Integrating Solar Thermal Capture with Compressed Air Energy Storage

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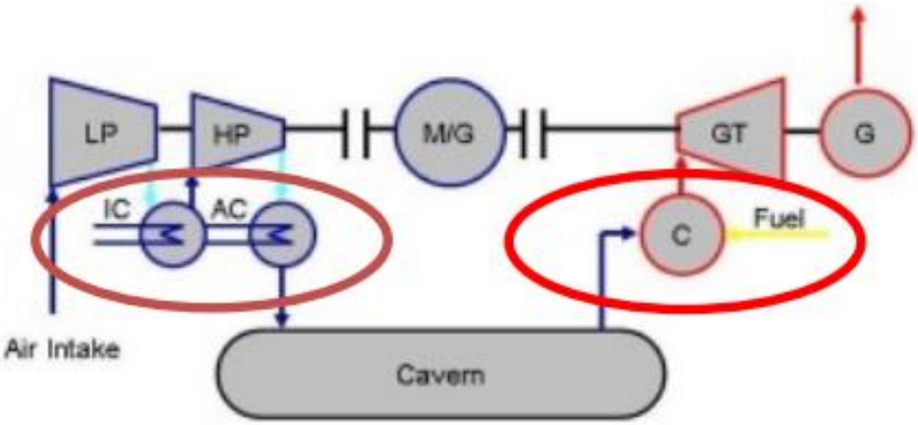
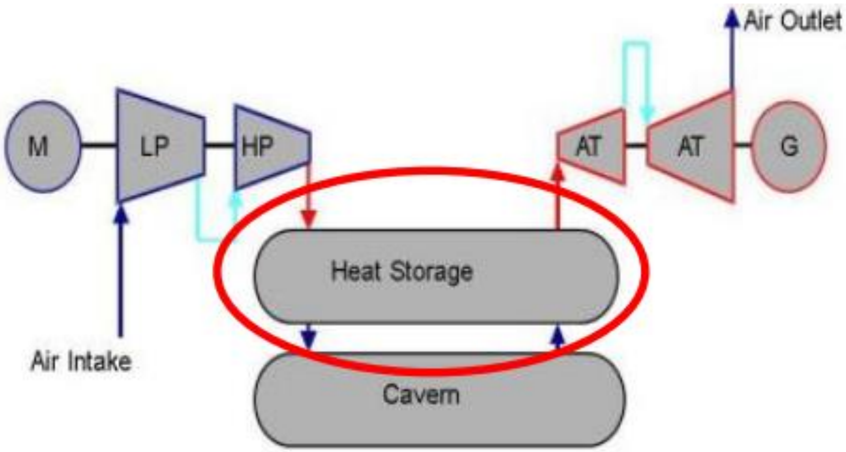
CAES variants



Diabatic CAES
- Heat of compression lost;
- Reheat using natural gas.



Adiabatic CAES
- Heat of compression stored and re-used during discharge.

Isothermal CAES
- Compression and expansion take place at near ambient temperature, with environment as heat store.

Choices in CAES

Overall architecture

- Diabatic / Adiabatic / Isothermal

Air storage

- Above ground / underground / underwater
- Isochoric / Isobaric air storage

Thermal energy storage (TES)

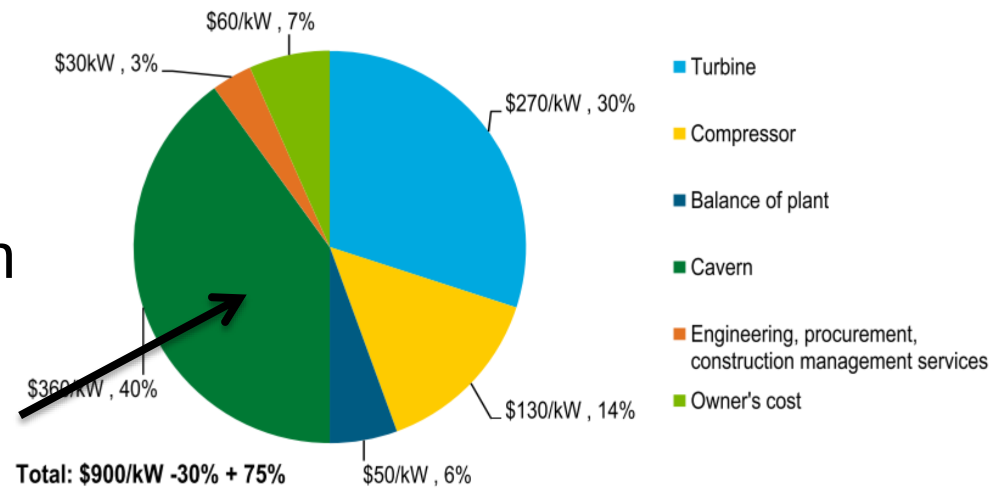
- Pressurised water / packed bed thermocline / phase change / molten salt
- Direct heat exchange with TES / indirect (with HX)

Dominant costs

2012 Black & Veatch study of 262 MW plant with 15 hours of storage predicted capital cost of $900/kW (c.f. £900/kW for Larne).

Cavern cost accounts for 40%. High fixed and low marginal costs of salt cavern mean this depends only weakly on capacity.

Cavern



For small-scale CAES, the cost of pressure vessels scales with gauge pressure x volume.

Use of pressure containment

Exergy in isochoric store with pressure ratio, r

$$B_{HP-air} = \left(p_0 \times V_{store}\right) \times \left(r \log r - r\right)\Big|_{r=(p_L/p_0)}^{r=(p_H/p_0)}$$

Exergy in isobaric store with press. ratio, r

$$B_{HP-air} = \left(p_0 \times V_{store}\right) \times \left(r \log r - (r-1)\right)$$

Or, if the HP air is displaced naturally by hydrostatic head (removes energy input for pumping)

$$B_{HP-air} = \left(p_0 \times V_{store}\right) \times \left(r \log r\right)$$

e.g. $p_H = 100\, p_0$, $p_L = 50\, p_0$

214.9

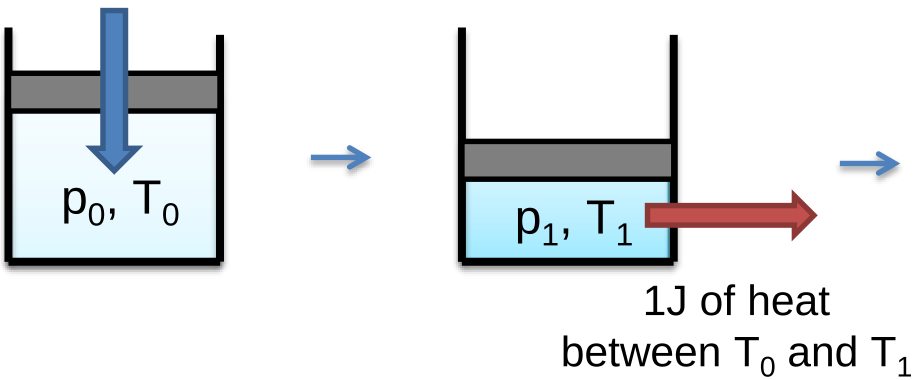
361.5

460.5

Compressing and cooling air

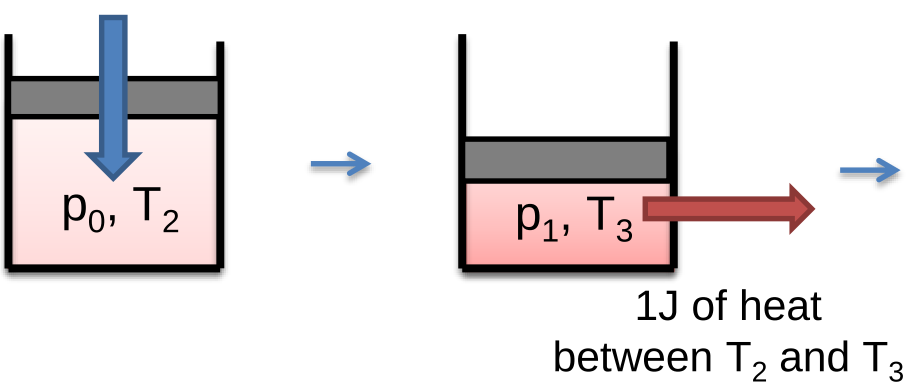
Compression | Cooling | Result

1J of work on ambient air



All exergy in pressurised air (if $T_0 \approx T_1$)

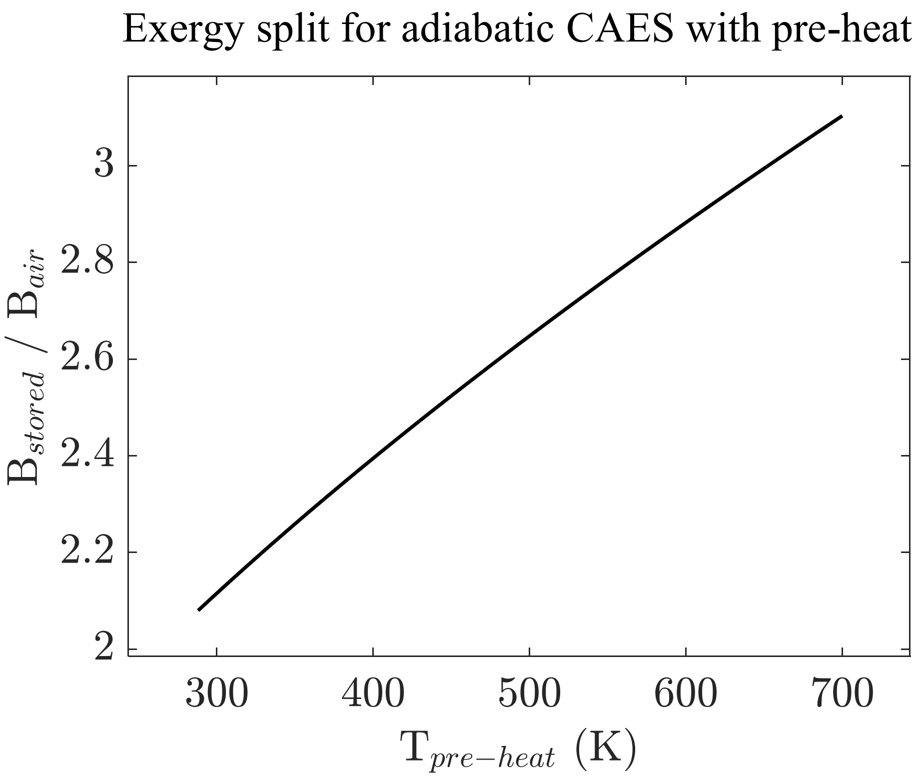
1J of work on pre-heated air



Exergy split between air and high temperature heat

Pressurised air vs thermal storage

Modelled as reversible with isobaric storage



Storage pressure	80 bar
Max temperature (after compression)	1000K

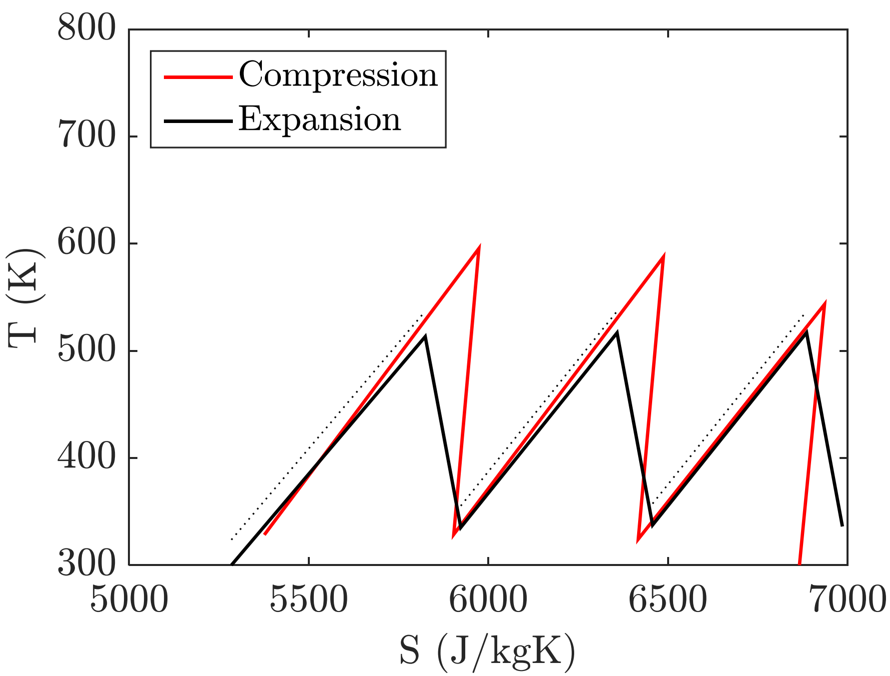
	B_{stored}/B_{air}
Isothermal CAES	1.00
Adiabatic CAES	2.08
Adiabatic CAES with pre-heat to 660K	3.01

For a given pressure store size, pre-heating air increases the total exergy stored significantly.

Effect of pre-heated compression

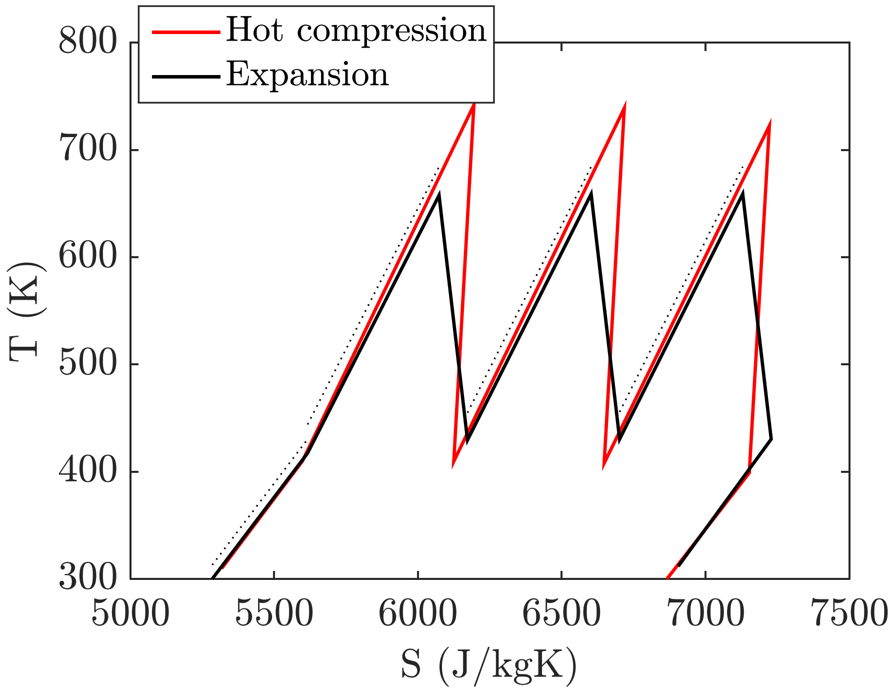
200kW / 3200kWh system with isobaric air storage
3 stage compression to 250 bar, 69% roundtrip efficiency

No pre-heat



Air store size: 74m³

Pre-heat to 400K



Air store size: 58m³

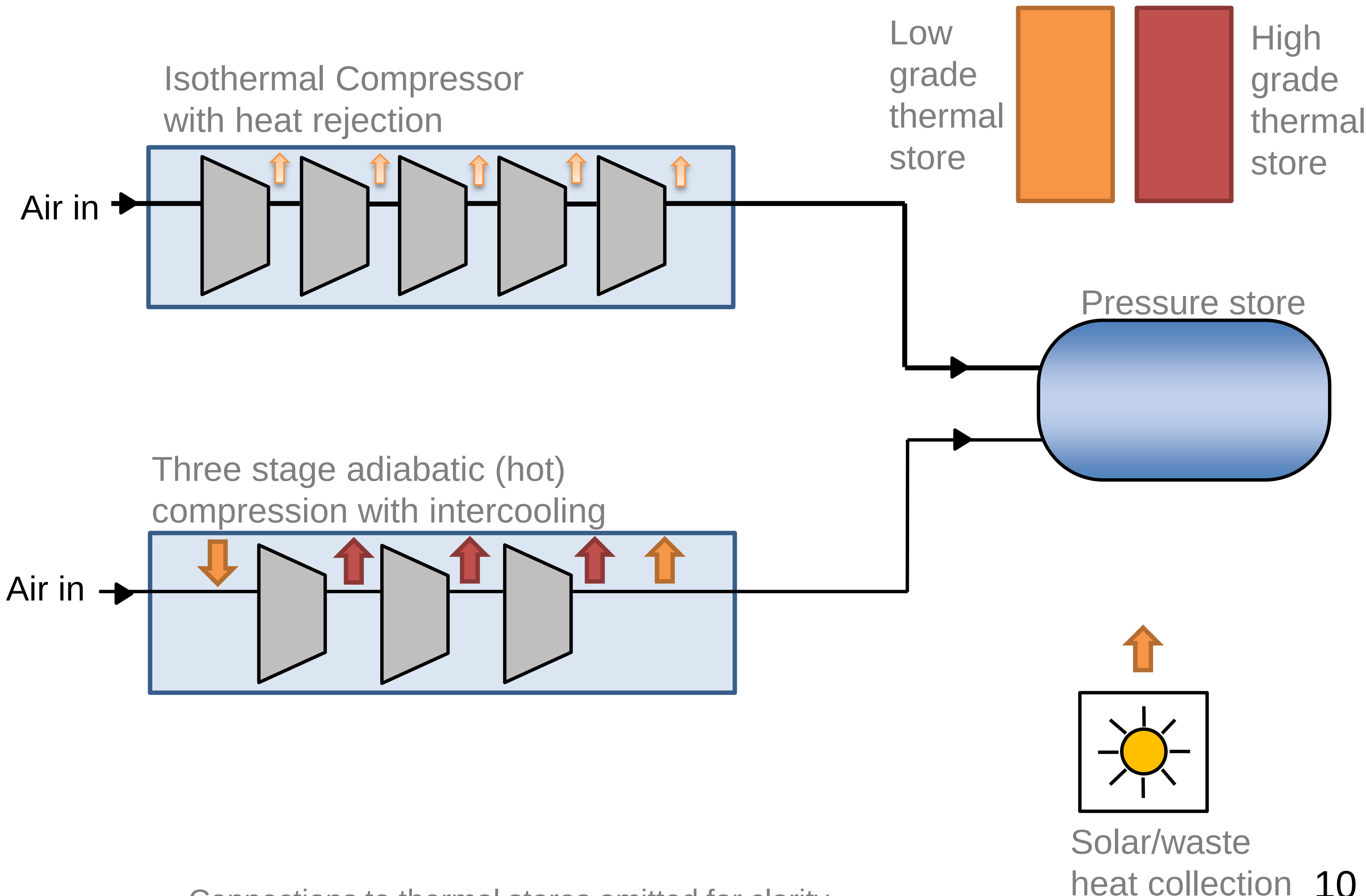
28% smaller

Solar-integrated CAES

Pre-heated CAES variant lends itself to integration with solar thermal generation.

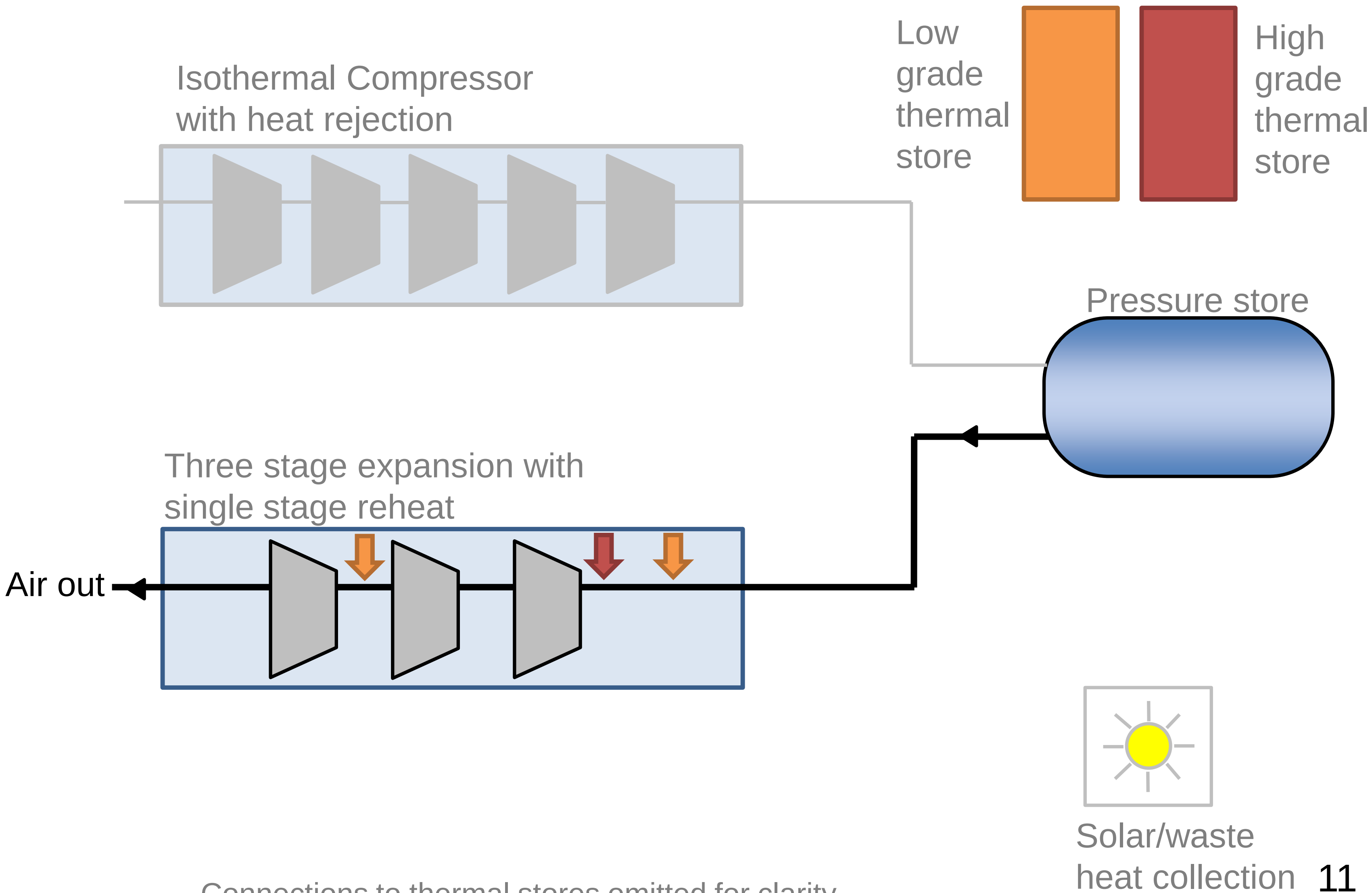
Resulting system combines grid-scale energy storage with large-scale generation.

Solar-integrated CAES - charging



Connections to thermal stores omitted for clarity

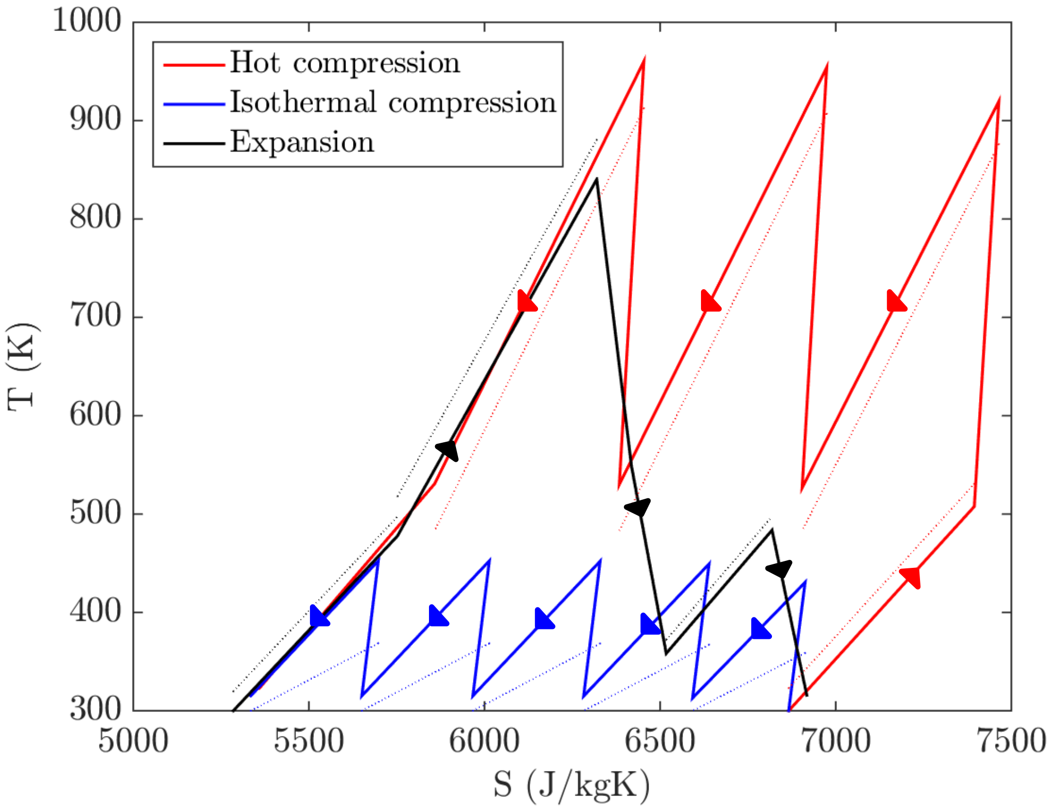
Solar-integrated CAES - discharging



Connections to thermal stores omitted for clarity

Solar-integrated CAES

200kW/3200kWh system with isobaric air storage
3 stage compression to 250 bar



Applications

Most relevant where there is strong solar resource/waste heat and low-cost pressure storage, such as salt caverns or deep water.

Candidate locations include:

- Chile
- Mediterranean countries, esp. Spain
- Gulf of Mexico
- India

Where solar resource is not available, waste gases may be used as a least-worst solution.

Conclusions

A variant on CAES incorporating pre-heating and solar thermal capture has been proposed.

Preliminary modelling indicates greatly increased exergy storage for a given pressure store.

Further work

Techno-economic assessment of costs and value of generation and storage service provided.

Engineering design of high-temperature compression machinery.

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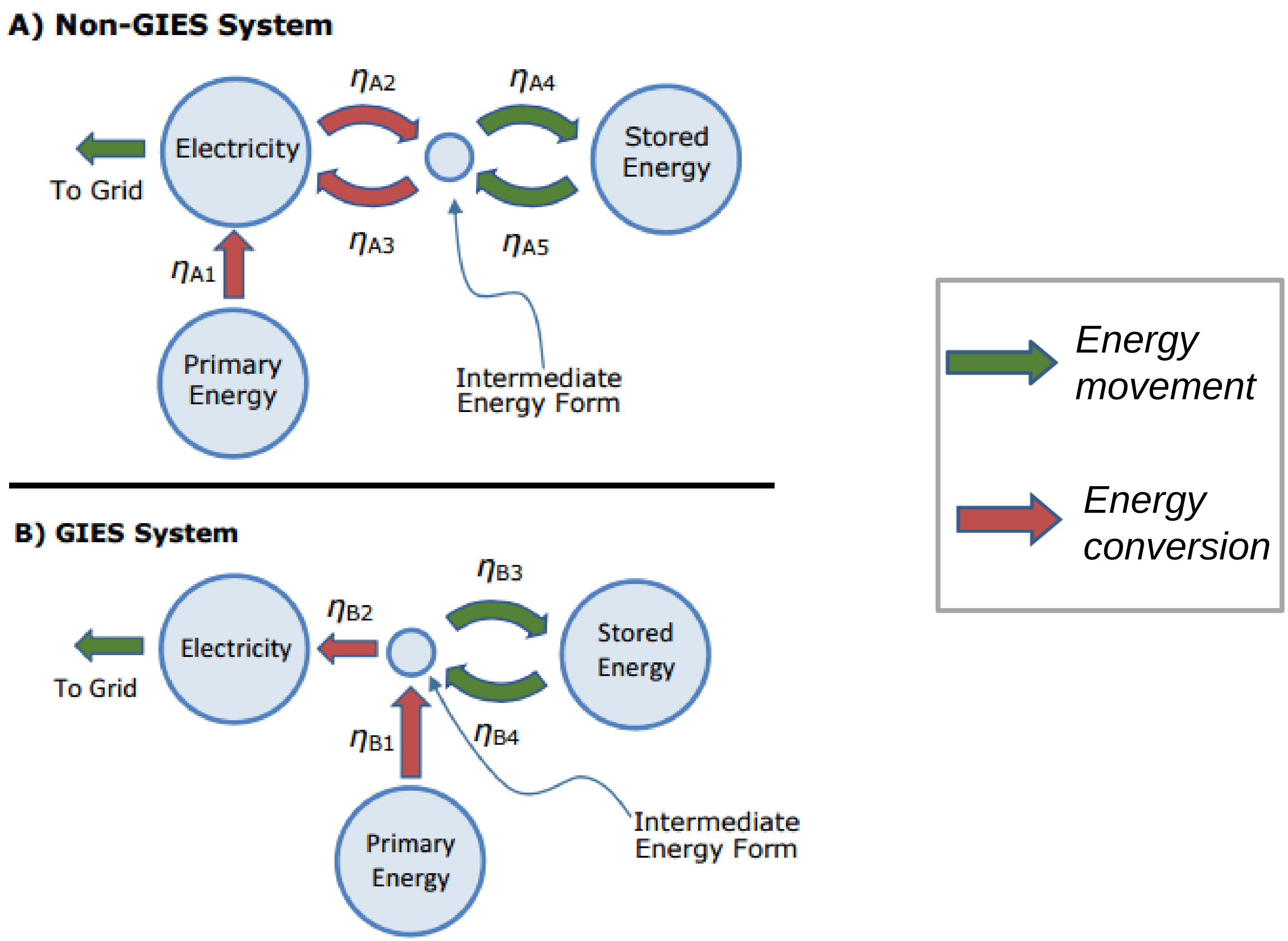
GIES versus non-GIES



From Garvey SD et al, “On Generation-Integrated Energy Storage,” Energy Policy, vol. 86, pp. 544-551, Nov 2015.