CONCEPTS FOR COMBINING CONCENTRATING SOLAR MIRRORS WITH PV MODULES

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DLR

Concentrating Solar Thermal (CST) Systems

Plataforma Solar de Almería, owned by CIEMAT

Moritz Ruhwedel, Institute of Solar Research, 19.03.2024

CST Systems and Photovoltaics (PV)

Photovoltaics

Sunlight

↓

Electricity

CST Systems

Sunlight

↓

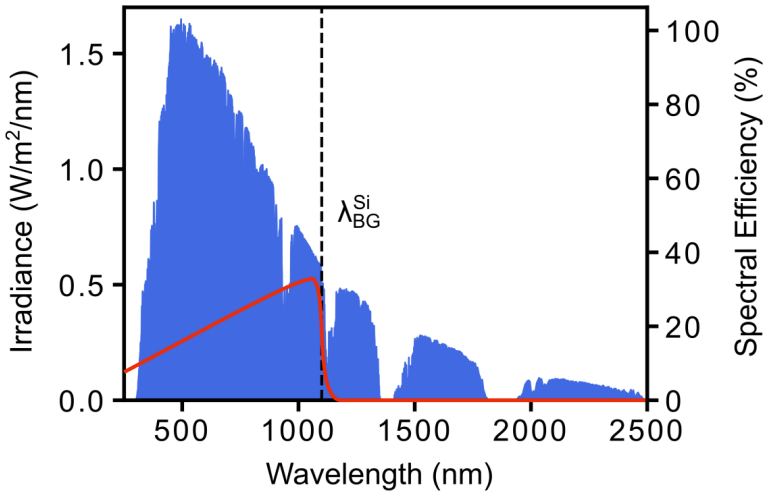
Heat

↓ Concentrating Solar Power (CSP)

Electricity

CST Systems and PV

Photovoltaics



CST Systems

Image: BrightSource – www.brightsourceenergy.com

Pyromark 2500:

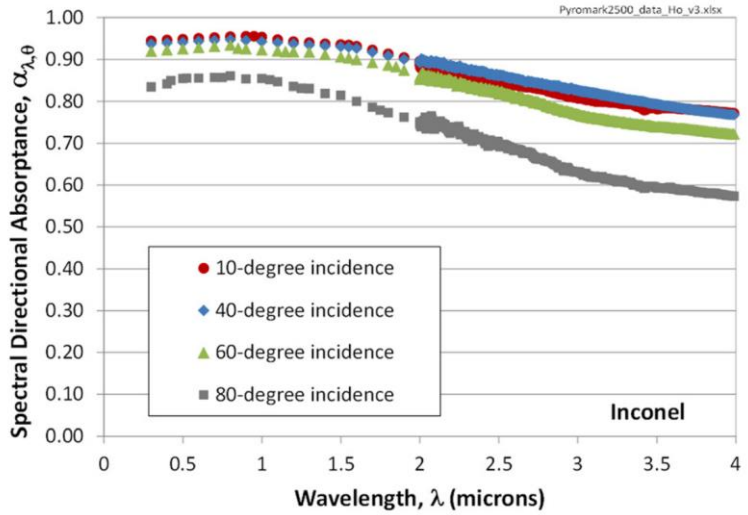


Image: Ho et al. 2014[1]

→ PV efficiency is wavelength dependent while CST efficiency in principle is not

[1]Ho et. al., *Characterization of Pyromark 2500 Paint for High-Temperature Solar Receivers*, 2014, Journal of Solar Energy Engineering

Central Receiver System (CRS)

Concentration → lower heat loss → high temperatures

Individual heliostats

Image: Grupo Cerro - www.grupocerro.com

Concentration onto tower

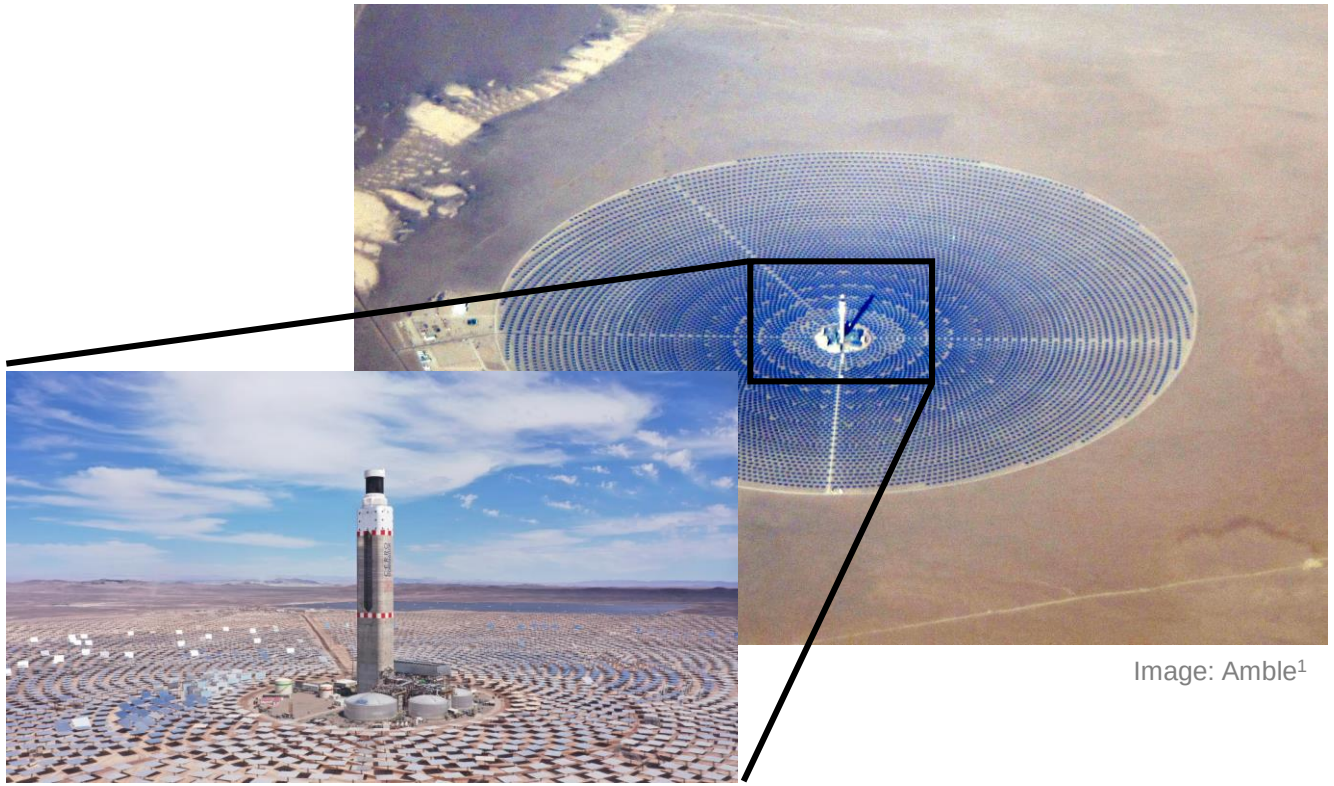


Image: Amble[1]

Image: KfW Entwicklungsbank - www.kfw-entwicklungsbank.de

[1] "File:Crescent Dunes Solar December 2014.JPG" by Amble is licensed under CC BY-SA 4.0. To view a copy of this license, visit https://creativecommons.org/licenses/by-sa/4.0/?ref=openverse, partly superimposed

Parabolic Trough collectors

Plataforma Solar de Almería, owned by CIEMAT

Electricity Production: CSP and PV

Levelized cost of electricity (LCOE) – IRENA, 2021[1]:

PV: ~0.05 USD/kWh

CSP: ~0.11 USD/kWh

Storage:

- Storing heat is much cheaper than storing electricity
- For storage durations of over 4-10h CSP is expected to remain cheaper than PV with storage[2]

Image: U.S. Department of Energy - www.energy.gov

→ PV for immediate demand, CSP for dispatchable generation, CST for heat

[1]International Renewable Energy Agency, *Renewable Power Generation Costs in 2021*, 2022
[2]Schöniger et. al., *Making the sun shine at night: comparing the cost of dispatchable concentrating solar power and photovoltaics with storage*, 2021, Energy Sources, Part B: Economics, Planning, and Policy

CST-PV Hybrid Concepts

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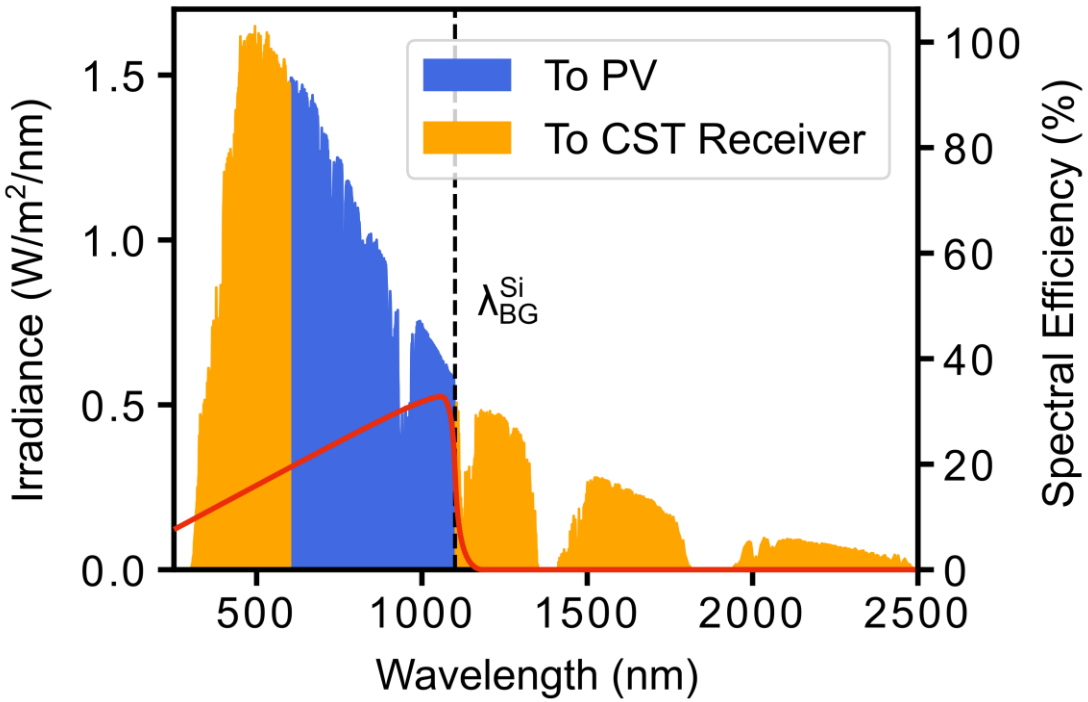
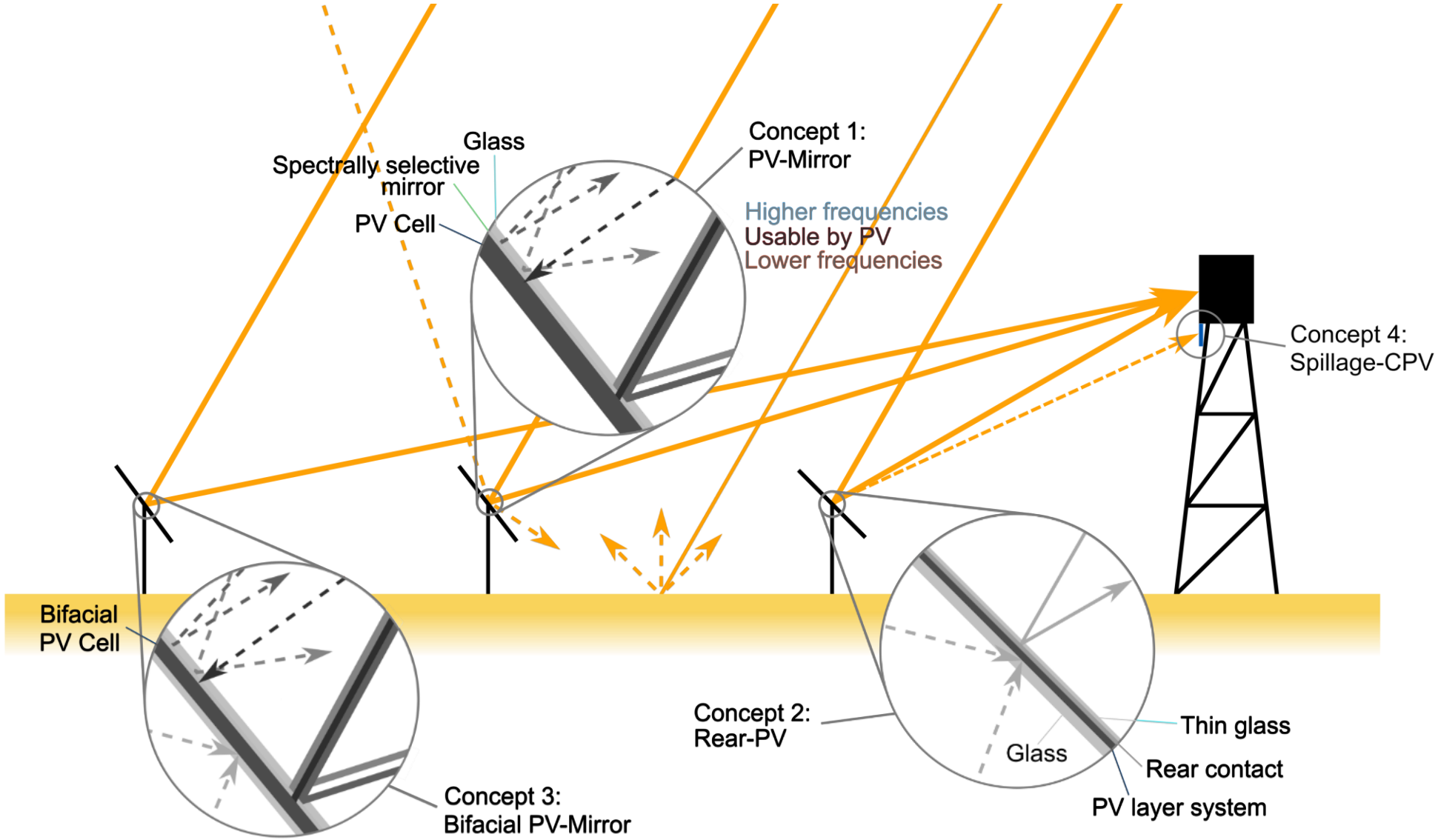
Motivation: PV-Mirror

PV conversion efficiency depends on wavelength:



→ Hybridization: utilize loss channels

Concepts for Integrating PV in a CST System



Yield and Investment Cost

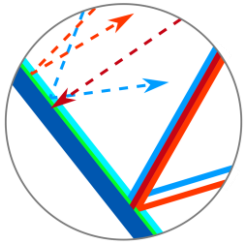
Plataforma Solar de Almería, owned by CIEMAT

Yield and Investment Cost

Concepts utilize loss channels → **Power plants using them could be reoptimized**

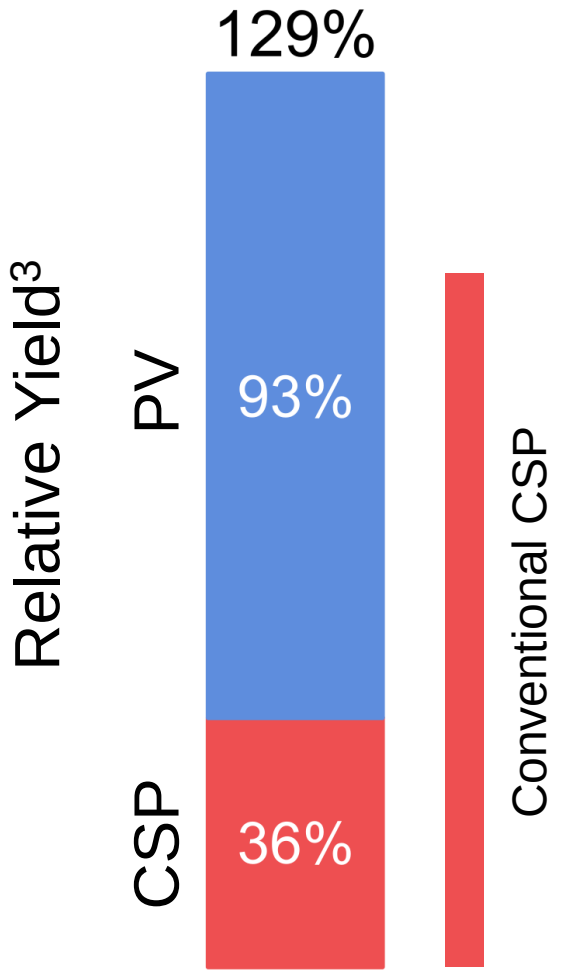
→ Here comparison of use of the concepts in **conventional power plant configuration**

Yield – PV-Mirror



Based on: simulation of PV-Mirror in Themis plant[1]

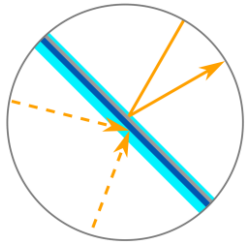
Image: PROMES-CNRS[2] - www.promes.cnrs.fr



→ Results heavily depend on mirror configuration

[1]Ziyati et. al., *A multiphysics model of large-scale compact PV–CSP hybrid plants*, 2021, Applied Energy
[2]Procédés Matériaux et Energie Solaire - Centre national de la recherche scientifique
[3]Ruhwedel et. al., *Integrated Concentrating Solar/Photovoltaic Hybrid Concepts—Technological Discussion, Energy Yield, and Cost Considerations*, 2024, Energy Technology

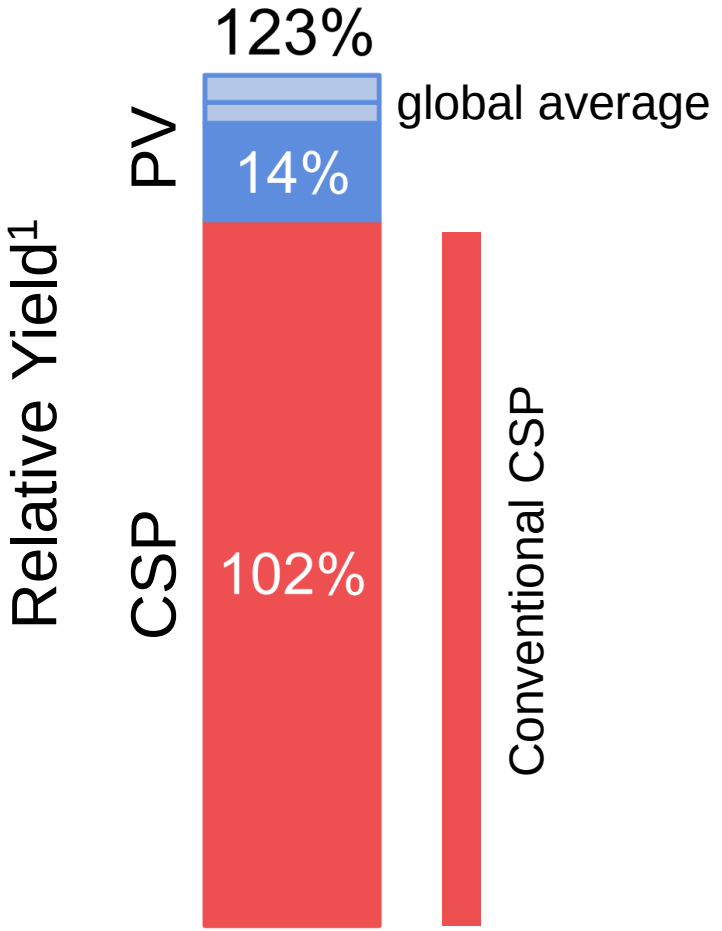
Yield – Rear-PV



Based on: data of bifacial PV

- radiation flux on the back is 4-15% of the radiation flux on the front[1]

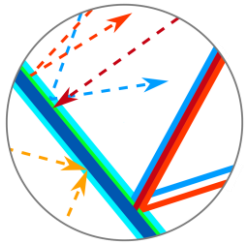
Image: DNV - www.dnv.com



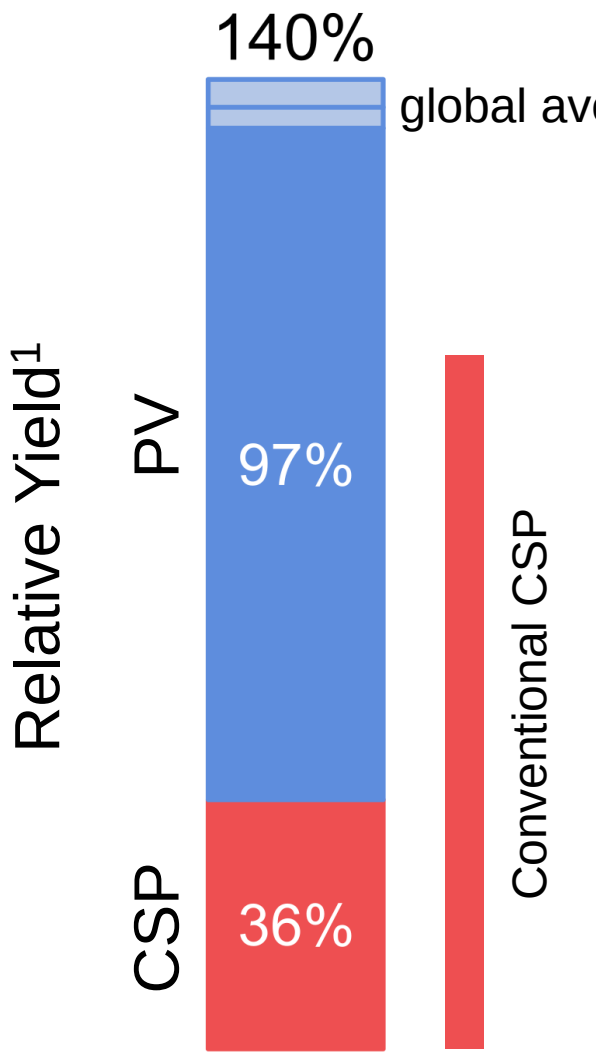
→ Increased CSP output due to usability of thin-glass mirrors

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

Yield – Bifacial PV-Mirror



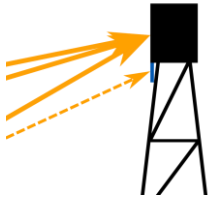
Based on: PV-Mirror with additional yield as the Rear-PV



→ Highest additional output of all concepts

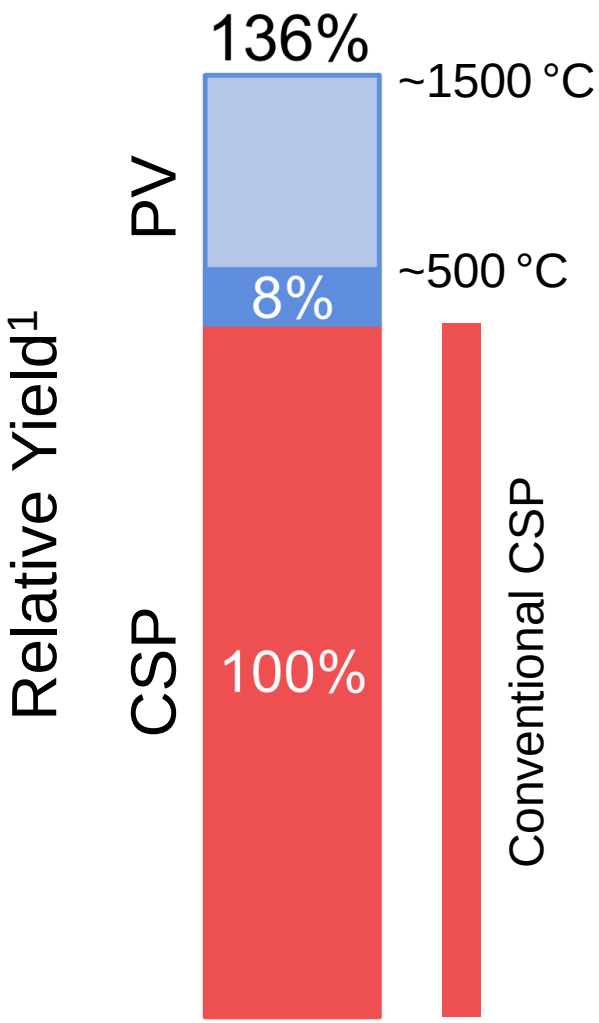
[1]Ruhwedel et. al., *Integrated Concentrating Solar/Photovoltaic Hybrid Concepts—Technological Discussion, Energy Yield, and Cost Considerations*, 2024, Energy Technology

Yield – Spillage-CPV



Based on: assumed CPV efficiency of 32%

Image: RayGen - www.raygen.com



→ PV output depends on type of power plant

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

Investment Cost

→ PV for immediate demand, CSP for dispatchable generation, CST for heat

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])

→ Criterion for cost of concepts replacing the mirrors

[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 – (Bifacial) PV-Mirror, Rear-PV

Conventional solar mirrors[1]: 17 USD/m^2

	PV-Mirror	Rear-PV	Bifacial PV-Mirror
Break-even cost (USD/m^2)[1]	**82**	**44** with a range of 39 to 51	**92** with a range of 87 to 97
PV module price (USD/m^2)[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

Investment Cost – Spillage-CPV

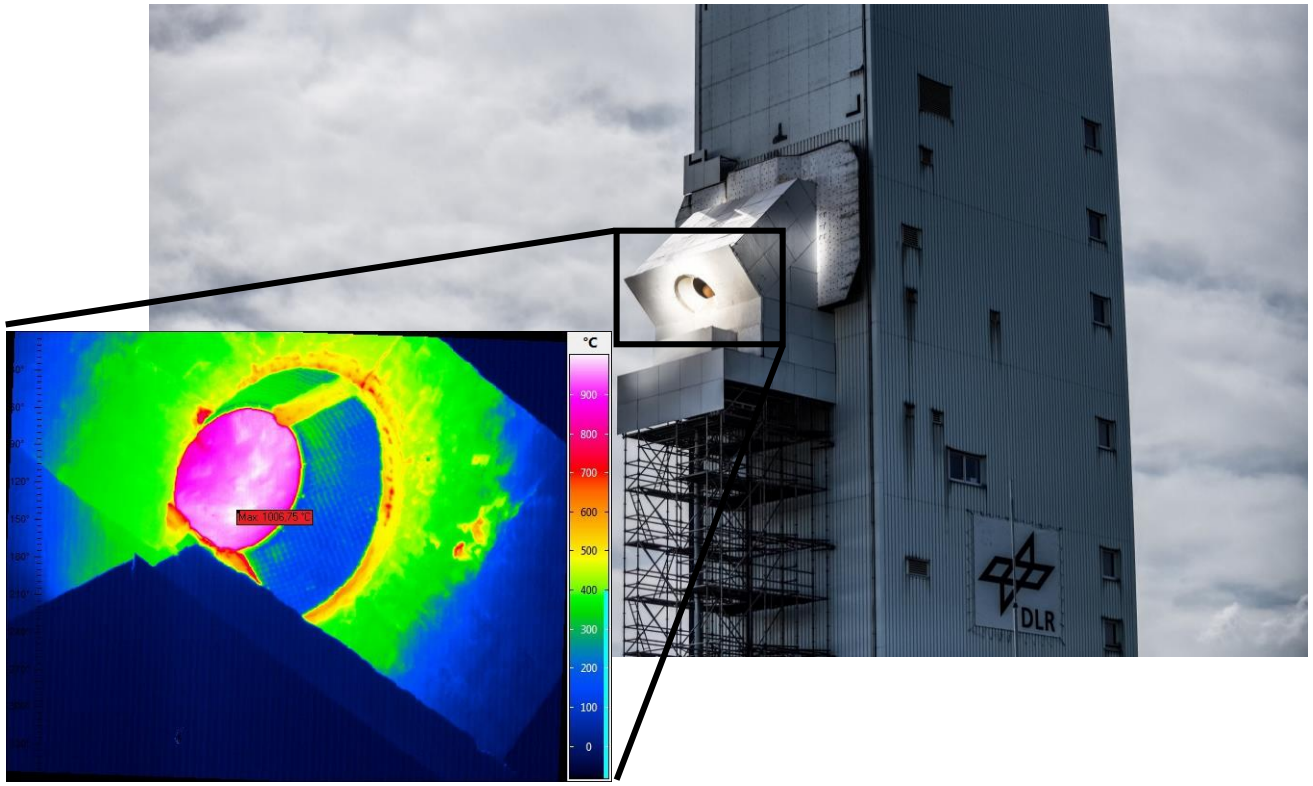
CPV modules[1]: 48000 USD/m²

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

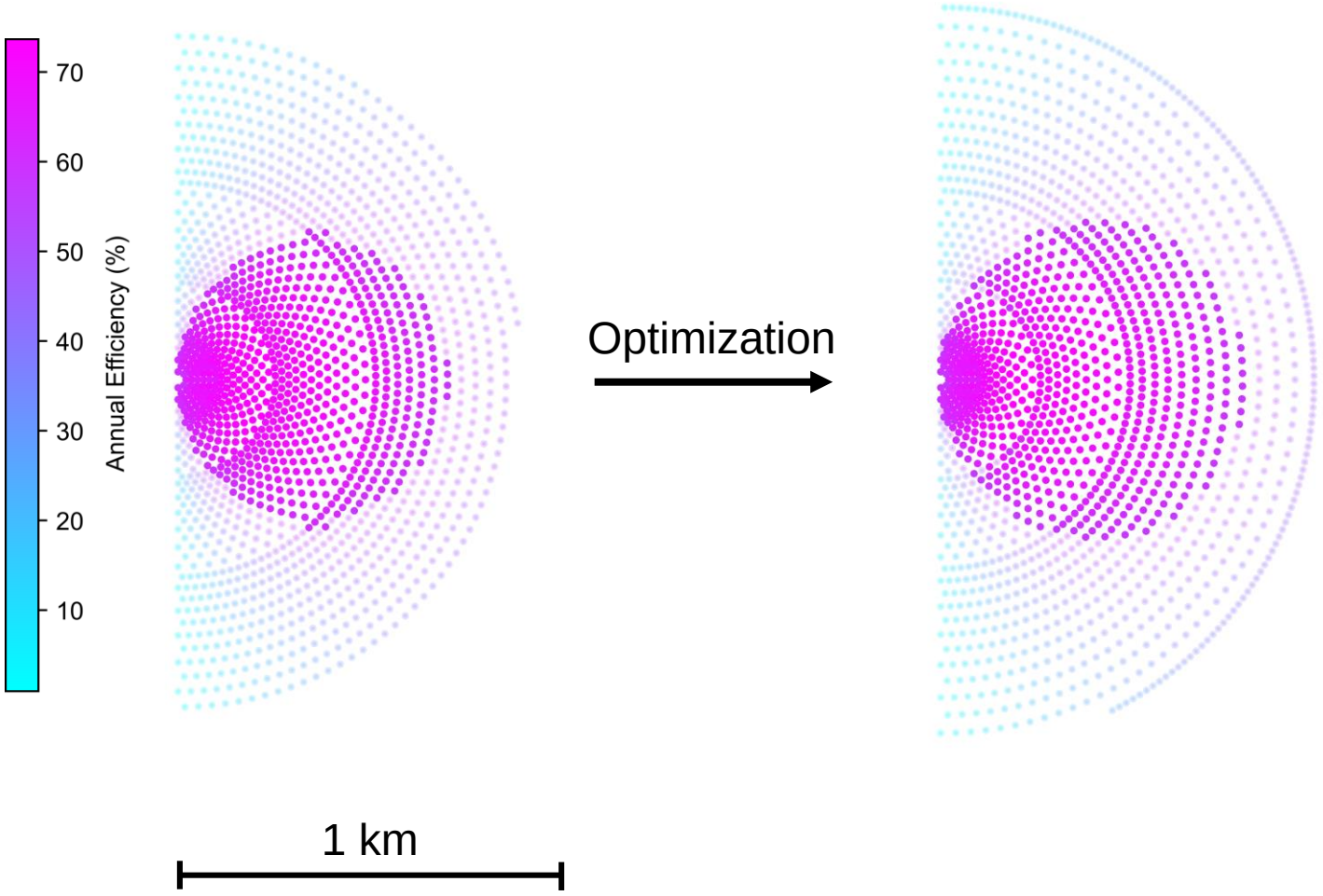


→ Spillage-CPV most interesting in high-temperature receivers

[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

Discussion

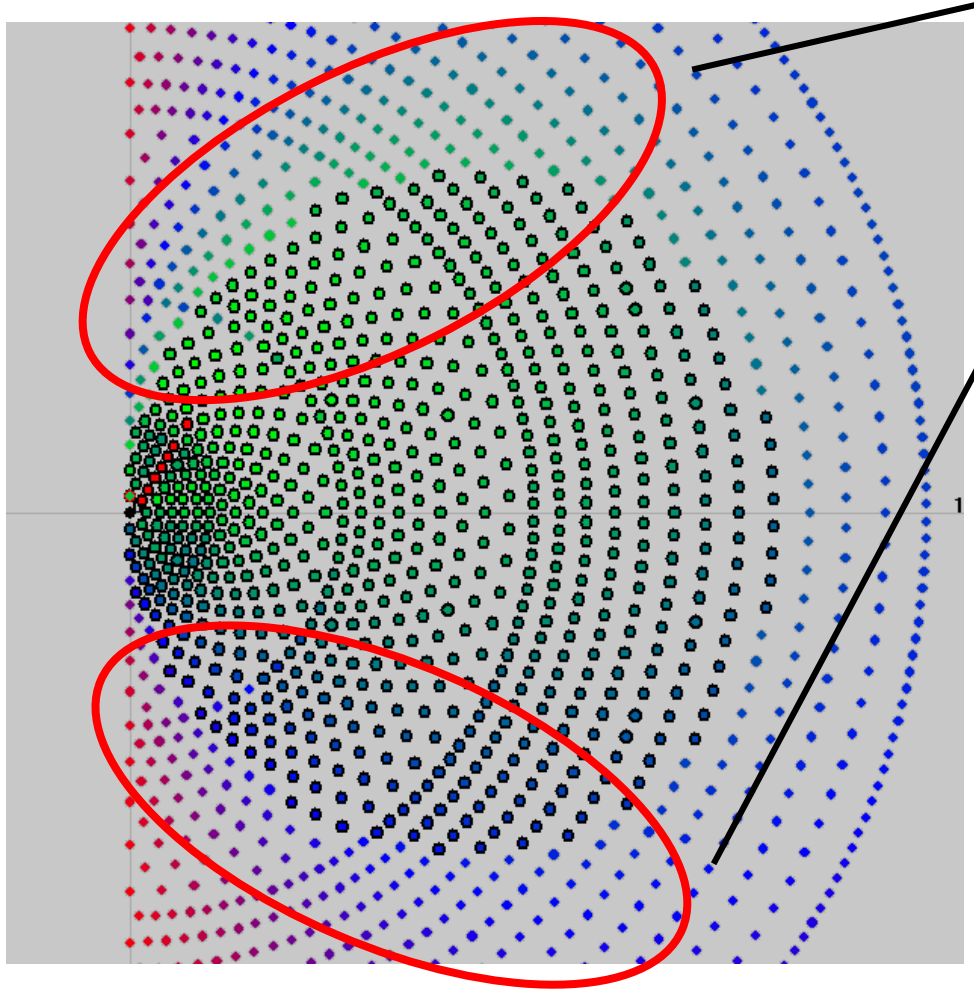
Radial staggered algorithm:

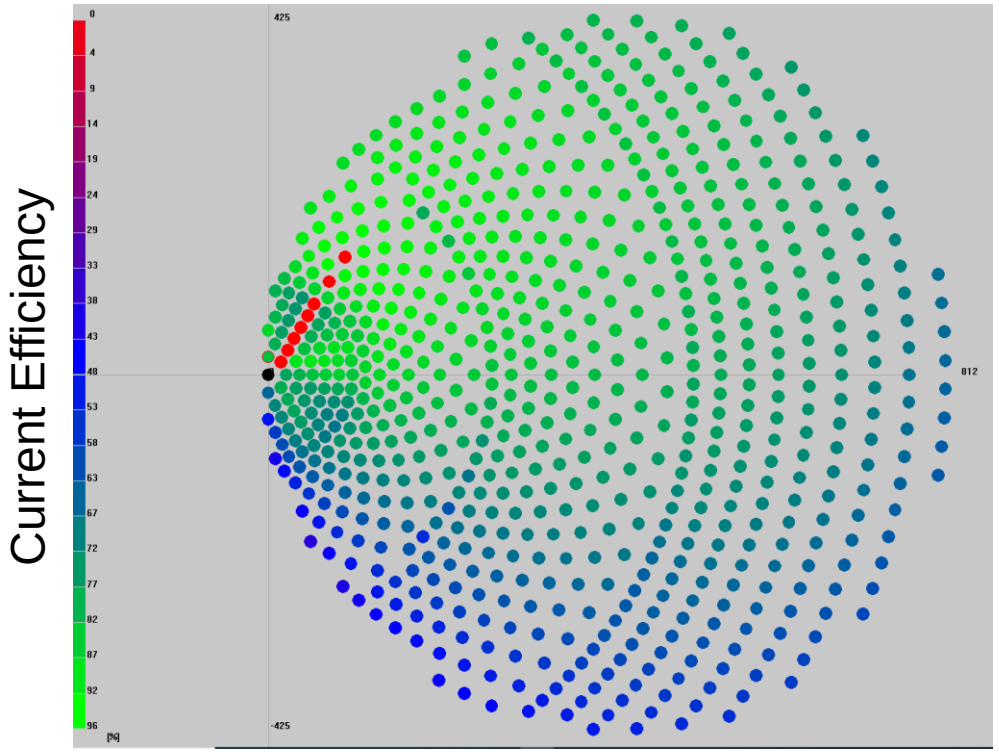


PS10 – 11 MW

Discussion

Use this heliostats with Rear-PV





→ Additional Rear-PV heliostats can increase solar field efficiency

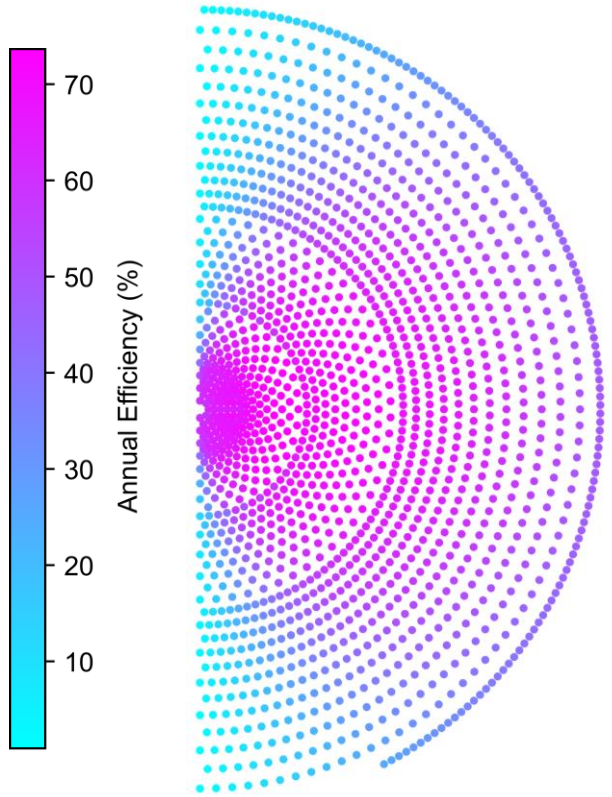
Conclusion

Maybe feasible in conventional CSP

(Bifacial) PV-Mirror, Spillage-CPV

Probably not feasible in conventional CSP

Rear-PV



CST systems have to be reoptimized using hybrid concepts

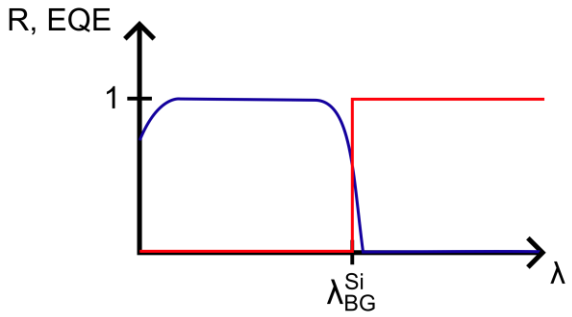
Outlook – Bifacial PV-Mirror

Prototypes: Loaded long-term tests

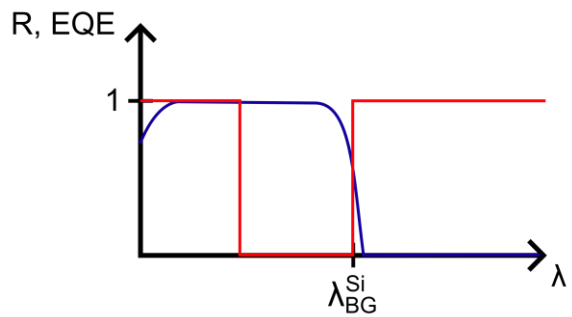
→ Modelling of PV cell under spectrally selective mirror

Mirror configurations:

Low reflection



High reflection



Imprint

Topic:	**Concepts for combining concentrating solar mirrors with PV modules**
Date:	2024-03-19
Author:	Moritz Ruhwedel, Florian Sutter, Stephan Heise, Kai Gehrke, Eckhard Lüpfert, Peter Heller, Robert Pitz-Paal
Institute:	Institute of Solar Research
Image sources:	All images “DLR (CC BY-NC-ND 3.0)” unless otherwise stated

Cost Criterion – (Bifacial) PV-Mirror, Rear-PV

$$z_i < \left(\frac{a_i}{r_i} \frac{\sigma_{\mathrm{PV}}}{\sigma_{\mathrm{CSP}}} + m_{\mathrm{CSP}} \left(1 - \frac{1}{r_i} \right) \right) \frac{r_i}{l_{\mathrm{CSP}}} + r_i$$

Cost Criterion – Spillage-CPV

$$\sigma_{\mathrm{SCPV}} = \left(\sigma_{\mathrm{SCPV}}^{\mathrm{Inverter}} + \sigma_{\mathrm{SCPV}}^{\mathrm{Switchgear}} + \sigma_{\mathrm{SCPV}}^{\mathrm{Cooling}} \cdot \frac{1 - \eta_{\mathrm{CPV}}}{\eta_{\mathrm{CPV}}} + \frac{\sigma_{\mathrm{SCPV}}^{\mathrm{CPV}}}{F \cdot \eta_{\mathrm{CPV}}} \right) \cdot (1 + \mathrm{BoP})$$