COMPASsCO$_2$

PLANT LAYOUT AND STATE-OF-THE-ART MATERIALS SELECTION

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COMPASsCO2 Final Workshop

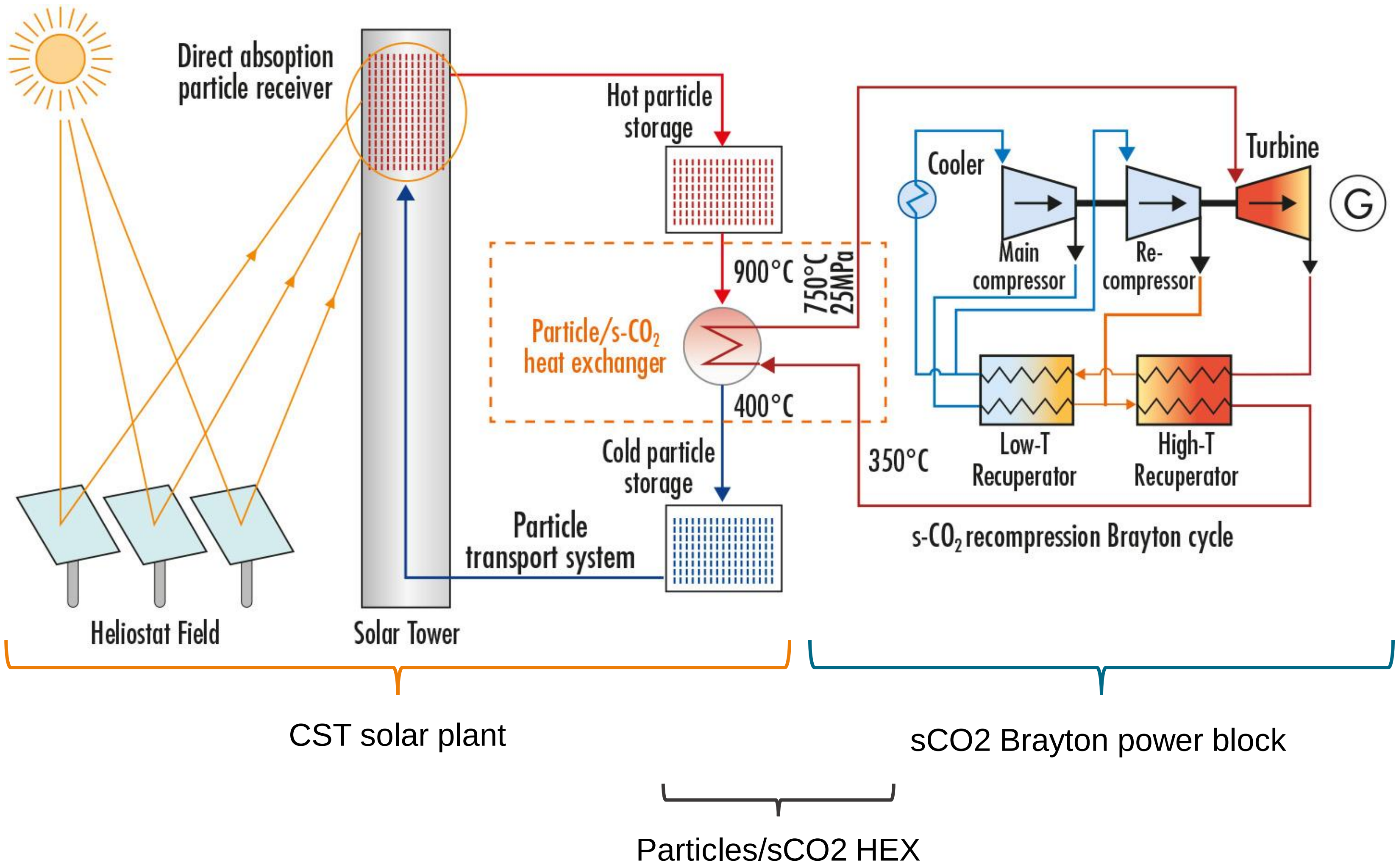
Back to the Future: A Forward-Thinking Approach to Concentrating Solar Technologies - Key Takeaways from the COMPASsCO$_2$ Project

April 24th, 2025

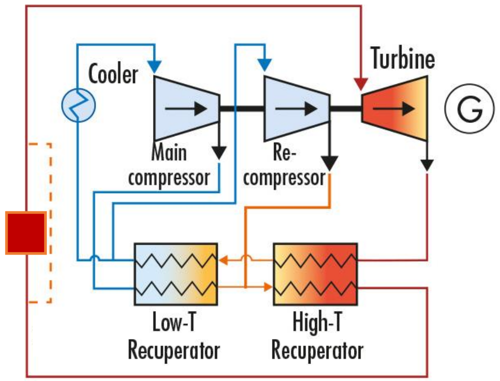
9h30 – 14h30 CEST

Husinec u Řeže, Czech Republic & Online lifesize

Overall Plant Layout



Brayton cycle selection

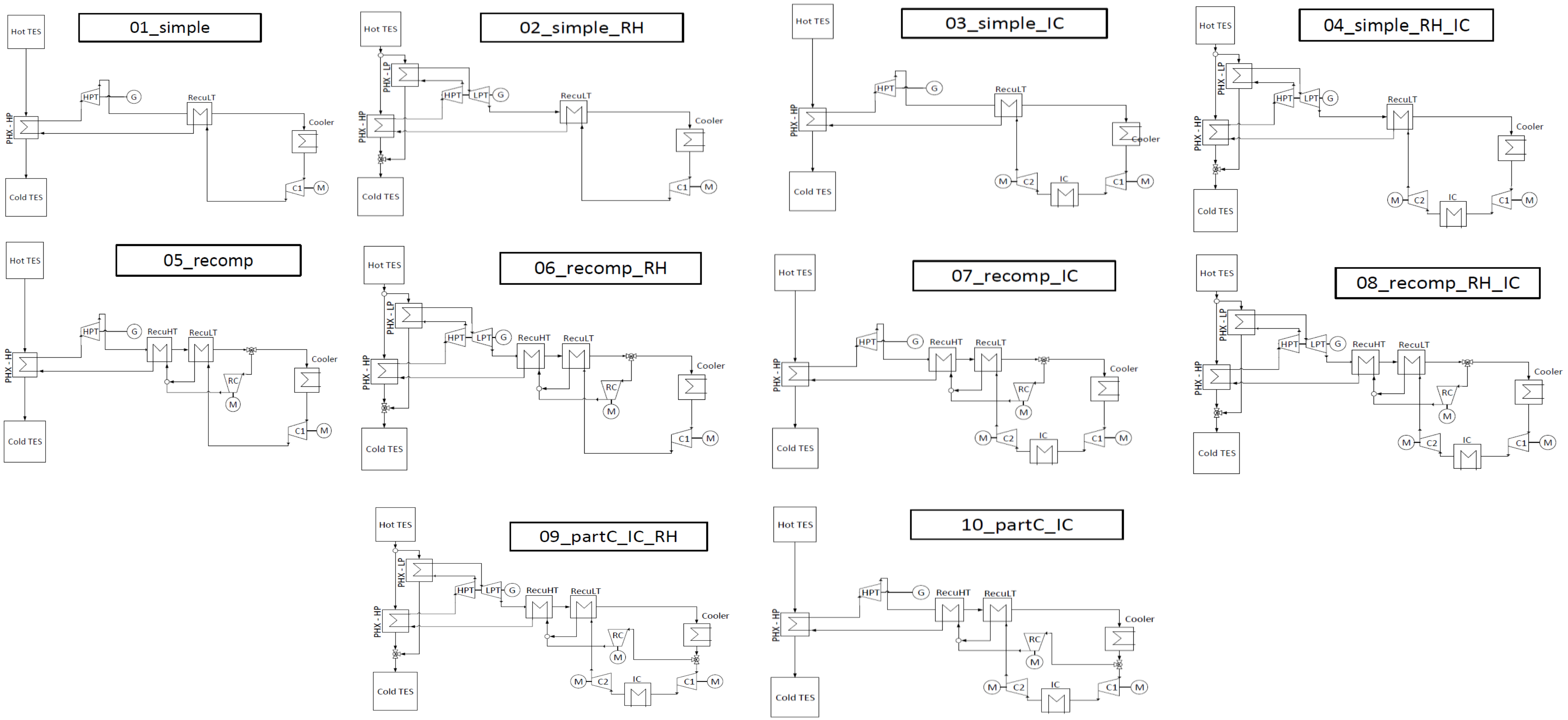


s-CO_2 recompression Brayton cycle

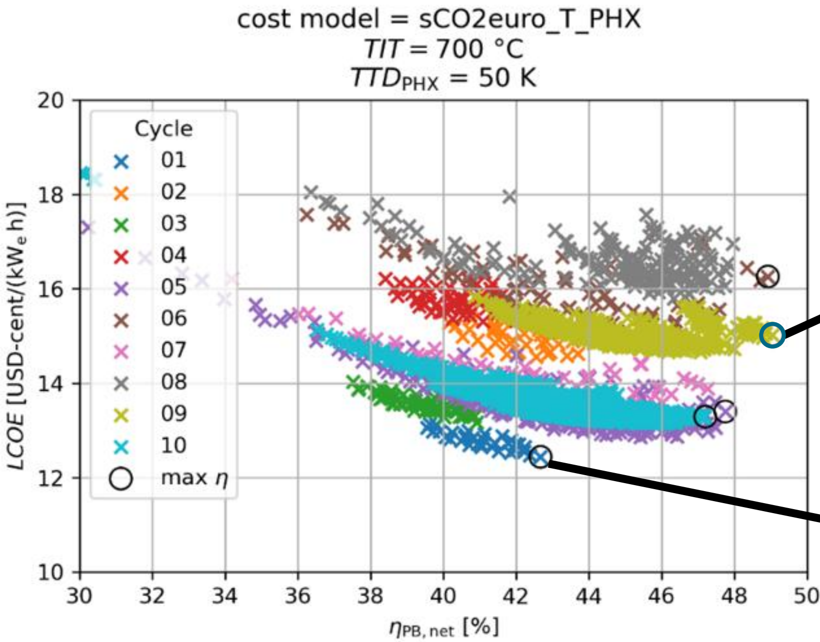
- The cycle should have a very high efficiency, as this is one key requirements of the Work Program funding the project (H2020 LC-SPIRE-08-2020)
- Literature review of Brayton sCO_2 cycles (also non-solar)
- Parametric study for 10 Brayton sCO2 cycles and hundreds of parameter combinations
- Implementation of preliminary component cost models
- Results published in project Deliverable 1.1 "**Process parameters of solar sCO2 Brayton cycle**" https://doi.org/10.5281/zenodo.4733988

Brayton cycle selection

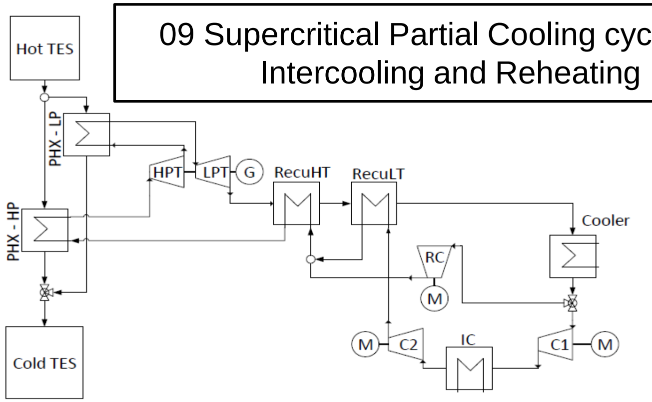
10 sCO2 cycles preselected



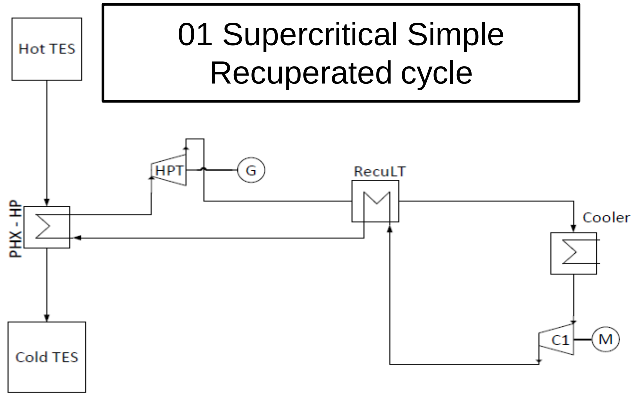
Brayton cycle selection



09 Supercritical Partial Cooling cycle with Intercooling and Reheating



01 Supercritical Simple Recuperated cycle



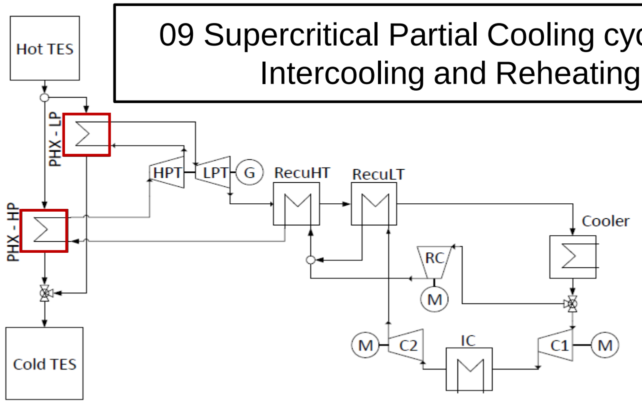
Optimization towards maximum efficiency

Results are not very accurate due to ***low TRL*** *of sCO2 Brayton cycles*

Key data such as ***component costs, pressure drop and auxiliary power consumption not fully available***

Main process parameters

09 Supercritical Partial Cooling cycle with Intercooling and Reheating

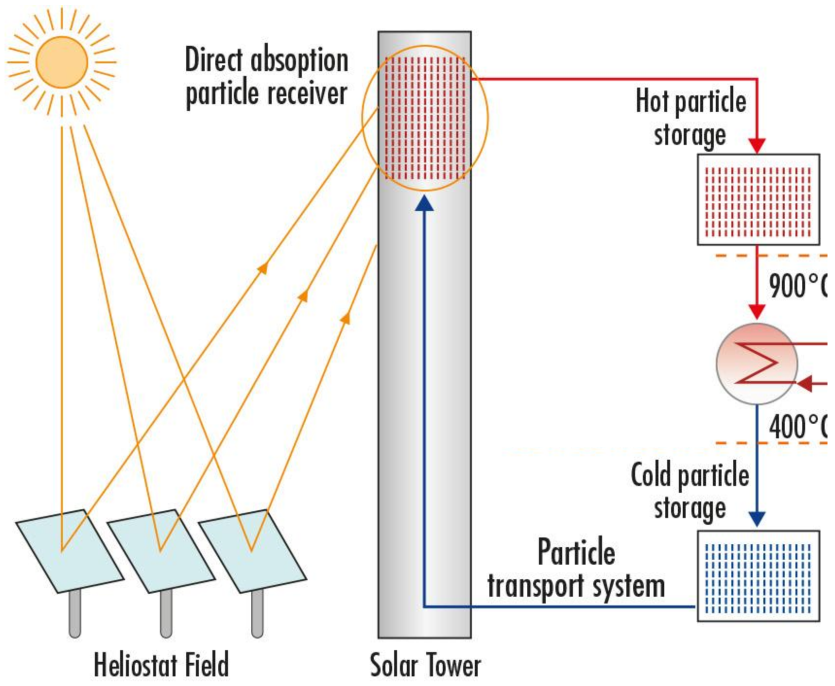


Parameters	Particles (high pressure PHX)	Particles (low pressure PHX)	sCO2 (high pressure PHX)	sCO2 (low pressure PHX)
Inlet temperature [°C]	900	900	532.8	583.4
Outlet temperature [°C]	582.8	633.4	700	700
Inlet pressure [bar]	/	/	265.3	110.4
Outlet pressure [bar]	/	/	260	108.2
Mass flowrate [kg/s]	355.9	288.3	632.6	632.6

Solar Particle Loop

Main Components:

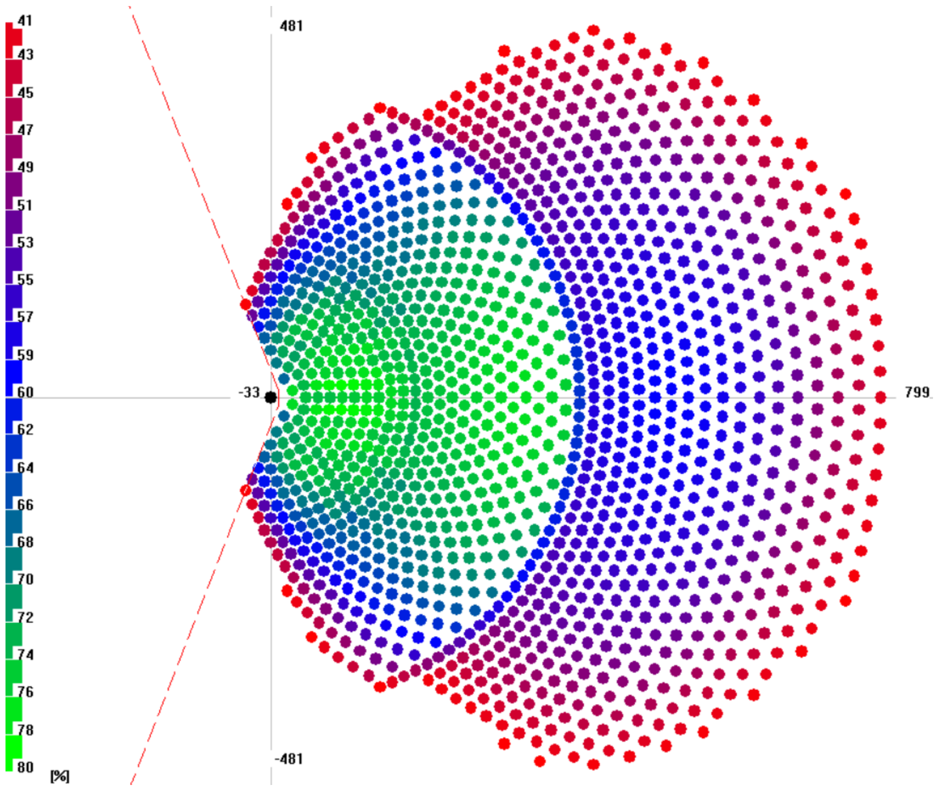
- ➢Thermal receiver on top of a tower
- ➢Heliostat field
- ➢Particle transport system
- ➢Thermal energy storage system



Solar Field Optimization

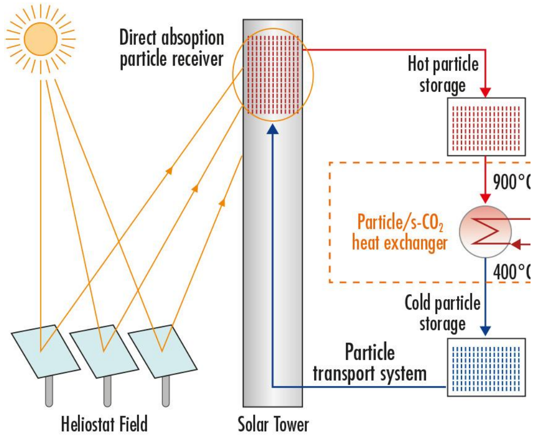
- DLR software HFLCAL was used to determine LCOE-optimized solar field design
- Variation of heliostat number, positions, tower height and receiver size
- Optimization for lowest LCOE

Parameter	Unit	Value
Height of receiver center above ground	[m]	133.6
Receiver aperture diameter	[m]	7.58
Mean solar flux at receiver aperture @ dp	[MW/m²]	2.38
Heliostat aperture area (per tower)	[m²]	170 000
Particle inventory (per tower)	[t]	5172
Field efficiency @ dp	[-]	63.6 %
Field efficiency, annual average	[-]	54.2 %
Receiver efficiency @ dp	[-]	89.7 %
Receiver efficiency, annual average	[-]	87.4 %



Heliostat field layout showing average annual efficiency per heliostat (color code)

Boundary Conditions – Solar Plant

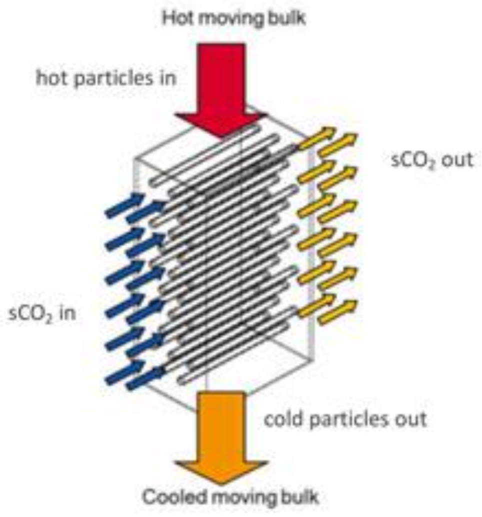


Parameter	Value	Comments
Location	Postmasburg, South Africa	Good solar resource
Power block net power	112.8 MW_e	Based on cycle chosen in Deliverable 1.1
Particle inlet temperature to the HX	900 °C	
Mean receiver outlet temperature @ dp	905 °C	Sufficient to reach particle inlet temperature to the HX
Max. particle temperature	~1000 °C	Due to inhomogeneous temperature distribution
Receiver inlet temperature @ dp	605.5 °C	Derived from HX design
Receiver thermal power @ dp	96.23 MW_t	Per unit
Number of towers and receivers	6	
Solar multiple	2.5	Oversizing of solar field relative to power plant design point thermal demand
Thermal storage capacity	12 h	hours of discharging at full load

Boundary Conditions – Particles

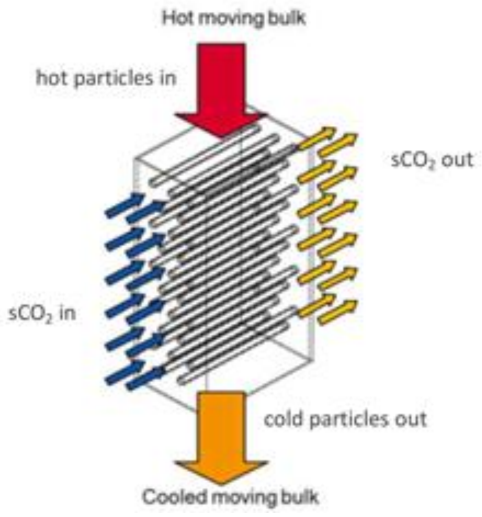
Category	Property	Priority	Target values
Dimensional	Shape	B	Sphericity > 0.9 (aspect ratio of maximum and minimum diameter) Roundness (defined sharpness of edges): as good as bauxite
	Size	B	0.3 mm - 1.19 mm (diameter range within batch impacts the cost)
Optical	Solar absorptance α	C	> 0.9 (even lower values acceptable in cavity receivers)
	Optical stability	C	Decrease in solar absorptance < 5% at T>900°C
Material	Bulk Density	A	2 g/cm^3
	Material Density ρ	A	> 3.5 ~ 4 g/cm^3
	Heat capacity c_p	A	c_p ≥ 1.5 J/(g·K) between 480-900°C (only if cost is acceptable)
	Thermal conductivity	C	Al_2O_3 (> 25 W/(m·K) at room temperature > 8 W/(m·K) at ≈700 °C) Low thermal conductivity might even be beneficial in thermal storage
Thermal	Max. operational temperature	A	Sintering- (viscous flow temperature)> 1000°C
	Phase stability	B	At T > 900°C
Mechanical	Wear/ attrition resistance	A	mass loss by attrition < 0.5 kg/$MWh_{th,transferred}$
	Hardness	A	900-1100 (Vickers) (bauxite reference)
	Strength	A	Breaking force > 140 N
Operational	Target lifetime	A	> 10 years
	Target operational hours	A	> 60,000 hours
	Number of cycles	A	2 per day / > 7300 total
	Maximum impact velocity	A	5m/s (falling distance 17 m (Sandia))
Economic	Cost	A	< 1€/kg for particles of c_p< 1.2J/(g·K) (depending on heat capacity and bulk density)

Boundary Conditions – HEX Tubes Material

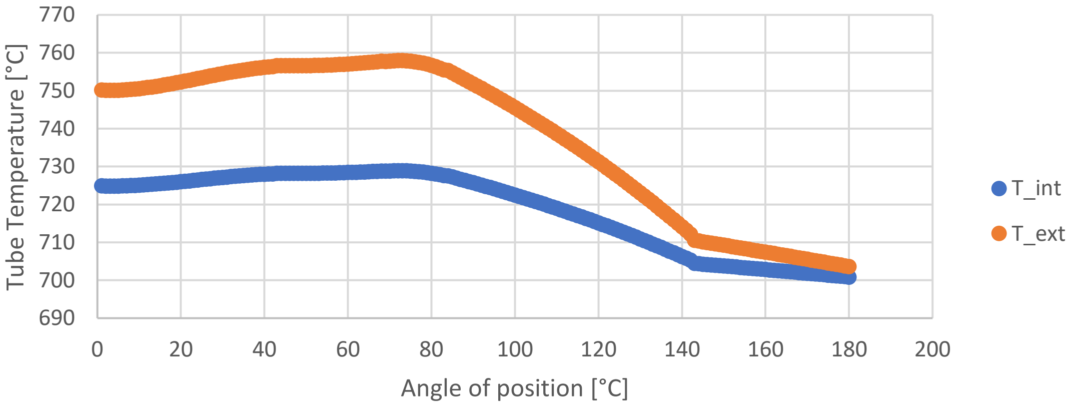


Parameter	Value
Operating temperature	≥ 760°C
Internal pressure	≥ 250 bar
Strength	> 400 MPa at 23°C, > 200 MPa at 600°C, > 50 MPa at 800°C
Elongation strain to failure	> 5%
Minimum creep rate	< 10^{-6} 1/s at 200 MPa and 600-800°C
Wear by particle erosion	< 0.5% of material thickness/year
Oxidation/carburization rate	< 0.5% of material thickness/year
Lifetime	25 years

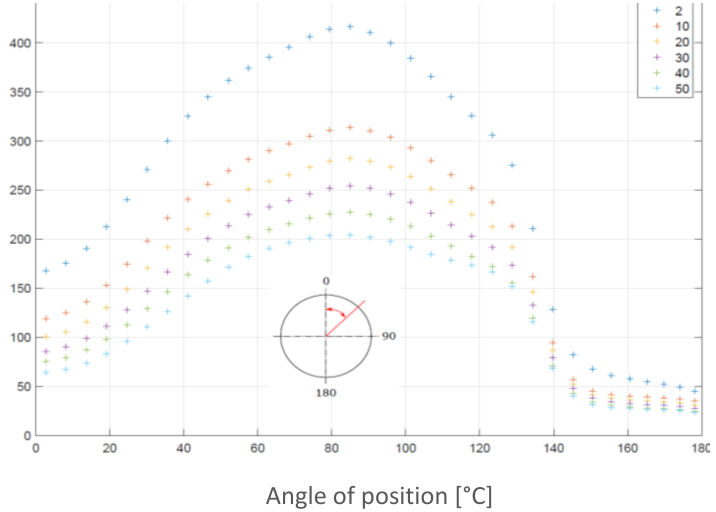
Boundary Conditions – HEX Tubes Material



Temperature angular distribution along the most extreme tube



Heat transfer coefficient distribution over a tube [W/(m².K)]



⇒ Non-homogeneous distribution of temperature along the most extreme tube
⇒ Angle-dependant particle heat transfer coefficient
⇒ Thermal stress

Boundary Conditions – HEX Tubes Material

Alloy		Maximum Allowable Stress	Erosion	Oxidation/corrosion	Cost
Ferritic	P92	Only applicable at 600°C due to the low MAS values	Promising erosion protection due to BCC and high hard phases in matrix	Low protection against sCO_2 due to fast C diffusion in matrix Low oxidation protection	4.5-6 $/kg
	VM12				
	AISI441		Low erosion resistance	Low protection against sCO_2 due to fast C diffusion in matrix	5.1-6.4 $/kg
Austenitic	316		Unknown	Low protection in case of impurities in sCO_2	1.5-4 $/kg
	304H				
	310HCbN	Only applicable below 650°C due to low MAS	Good erosion resistance due to high hard phases in matrix	Low protection in case of impurities in sCO_2	3.65 $/kg
	HR 120		Unknown		
	Sanicro 25	Only applicable below 675°C due to the low MAS value		Good oxidation protection	45.7 $/kg
	ET 45 Micro	Potential candidate but never tested at the target conditions (good MAS and oxidation protection)			
	G4859	Manufacturing limits in order to achieve designed dimensions (lowest external diameter limit of 50mm)			
Ni base	625	Does not reach the MAS at 725°C by tenths	Brittle at high temperatures	Good oxidation and sCO_2 protection	
	617B		Low erosion resistance		
	230		Maybe high W amount detrimental		52.2 $/kg
	282	OK for 725°C and up to 760°C	Unknown	Potential candidates according to published literature	60 $/kg
	740				47.5 $/kg
	247			Alumina scale might be problematic at such low temperatures	140 $/kg
Co-base	MAR-M-509		Good in literature	Unknown	

State-of-the-art Materials Selection

Heat exchanger tube material	Material	Temperature range	Pressure limit	Selected materials	Supplier
	Creep-strength enhanced ferritic and advanced austenitic stainless steels	590°C < T < 620°C	250 bar	**P92** **Sanicro 25**	OCAS Sanvik
	Ni-based alloys	up to 760 °C	350 bar	**Haynes 282** **Inconel 740** **Inconel 617**	Haynes Special Metals

Heat carrier particles	Material	Particle diameter		Supplier
	BL	16/30	590/1190 µm	Saint-Gobain
	BL	30/50	297/560µm	
	IP	30/50	297/560µm	
	SB	30/50	297/560µm	

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THANK YOU

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