Loughborough University

Next-generation CAES & Project SAVECAES

Medium duration energy storage, 12/1/2024

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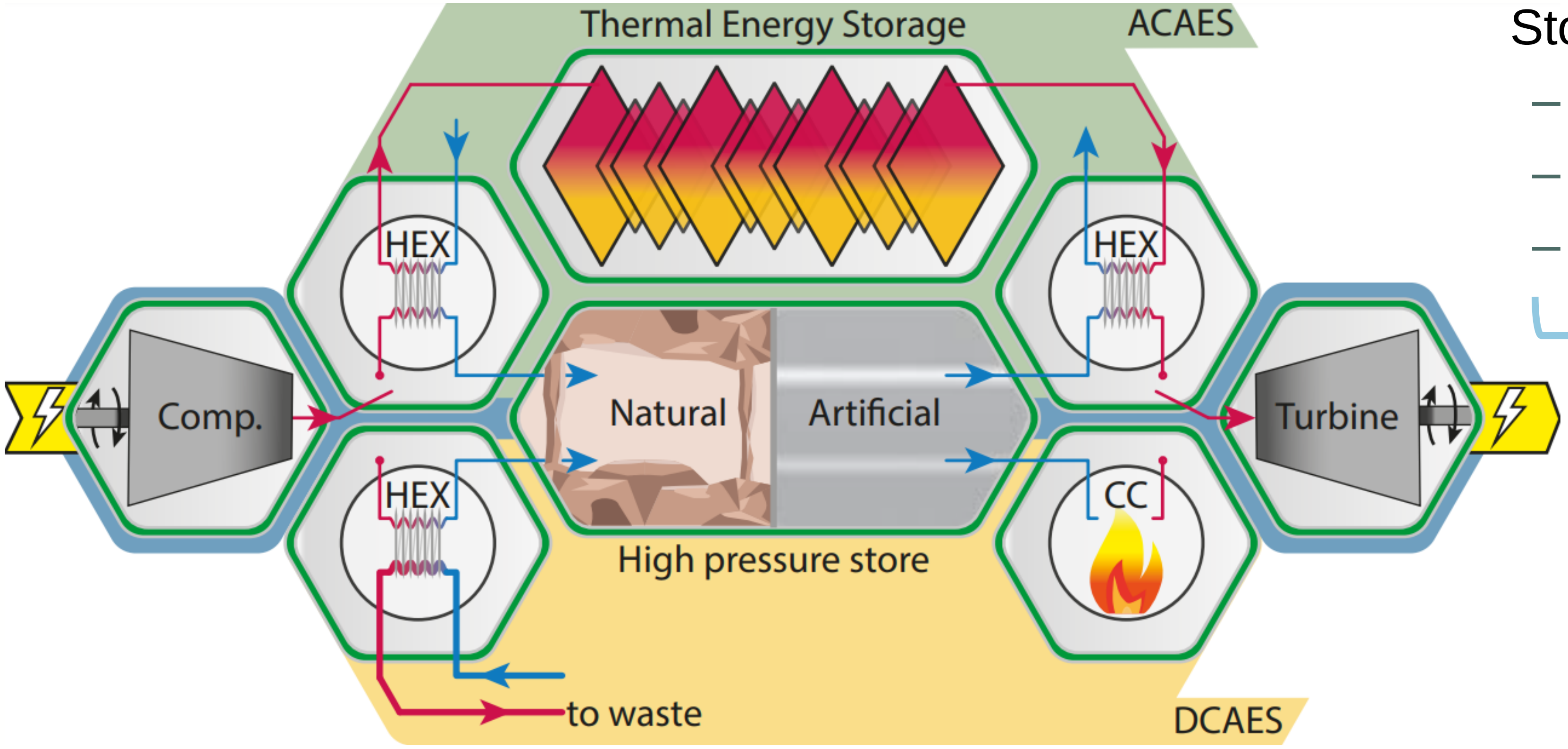
What is next-generation CAES?



- What is Compressed Air Energy Storage (CAES)?
  - Diabatic, Adiabatic, Isothermal
  - Isobaric, Isochoric
  - Co-generative, Trigenerative

CAES is a family of technologies

Barbour, E., & Pottie, D. L. (2021). Adiabatic compressed air energy storage technology. Joule, 5(8), 1914-1920.

CAES is often misunderstood

- CAES is a thermomechanical system, where both ***work*** and ***heat*** have a value.
- Different CAES variants balance work and heat differently.
- *'if the compressor and expander each operate at an efficiency of 80%, then the process efficiency cannot be greater than 64% (80% x 80%)'* – Findings from Storage Innovations 2030: Compressed Air Energy Storage, USDOE.
- If 80% isentropic efficiency:

$$w = \Delta h_1 \qquad T_{c,o} = T_{c,i}\left[1 + \frac{\left(\frac{p_{high}}{p_{low}}\right)^{\frac{\gamma-1}{\gamma}} - 1}{\eta_c}\right] \qquad T_{e,o} = T_{e,i}\left[1 - \eta_t\left(1 - \left(\frac{p_{low}}{p_{high}}\right)^{\frac{\gamma-1}{\gamma}}\right)\right]$$

For $\frac{p_{high}}{p_{low}} = 10$ & $\eta_c = \eta_e = 0.8$, we find that 9.8% exergy is destroyed in compression and the system will recover 72% of the work input

$$\Delta(\text{exergy}) = \Delta h - T_0 \Delta s \qquad \Delta s = c_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{p_2}{p_1}\right)$$

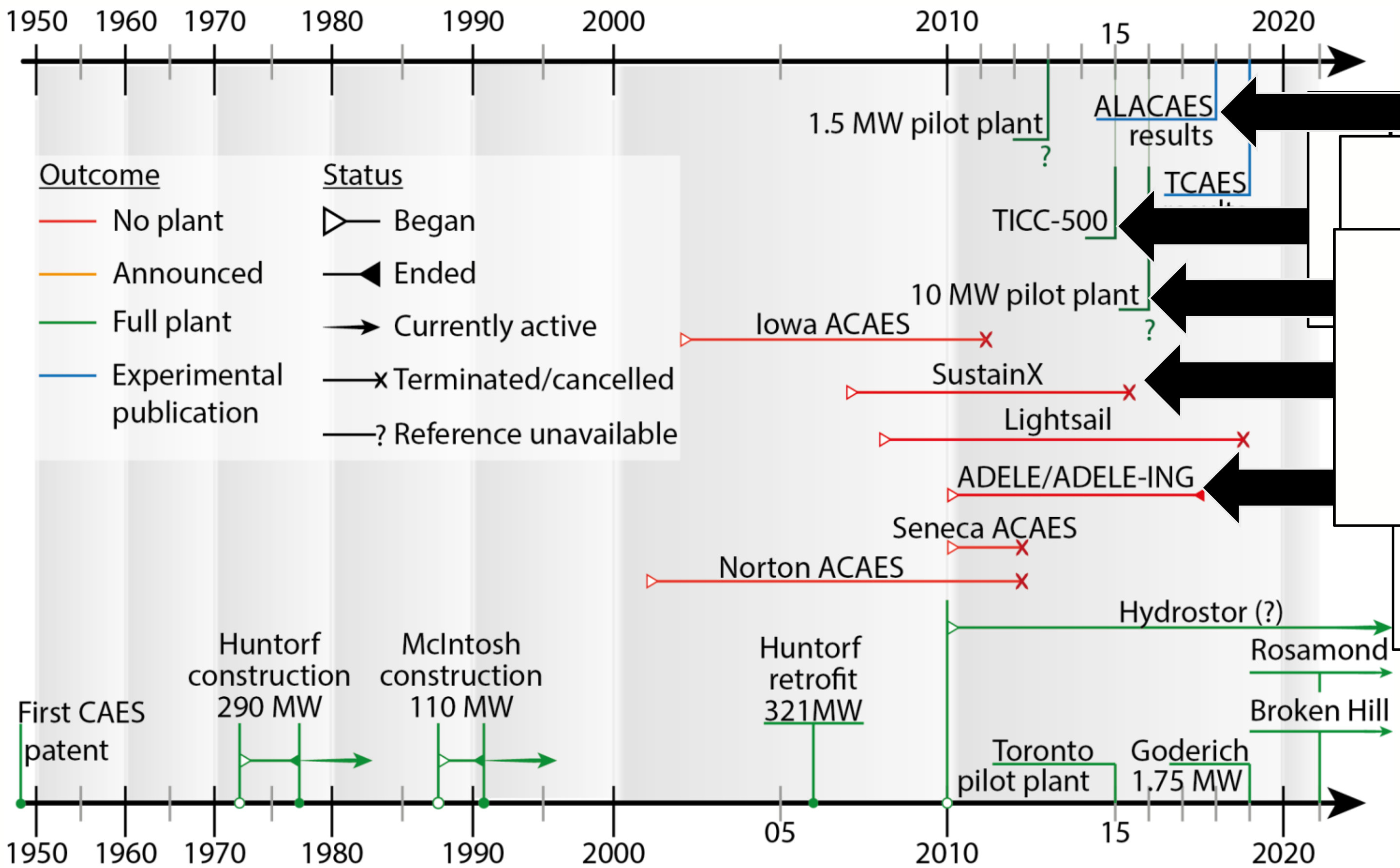
Challenges for next-generation CAES

- The thermodynamic concepts are well established.
- Challenges relate to engineering of the constituent components.
- Off-the-shelf components are not generally suitable.

	Off-the-shelf	Optimal for CAES
Compressor	Min. work per unit air	Reversibility (high T_{out})
Turbine	Max. work → (high T_{in}, high pressure ratio)	Low pressure ratio; low T_{in}

- Next-generation CAES designs require innovation across multiple components.
- A healthy scepticism around previous claims is useful.

Challenges for next-gen CAES



Adapted from Barbour, E. R., Pottie, D. L., & Eames, P. (2021). Why is adiabatic compressed air energy storage yet to become a viable energy storage option?. IScience, 24(5).

63-74% round trip efficiency.
world's first AA-CAES pilot scale plant[4].

In excess of 60%RTE[5].

Turnaround efficiency 54%[2].

Instantaneous efficiency definition based on power (instead of energy).

technical details. No experiment or plant.

1 Zunft, Stefan, et al. "Electricity storage with adiabatic compressed air energy storage: Results of the BMWi-project ADELE-ING." International ETG Congress 2017. VDE, 2017.
2http://large.stanford.edu/courses/2015/ph240/burnett2/docs/bollinger.pdf
3 Wang, Sixian, et al. "Experimental study of compressed air energy storage system with thermal energy storage." *Energy* 103 (2016): 182-191.
4 Geissbühler, Lukas, et al. "Pilot-scale demonstration of advanced adiabatic compressed air energy storage, Part 1: Plant description and tests with sensible thermal-energy storage." Journal of Energy Storage 17 (2018): 129-139.
5 Wang, Jidai, et al. "Overview of compressed air energy storage and technology development." Energies 10.7 (2017): 991.

Introducing SAVECAES

- Sustainable, Affordable and ViablE Compressed Air Energy Storage
- £1.1 Million EPSRC-funded project
- Based on the hypothesis that *energy systems incorporating suitably-sized CAES plants can deliver huge cost savings to UK.*

Loughborough University

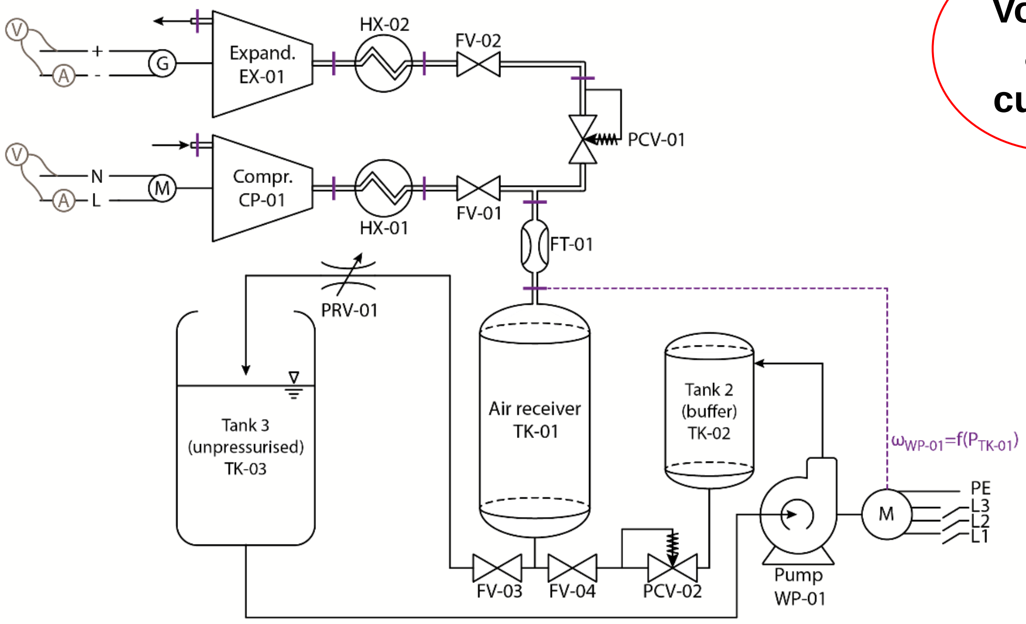
UNIVERSITY OF LEICESTER

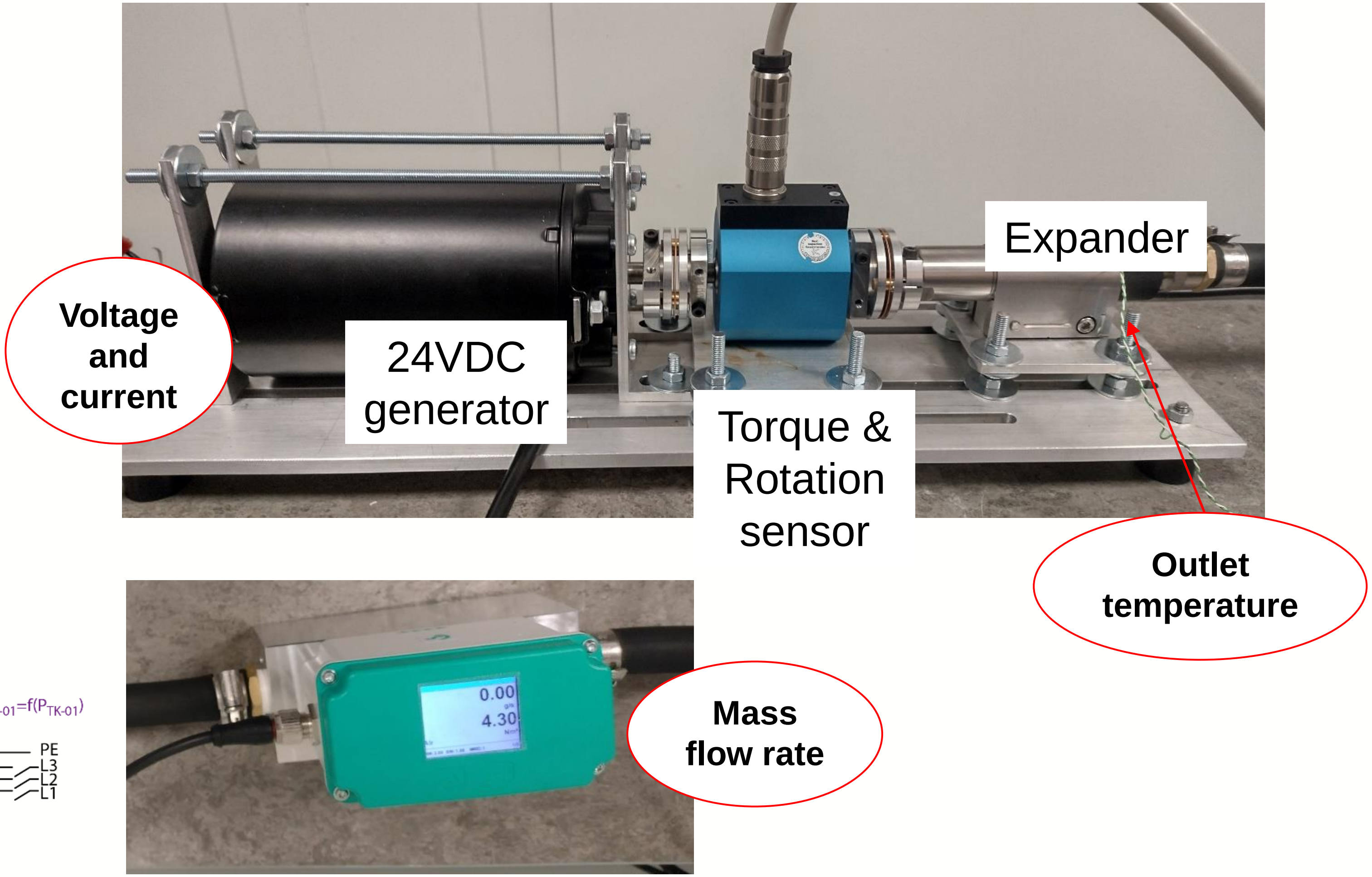
The University of Nottingham

BGS British Geological Survey

How SAVECAES is contributing

- ☐ **Experimental work (LU)**
- ☐ Ultra-high pressure (UoN)
- ☐ Heat management (UoL)
- ☐ Resource availability (BGS)





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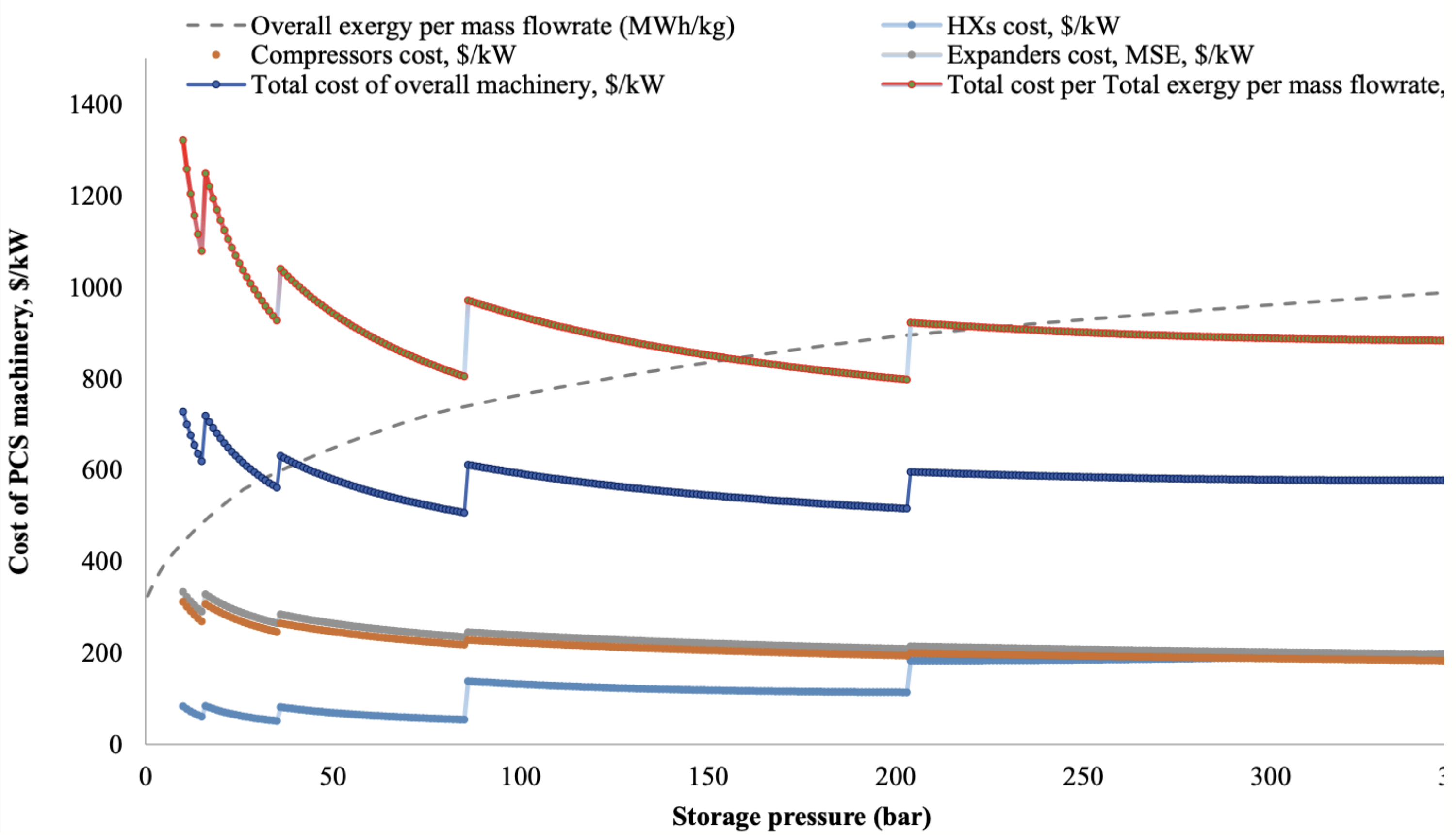
To establish an AA-CAES plant with storage pressure 200 bar instead of 50 bar with the same mass flowrate, there is a potential for a 7.8% reduction in $/kW expenditure to achieve 44% more exergy (MWh/kg).



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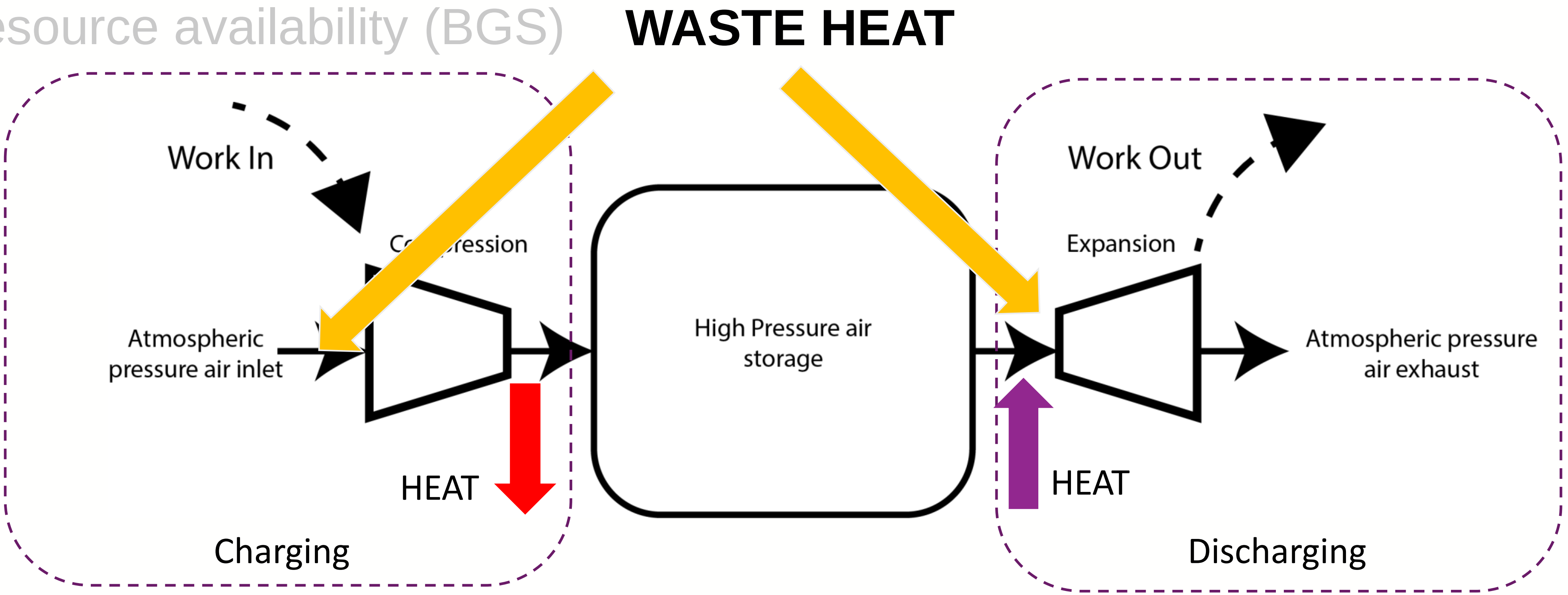

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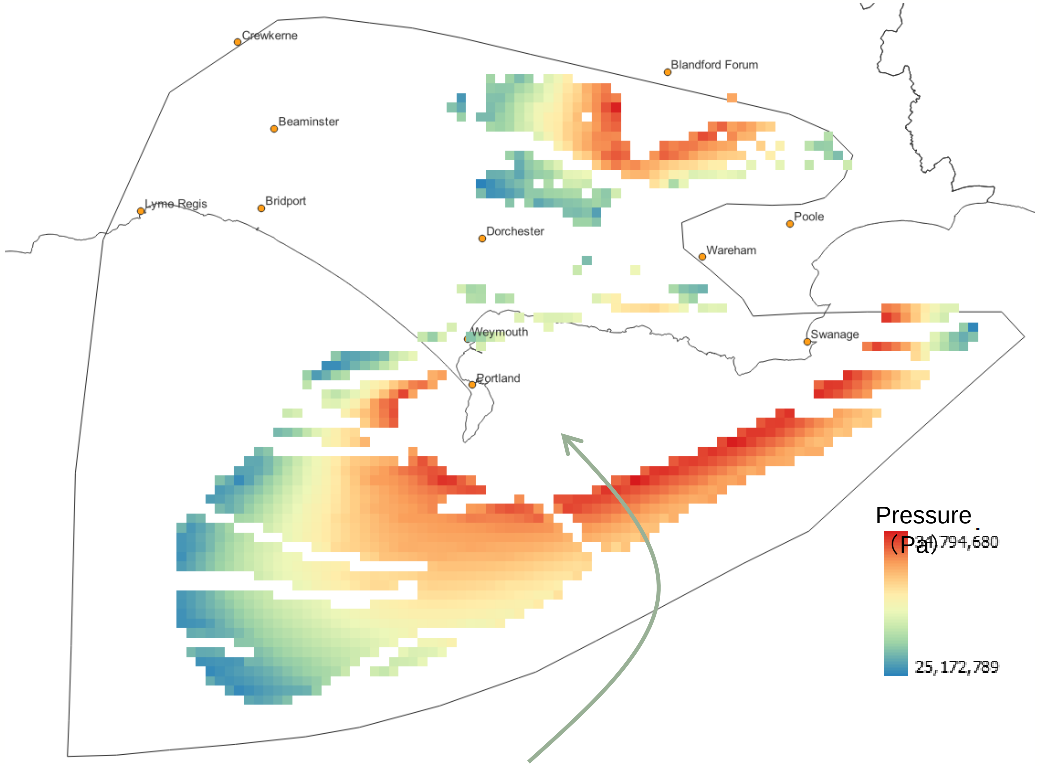
- ☐ **Resource availability (BGS)**

location	Pressure range （bars）	Number of caverns	Combined usable volume of all caverns (Million m³)	Combined theoretical exergy storage capacity of all caverns (TWh)
Wessex	250 - 350	8609	2428.7	7.643
	>=350	3447	1453.0	5.743
	Total	12056	3881.7	13.386



Maximum pressures exceed 350 bar

Conclusions

- Next generation (fuel-free) CAES is achievable, however engineering innovations are still required across multiple components.
- A healthy scepticism around previous claims is useful.
- We badly need more transparent experimental work, focussed on engineering practicality.
- Exciting directions for the future include isobaric operation, ultra-high-pressure systems and colocation/integration with waste/other heat sources.