



# Enhancing Metal Hydride – Phase Change Material Hydrogen Storage Systems Efficiency with Expanded Graphite

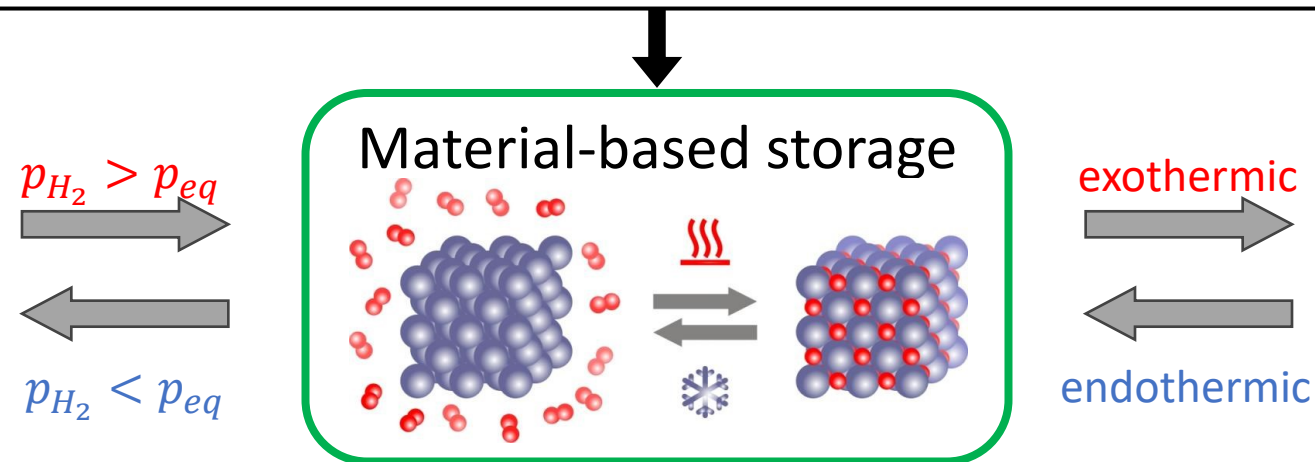
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# Hydrogen storage

- Growing need for safe, efficient, and affordable energy storage systems
- **Solid-state** hydrogen storage works at low pressure and temperatures



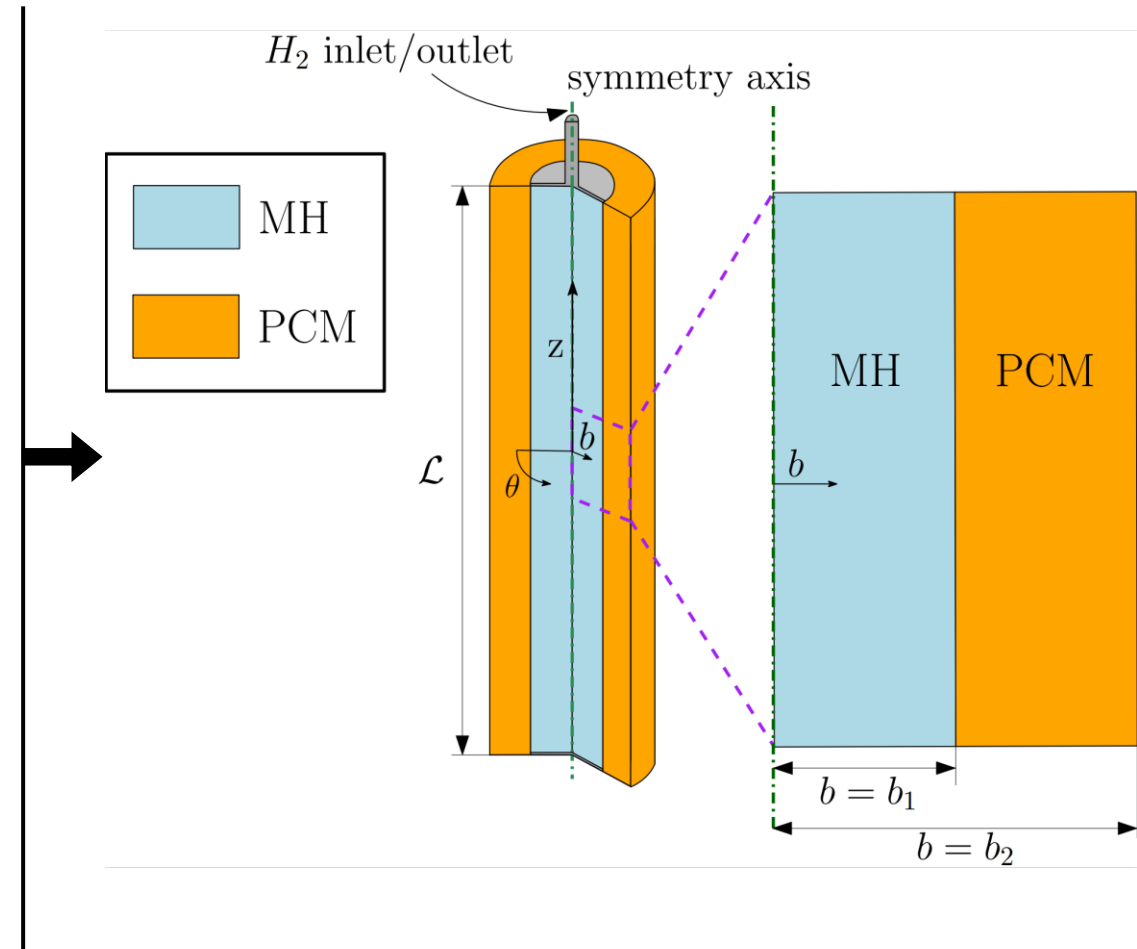
- Need for an efficient Heat Management System (HMS)

# MH-PCM storage design

- Coupling the Metal Hydride (MH) with a Phase Change Material (PCM) to:
  - ✓ passively control the MH temperature
  - ✓ provide a heat reservoir
  - ✓ increase heat transfer rate

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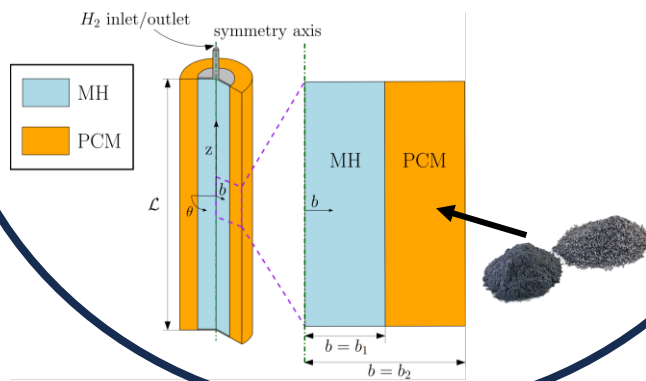
MH-PCM hybrid hydrogen storage system



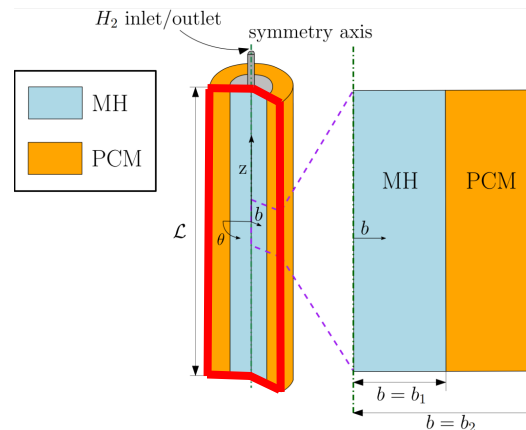
# ICAE 2023 – Qatar 3-5 December

Future developments included:

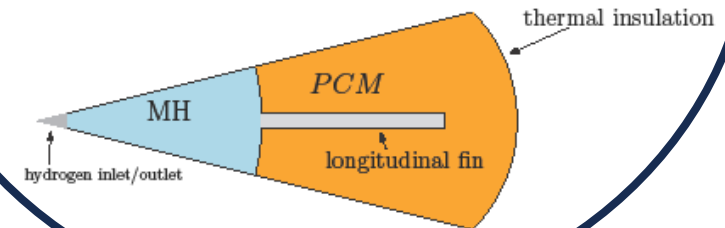
analysis for several thermo-physical configurations



change the Neumann boundary condition



1D and 2D analysis on finned geometry



# Methodology

## MH modeling

$$\begin{cases} \frac{dm_{H_2g}}{dt} = f_{in,H_2} - r m_s \frac{MW_{H_2} SC}{MW_{MH}} \\ r = C_a e^{-\frac{E_a}{RT}} \ln \frac{P}{P_{eq}} \left(1 - \frac{m_{MH}}{m_s}\right) \\ \frac{\delta T}{\delta t} = \alpha \nabla^2 + \dot{q}_a / \rho c_p \end{cases} \quad \text{absorption}$$

$$\begin{cases} \frac{dm_{H_2g}}{dt} = -f_{out,H_2} - r m_s \frac{MW_{H_2} SC}{MW_{MH}} \\ r = C_d e^{-\frac{E_d}{RT}} \ln \frac{P - P_{eq}}{P_{eq}} \left(\frac{m_{MH}}{m_s}\right) \\ \frac{\delta T}{\delta t} = \alpha \nabla^2 + \dot{q}_b / \rho c_p \end{cases} \quad \text{desorption}$$

## PCM modeling



Enthalpy method

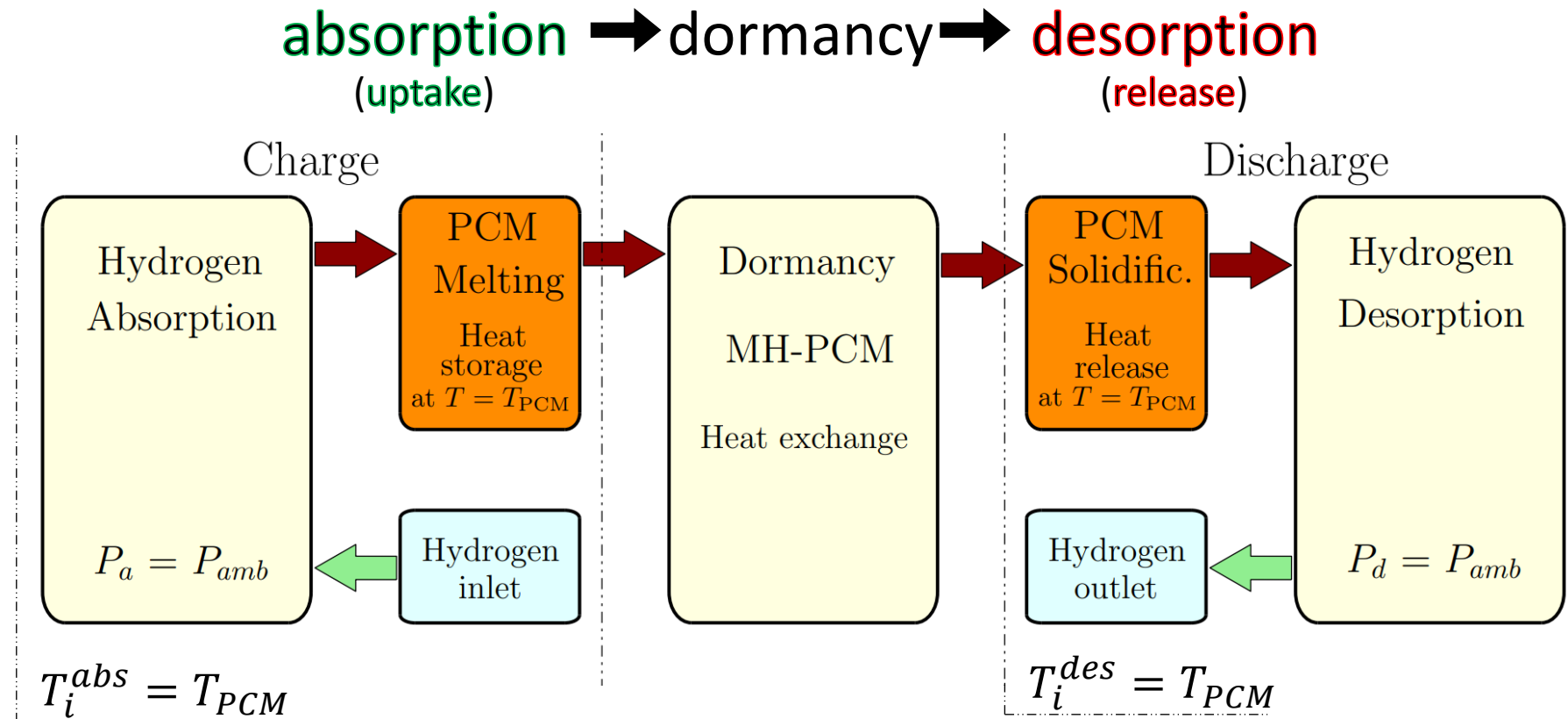
$$\rho \frac{\partial H}{\partial t} = \frac{\partial}{\partial x} \left( k \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left( k \frac{\partial T}{\partial y} \right)$$

$$T = \begin{cases} H / c_p & H \leq c_p T_m \\ T_m & c_p T_m \leq H \leq c_p T_m + \lambda \\ \frac{H - \lambda}{c_p} & H > c_p T_m + \lambda \end{cases}$$

$$k_{PCM}^e = \frac{k_{PCM} \cdot (2k_{PCM} + k_{NP} - 2\varepsilon \cdot (k_{NP} - k_{PCM}))}{2k_{PCM} + k_{NP} - \varepsilon \cdot (k_{NP} - k_{PCM})}$$

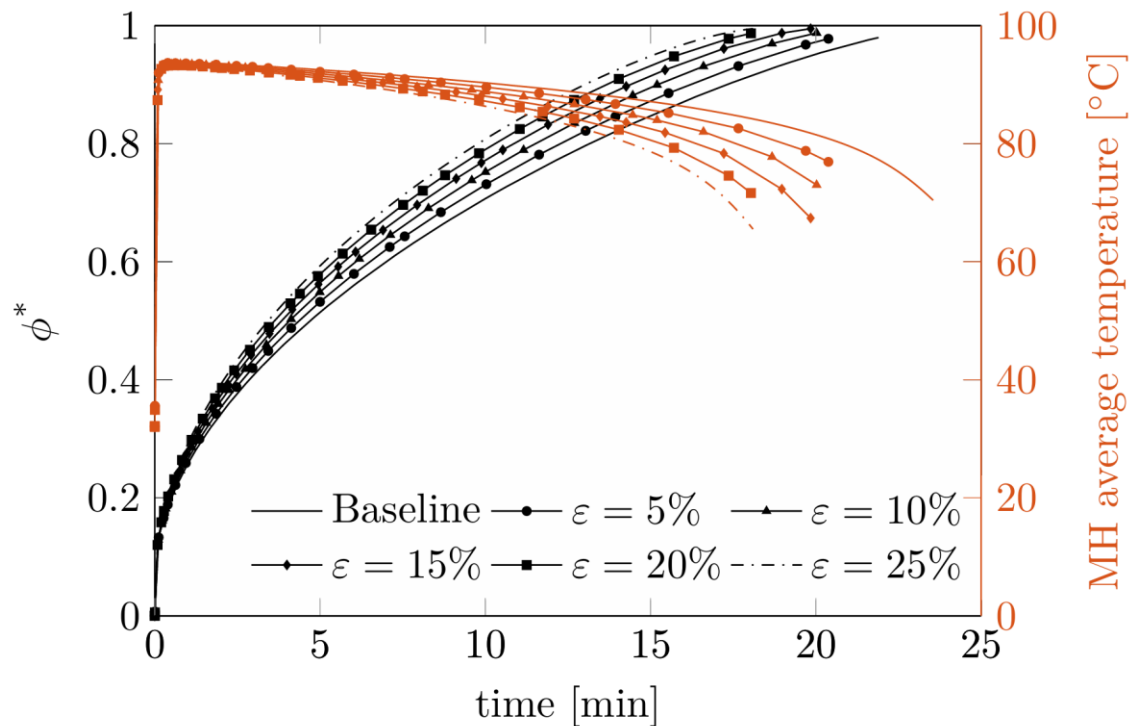
# Methodology

## Complete cycle

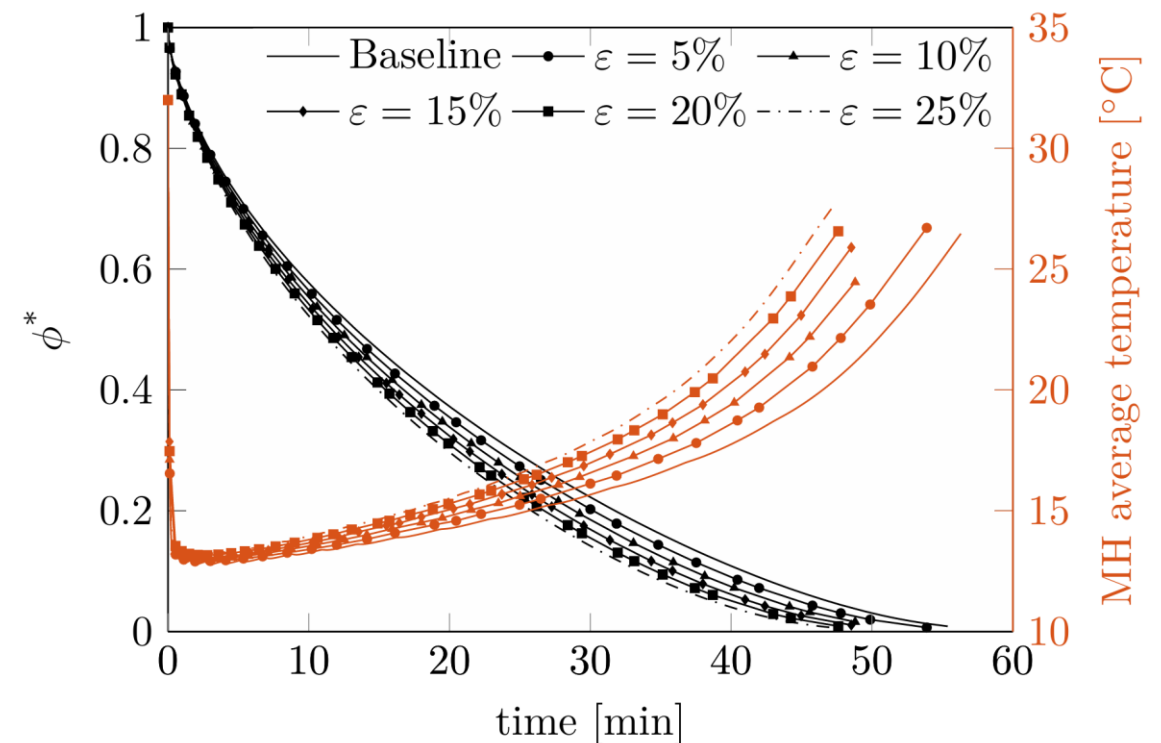


# Results – ab/desorption curves

## absorption profile



## desorption profile

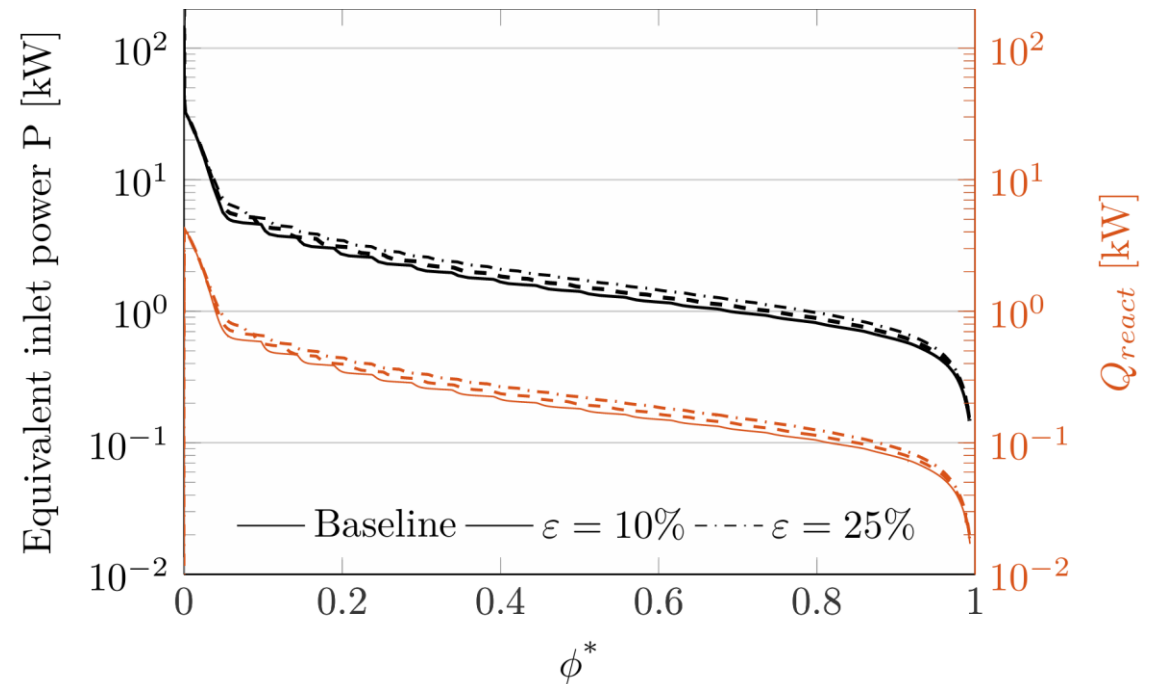
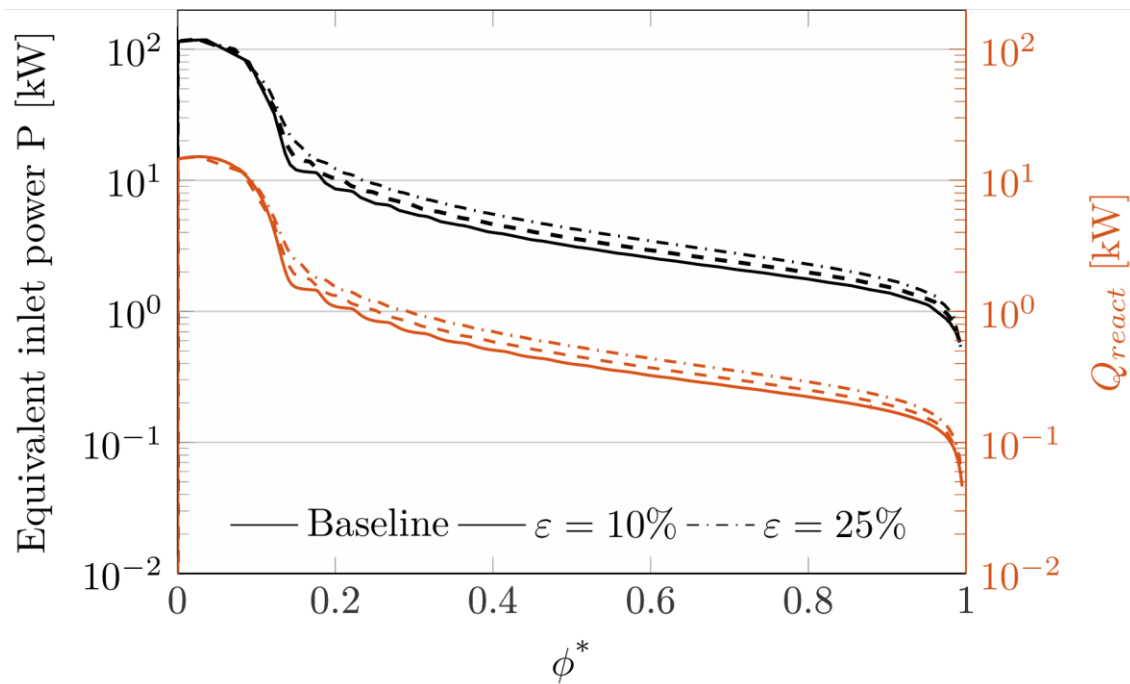


- ab/desorption time is reduced by 20.9% with  $\epsilon = 25\%$
- MH temperature is lower/higher during ab/desorption, respectively

# Results – ab/desorption eq. Power

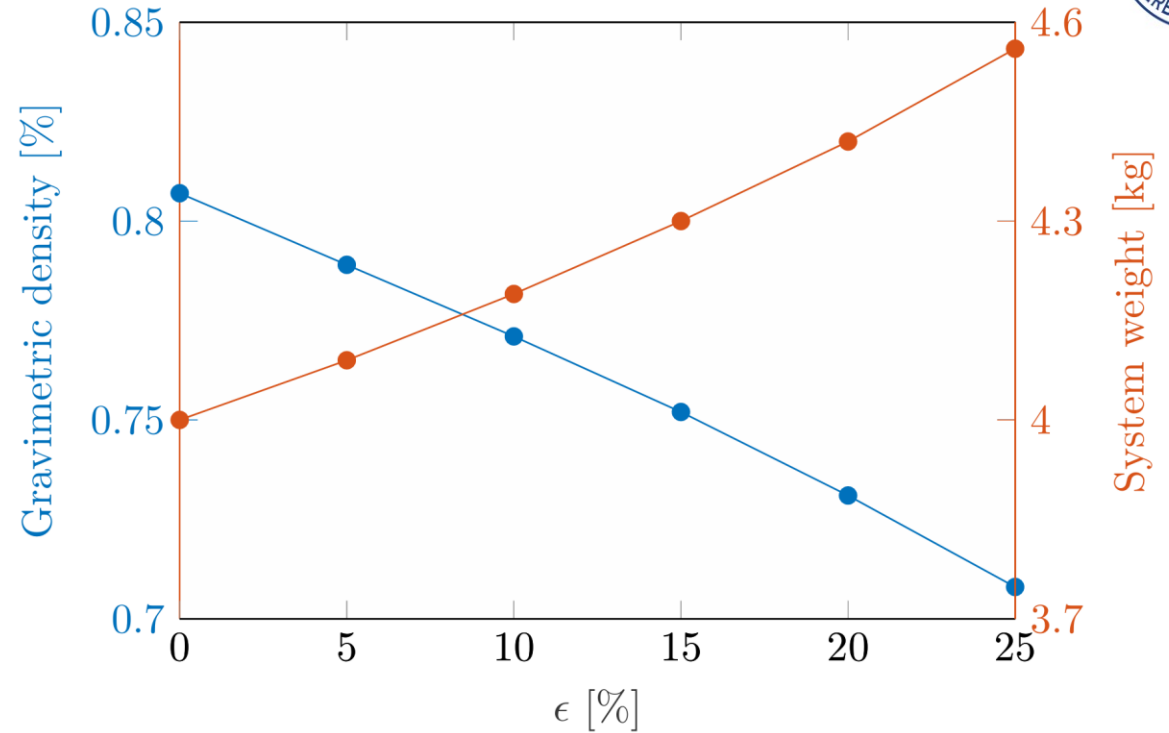
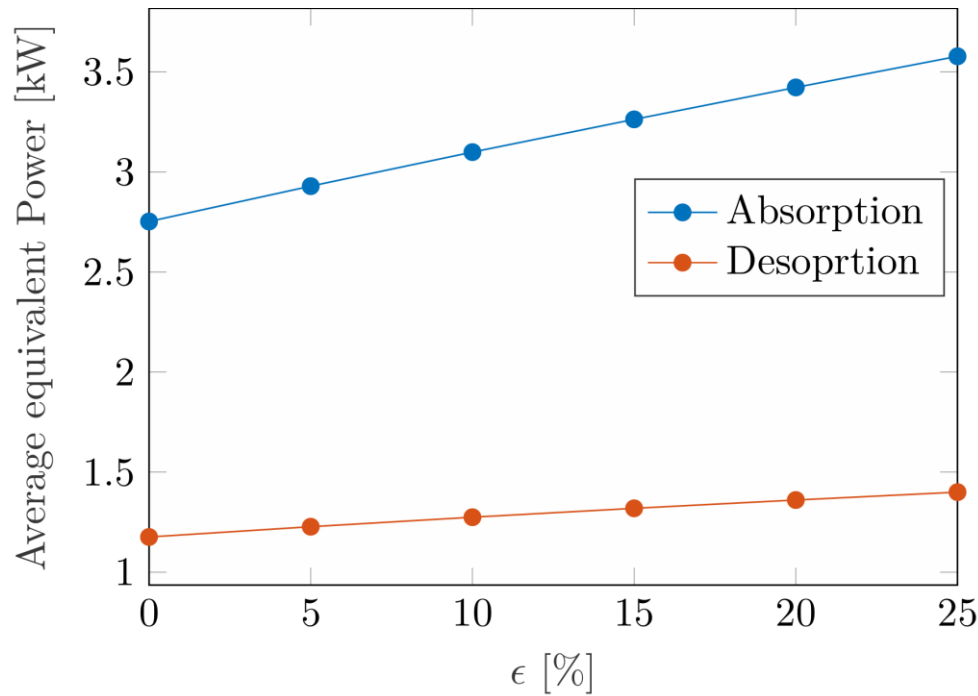
absorption profile

desorption profile



- the in/outlet equivalent power  $P = f_{H_2} \cdot H_i$  increases with  $\varepsilon$
- PCM only effective for  $\phi^* = \frac{m_{MH}^*}{m_t} > \phi_c^* \approx 0.15$

# Results – performance indicators



- linear increase of ab/desorption average power  $\frac{\int P \cdot dt}{t_{end}} = E/t_{end}$  with  $\varepsilon$
- non-linear decrease of storage gravimetric density %wt =  $m_{H_2}/m_t$  due to  $\lambda_{PCM}$

# Conclusions

When increasing  $\varepsilon$  from 0% to 25%:

*Cycle time -20.9%*

*ab/des power + 30%/+19%*

*%wt - 12.3%*

✓ ENG more effective for reducing charge time than discharge time

- $\text{LaNi}_5$  was used as hydrogen absorption powder
- $\text{LiNO}_3 - 3\text{H}_2\text{O}$  was used as surrounding Phase Change Material
- Expanded Graphite is dispersed in the PCM to enhance  $k_{PCM}$





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