Next-CSP Concept with Particle Receiver Applied to a 150 MW_e Solar Tower

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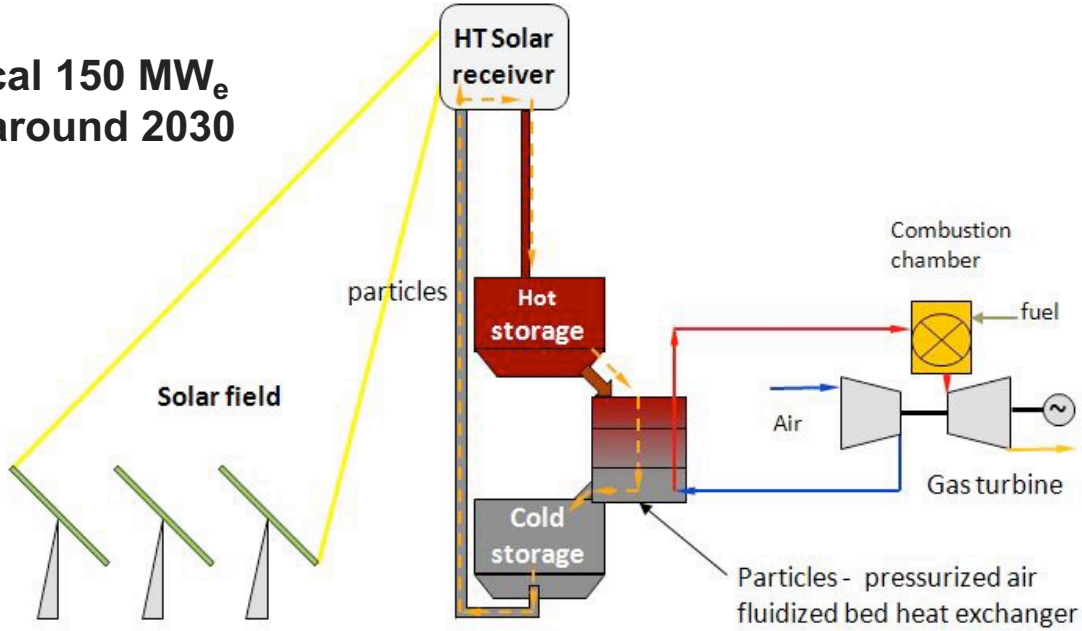
NEXT-CSP PROJECT: OBJECTIVES AND CONCEPT

General objectives of Next-CSP

- Development of a particle Upward Bubbling Fluidized Bed (UBFB) solar receiver reaching ~800°C, thus allowing for a higher cycle efficiency
- Design, construction and testing of a demonstration-scale (1.2 MW_e) solar tower that uses particles as both HTF and storage medium and a gas turbine for power generation
- **Preliminary study of a typical 150 MW_e Next-CSP plant to be built around 2030**
- DNI = 2635 kWh/m^2.year
  Latitude = 31°
  Dry cooling – Sea level



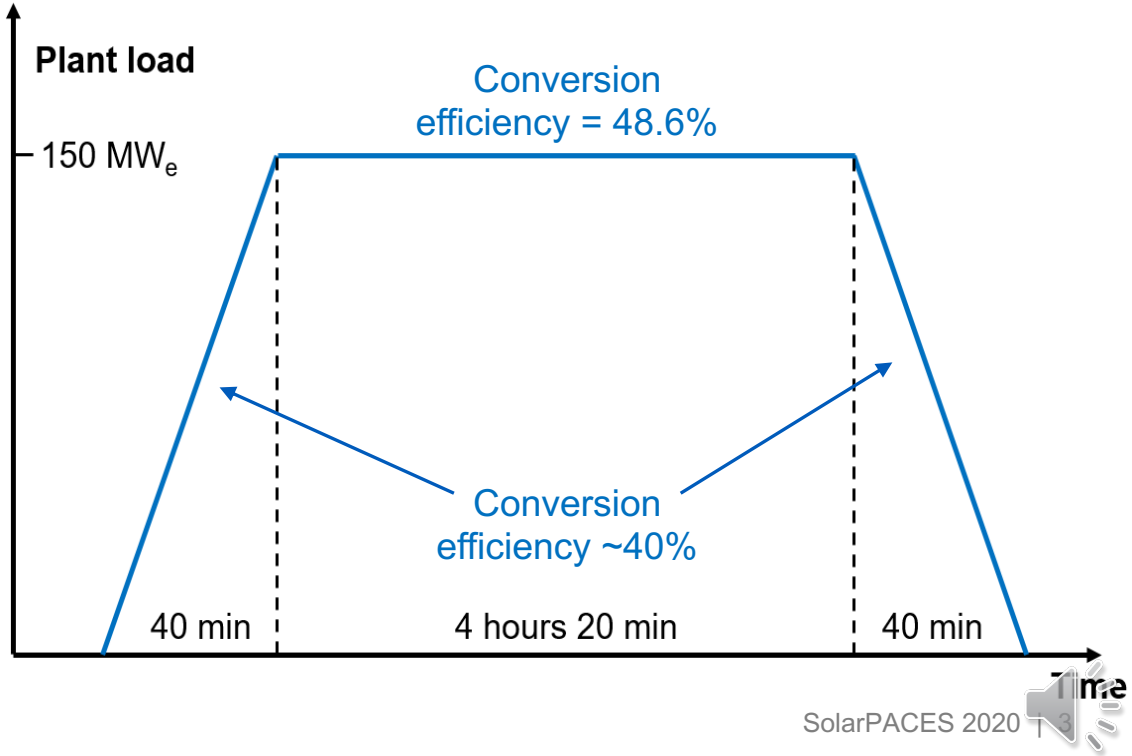
DISPATCH STRATEGY CHOSEN

- Only peaker or mid-peaker CSP plants make sense. Daytime power generation must be avoided

- Dispatch strategy is project-dependent. The most likely ones are:
  - early morning + evening
  - evening only

- We chose the latter: 5 hours of full-load generation during the evening

- A daily amount of 1.6 GWh of heat must be provided to the power cycle to meet the dispatch commitment



ARCHITECTURE OF THE SOLAR ISLAND

Inherent limitations of the Upward Bubbling Fluidized Bed Solar Receiver

- Moderate heat transfer between receiver tubes and particles
  → Maximum net average flux on solar panel ~550 kWm^{-2}
  → Cavity receiver mandatory to mitigate the thermal losses (particle T°> 800°C)

- Maximum tube irradiated height = 8 m due to hydrodynamic limitations (slugging and reduced wall-to-bed heat transfer) in the highest part of the tubes

- All the above + A maximum Width/Height ratio of the panel reasonably set at 1.63
  → Thermal power of the solar receiver < 60 MW_{th}

- Consequently, several receivers (5 to 7) are required → Multi-tower architecture

- We chose to install only one receiver per tower, each one with a north field
  (for a plant located in the northern hemisphere)

SIZING OF SOLAR ISLAND AND STORAGE

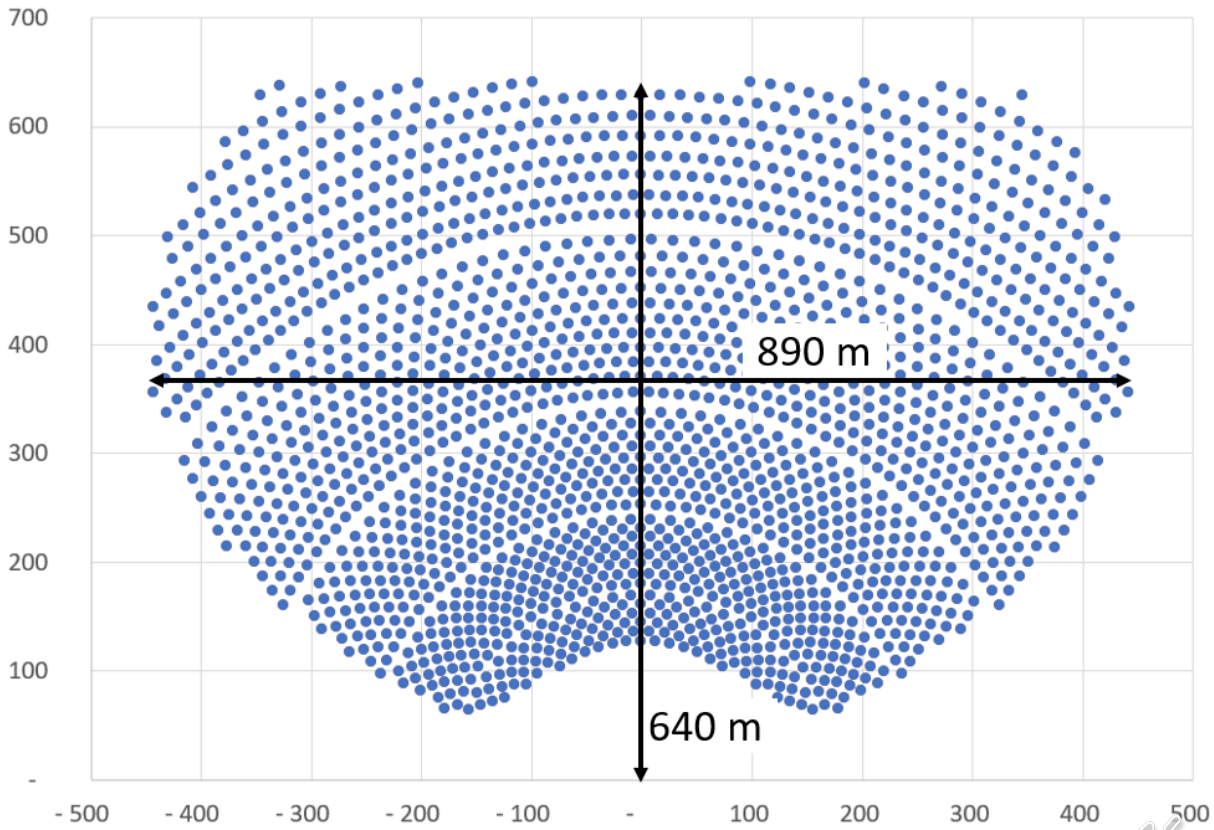
Sizing of the solar island: 6 x 56.2 = 337 MW_{th}

- Allows the plant to fully fulfill the dispatch requirement during about 280 days per year
- No power generation during ~20 days per year

- **Sizing of the thermal storage: 2 GWh_{th}**
- Nearly all the heat collected during the day is stored (only ~6% is used at the end of daytime when power generation begins)
- The storage system is sized for a day corresponding to the first quartile (in terms of heat collected) of the 345 days per year with power generation
- Corresponds to 30 000 tons (~15 000 m^3) of olivine
- Hot particles stored at 815°C, “cold” particles at 600°C

CHARACTERISTICS OF EACH SOLAR MODULE

- 1879 Stellio® heliostats (48.5 m² each)
- Tower height: 126 m (from mirrors to mid-panel height)
- “Wide” field, well suited to the wide aperture of the receiver
- Optical efficiency of the field & receiver = 81%
- Thermal efficiency of the receiver: Objective 85 %

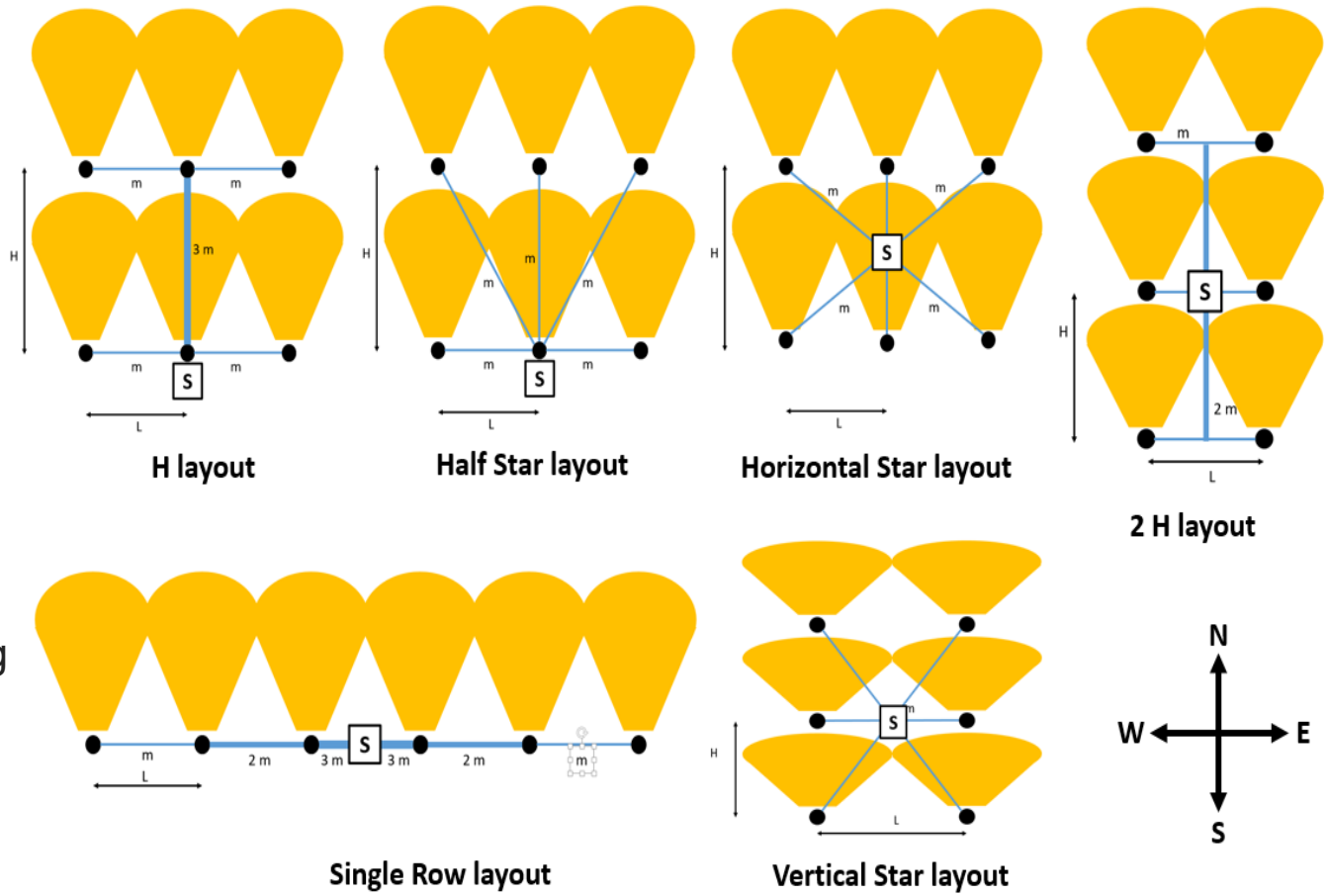


MULTI-TOWER LAYOUTS ENVISIONED

These layouts were compared for three Height/Width ratios of the individual fields:

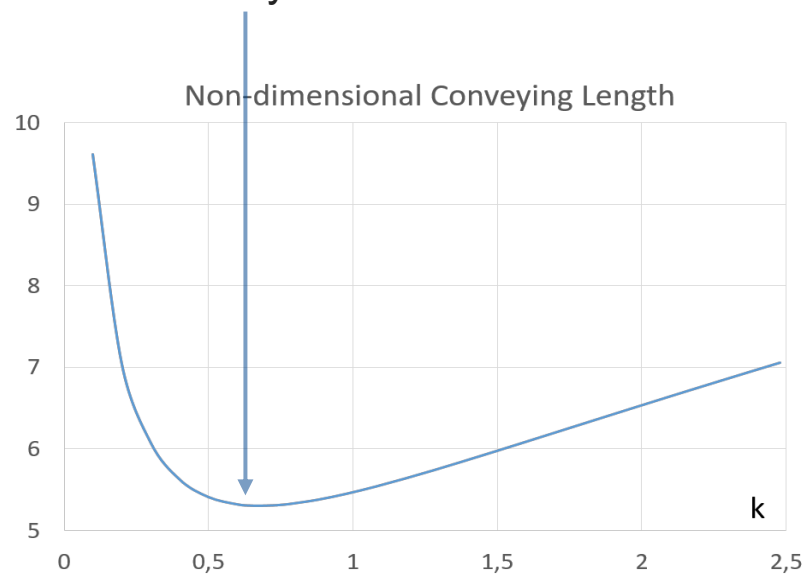
- H/W = 0.5
- H/W = 0.73 (our field)
- H/W = 1.0

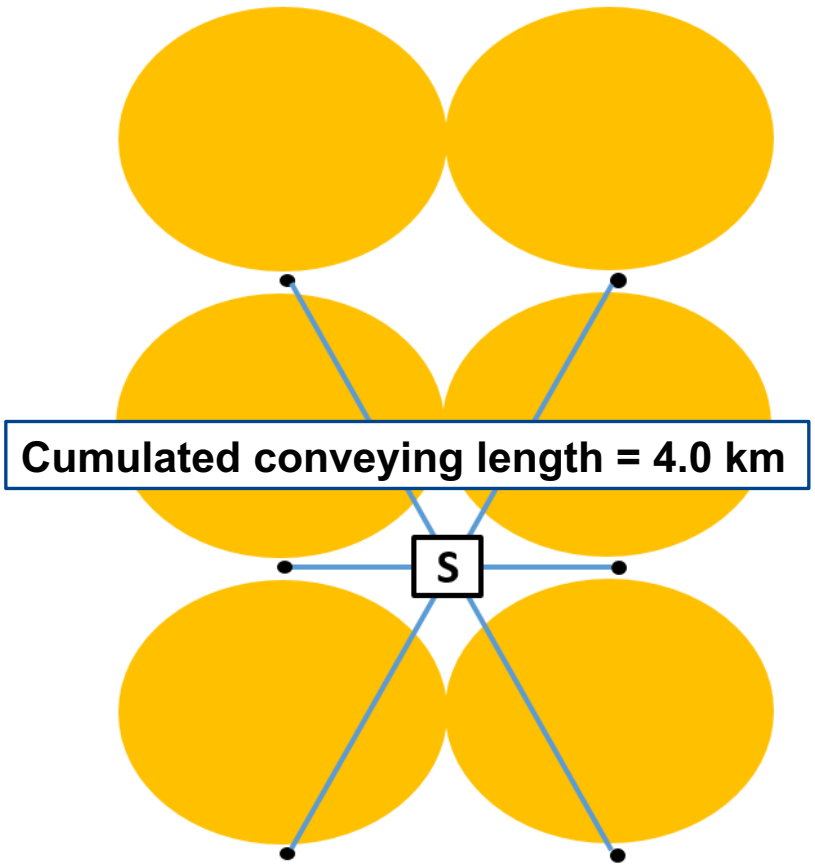
<u>Criterion:</u> minimizing the cumulated conveying length



BEST LAYOUT: VERTICAL STAR

- For H/W > 1 the horizontal star wins
- For H/W < 1 (our case) the vertical star wins
- Our H/W = 0.73 ratio is quite optimal for the vertical star layout

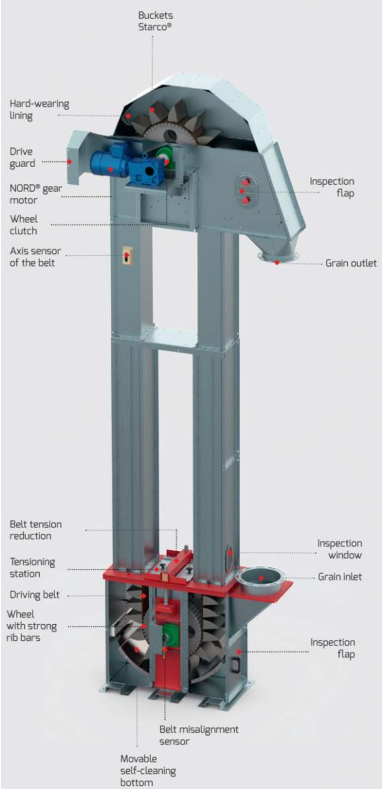




PARTICLE HANDLING (STORAGE ←→ TOWERS)

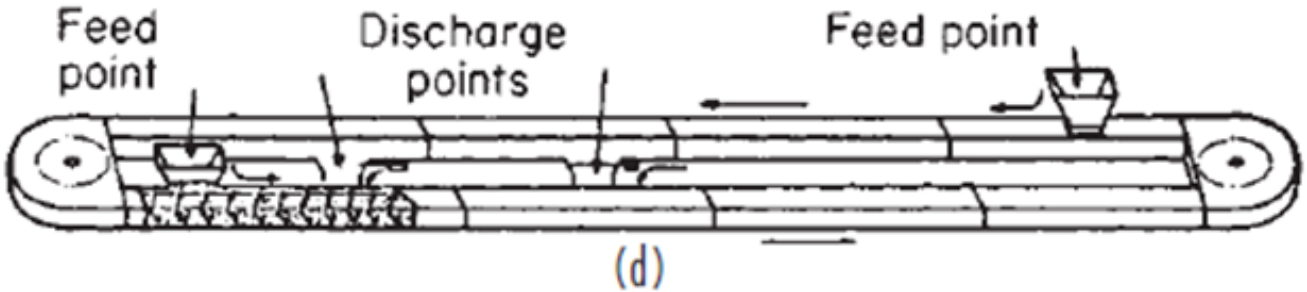
Vertical: bucket elevators

- Skip hoists (derived from those used in the mining industry) as well as railway wagons were also envisioned
- Bucket elevators were chosen because their near-continuous operation allows reducing the buffer storage located atop the tower →



Horizontal: continuous-flow conveyors

- Main objective: mitigating the thermal losses. That is why apron conveyors were envisioned but eventually rejected



PARTICLE CONVEYING: POWER CONSUMPTION AND THERMAL LOSSES

Auxiliary consumption: 2.5 MW_e

- Albeit significant, this amount of power is consumed during the day
- → It can be provided by a PV farm and a small (~1 hour capacity) battery → Low Capex

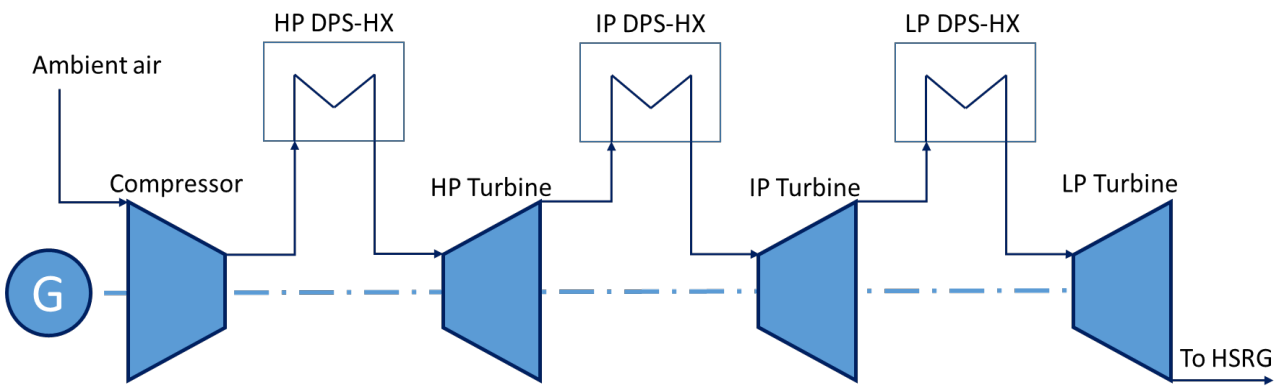
Thermal losses

- First estimate: ~17,6 MWth, ~5% of the heat delivered by the solar island: **too much!**
- This is a conservative estimate that was made considering apron conveyors
- Proper engineering + Replacing the apron conveyors with continuous-flow conveyors will cut these thermal losses by half

POWER CYCLE: COMBINED CYCLE WITH EXTERNALLY-HEATED GAS TURBINE

- No supplementary firing (unlike Next-CSP the demonstration plant)
  → The Turbine Inlet Temperature (TIT) is limited by the particle temperature
  → TIT = 780°C

- In order to approach a 50% combined cycle efficiency with such a low TIT, a double reheat configuration is required



The bottoming steam cycle is off-the-shelf: three pressure, reheat, with air-cooled condenser

PARTICLE-TO-AIR HEAT EXCHANGERS

Competing requirements:

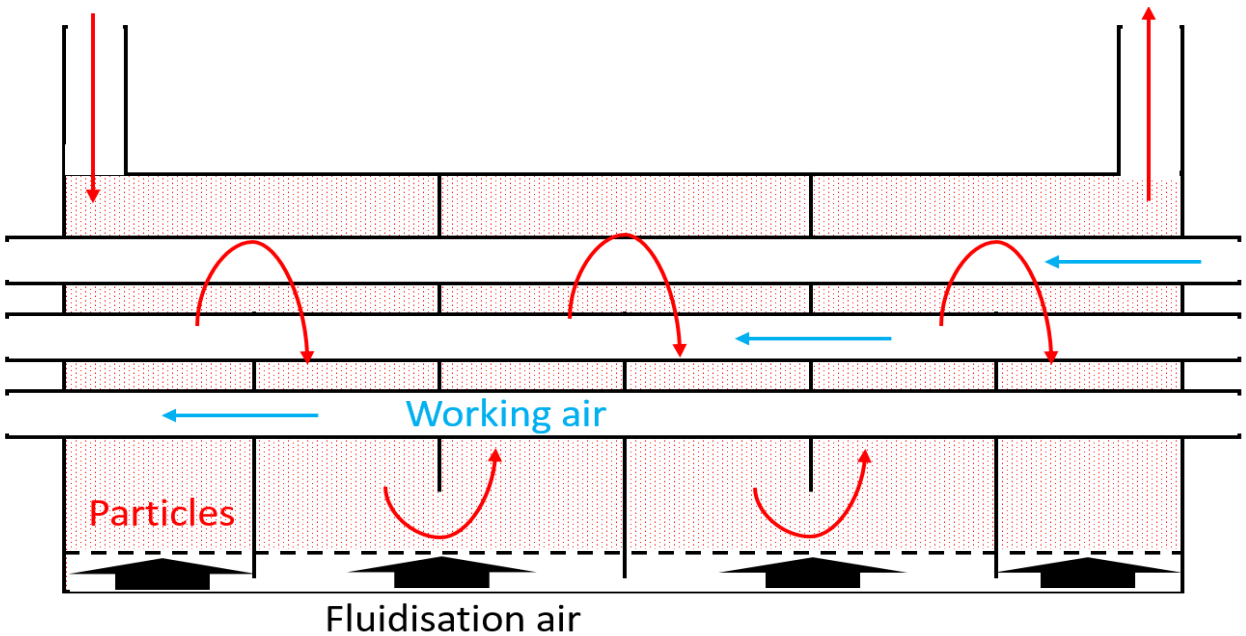
- Low temperature difference because a TIT around 800°C is already too low
- Low pressure drops because Brayton cycles are very sensitive to them

Consequence:

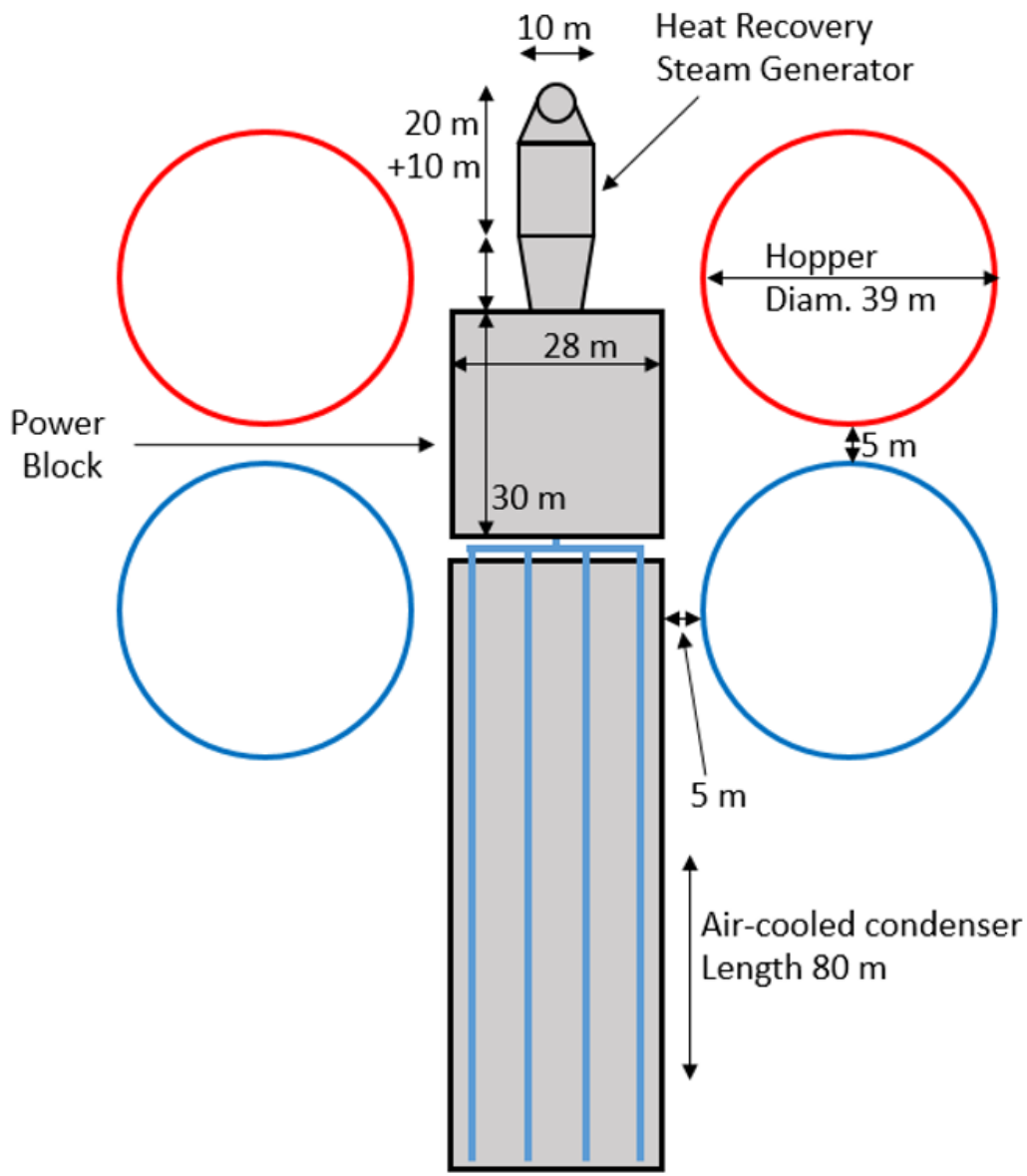
- Bulky HEXs
- Various HEXs in // to increase the cross-section

Thermal losses

- First design → ~4%
- Will be reduced



ARRANGEMENT OF THE POWER ISLAND

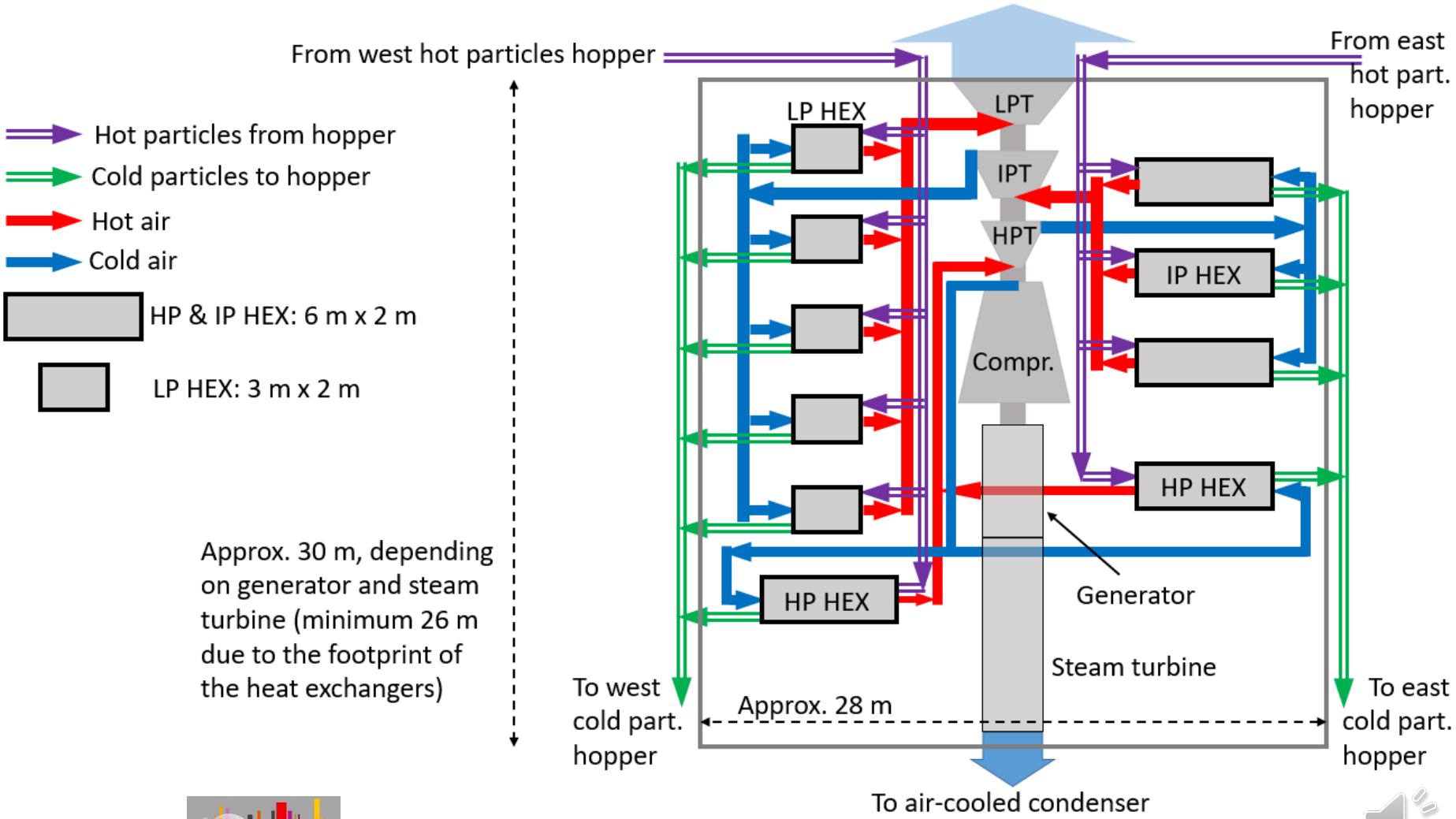


Four particle hoppers:

Two for the three east towers

Two for the three west towers

ARRANGEMENT OF THE GAS TURBINE HOUSE



KEY TAKEAWAYS

- A scaled-up solar tower based on the Upward Bubbling Fluidized Bed concept developed in Next-CSP is feasible…
- … but only with a multi-tower configuration that requires several kilometers of particle conveying
- Specific attention must be paid to mitigate the thermal losses of the conveying network, the solar receiver and the particle-to-air heat exchangers
- The design of the utility-scale solar receiver raises several challenges that can nonetheless be mitigated through proper R&D and engineering practices
- If very cheap particles with appropriate heat capacity prove applicable for our application, a much bigger storage than those commonly practiced so far could be envisioned

THANK YOU

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