Integrated Solar Combined Cycle Using Particles as Heat Transfer Fluid and Thermal Energy Storage Medium for Flexible Electricity Dispatch

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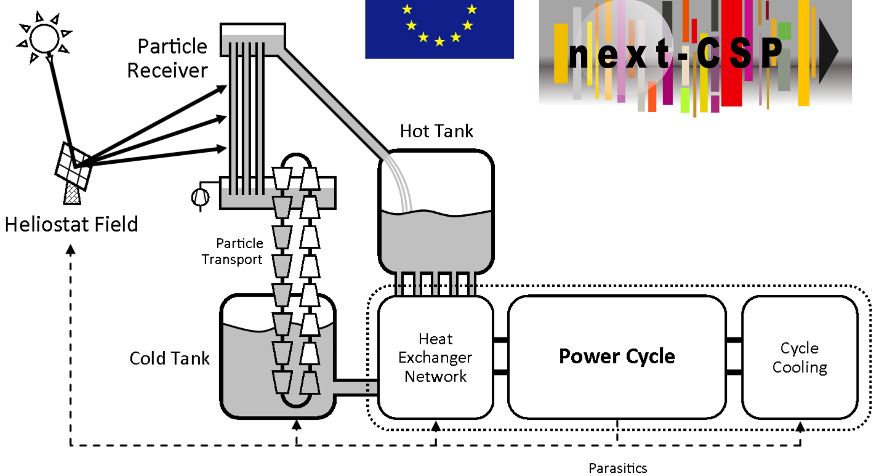
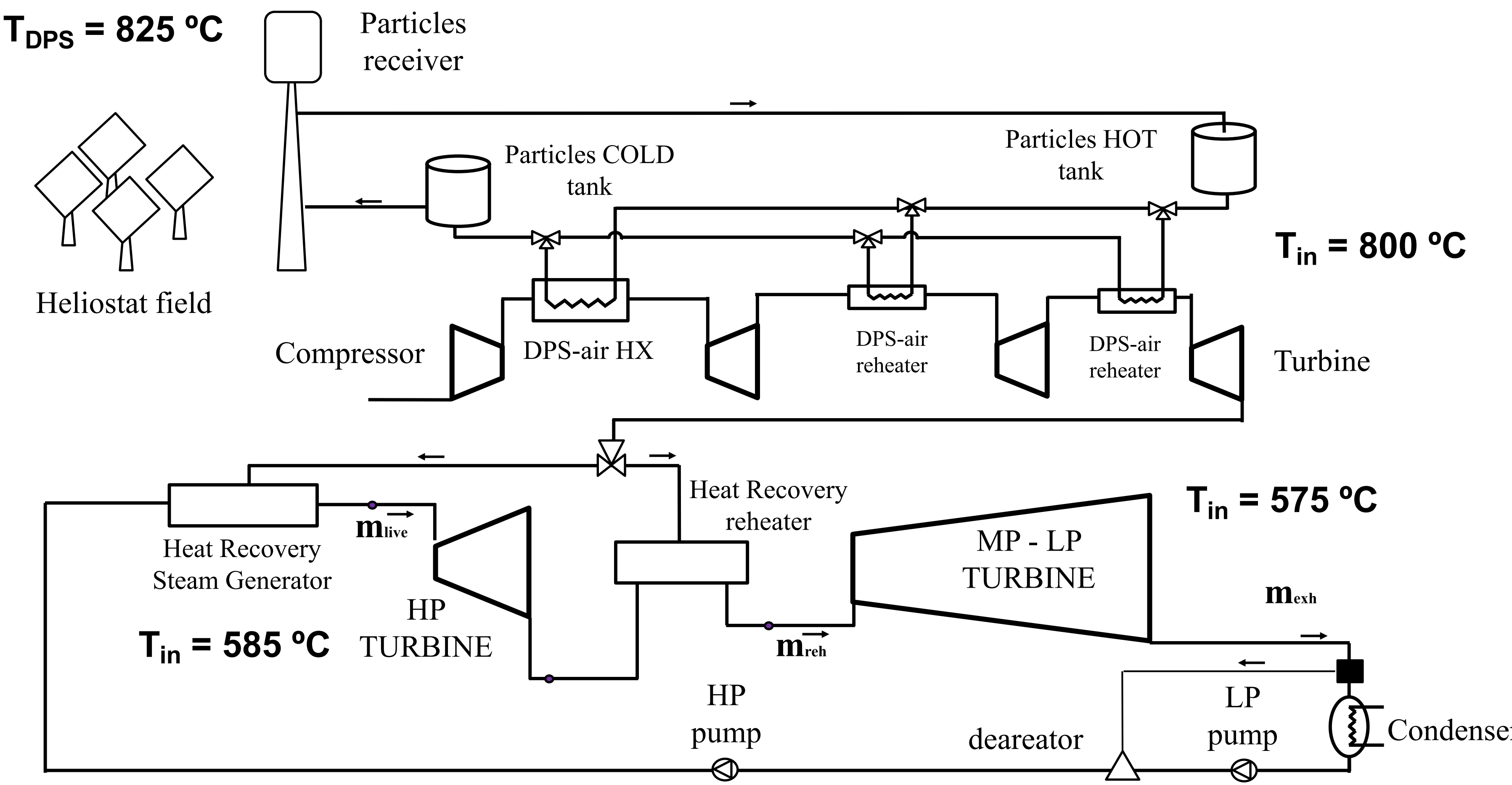
Objectives



- Solar plant concept being investigated under **NEXT-CSP** project
- Dedicated modelling of Integrated Solar Combined Cycle (**ISCC**) **pure-solar** plant that uses **particles** as **heat transfer fluid** and **storage medium**
- **Plant components optimization** (solar field, receiver, Brayton topping cycle, Rankine bottoming cycle, particles-based heat exchangers network) to **maximize** ISCC **efficiency** *(design-point conditions)*
- **Multi-tower** solar plant **arrangement** for commercial **scaling-up** (150 MW_e)
- **Dispatch strategies** definition to maximize electricity power output *(annual performance)*

Plant Layout Description

- Solar **particles receiver** was designed to reach **825 ºC**
- Double-reheated Brayton & reheated Rankine cycles to maximize ISCC efficiency
- Dedicated design of particles-based heat exchanger network connecting solar loop & power cycle



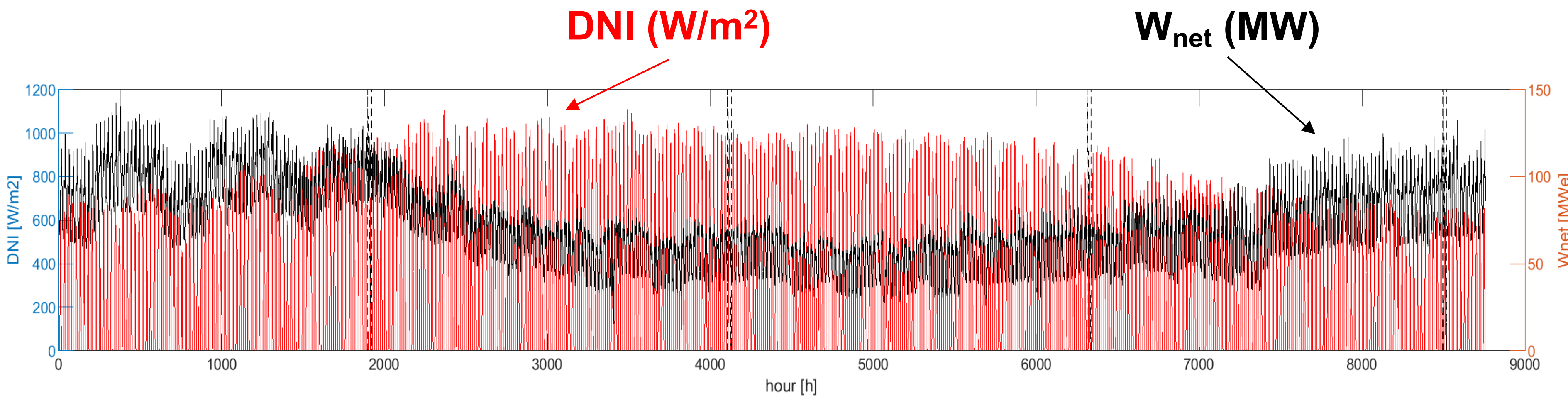
Boundary conditions (*design point*)

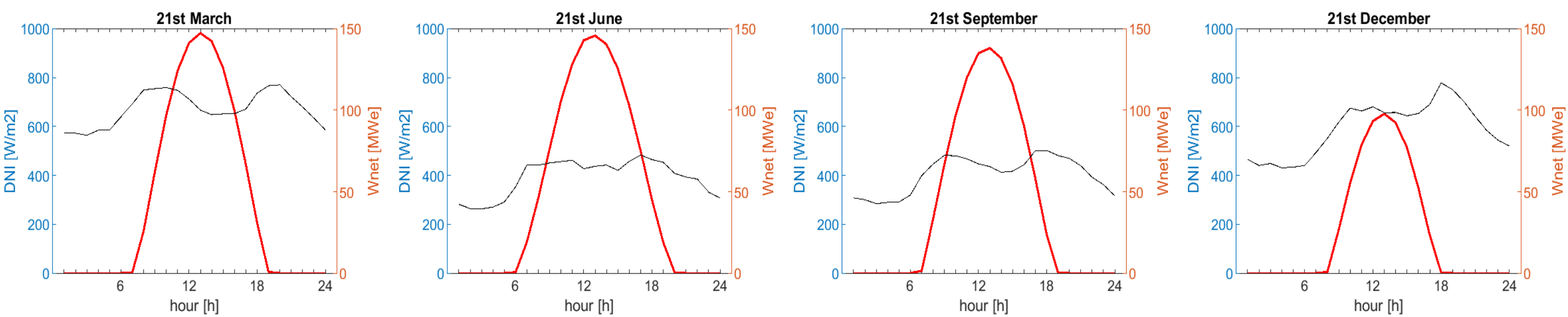
Solar plant location	Ouarzazate, Morocco 30.9° N, 6.93° W
Design DNI	900 W/m^2 @ noon 21st March
Heliostats area	49 m^2 (Stellio heliostat)
Aperture incident flux	2,000 kW/m^2
Thermal power onto aperture	55 MW
Particles maximum temperature (at receiver outlet)	825 ºC
Preferred commercial size (electrical power output)	150 MW$_e$

Multi-tower (& solar fields) configuration is required to achieve design-point dispatch power (150 MW$_e$ – pure solar)

Boundary conditions (*annual performance*)

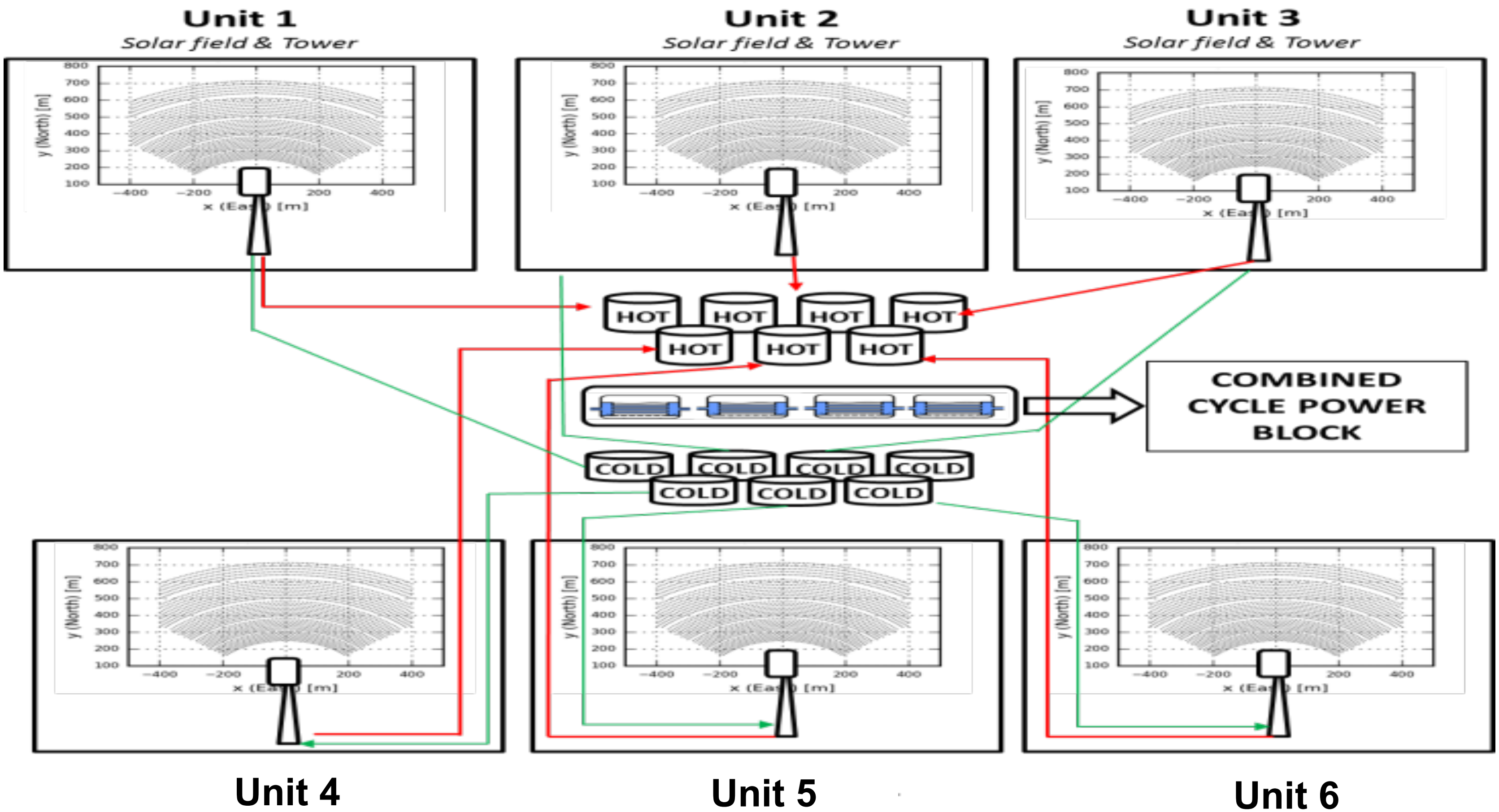
- Annual DNI (15-min based) from Ourzazate
- Typical electric grid demand curve from Mediterranean area





Plant Layout Description

- Multiple solar-fields & towers feeding single Combined Cycle Power Block
- Particles transportation system between multi-solar fields units & common particles TES & heat exchangers network



Design-point optimization

Solar plant & receiver

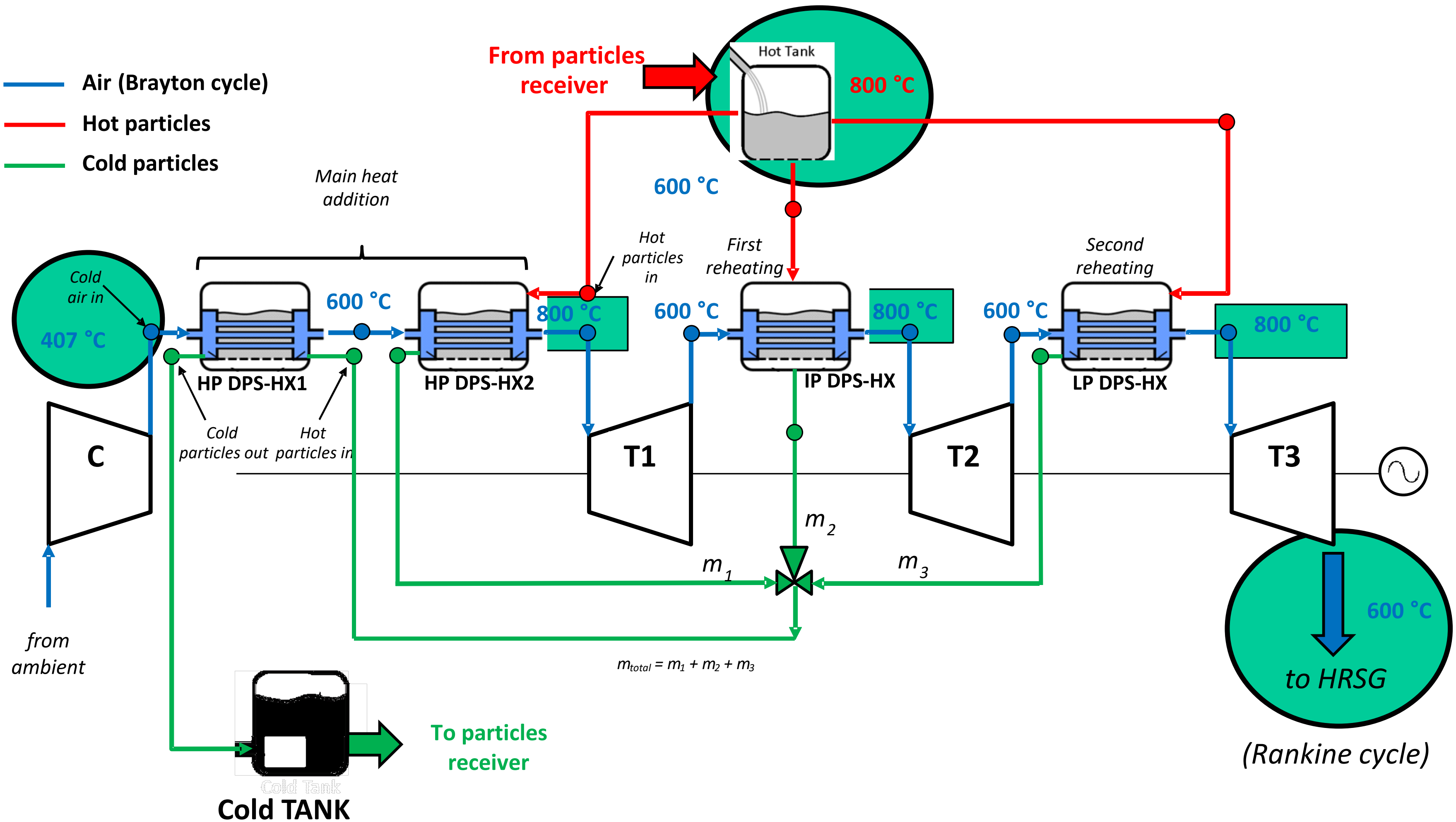
Solar Field		Solar Receiver	
Power incident on field	75.5 MW	Power onto aperture	55 MW
Number of heliostats	1731	Absorbed thermal power	44 MW
Heliostats area	49 m^2	Thermal efficiency	79.4 %
Design day	noon 21st March	Tubes height	7 m
Design DNI	900 W/m^2	Number of tubes	240
Tower optical height	110 m	Particles inlet temperature	606 ºC
Aperture tilt angle	30º	Particles mass flow	165 kg/s
Aperture incident flux	2,000 kW/m^2	Receiver average flux	500 kW/m^2

Power cycle

Topping cycle		Bottoming cycle	
HP inlet pressure	14.3 bar	HP inlet pressure	160 bar
MP inlet pressure	6.1 bar	MP inlet pressure	20 bar
LP inlet pressure	2.5 bar	HP inlet temperature	585 ºC
HP – MP – LP inlet temperature	800 ºC	MP inlet temperature	575 ºC

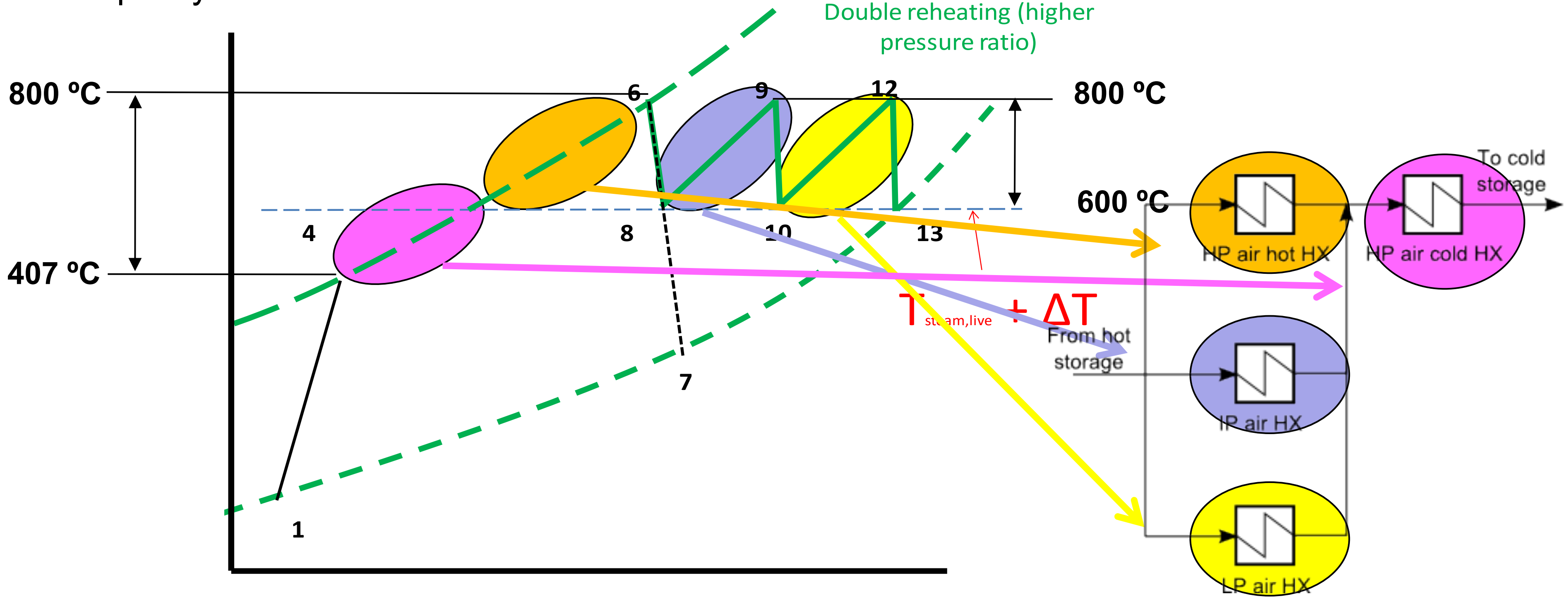
Particle-based heat exchanger network

Very regenerative configuration (double turbine reheating of the Brayton cycle) leading to reduced temperature difference across heat exchangers → high particles mass flow



Particles-based heat exchanger network

Very regenerative configuration also leading to high temperature of “cold” particles sent back to the tanks and receiver → higher particles receiver area and storage tanks capacity



Mass flow distribution:

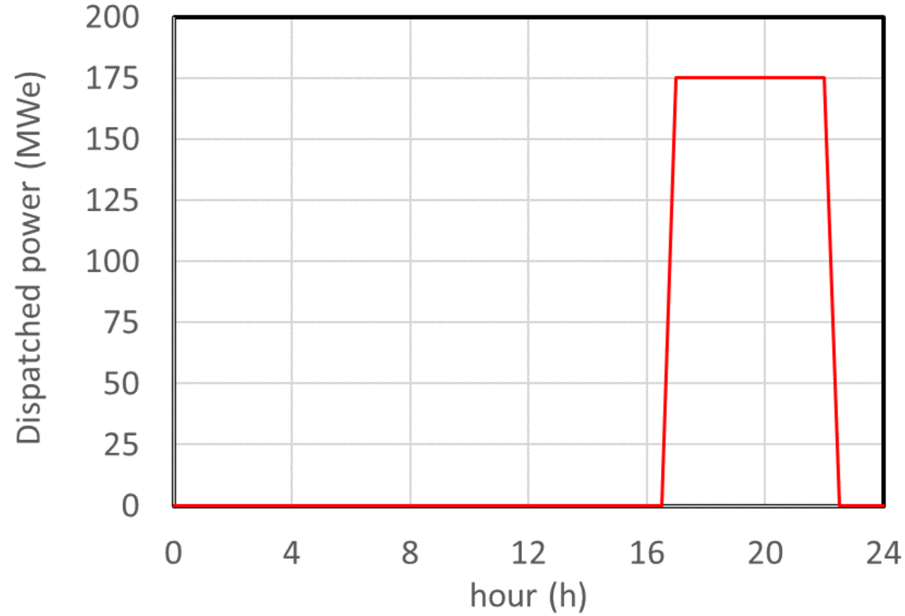
- **m_{air}** (HP hot DPS-HX) = **m_{air}** (IP DPS-HX) = m_{air} (LP DPS-HX) = **m_{air}** (HP cold DPS-HX)
- **m_{DPS}** (HP hot DPS-HX) ≈ **m_{DPS}** (IP DPS-HX) ≈ **m_{DPS}** (LP DPS-HX) ≈ **3 · m_{DPS} (HP cold DPS-HX)**

Dispatch strategies (plant operation)

Strategy A

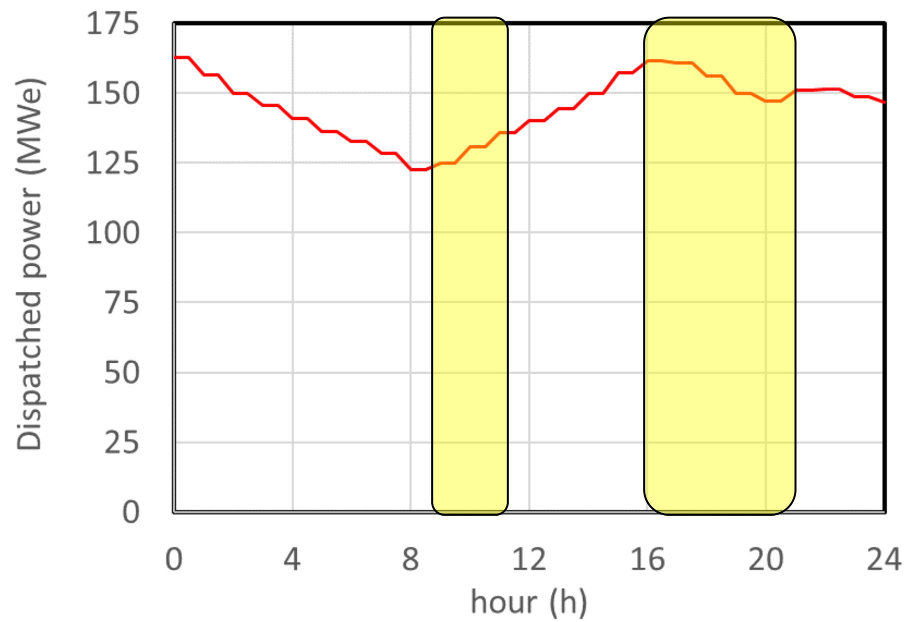
Constant power output (nominal power) from 17h – 22h

30 minutes ramp-up & ramp-down



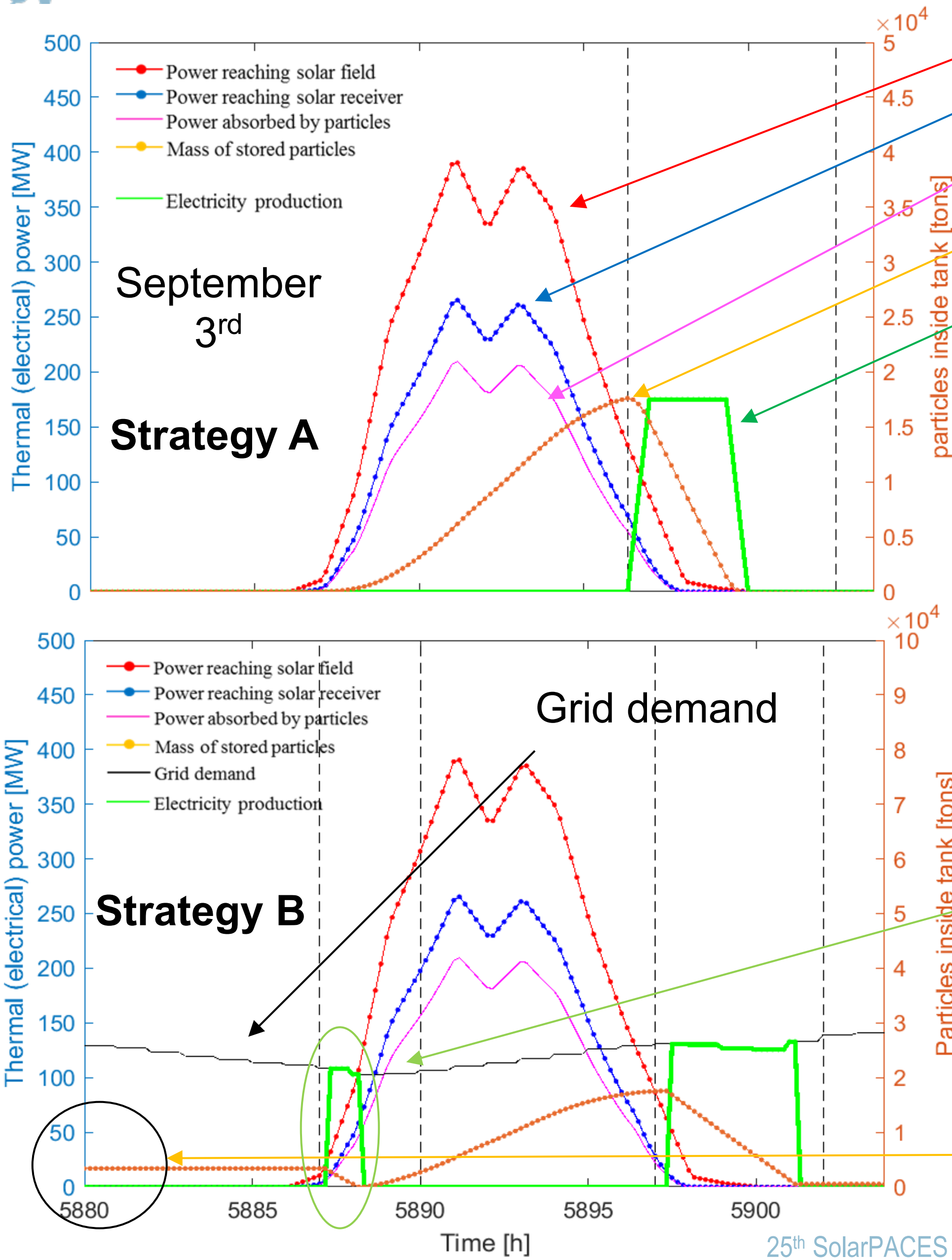
Strategy B

Following grid demand during morning-peak (9h – 11h) and evening-peak (17h – 21h)



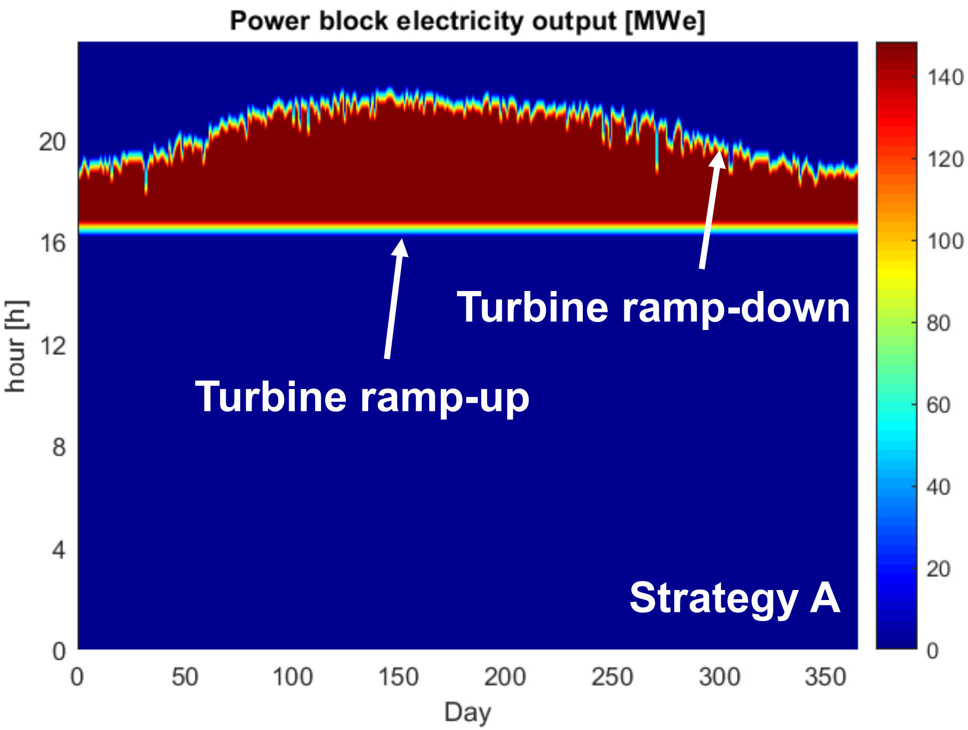
Thermal energy surplus to be stored as hot particles (tanks sizing)

Results Analysis: Daily Operation



- Energy harvesting and electricity production are decoupled. Power cycle runs taking thermal energy from storage tanks
- Tanks sizing according to dispatch strategy and electricity demand
- Depending on DNI, grid demand and existing TES capacity, dispatch electricity could not be enough to cover the demand

Results analysis: Annual performance

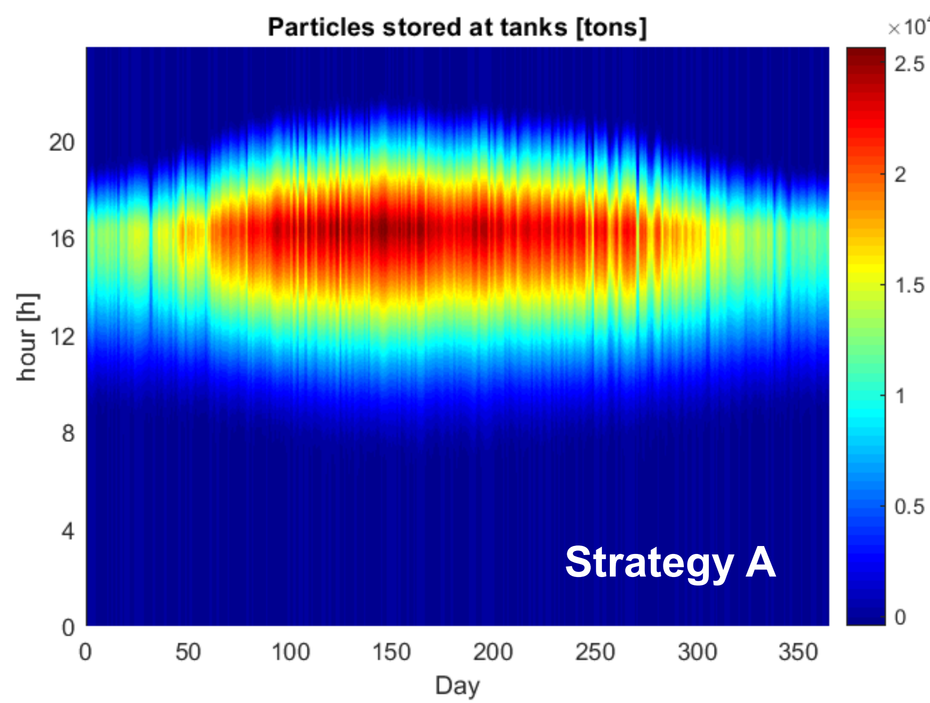


Electricity annual production (MWe)

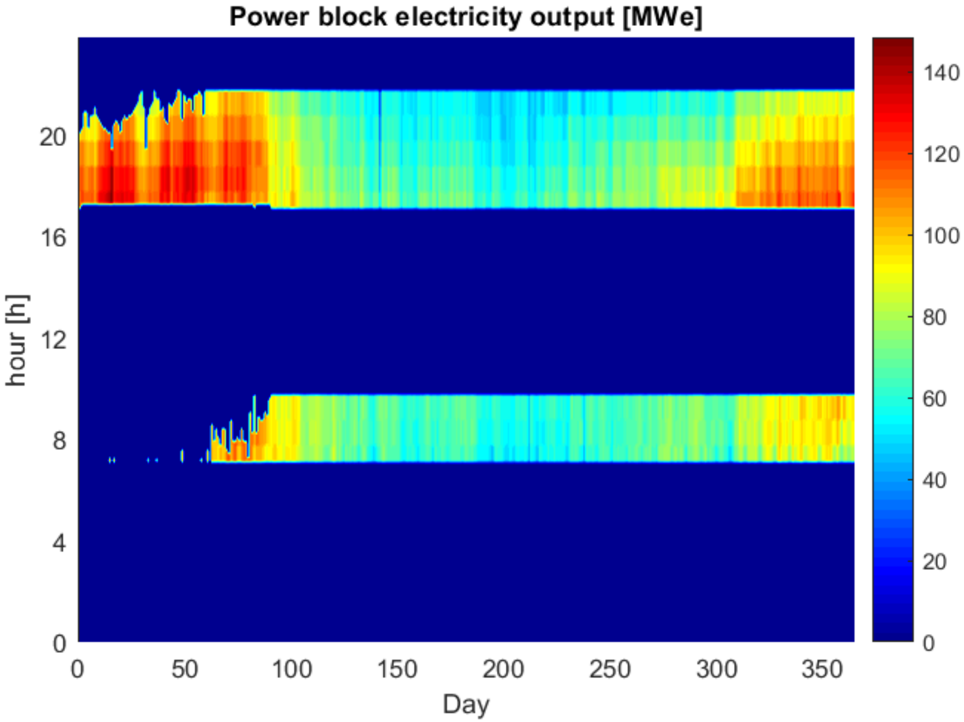
- Winter months: not enough thermal power to dispatch 5 hours @ full load

Particles stored at tanks (tons)

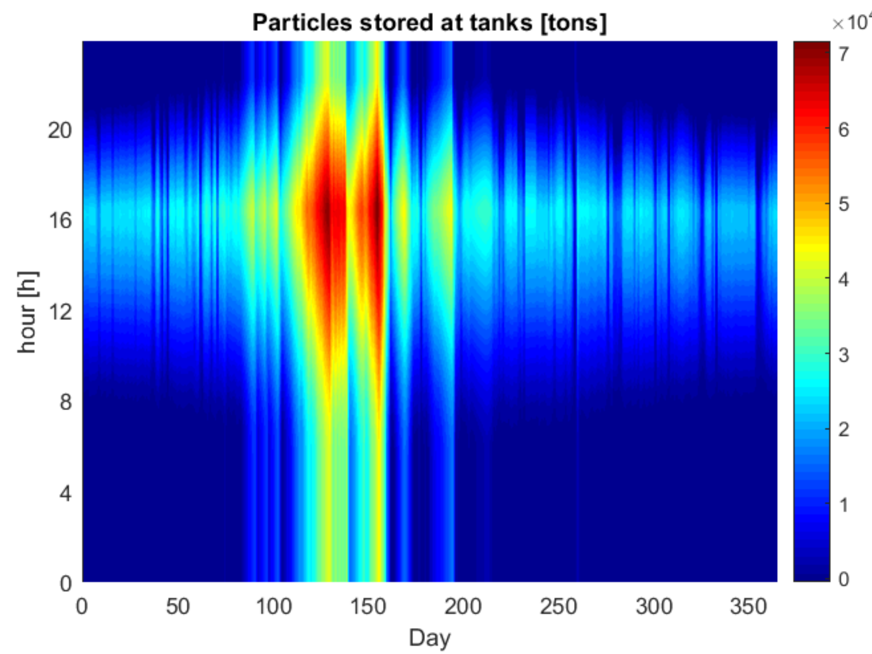
Maximum amount of particles stored during central months of the year and before power cycle operation (before 17 h)



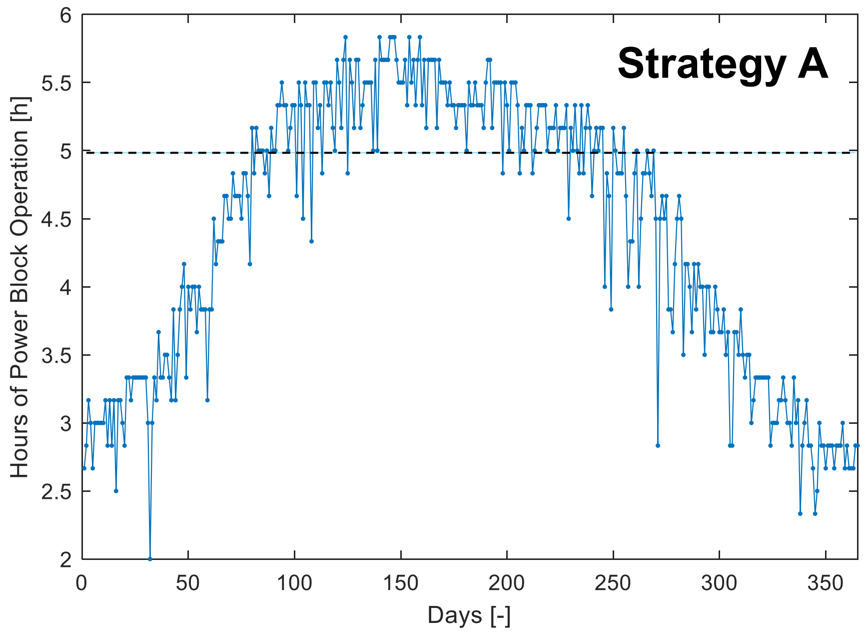
Results analysis: Annual performance

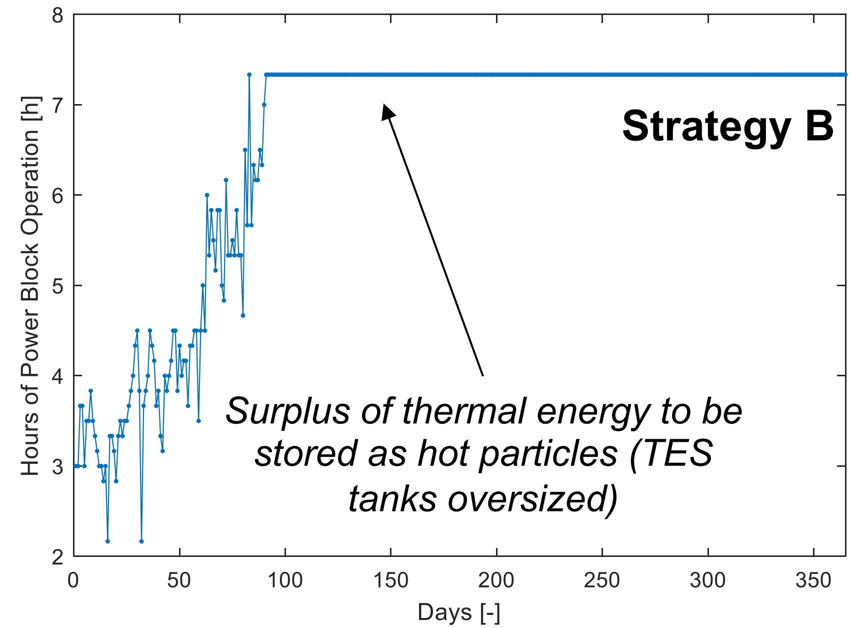


- Exceeding thermal power stored as hot particles by the end of the day (during those months when the solar resource is higher but the electricity demand is lower)



Results analysis: Annual performance





Conclusions

- Pure-solar Integrated Solar Combined Cycle (ISCC) optimized at design-point conditions
- 2 dispatch strategies analyzed:
    - Constant nominal power output (17h – 22h)
    - Flexible dispatch power output to cover morning & evening peaks
- Thermal storage sizing largely depends on dispatching scenario, so that a case-by-case analysis (dispatching, resource, demand) is necessary
- Solar-to-electricity efficiency is not a good figure when similar times of full load plant operation and turbine ramp up/shut off penalizes solar-to-electricity efficiency.
- More detailed analysis on operation modes based on dynamic modelling of transients and economic analysis are absolutely needed to support power plant viability

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THANKS FOR YOUR ATTENTION !

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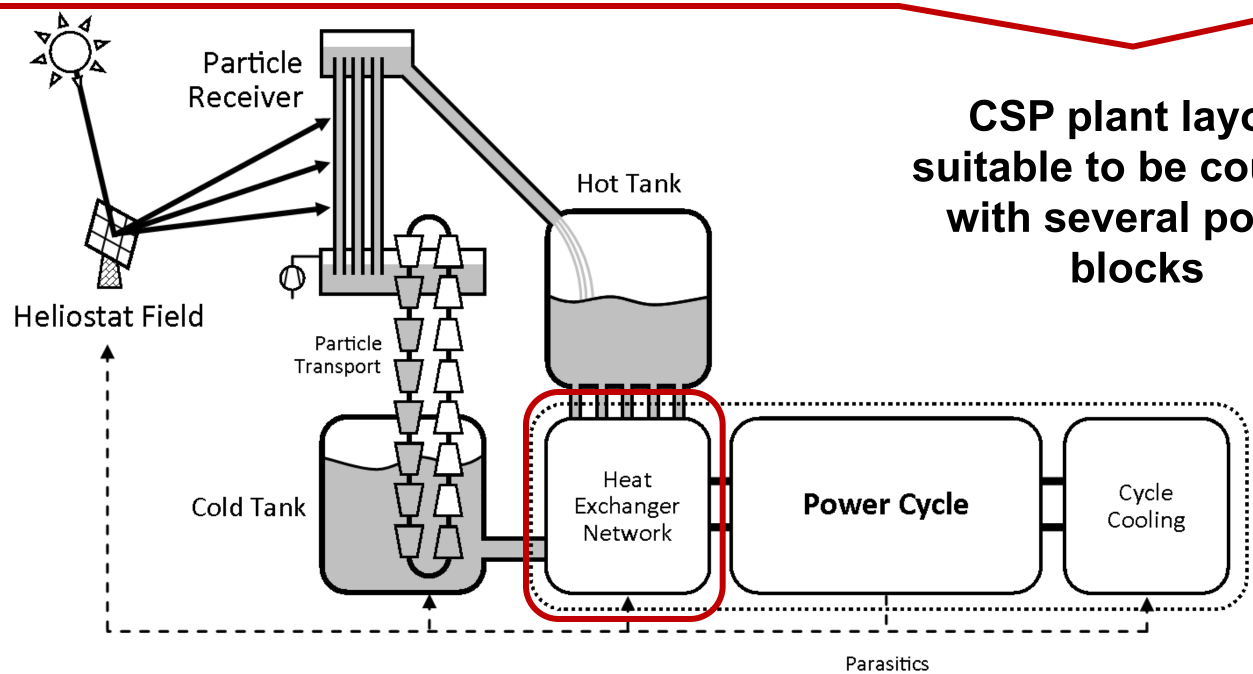
Motivation

- Novel heat transfer fluid based on *Dense Particles Suspension* (**DPS**) to be used at central solar receiver and for direct Thermal Energy Storage (TES)
- Excellent thermophysical properties of DPS

DPS HTF advantages

- ✓ High Temperature (> 650 ºC)
- ✓ No freezing risk
- ✓ No hazardous
- ✓ Cheap and abundant
- ✓ High energy density
- ✓ High heat transfer coefficient (> 2,000 W/m² K)



CSP plant layout suitable to be coupled with several power blocks

Plant layout proposal: A high-efficiency solar thermal power plant using a dense particle suspension as the heat transfer fluid, J. Spelling, A. Gallo, M. Romero, J. González-Aguilar. **SolarPACES 2014**