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Feedheat-integrated storage for load-following nuclear

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Outline

i. Why integrate with the feedheat train?

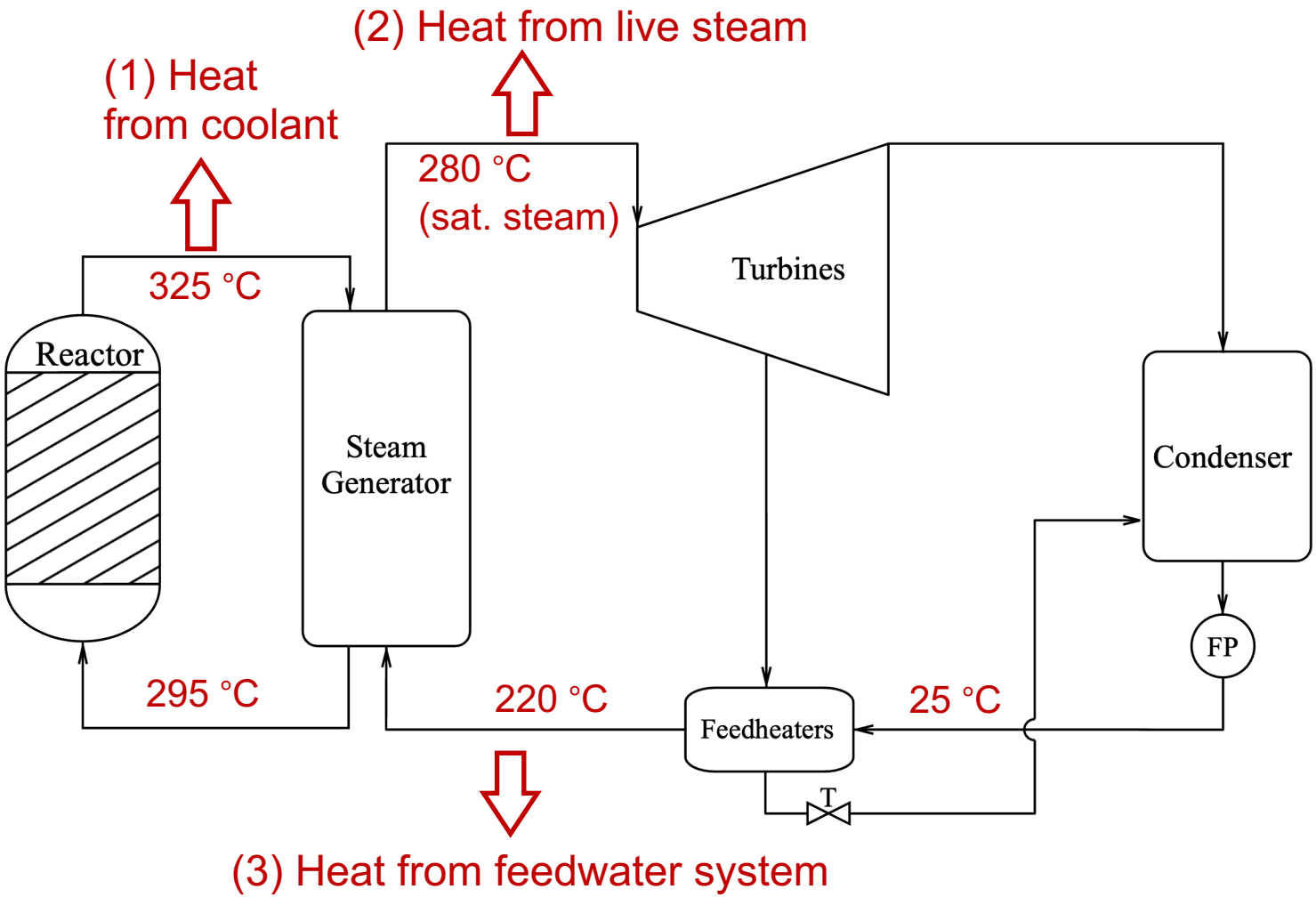
ii. Plant performance and storage options

iii. Optimisation of system

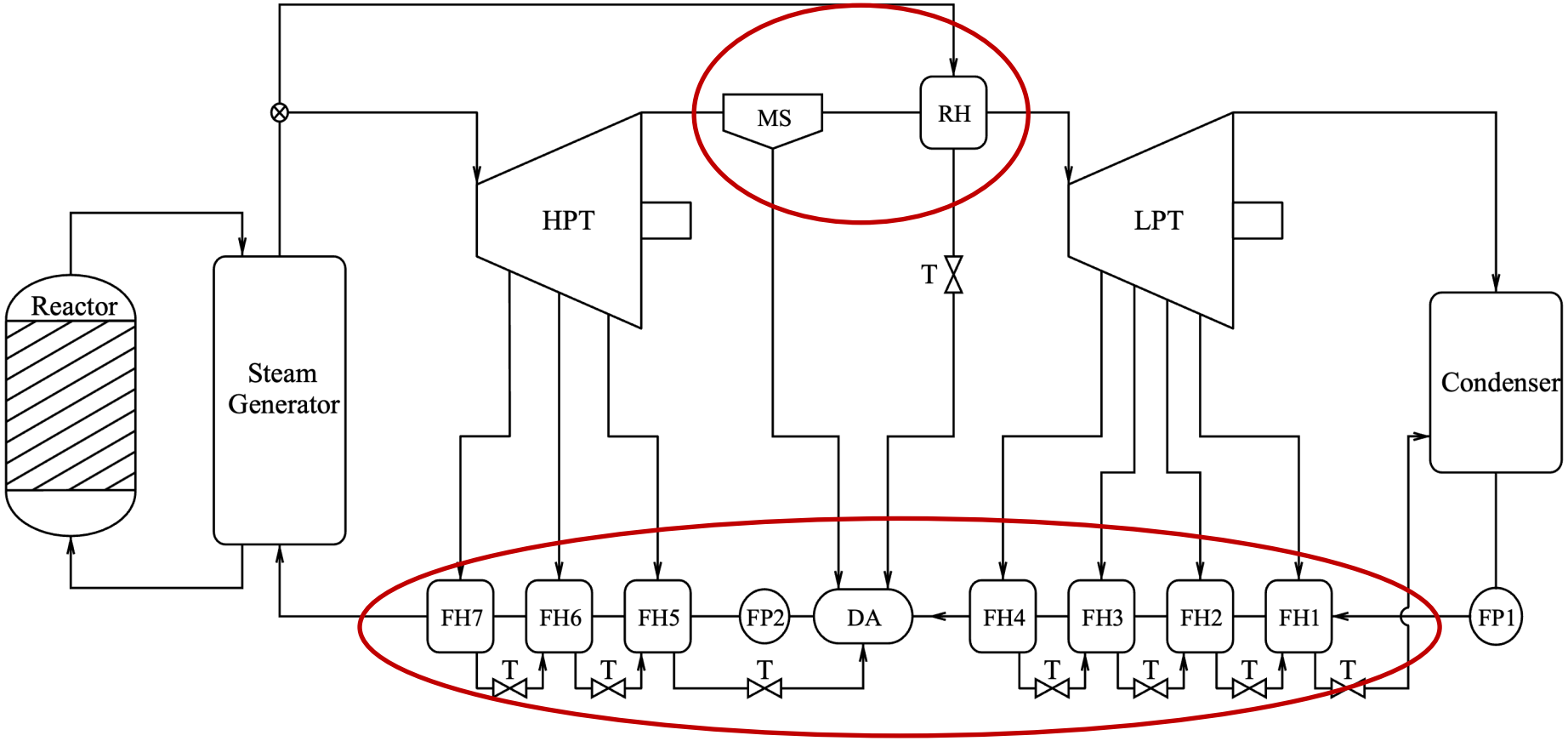
Why integrate? Why the feedheat train?

- Make use of existing components – i.e., lower costs
- Efficient

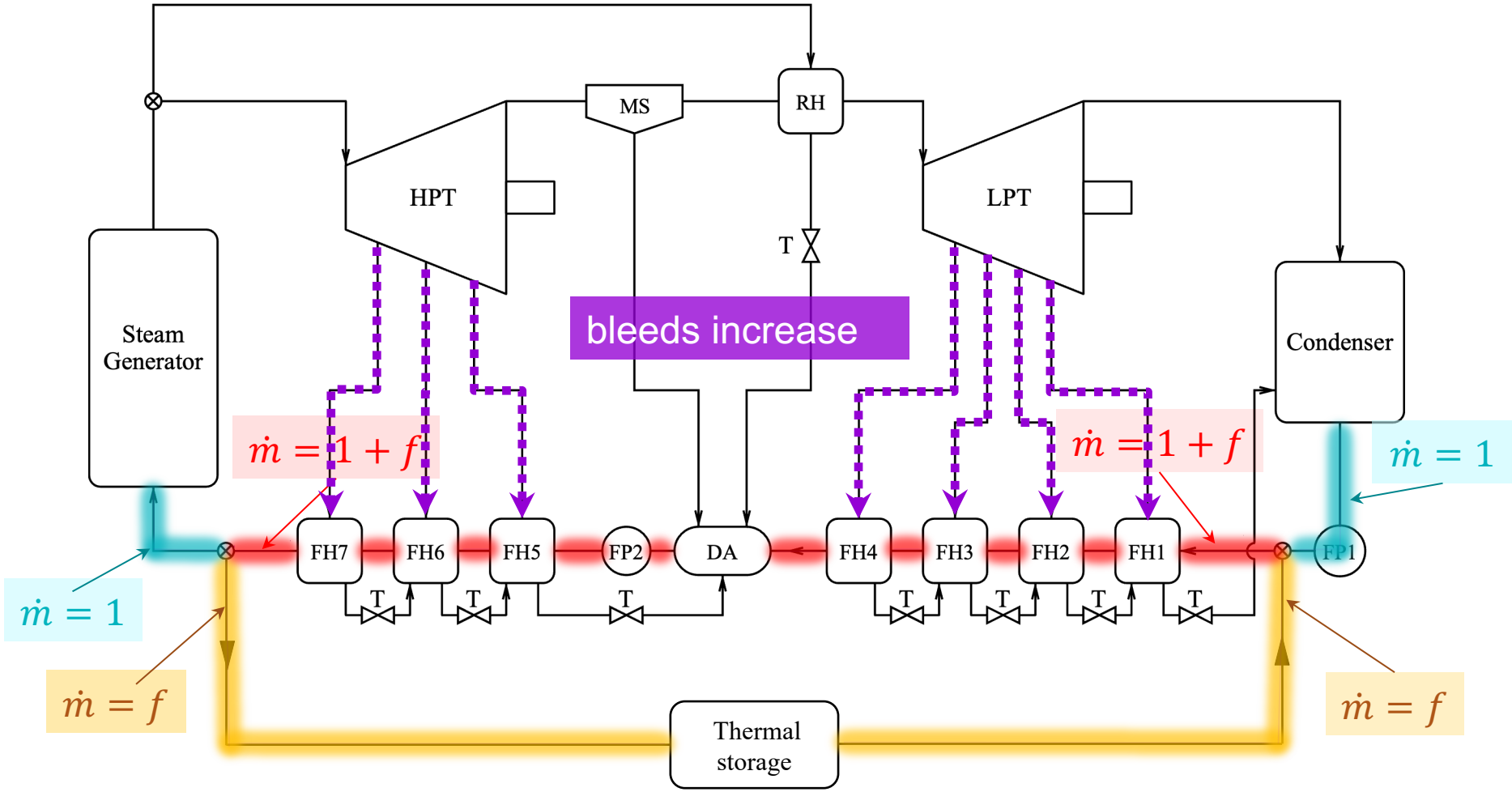
Locations for storage integration



Detailed nuclear plant

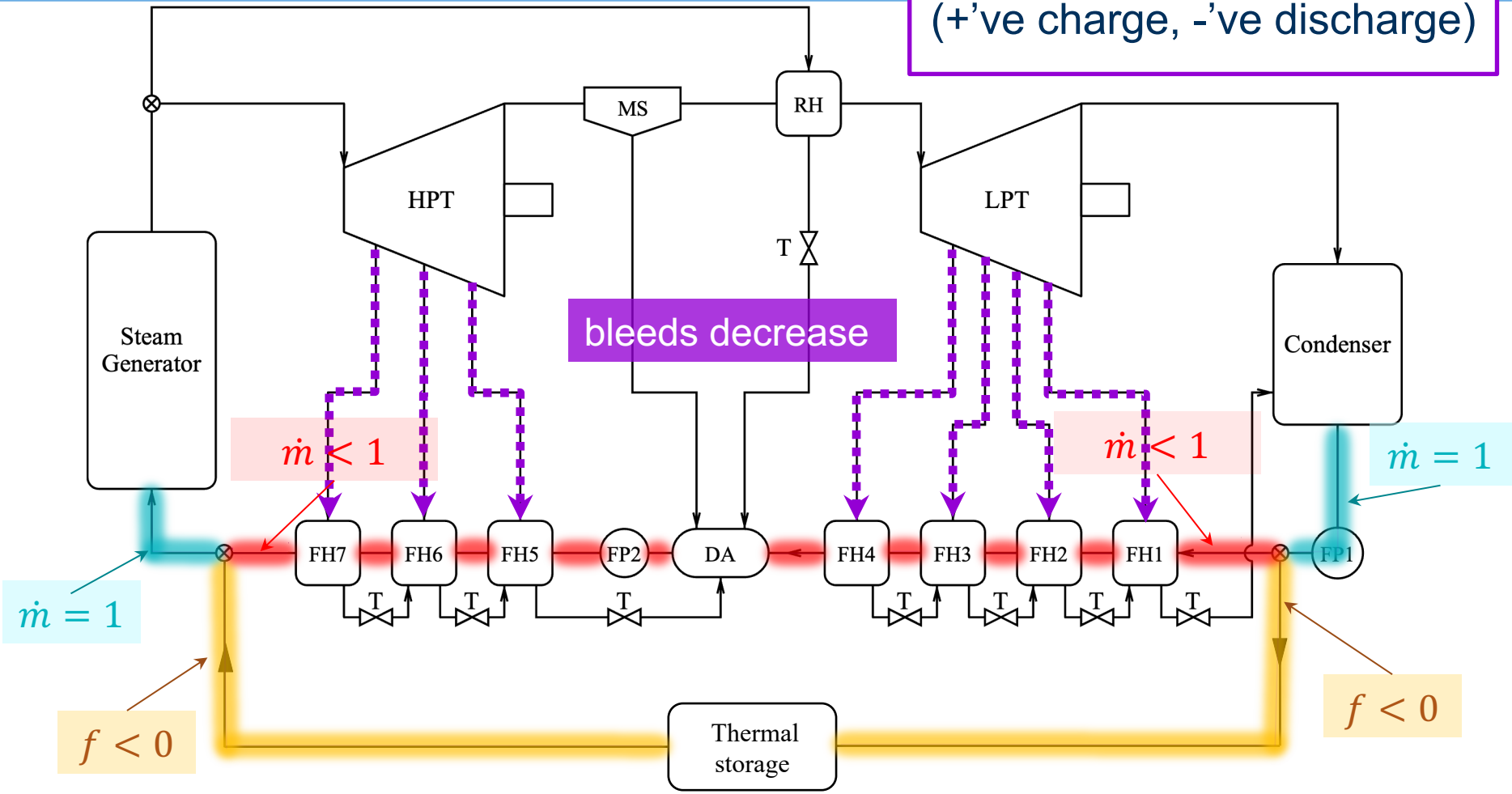


Details of feedheat integration – charge

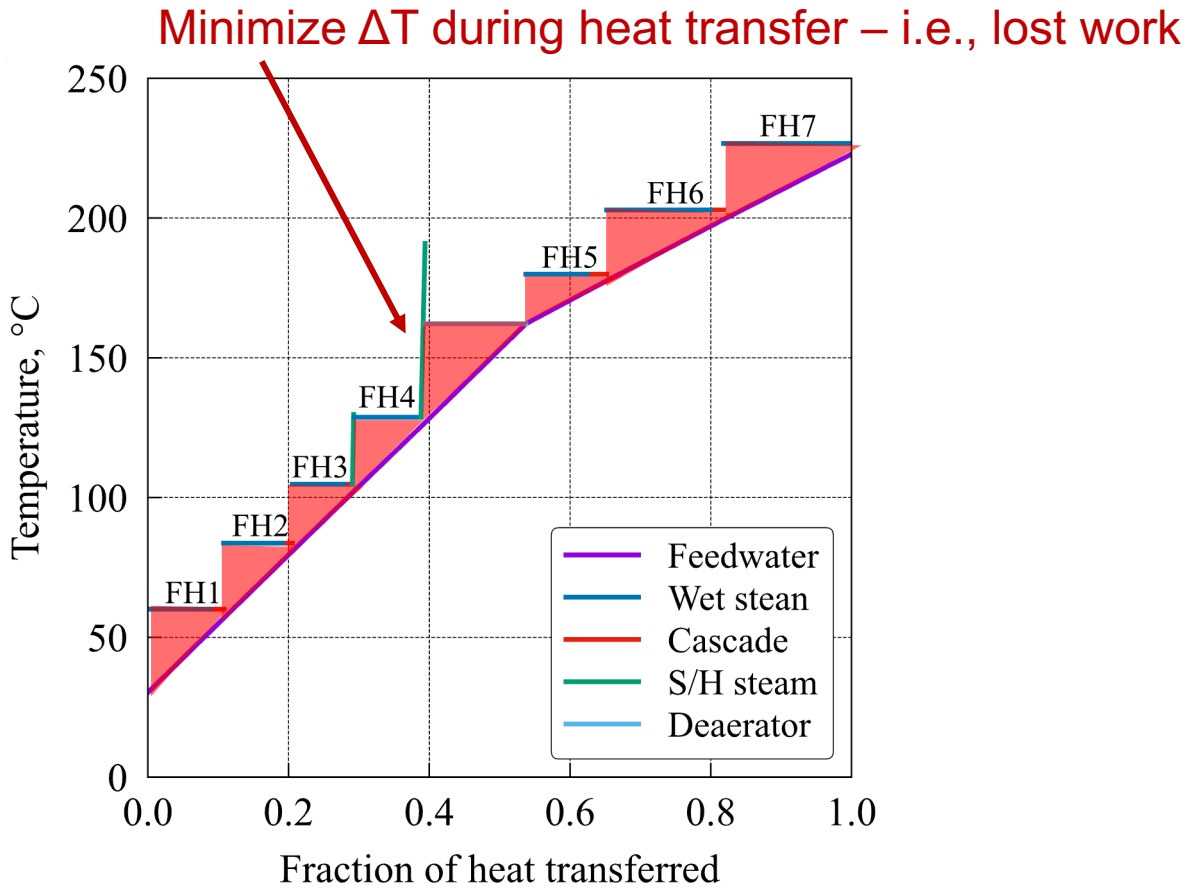


Details of feedheat integration – discharge

f = flow diverted to store
(+'ve charge, -'ve discharge)

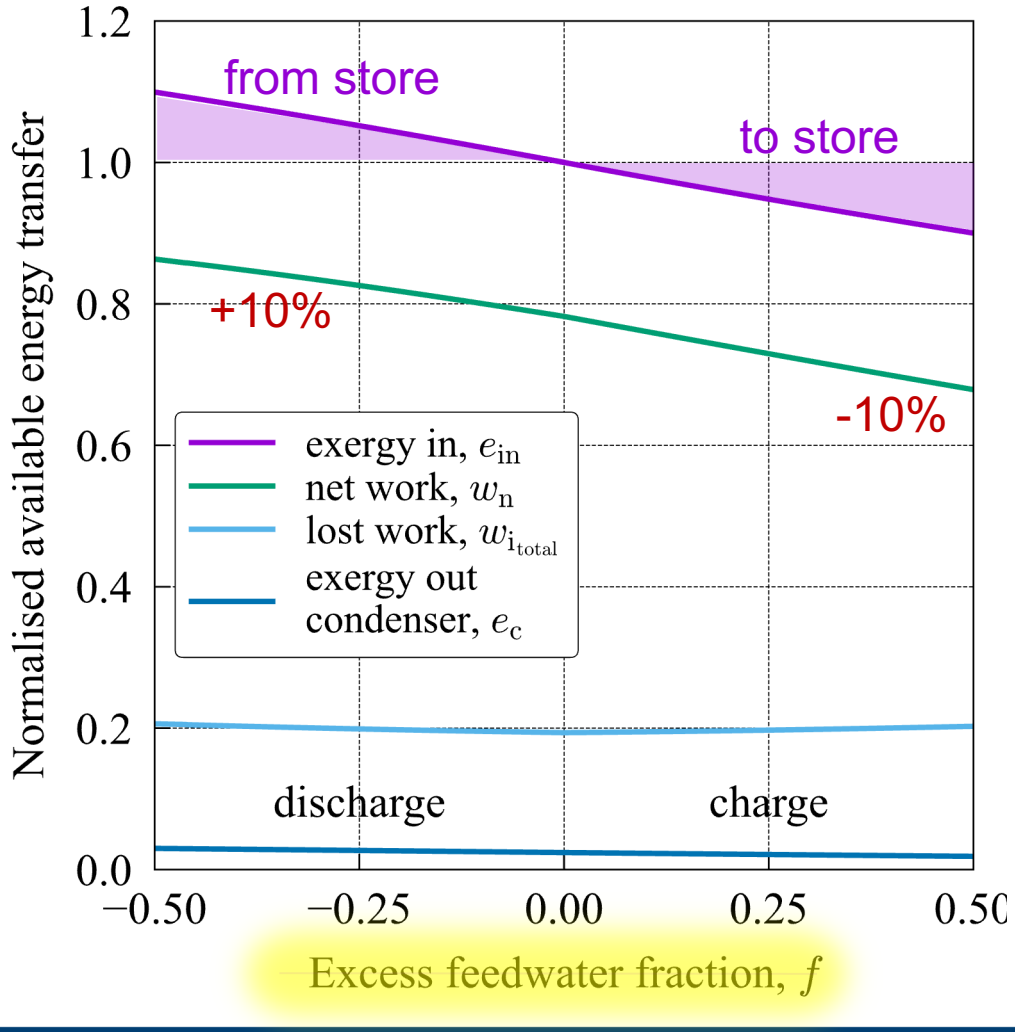


Why is the feedheat train attractive?



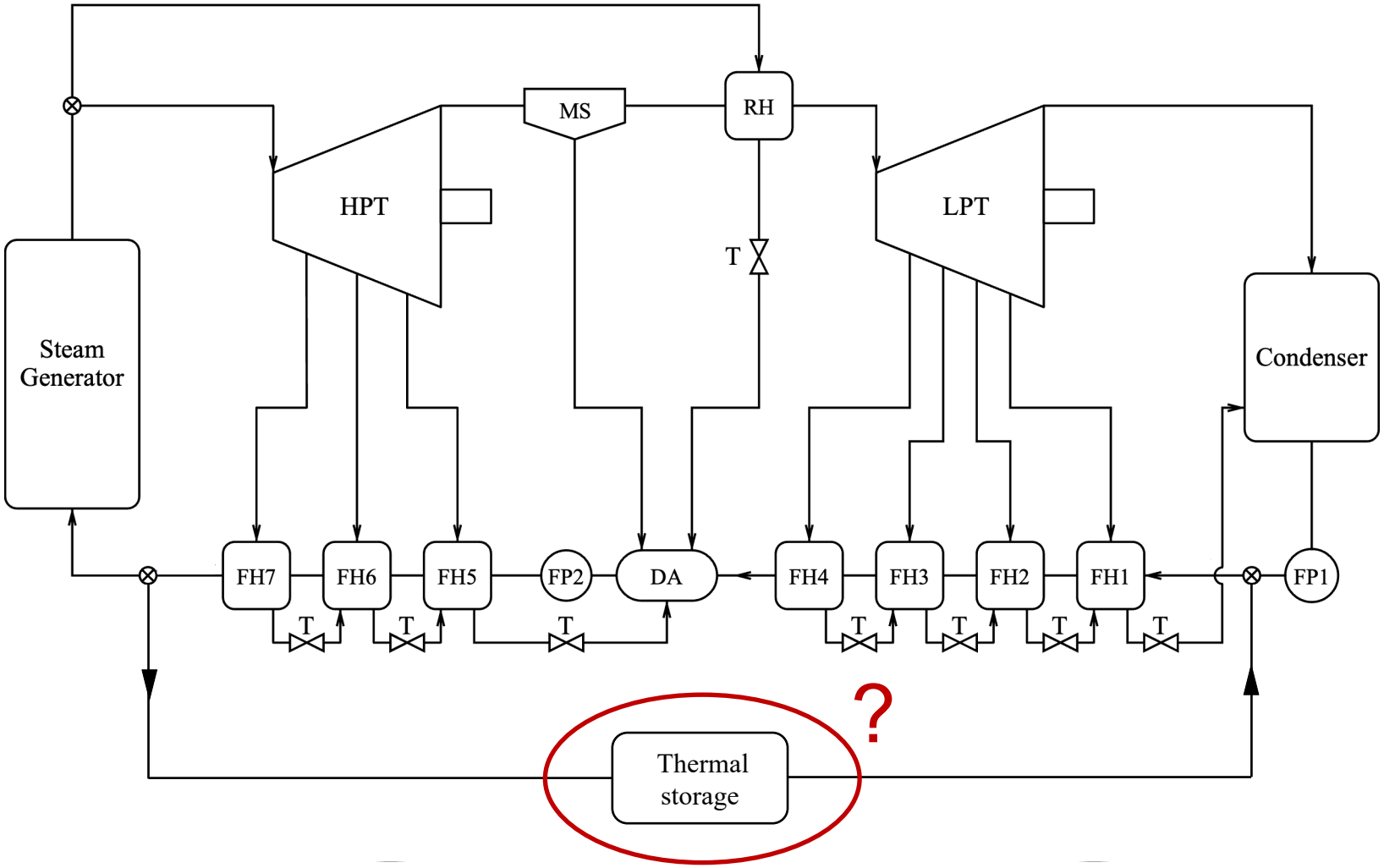
Plant performance & storage options

Plant performance



[1] Lazenby *et al.*, *IMechE Part A* (2024)

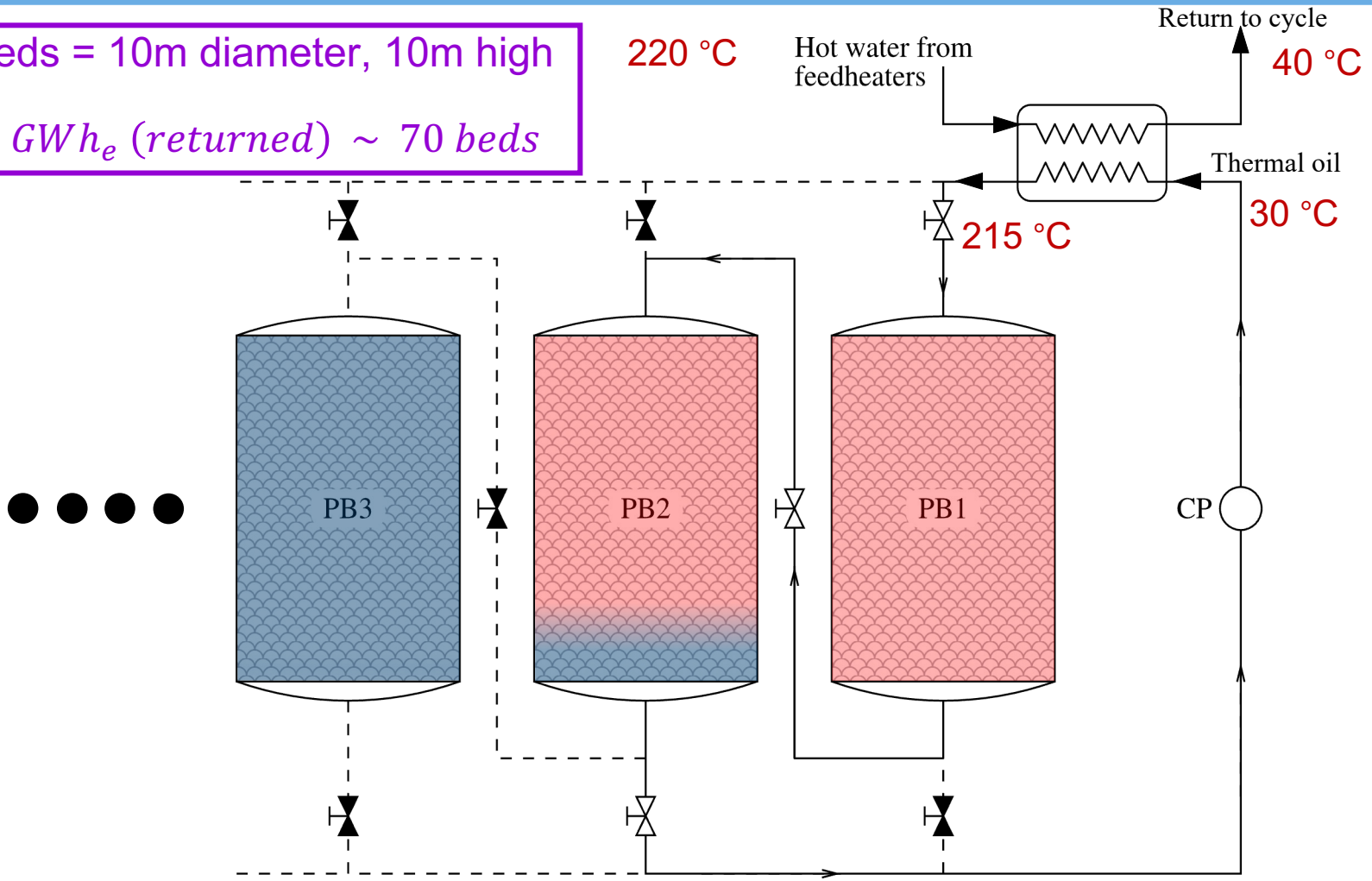
Storage options?



Thermal oil and multiple packed beds

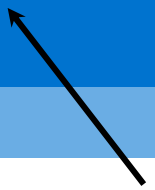
Beds = 10m diameter, 10m high

$1\ GWh_e\ (returned) \sim 70\ beds$



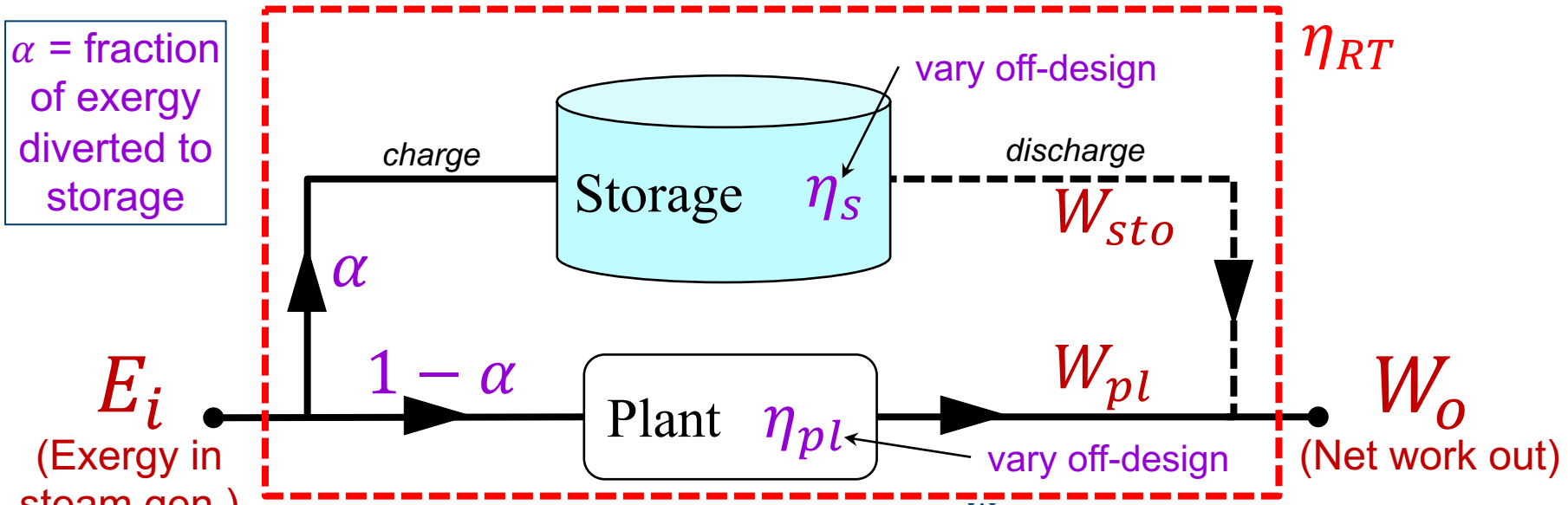
Optimisation of system

What is the "best" design of the FH train & storage?



- efficient - objective #1
- low cost - objective #2

Efficiency definitions – Objective # 1



- η_{pl} = plant efficiency = ~~$\frac{W_o}{E_i}$~~ = $\frac{W_{pl}}{(1-\alpha)E_i}$
- η_s = storage efficiency = $\frac{W_{sto}}{(\alpha)E_i}$
- η_{RT} = round-trip efficiency = $\frac{+\Delta W_{dis}}{-\Delta W_{chg}}$
- η_{TP} = throughput efficiency = $\left(\frac{W_o}{E_i}\right)_{chg-dis}$

Capital cost – Objective # 2

total capital cost = capital cost of power components + capital cost of energy components

$$C_t = C_p + C_e$$

$$= Z_p(P_d) + Z_e(P_d t_d)$$

marginal cost of power ($/MW)

i. marginal increase in FH
ii. marginal increase in turbine
iii. marginal increase in condenser
iv. storage HEX

marginal cost of energy ($/MWh)

i. packed beds
   - vessels
   - insulation
   - rock
ii. thermal oil

20-30 $/kWhe [1,2]

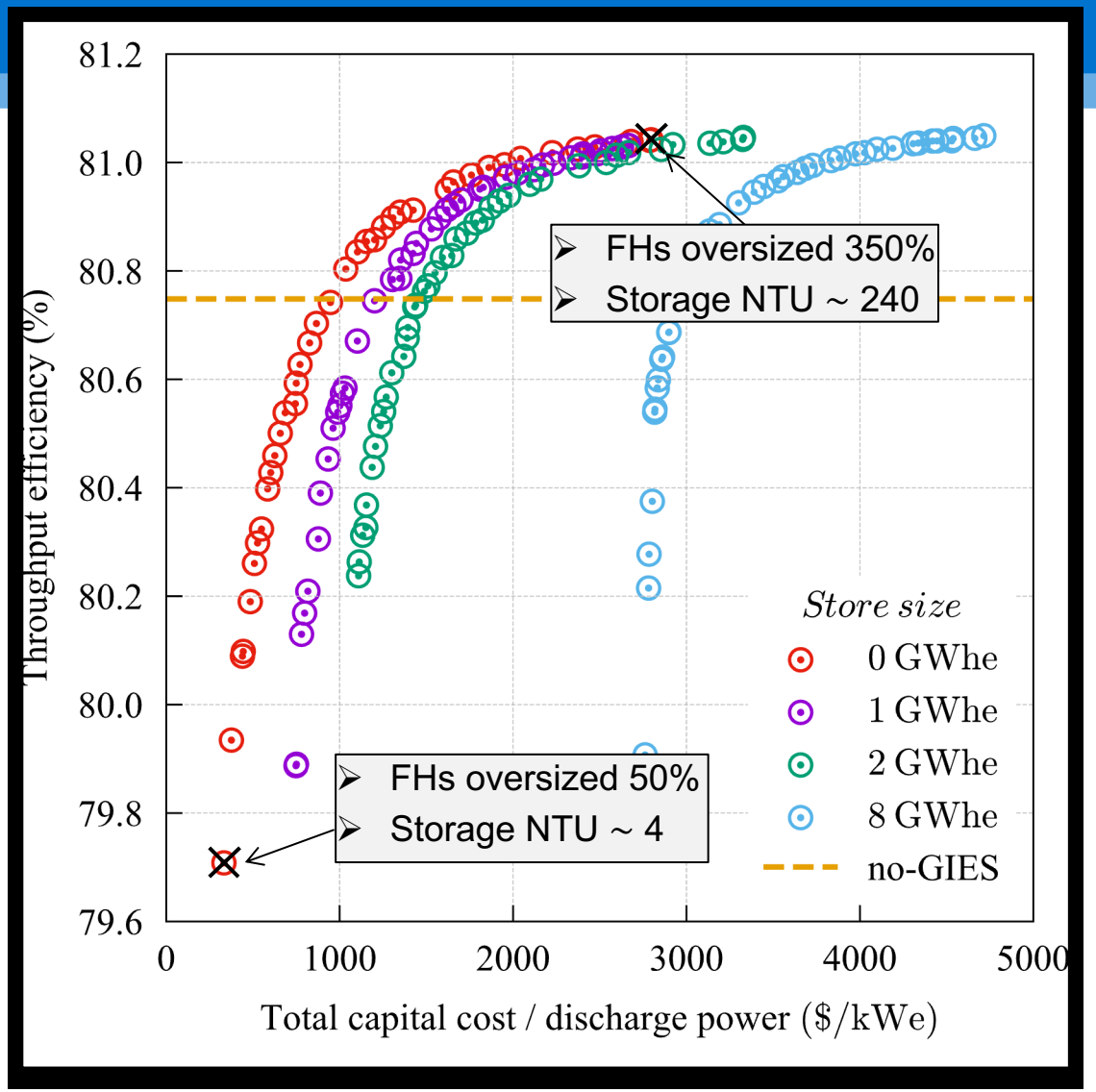
[1] Lazenby *et al.*, *IMechE Part A* (2024)
[2] McTigue *et al.*, *Applied Energy* (2018)

Optimisation results

- NSGA-II (genetic algorithm)
- Objectives (2):
  - ↑ throughput efficiency
  - ↓ total capital cost / kWe
- Design Variables (8):
  - FH area x 7
  - storage NTU

$$C_t = Z_p\, P_d + Z_e\, P_d t_d$$

$$\frac{C_t}{P_d} = Z_p\ + Z_e\, t_d$$



Summary

Summary

- Paradigm shift of “generation-integrated” energy storage:
  - High efficiency and low cost

- More nuclear on the grid:
  - (1) Less overall energy storage needed [1]
  - (2) Ideal for storage integration
  - Nuclear roadmap = 24GW by 2050

- Proposed feedheat system:
  - 100MWe, ‘tens’ of GWhe of storage
  - Marginal cost of energy: 20-30 $/kWhe
  - Marginal cost of power: 350-1000 $/kWe

Questions?

[1] Cebulla *et al.*, *Journal of Cleaner Production* (2018)