High Performance CAES through elevated temperature thermal storage

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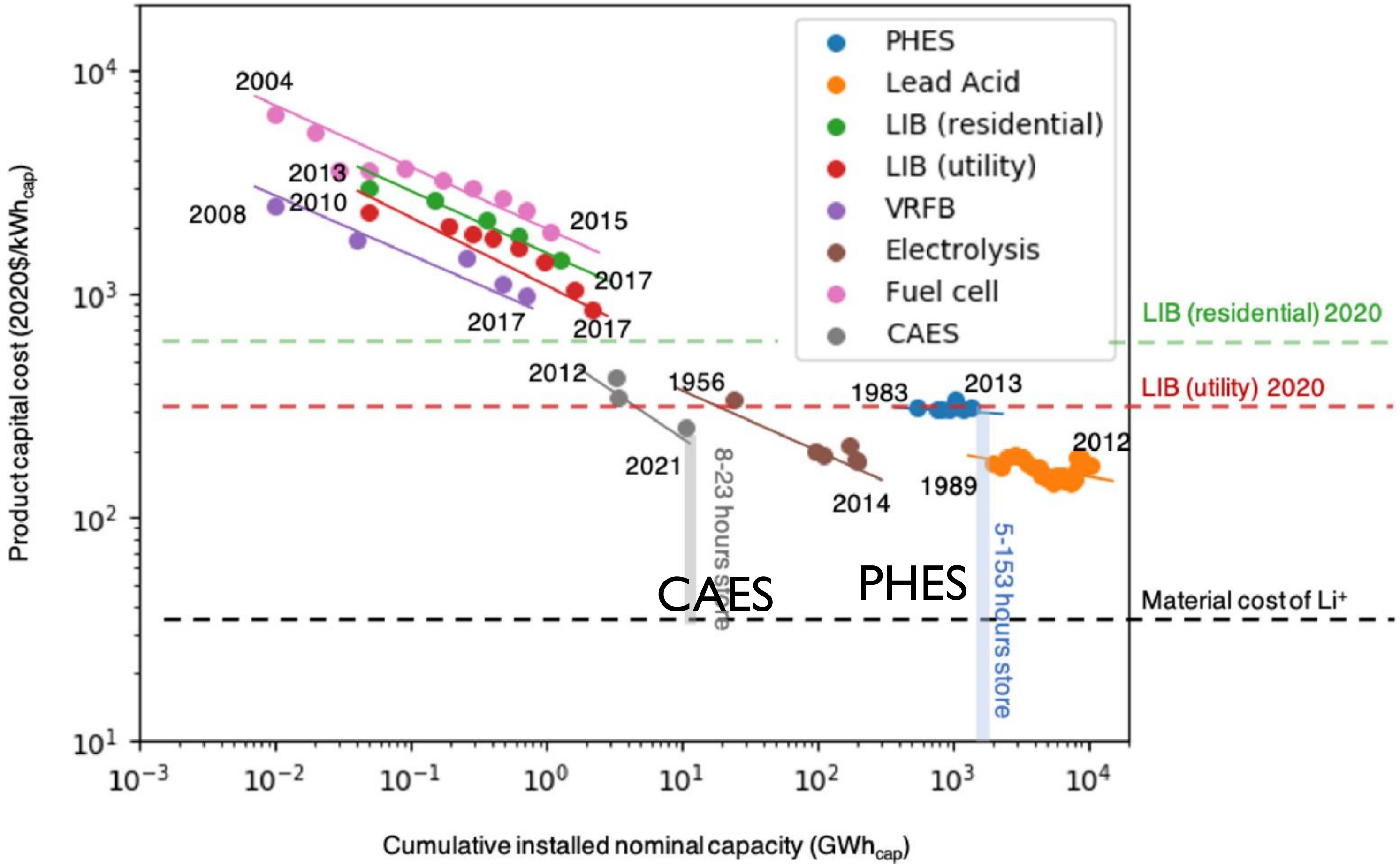
Why CAES



CAES has a potential to be low cost for long-duration large-scale energy storage

A learning curve of CAES seems to start

He et al 2022
Schmidt et al 2017

Why CAES

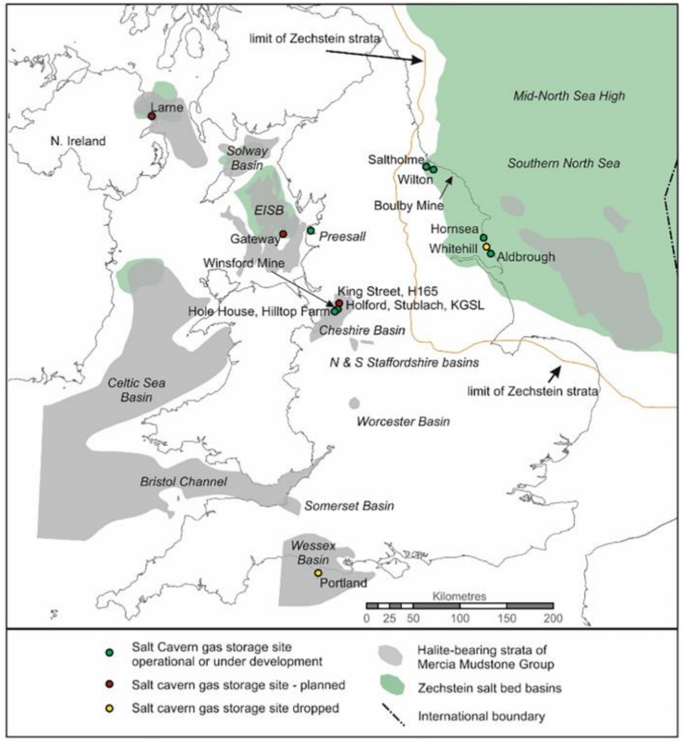


Fig. 1. Diagrammatic map of UK sedimentary basins containing massive, bedded halite deposits and the location of operational, planned and cancelled UK gas storage facilities (after [24]). Note that thin, aerially restricted onshore lateral equivalents of thick offshore Triassic halite formations are not shown. Abbreviations: EISB – East Irish Sea Basin; KGSL – Keuper Gas Storage Limited. Contains Ordnance Survey data © Crown copyright and database rights 2015. Ordnance Survey Licence no. 100021290.

Sufficient geological facilities in the UK and other regions:

Potential salt-cavern based CAES capacity is in the range of several tens of TWh to several hundreds of TWh exergy storage

Task #42:

Large-Scale, Medium-Duration Energy Storage

energy storage
IEA Technology Collaboration Programme

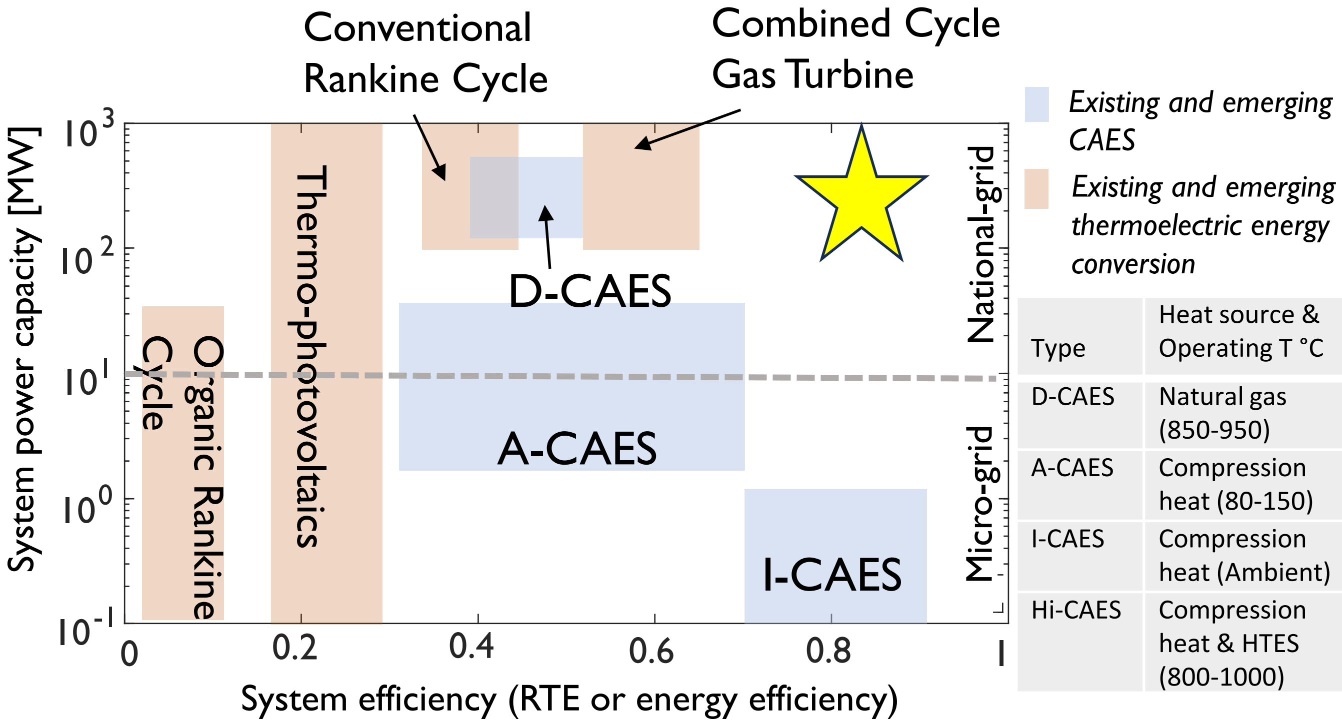
Subtask #3: Kickoff

MDES: Regional Dimensions

www.TinyURL.com/LS-MDES-task

Williams et al. 2022
Evens et al 2021

Why high-temperature CAES for grid-scale ES



Type	Heat source & Operating T °C
D-CAES	Natural gas (850-950)
A-CAES	Compression heat (80-150)
I-CAES	Compression heat (Ambient)
Hi-CAES	Compression heat & HTES (800-1000)

Fig. 1 CAES and Thermal-power generation technology comparison

Current A-CAES systems have lower power capacities and lower operating temperature than conventional heat engines

High-power high-efficiency CAES could lead to a smoother transition for the system operators

Hi-CAES project

UK Research and Innovation

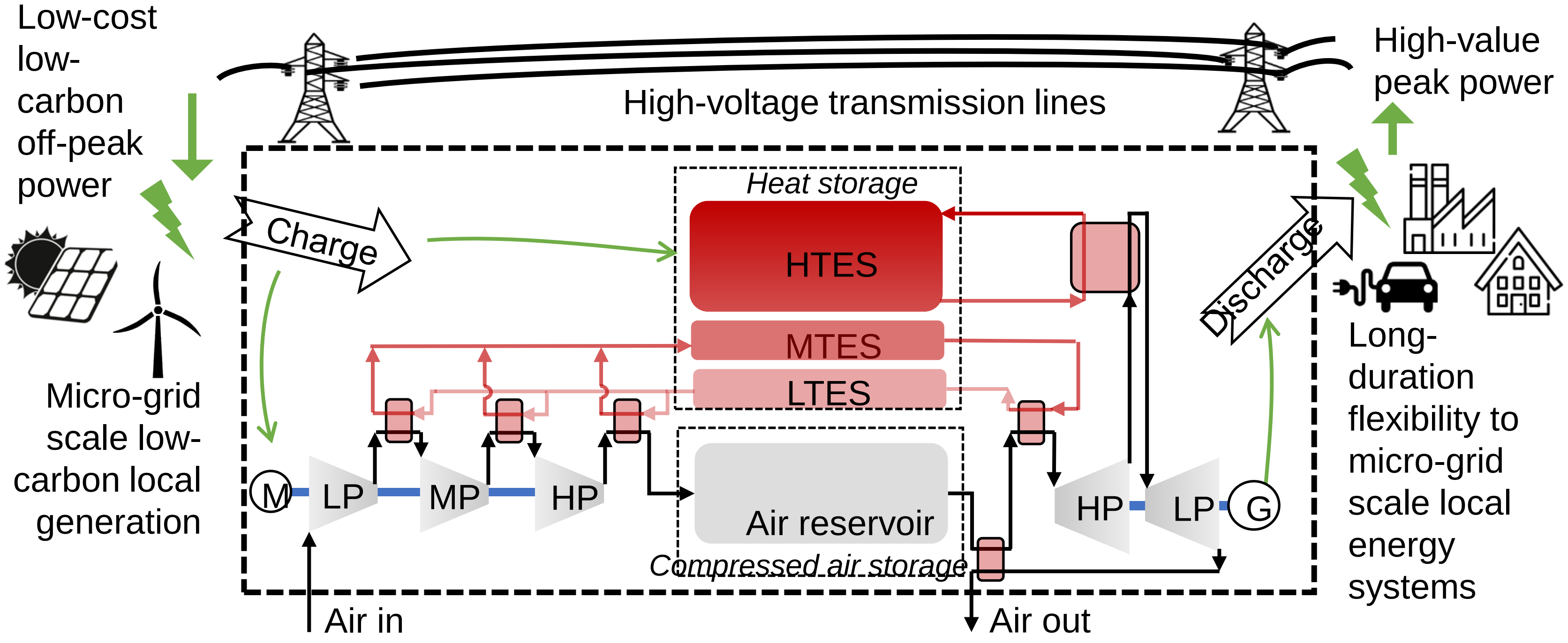
CATAPULT Energy Systems

XRENEWABLE

FutureBay

Storelectric

Highview Power Reshaping renewables



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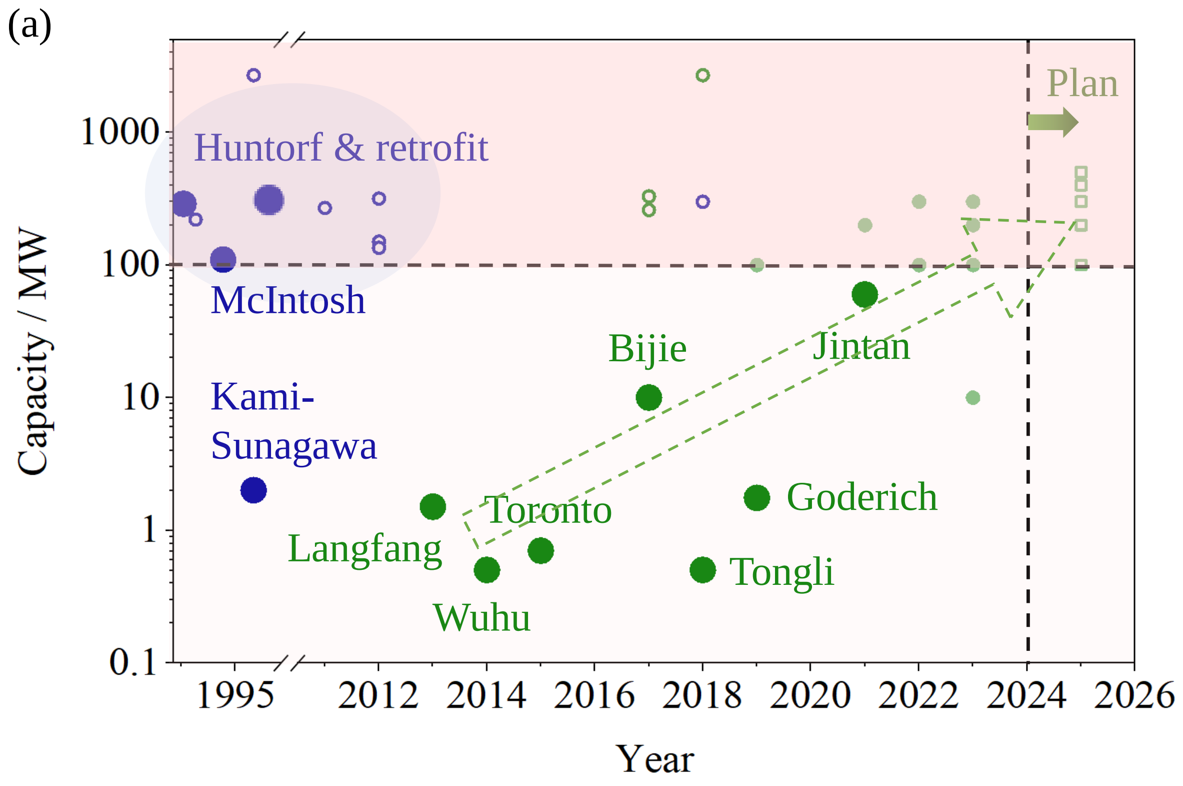
Steady and dynamic system integration and operation

Hi-temperature TES: materials and devices

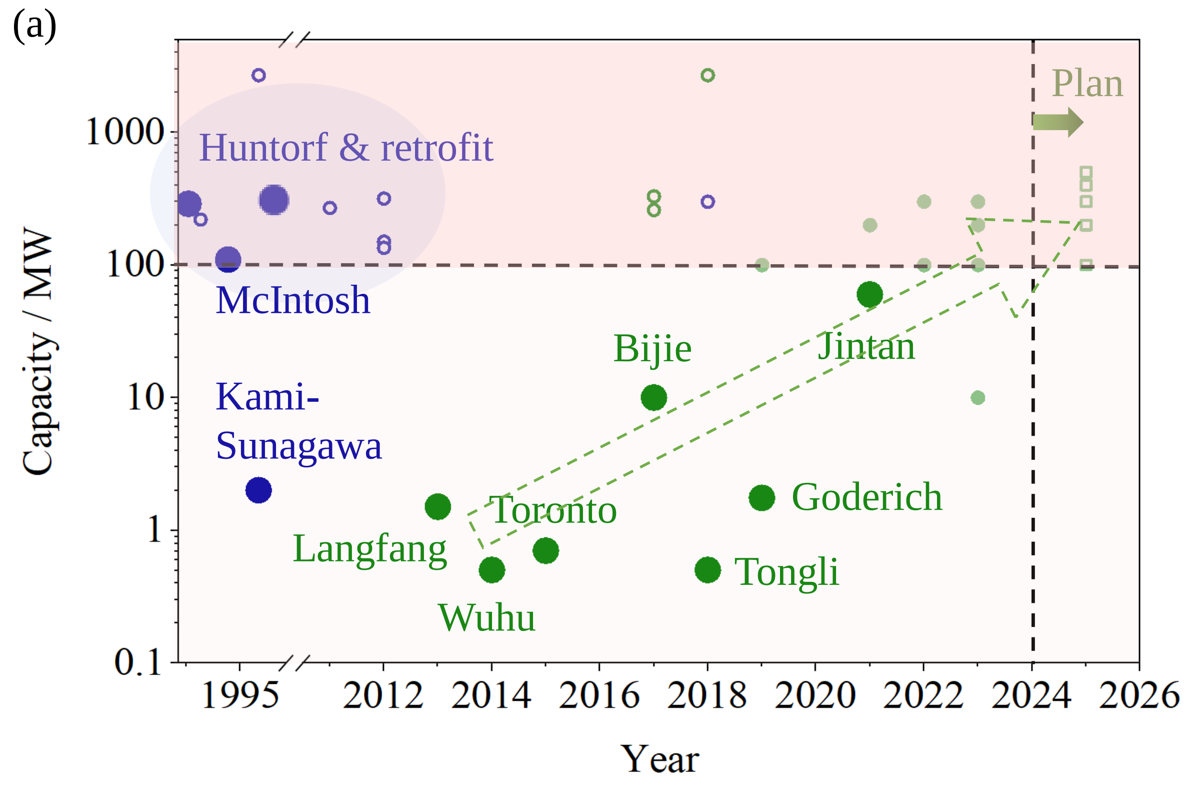
High-voltage to high-temperature conversion

Research & development trend in grid-scale CAES

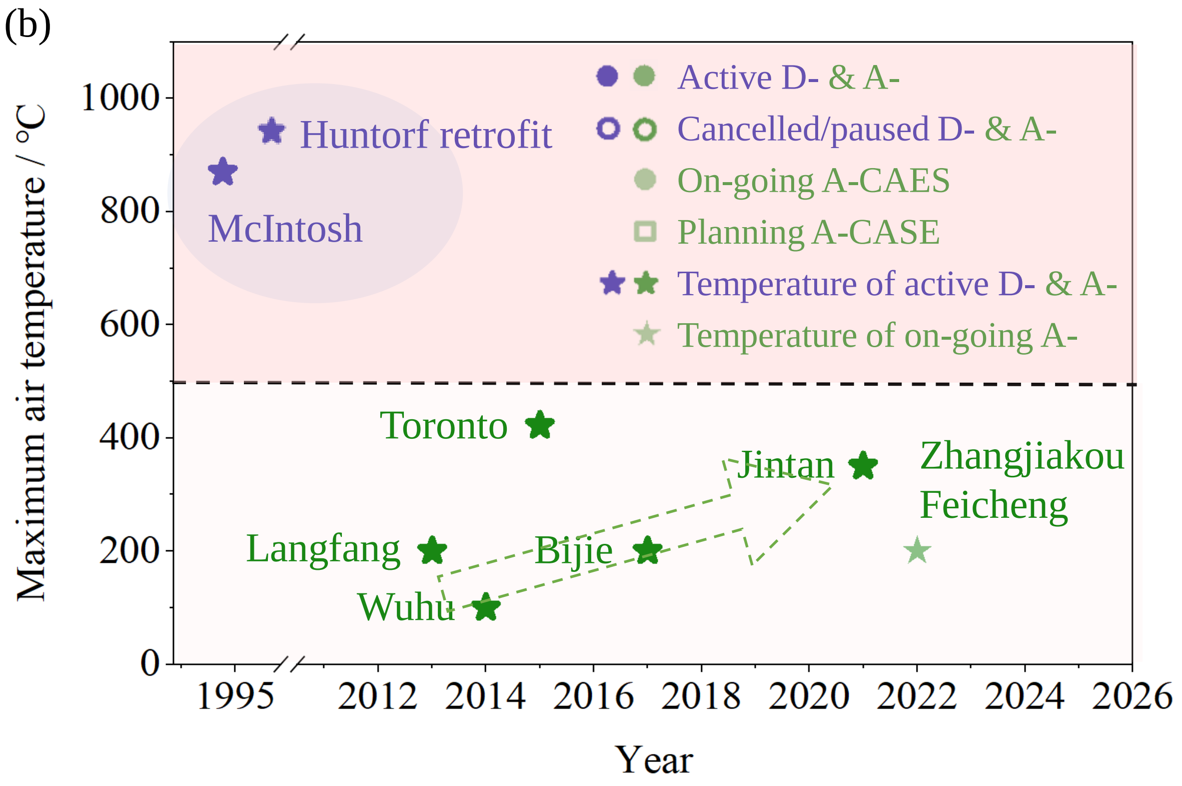


The deployment of A-CAES is accelerating, after a decade-long development globally

Research & development trend in grid-scale CAES



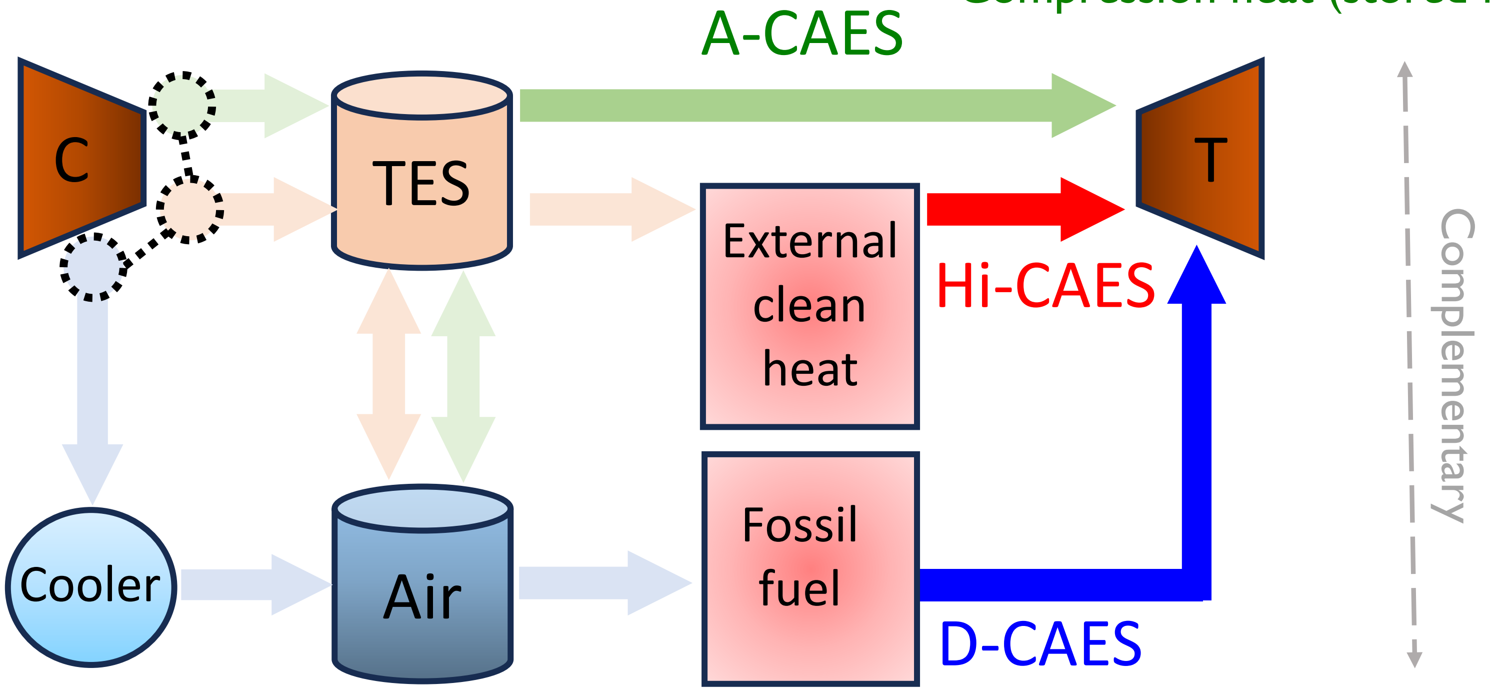
The deployment of A-CAES is accelerating, after a decade-long development globally



The operating temperature of A-CAES increased with the capacity, but still much lower than conventional heat engines

What is Hi-CAES

Per Unit Power (<100MW) ☹
Round-trip Efficiency (60-70%) ☺
Fossil fuel (no fossil fuel) ☺
Compression heat (stored in TES) ☺

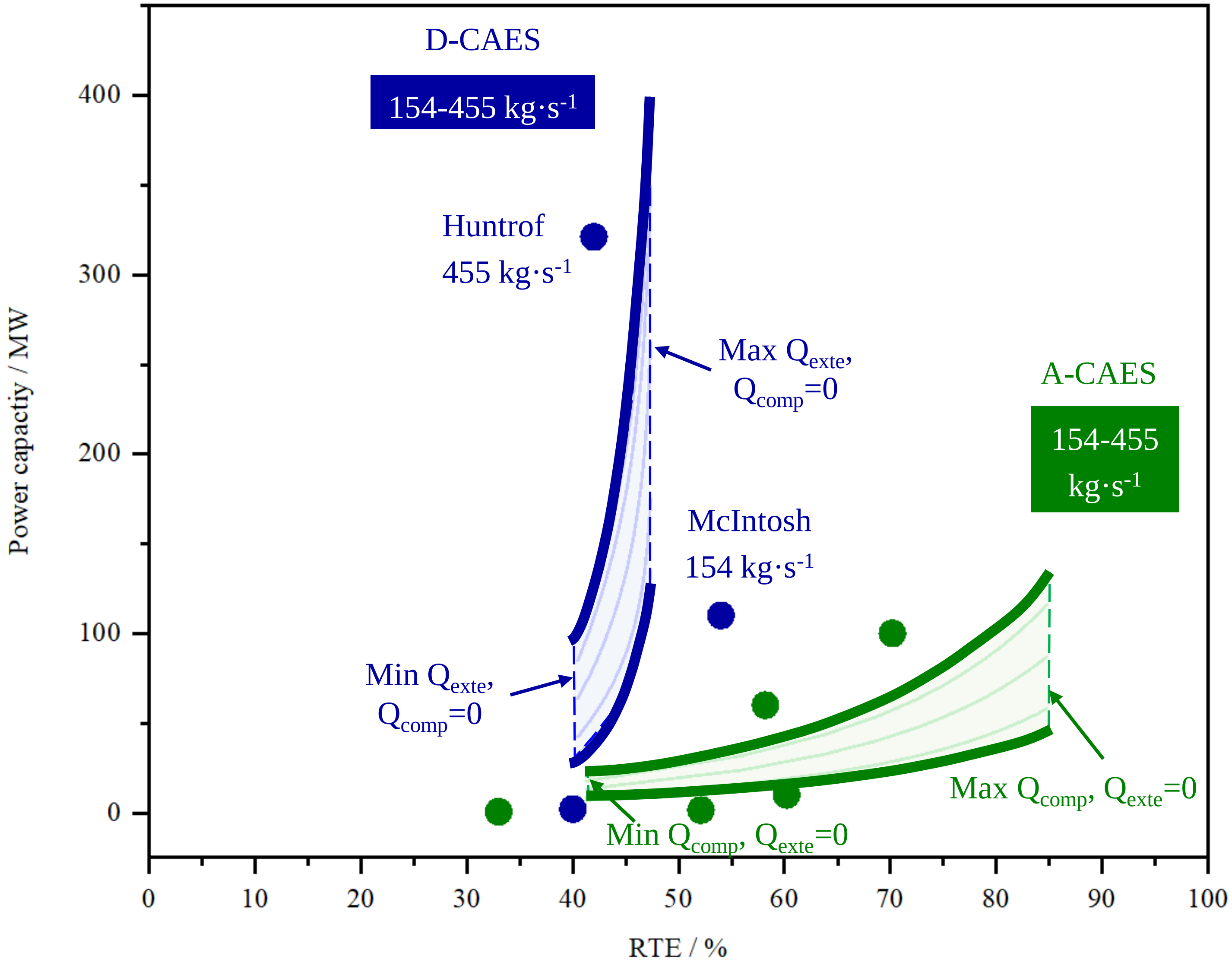


Per Unit Power ☺
Round-trip Efficiency ☺
Fossil fuel ☺
Compression heat ☺

Per Unit Power (>100 MW) ☺
Round-trip Efficiency (30-50%) ☹
Fossil fuel (natural gas or oil) ☹
Compression heat (wasted) ☹

The Hi-CAES framework could lead to high-power high efficiency CAES without fossil fuels

Theoretical analysis of Hi-CAES – power and efficiency



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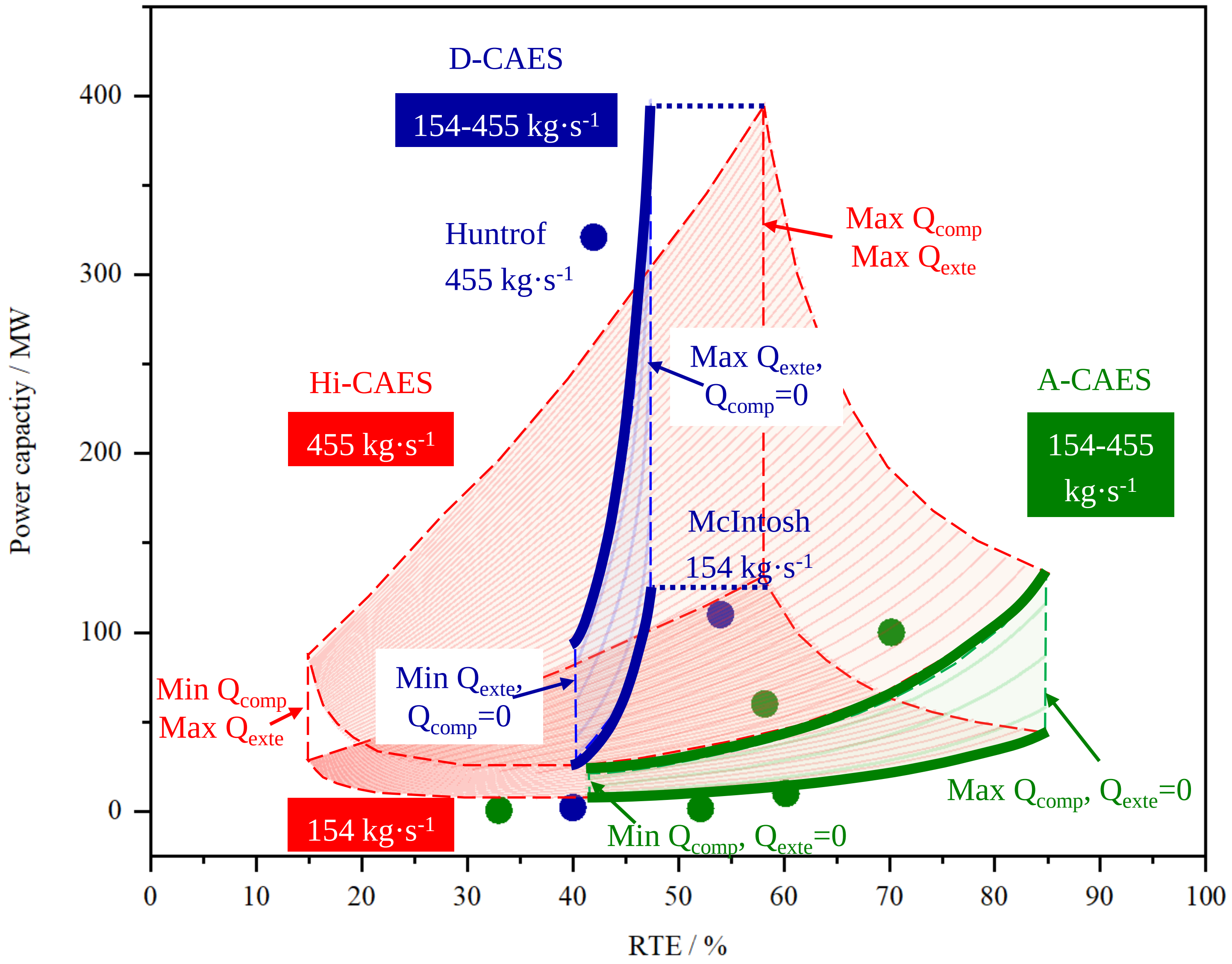
The theoretical modelling could capture of key CAES features

Theoretical analysis of Hi-CAES – power and efficiency



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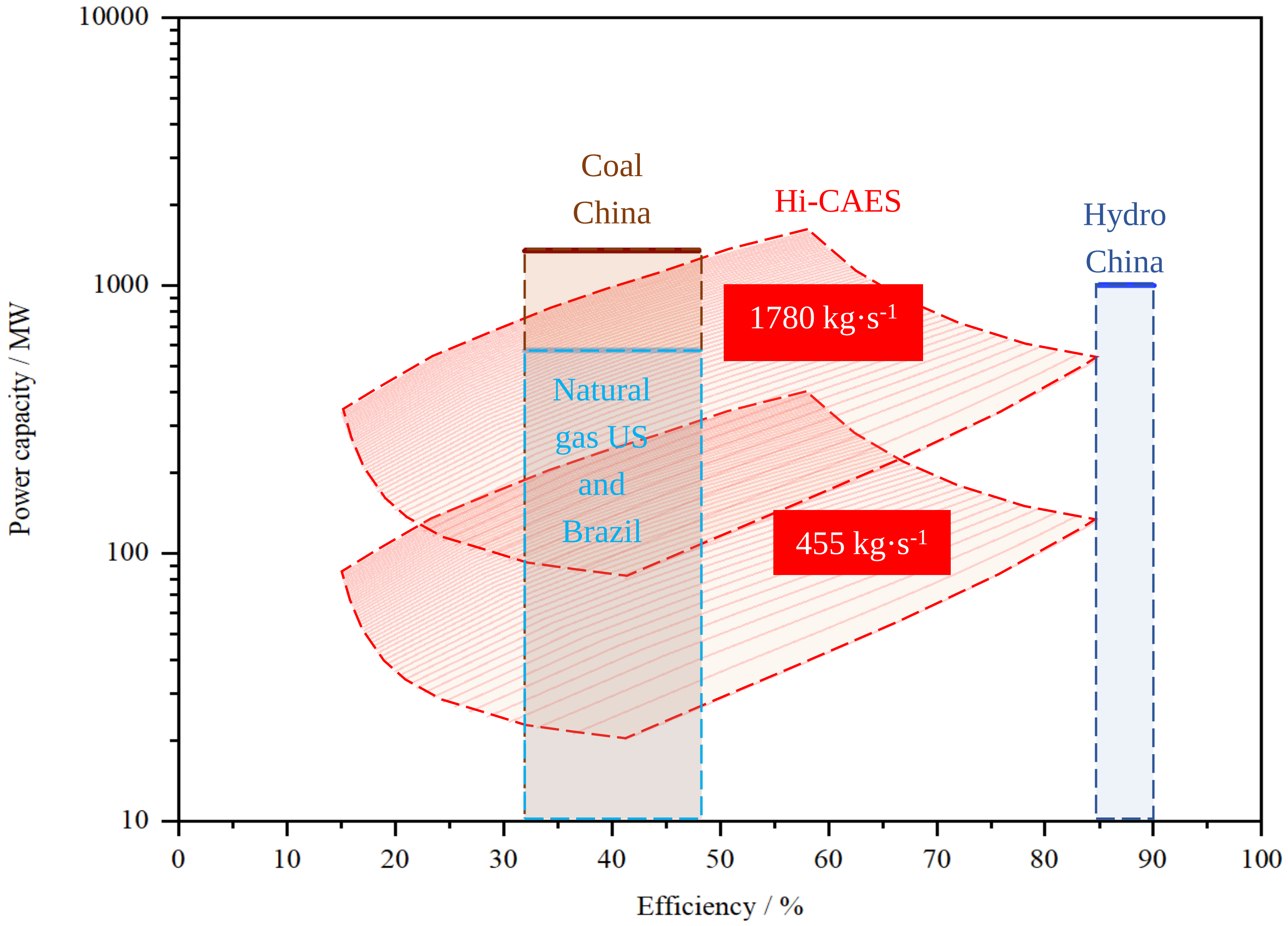
Hi-CAES systems bridge D-CAES and A-CAES for high-power, high-efficiency CAES

Theoretical analysis of Hi-CAES – power and efficiency



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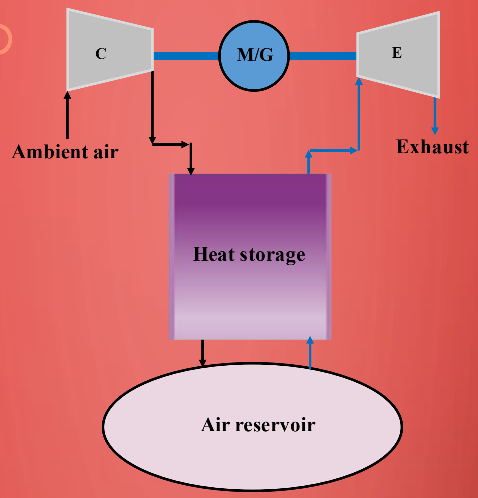
Hi-CAES systems have potential to be competitive to current high-power generators



Hi-CAES: High Performance Compressed Air Energy Storage elevated through High-temperature Thermal Storage

by
Dr. J Sunku Prasad and Prof. Jihong Wang

MDES 2024
MEDIUM DURATION ENERGY STORAGE 2024

FRIDAY, 12 JANUARY 2024

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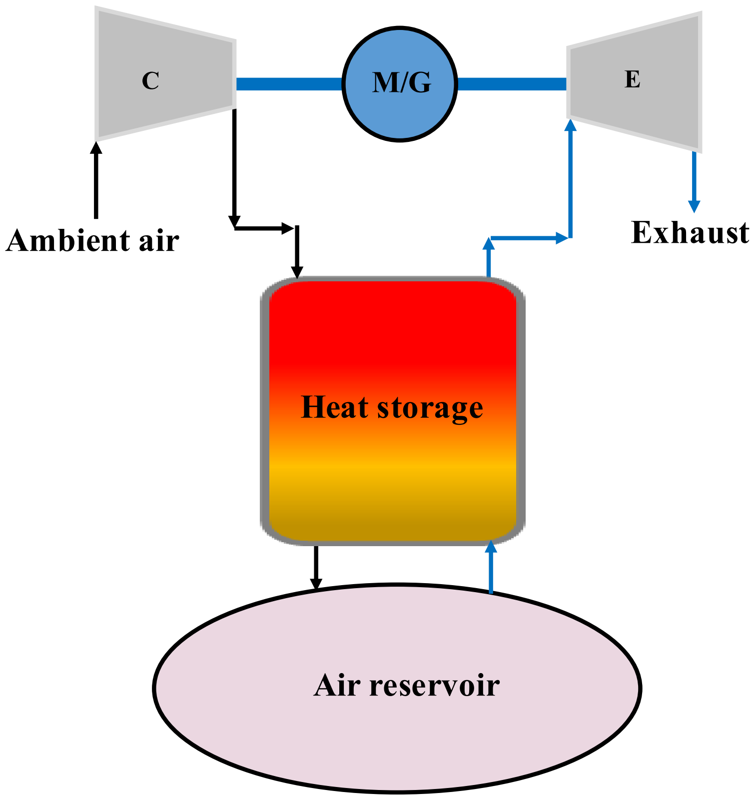
ACAES system



Constant volume cavern

Assumptions

- Air is compressed to maximum cavern pressure and throttled to current pressure of the cavern.
- Inlet temperature to compressor 1 and compressor 2 is same (20°C).
- Charging time = discharging time.
- Mass flow rate is same for both charging and discharging.
- Constant pressure discharge (lower limit of cavern pressure).
- Air is throttled to minimum operating pressure of cavern during discharging.
- The compression heat is stored in a packed bed thermal energy storage (PBTES).
- No mixing as well as heat losses from the PBTES during charging, storage and discharging processes.
- Inlet temperature to the turbine is same as the outlet temperature of the compressor.

Perfectly adiabatic

$$RTE_{ACAES} = \frac{\left(r_{p,t}^{\left(\frac{\gamma-1}{\gamma}\right)\eta_{poly,turbine}} - 1 \right) r_{p,c}^{\frac{\gamma-1}{\gamma\eta_{poly,compressor}}}}{r_{p,t}^{\left(\frac{\gamma-1}{\gamma}\right)\eta_{poly,turbine}} \left(r_{p,c}^{\frac{\gamma-1}{\gamma\eta_{poly,compressor}}} - 1 \right)}$$

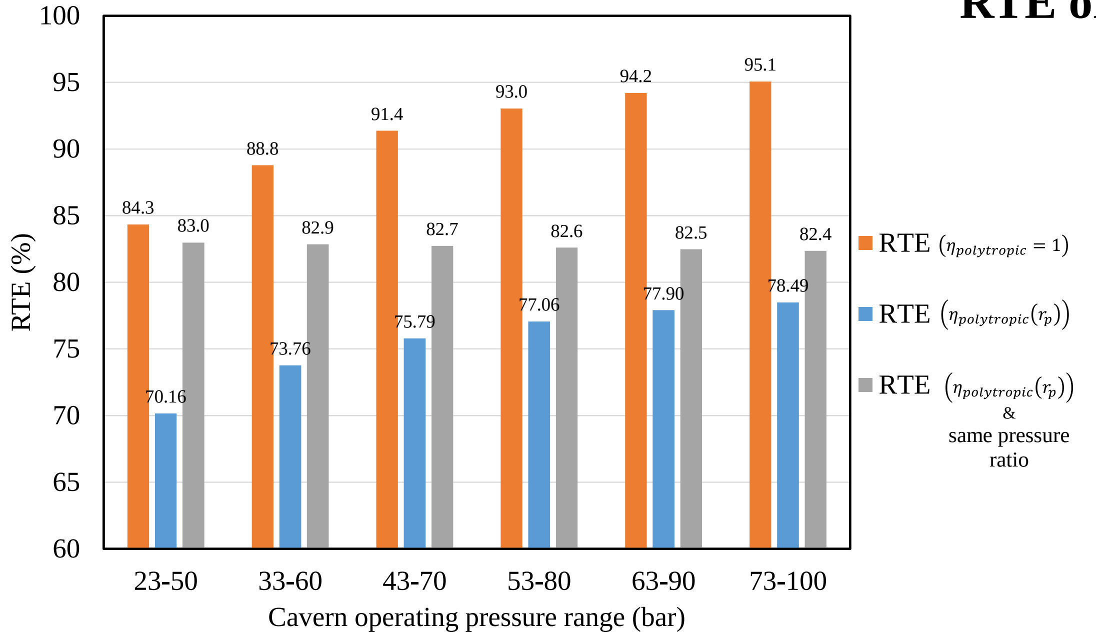
Parameters

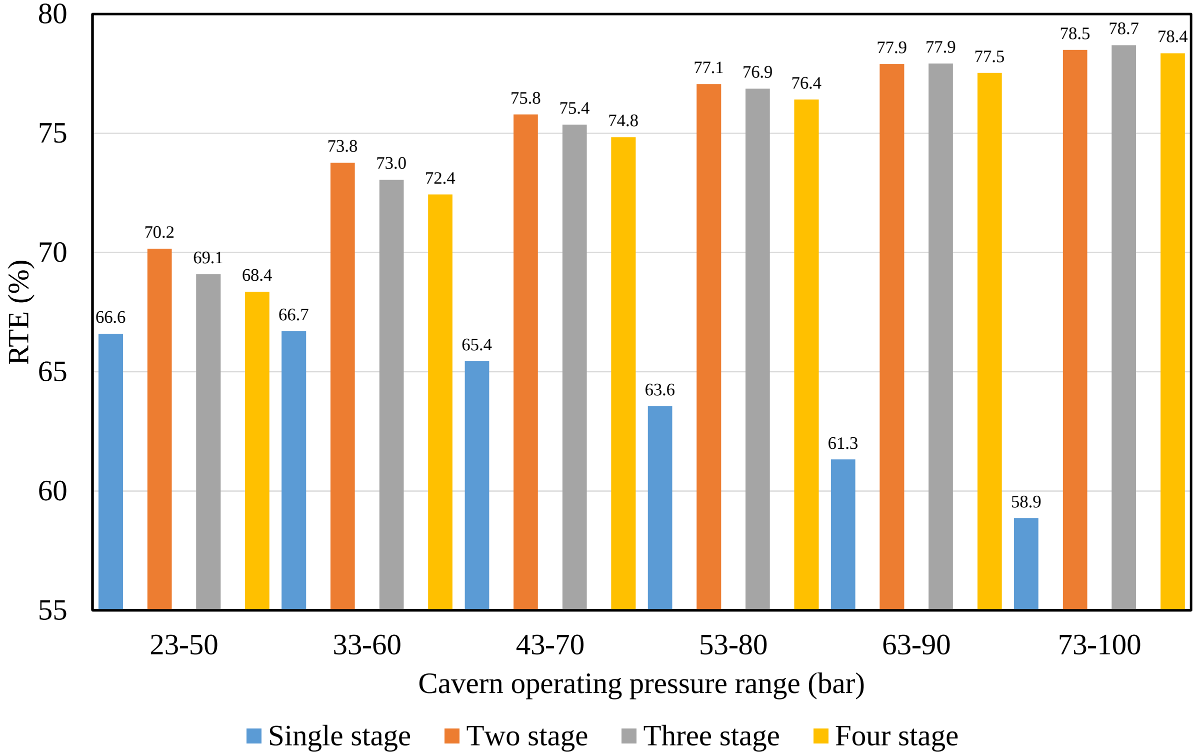
- Cavern operating pressure range
- Number of compression/expansion stages

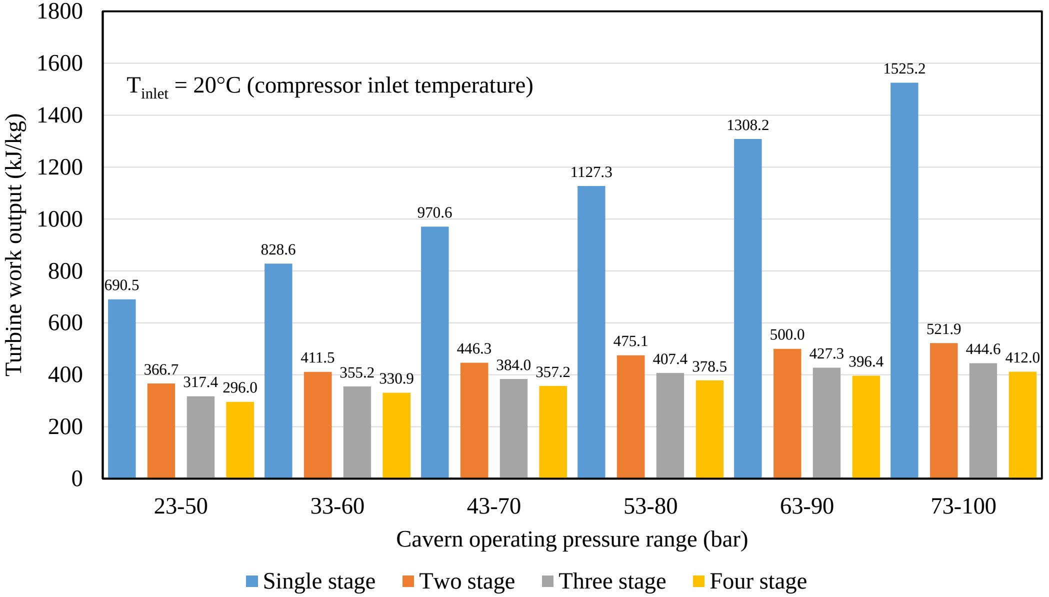
Losses considered

- Throttling losses
- Irreversibilities in compressor and turbine

RTE of ACAES system

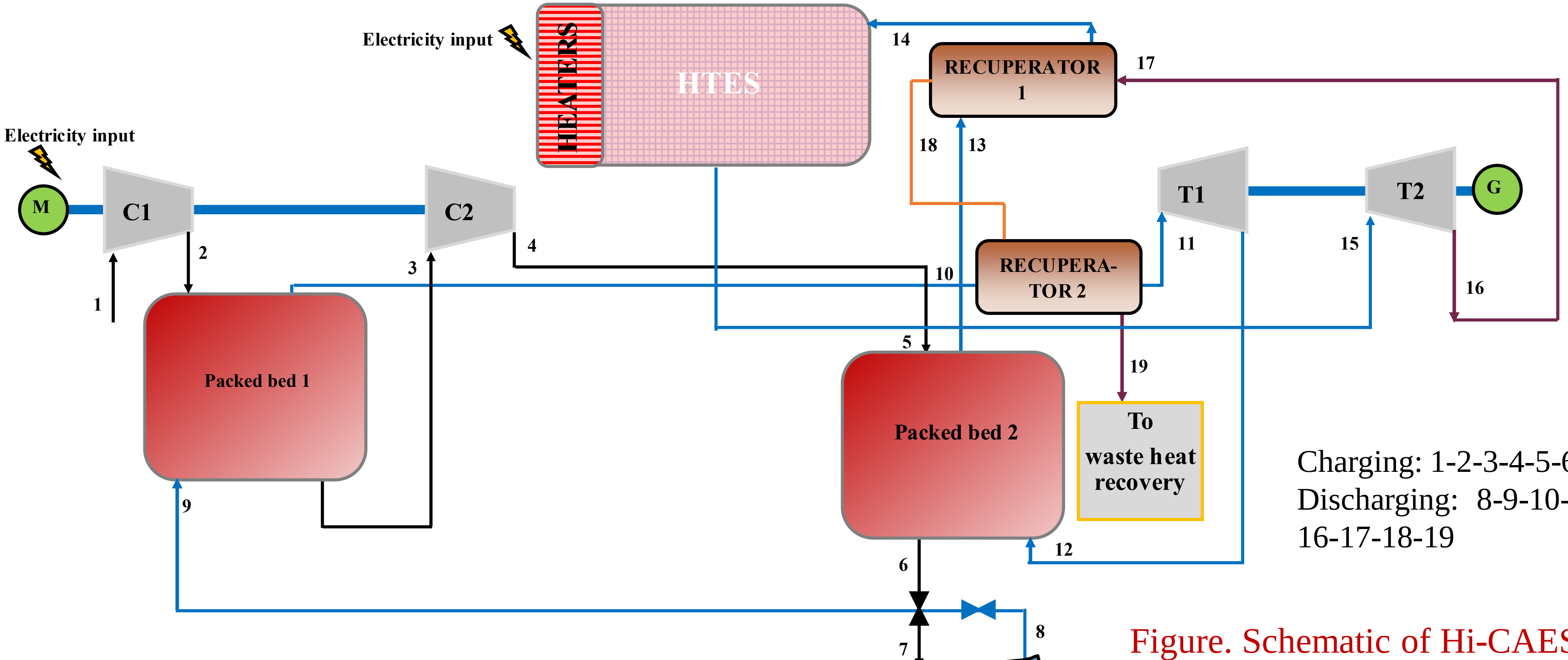






- Maximum RTE of 79.9% is obtained for 143-170 bar beyond which there is no change
- There is no significant change in the RTE after two stages
- Work produced by the turbine is reduced with the increase in the number of stages, which affects the energy storage density.
- Power output of the turbine increases with increase in the cavern operating pressure range
- Outlet compressor temperatures for single stage: 1000-2600°C (practically not possible)

Hi-CAES system



Charging: 1-2-3-4-5-6-7
Discharging: 8-9-10-11-12-13-14-15-16-17-18-19

Figure. Schematic of Hi-CAES system

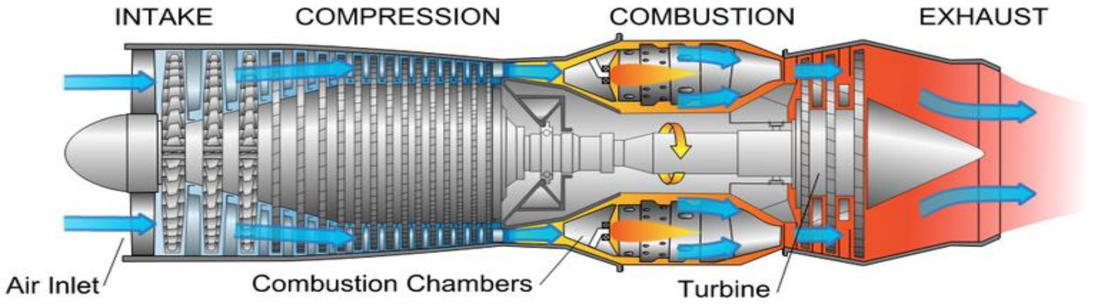


Figure. Diagram of a gas turbine engine

HTES = Combustion chamber

- Direct Joule heating/ HT heat pump
- Indirect heating
- Operating temperatures: 800-1600°C

Hi-CAES system

- Inlet temperature to the second stage turbine is fixed and varied from **800 to 1500°C** (i.e., $\mathbf{T_{15}}$)

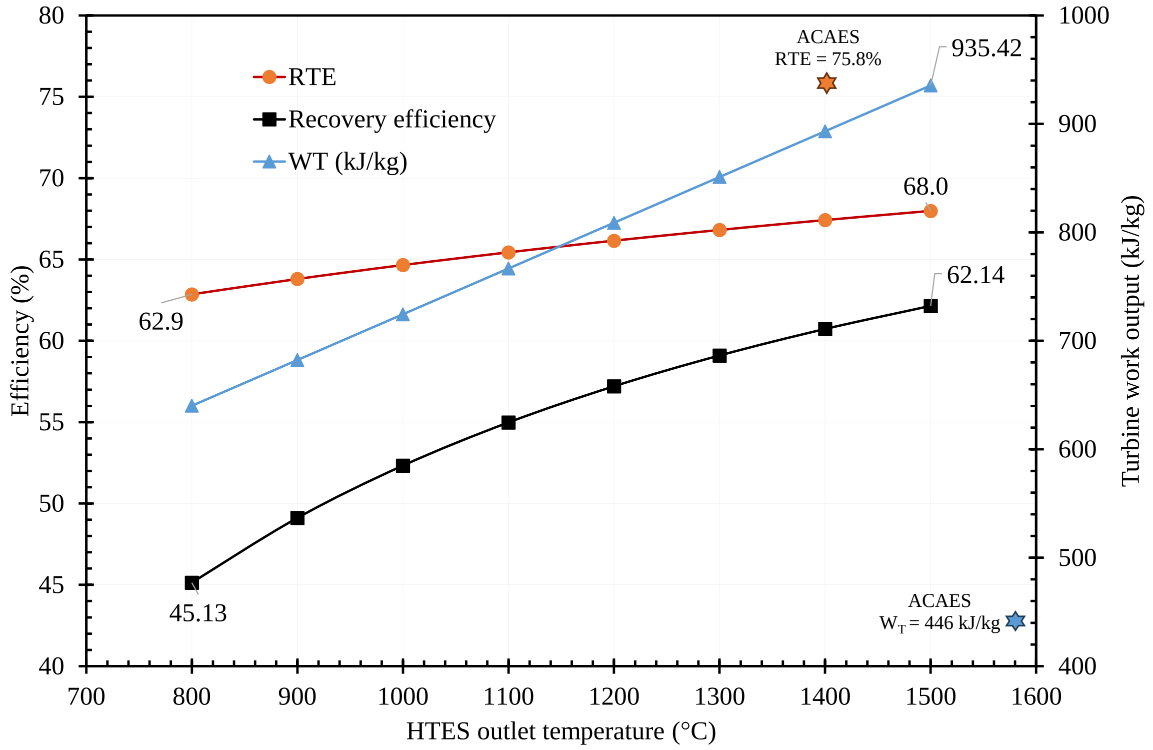
Performance parameters

$$RTE = \frac{Energy\ discharged}{Energy\ charged} = \frac{W_T}{W_C + Q_{HTES}}$$

$$Heat\ recovery\ efficiency = \eta_{recov} = \frac{W_{T_{Hi-CAES}} - W_{T_{ACAES}}}{Q_{HTES}}$$

$$Energy\ storage\ density = \frac{W_T}{Volume\ of\ storage\ reservoir}$$

For Hi-CAES:



- Power capacity of Hi-CAES is doubled than the ACAES.
- RTE of Hi-CAES is 68% than 75.8% for ACAES.
- $T_{exhaust}$ (Hi-CAES) = 310-330°C, which has potential for WHR.

- Hi-CAES provides more flexibility
- Higer power capacity

Note: Effectiveness of recuperator is considered as 0.8

Questions?

Acknowledgement:
Hi-CAES project consortium