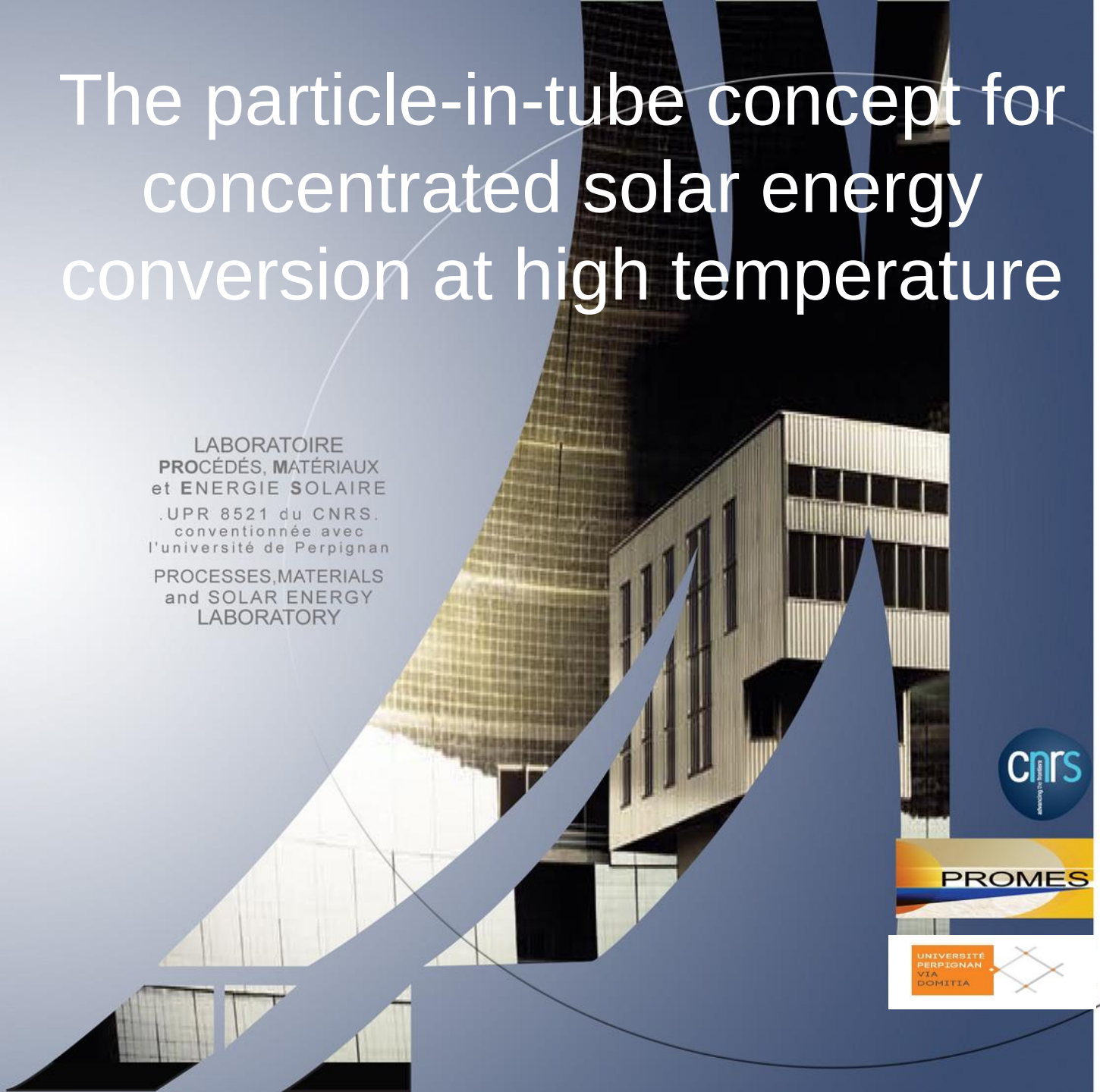
The particle-in-tube concept for concentrated solar energy conversion at high temperature

PTWG WORKSHOP
19-20/4/2017, Holiday Inn, Al-Izdihar, Riyadh, KSA



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PROMES-CNRS

Content

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- Main steps of the concept development
- Principle
- State-of-the-art
- Work in progress towards testing an industrial pilot including a GT
- Key issues
- Applications to thermochemical solid-gas reaction processing
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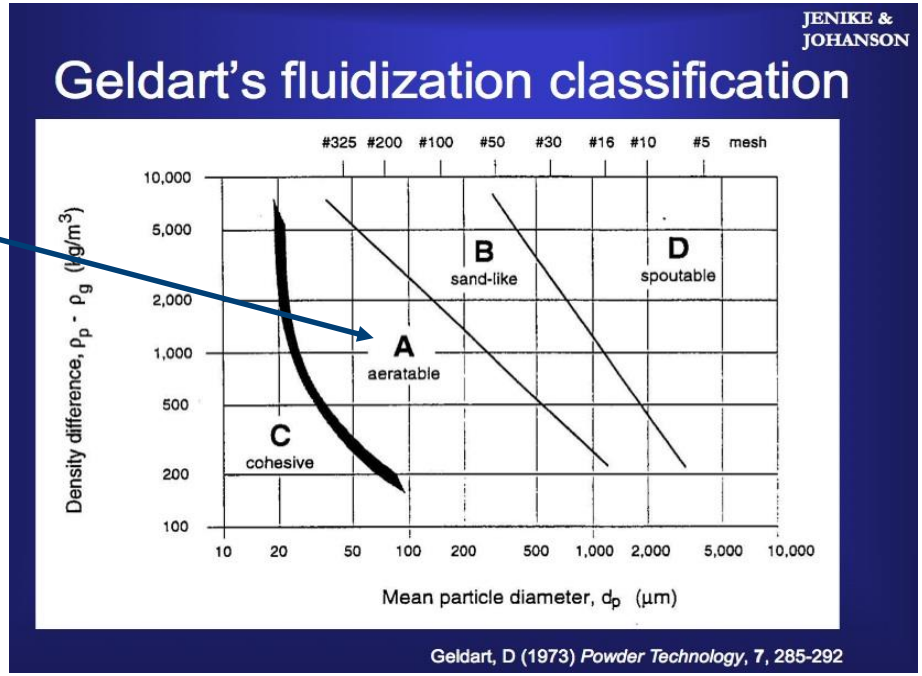
Concept

Fluidized solid particles are moving upward in vertical tubes that constitute the solar receiver.

Particles are circulating in a closed loop including the solar receiver, the hot and cold storage tank and a particle heat exchanger.

Type A particles

Advantages:
- Homogeneous fluidization with small bubbles
- Low air velocity (some cm/s)



Main steps of the concept development

- 2010, Patent
- 2011, CNRS funded project
- 2011, EU funded project, CSP2

(*Concentrated Solar Power in Particles*, N° 282932, 2011-2015)

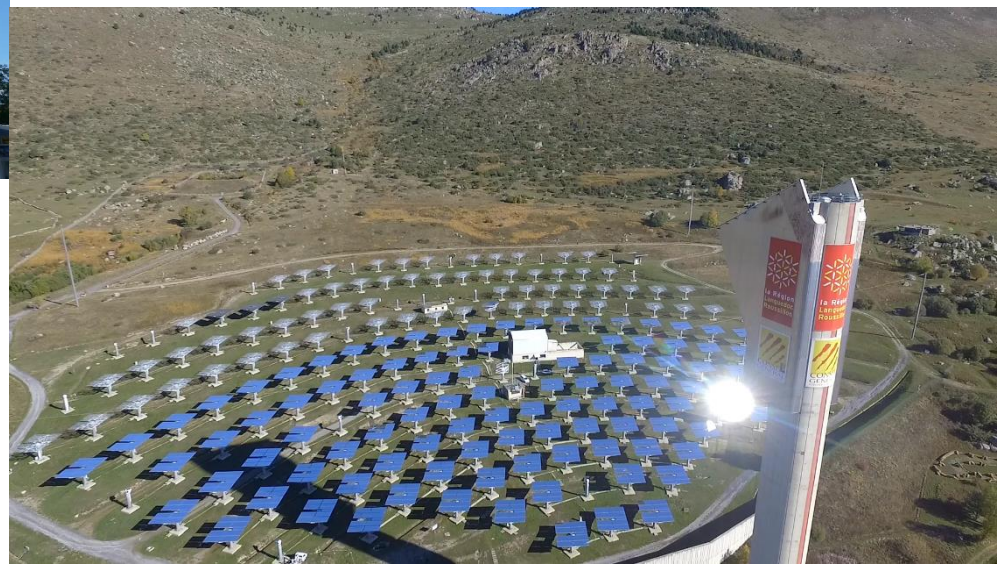
- 2016, EU funded project, next-CSP

(*High temperature concentrated solar thermal power plant with particle receiver and direct thermal storage*, N°727762, 2016-2020)

Main steps of the concept development

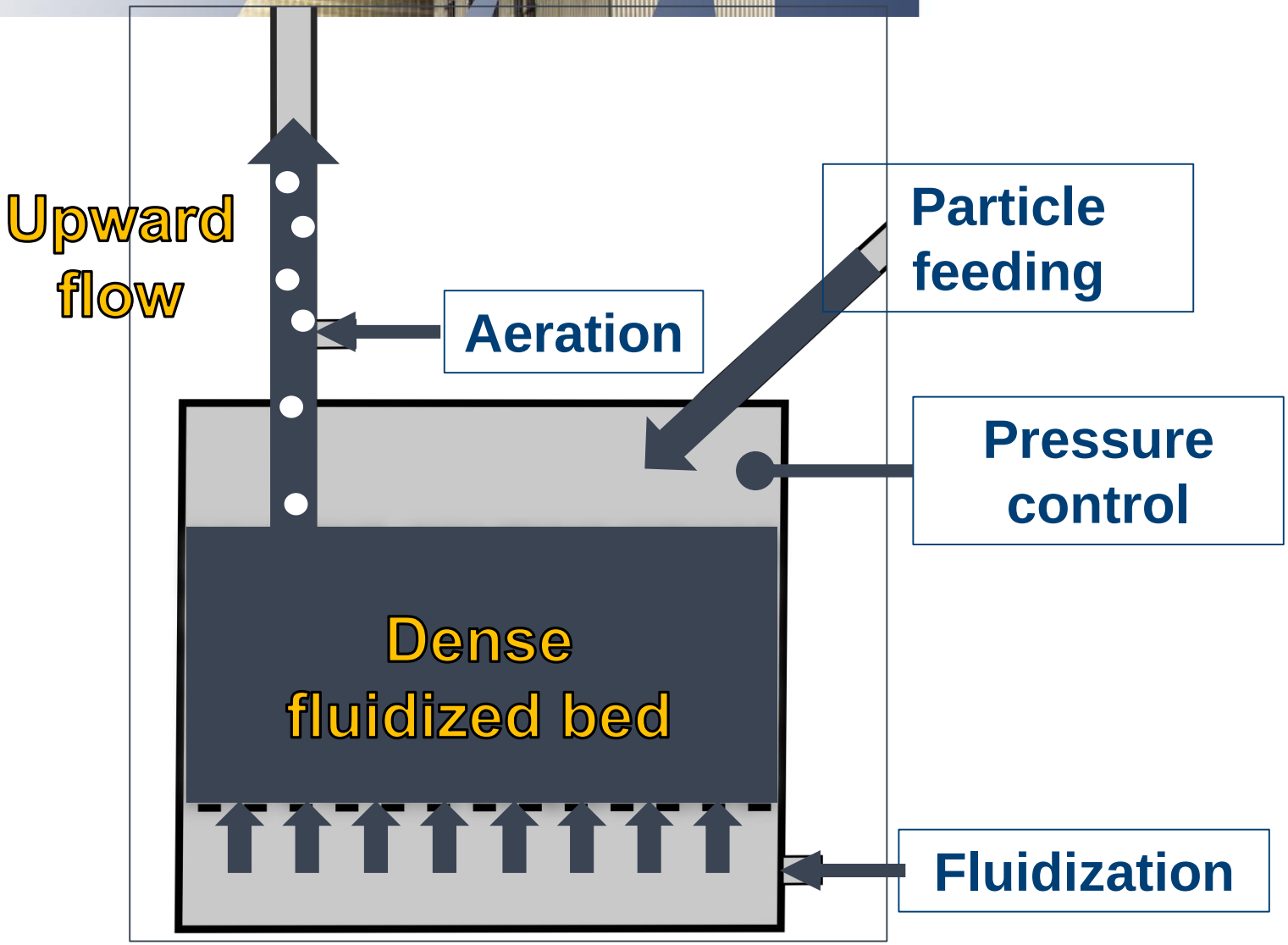
Solar Facilities

The 1 MW CNRS solar furnace



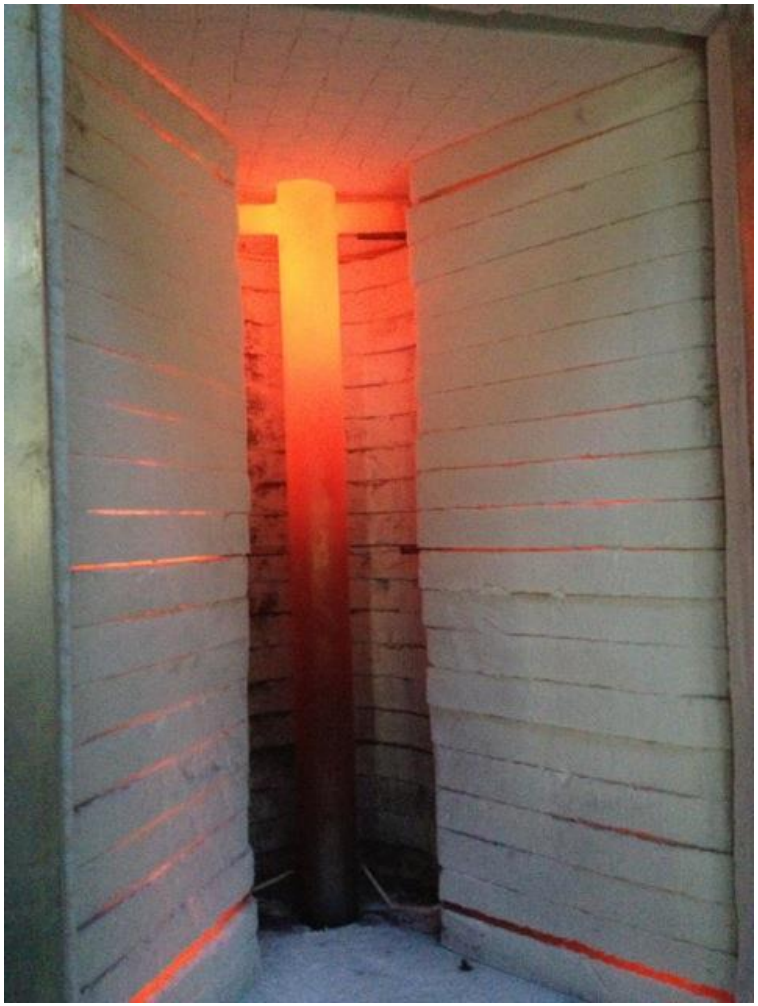
The 5 MW Themis solar tower

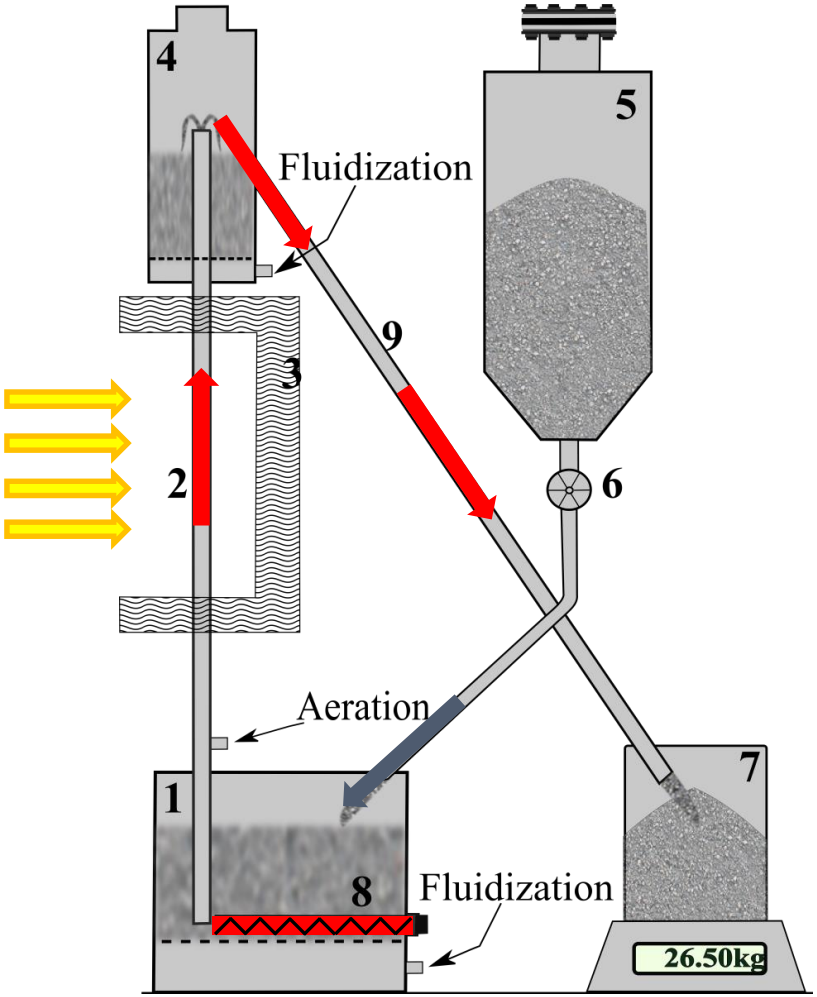
Principle


Upward flow
Aeration
Particle feeding
Pressure control
Dense fluidized bed
Fluidization

State of-the-art

Single tube

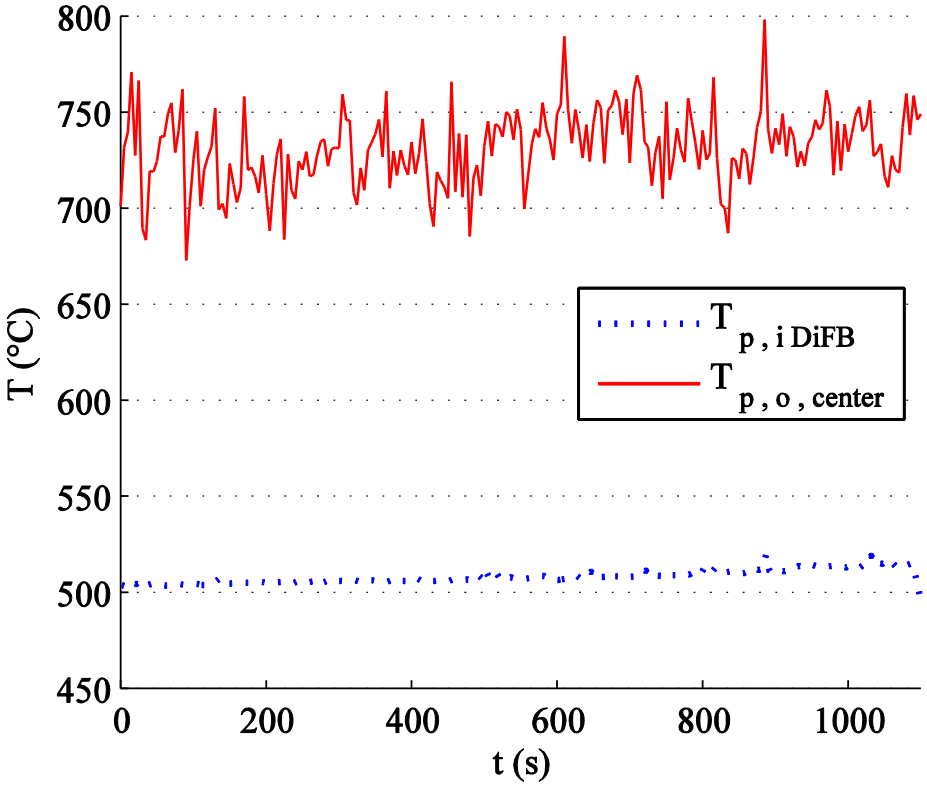




State of-the-art

Single tube

- **Achieved outlet particle temperature: 750 °C**
- Temperature increase: 250 °C for 0.5 m tube irradiated length

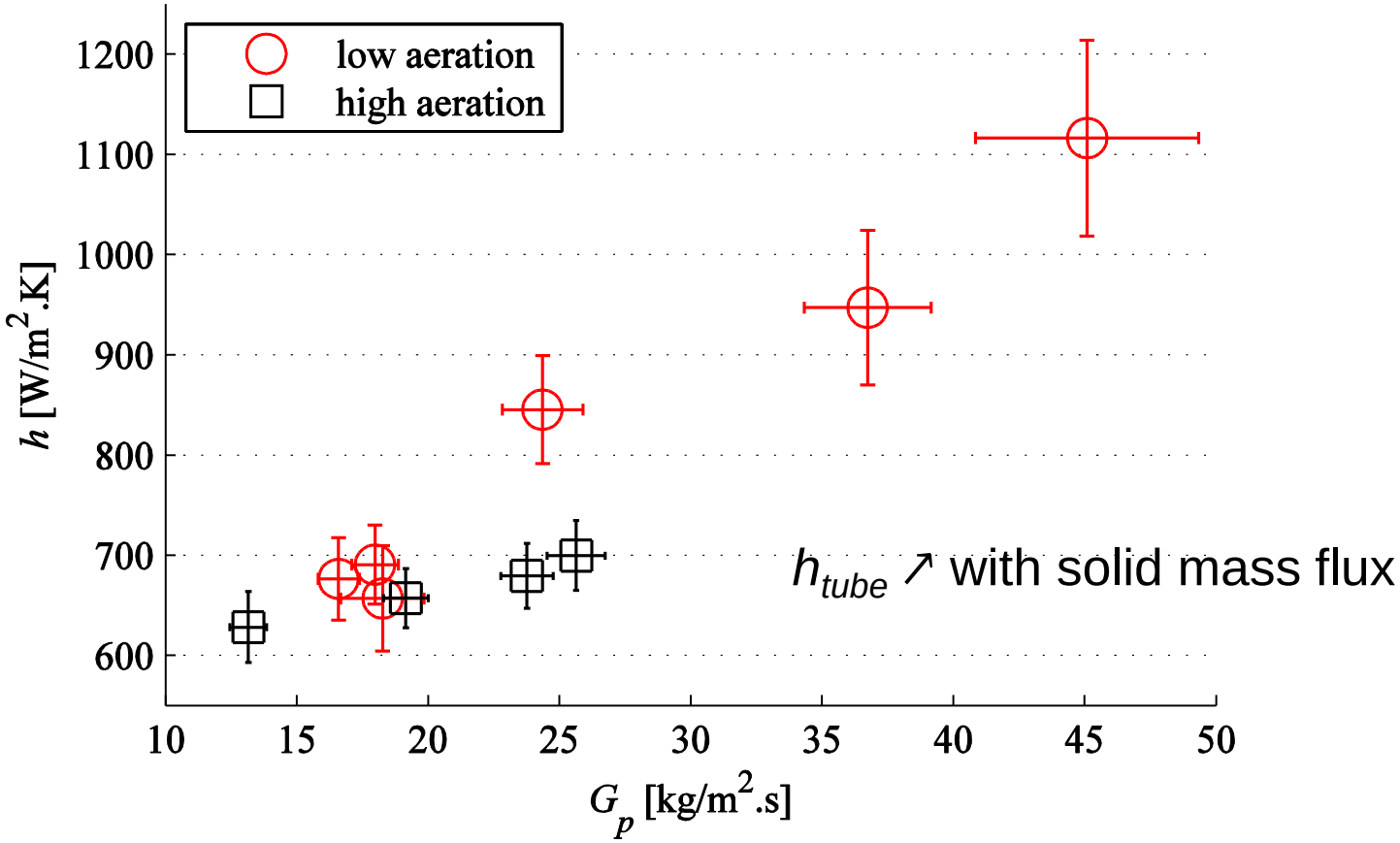


State of-the-art

Single tube

Wall-to-Fluidized bed heat transfer coefficient

SiC
d_p = 64 µm



State of-the-art

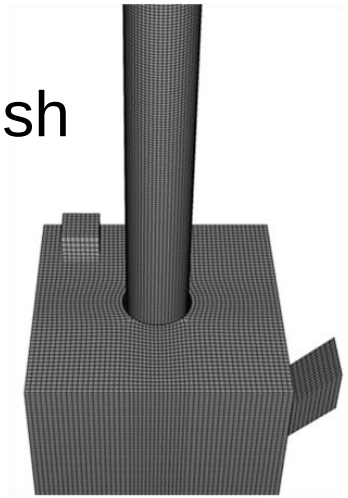
Single tube

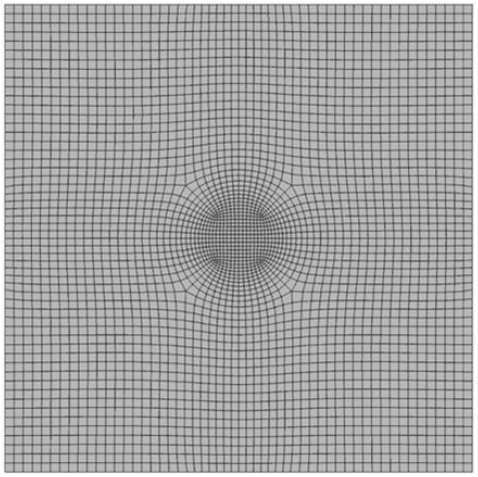
Numerical simulation

- Simulated geometry: cold flow
- Uniform heat flux density
- NEPTUNE-CFD code
  (EDF, Areva, IRSN; fluid-particle – IMFT)
- Calculation time for 1 case: 1 month on 140 cores

Number of cells = 1 650 000

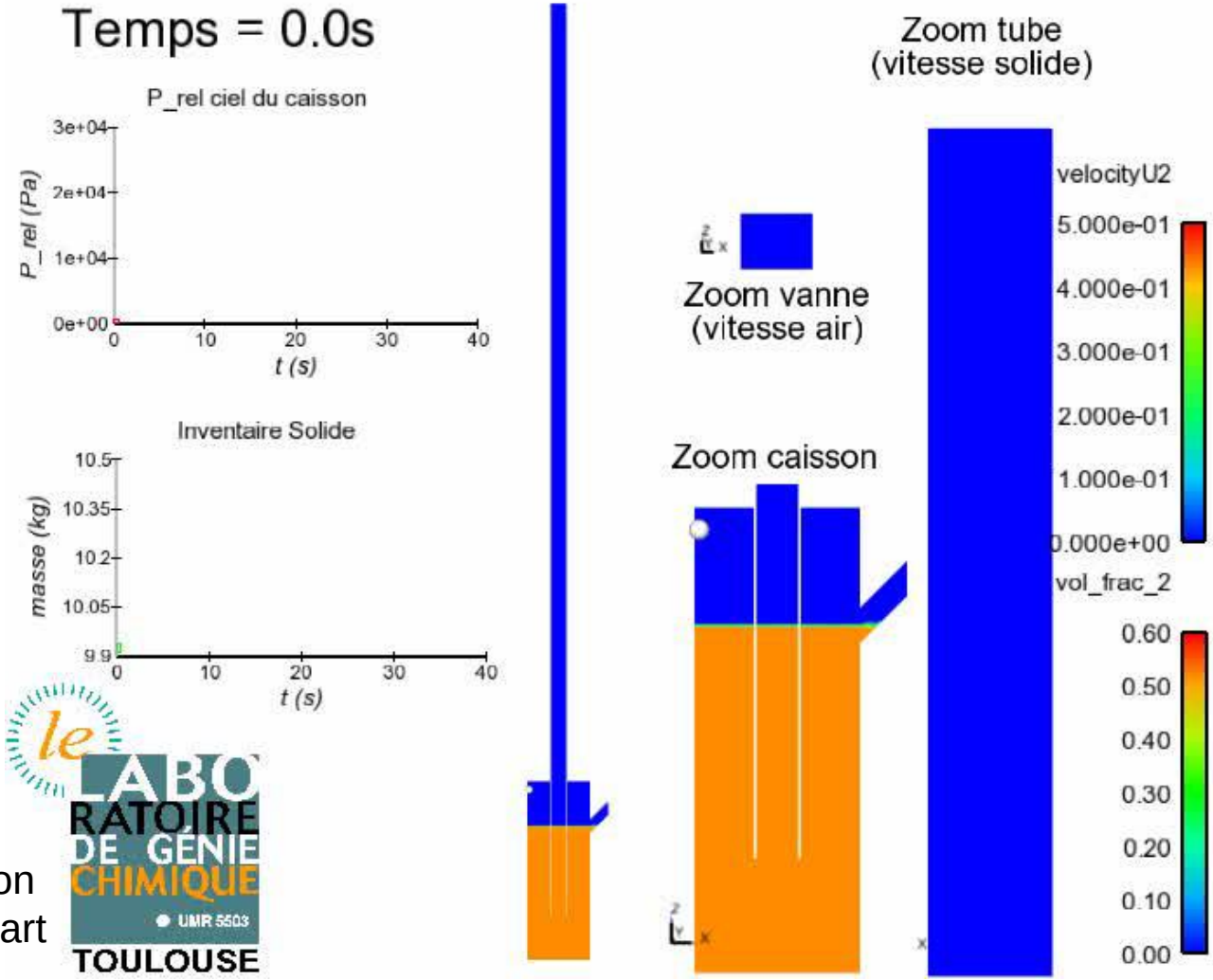
3D Mesh





State of-the-art

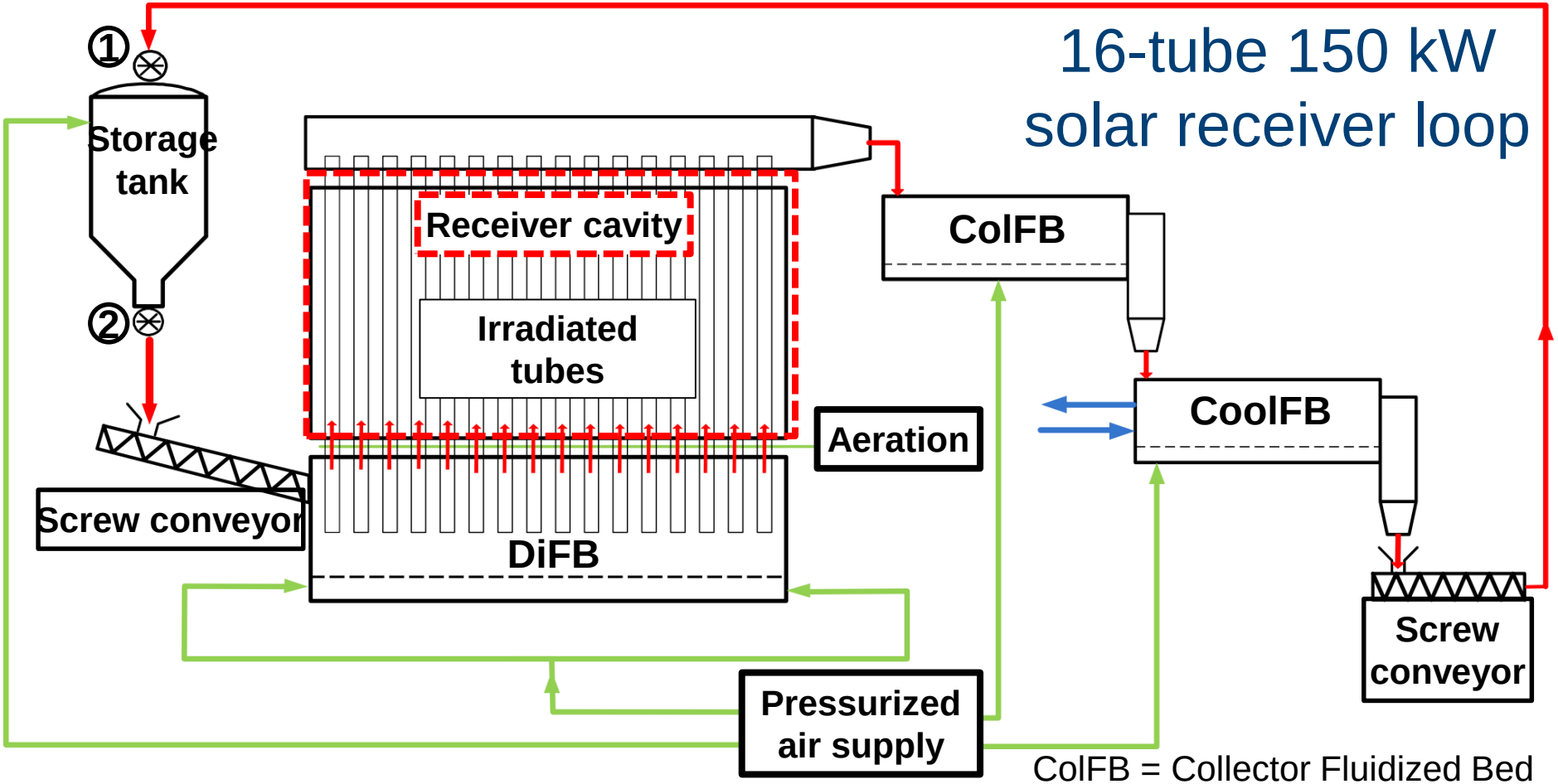
Single tube



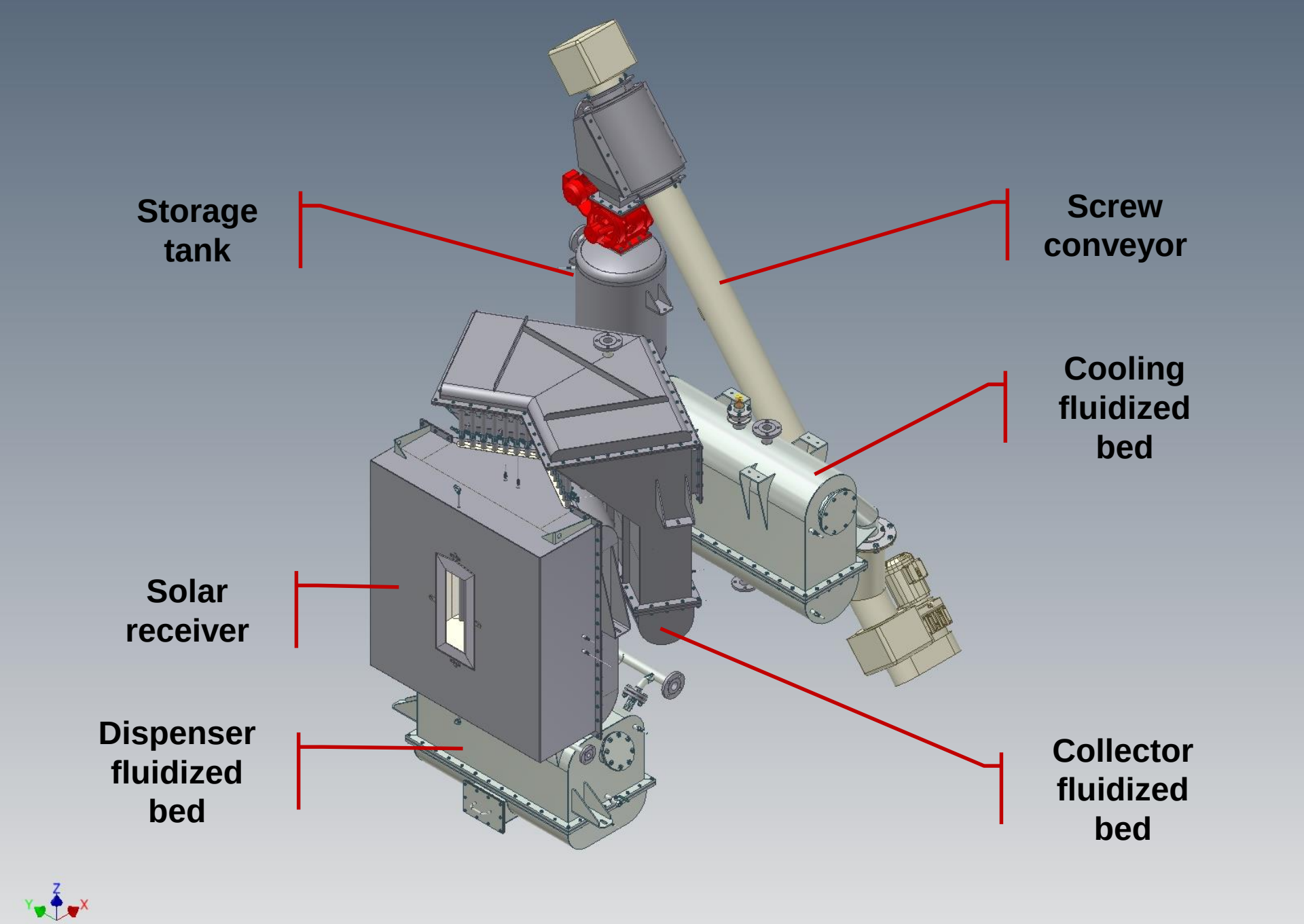
Collaboration with R. Ansart

State of-the-art

16-tube 150 kW solar receiver loop



ColFB = Collector Fluidized Bed
CoolFB = Cooling Fluidized Bed
DiFB = Dispenser Fluidized Bed
①,②: Rotary valves



3D view of the pilot solar receiver loop (conception, execution: COMESSA)

State of-the-art

16-tube 150 kW solar receiver

State of-the-art

16-tube 150 kW solar receiver

- 100 Hours of on-sun experiments performed
- 30 Hours of stable periods

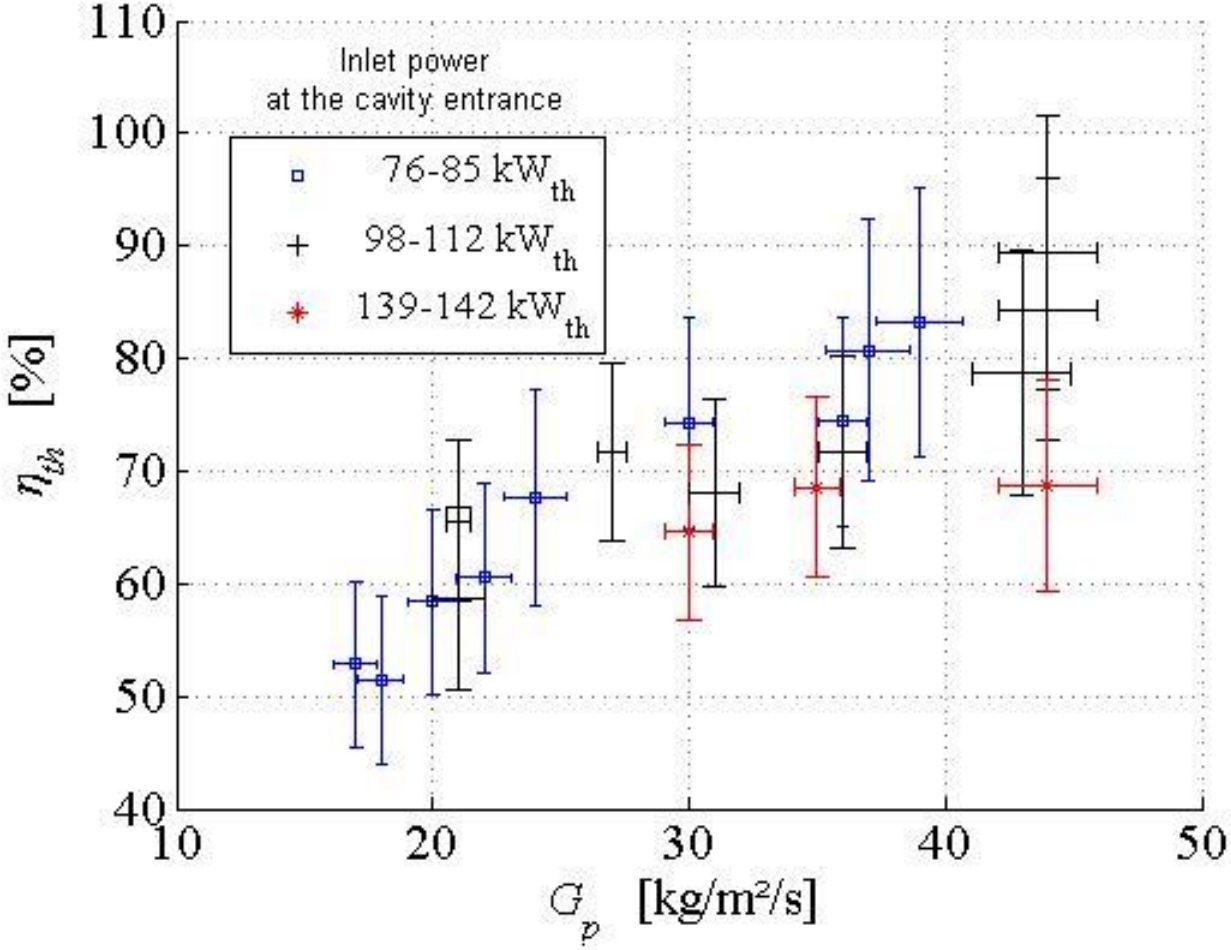
- Operating parameters ranges:
  - Inlet Power: 60-140 kW_{th}
  - Solid mass flow rate: 660-1750 kg/h (= 17-44 kg/m².s)

- Experimental result ranges (time averages):
  - Tp increase between DiFB and ColFB: 140-340 °C
  - Tp difference between tubes outlet: 130-350 °C

State of-the-art

16-tube 150 kW solar receiver

Thermal efficiency



State of-the-art

16-tube 150 kW solar receiver

Main problems encountered

- Incident solar flux heterogeneity links to the 1MW solar furnace optical characteristics (not due to the solar receiver concept)
- Some particle agglomeration due to Si content in SiC (impurities)

Nevetheless: stable solid flow and easy operability

Work in progress

Next-CSP project

Project partners

PROMES

cnrs

EDF

euronovia

institute IMDEA

comessa

WEL ENERGY TRUST

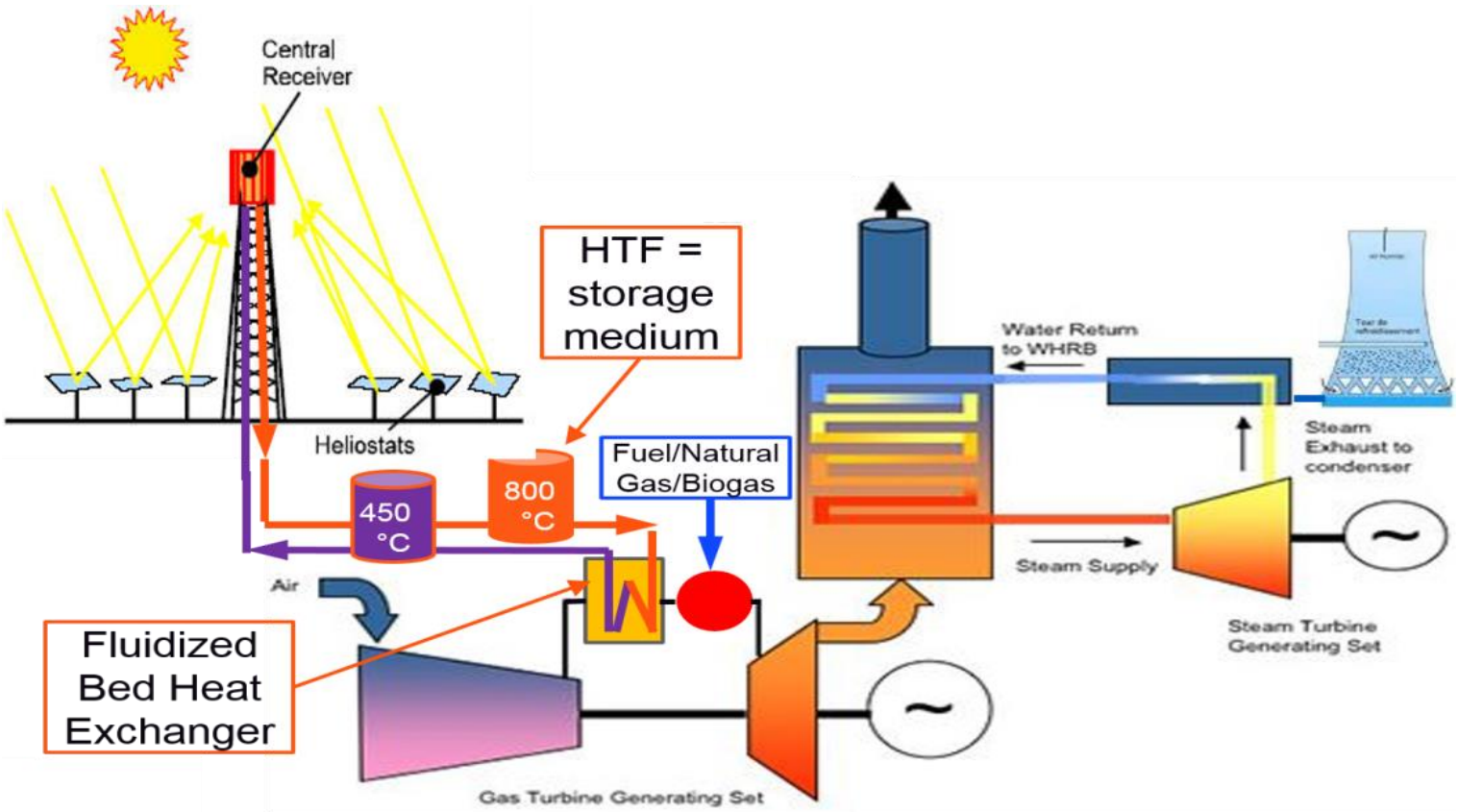
KU LEUVEN

INP TOULOUSE

Work in progress

Next-CSP project

Project concept,
hybrid solar combined cycle with 50% cycle efficiency



Work in progress

Next-CSP project

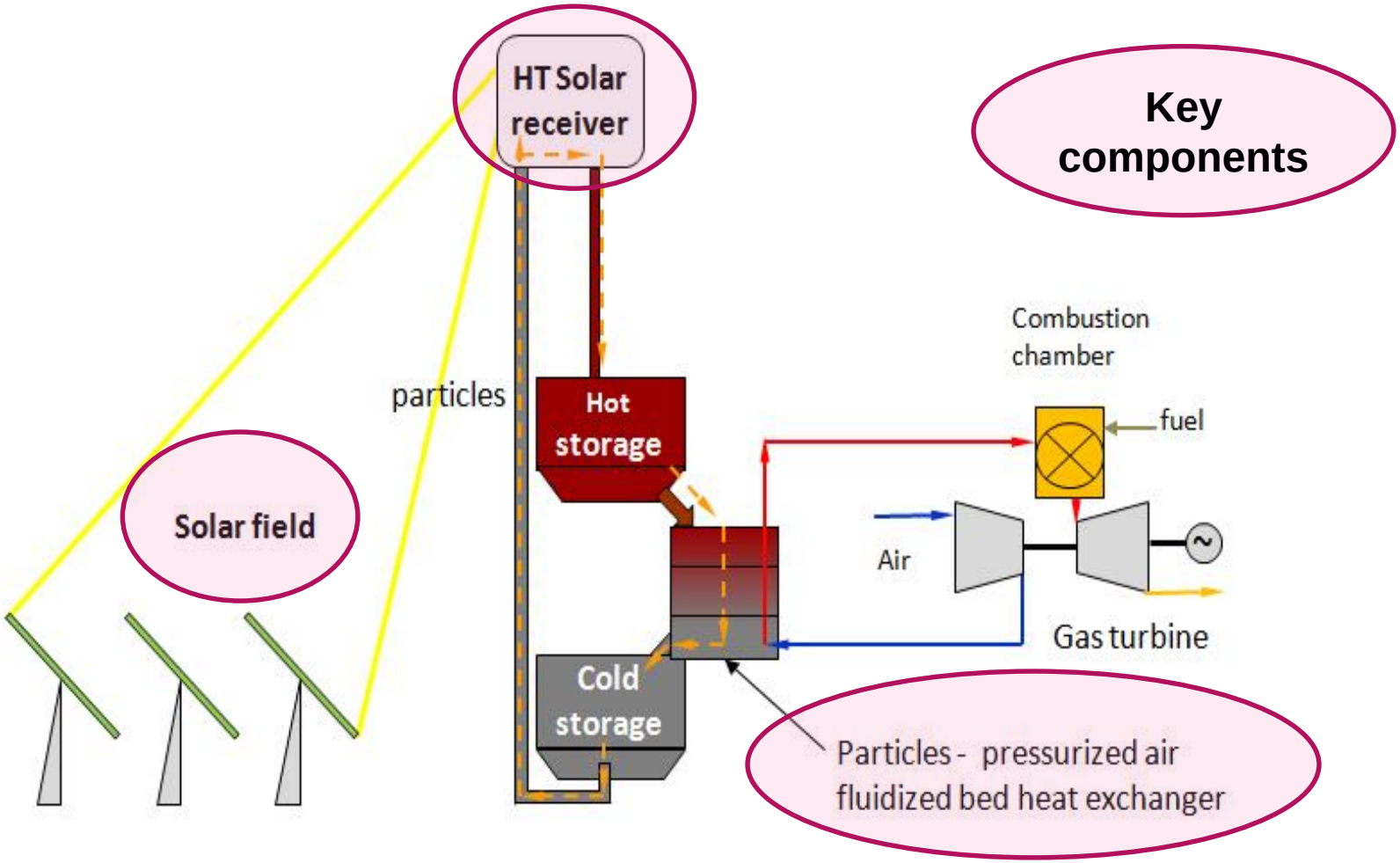
Project objectives

- To demonstrate at industrial pilot scale (TRL5) the validity of the particle-in-tube concept atop the Themis facility solar tower.
- To construct and to test a 4-MWth tubular solar receiver able to heat particles up to 800°C
- To validate the rest of the loop: a two-tank particle heat storage and a particle-to-pressurized air heat exchanger coupled to a 1.2 MWel gas turbine.
- To study the various options for high efficiency cycles
- To design a commercial scale power plant (150 MWel) and to assess the associated costs

Work in progress

Next-CSP project

Project test loop design



Work in progress

Next-CSP project

Key issues

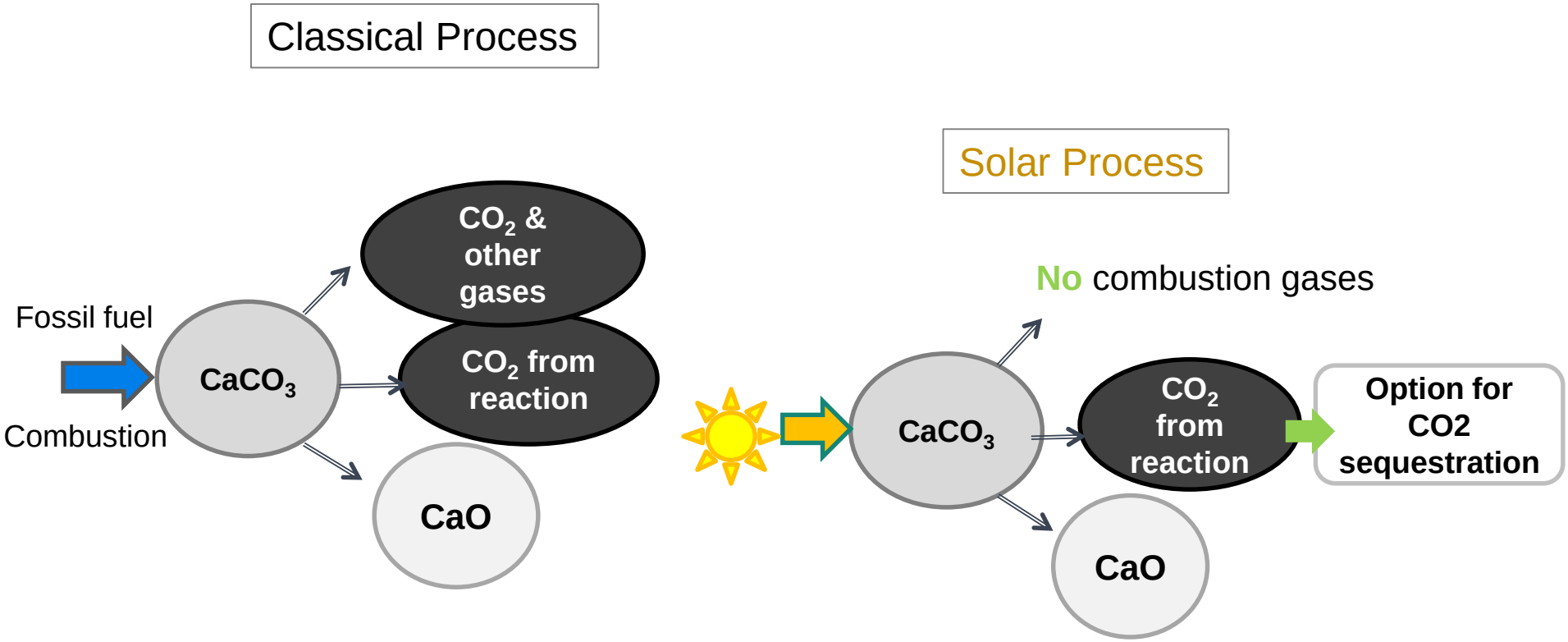
- To control the solar flux distribution on tubes (3m long)
- To increase wall-to-fluidized bed heat transfer coefficient, 2000 $W/m^2.K$ expected
- To control the particle circulation by managing the pressure equilibrium
- To reduce as low as possible the pressure loss in the particle - working fluid heat exchanger

Efficiency of reversible Brayton cycle: $\eta_c = (\lambda-1)/\lambda$ $\lambda = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$ $\gamma = C_p/C_v$

Work in progress

SOLPART project

Application of the concept to reactive particles



List of papers

-FLAMANT G, GAUTHIER D, BENOIT H, SANS J-L, GARCIA R, BOISSIERE B, ANSART R, HEMATI M. Dense suspension of solid particles as a new heat transfer fluid for concentrated solar thermal applications: On-sun proof of concept. Chemical Engineering Science (2013), 102, pp. 567-576.

-BOISSIERE B., ANSART R., GAUTHIER D., FLAMANT G., HEMATI M. Experimental hydrodynamic study of gas-particle dense suspension upward flow for applications as new heat transfer and storage fluid. The Canadian Journal of Chemical Engineering (2015), 93, pp.317-330

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-REYES URRUTIA A., BENOIT H., ZAMBON M., GAUTHIER D., FLAMANT G., MAZZA G. Simulation of the behavior of a dense SiC particle suspension as an energy transporting vector using computational fluid dynamics (CFD). Chemical Engineering Research & Design (2016)106, pp. 141-154. DOI 10.1016 J.CHERD.2015.12.008

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-ANSART R, GARCIA-TRINANES P, BOISSIERE B, BENOIT H, SEVILLE J, SIMONIN O. Dense gas-particle suspension upward flow used as heat transfer fluid in solar receiver: PEPT experiments and 3D numerical simulations. Powder Technology (2017), 307, pp. 126-137.

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