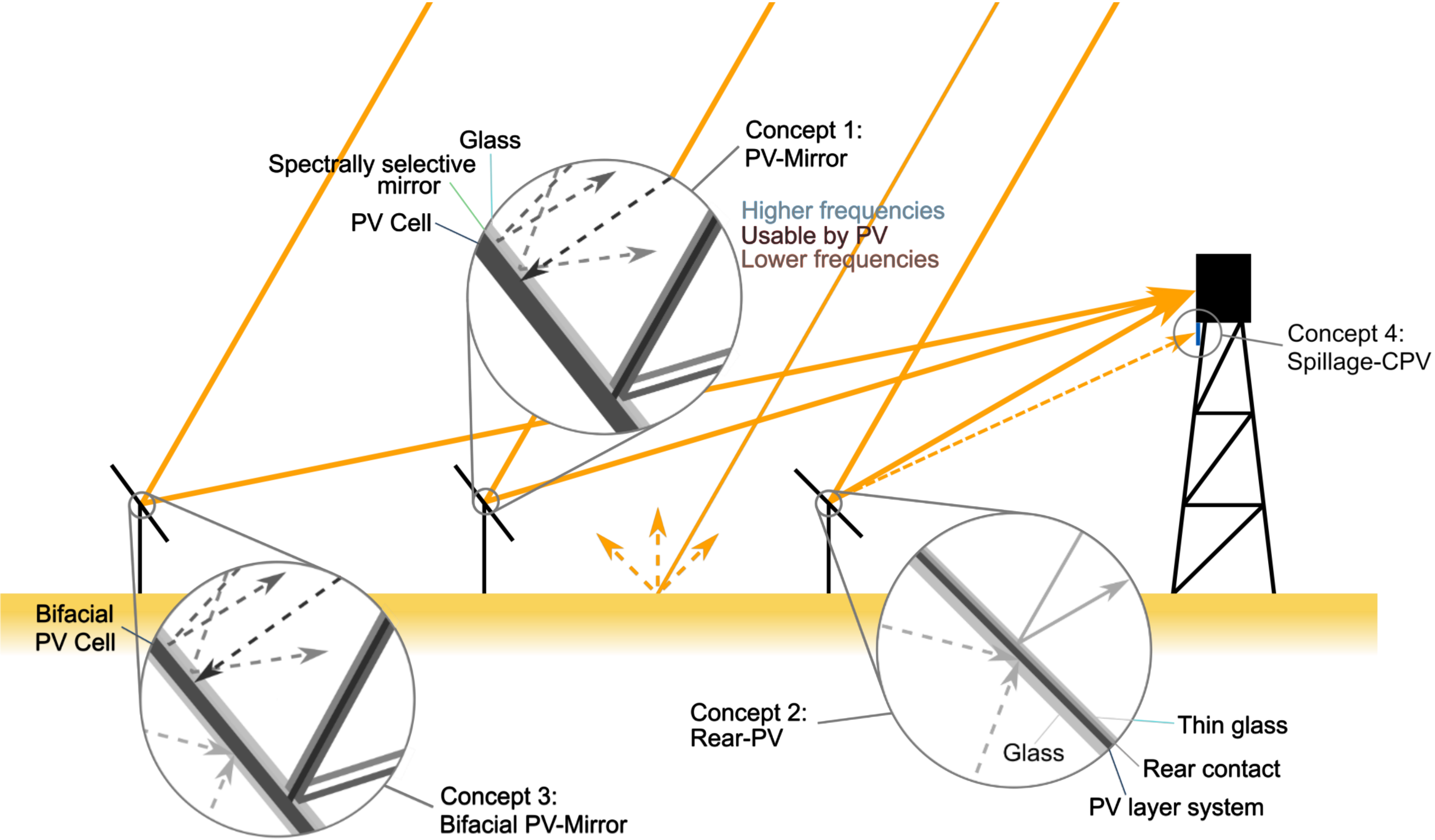
Motivation: PV-Mirror

Spectral PV conversion efficiency depends on wavelength:



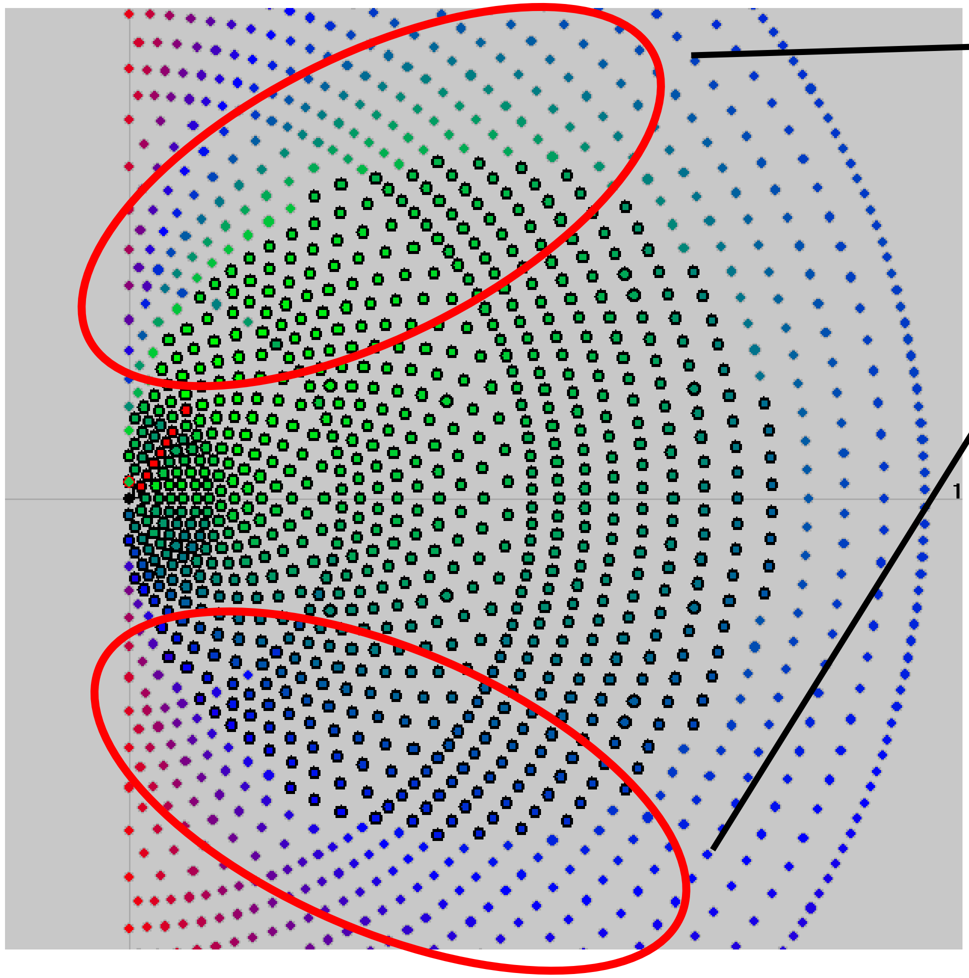
→ Hybridization: utilize loss channels → increase efficiency → decrease cost?

Concepts for integrating PV in a CST system



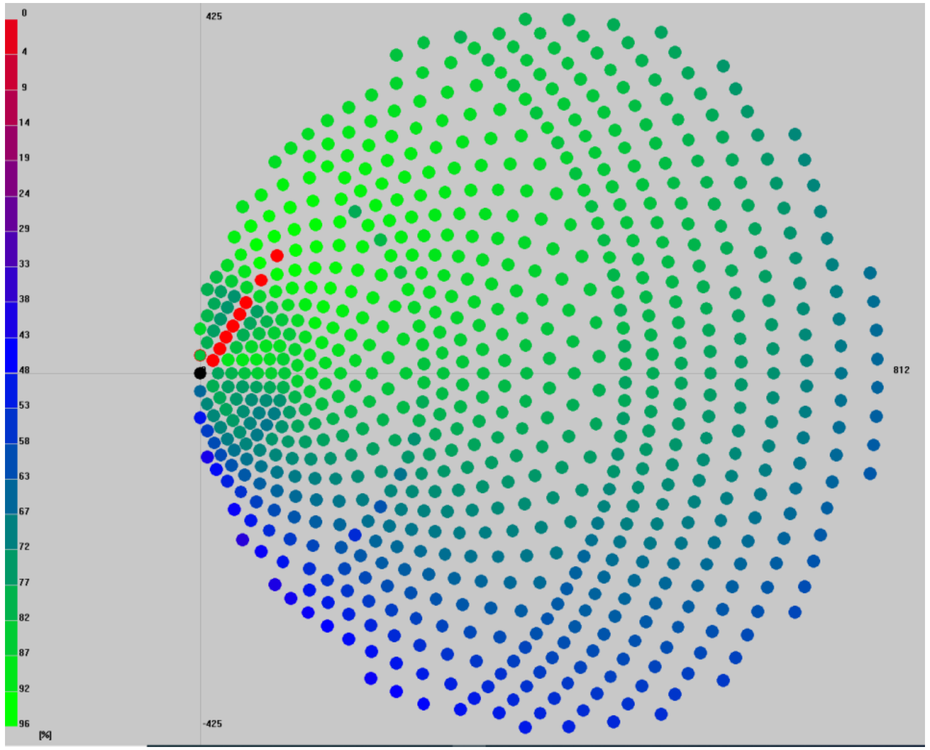
Power plant configuration can be reoptimized

Current Efficiency



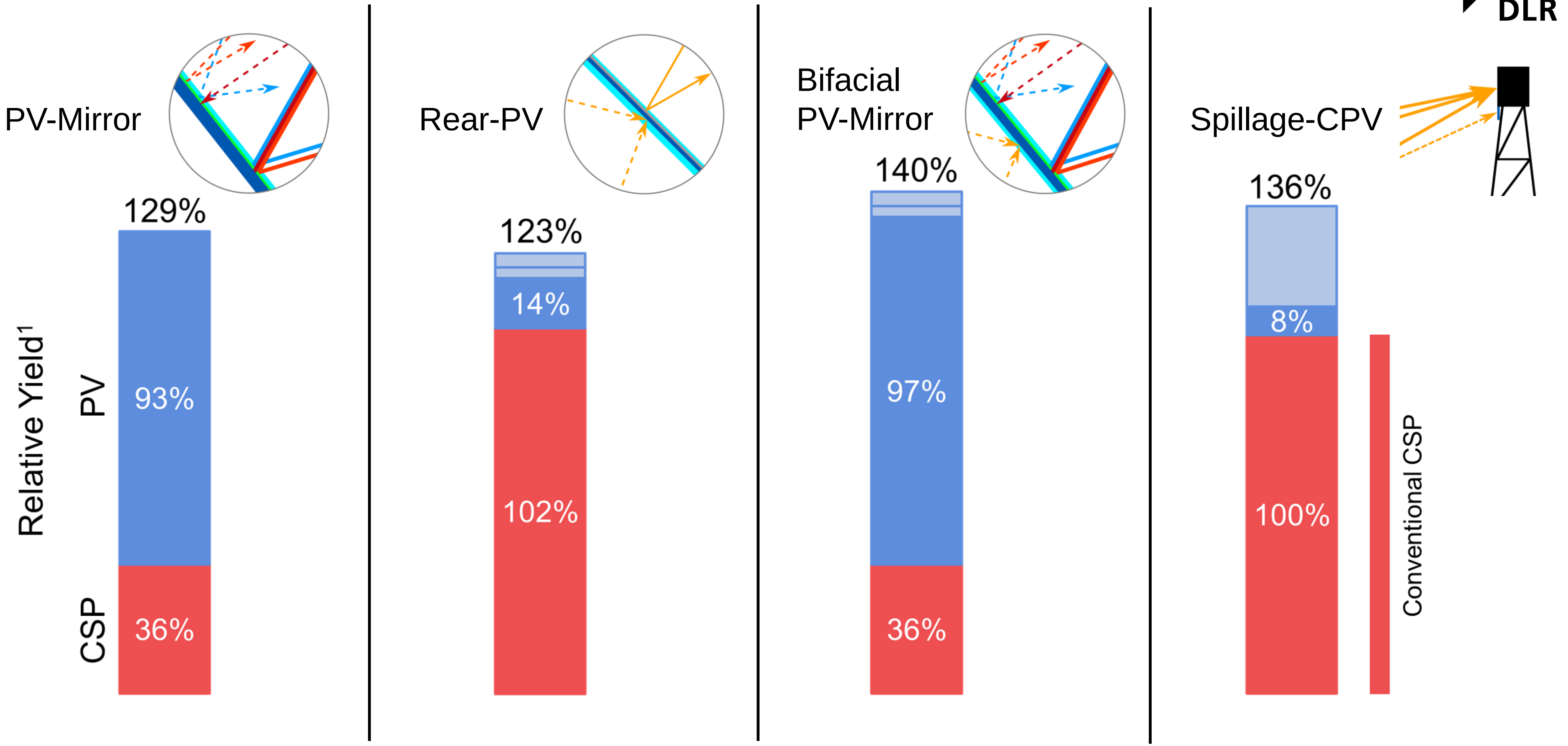
Use these heliostats with Rear-PV

Current Efficiency



→ Additional Rear-PV heliostats can increase solar field efficiency

Yield in conventional power plant configuration



[1]Ruhwedel et. al., *Integrated Concentrating Solar/Photovoltaic Hybrid Concepts—Technological Discussion, Energy Yield, and Cost Considerations*, 2024, Energy Technology

Investment cost in conventional power plant configuration

→ Maintain PV and CST/CSP capacity

Assumptions:

- Additional PV output reduces need for stand-alone PV (883 USD/kW[1])
- Concentrating structure has to be scaled to maintain radiation flux on receiver (576 USD/kW excluding mirrors[2])

[1]International Renewable Energy Agency, *Renewable Power Generation Costs in 2021*, 2022
[2]Ruhwedel et. al., *Integrated Concentrating Solar/Photovoltaic Hybrid Concepts—Technological Discussion, Energy Yield, and Cost Considerations*, 2024, Energy Technology

Investment cost in conventional power plant configuration – Spillage-CPV

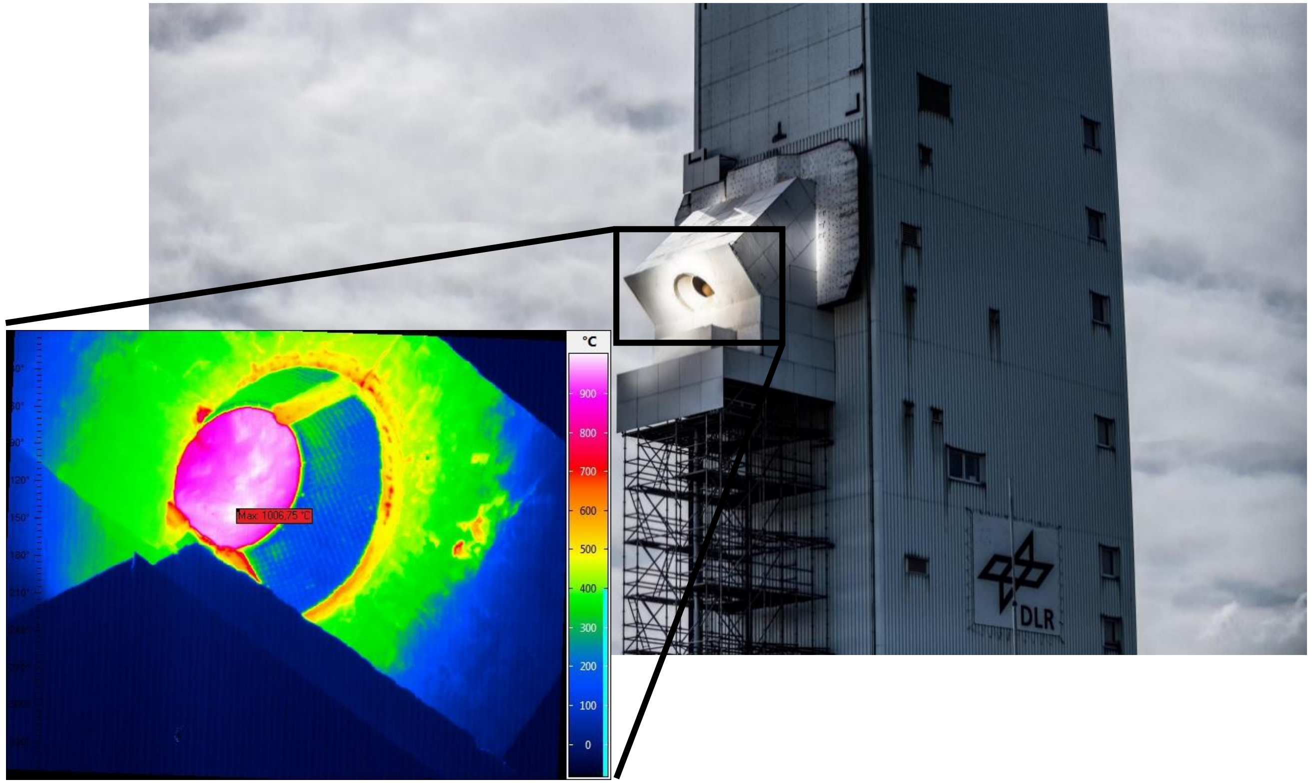
CPV modules[1]: 48000 USD/m^2

Periphery[1]: 308 USD/kW

Stand-alone PV[2]: 883 USD/kW

→ Break-even for radiation fluxes of **~350 kW_{solar}/m^2**

CentRec® Receiver – over 900 °C



→ Spillage-CPV most interesting in high-temperature receivers

[1]Ruhwedel et. al., *Integrated Concentrating Solar/Photovoltaic Hybrid Concepts—Technological Discussion, Energy Yield, and Cost Considerations*, 2024, Energy Technology
[2]International Renewable Energy Agency, *Renewable Power Generation Costs in 2021*, 2022

Investment cost in conventional power plant configuration – (Bifacial) PV-Mirror, Rear-PV

Cost of components replacing the mirrors unknown → Criterion for cost of them

Conventional solar mirrors[1]: 17 USD/m²

	PV-Mirror	Rear-PV	Bifacial PV-Mirror
Break-even cost (USD/m²)[1]	**82**	**44** with a range of 39 to 51	**92** with a range of 87 to 97
PV module price (USD/m²)[1]	Monofacial: **78**		Bifacial: **87**

→ (Bifacial) PV-Mirror might be feasible in conventional power plants, Rear-PV probably not

[1]Ruhwedel et. al., *Integrated Concentrating Solar/Photovoltaic Hybrid Concepts—Technological Discussion, Energy Yield, and Cost Considerations*, 2024, Energy Technology

Finding the ideal power plant configuration for the Bifacial PV-Mirror

Model CST part ⟷ Model PV under spectrally selective mirror

- HFLCAL
- STRAL
- SolTrace

⋮

- e.g. adaption of Slauch et. al. 2019[1]

→ **Lacks validation**

→ Experimental data of PV under spectrally selective mirror needed

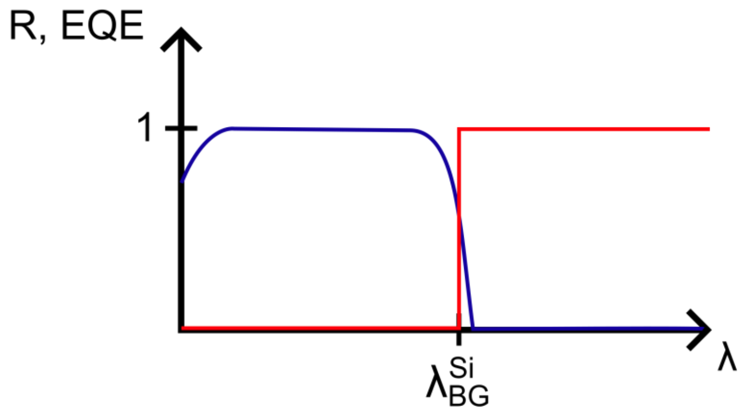
[1]Slauch et. al., *Spectrally Selective Mirrors with Combined Optical and Thermal Benefit for Photovoltaic Module Thermal Management*, 2018, ACS Photonics

Experimental investigation of the Bifacial PV-Mirror

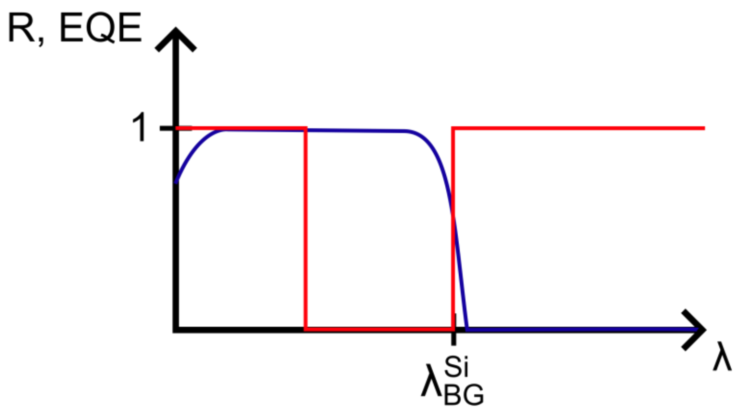
- Test prototypes under real-life conditions
  →Measure PV performance and temperature

Mirror configurations:

Low reflection

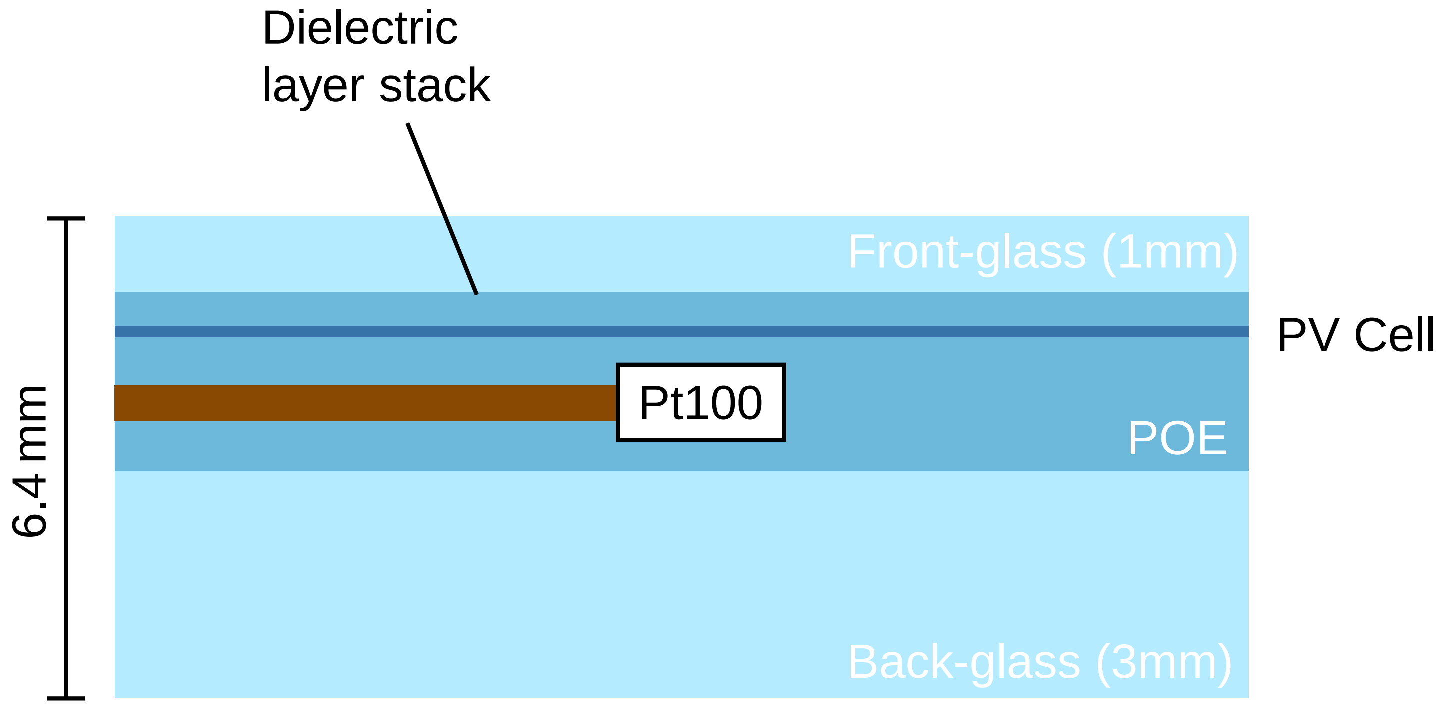


High reflection



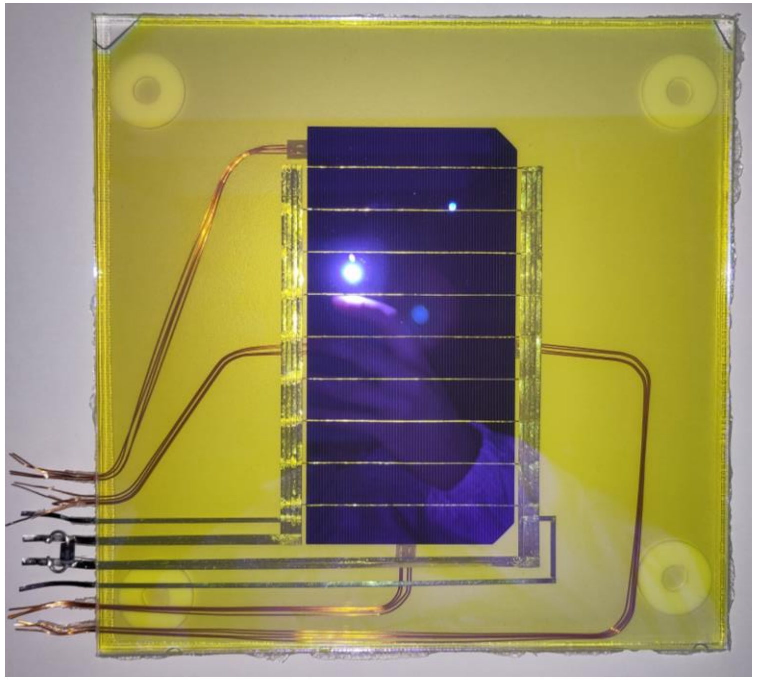
Experimental investigation of the Bifacial PV-Mirror – The prototypes

- Glass-glass
- Encapsulant: Polyolefin (POE)
- Cell: 9BB TOPCON 166mm halfcell
- Connected to electronic load



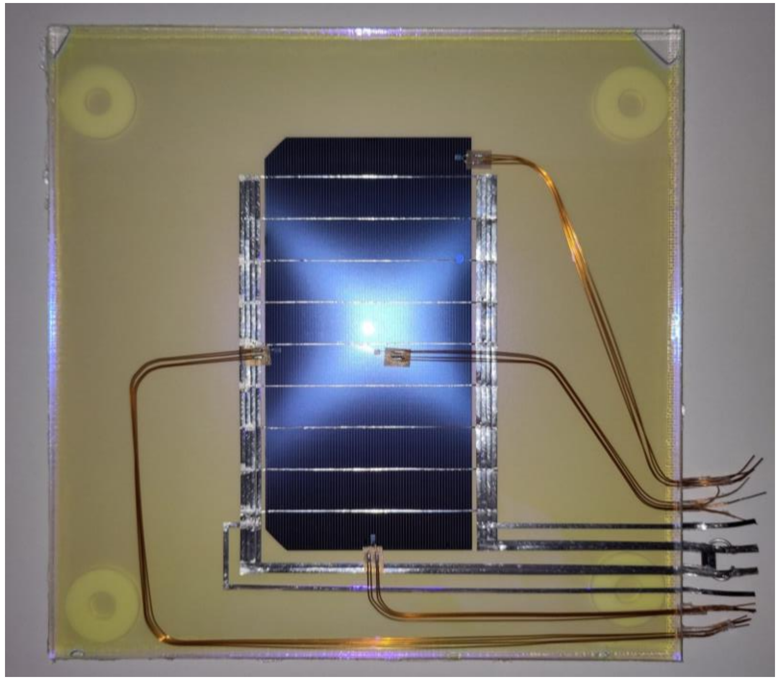
Experimental investigation of the Bifacial PV-Mirror – The prototypes

Front:



25 cm

Rear:



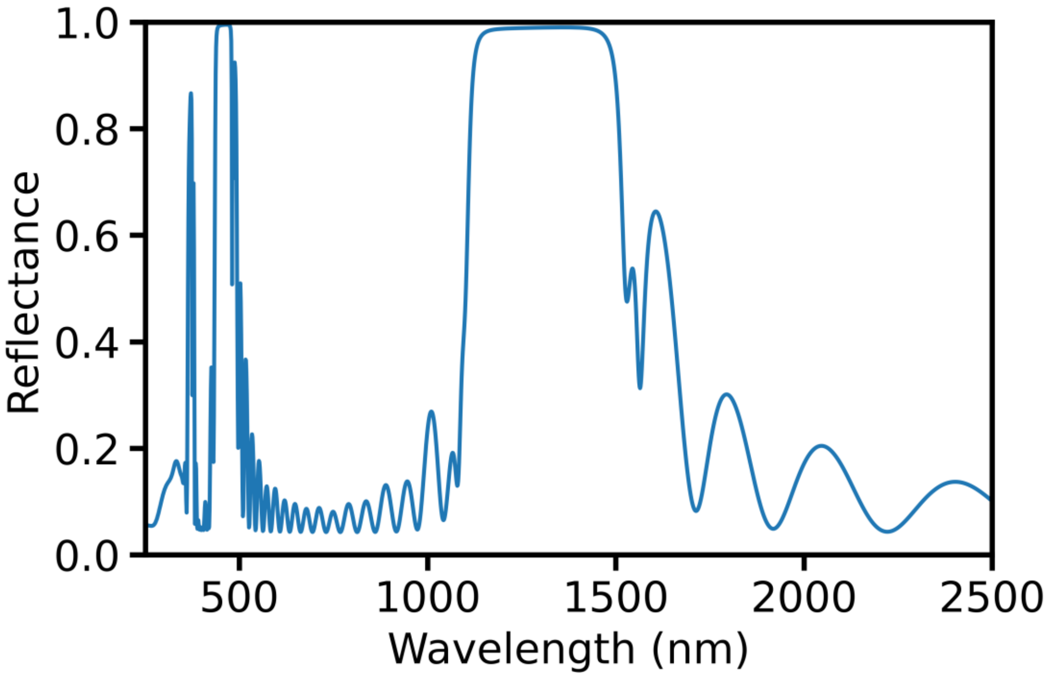
Experimental investigation of the Bifacial PV-Mirror – The spectrally selective layer stack

- Deposited by sputter deposition
- SiO_2/TiO_2 stacks
- Optimized for 30° angle of incidence
- 2 configurations optimized from λ/4 stacks
- 1 configuration optimized by Antoine Grosjean using SolPOC[1]

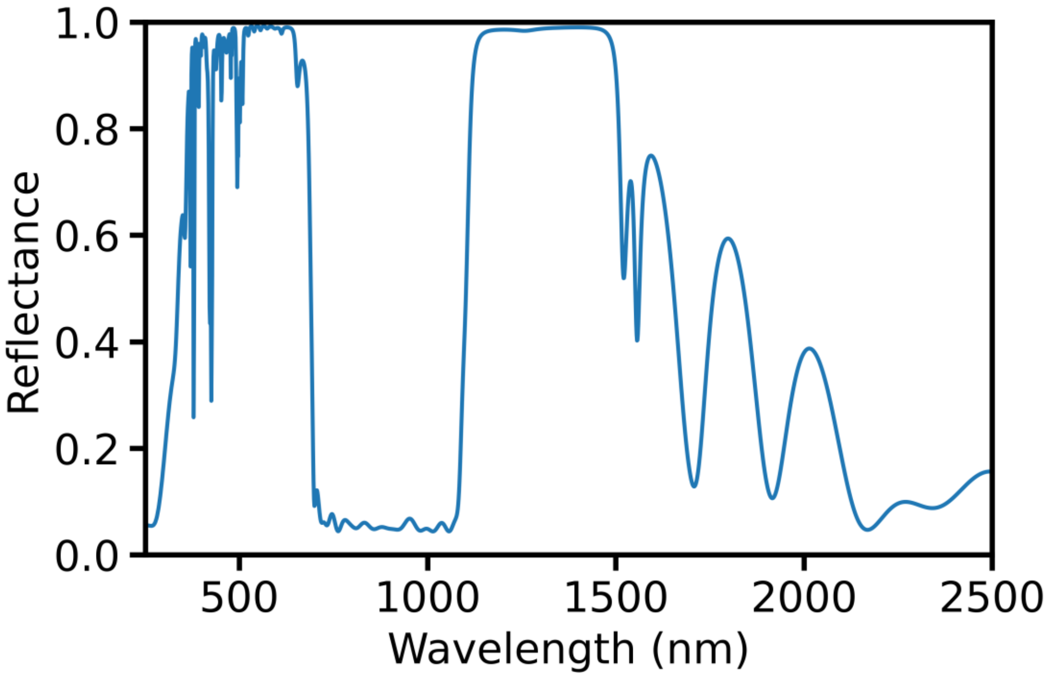
[1]https://github.com/SolPOCandCo/SolPOC

Experimental investigation of the Bifacial PV-Mirror – The spectrally selective layer stack

SB reflector (21 layers):
Solar reflectance (SolarPACES): 29%



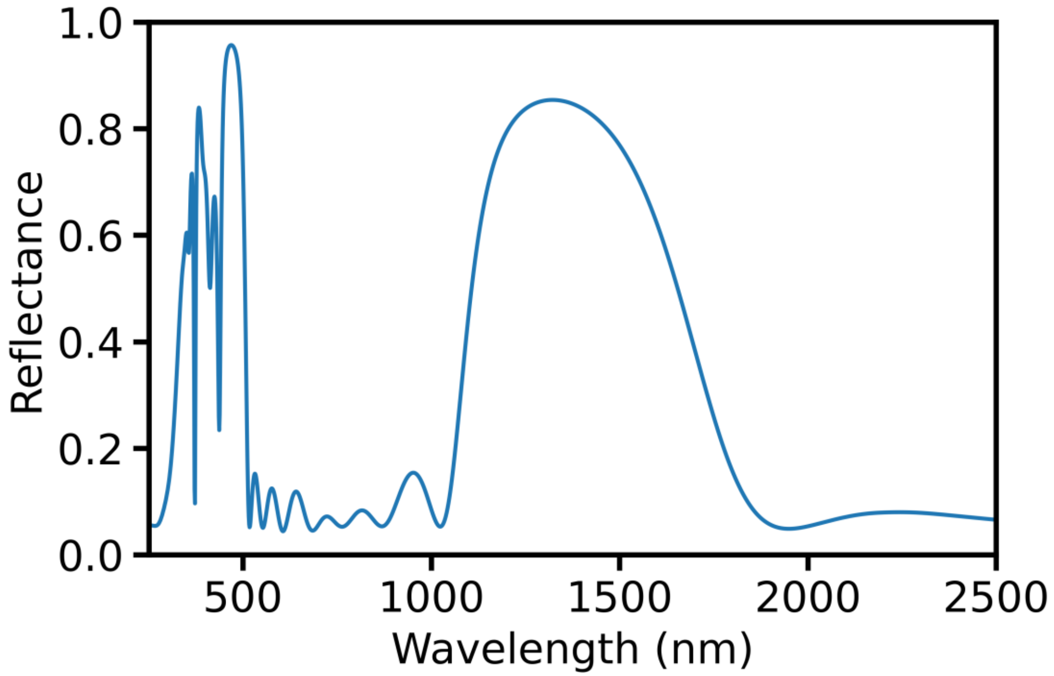
SB+UV reflector (40 layers):
Solar reflectance (SolarPACES): 57%



Experimental investigation of the Bifacial PV-Mirror – The spectrally selective layer stack

Optimized using SolPOC (10 layers):

Solar reflectance (SolarPACES): 30%



- Target transmission window: 500-1100 nm
- Target reflection windows: 280-500 nm and 1100-2500 nm

Experimental investigation of the Bifacial PV-Mirror – Test under solar simulator

Reference module:

T_{eq} = 62 °C, P_{MPP} = 2.54 W

Module	R (0°)	ΔT (°C)	ΔP (W)	Rel. ΔP
SB	31%	-10	-0.49	-19%
SB+UV	61%	-19	-1.10	-43%
SolPOC	31%	-9	-0.35	-14%

Conclusion

Maybe feasible in conventional CSP

(Bifacial) PV-Mirror, Spillage-CPV

Probably not feasible in conventional CSP

Rear-PV

→ Optimization required to judge feasibility of concepts

Upcoming: Experimental investigation of Bifacial PV-Mirror

Imprint

Topic:	**Concepts for combining concentrating solar mirrors with PV modules**
Date:	2024-10-10
Author:	Moritz Ruhwedel, Florian Sutter, Stephan Heise, Kai Gehrke, Eckhard Lüpfert, Antoine Grosjean, Peter Heller, Robert Pitz-Paal
Institute:	Institute of Solar Research
Image sources:	All images “DLR (CC BY-NC-ND 3.0)” unless otherwise stated