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Pumped Thermal Electricity Storage (PTES) For Large-Scale Electrical Energy Storage Applications

Christos N. Markides, Joshua D. McTigue, Alexander J. White

c.markides@imperial.ac.uk

Senior Lecturer in Clean Energy Processes

Clean Energy Processes (CEP) Laboratory

Department of Chemical Engineering

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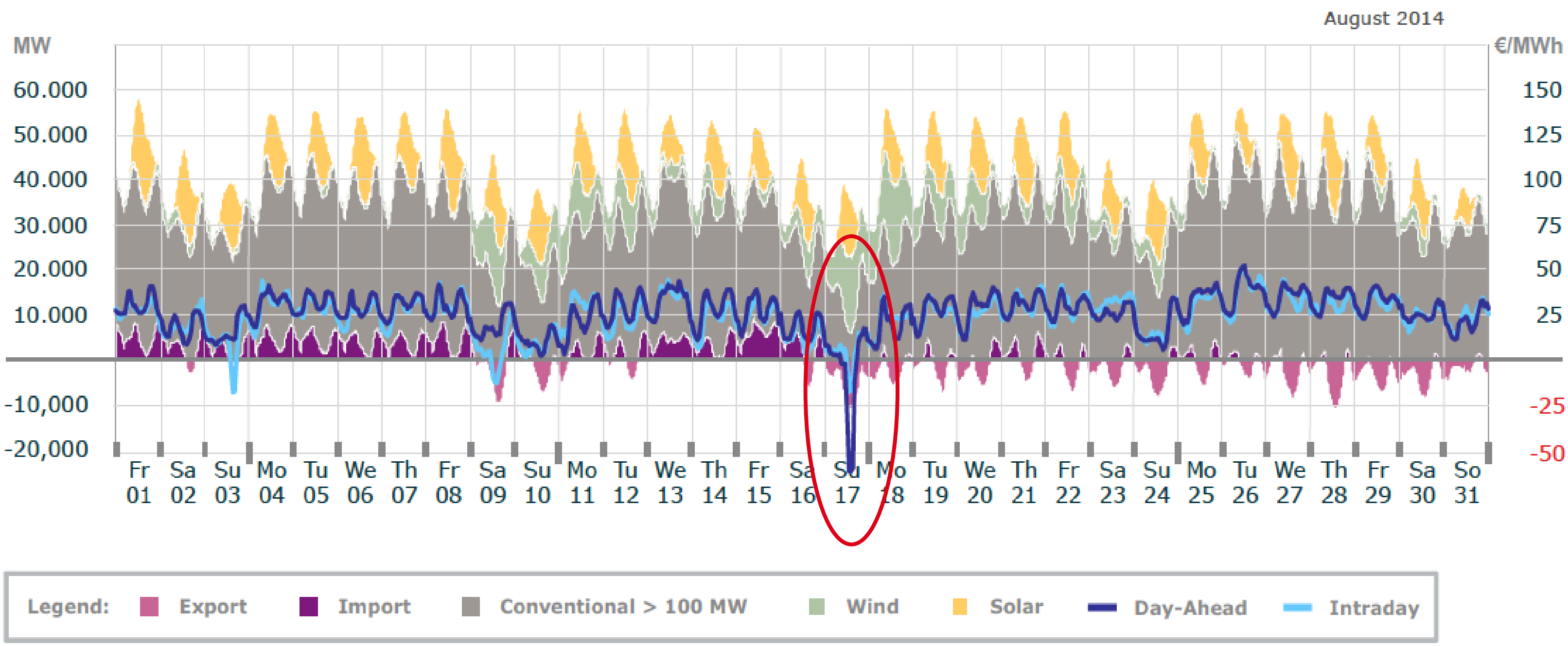
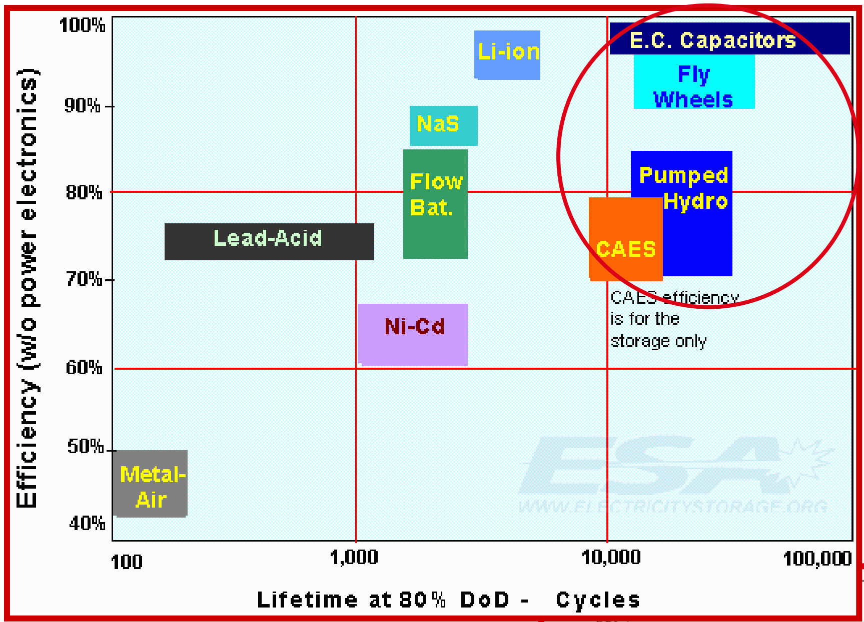
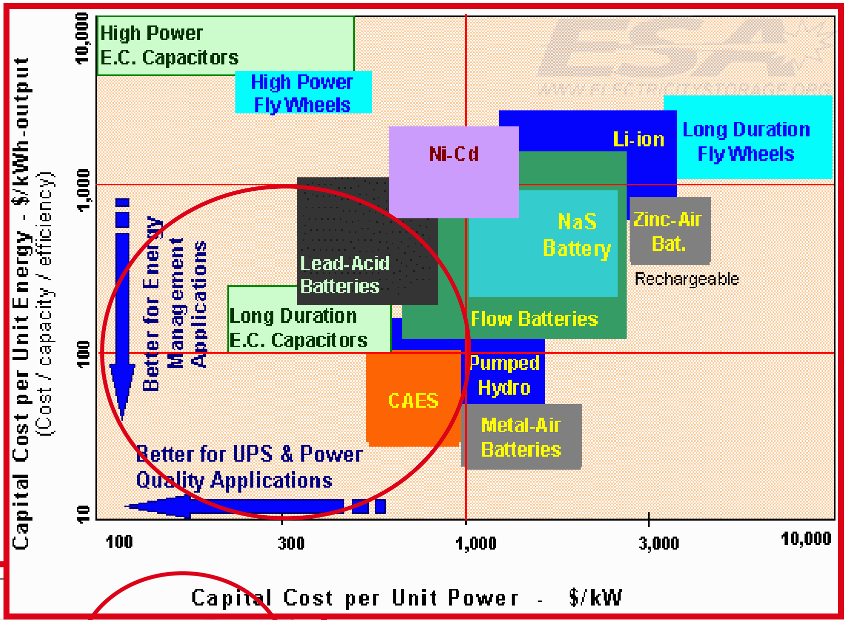
A probable ‘near-term’ UK energy future?

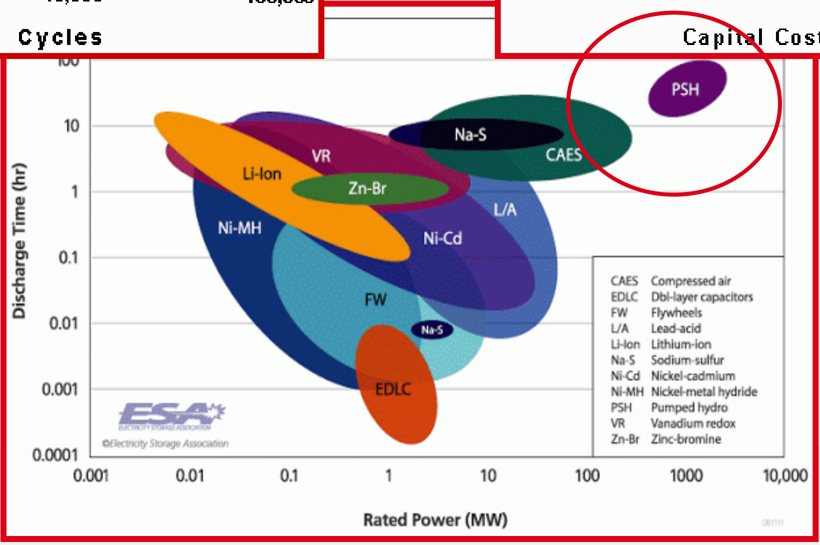


~30 GWh → 100s of GWh

Technology comparison (ESA)

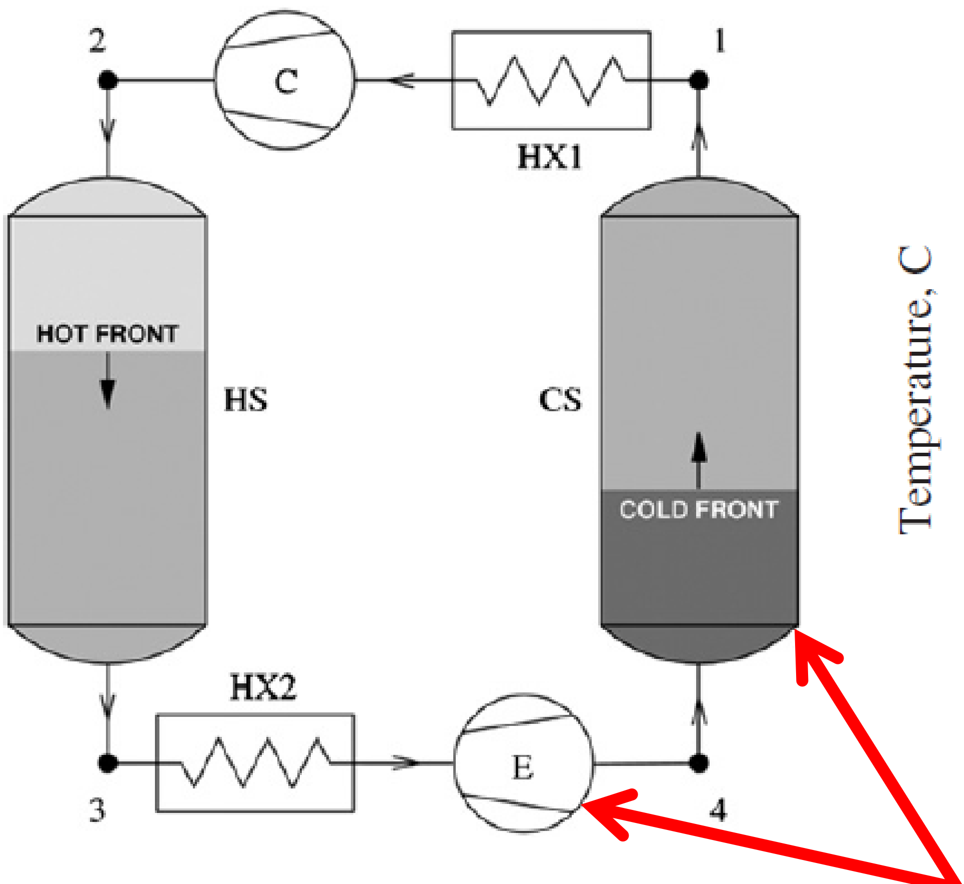


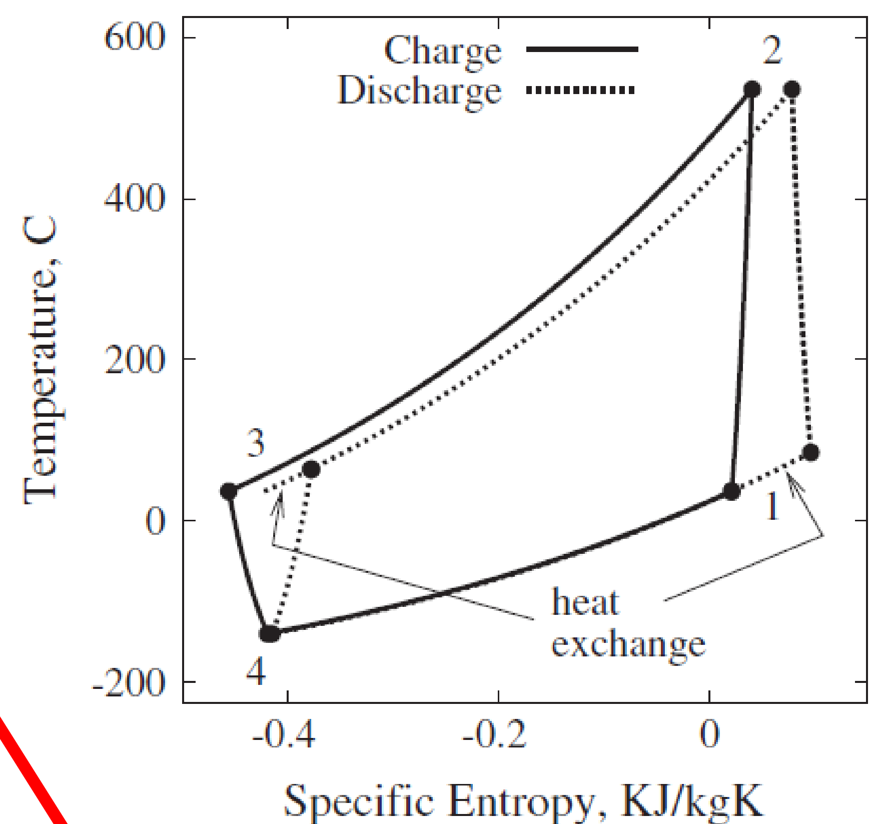




Large-scale TES-based technologies:
LAES
AA-CAES
PTES

Pumped Thermal Electricity Storage (PTES)





Reversible device: 100% round-trip efficiency → Losses?

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Overview

Energy and power densities for a few storage technologies.

	PTES[a]	PHS[b]	CAES[c]	GT[d]
Storage medium:	Gravel	Water	Air	–
Working fluid:	Argon	Water	Air	air
Energy density, ρ_E (kWh/m^3)	50	1.4	10	–
Power density, ρ_P (kW/m^{3}s^{-1})	240	5000	–	330

[a] With $T_1 = T_3 = 300$ K, $p_1 = 1$ bar, $\tau = 2.58$ (solid line in Fig. 1 and the approximate conditions for the system in ref. [4]).
[b] With altitude drop $\Delta h = 500$ m; both ρ_P and ρ_E are given by $\rho_{H2O}\, g\Delta h$.
[c] With storage at 100 bar; see ref. [6] for the energy density expression for CAES.
[d] With $\tau = 2.05$ (pressure ratio ~12) and $T_{max} = 900\,^\circ$C.

J.D. McTigue, A.J. White, C.N. Markides, Parametric studies and optimisation of pumped thermal electricity storage, *Applied Energy* (in press), doi:10.1016/j.apenergy.2014.08.039.

A. White, J. McTigue, C. Markides, Wave propagation and thermodynamic losses in packed-bed thermal reservoirs for energy storage, *Applied Energy* (2014) 130:648-657, doi:10.1016/j.apenergy.2014.02.071.

A. White, G. Parks, C.N. Markides, Thermodynamic analysis of pumped thermal electricity storage, *Applied Thermal Engineering* (2013) 53-2:291-298, doi:10.1016/j.applthermaleng.2012.03.030.

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AIM: Examine PTES technology potential (and losses)

→ 2 MW & 16 MWh ←

Hot and cold reservoir details for a nominal 16 MW h PTES system. The storage material is Fe_3O_4 (density 5.175 tonne/m^3) in the form of a packed bed with an assumed void fraction of 0.35.

	P (bar)	T (K)	ρ_g (kg m^{-3})	M_g (kg)	$\bar{c}_s$ (J kg^{-1} K^{-1})	M_s (tonne)	V (m^3)
Hot							
Chg	10.5 bar	778	6.5	162	860	238	71
Dis.	10.5 bar	310	16.3	405			
Cold							
Chg.	1.05 bar	123	4.1	168	520	394	117
Dis.	1.05 bar	310	1.63	67			

Details of the compression–expansion devices for a nominal power of 2 MW. A clearance ratio (V_{min}/V_{max}) of 0.05 and a cylinder aspect ratio (stroke/diameter) of 0.25 and have been assumed for both devices.

	Speed (RPM)	V_s (total) (m^3)	N_{cyl}	D (m)	Stroke (m)	Clearance (mm)
Hot cylinders (CE)	1200	0.50	6	0.75	0.19	10
Cold cylinders (EC)	1200	0.20	6	0.55	0.14	7.4

Nominal, minimum and maximum values of quantities varied for the parametric study. Note that the loss factors are for each compressor/expander, CE and EC, with half the pressure loss assigned to each side of the device.

	Loss factors			Operating conditions					Geometric parameters			
	f_p	$1-\eta$	α	T_1 (K)	T_3 (K)	β_{chg}	β_{dis}	Π	$(L/D)_{CR}$	$(L/D)_{HR}$	d_p^{CR} (cm)	d_p^{HR} (cm)
Nominal	0.02	0.02	0.02	310	310	10.0	10.0	0.75	1.00	1.00	2.0	2.0
Min	0.00	0.00	0.00	273	273	5.00	5.00	0.50	0.10	0.10	0.5	0.5
Max	0.04	0.04	0.04	347	347	15.0	15.0	1.00	1.90	10.0	3.5	3.5

Lower and upper bounds for parameters used in optimisation. Ambient temperature is $T_0 = 298$ K.

	L/D	d_p (cm)	Π	β	T_1 (K)	T_2 (K)	T_3 (K)	T_4 (K)
Lower bound	0.10	0.50	0.10	2.00	$T_0 + 10$	$T_3 + 50$	$T_0 + 10$	103
Upper bound	10.0	10.0	0.99	20.0	773	873	773	$T_1 - 50$

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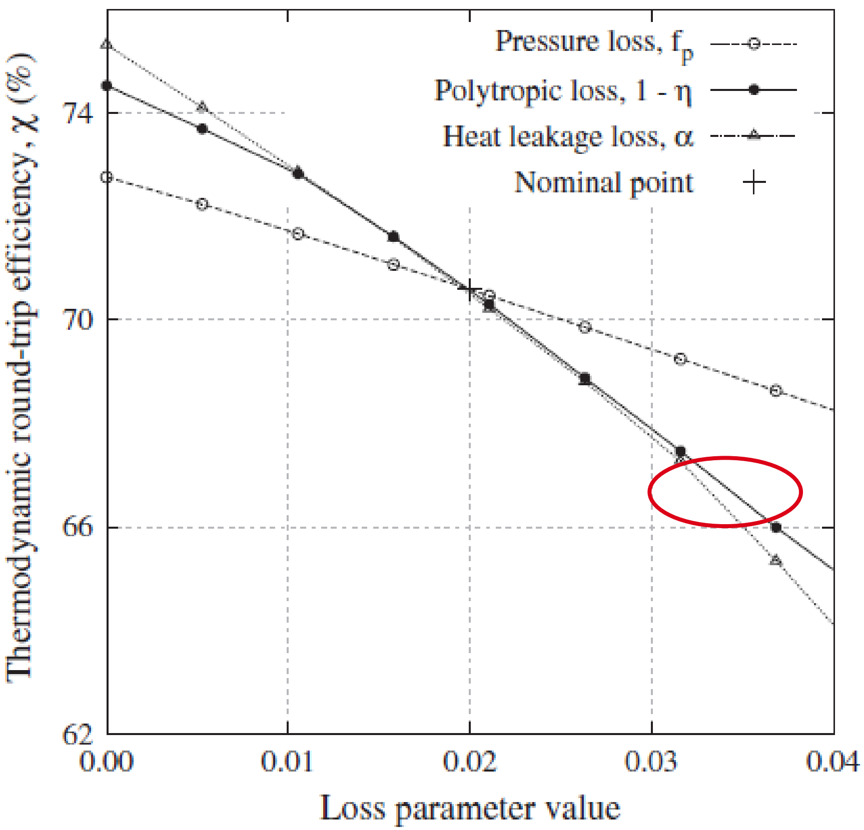
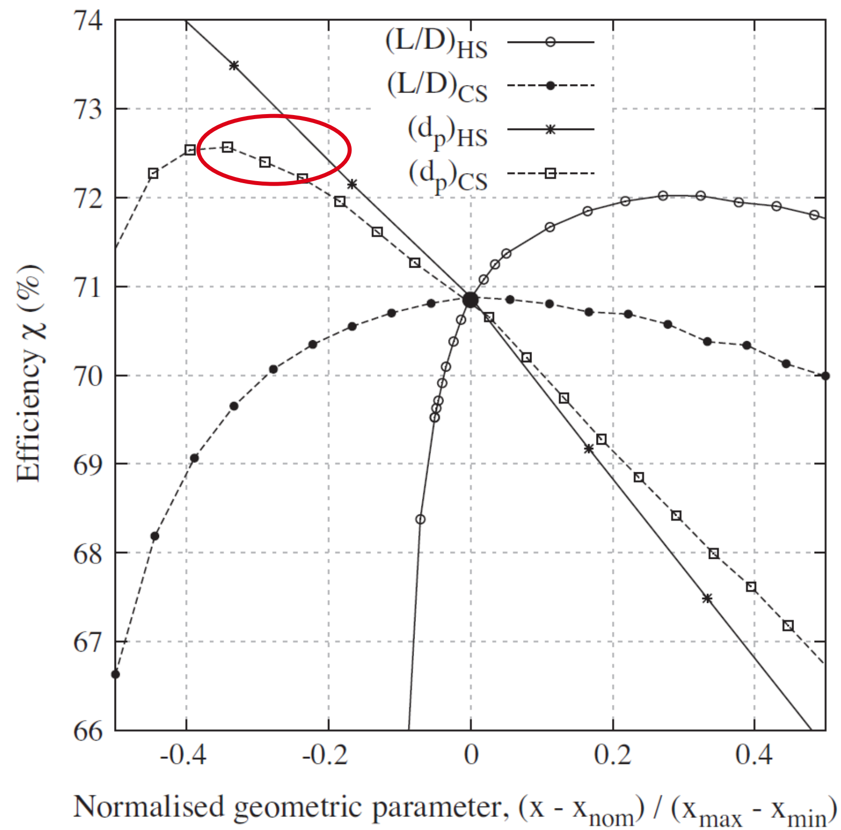
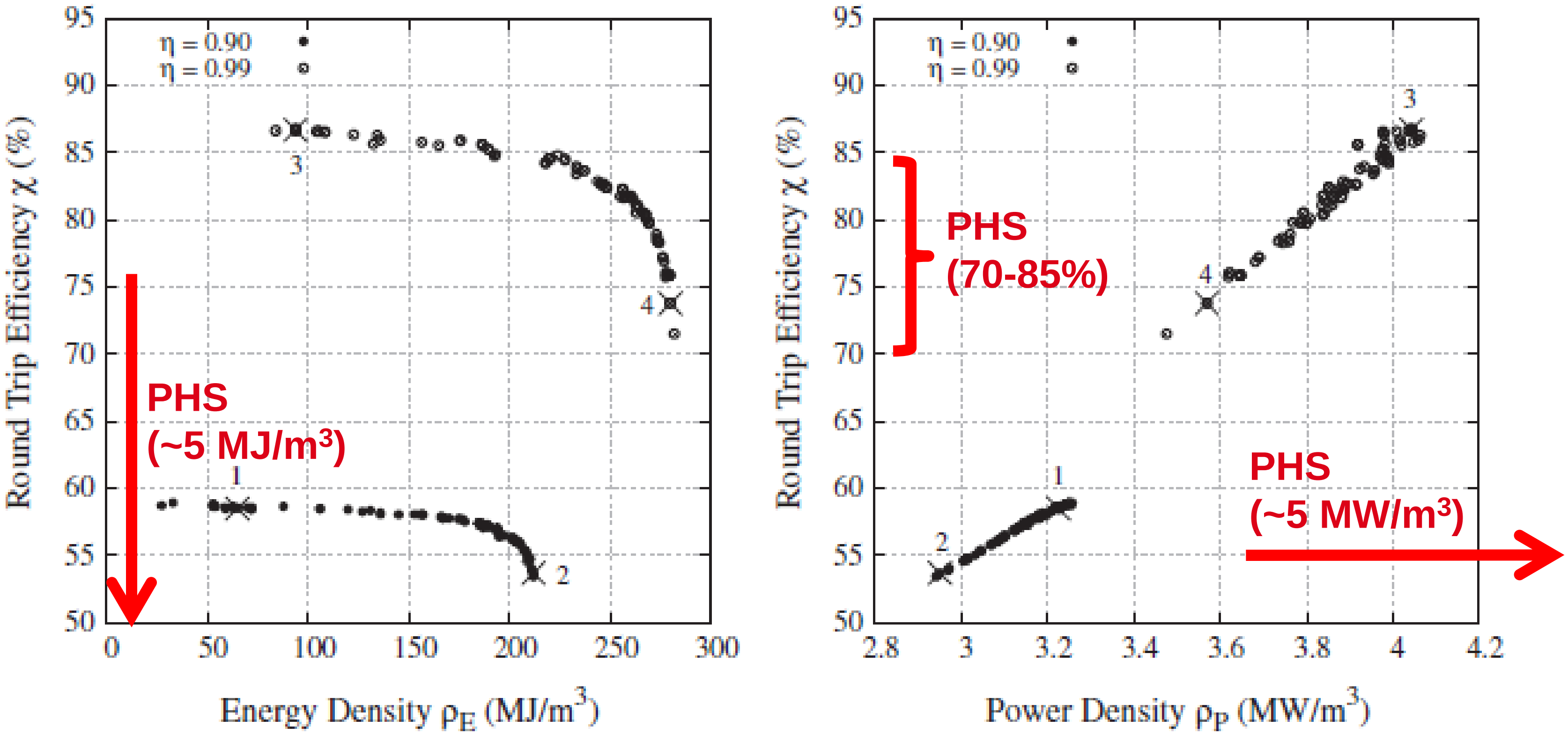
Parametric analysis





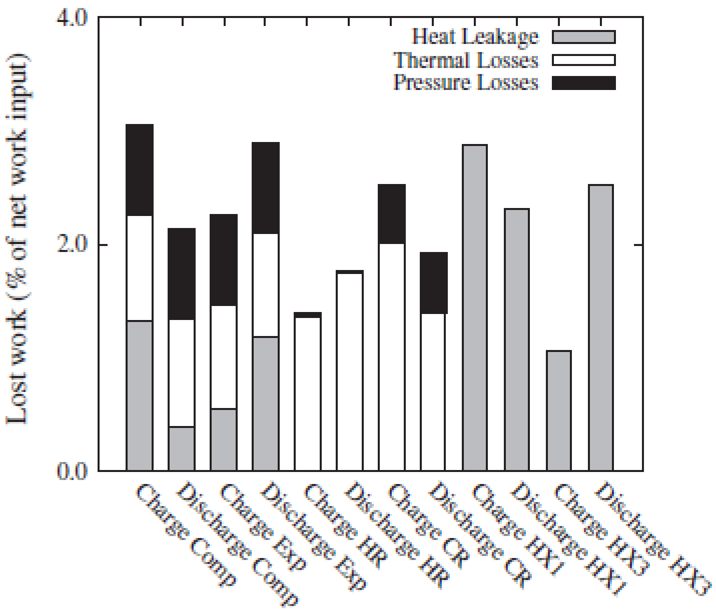
Optimisation



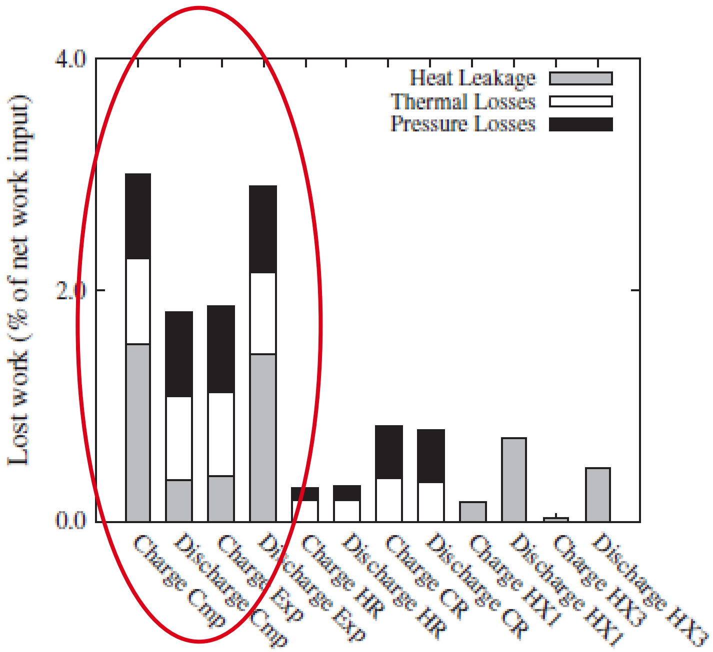
(a) Efficiency vs. Energy Density

(b) Efficiency vs. Power Density

Losses and opportunities



(a) Nominal Design. Total loss = 26.8 %



(b) Optimal Design (point 3). Total loss = 13.2 %

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Efficient compressors/expanders and thermal reservoirs

26/11 – 09:30 (CHANCELLOR'S SUITE)
Thermal Energy Storage Session:
Dr. Alexander White, Analysis And Optimisation Of Packed Bed Thermal Reservoirs For Energy Storage Applications

26/11 – 17:20 (CHANCELLOR'S SUITE)
Mechanical Energy Storage Session:
Dr. Richard Mathie, Losses In Reciprocating Compressors And Expanders For Energy Storage Applications: An Experimental And Computational Study

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