STATUS AND PERSPECTIVES OF HIGH TEMPERATURE CST SYSTEMS

Institute of Solar Research

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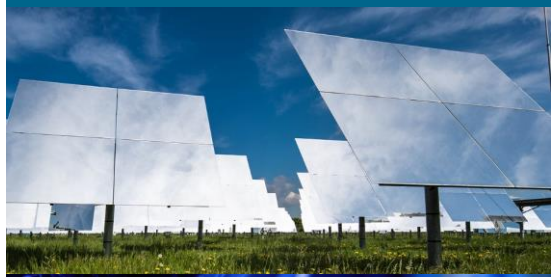
24.04.2025, Final Workshop COMPASsCO_2

DLR

German Aerospace Center DLR e.V.
Research Centre + Space Agency + Project Management Agency

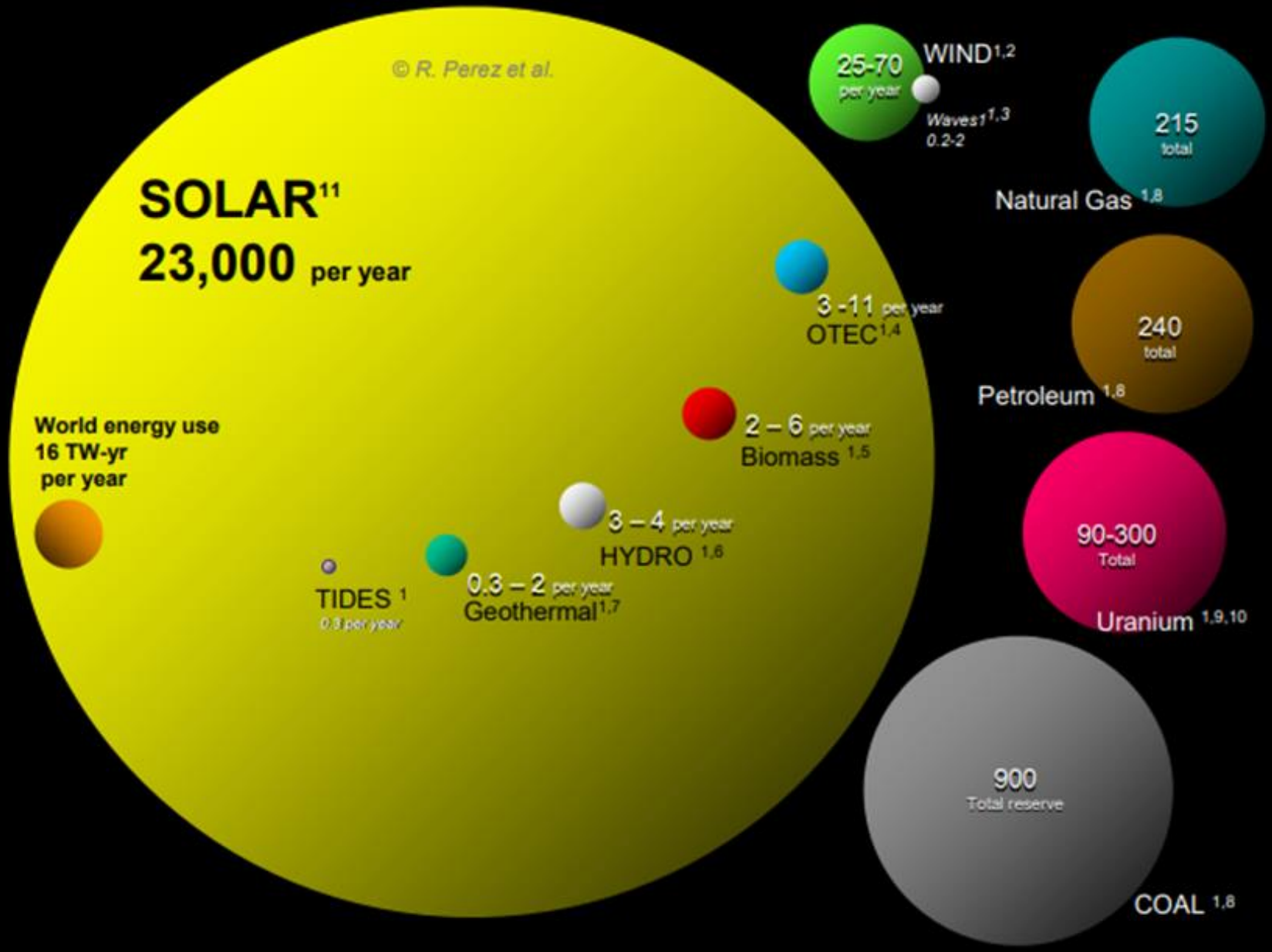
AERONAUTICS	SPACE	ENREGY	TRANSPORT
			

SECURITY
Civil & defense security research

DIGITALIZATION, QUANTUM TECHNOLOGIES AND SYSTEM MODELLING

- Europe's largest research center for aviation and space travel
- Close cooperation with science, research, business and industry
- Leading ministry BMWK, institutional funding by BMVg
- Project funding by BMI, BMDV, BMUV, BMZ, among others

Sun: Energy for the future



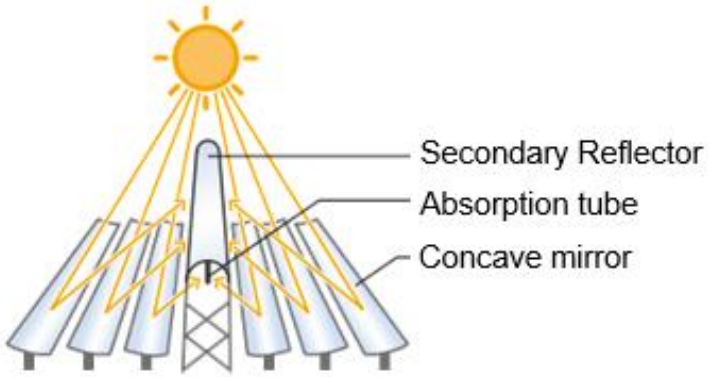
Available solar energy:

- More than 90% resources of renewable energies
- Energy for 10000 Earths

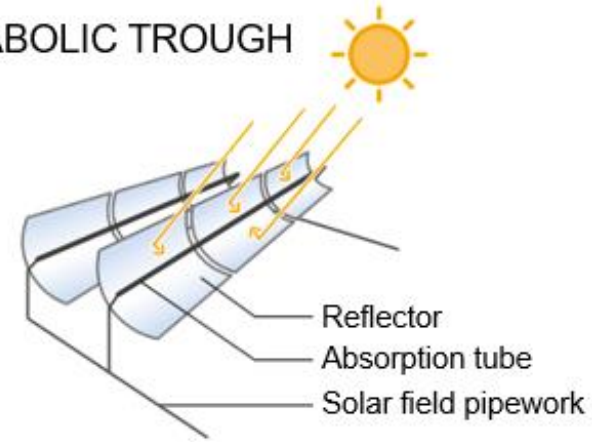
Quelle: Perez et al. (2009): A fundamental look at energy reserves for the planet. The IEA SHC Programme Solar Update, Volume 50, 2009.

CST process temperature dependency

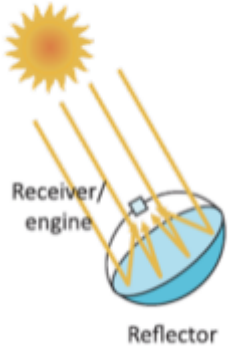
LINEAR FRESNEL REFLECTORS (LFR)



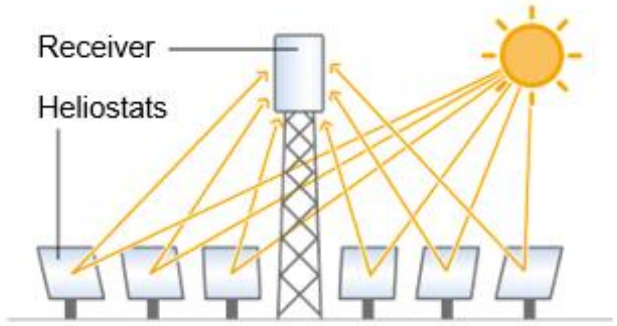
PARABOLIC TROUGH

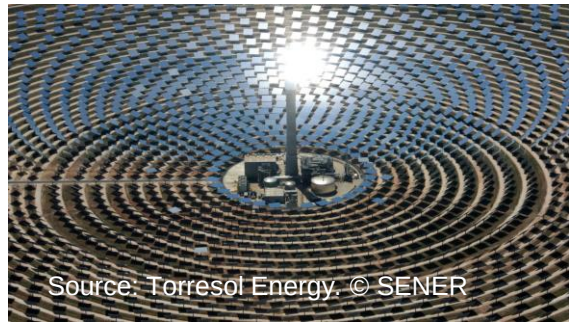


DISH COLLECTORS

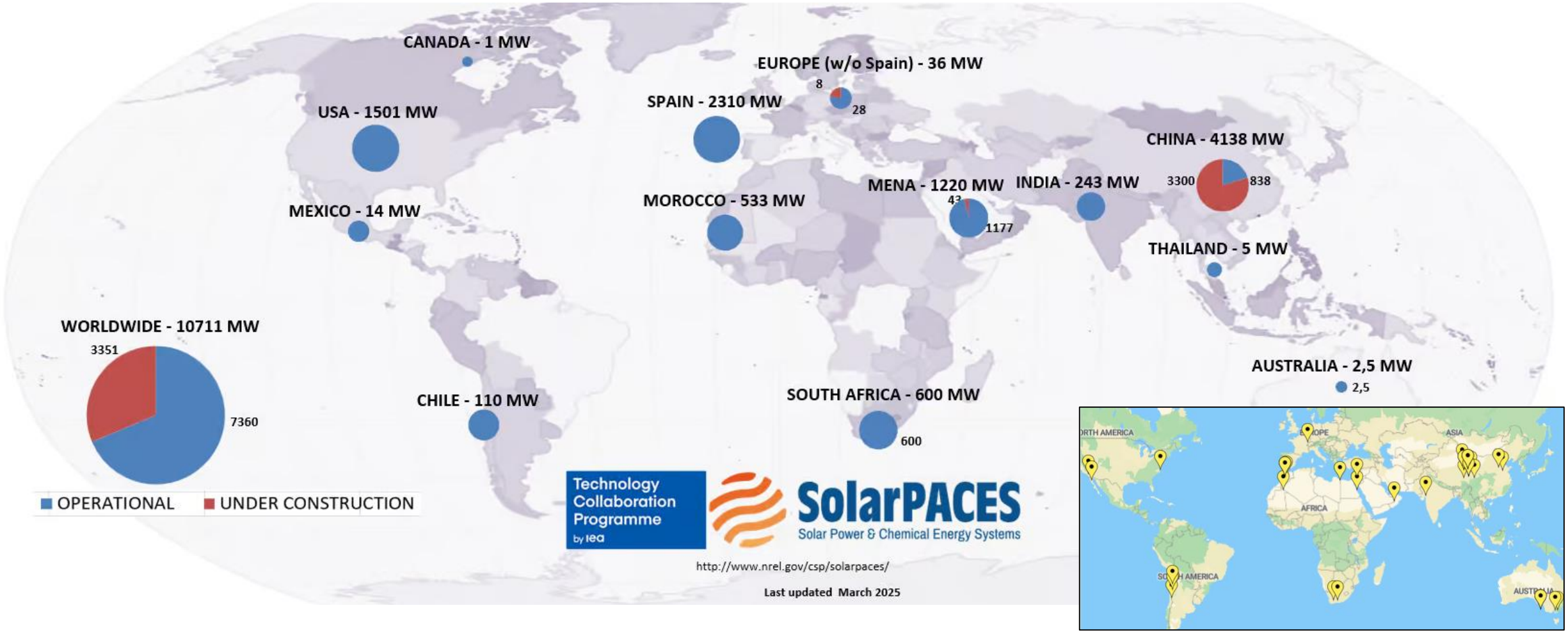


SOLAR TOWER





CSP/CST Projects Around the World



- China currently has the highest number of CSP/CST Projects „under development“

Applications of CST
Power generation on industry scale and process heat supply

- Tipical facilities:
  - Power 50-150 MW
  - Storage capacity 6-12 h
- Facilities in operation:
  - 4,8 GW Parabolic Trough oil as HTF @393°C
  - 1,3 GW Tower systems molten salt as HTF @565°C
  - Spain, USA, China, UAE,

  Marokko, Südafrika, ...

→ **State of the art @ CST**

Quelle: US department of energy. Download 23.11.2020 von https://www.energy.gov/lpo/solana

Applications of CST
Hybrid CSP-PV electricity production: Saudi Arabia (DEWA)

Source: Acwa Power

DEWA plant (United Arab Emirates)

Combination of different technologies.

- 3 x 200 MWel Parabolic Trough
- 100 MWel Solar Tower, both with molten salt storage for power generation at night
- Additional 250 MWel PV for direct generation during daytime

Installations in China

- A number of hybrid plants with hybridization ratio 1:6 or 1:9 with PV/wind are being build.
- Further projects up to 5 GW in the next 5 years in planning

Solar power plant NOOR III (Marokko)

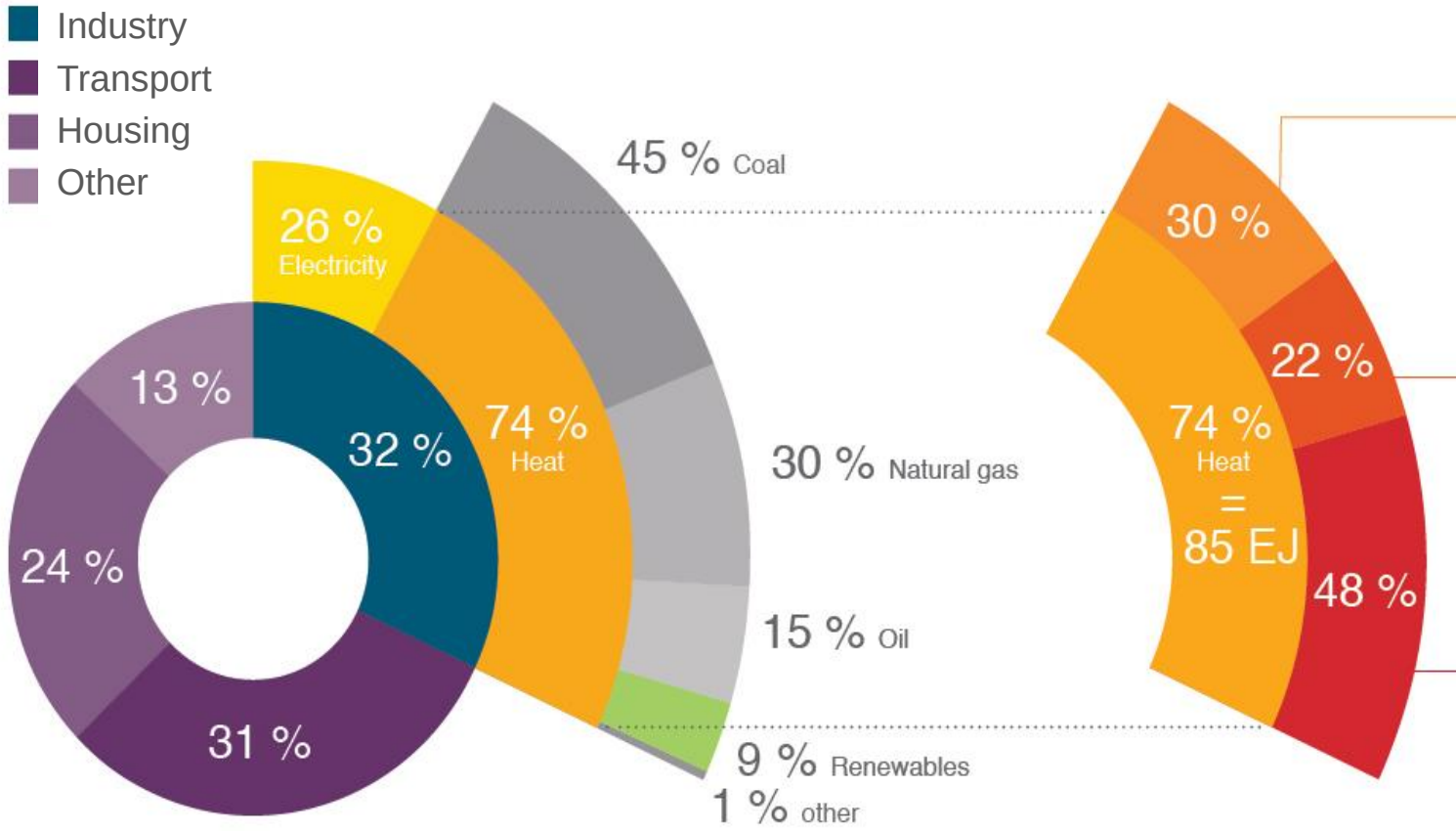
	I	II	III	IV
Area (in Hectar)	460	630	600	140
Installed capacity (in Mw_{el})	160	200	150	70
Power generation after sundown (in hours)	3	7	7	

The NOORo III solar power plant near Ouarzazate (Morocco), photographed from an airplane on April 1, 2017, Source: dpa-Bildfunk.

Solar thermal power generation (CSP)
Market size and current status

- 2023 worldwide installed renewable capacity: 4 TW → 7 GW CSP
- CSP will reach 48 GW by 2030 and 427 GW by 2050 (IEA Forecast)
- Asia pacific dominated the global market share (44%) in 2024
- Hybrid CSP-PV is cost-competitive for night power supply > 5h
- Parabolic trough had the biggest market share in 2024, but solar tower is estimated to increase market gain → **production of HT process heat 24/7**
- Investment costs:
  - CSP costs dropped by 58% in 2010-2022 to USD 4274/kW (IRENA 2024a)
  - Solar towers were 37% more expensive than parabolic trough plants in 2023
  - However, tower systems costs dropped by 45% between 2011 and 2024

Process heat: heat consumption in the industrial sector



Low-temperature heat
(under 150 °C)
Cooking, pasteurizing, sterilizing, cleaning, drying, washing, bleaching, steaming, pickling, boiling

Mid-temperature heat
(150 to 400 °C)
distillation, nitrate melting, dyeing, pressing, drying

High temperature heat
(over 400 °C)
Raw material and ore processing
Calcination, sintering
Steam reforming
Reduction
Fuel generation
Cheaper Hydrogen production through hybrid Sulphur cycle

Final energy consumption of heat in the industrial sector. Source: Epp (2017) based on data from IEA, IRENA

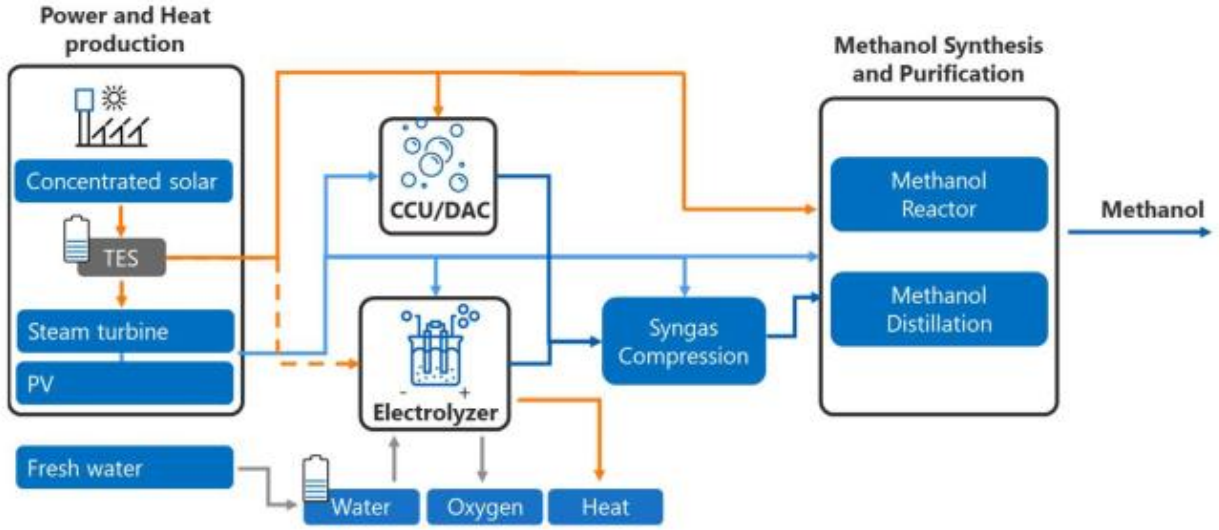
Applications of CST
Renewable Fuel Production, hydrogen, drying…

- Examples:
  - Methanol production powered by a CSP/PV hybrid system
  - Hydrogen production from electrolysis and high temperature electrolysis
  - Ammonia production power by CST
  - Phosphate drying with solar heated air and long distance transport with particles
  - Chemical processes in solar heated receivers, e.g. heat for syngas

→ Plants preferably located in sunny regions. Products to be imported to Europe.

Applications of CST (1)

Combined heat and power supply for solar methanol production (Source: Fichtner)



Source: Vast Energy

- **First demonstration project** (SM1/SA Solar Fuels) under development, supported by the Federal Ministry of Education and Research (BMBF) and the Australian Renewable Energy Agency (ARENA) under the HYGATE initiative.
- **Key partners**: Mabanaft, Deutsches Zentrum für Luft-und Raumfahrt e.V., Vast and CSIRO

Demo plant to be constructed in Australia next to Vast's VS 1 Project – target 7,500 t p.a. of methanol

Applications of CST (2)

Cooperation DLR with Synhelion SA: syngas production

Milestones

2019 Test of the new technology in the **Synlight high-performance artificial sun facility**

2022 First production of syngas at DLR's multifocus tower

2023 World's first industrial plant at Brainergy Park Jülich

- In 2021, Synhelion merged with the DLR spin-off HelioKon
- Synhelion SA is a pioneer in the solar production of synthetic fuels
- World’s first industrial-scale solar fuel plant

Comparison of CSP technologies using different heat-transfer (storage) media

Ho et al., Overview and design basis for the Gen 3 Particle Pilot Plant (G3P3); AIP conference Proceedings 2303 (2020)

Feature	Solid Particle Technology	Molten Nitrate Salt Technology	Molten Chloride Salt Technology	Gas Receiver Technology
Operating temperatures	Ambient to >1000°C	~300°C – 600°C	~400°C – 800°C	Ambient to >1000°C
Solar flux	No flux limitations on particles	Limited to tube-wall fluxes of 800-1200 kW/m2	Limited to tube-wall fluxes of 800-1200 kW/m2	Limited to tube-wall fluxes of 800 kW/m2 or less
Freezing	No freezing	Freezing below 200 – 300 °C; requires trace heating	Freezing below 200 – 300 °C; requires trace heating	No freezing
Corrosion	Inert materials, non corrosive	Corrosive to the containment materials	Extremely corrosive to the containment materials in the presence of air or water	Potentially corrosive depending on gas
Storage	Direct thermal storage	Direct thermal storage	Direct thermal storage	No direct thermal storage; requires intermediate heat exchanger
Ducting and containment	No hermetic seals required	Hermetic seals required	Hermetic seals required	Hermetic seals required
Conveyance	Particle lift (bucket elevator or skip hoist)	Long-shafted pumps	Long-shafted pumps	High-temperature blowers; lifts for particles if used as storage media

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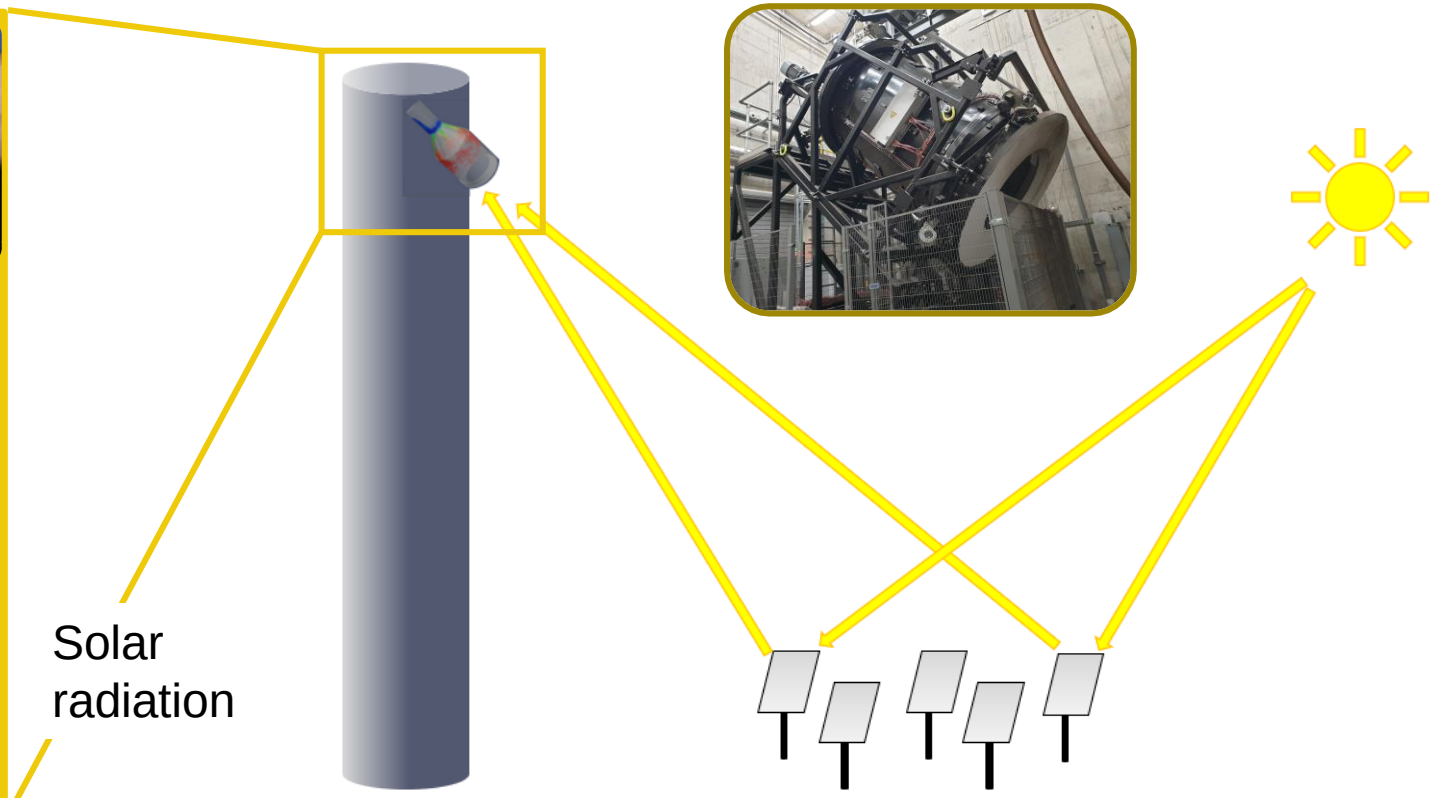
Component development
CentRec® Solar particle receiver

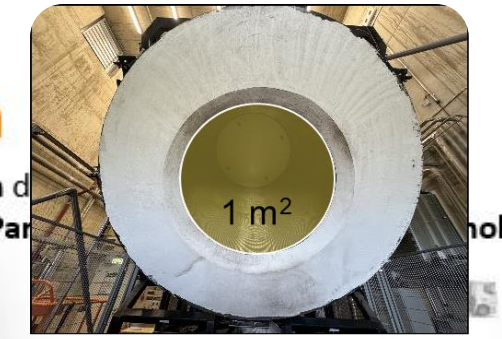


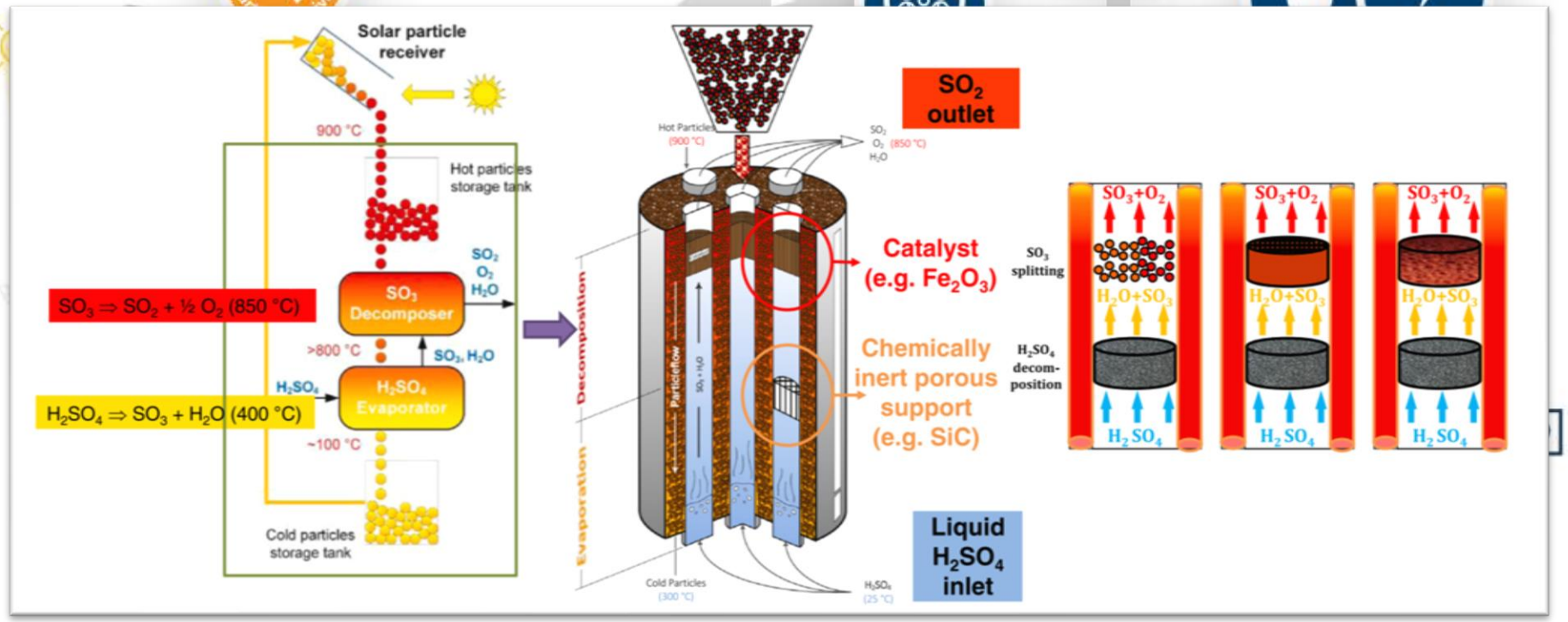
- Control of particle residence time by adjusting the rotation speed
- Thin, optically dense layer for all load conditions
- Patented DLR technology

Applications of CST (3)

CST particle technology @ 900°C: EU HySelect

- **Objective:** Production of **H_2** through the Hybrid Sulphur cycle using **Particle CST (CentRec®)**
- **Process heat supply** @ 900°C
- Industry partner: **Grillo-Werke AG** (liquid Sulphur dioxide)

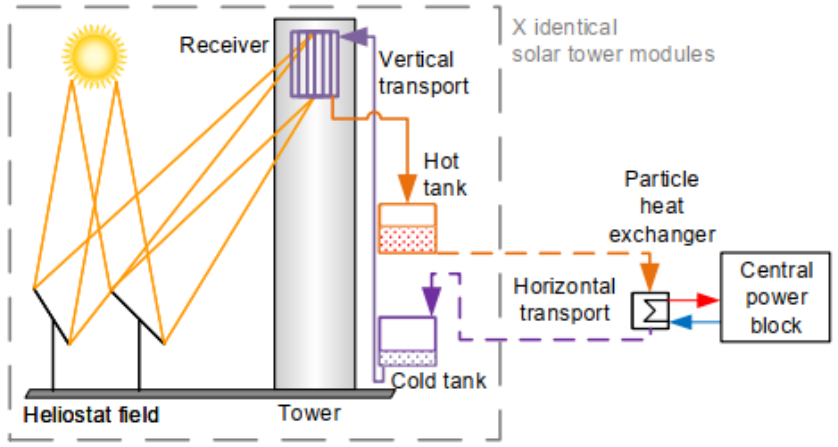


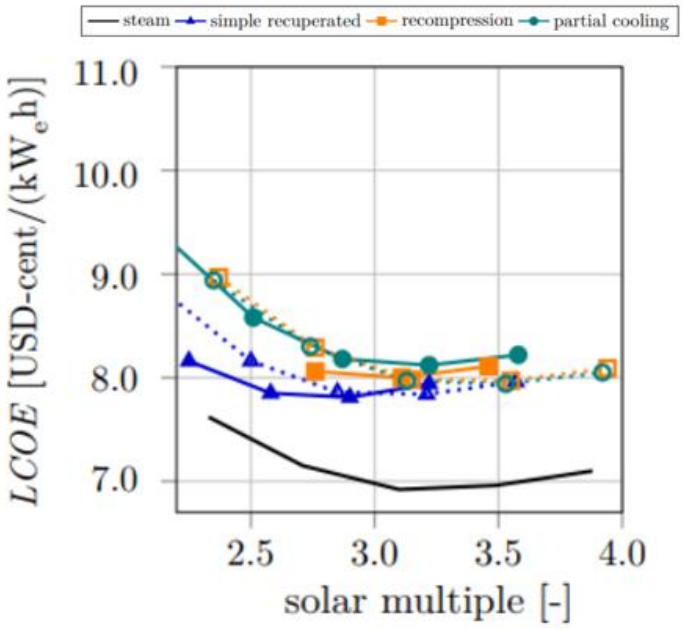


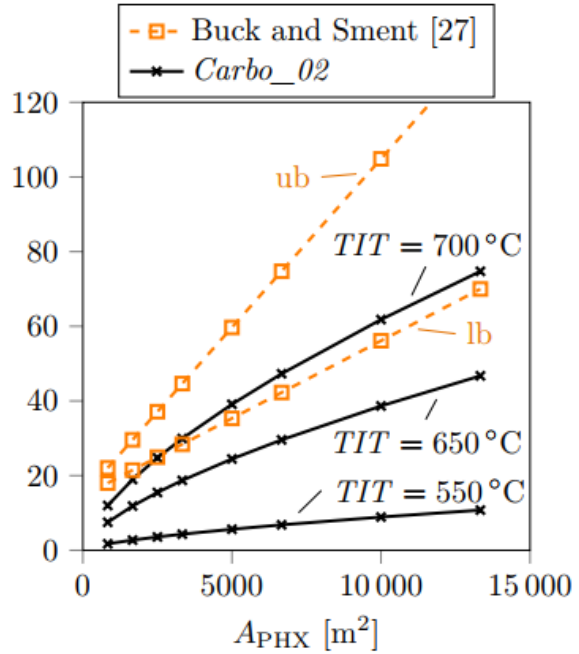
Carbosola Project

Supercritical CO2 (sCO2) power cycles with particles

- detailed techno-economic comparison is needed to assess potential benefits over state-of-the-art steam cycles → comparison of particle based solar tower systems with sCO2 cycles with ref.
- hourly simulations to derive the plants' annual energy yields and levelized cost of electricity
- levelized cost of any sCO2 process is at least 9 % higher than that of the reference system (steam)
- two TIT levels (550°C and 650°C – lowest LCOE), 112 MWe, location in SA







Outlook
High temperature CST systems

- Strategy: 24/7 heat supply for the industry (Hydrogen, Methanol, Drying…)
- Adjustable hybrid systems with PV and HTHP
- Waste heat from industrial processes for district heating
- Decarbonization of materials and chemical products (>700°C)
  - Cement, clay activation, calcination
  - Steel
  - Ore drying
- Power2Heat with Sustainable energy particle storage
  - Low-cost heat storage systems with large capacity
  - High temperature process with lower CAPEX costs

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THANK YOU FOR YOUR ATTENTION!