Australian National University

Resistive Thermal Energy Storage an Electricity Storage Alternative for the Australian Grid

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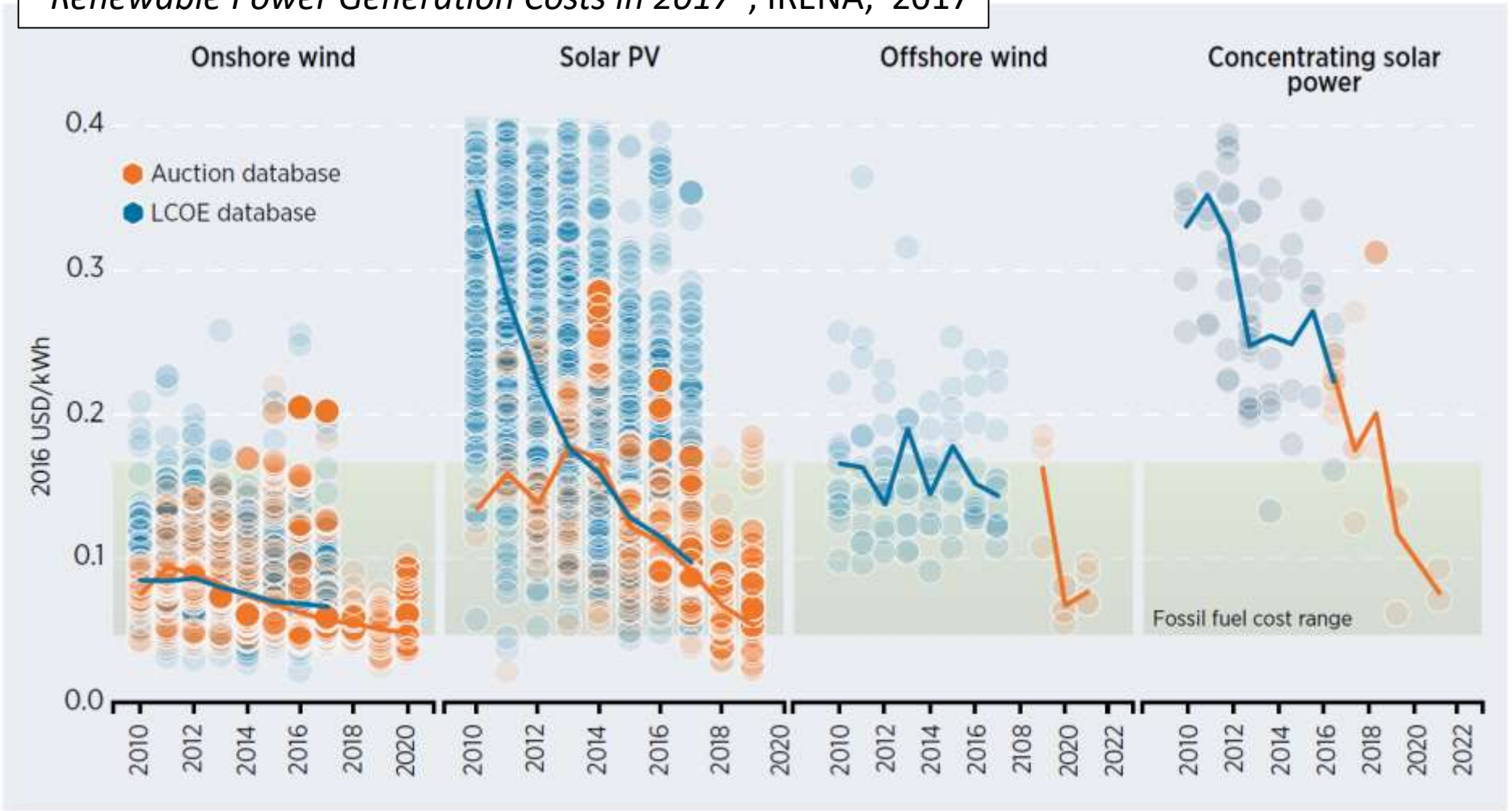
Outline

- Context: Large scale electricity storage
- Resistive Thermal Energy Storage (RTES)
  - Technology
  - Levelised Cost Of Storage (LCOS) benchmark
  - Sensitivity analysis
  - Resistive heater design
- Conclusions and outlook

Context: large scale storage

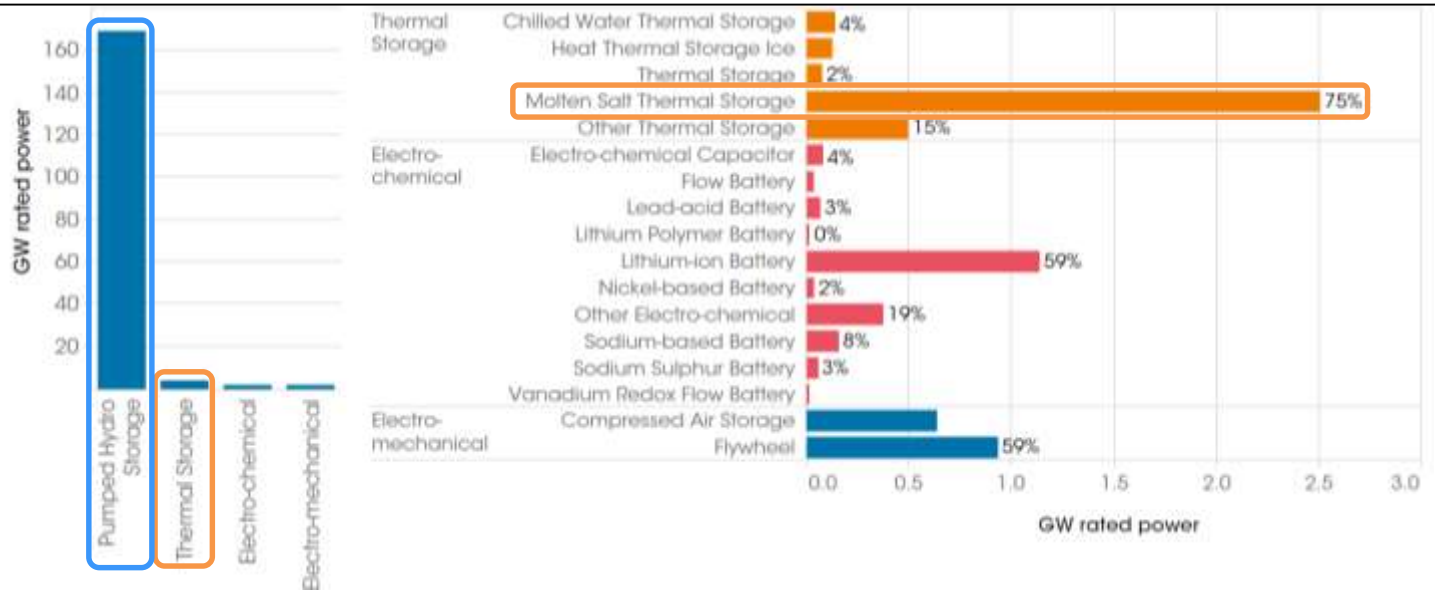
- Incoming cheap renewable energy!

"Renewable Power Generation Costs in 2017", IRENA, 2017



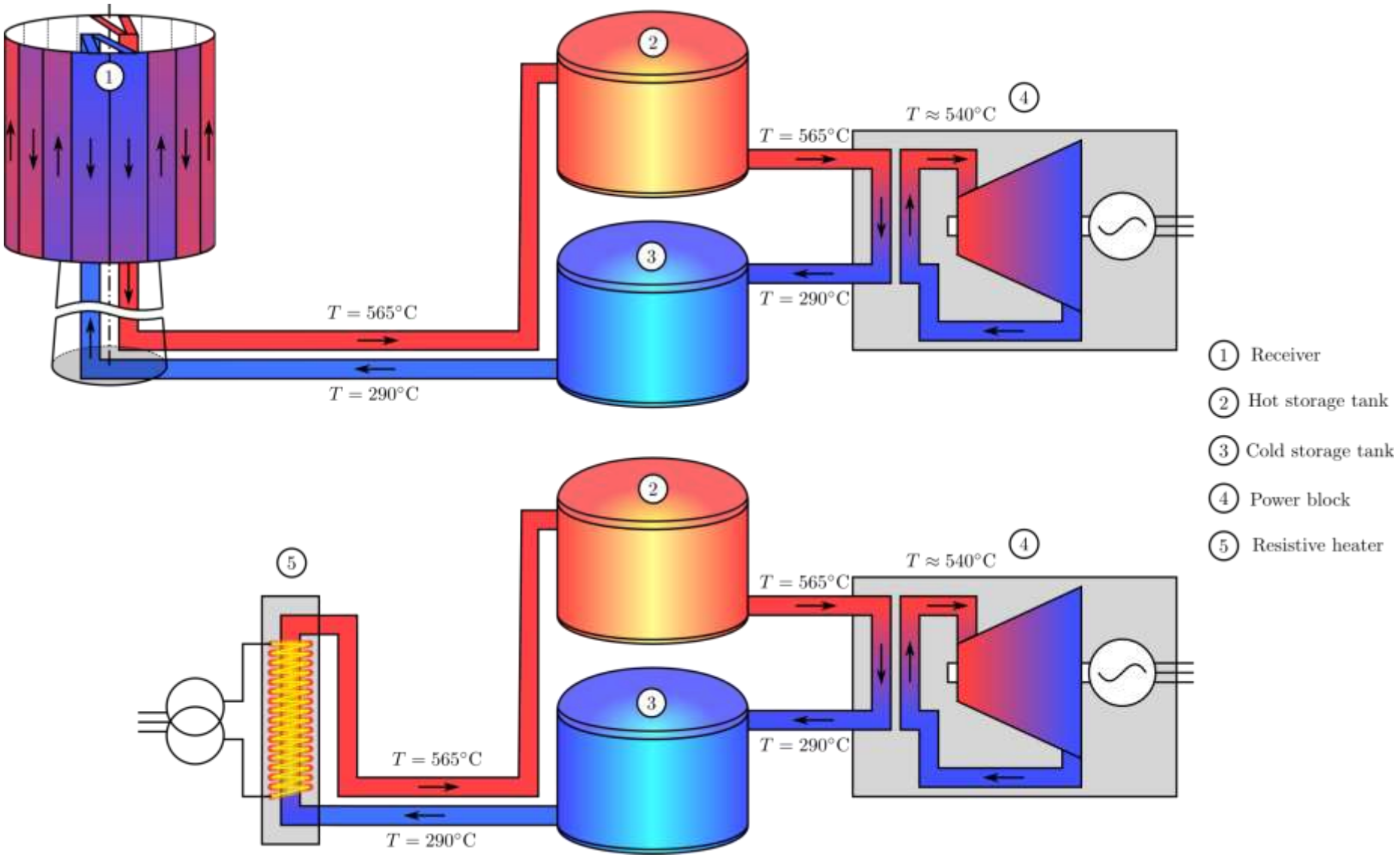
Context: large scale storage

"Electricity Storage and Renewables: Costs and Markets to 2030", IRENA, 2017



- IRENA, 2017: doubling of VRES penetration
  - Electricity storage grows 155 - 227% from 2017 to 2030
  - 96% Pumped-Hydro Electricity Storage (PHES):
    - Open-loop: 320 plants operational, 167.9 GW, energy capacity unknown.
    - Closed-loop: 2 plants operational, 2.1 GW, 10.8 GWh (DOE database)
  - 1.9% Thermal Energy Storage (TES):
    - 75% of Molten Salt thermal Storage (CSP plants): 2.5 GW, 17.5 GWh (DOE database)
  - 1.1% Batteries:
    - Total capacity: 1.9 GW, ~3.5 GWh (DOE database)

RTES: Technology



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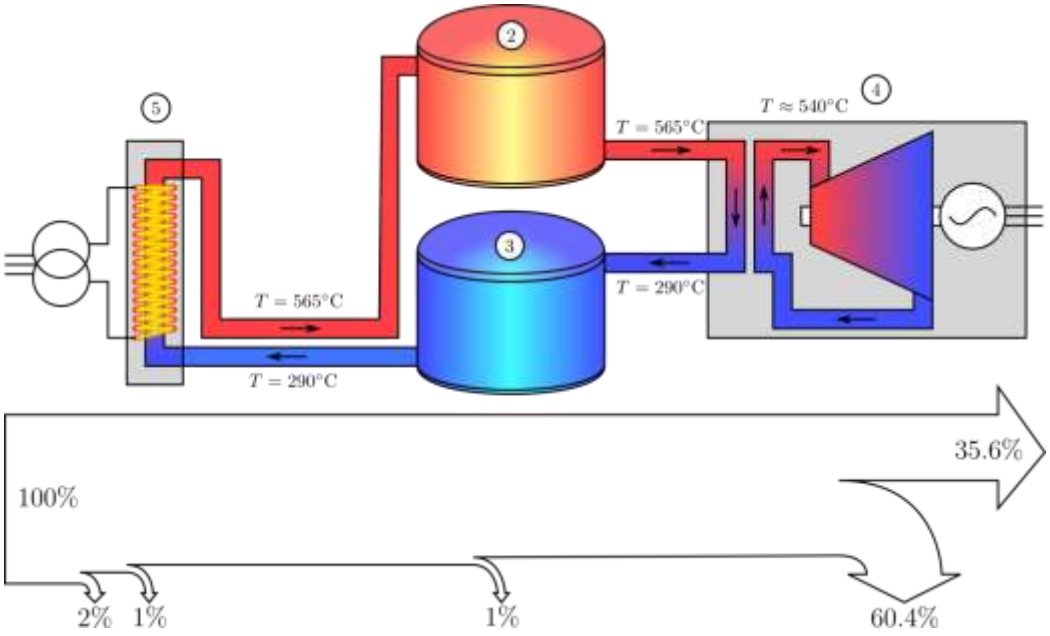
RTES: Technology

- Characteristics:
  - Turbine startup time: ~30 min
  - Charging efficiency: 97%
  - Thermal storage efficiency: 99%
  - Power block net efficiency: 37.1 %
  - Round-trip efficiency: 35.6%
- Mature engineering components:
  - Stainless steel tanks and piping
  - Steam turbine
  - Air-cooled condenser
  - Heat exchanger
- New component:
  - Large scale molten-salt resistive heater

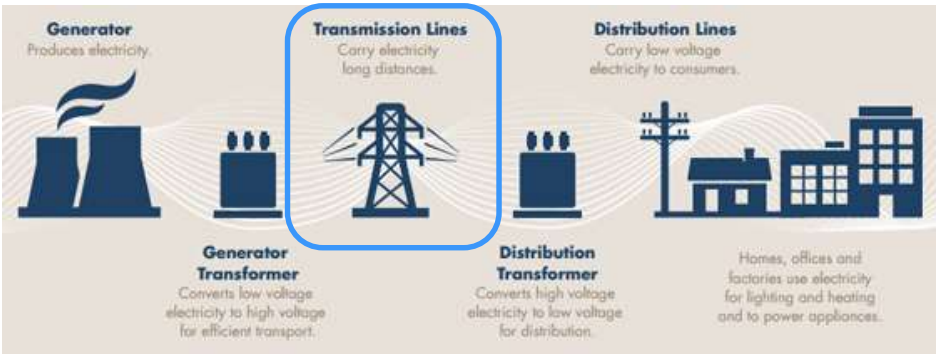


RTES: LCOS benchmark

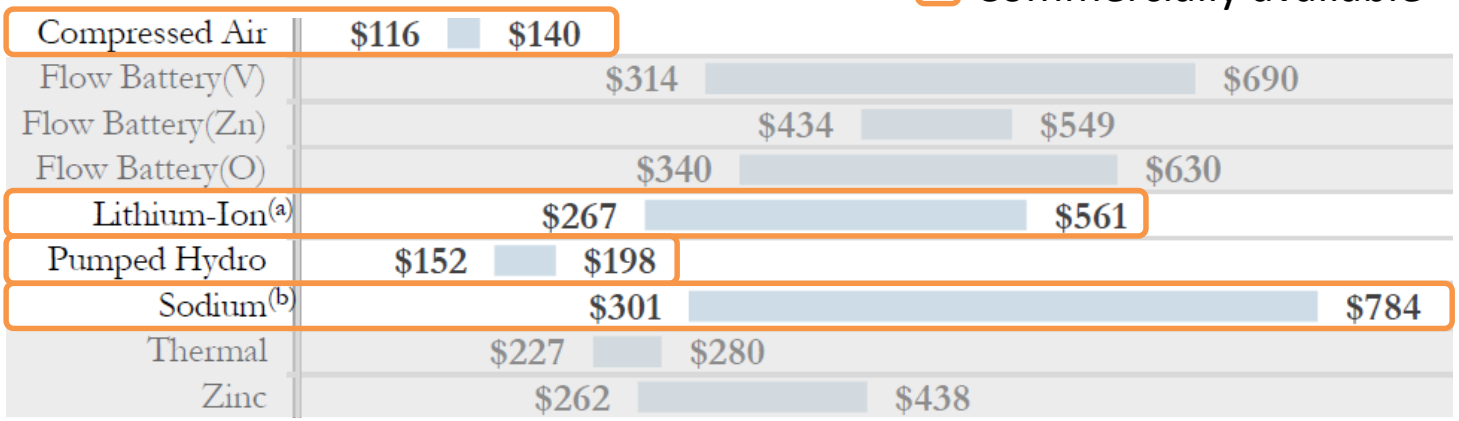
- Benchmark:
  - Lazard Levelised Cost of Storage 2.0 (2016)
- Transmission level:
  - 8 hours of storage
  - 100 MW power output
  - 350 days of operations/year
  - 1 cycle of full discharge/day
  - Cost of electricity **35 USD/MWh**
  - LCOS: ($/kWh$_e$ delivered)

LAZARD'S LEVELIZED COST OF STORAGE—VERSION 2.0

LAZARD



Commercially available

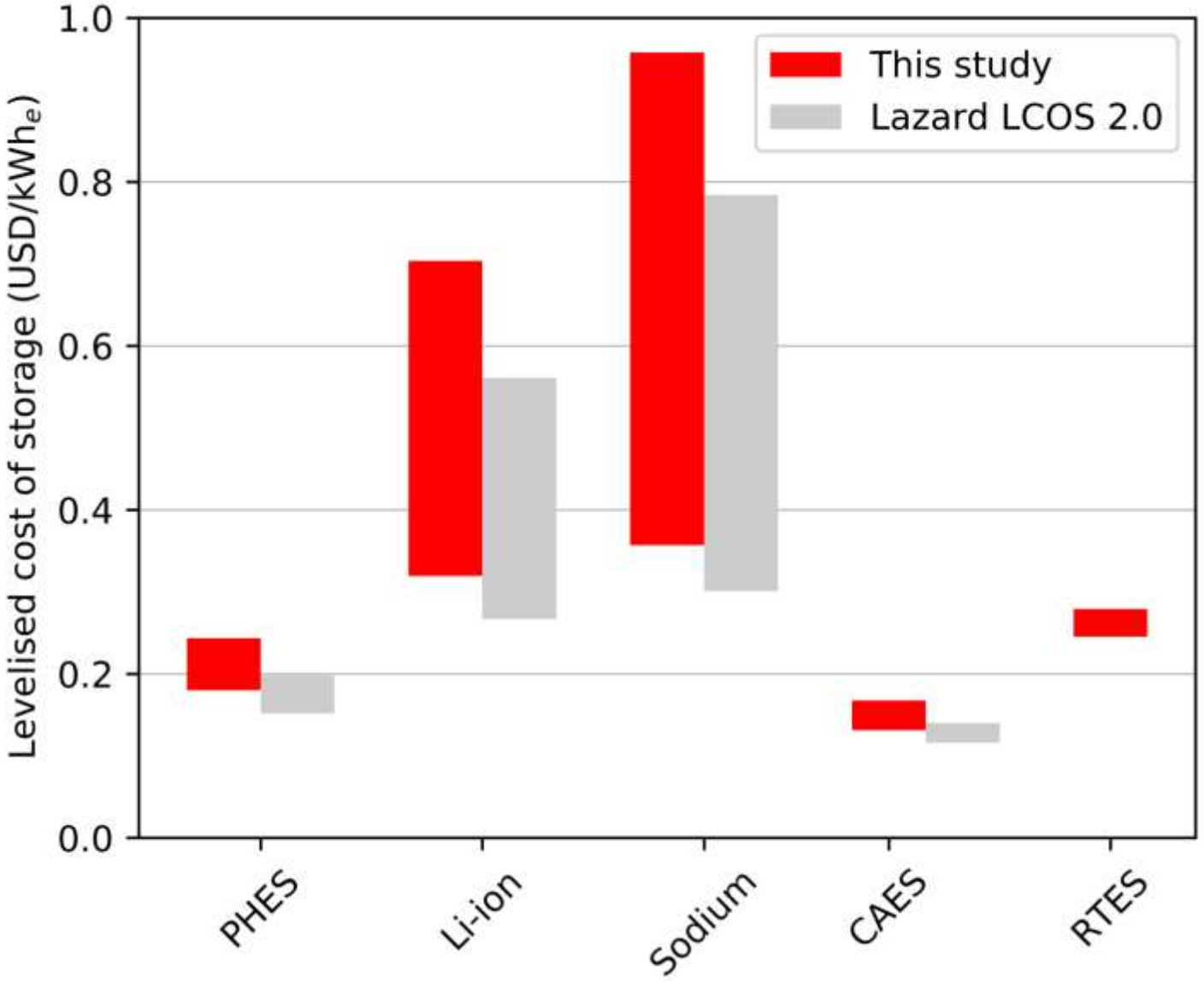


RTES: LCOS benchmark

- RTES costing assumptions:
  - NREL System Advisor Model (SAM) cost breakdown for CST
  - Remove the Capital cost of the heliostat field and tower
  - Keep the full cost of the balance of plant (BOP)
  - 2 cost scenarios for the resistive heater and the power block:
    - High cost: the switch to resistive heating represents a doubling of the cost of the BOP of the reference CST system.
    - Low cost: the switch to resistive heating is negligible when compared with the cost of the BOP of the reference CST system.

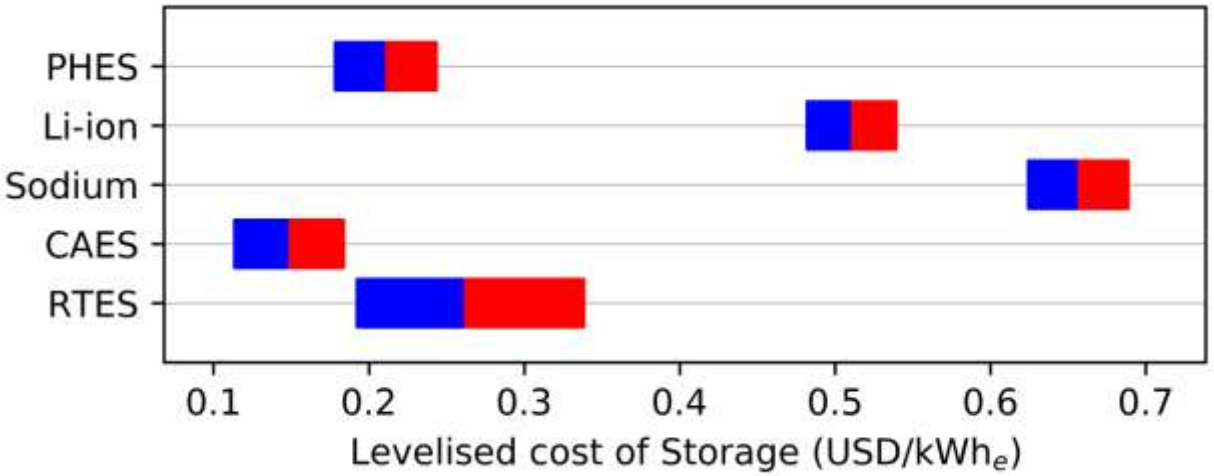
	High cost	Low cost
Cost of thermal storage (USD/kWh$_{th}$)	24	
Cost of BOP (USD/kWh$_e$)	340	
Cost of resistive heating (USD/kWh$_e$)	340	0
Cost of power block (USD/kWh$_e$)	1100	1000
EPC and owner cost ratio	0.13	

RTES: LCOS benchmark

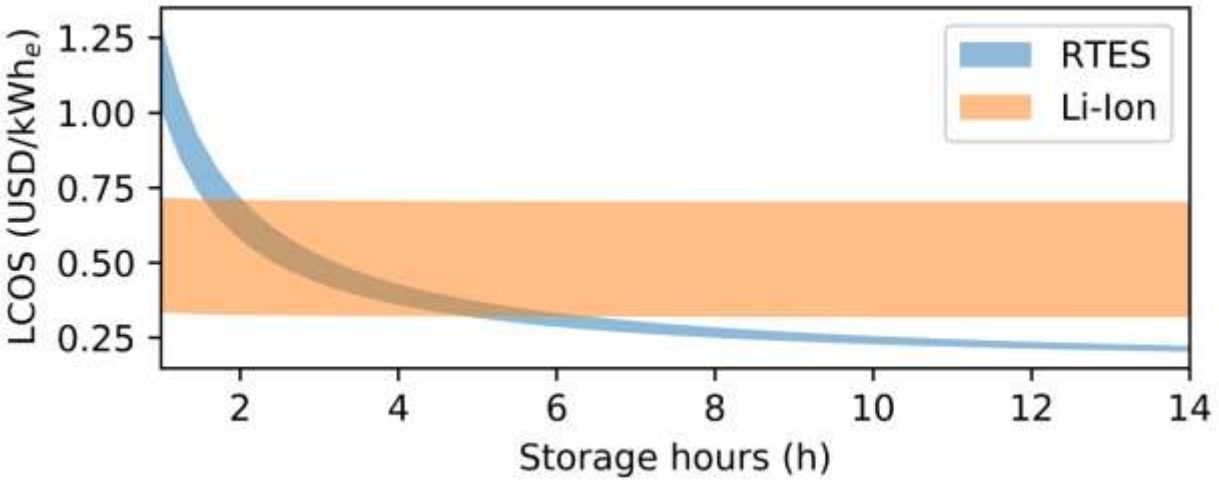


RTES: Sensitivity analysis

- Cost of electricity: 8.8 – 61 USD/MWh



- Storage volumes:1 to 14 hours (100 MWe)



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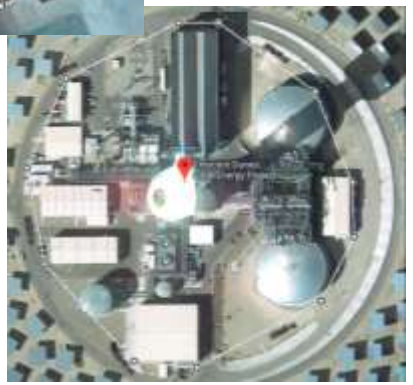
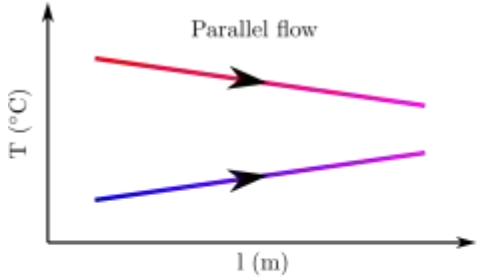
Conclusions and outlook

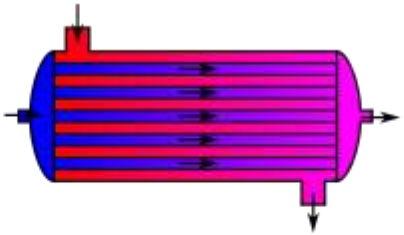
- Preliminary and conservative cost estimations look very promising
- Aspects not considered yet:
  - Arbitrage:
    - Start-up time of the steam turbine is ~30 min with the current technology
    - Power regulation on both charge and discharge
  - Very small footprint and site independent:
    - Low project risks
    - Low environmental impacts
    - Transmission loss is greatly reduced
    - Can be installed at the substation level for local grids
  - Life cycle potential:
    - Solar salt is a fertiliser at the end of the plant life
    - Most of the plant is steel and can be recycled

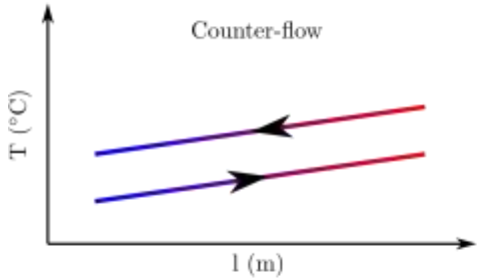


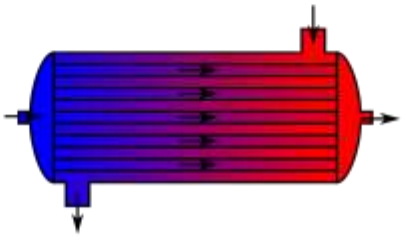
RTES: resistive heater design

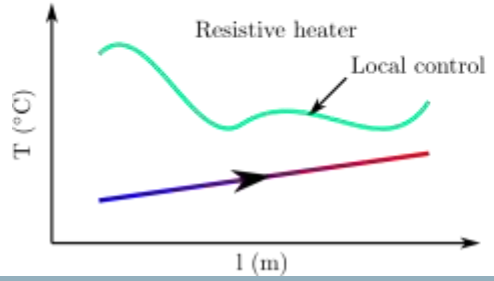
- Develop preliminary designs:
  - Molten-salt film temperature < 595°C
  - Flow velocity < 3 m/s
  - Operation range from 290°C to 565°C

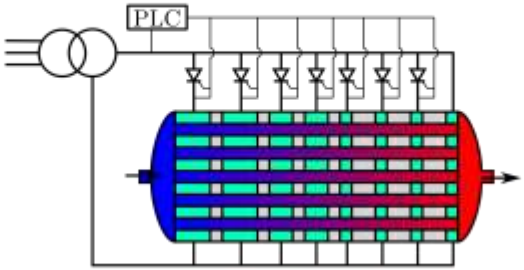


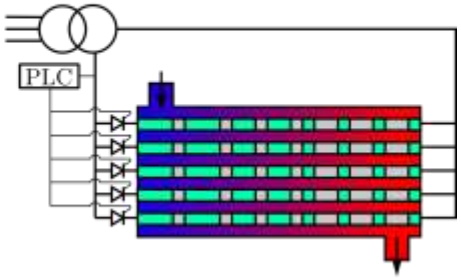












Resistive heater size depends on charging power required

Conclusions and outlook

- Refine costing and preliminary design:
  - Assess the cost reductions compared to the CST system such as: BOP, resistive heater, O&M, turbine size.
- Integration with CST:
  - Oversized storage with resistive charger
  - Compare the charging cost with CST, grid, PV and wind.
- System integration case studies including grid dynamics:
  - Electricity pricing variability
  - Isolated grid with high VRE penetration
- Progress in high-temperature (> 700°C) storage
  - More efficient generation using sCO_2 Brayton cycle: from 37% to 50% power block efficiency.
  - Higher storage density and lower costs

Thank you

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Annex: financial parameters

Technical Operating Parameters and Specifications	Value_orig
Design Storage Capacity (kWh-e)	800000
Design Power Output (kW-e)	100000
Storage Hours (h)	8
Days of Operation in a year	350
Annual Storage Capacity	280000000
Reference year	2017
Assumed start-up year	2020
Basis year	2015
Plant life (years)	20
Analysis period (years)	20
Depreciation Schedule Length (years)	20
Discount Rate	8.00%
Debt period (years)	20
Salvage value (% of total capital investment)	10.00%
Inflation rate (%)	1.90%
After-tax Real IRR (%)	0.00%
Taxes	38.90%
Site Prep	0.00%
Services	18.00%
Contingencies and contractor fee	0.00%
Land Cost	2.00%
Startup cost	10.00%
Number of operators	4
Annual Wages	139000
Insurance	2.00%
OandM	1.50%
Electricity cost per kWh	0.035