Status and Perspectives of Concentrating Solar Power Technologies

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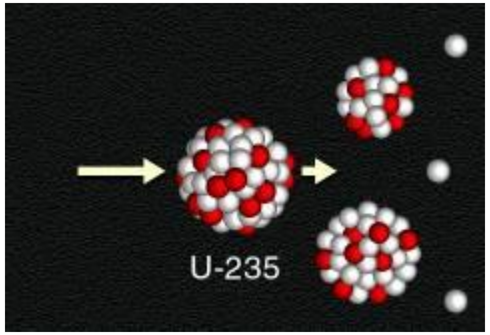
Outline

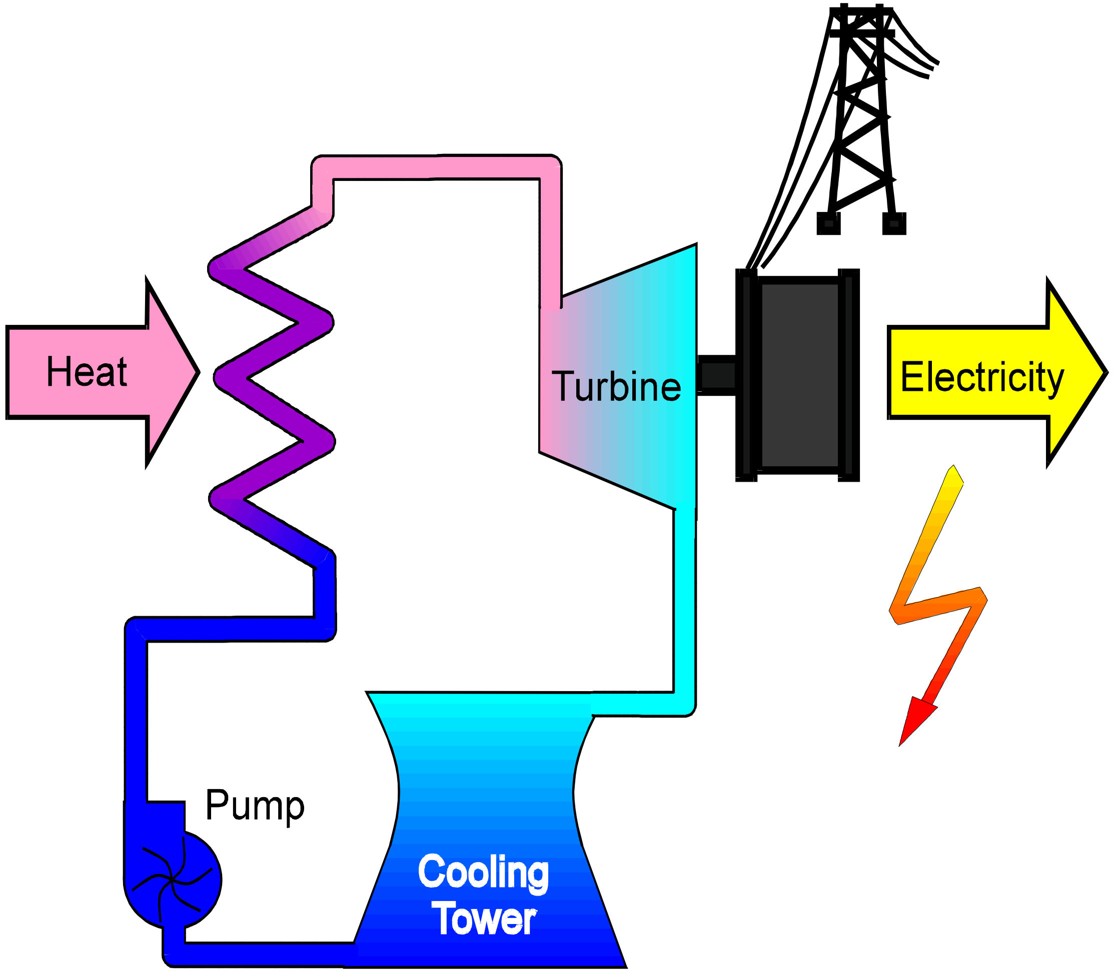
1. Introduction to Concentrating Solar Technologies
2. Actual Market and Cost Situation
3. A comparison with PV and potential Synergies
4. Perspectives for Cost Reduction
5. Conclusions

1. Introduction to Concentrating Solar Technologies

What is CSP?

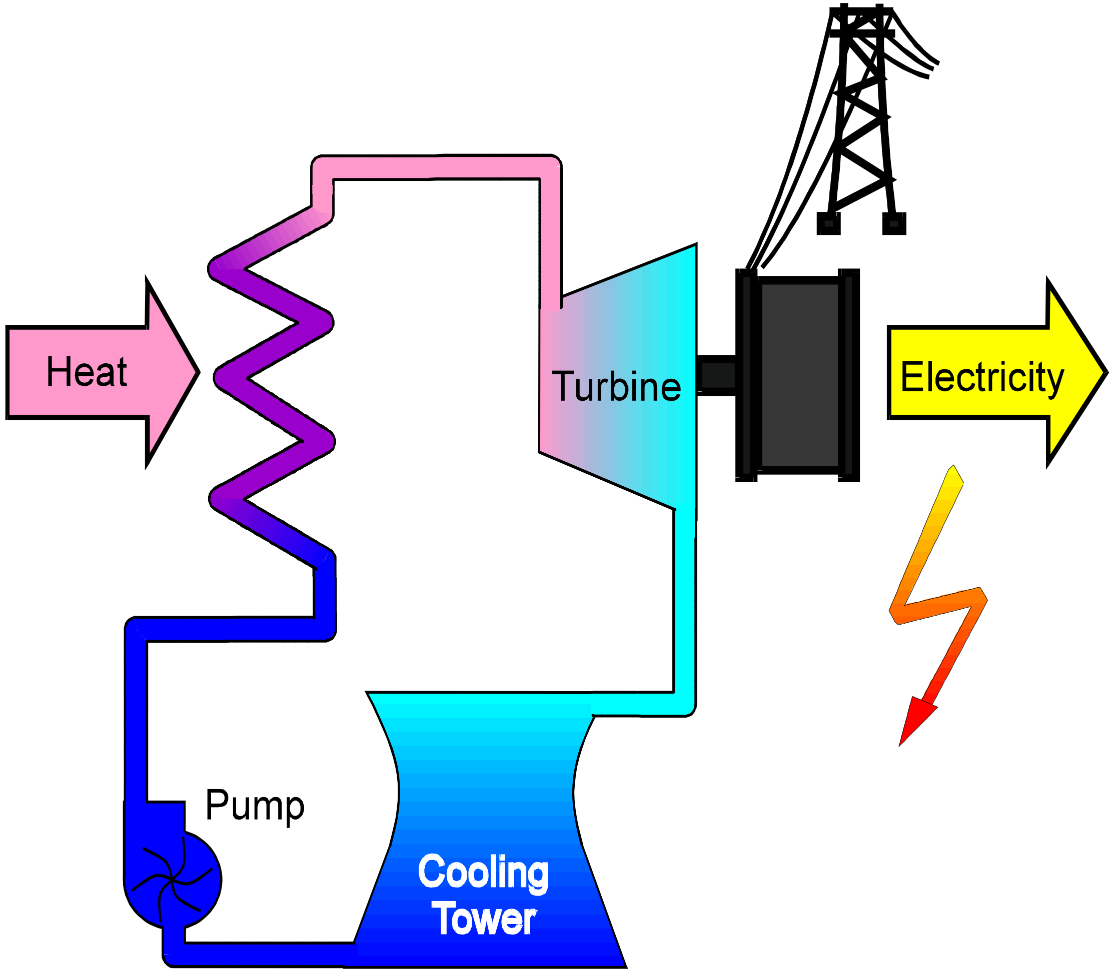


Conventional power plant

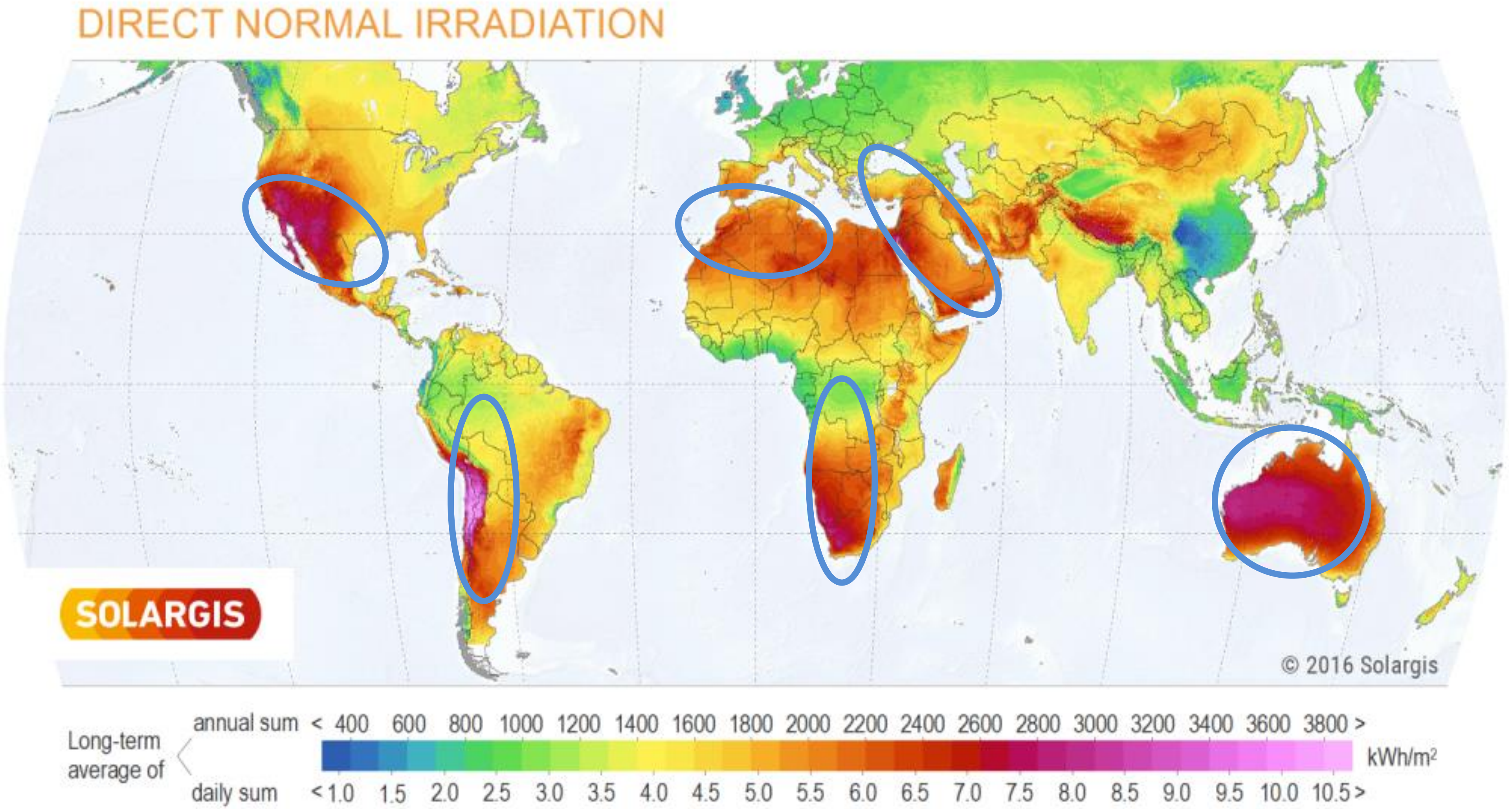


What is CSP?

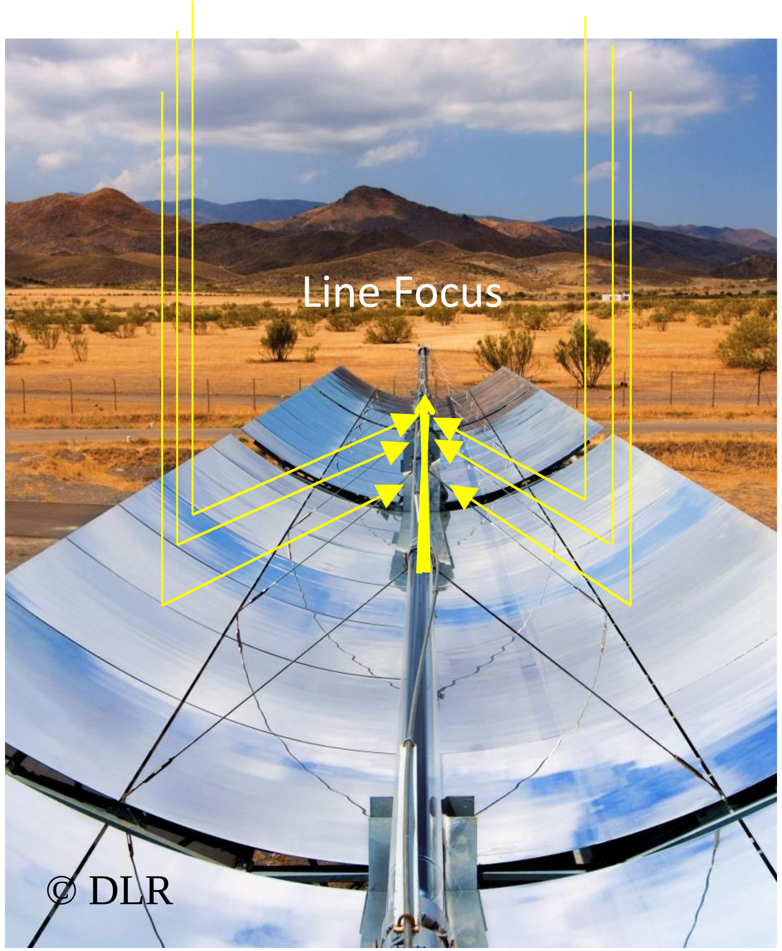
Concentrating solarpower plant

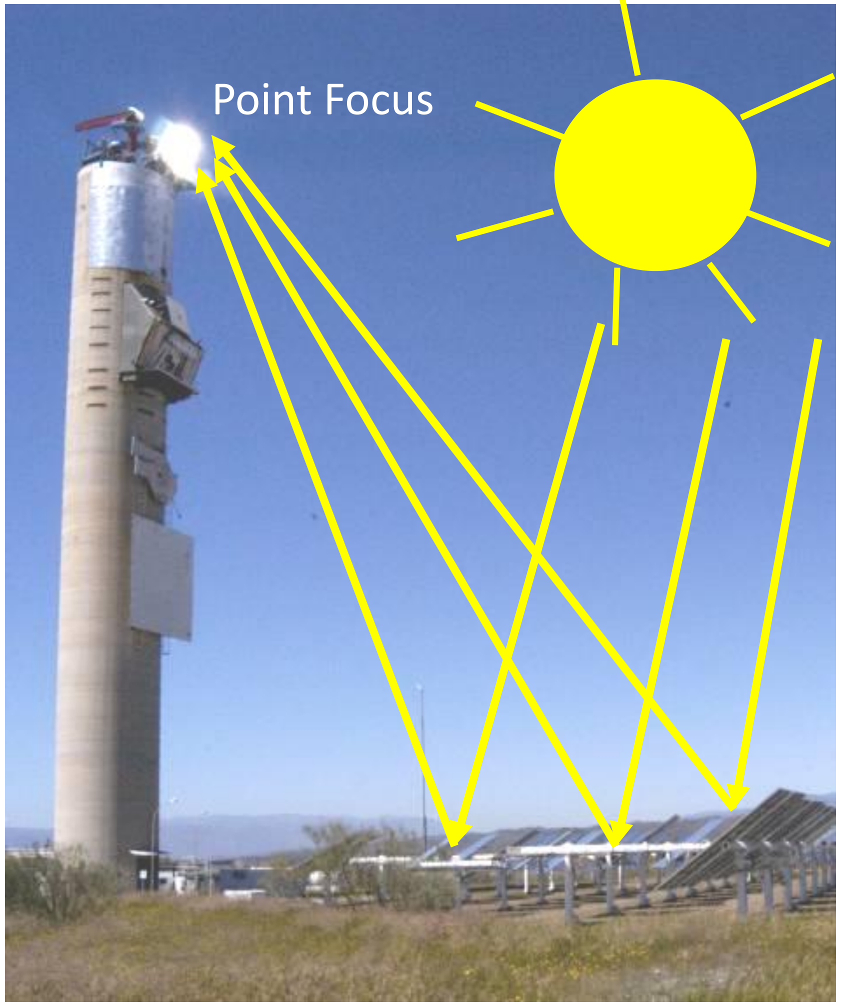


CSP only suitable in areas with high direct normal radiation



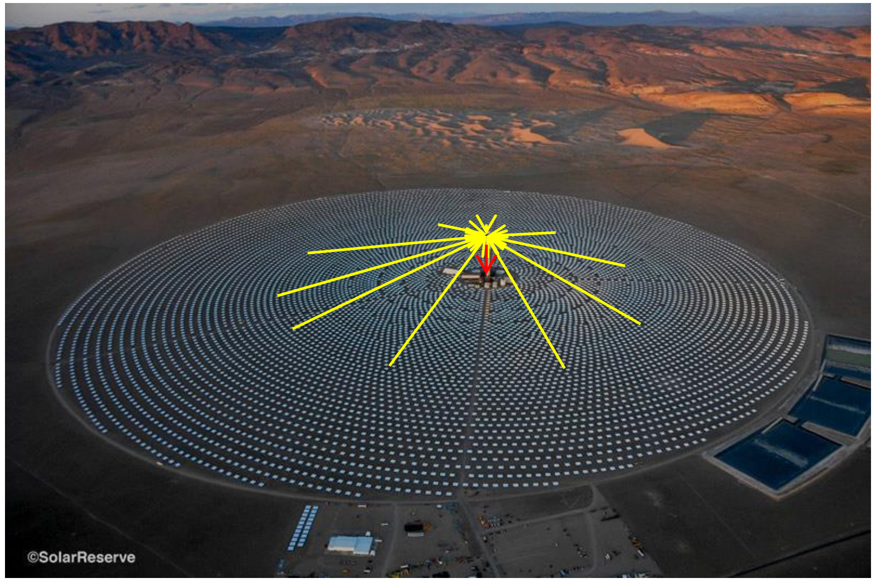
Trough vs. Tower

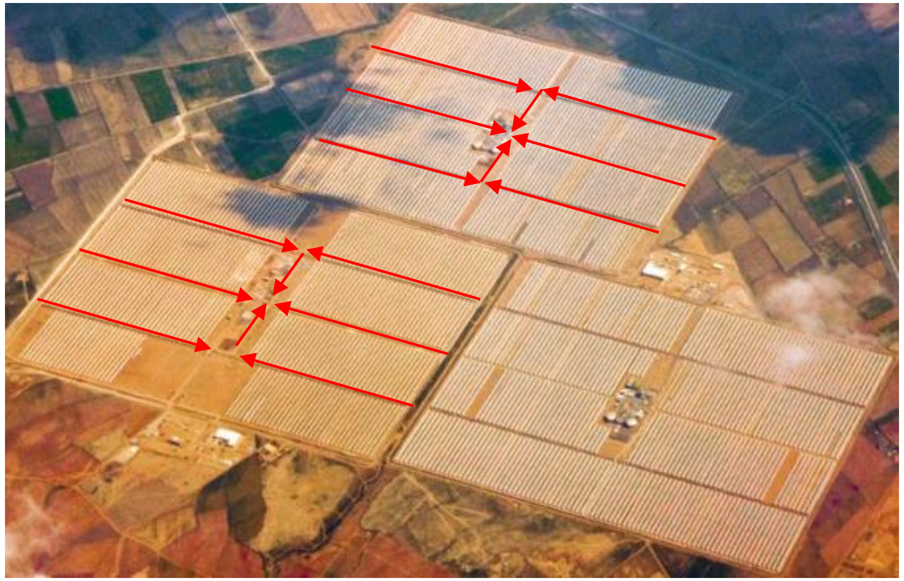




Trough vs. Tower

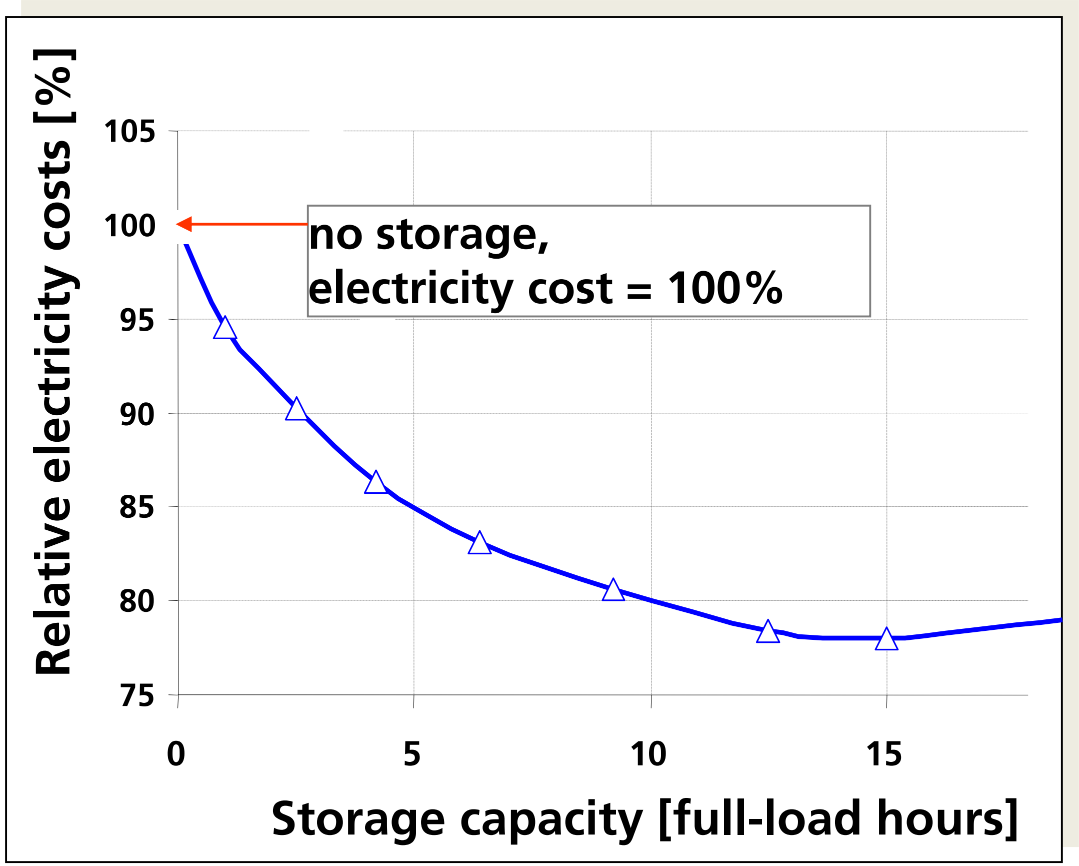
- Solar energy collected by reflection
- Solar energy collected by piping





CSP w/ storage cheaper than CSP w/o storage

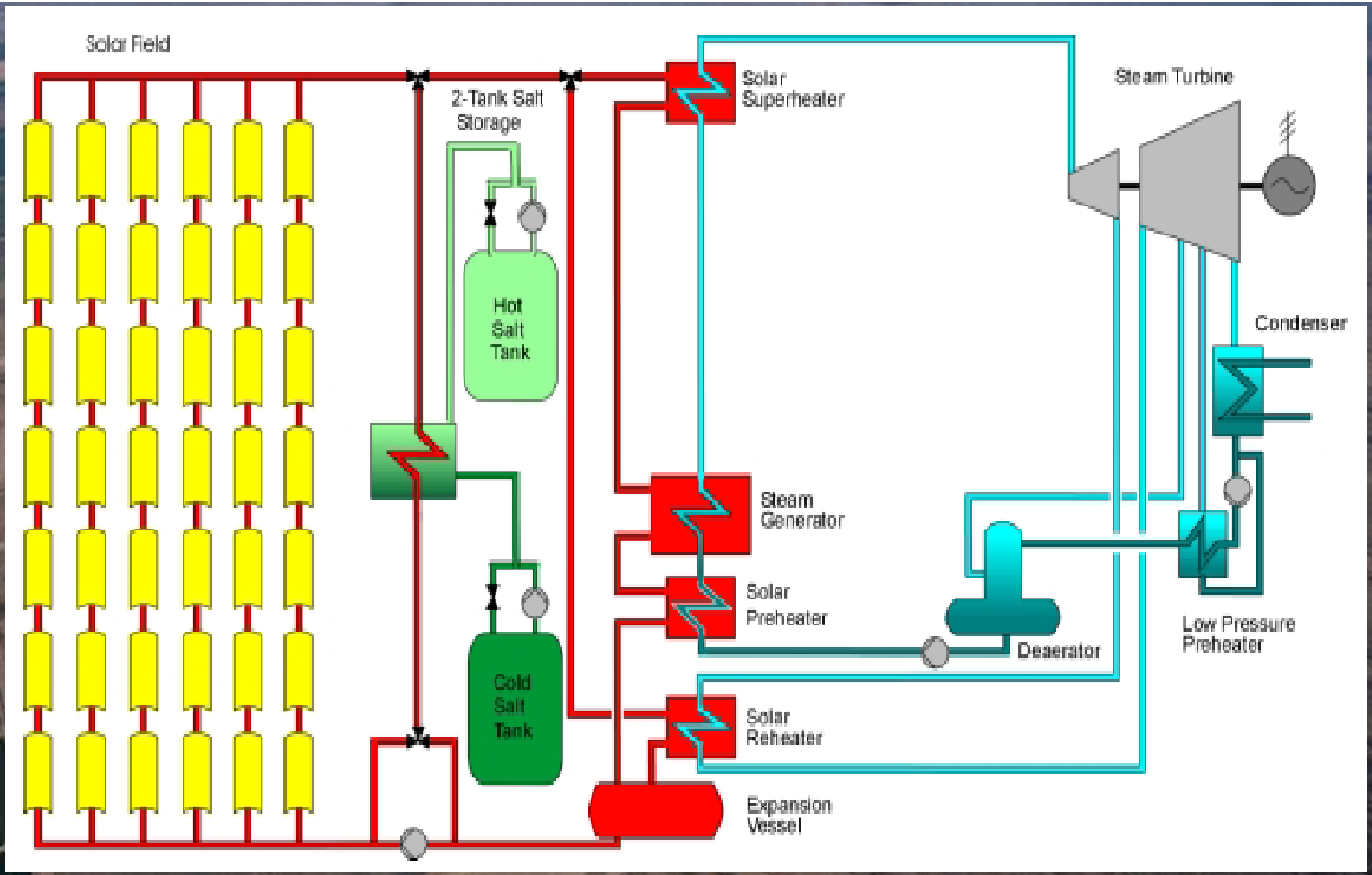
Thermal Storage = more operating hours = higher capacity factor = cost reduction



* assuming specific investment costs for the storage of 10 Euro/kWh

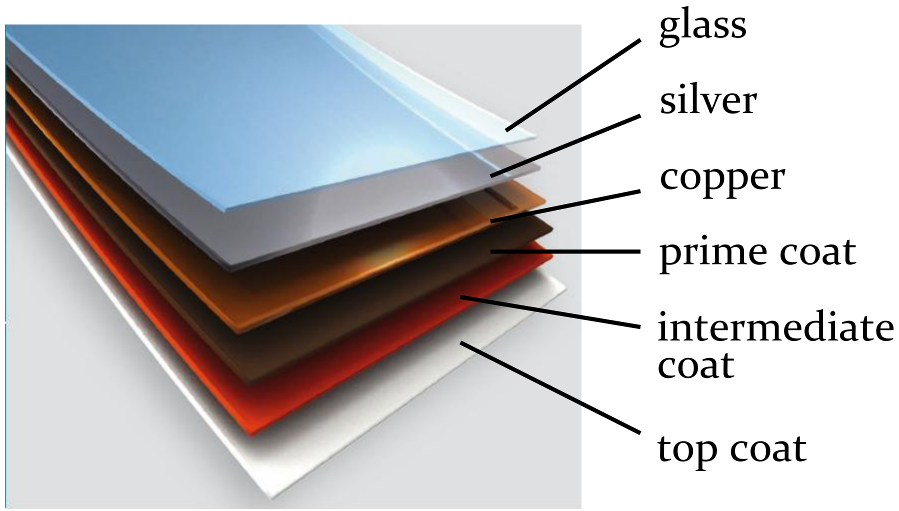
Parabolic Trough Power Plant Design

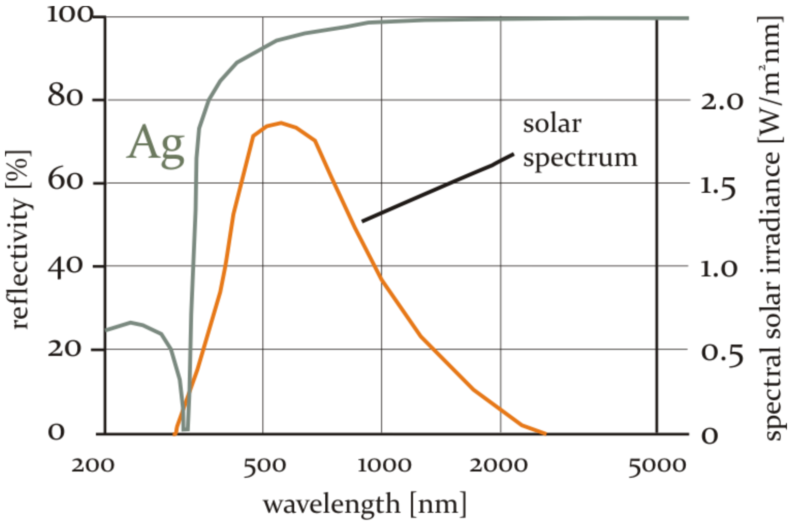
Country	United States
Location	Maricopa County
Coordinates	32°55′N 112°58′W
Status	Operational
Construction began	December 2010
Commission date	2013
Construction cost	US$2 billion
Owner(s)	Atlantica Sustainable Infrastructure[1] Liberty Interactive Corporation
Operator(s)	Arizona Solar One LLC
Solar farm	
Type	CSP
CSP technology	Parabolic trough
Collectors	3,232
Total collector area	2,233,958 square metres (552.023 acres)
Site area	1,920 acres (780 ha)
Power generation	
Units operational	2
Make and model	Siemens[2]
Nameplate capacity	250 MW
Capacity factor	33.9% (five year average)
Annual net output	742 GW·h
Storage capacity	1,500 MW·h_e



Mirror material – silver coated glass mirrors

- used in all realized parabolic trough power plants
- proven technology
- no significant decrease of reflectivity over time

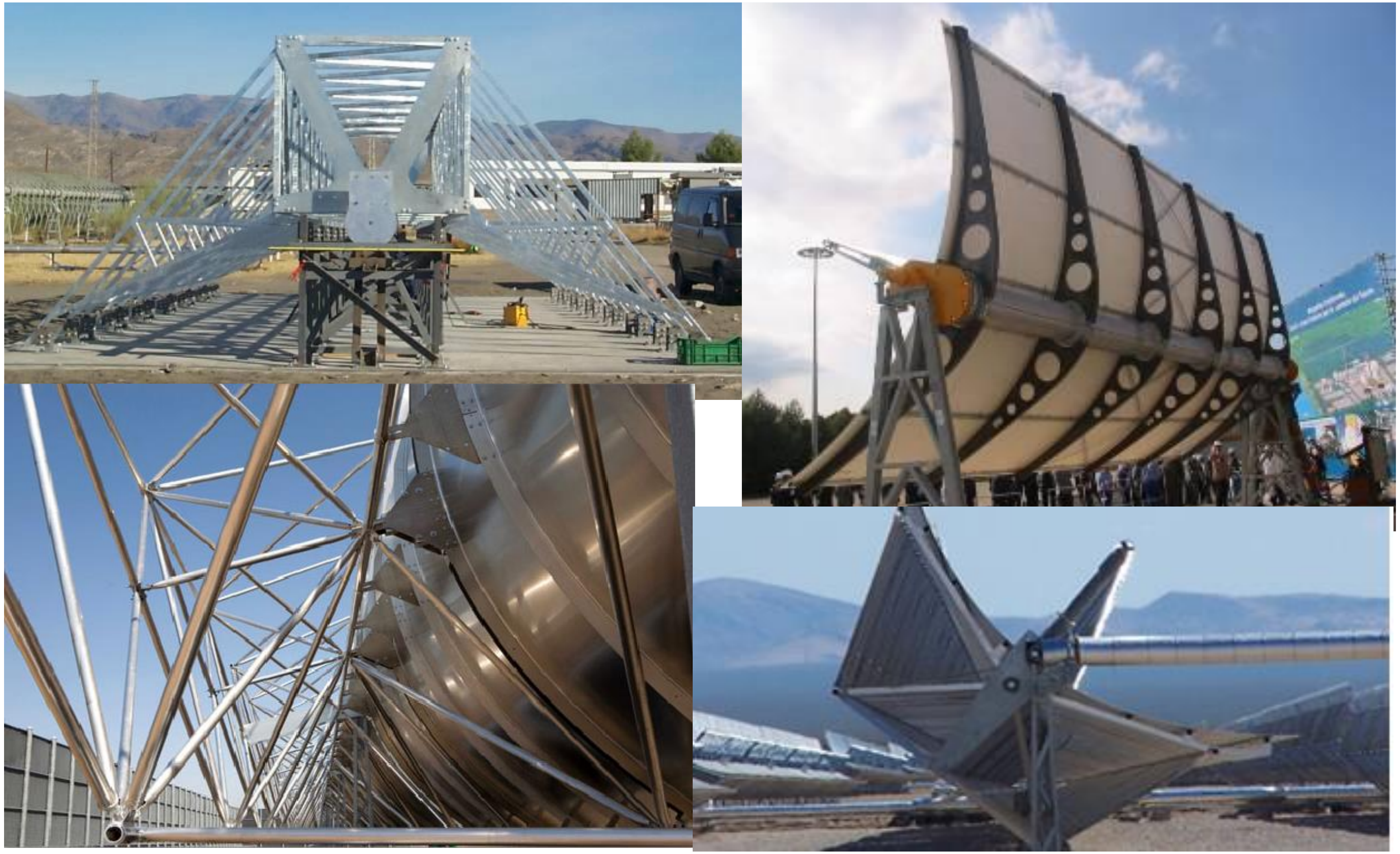




reflectivity: 93.5 %

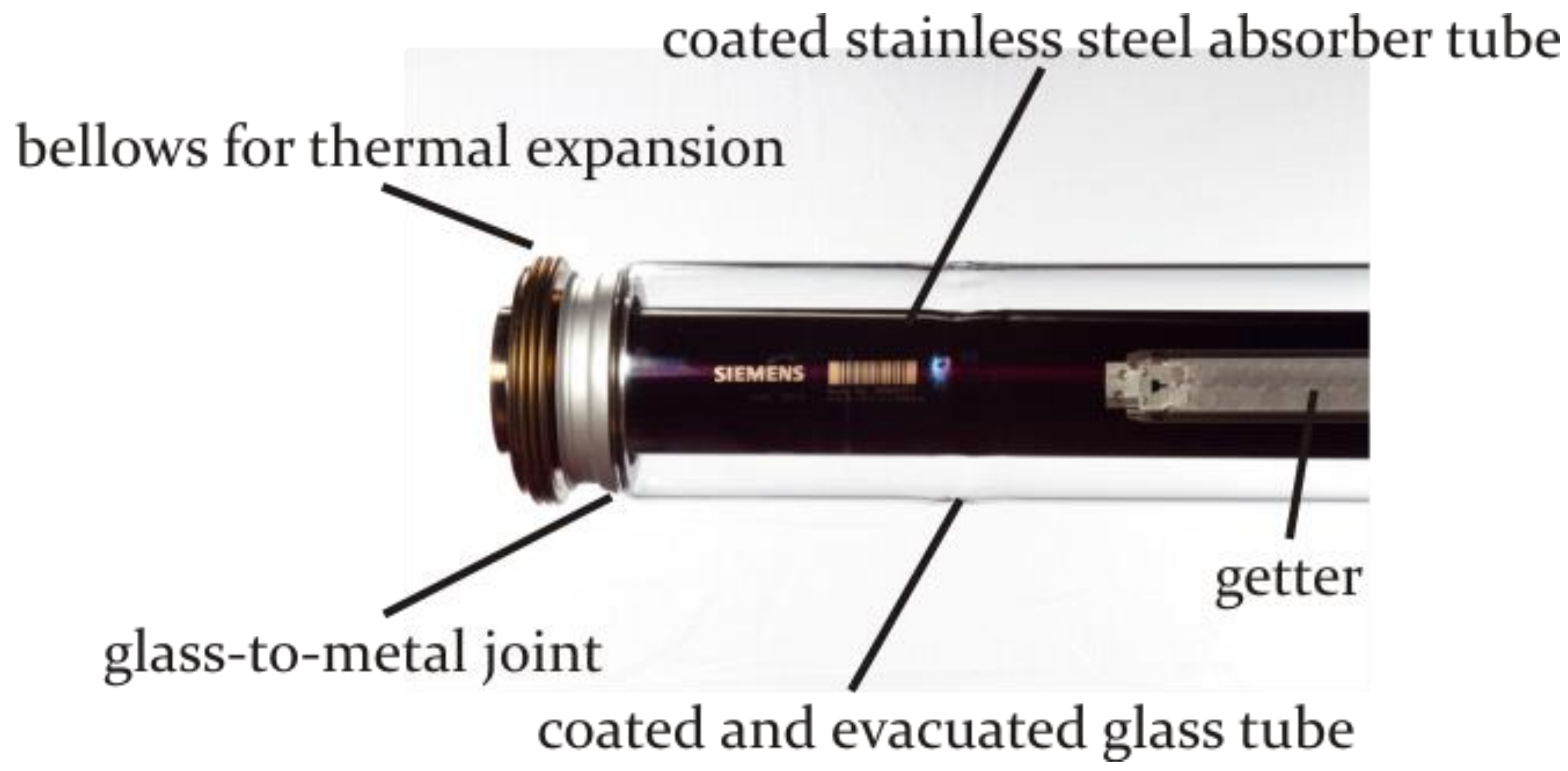
source: CSP Services, Schott

Bearing structure



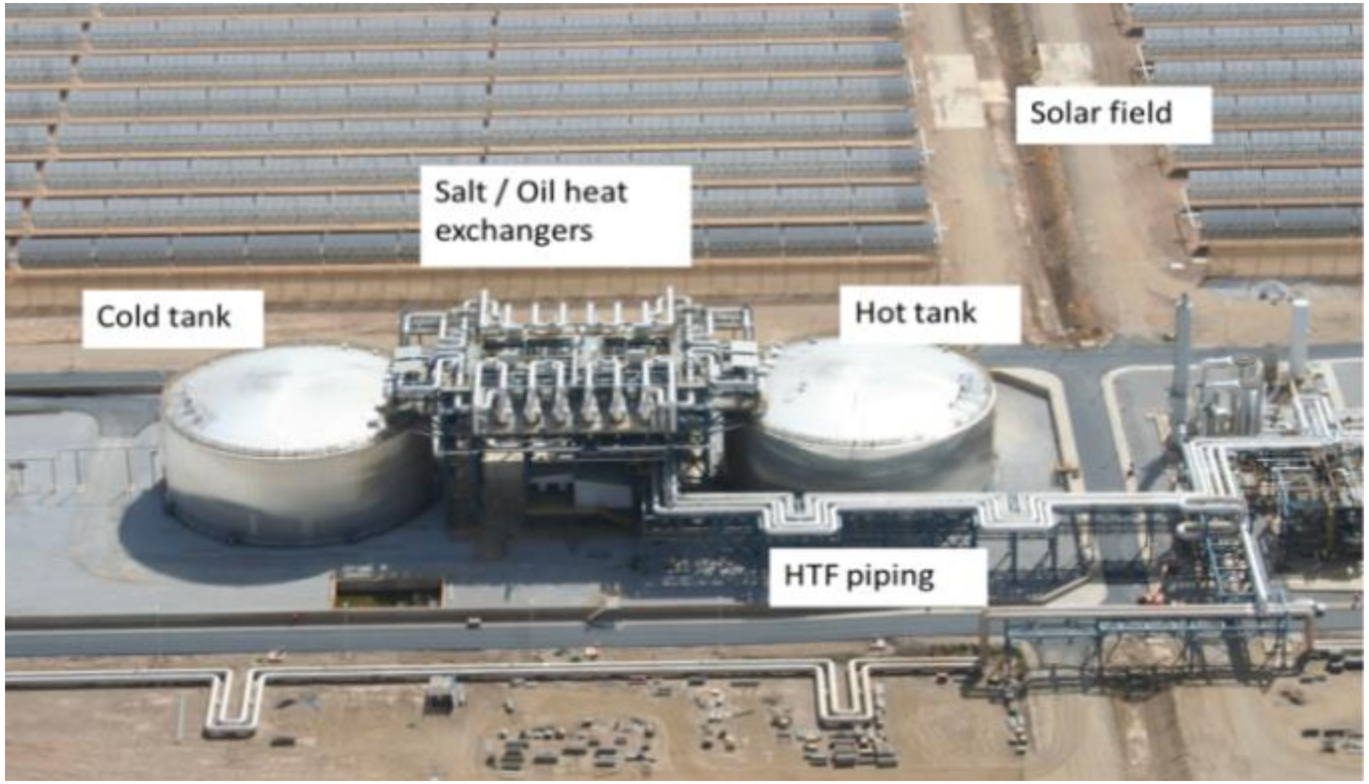
source: Lüpfert, DLR, ENEA

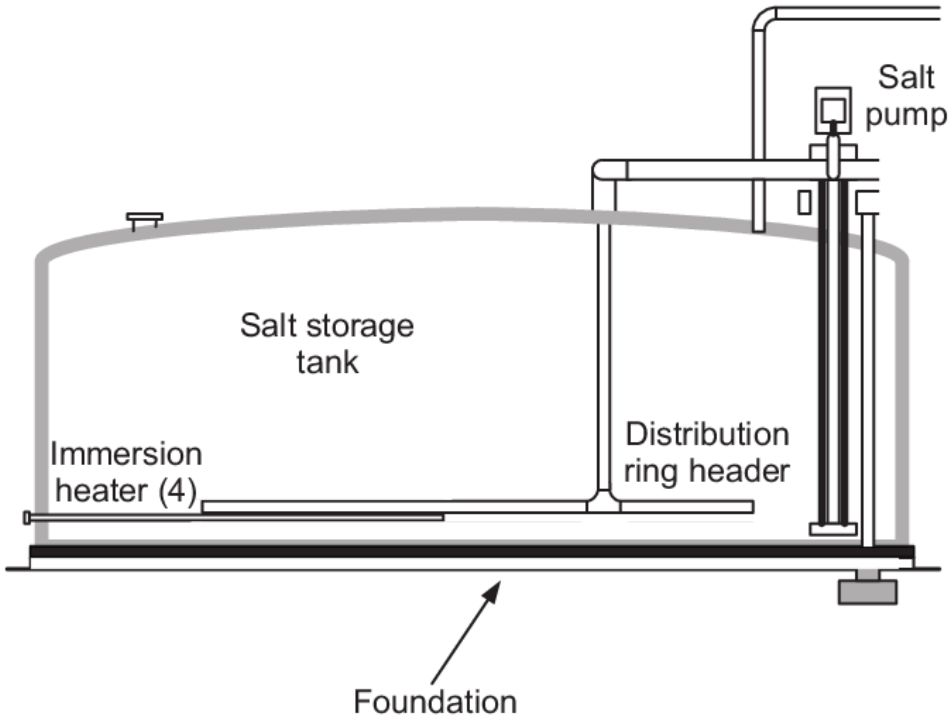
Receiver components

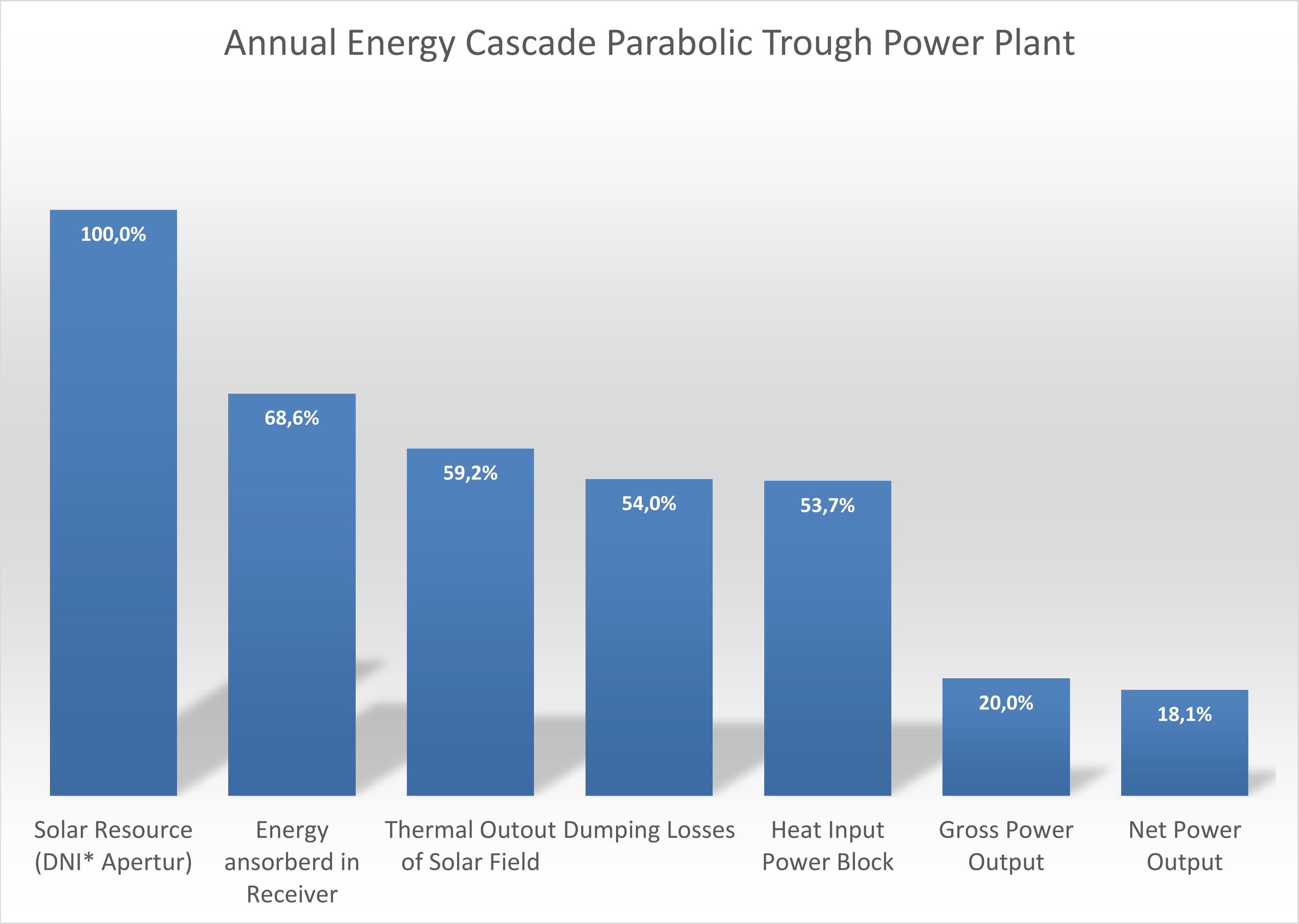


source: www.energy.siemens.com

Molten Salt Storage

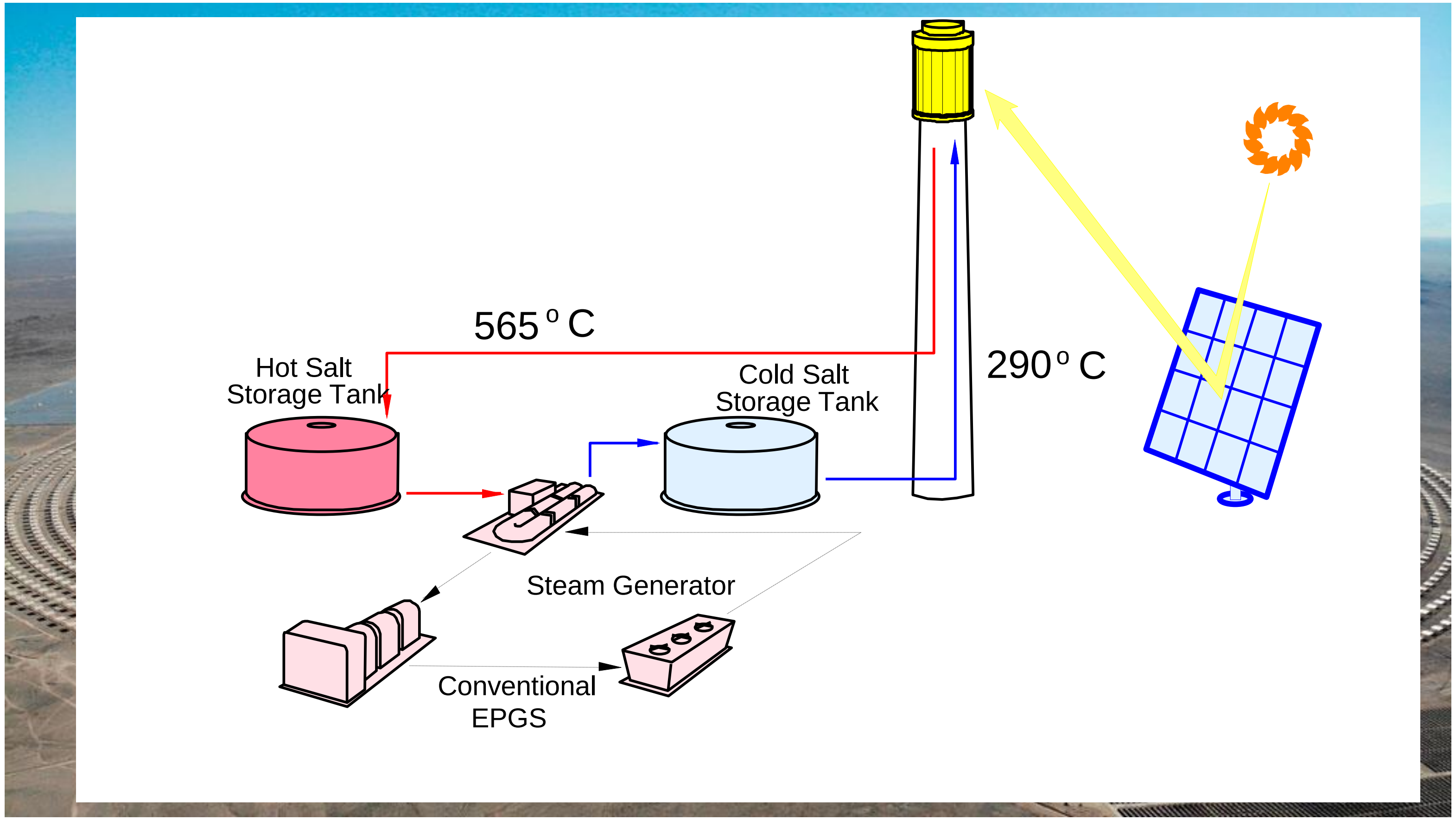





Annual Energy Cascade Parabolic Trough Power Plant
100,0%
68,6%
59,2%
54,0%
53,7%
20,0%
18,1%
Solar Resource (DNI* Apertur)
Energy ansorberd in Receiver
Thermal Outout of Solar Field
Dumping Losses
Heat Input Power Block
Gross Power Output
Net Power Output

Solar Power Tower Plant Design

Official name	Planta Solar Cerro Dominador
Country	Chile
Location	Antofagasta
Coordinates	22.77191°S 69.47994°W
Status	Operational
Construction began	May 2014[1]
Commission date	June 8th 2021
Construction cost	est. $1 billion
Owner(s)	EIG Global Energy Partners
Solar farm	
Type	CPVCSP
CSP technology	Solar power tower
Collectors	10,600
Site area	750 ha (1,900 acres)
Power generation	
Units operational	100 MW
Units under const.	110 MW
Nameplate capacity	210 MW
Annual net output	950 GW·h (secured sale)
Storage capacity	1,925 MW·h_e



Solar Tower System

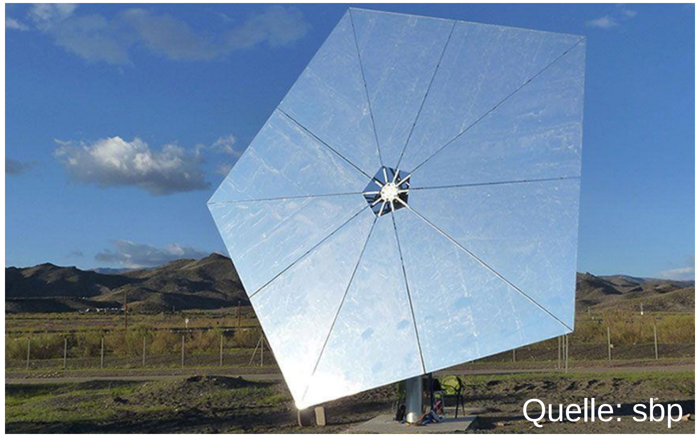
Concentration of Solar Radition by Heliostats

Quelle: New Energy Update 2018

Typical construction o a Heliostat

Quelle: Plataforma Solar de Almería

Different Heliostat Designs


Quelle: sbp


Quelle: Plataforma Solar de Almería


Quelle: Abengoa Solar


Quelle: Technikjournal

Heliostat Cleaning

Manuel Cleaning

Automatic Cleaning

Heliostat Arrangement

North Field

Surround Field

Quelle: REVE

Quelle: Torresol Energy

Quelle: DLR

Quelle: Solar Reserve

Receiver concepts


Quelle: CSIRO


Quelle: DLR


Quelle: Galenbeck


Quelle: eSolar

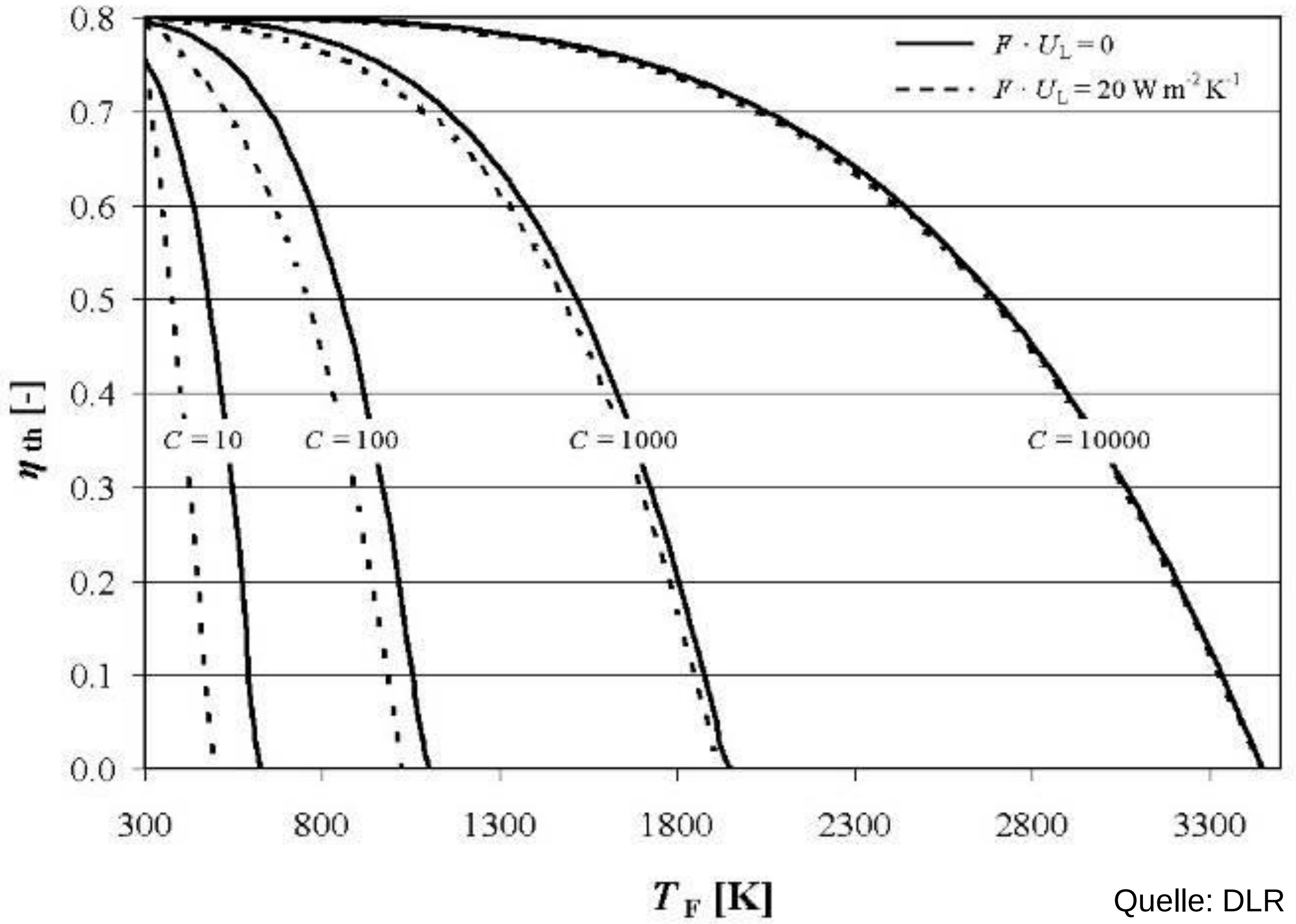

Quelle: SolarReserve


Quelle: Prashant Karhade


Quelle: CMI Group

Receiver-Efficiency

Receiver efficiency as a function of the average fluid temperature

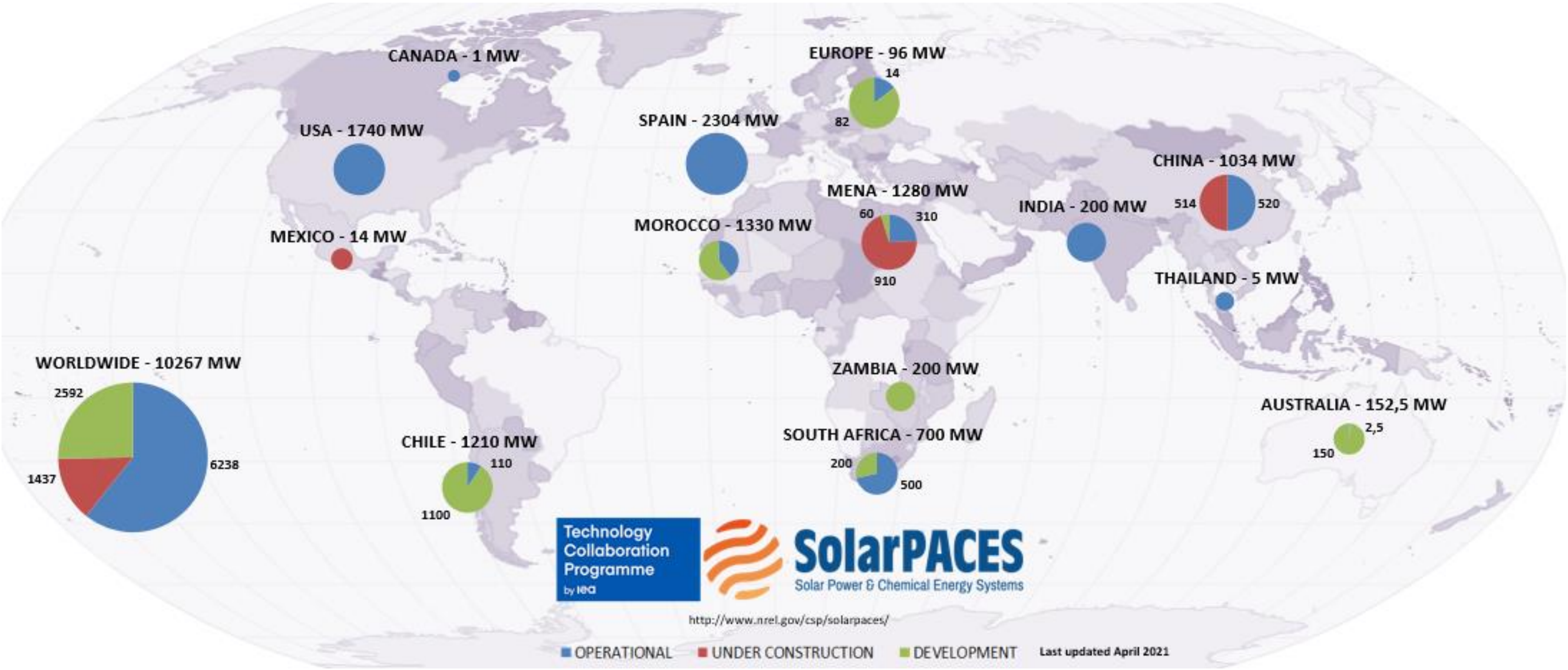


Quelle: DLR

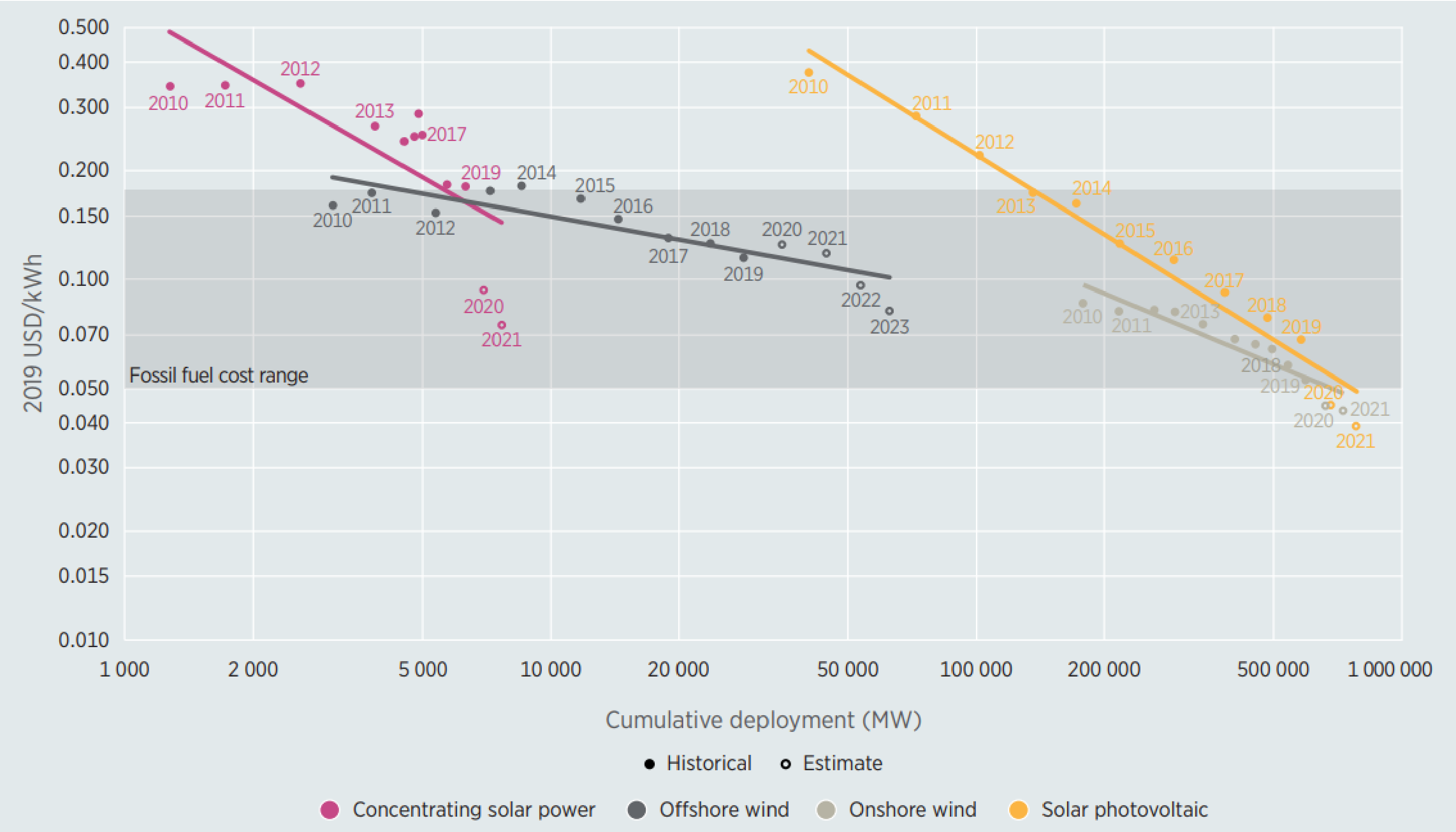
2. Actual Market and Cost Situation

Current Market Overview CSP: 6.2 GW operational around the world

https://www.solarpaces.org/csp-technologies/csp-projects-around-the-world



Strong cost degression in CSP at relatively low total deployment



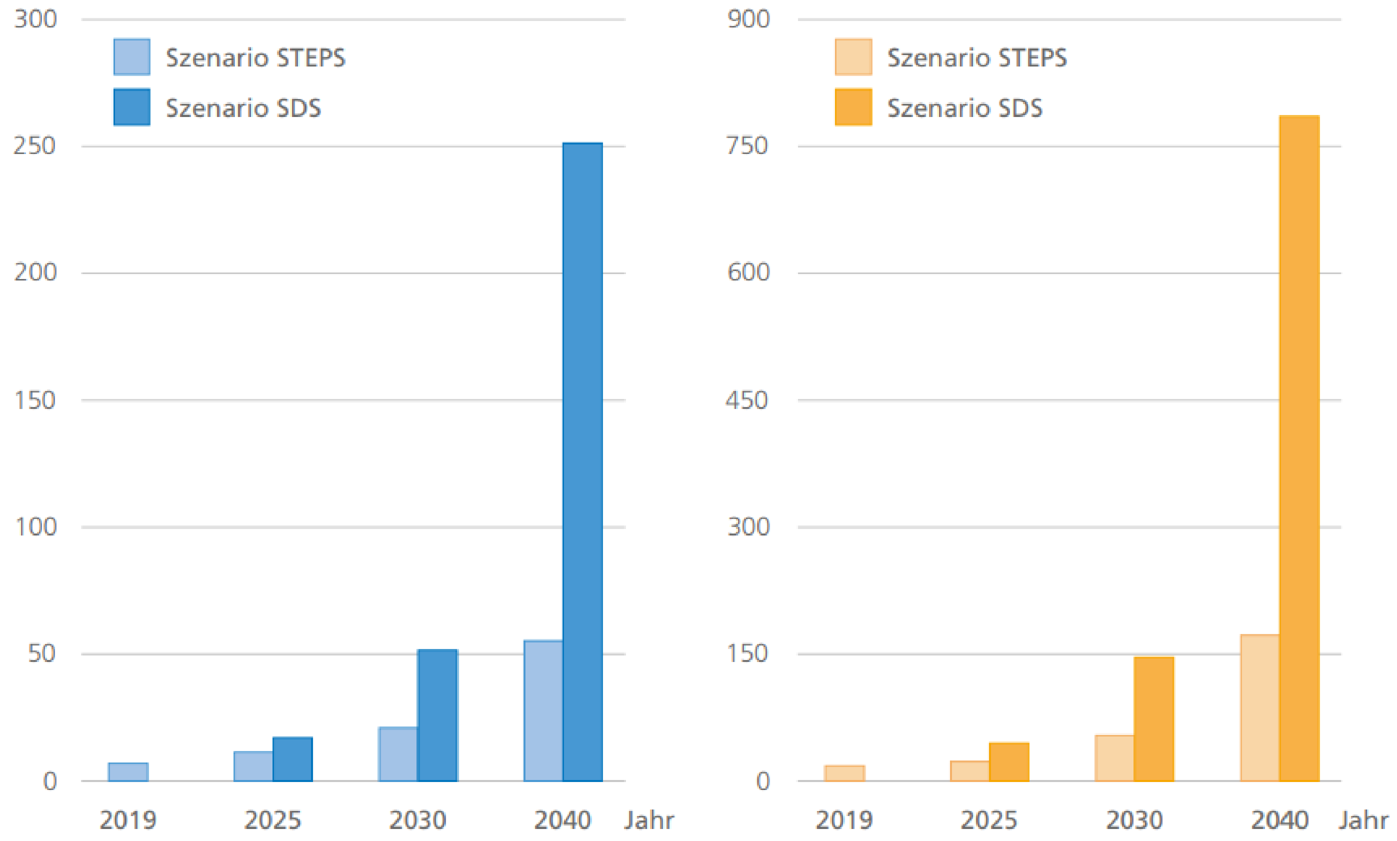
Source: IRENA, RENEWABLE POWER GENERATION COSTS IN 2019, Figure 1.11 The global weighted-average LCOE and Auction/PPA price learning curve trends for solar PV, CSP, onshore and offshore wind, 2010 – 2021/23

Possible CSP growth scenarios of IEA 2020-2040

(in conjunction with growing capacities of PV and Wind)

15-25% annual growth rate estimated

Capacity (GW) **Electricity Generation (TWh)**



STEPS: Stated Policies; SDS: Sustainable Development (<1,5 °C)

Source Data from IEA-WEO 2020, Table A.3

3. A comparison with PV and potential synergies

CSP-PV Hybrid Solutions

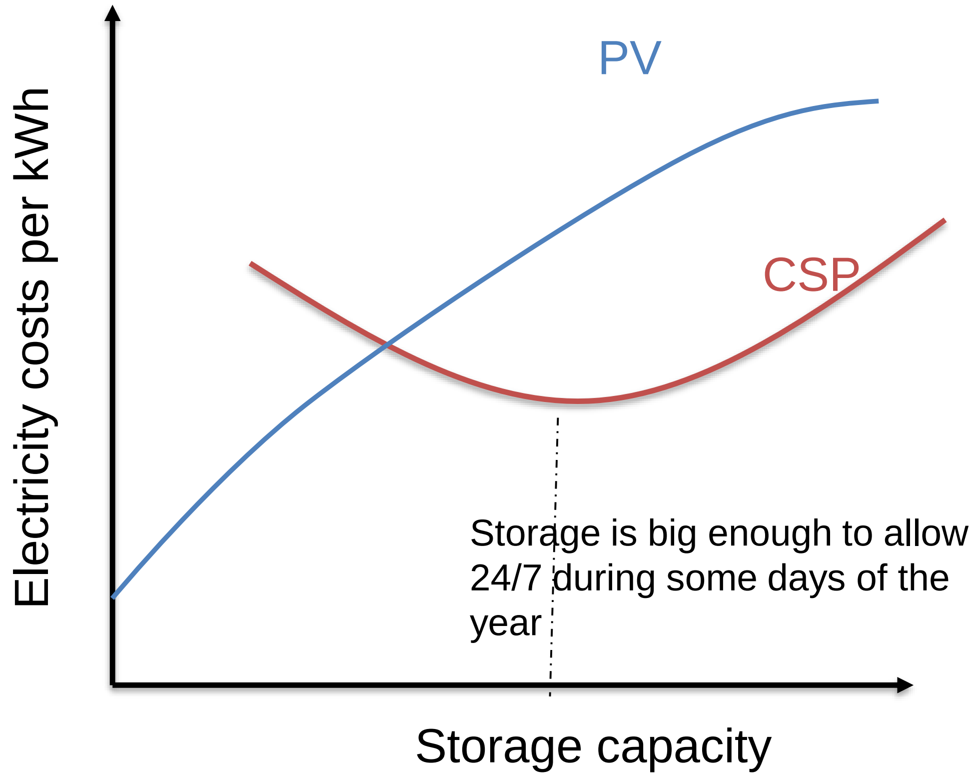
- **photovoltaic power** plants can provide **cheap** electricity from solar when the sun is shining
- **Storage solutions** are required to satisfy demand **after sunset**
- Battery storage systems are expensive, particularly for large power units with several hours of storage capacity
- **Concentrating solar power** plants offer **dispatchable** solar power generation with cheap and proven **thermal storage** units
- **CSP** spinning turbine provides **ancillary services to the grid**
- Combining both solar power generation technologies offers **low cost and dispatchability**

Source: Powerway Renewable Energy Co., Ltd

Source: Solar Millennium AG

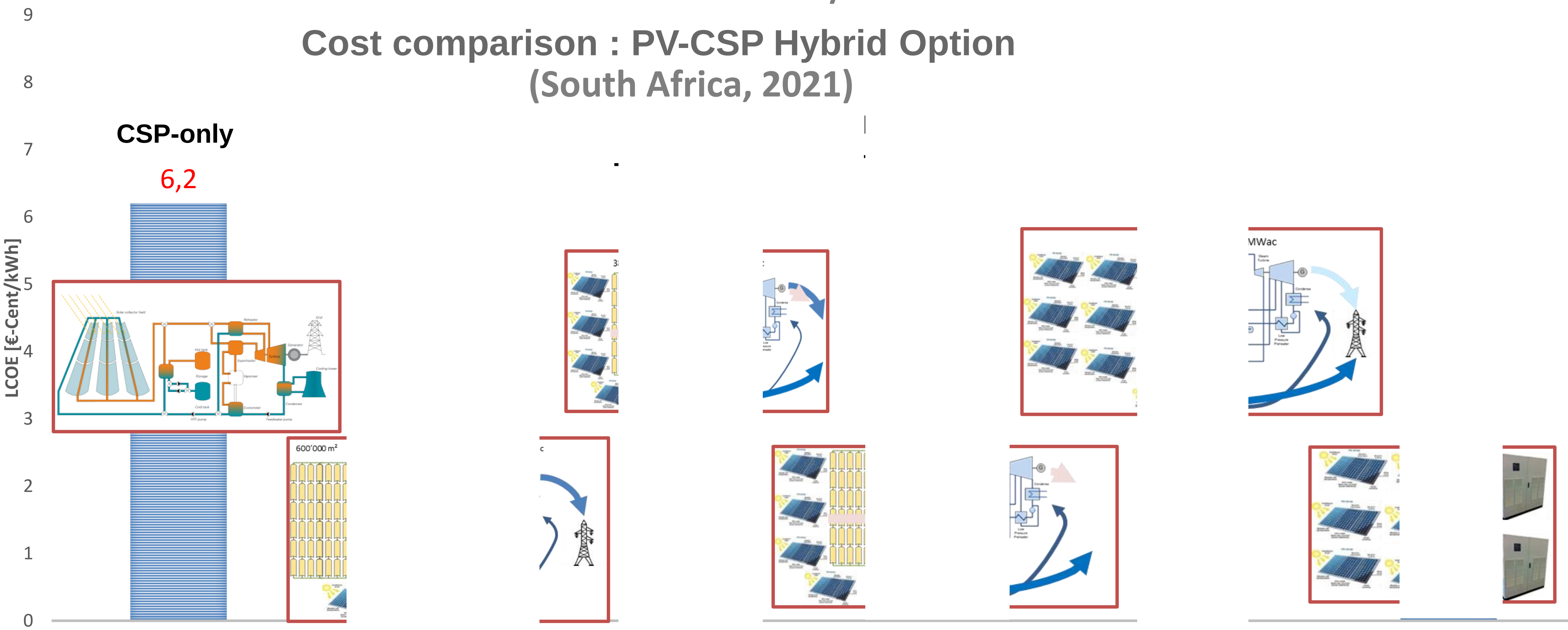
Trend: Hybrid PV-CSP Plants

- Standalone CSP or PV-plants are typically optimized for least cost electricity production (the nominal power output must be fixed in advance)
- For CSP plants the least cost design version often includes thermal storage because this part is cheap and helps to improve the economy of the whole plant
- For PV plants a system without storage has always the lowest electricity cost
- Hybrid plants are beneficial if one of the following conditions apply
    - A certain fraction of power production during night time
    - A limit for the power fed to the grid at any time
    - Time-of-delivery-tariffs to favor night time production over direct feed-in



LCOE in €-Cents/kWh

Cost comparison : PV-CSP Hybrid Option (South Africa, 2021)



For Details see Riffelmann, Weinrebe, Balz (2020): "Hybrid CSP-PV Plants with Integrated Thermal Storage"
proceedings SolarPACES 2020 online conference, demnächst verfügbar

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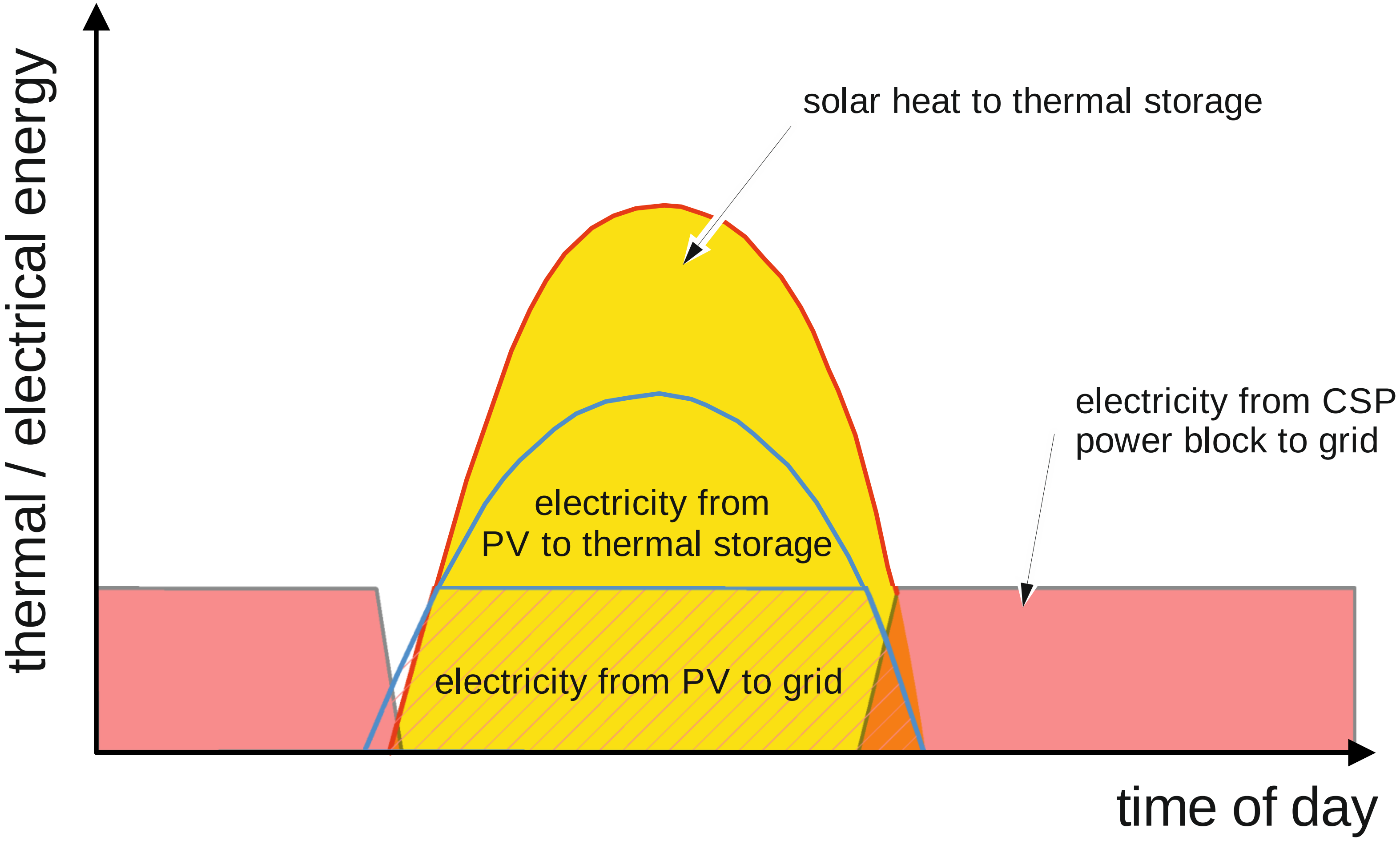
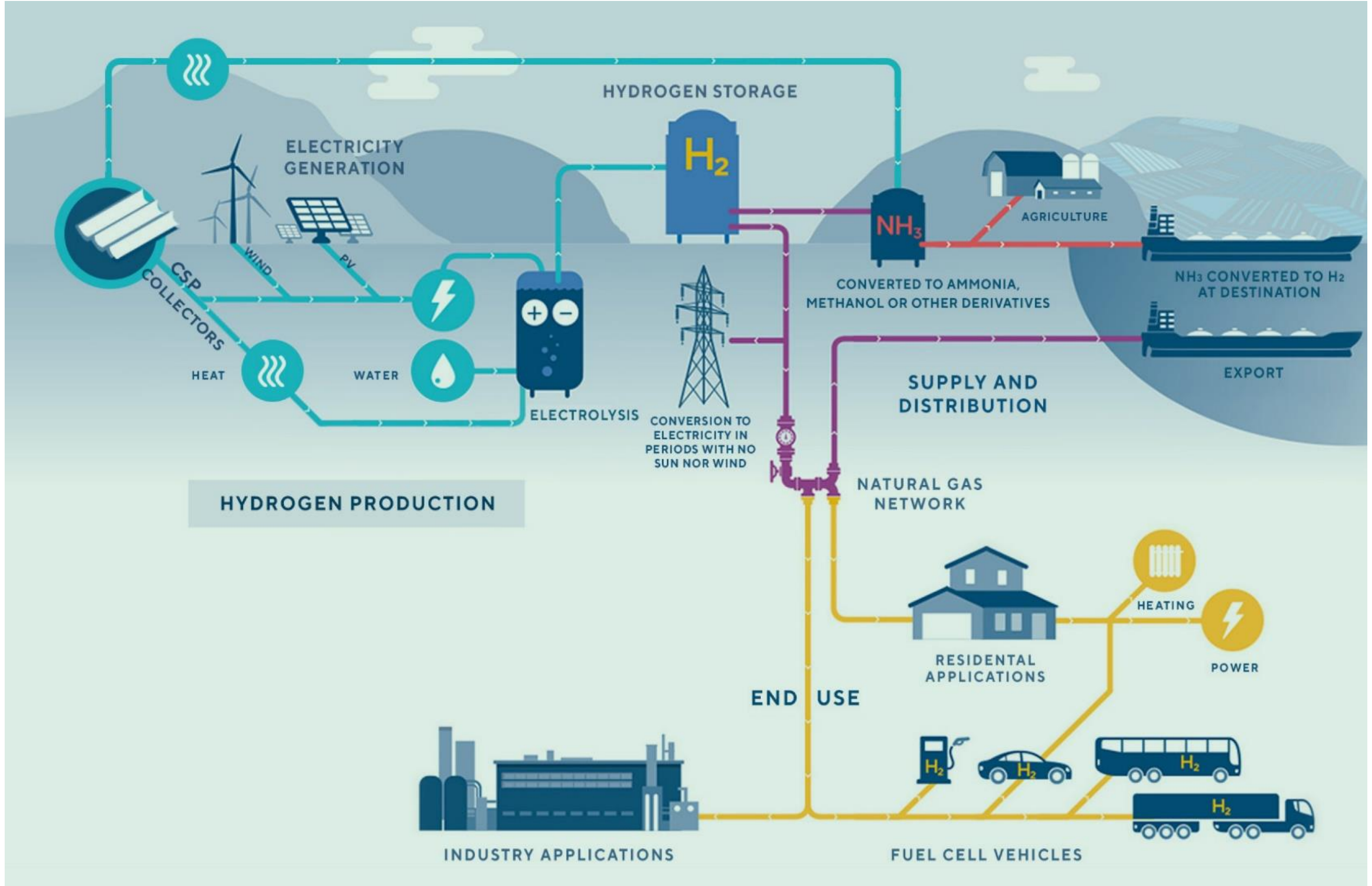
Typical daily production of a CSP / PV Hybrid Power planz

- During sunshine hours the PV plants delivers electricity to the grid
- Additionally, it delivers electricity to the thermal storage (via electric resistance heaters)
- The CSP power block is not operating during daytime, only the storage is charged
- The hybrid plant will be capable to deliver „round the clock“ solar electricity, for lower cost than two standalone plants



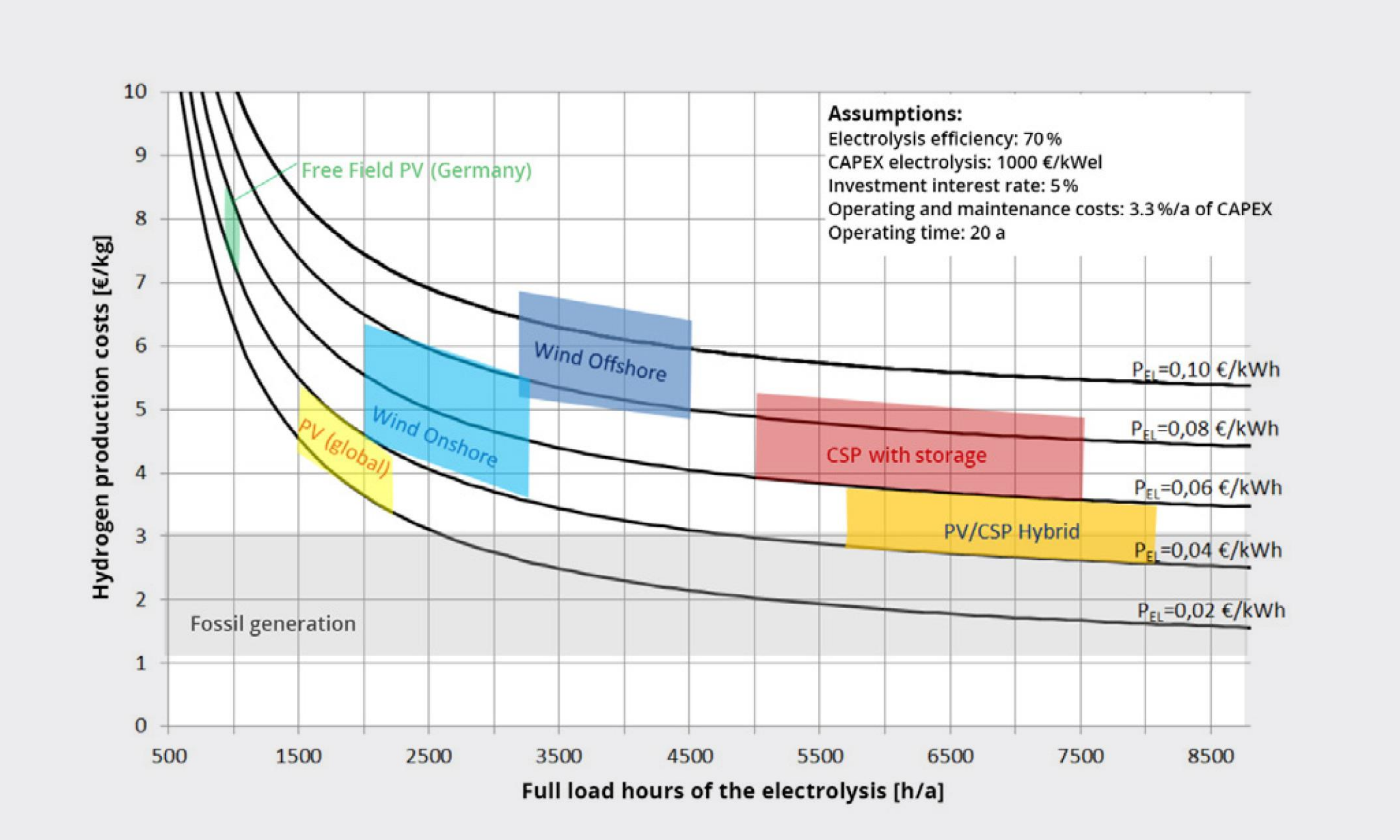
The contribution of CSP to hydrogen production

- CSP/PV-hybrids offer high full load hours at low electricity and lowest heat generation costs
- Constant utilization of the electrolyzer enables high conversion efficiencies
- Cost reduction potential through high-temperature electrolysis
- Use of the heat for further processing of the H_2 into derivatives



Source: DCSP 2021, modified presentation according Herbert Smith Freehills

Production costs for green hydrogen

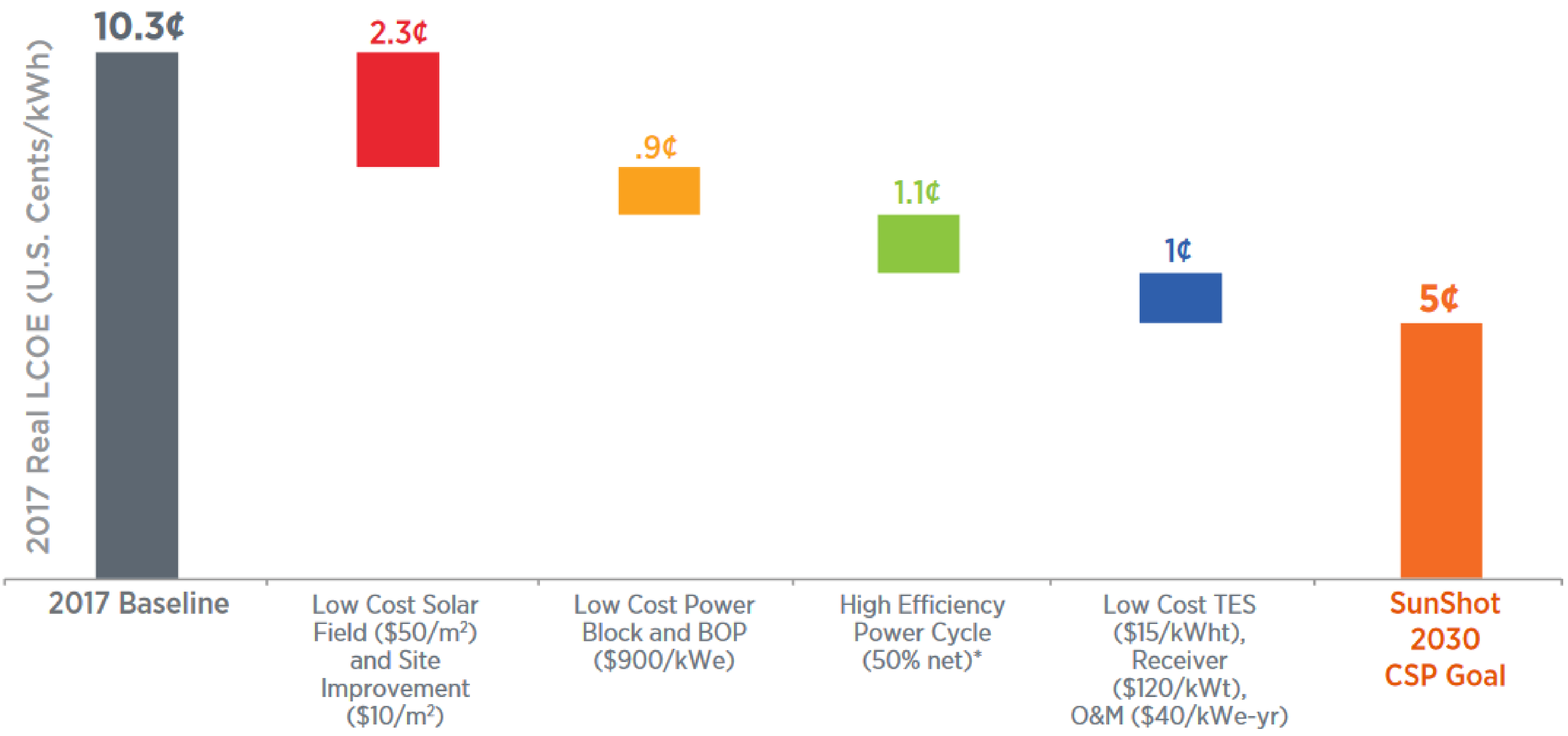


Assumptions Electrolysis:
Smolinka, T., et al., *Study IndWEDe Industrialisierung der Wasserelektrolyse in - Deutschland: Chancen und Herausforderungen für nachhaltigen Wasserstoff für Verkehr, Strom und - Wärme.* 2018. https://www.now-gmbh.de/wp-content/uploads/2020/09/indwede-studie_v04.1.pdf

Electricity generation costs:
Kost, C., et al., Study *Fraunhofer ISE: Stromgestehungskosten Erneuerbare Energien, 2018.* https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/DE2018_ISE_Studie_Stromgestehungskosten_Erneuerbare_Energien.pdf

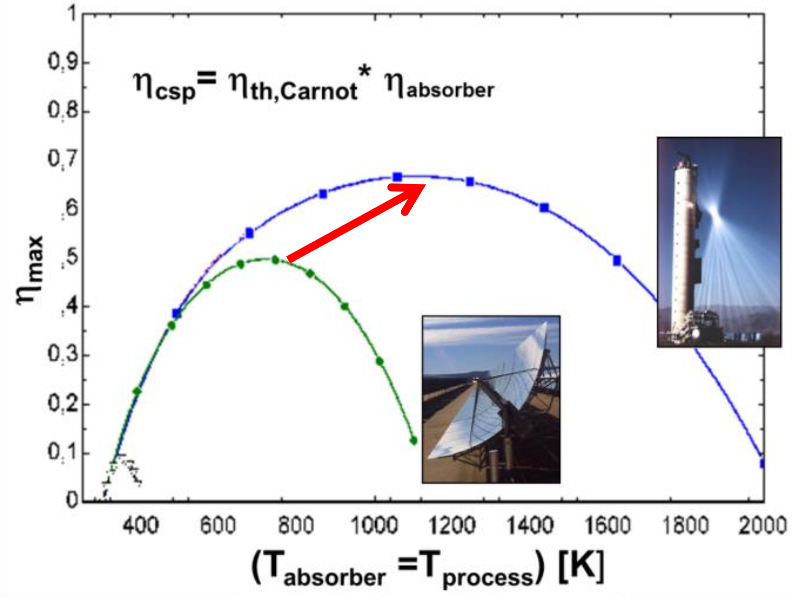
4. Perspectives for Cost reduction

Cost reduction scenario of DOE



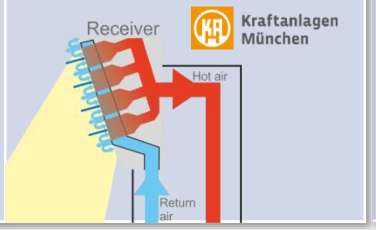
*Assumes a gross to net conversion factor of 0.9

Strategy for Cost Reduction



- High Concentration + High Temperature = High Efficiency = Low Cost
- Advanced heat transfer media needed for:
  - High temperature operation
  - Efficient storage integration

→ Break todays temperature limit of 400°C (trough) / 560°C (tower)

Silicon Oil T_{max} = 480°C	Air T_{max} > 700°C	Advanced Salt T_{max} > 600°C	Particles T_{max} > 900°C	Liquid Metal T_{max} > 800°C
				

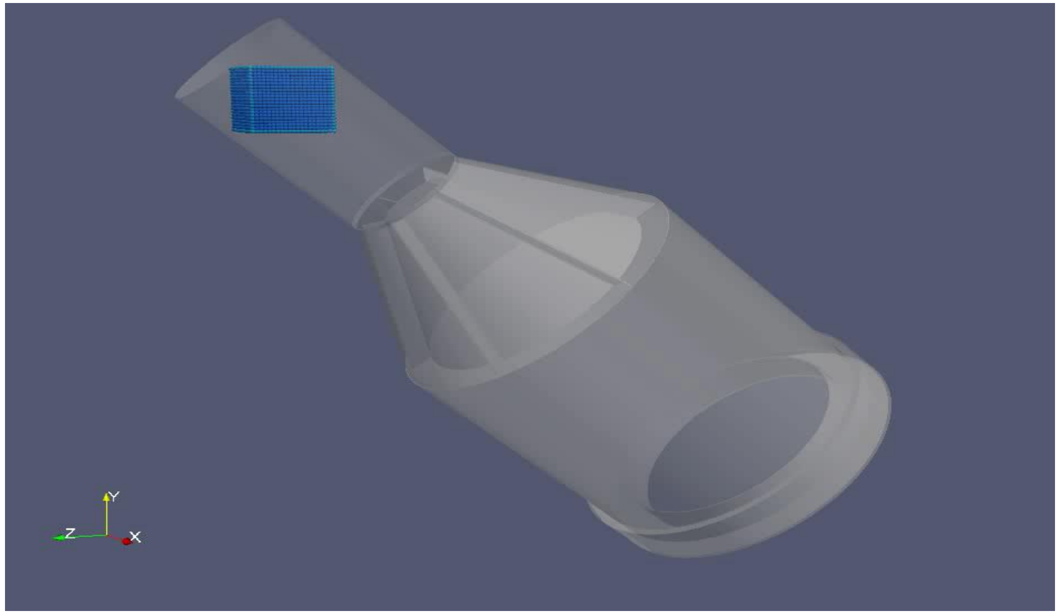
Third party funding — Risk — Helmholtz Funding

Concept of Particle Receiver

Bauxite particles

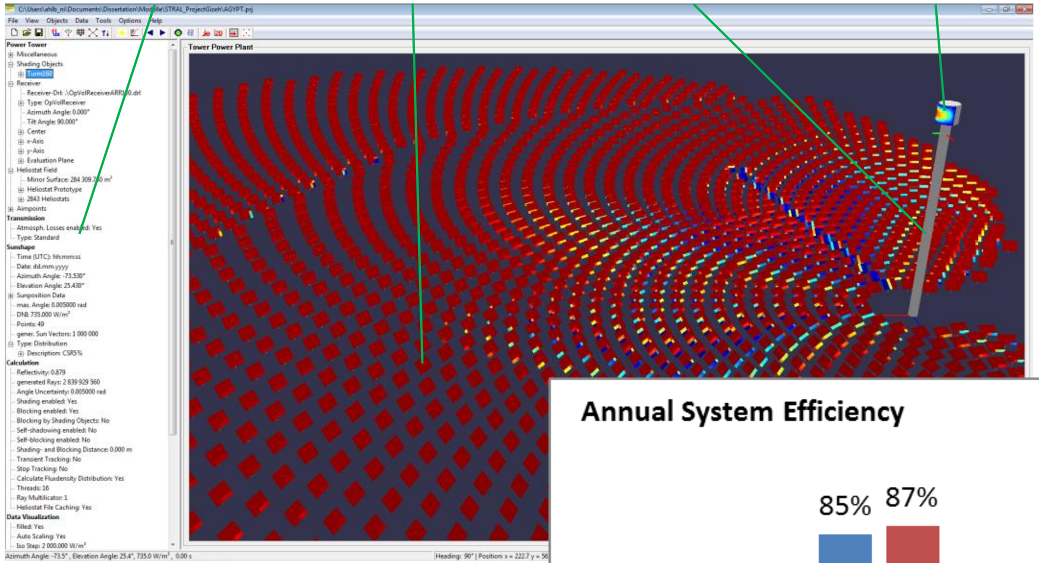
- Cheap (500 – 1000 €/t)
- Stable >1000°C
- Direct absorption
- Direct storage
- Low cost to move

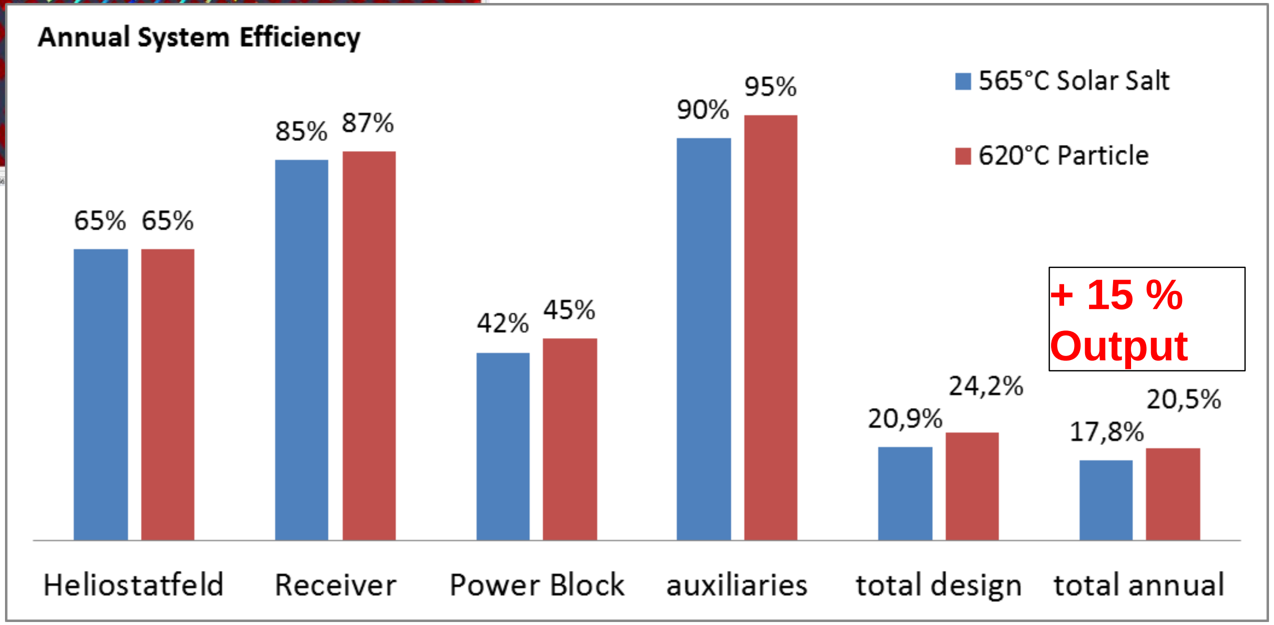
CentRec® rotating receiver concept



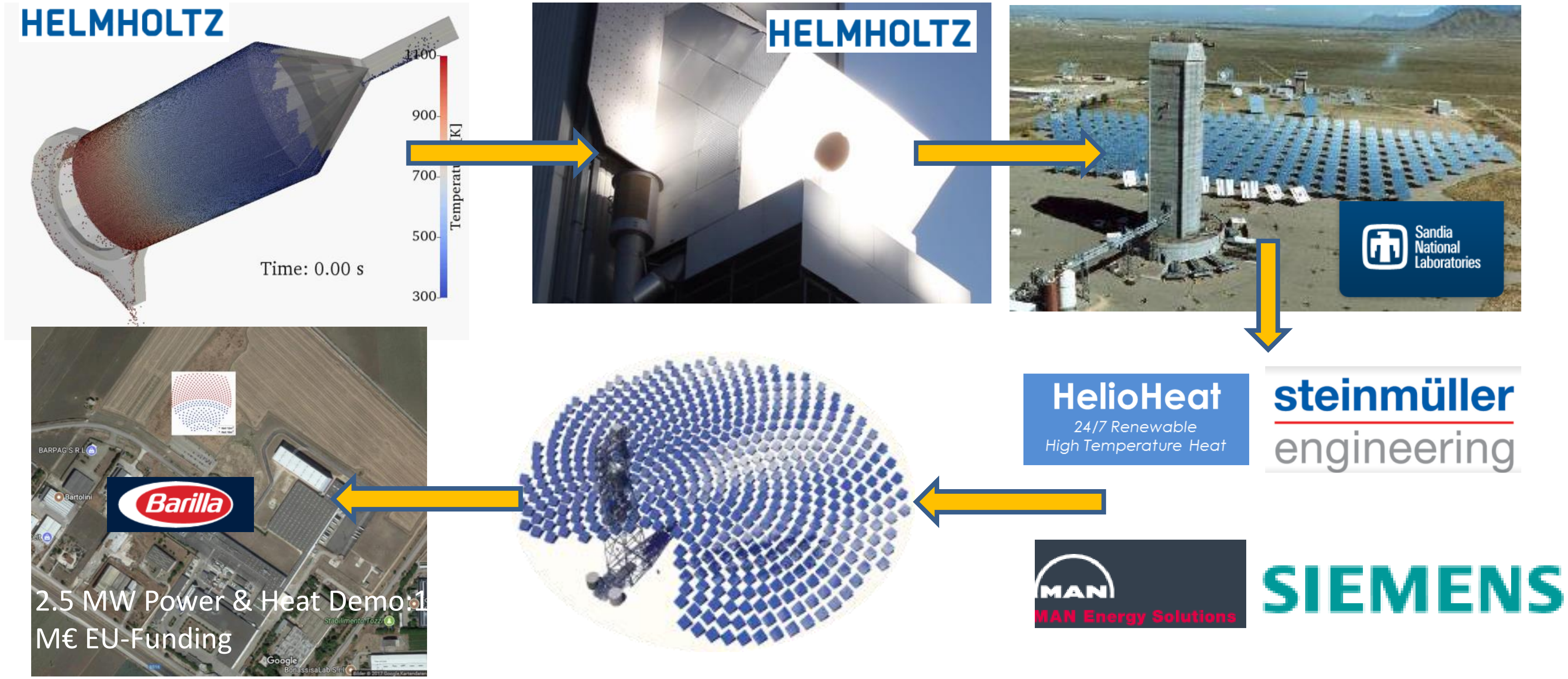
- Residence time controlled by rotational speed
- Cylinder walls isolated by particle layer

Results: Particle Receiver – Detailed Modelling





Example for CSP Solid Particle System



5. Conclusions

Summary and Conclusion

- With 6.2 GW installed capacity, CSP can be considered as a mature technology
- During the last 10 years a significant cost reduction can be achieved
- In combination with PV, CSP can provide 24/7 energy services for < 4 $cents/kWh in sun-rich countries
- This is cheaper than base-load from gas or nuclear power pants
- Further cost reductions of up to 50% are anticipated in the next 10 years in particular through mass production and the integration of high temperature cycles