Long Duration Energy Storage Viability Survey

Determining the Cost Floor for Energy Storage Technologies

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NETL Support Contractor

Thermo-Mechanical-Chemical Energy Storage Workshop

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Paper Summary

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- Found promising technologies for long-duration energy storage (LDES) by calculating energy capital cost floor for 376 Storage media.

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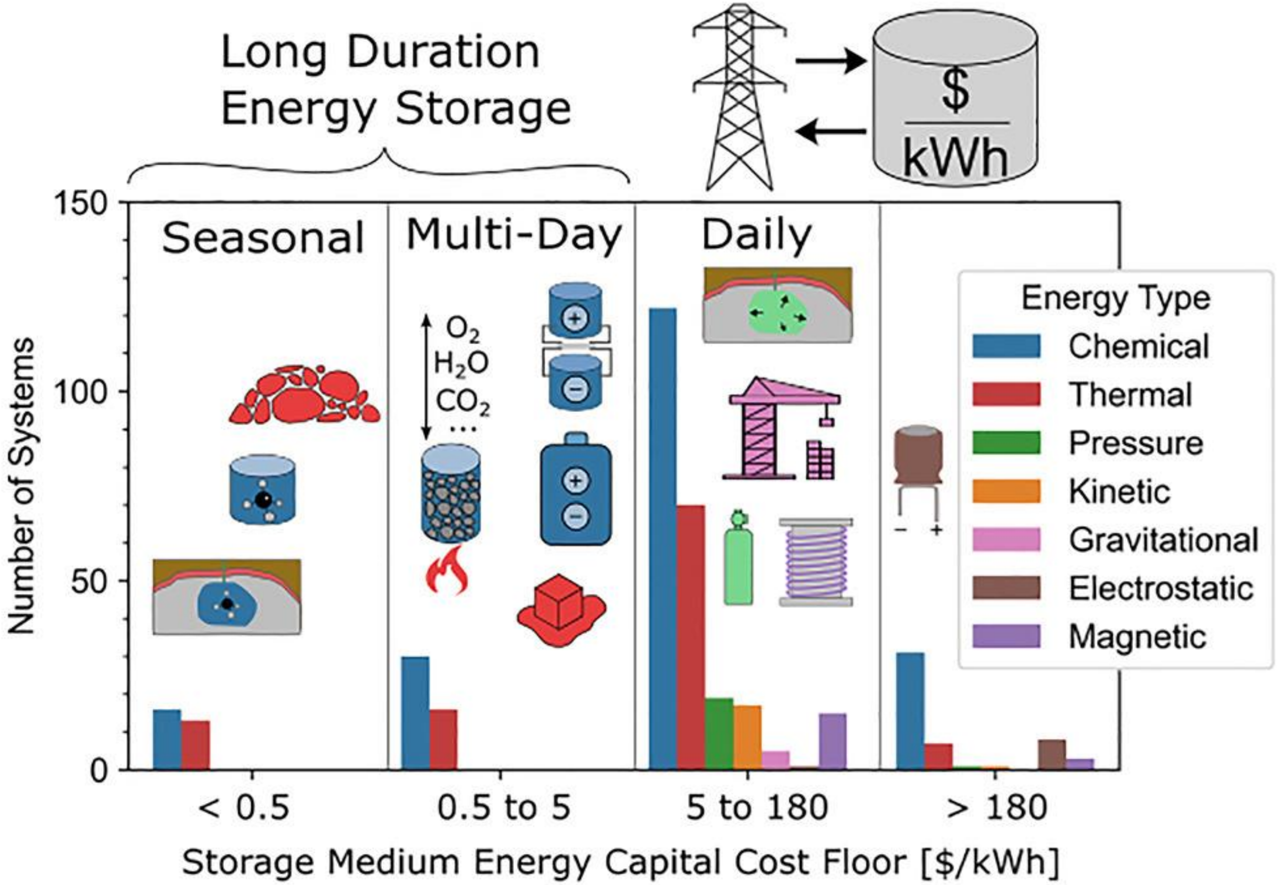
Perspective

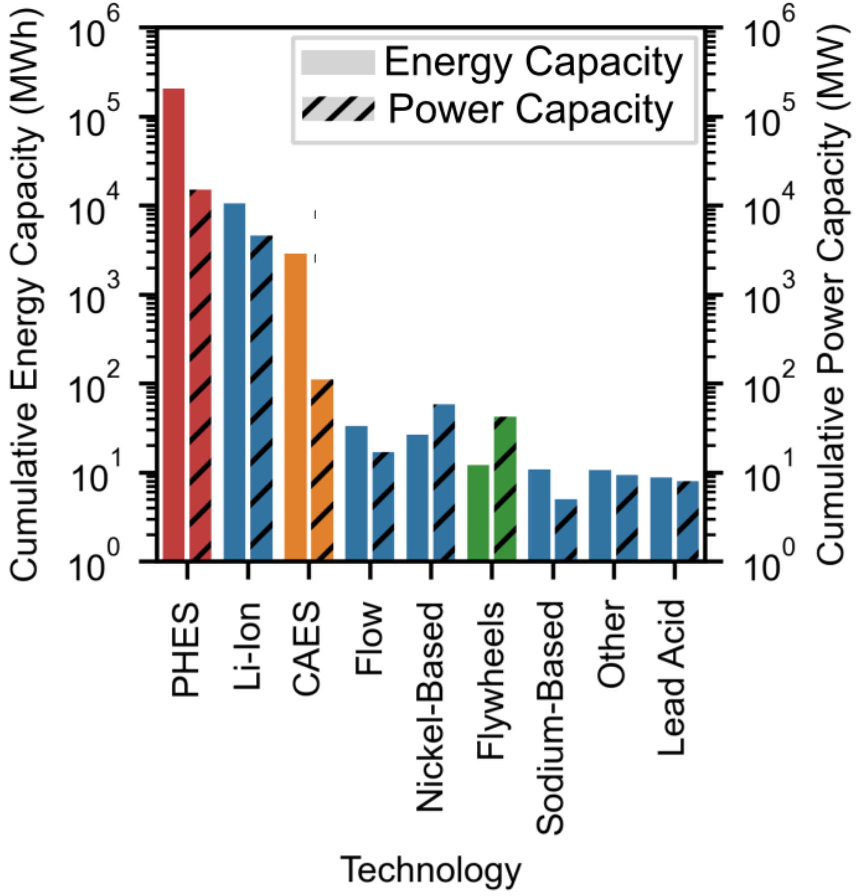
A techno-economic survey of energy storage media for long-duration energy storage applications

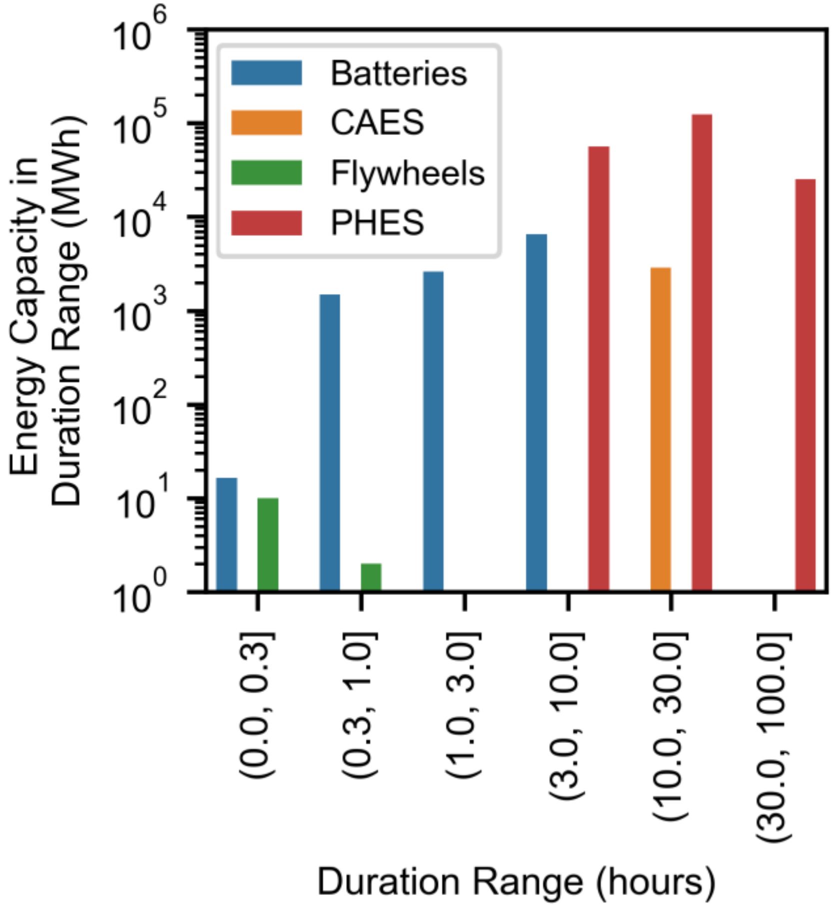
Lee Aspitarte[1,2], C. Rigel Woodside[1]



Current U.S. Energy Storage Capacity

Cross-Referencing Sandia Global Energy Storage Database and EIA Data





- Pumped Hydro (PHES) and Compressed Air (CAES) are only energy storage > 10 hours

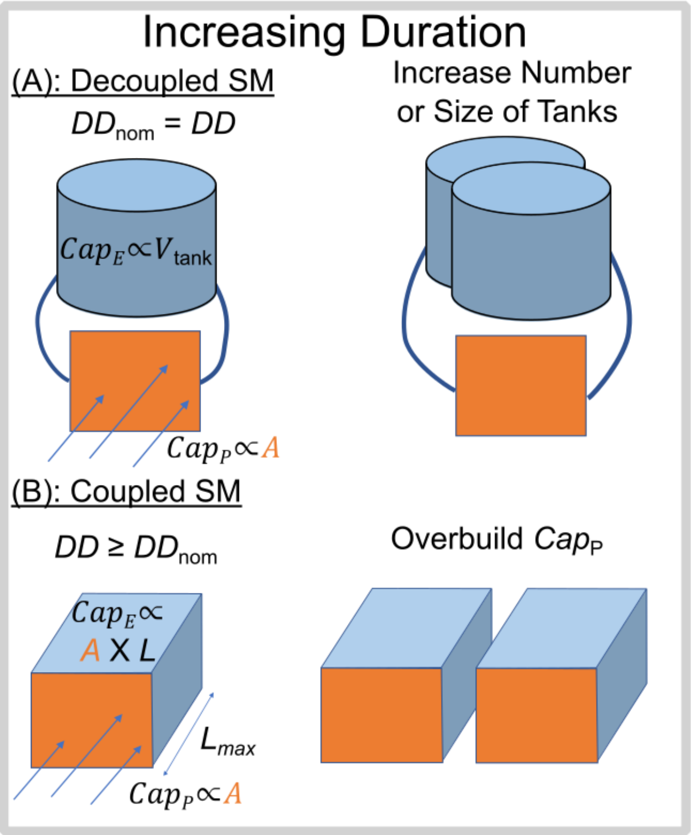
Need $\sim \frac{1kW}{person} * 10\ B\ people\ * 100\ hours = \mathbf{10^9\ MWh}$

Pickard, William F., "Massive Electricity Storage for a Developed Economy of Ten Billion People", *IEEE Access* (2015)

Coupled and Decoupled Storage Media

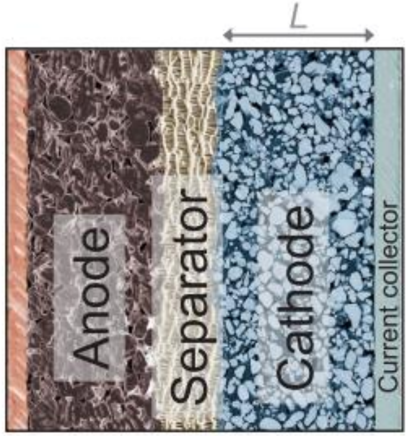
- Coupled or Decoupled energy capacity (Cap_E) and power capacity (Cap_P).
- Coupled Storage Medium (SM) have a limited **nominal discharge duration**

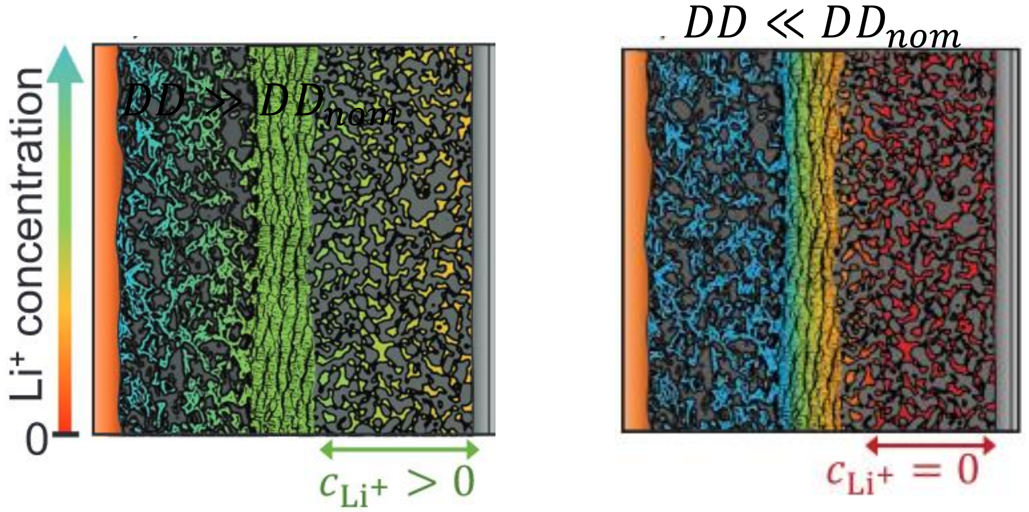
$$DD_{nom} = \frac{\eta_d Cap_E}{Cap_P}.$$



Example: Lithium-ion batteries

- Coupled: cannot increase thickness independent of area.
- Practically limited to ~100 um and $DD_{nom} \sim 1\ hour$.
- Increasing Cap_E (thickness) limits Cap_P.





Christian et al. "Diffusion-Limited C-Rate: A Fundamental Principle Quantifying the Intrinsic Limits of Li-Ion Batteries." *Advanced Energy Materials* 10 (2020): https://doi.org/10/gjq5w2.

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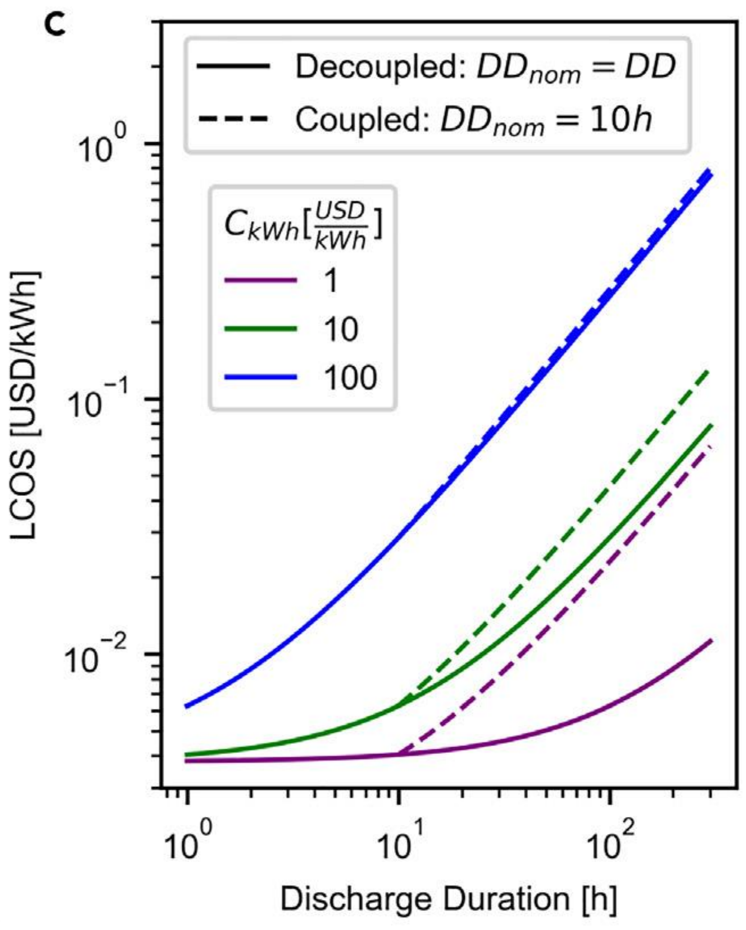
Techno-Economic Analysis

Levelized Cost of Storage (LCOS) Based on Price Arbitrage



Inefficiency Premium — Energy capital repayment — Power capital repayment

$$\mathrm{LCOS}\left[\frac{\mathrm{USD}}{\mathrm{kWh}}\right] = P_{chg}\left(\frac{1}{\eta_{RT}} - 1\right) + \frac{1}{CF * 8760 * LT_{eff}}\left(\frac{C_{kWh}}{\eta_d}\mathrm{DD} + \mathrm{C}_{kW}\frac{\mathrm{DD}}{DD_{nom}}\right)$$

$C_{kW(h)}$- Power (Energy) Capital Cost

P_{chg}- Electricity Price

η- Discharge/Round Trip Efficiency

LT_{eff} - Effective system lifetime

CF- Capacity Factor

- Quantified effect of decoupled vs coupled systems.
  - Assume decoupled ($DD = DD_{nom}$) for consistency/best-case.
- Energy capital costs drive LCOS in the linear ‘long-duration regime’ ($\frac{C_{kwh}}{\eta_d}DD \gg C_{kW}$).

$C_{kwh,max}$ Targets for Long-Duration Energy Storage (LDES) Applications

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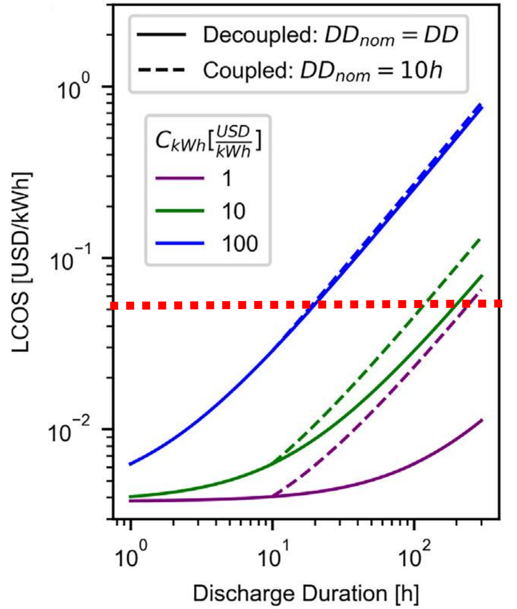
- C_{kwh} targets present in the literature but generally results of complex models.
- Developed quick $C_{kwh,max}$ Fermi estimate for different applications, valid in 'long duration regime'.

$$C_{kWh,max} = LCOS_{target} * N_c * LT_{eff} * \eta_d$$

N_c- Yearly Cycles, LT_{eff} - effective (discounted) lifetime, η_d - discharge efficiency

Table 1. Mid- and long-duration energy storage applications and associated $C_{kWh,max}$ values

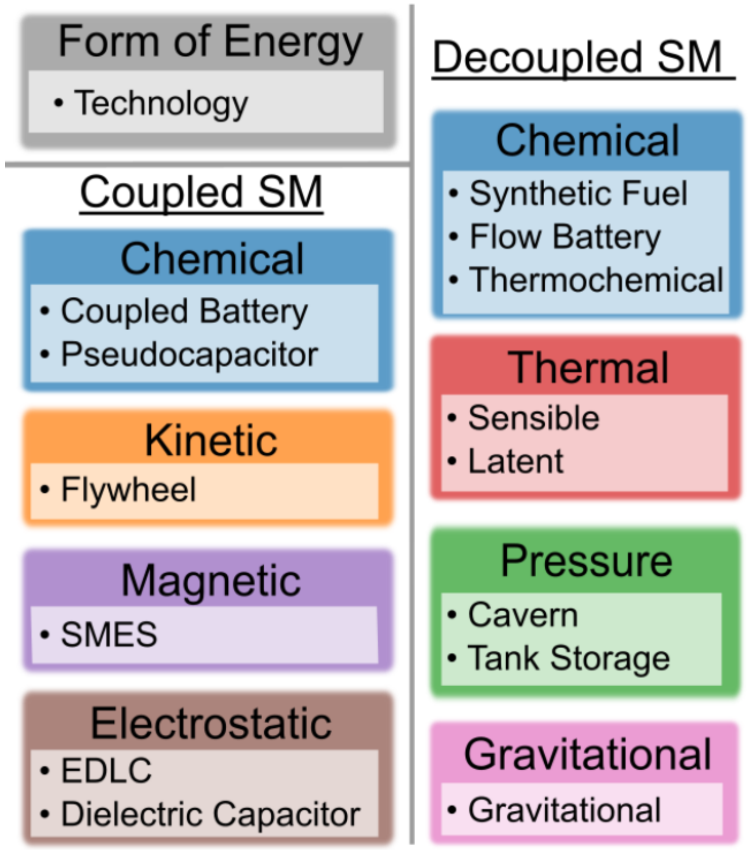
Application	$N_c = CF \frac{8,760 \left[\frac{h}{y}\right]}{DD[h]}$	$C_{kWh,max}$ (USD/kWh)	Description/ref.	Example application parameters
Mid-duration energy storage (MDES)	~365	~180	diurnal (intra-day) cycling[37,38]	DD = 12 h, CF = 0.5;
Multi-day LDES	~10	~5	multi-day shortfall[38,39]	DD = 100 h, CF = 0.1;
Seasonal LDES	~1	~0.5	annual worst ~ month (a.k.a. "Dunkelflaute")[40,41]	DD = 720 h, CF = 0.1
			seasonal shifting[37]	DD = 2,000 h, CF = 0.25

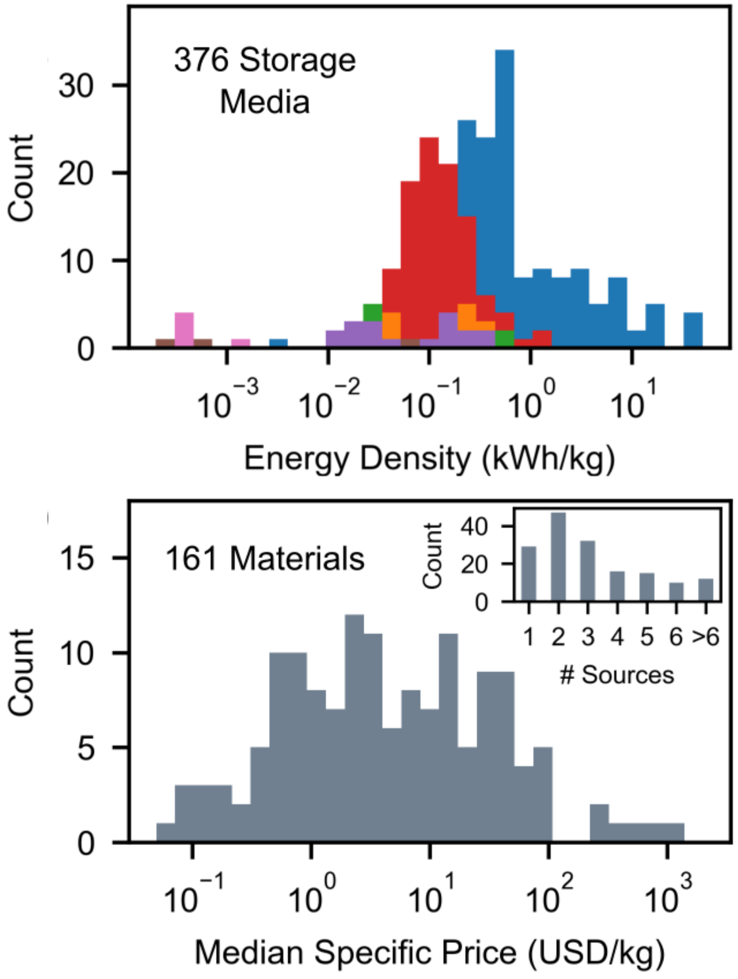


- Assumptions
  - $\frac{C_{kwh}}{\eta_d} DD \gg C_{kW}$
  - DOE $LCOS_{target} = 0.05\ UDS/kWh$
  - Discount rate -> $LT_{eff} \sim 10\ y$
  - $\eta_d \sim 1$

Broad Survey of C_{kWh} Material Cost Floors

Best Case Costs Based on Just Energy-Storing Materials





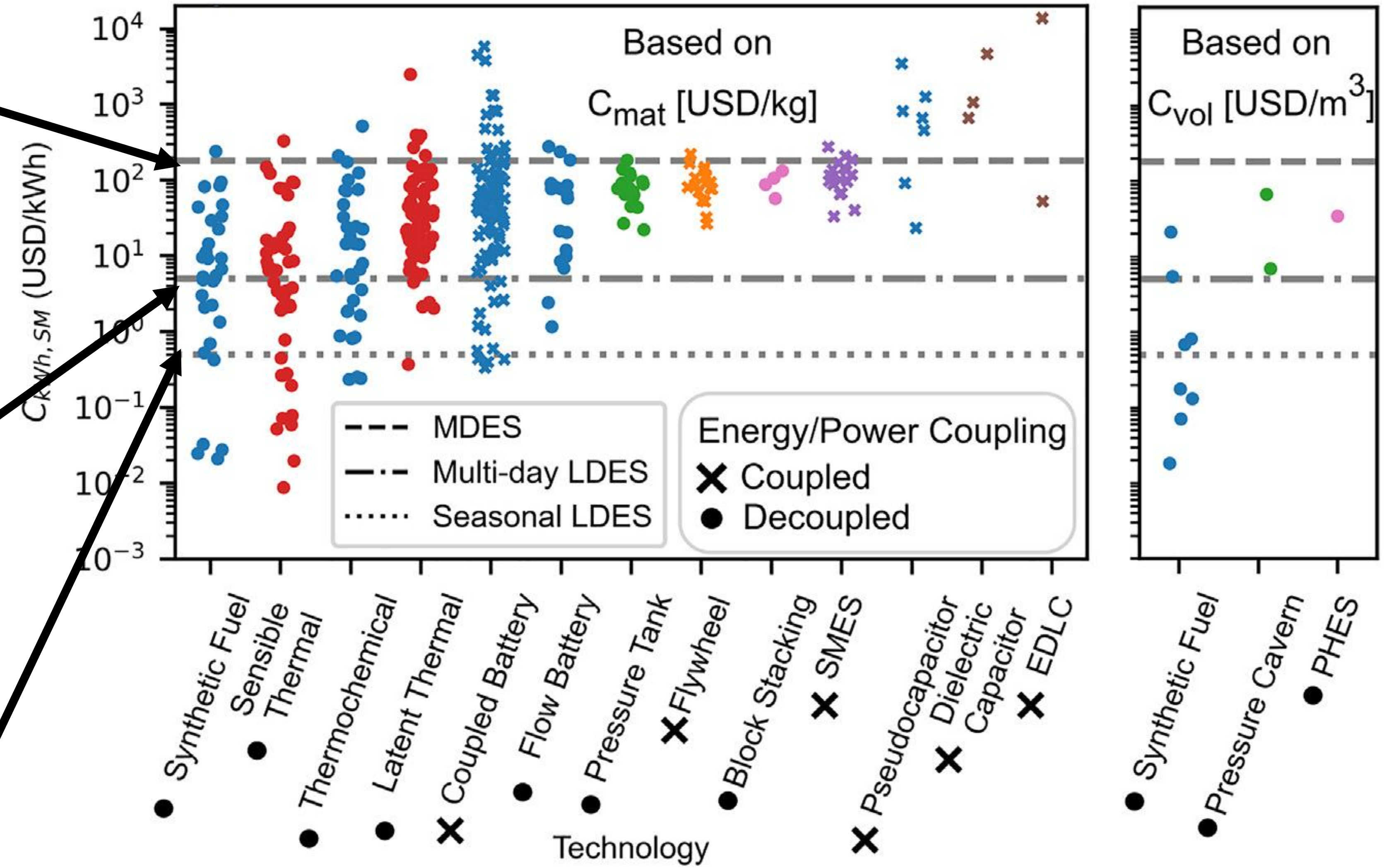
- Identified SM technologies and **energy density (ρ_E)** expressions from first-principles
- Developed a data collection framework to collect ρ_E data and **materials prices C_{mat}.**
- Used data to calculate material cost floor of C_{kWh},

$$C_{kWh,SM}\left[\frac{USD}{kWh}\right] = \frac{C_{mat}\left[\frac{USD}{kg}\right]}{\rho_E \left[\frac{kWh}{kg}\right]}$$

Energy Storage Material Cost Results

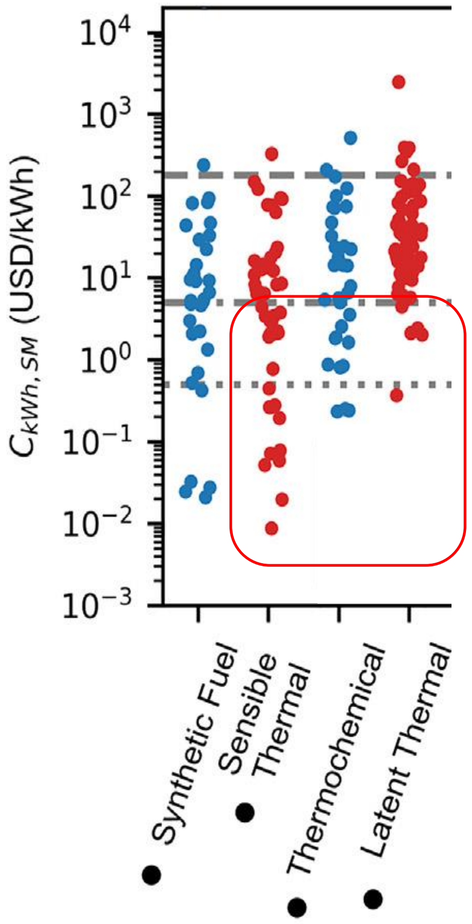
Technologies are potentially viable if below target cost lines for applications

- Most storage systems potentially viable for MDES (mid-duration).
- For multi-day LDES, **select** synthetic fuels, sensible thermal, thermomechanical, latent thermal, coupled battery, and flow battery potentially viable.
- Less systems can work for seasonal LDES.

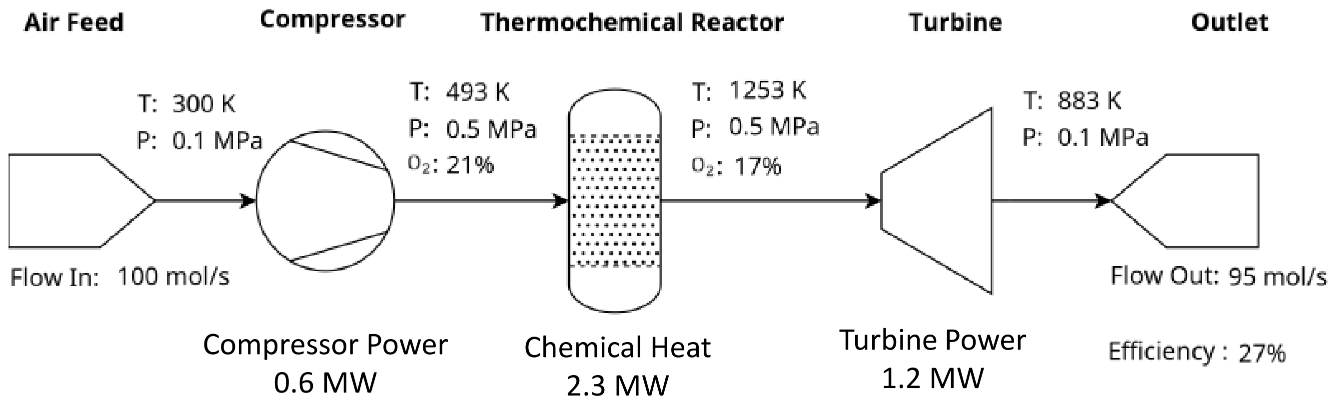


Ongoing Energy Storage Work

- Viability Analysis Confirmed Promise of Thermal/Chemical Storage



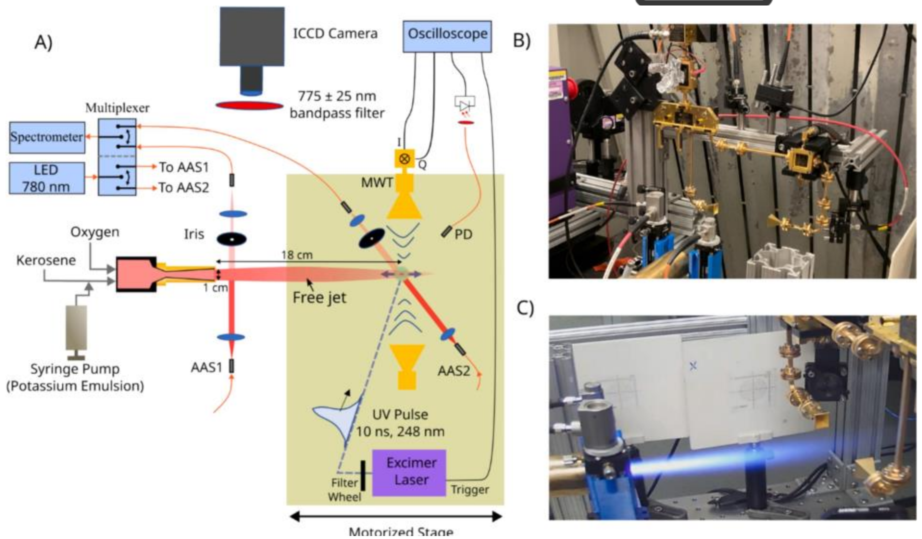
- Modeling of thermal energy storage integrated in fossil assets.
  - Developing models for thermal storage media in NETL's Institute for the Design of Advanced Energy Systems (IDAES) platform.
  - Currently exploring integration into subcritical coal plant to reduce thermal cycling.



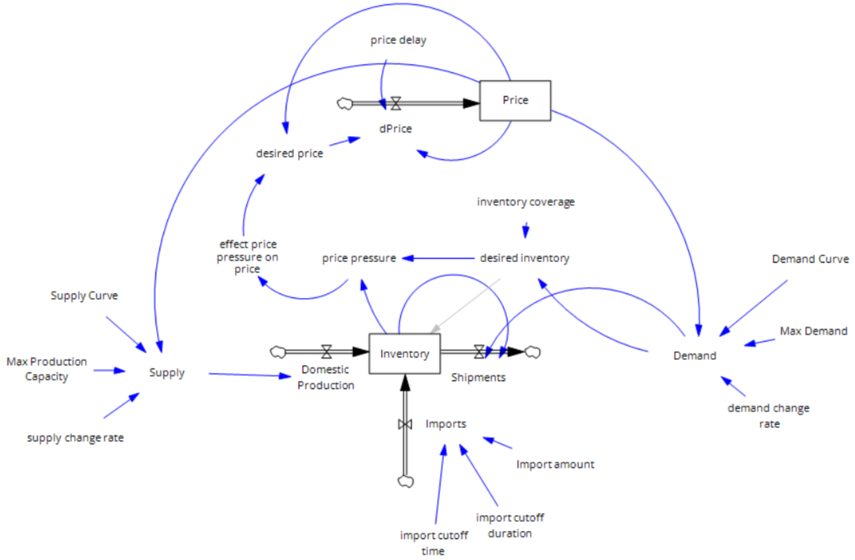
Iron oxide thermochemical storage in simple standalone Brayton cycle.

Other Projects at NETL

- Experimental physics in magnetohydrodynamic power generation laboratory
  - Recent publication "*Photoionization of seeded combustion products as a method of enhancing the efficiency of magnetohydrodynamic power generators*"
  - **Potential tie to energy storage:**
    - **Recently obtained TGA/DSC and interested in thermochemical materials research**



- (New) Critical minerals supply chain analysis
  - Starting system dynamics modeling of rare earth supply shortages
  - **Potential tie to energy storage:**
    - **Quantify material supply bottlenecks for energy storage technologies**
    - **Want better figure of merit than current material market price ($C_{mat}[\frac{USD}{kg}]$)**



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