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SUSTAINABLE PLACES 2022

Innovative energy storage system based on compressed heat: from design to experimental validation

CHESTER

Compressed Heat Energy Storage for Energy from Renewable sources

José Luis Corrales Ciganda
Maider Epelde Agirre
Felipe Trebilcock Kelly

Nice / Online

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Index

THE CHESTER project and the consortium

Objectives

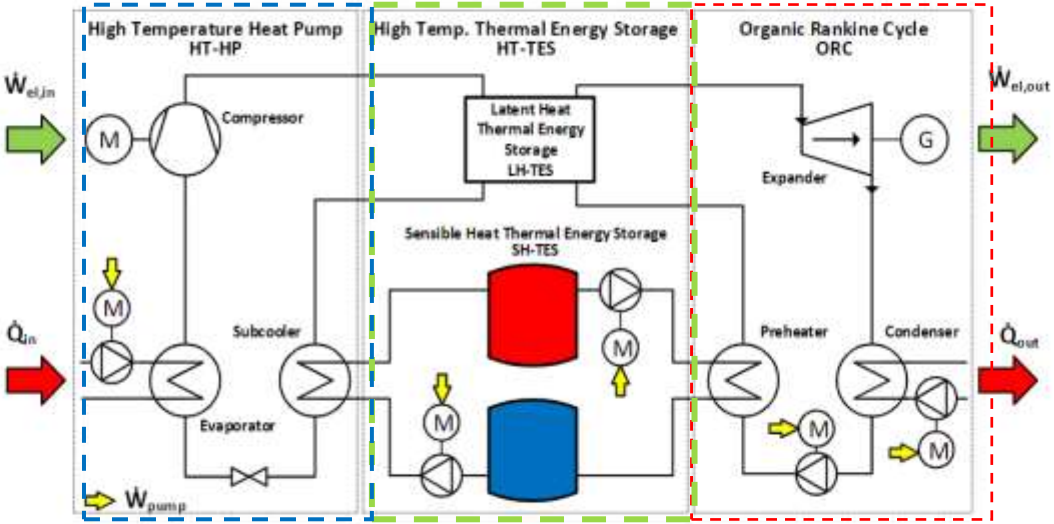
- I) Design and experimental test of a CHESTER (Compressed Heat Energy STorage for Energy from Renewable Sources) system
- II) Study integration case studies for Renewable Energy System
- III) Develop an energy management tool for the integration into existing grids
- IV) Develop business cases and an explotaiton roadmap for the technology

The CHESTER concept (a Pumped Thermal Energy System or PTES)

1) HTHP cycle
(Heat Upgrade/charge)

2) Thermal Energy Storage

3) ORC cycle
(Power Production/discharge)



Advantages over other Energy Storage Systems

- No geographical constrains
- Low temperature heat recovery (waste heat, geothermal, solar heat..) increases round trip efficiency
- High flexibility with regards to energy sources and sinks use

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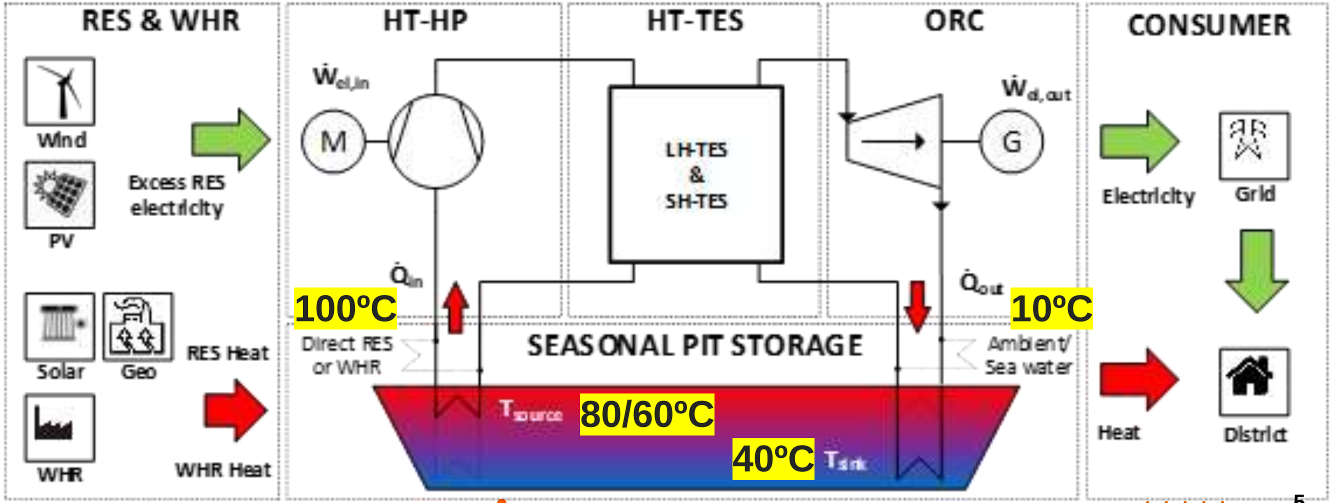
Operation modes and evaluated scenarios [1]

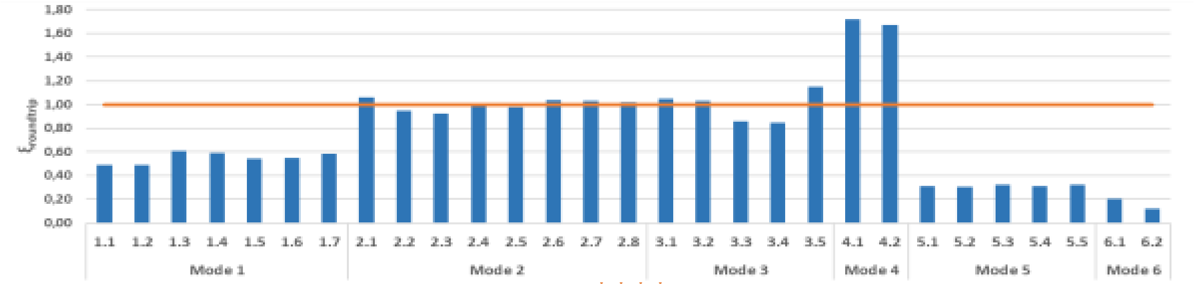
Season	Available energy			Energy Demand			Operating strategy
	PV	Solar	Wind	Heat	Elec Power	Re-charge*	
Summer	High	High	Medium	Low	High	Medium	Storage of electric energy (mainly).
Winter	Low	Low	High	High	High	---	Heat and electricity. Can provide domestic heat.
Transition	Medium	Medium	Medium	Medium	High	Low	Heat and/or electricity. *Re-charge of pit storage.

	T_{source}	T_{sink}	$\dot{W}_{el,in}$	$\dot{W}_{el,out}$
	ºC	ºC	MWel	MWel
Mode 1	80	40	1	0.66
Mode 2	80	10	1	1
Mode 3	100	40	1	1
Mode 4	100	10	1	1.5
Mode 5	60	60	1	0.3
Mode 6	40	60	1	0.2



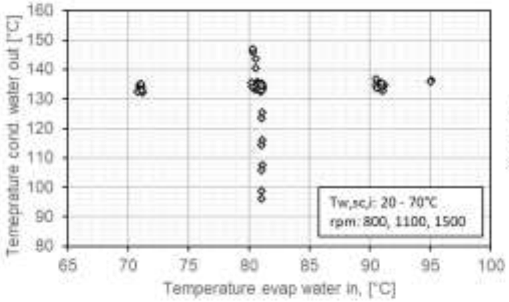
Conclussions from the numerical studies [1]

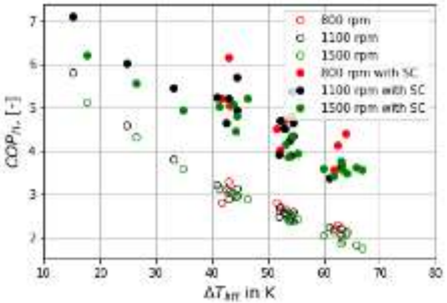
- **Heat source** should provide hot water **between 40-60ºC up to 100ºC**. **Heat sink** system must absorb heat from the ORC's condenser at a temperature **between 60ºC to 10ºC**.
- Set-up should be able to provide the **possibility to evaluate different capacities and level of charge** for the LH-TES and the SH-TES (**independent control of heating sources and sinks**)
- **HTHP and ORC systems, must be able to operate in part load** conditions in order to achieve a full validation of the charging and discharging procedures of the CHEST system.
- **Environmentally friendly refrigerants should be used** (in study, Butene and R1233zd(E)). Other promising refrigerants: R1224yd and R1336mzz(E) (adequate when **considering a PCM melting temperature of 133ºC** and for small-scale compressors and/or expanders).



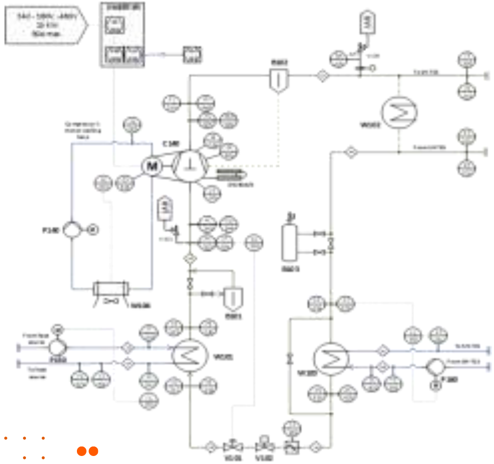
System component I) High Temperature Heat Pump , HTHP

- **Experimentally validated (Q_H in range 9-40kW)**
  - •Variable compressor speeds (800-1500 rpm)
  - •Heat source (wáter) inlet T: 70 - 100°C
  - •Heat sink (wáter) outlet T : 100 - 150°C





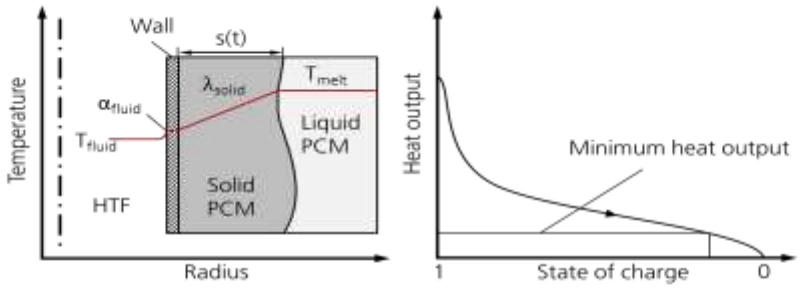
- First experimental tests for compressor with R-1233zdE
- COP_H in range 3-5 for Dtlif in range 20-60 K
- Good compressor efficiencies and stable operation



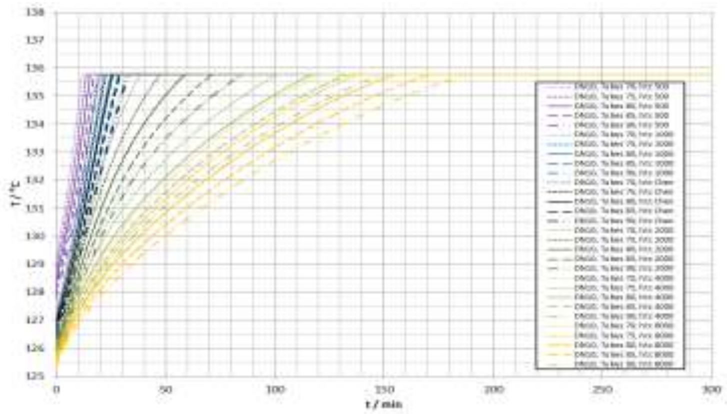
COMPONENTS	
Compressor	Viking HeatEngines Pistón, HBC 511 511cc
Evaporator	SWEP V200THx70
Condenser	SWEP B320HTLx100
Subcooler	B86Hx50
Refrigerant	**R-1233zdE (HFCO)**
Exp valve	Siemens MVL661.15-1.0

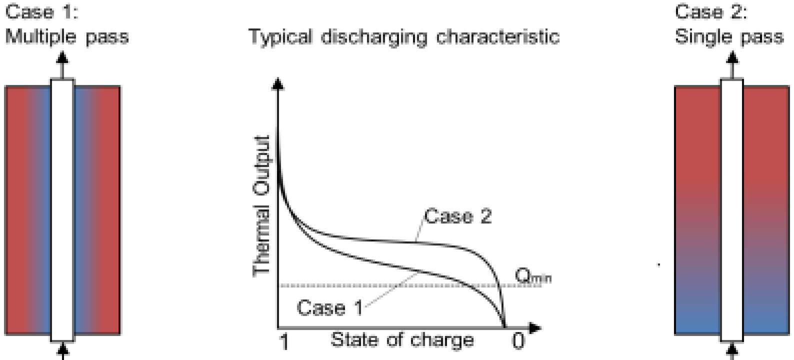
System component II) The PCM Thermal Energy Storage (TES)

- **LH-TES: design optimized with thermodynamic model**
  - PCM: KNO_3 – $LiNO_3$ / Fin: Al6060 / Tube: 16Mo3
  - Eutectic-Mixture PCM with melting temperature 133 ºC
  - Sim. Parameter: Nr of heat exchanger tubes and diameter
  - Compared 4 different fin designs



- **SH-TES: Taylor made design**
  - Charging time used as design criteria
  - Designed for 4 hours charging time
  - minimum volume of 1.667 m³ per single tank



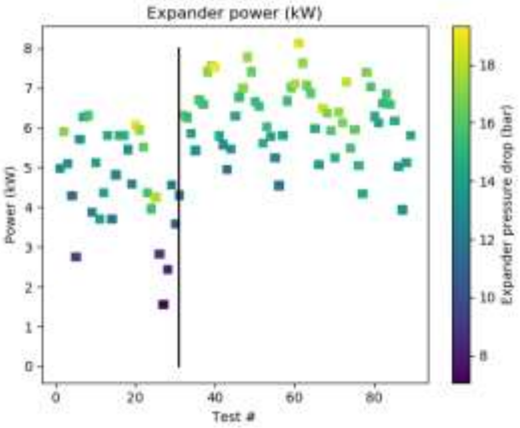


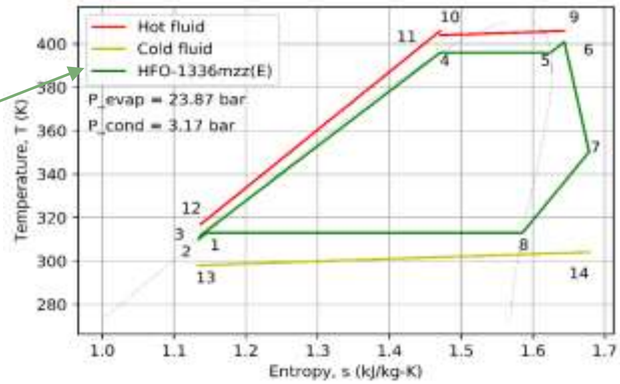
System component III) The ORC System [2]

- **Refrigerant selection based on simulated performance**
  - DR12 (R-1336mzz(E)) is the selected refrigerant
  - Optimized performance for 133ºC source heat temperature

- **Viking Heat Engines compressor selected**
  - Pistón expander with 15.5 kW_{el} nominal power output
  - Good part load operation and able to work with HFO
  - Tested with 4-9 kW_{el} el for ΔP between 12-19 bar

Refrigerant	ΔP (bar)	Power (Relative to R245fa)
R1234ze(Z)	18.79	1.08
R124	31.46	1.51
R236ea	22.03	1.23
R245fa	18.07	1
R600	20.04	1.12
R600a	25.36	1.23
RE 245cb2	20.53	1.32
DR-12	20.95	1.42
HFO-1336mzz(Z)	10.41	1.08
R1233zd(E)	14.67	0.51
R1234yf	**	0.74





CHESTER Prototype: The final experimental set up [2]

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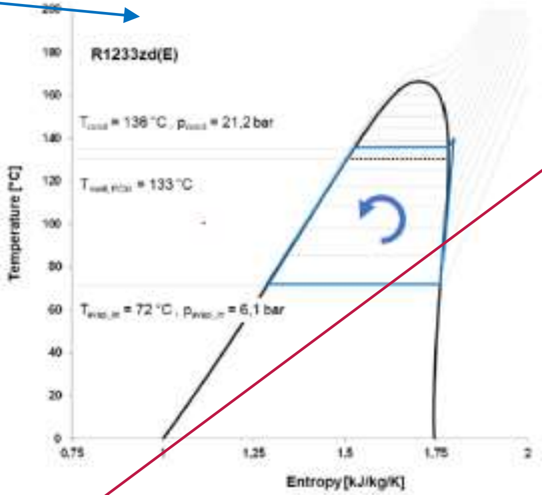
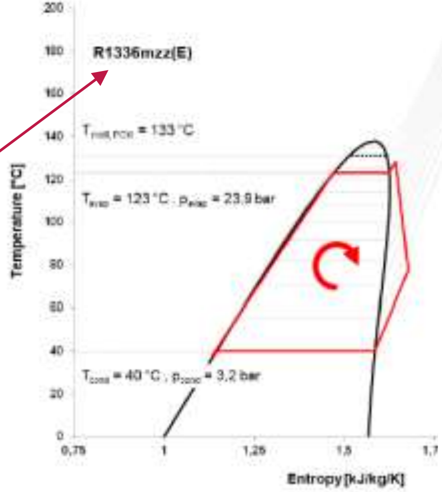
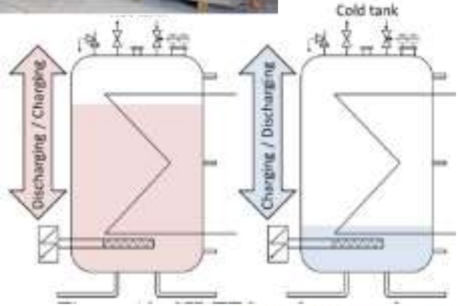
HTHP





SH-TES



ORC

LH – TES properties	
Storage	Circa 160 kWh
HX-Config.	Vertical tuve pairs
Eff tuve length	3 m
PCM mass	Circa 4400 kg

LH-TES

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CHESTER Prototype: first full cycle testing (ongoing)

DLR

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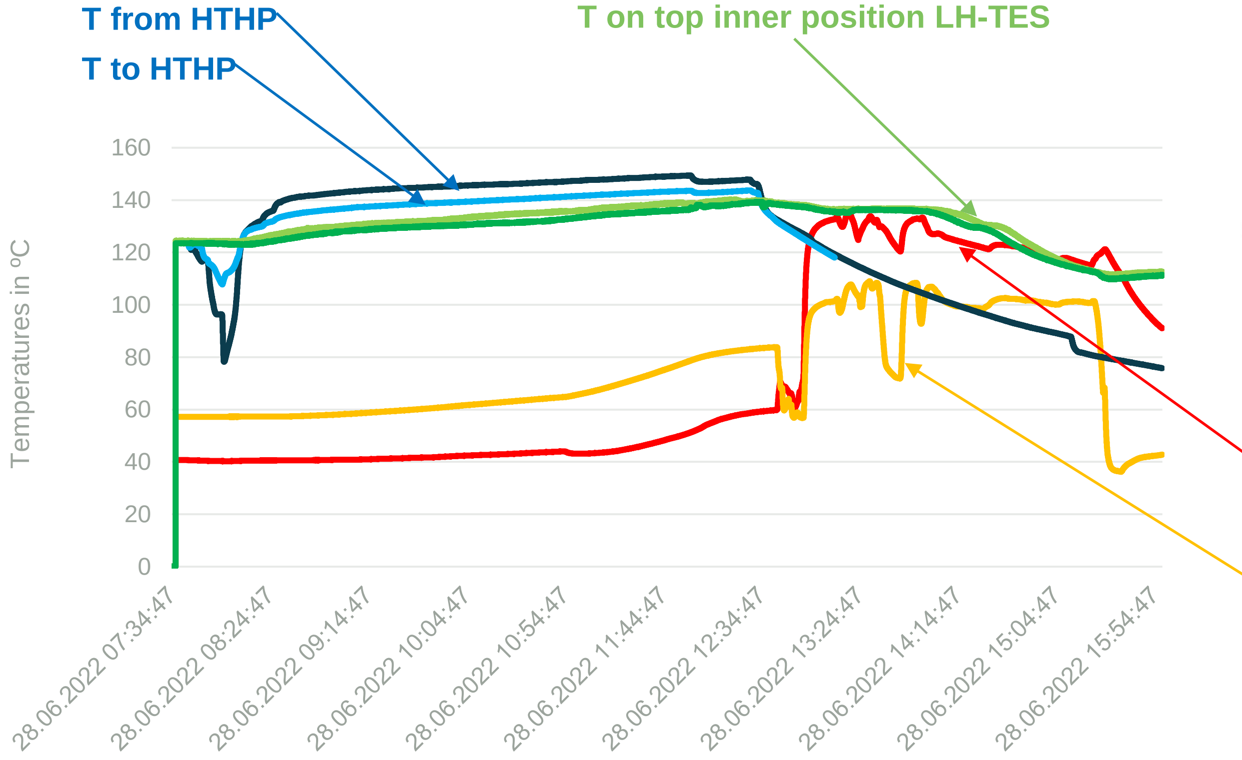

Conclusions

- Flexible CHESTER Storage system is able to store heat and power.
- The individual components of the system been tested individually:
  - 15kW$_{el}$ HTHP with R1233zd(E). COP$_H$ between 3,5..6,2 for Δ T$_{LIFT}$ between 40 and 65 K
  - 160kWh PCM LH-TES with a storage density of circa 70 kWh/m^3
  - 15kW$_{el}$ ORC with R1336mZZ(E). Tested with ΔP=12-19 bar obtaining 4-9 kW$_{el}$
- The ongoing charge/discharge tests of the full scale lab system are the **first experimental proof of concept of the CHESTER system**

CHESTER Publications

[1] *Trebilcock et al.* **Development of a Compressed Heat Energy Storage System Prototype**

IIR Rankine 2020 Conference - Advances in Cooling, Heating and Power Generation

[2] *Weller et al.* **Design, Build and Initial Testing of a Novel Energy Management System**

Heat Powered Cycles (HPC) Conference Proceedings - 2021