High-temperature sensible thermal energy storage (STES) Thermo-economic assessment for various designs, storage materials and heat transfer fluids

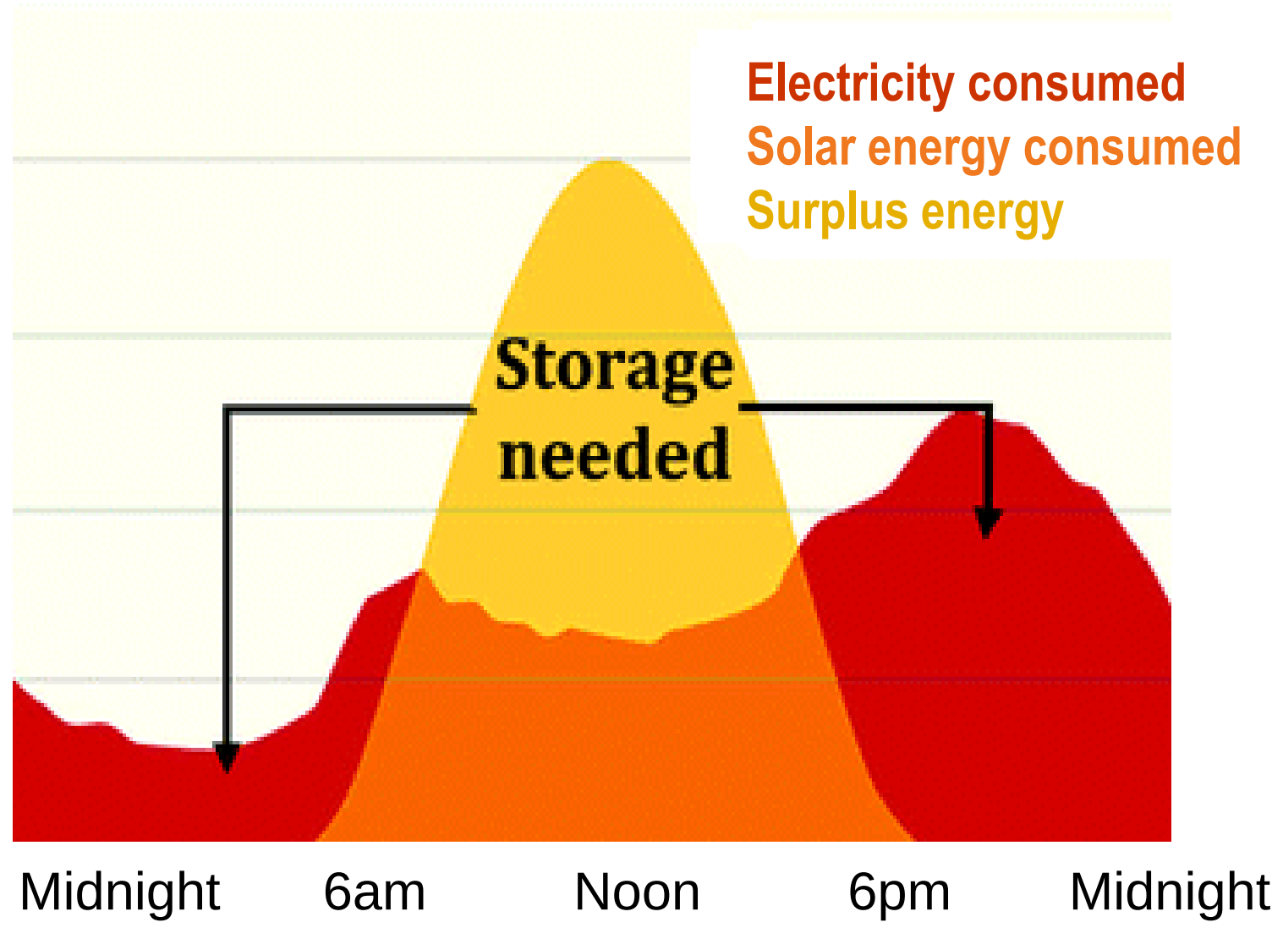
M.B. Mohankumar, Dr.-Ing. S. Unger, Prof. Dr.-Ing. habil. Dr. h. c. Uwe Hampel

Motivation

Increase demand for renewables

Intermittent and volatile power output

Energy storage is vital



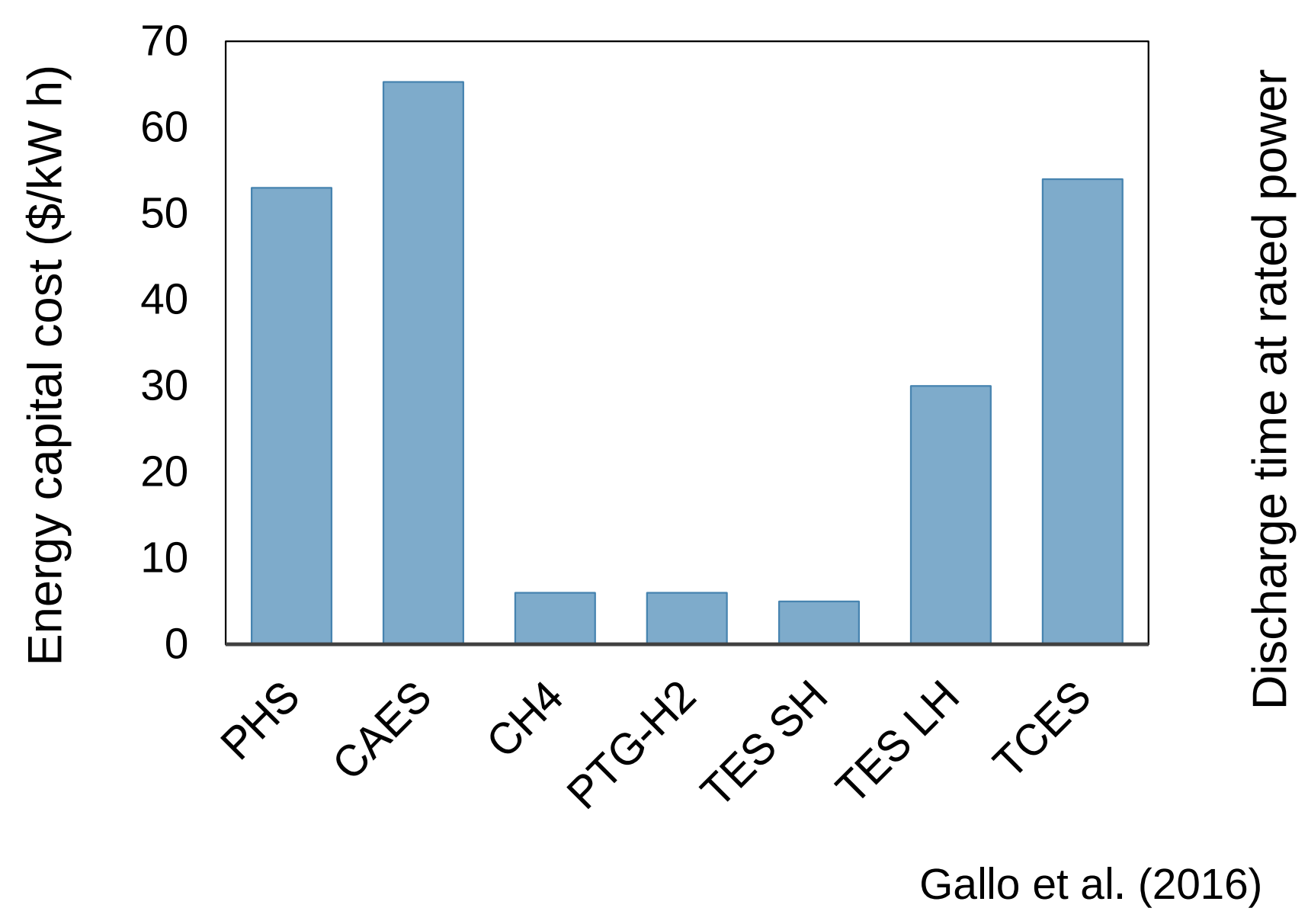
Provides:

- **Grid stability**
- **Energy security**
- **Power balance**
- **Sustainability**

Why Sensible thermal energy storage (STES) ?

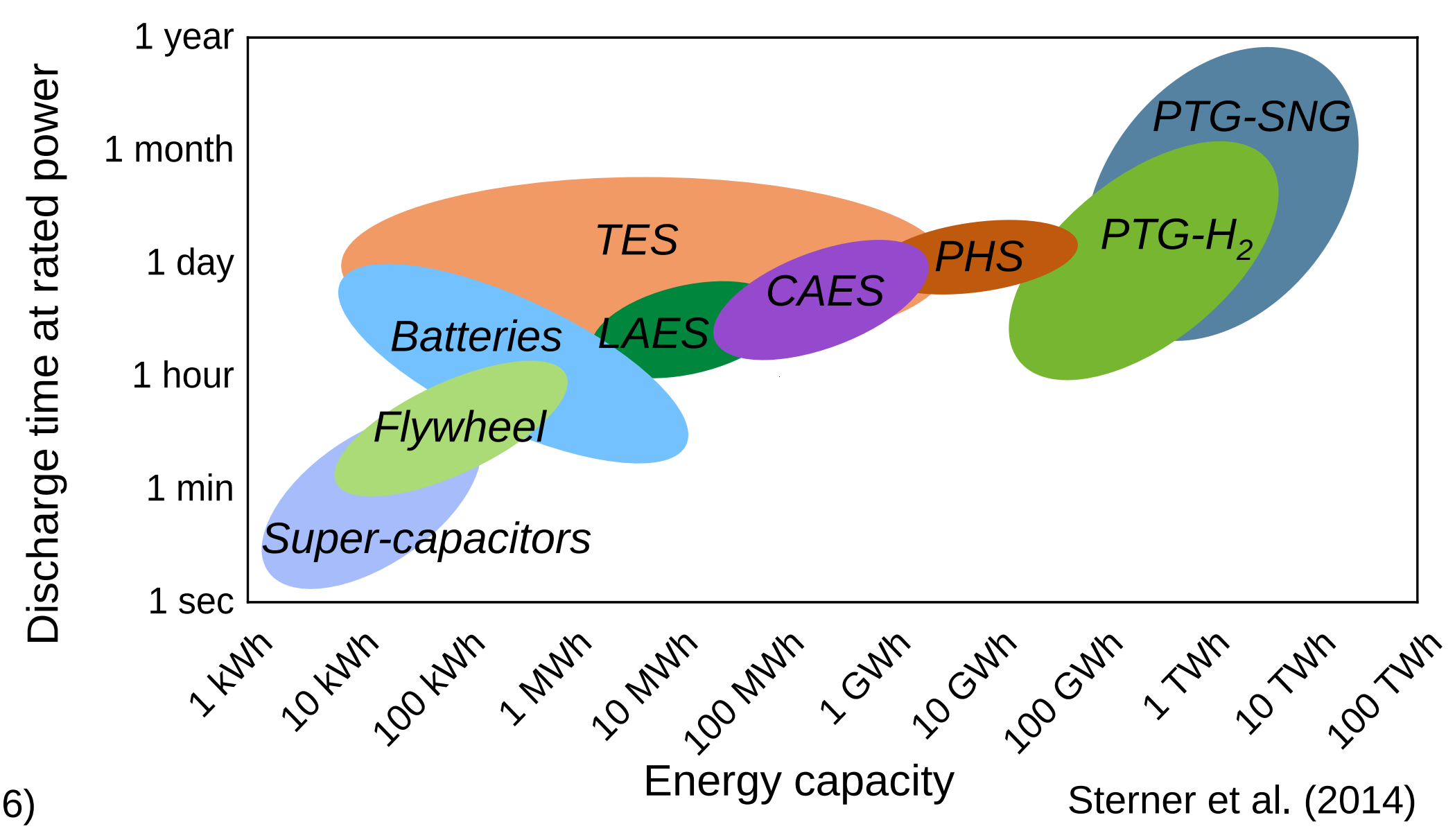
- Simple and Low cost
- Storage durability (from hours to months)
- Energy storage capacity (from kWh to GWh)

Cost comparison of long term energy storage



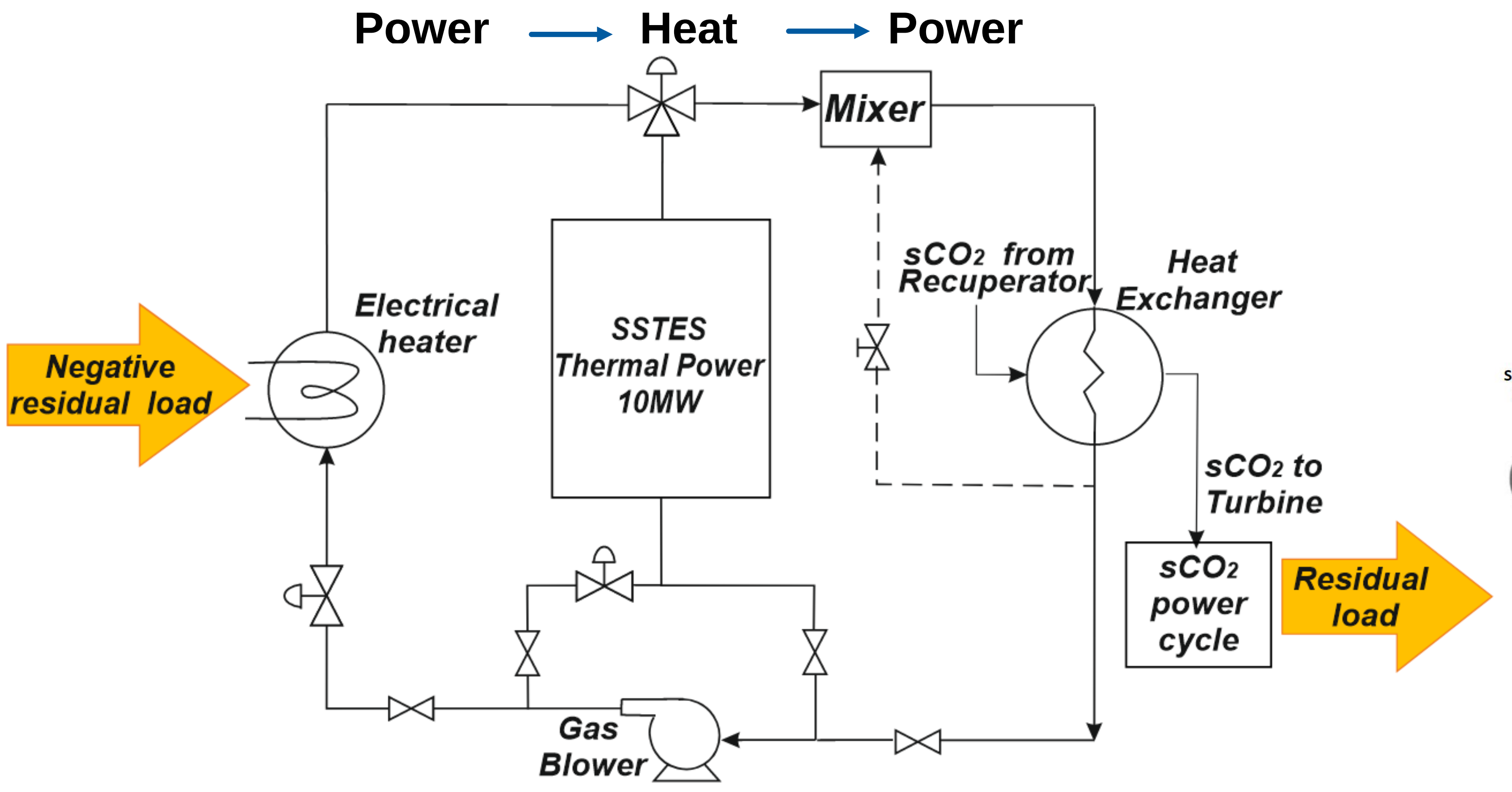
Gallo et al. (2016)

Energy storage capacity



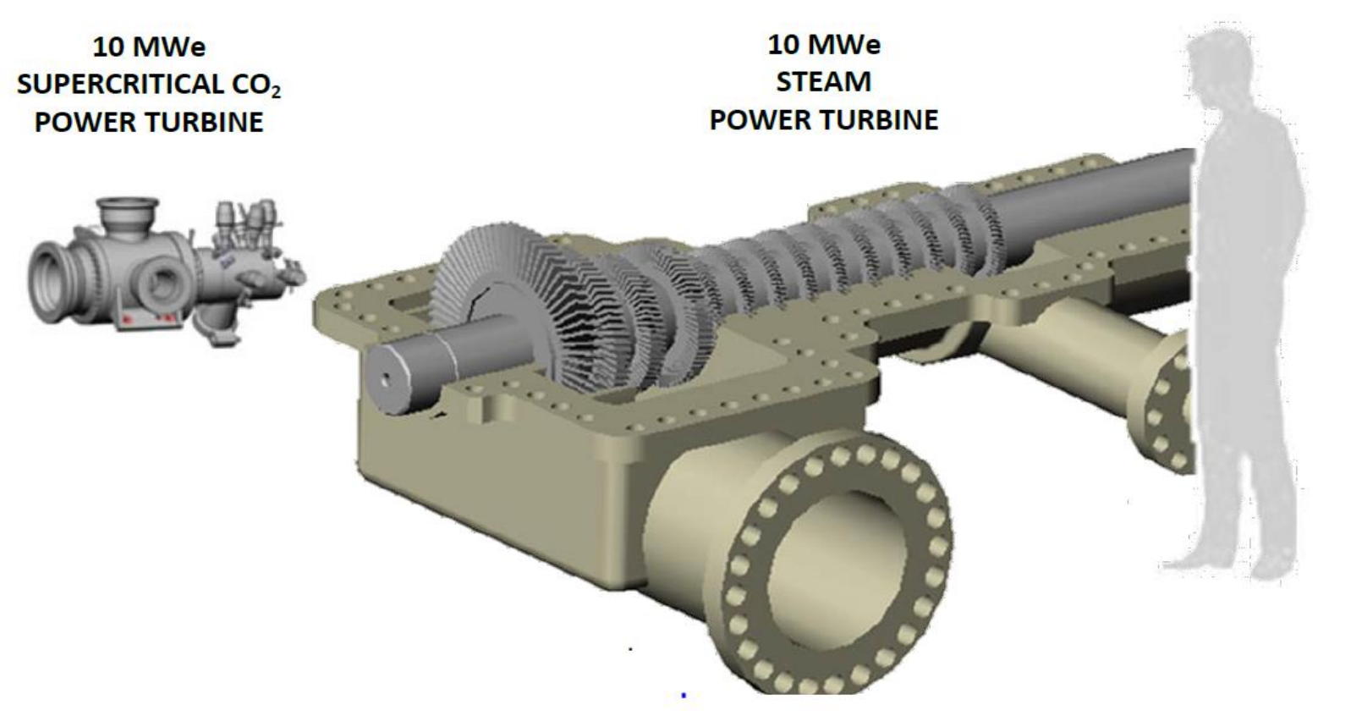
Sterner et al. (2014)

Integration with sCO_2 Power cycle

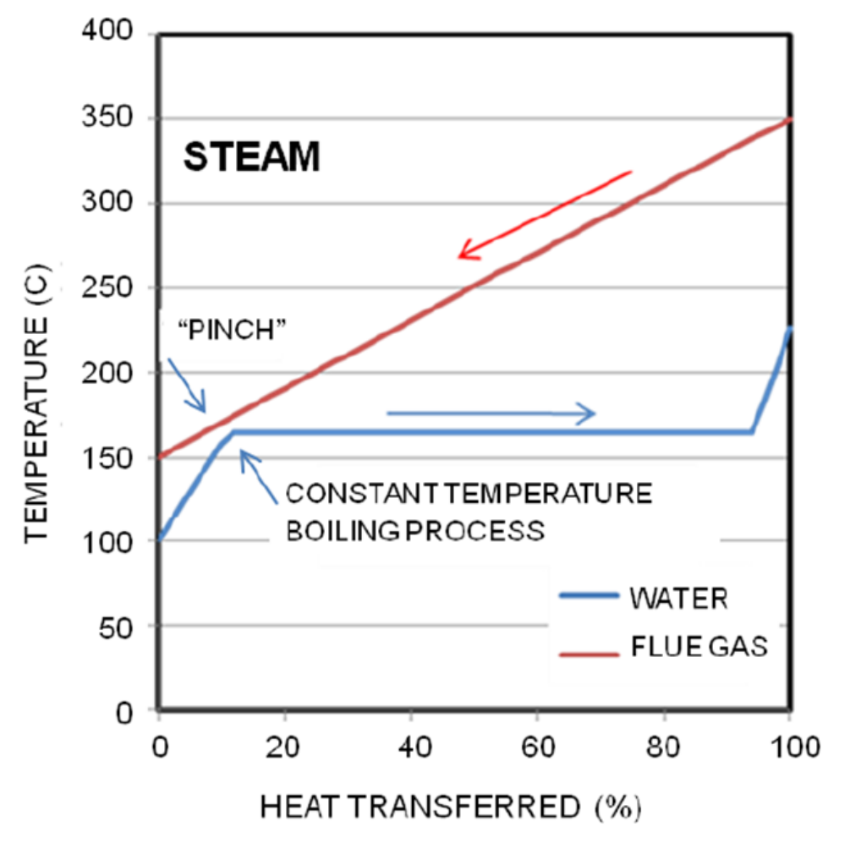


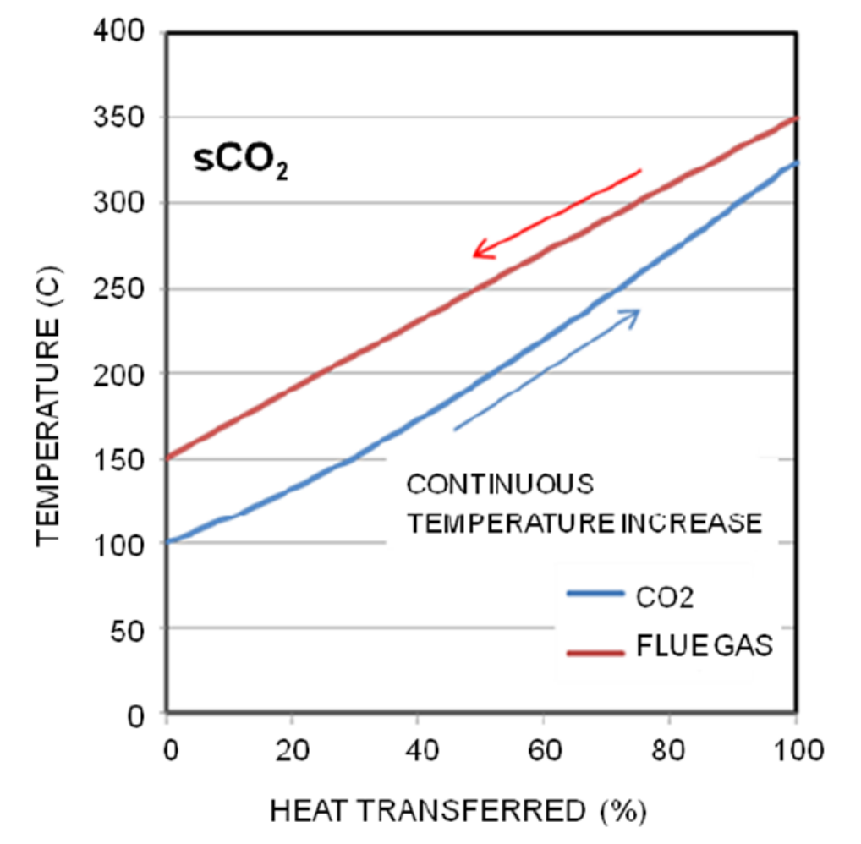
Why sCO_2?

- Acts like gas with density of liquid
- Compactness and low compressor work
- Lower temperature operation (crit. temp.)
- Effectively exchanges heat as there is no occurrence of pinch



Persichilli et al. (2012)





1D Mathematical Model for TES unit

- Heat balance for fluid and solid
- Finite difference Crank-Nicholson dissertation scheme
- Method of lines adopted in MATLAB to solve coupled heat equation

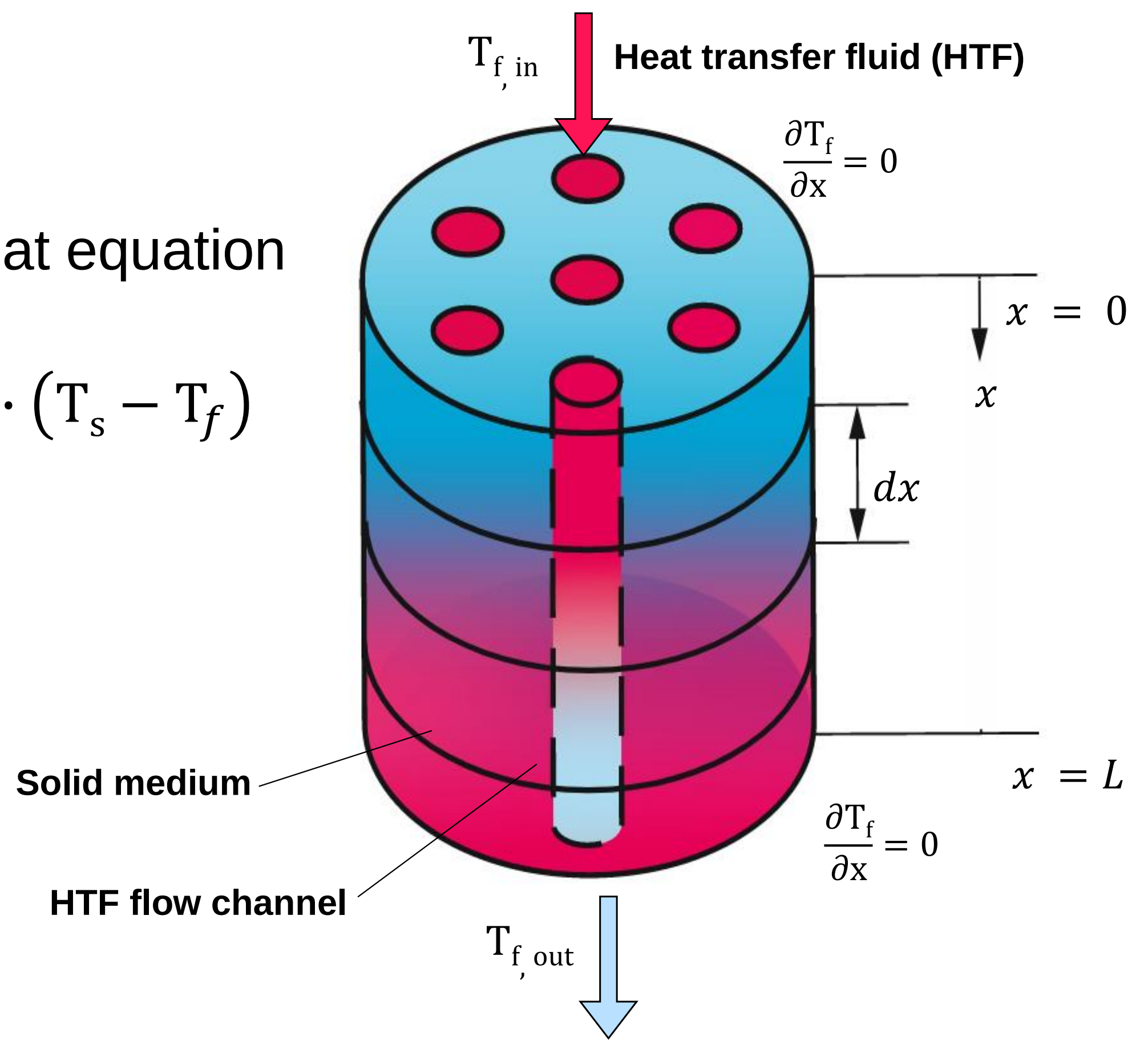
For Fluid: $\varepsilon \cdot (\rho\, c_p)_f \cdot \frac{\partial T_f}{\partial t} + \varepsilon \cdot (\rho\, c_p)_f U_f \frac{\partial T_f}{\partial x} = k_{feff} \cdot \frac{\partial^2 T_f}{\partial x^2} + h_v \cdot (T_s - T_f)$

For Solid: $(1-\varepsilon) \cdot (\rho\, c_p)_f \cdot \frac{\partial T_f}{\partial t} = k_{feff} \cdot \frac{\partial^2 T_s}{\partial x^2} + h_v \cdot (T_f - T_s)$

Solid medium: High temperature ceramic, high temperature concrete, fire bricks, Alferrock and vetrified flyash

Heat transfer fluid: Air, CO_2, Helium, Nitrogen

TES reference design

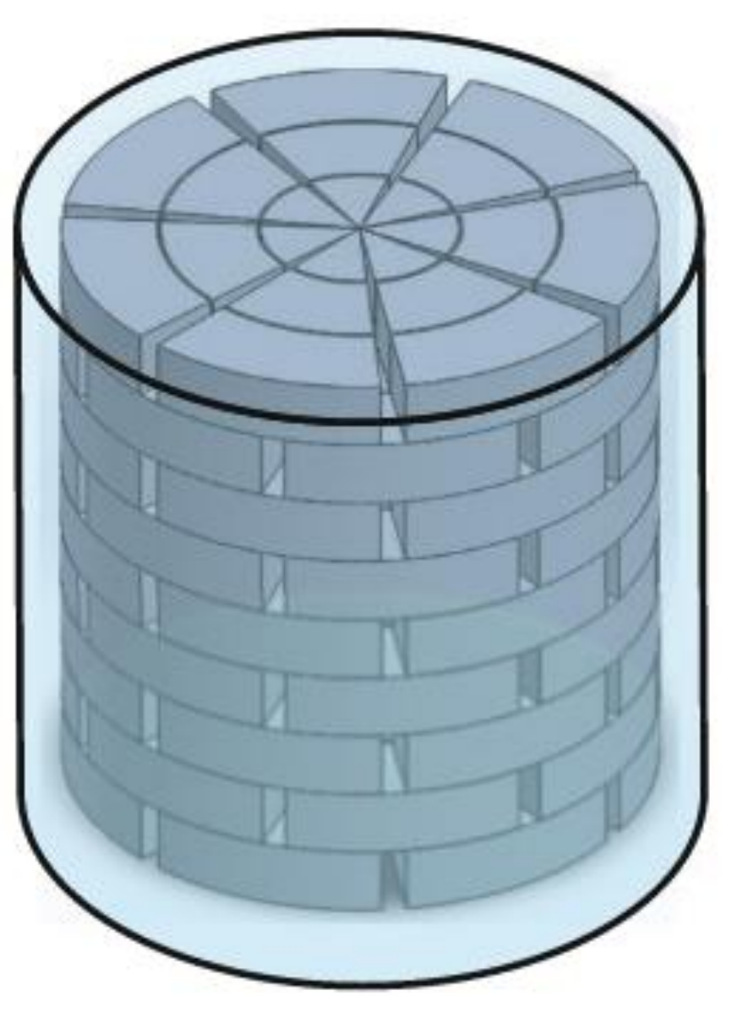


Boundary Conditions

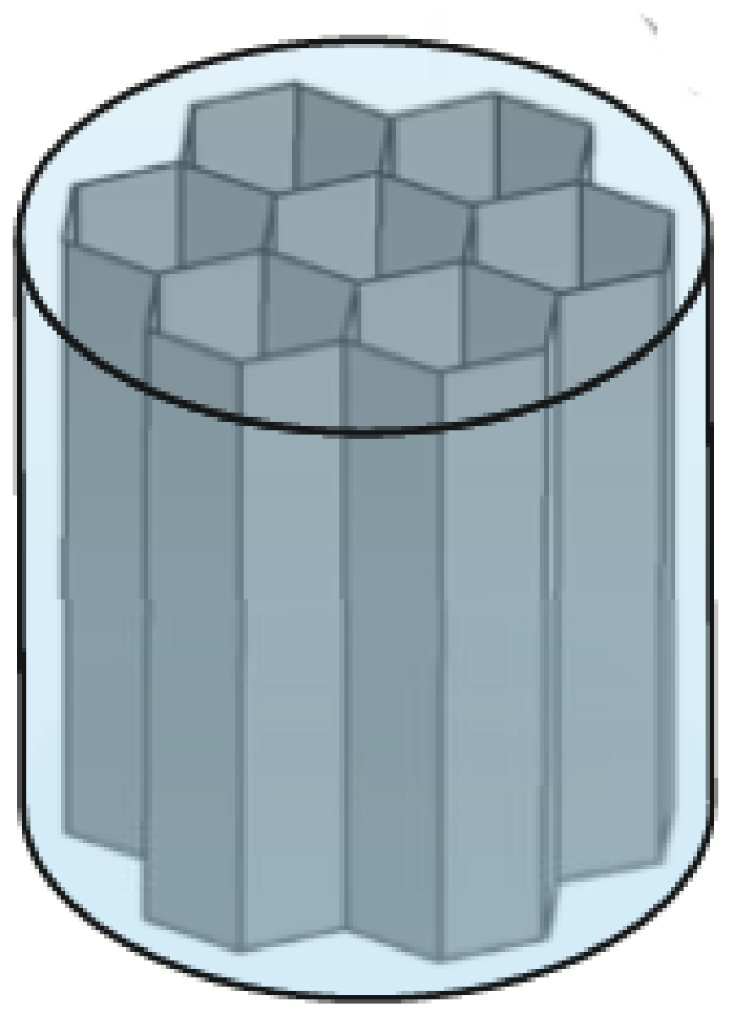
Parameters	Value
Thermal capacity, $[MWh_{th}]$	240
Fluid inlet Temperature $T_{f,\ in}$ [°C]	1000
Initial solid temperature $T_{s,\ in}$ [°C]	400
Fluid outlet temperature $T_{f,\ out}$ [°C]	600
Max solid temperature $T_{s,\ m}$ [°C]	1200
Pressure [bar]	1
Porosity ε	0.4
mass flow rate ṁ, [kg/s]	0.5,1,2,3

Novel TES design approach

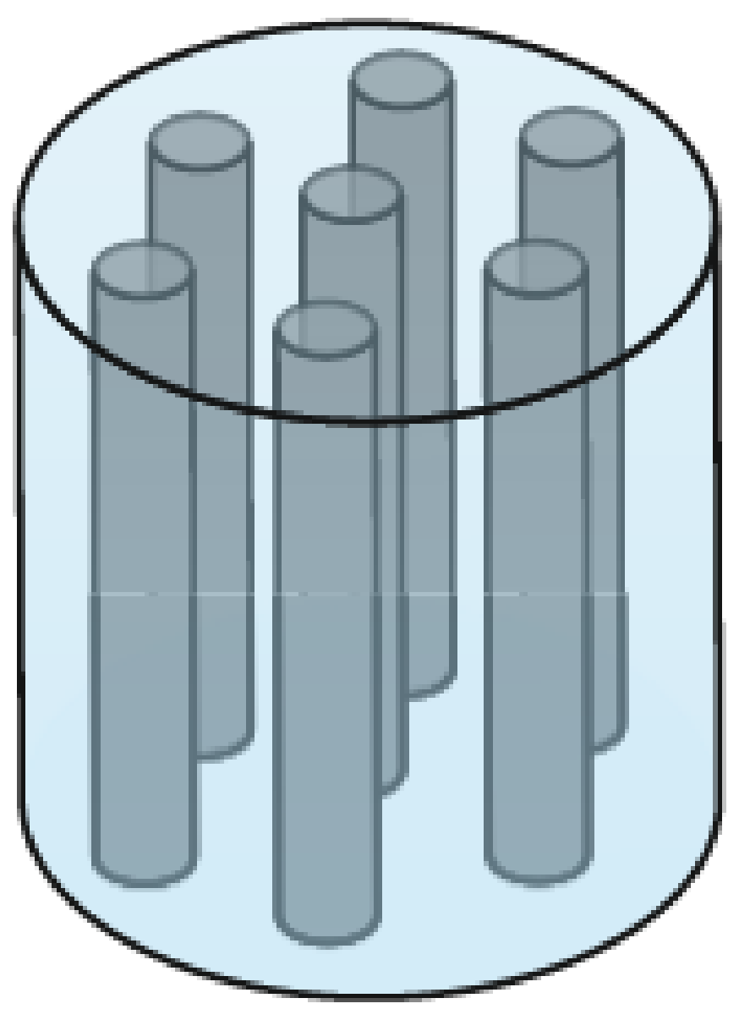
Segregated brick



Honeycomb



Solid rods



Expected outcome

Thermal performance evaluation:

- **Heat transfer fluid and solid medium design**
- **TES unit design**
- **Mass flowrate**
- **Flow geometry**

- **Evaluation of overall thermal efficiency**
- **Outlook on potential design and storage medium**
- **Evaluation and comparison of energy cost in €/MWh_{th}**

Institute of Fluid Dynamics . Experimental Thermal Fluid Dynamics
M. Sc. Malini Bangalore Mohankumar . m.bangalore-mohankumar@hzdr.de · www.hzdr.de