Thermal Energy Storage for Industrial Heat: Overview, System Analysis, and Research Pilots

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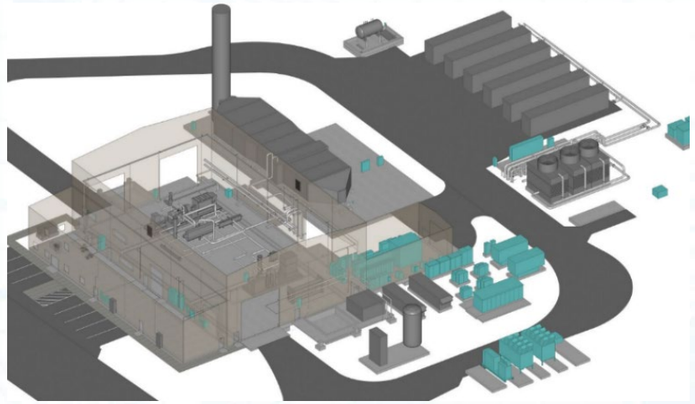
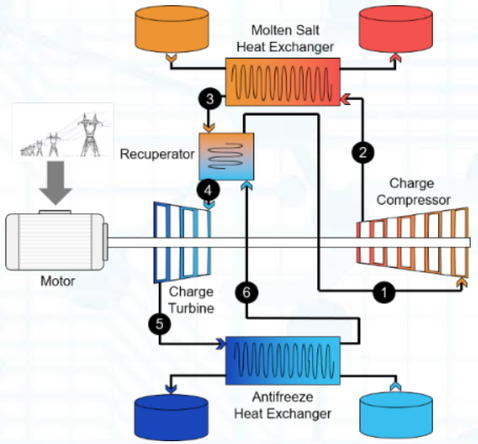
Industrial Process Emissions Reduction Workshop
San Antonio, Texas





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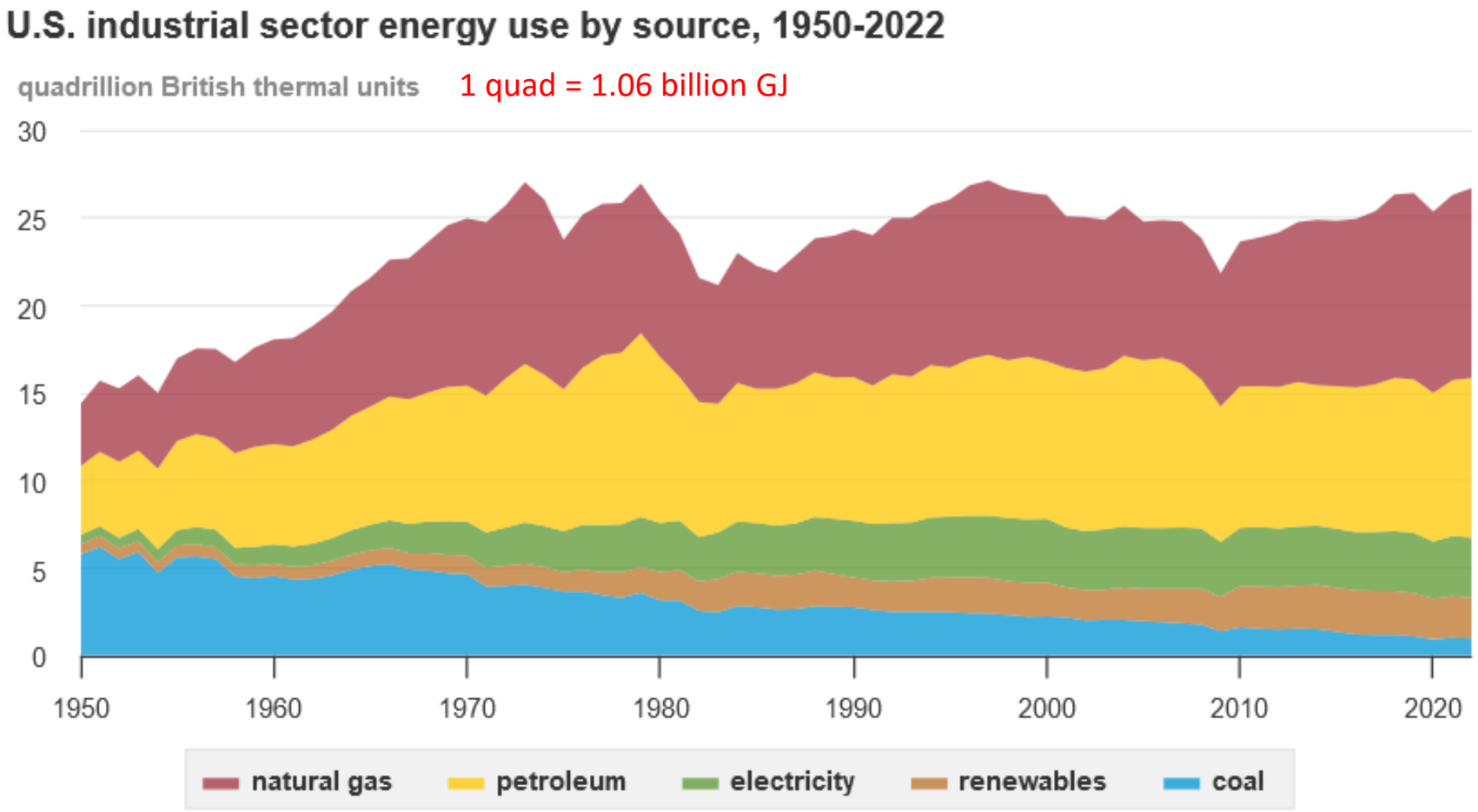
United States Historical Industrial Energy Use



Data source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 2.4, June 2023 , preliminary data for 2022

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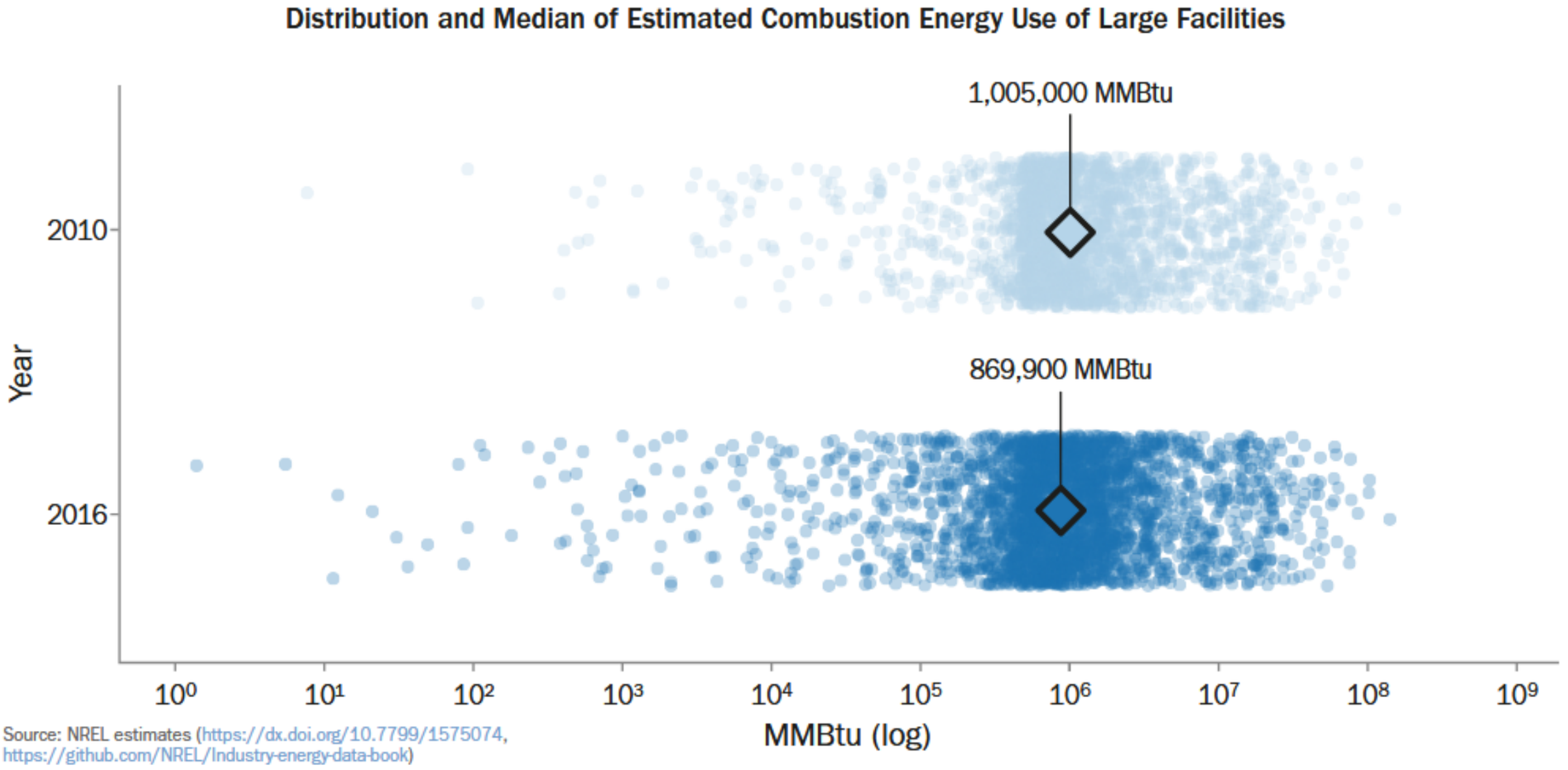
Report on Industrial Use in Large Facilities



Source: NREL estimates (https://dx.doi.org/10.7799/1575074, https://github.com/NREL/Industry-energy-data-book)

- 2018 NREL Study of Industry
- Distribution of annual use
- If facilities are continuously operated, median is 99 MMBtu/h
- If converted to electric the average facility use is 29 MW
- SwRI peak electric use is 22 MW, so location and utility costs are used in a case study

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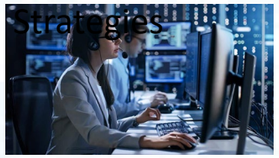
Detailed Python Model Toolset for Case Study

Federal Tax Incentives

Custom Dispatch Strategies



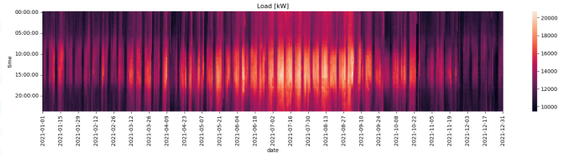
Campus Load Data

On-Site Generation

PyZ Model

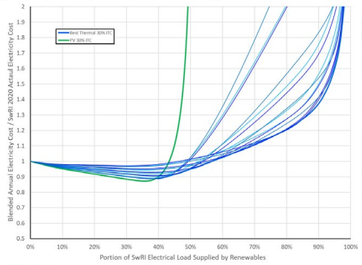
Generalized toolset developed under SwRI IR&D Project Z

Hourly energy balance against load

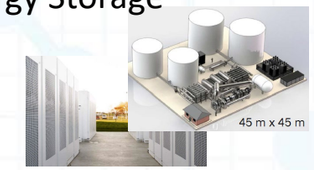


Techno-Economic Analysis of

- On-site generation
- Storage Options



Energy Storage



Utility Bills

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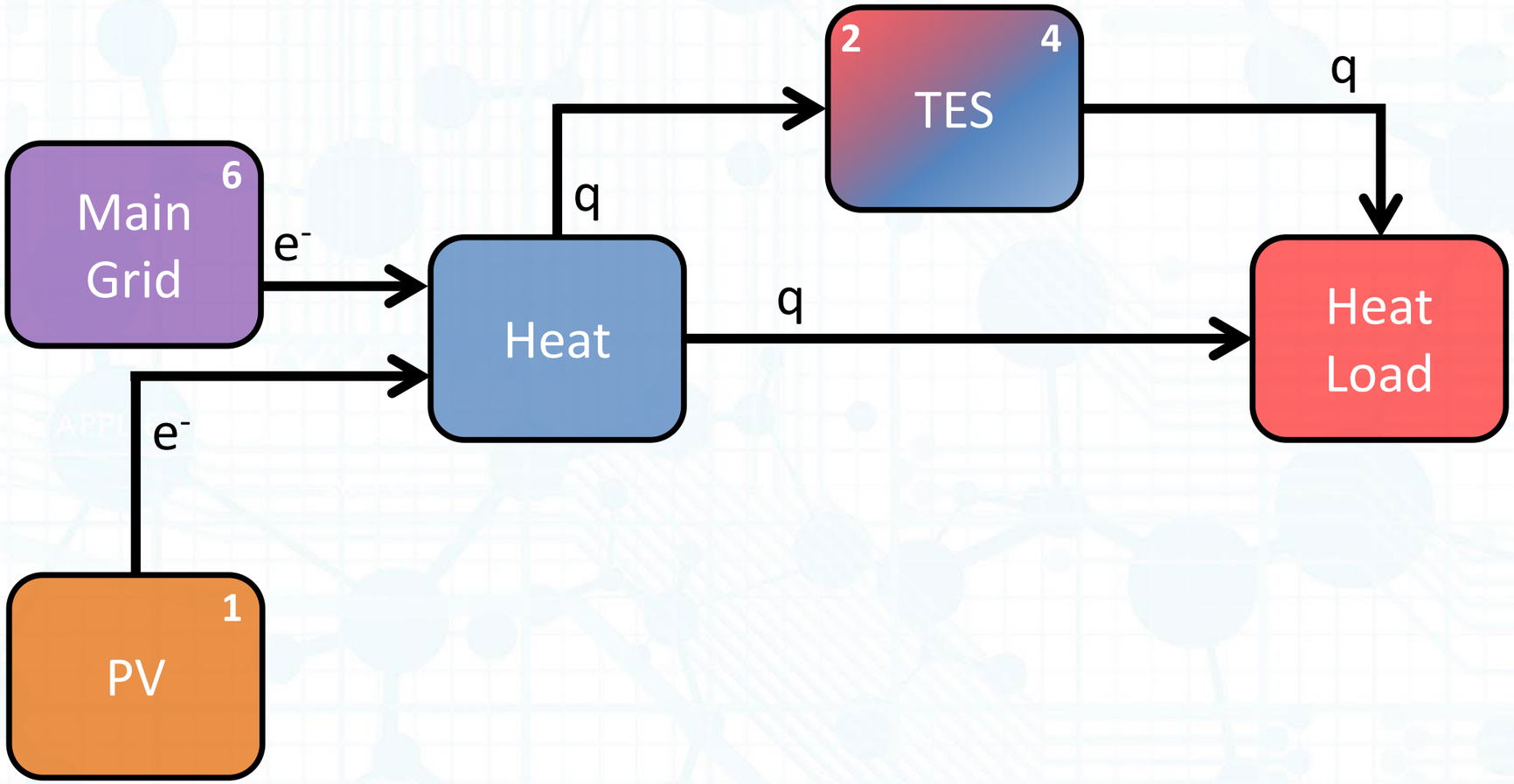
Grid + PV + TES Only



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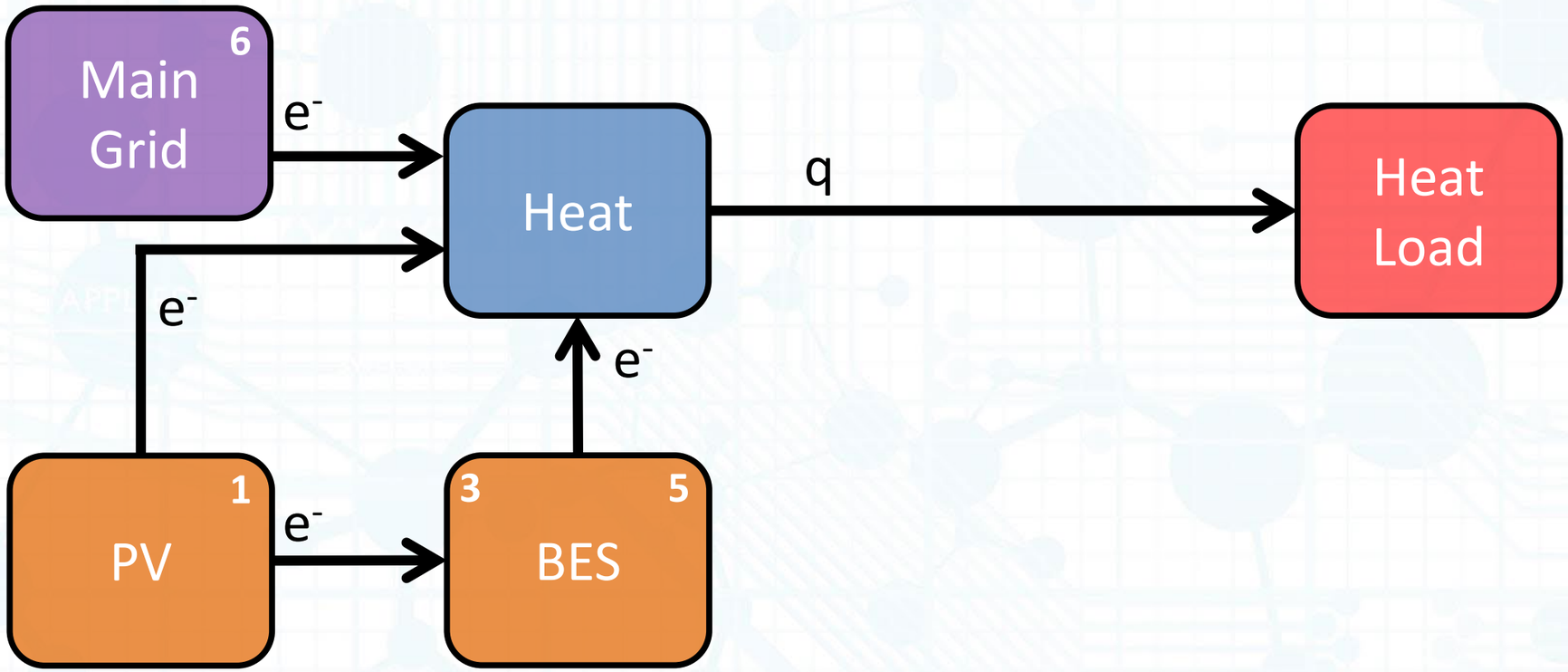
Grid + PV + ES (Lithium-Ion) Only



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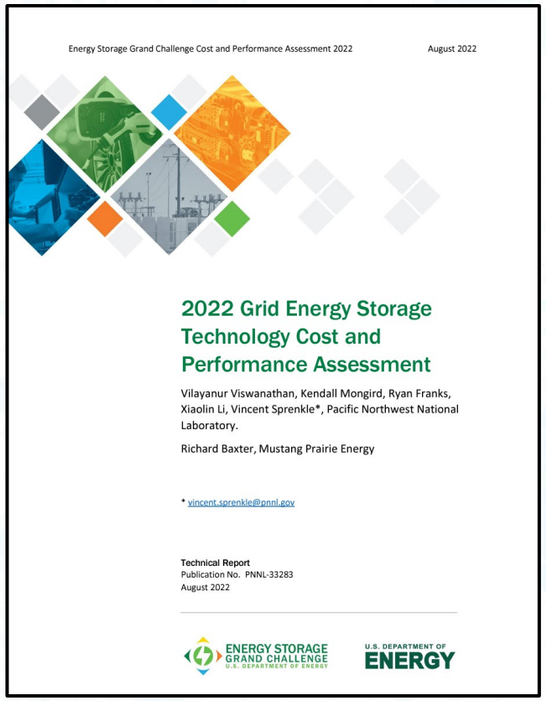
Techno-Economic Sources

- Public studies from reputable sources
  - National Renewable Energy Laboratory
  - Pacific Northwest National Laboratory
- Recent studies at similar sizes to the SwRI application
- Detailed cost breakdowns that separate major costs, like charging, storage, discharging, and EPC costs
- Performance and cost information should come from the same source
  - Older costs are escalated with inflation


Energy Storage Grand Challenge Cost and Performance Assessment 2022 August 2022

2022 Grid Energy Storage Technology Cost and Performance Assessment

Vilayanur Viswanathan, Kendall Mongird, Ryan Franks, Xiaolin Li, Vincent Sprenkle*, Pacific Northwest National Laboratory.

Richard Baxter, Mustang Prairie Energy

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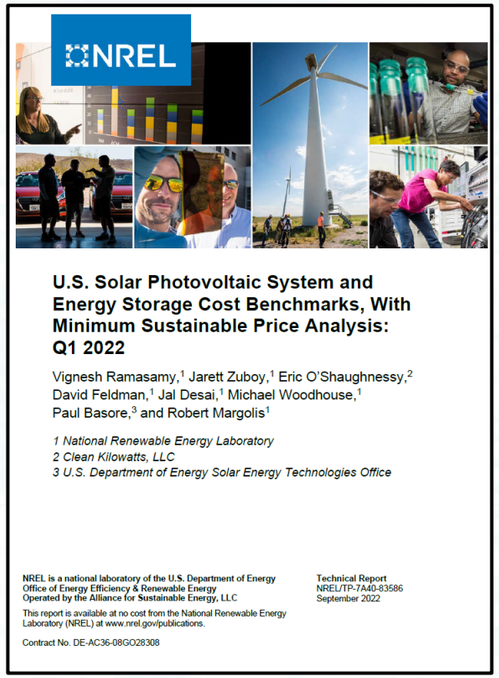
August 2022

ENERGY STORAGE GRAND CHALLENGE U.S. DEPARTMENT OF ENERGY

U.S. DEPARTMENT OF ENERGY



U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks, With Minimum Sustainable Price Analysis: Q1 2022

Vignesh Ramasamy,[1] Jarett Zuboy,[1] Eric O'Shaughnessy,[2] David Feldman,[1] Jal Desai,[1] Michael Woodhouse,[1] Paul Basore,[3] and Robert Margolis[1]

1 National Renewable Energy Laboratory
2 Clean Kilowatts, LLC
3 U.S. Department of Energy Solar Energy Technologies Office

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-7A40-83586
September 2022

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Overview of Analysis Parameters

- Load
  - Constant 20 MW(th) heat load
- PV System
  - CAPEX: 961 $/kW-installed
  - OPEX: 16 $/kW-installed

- Financial
  - No financing
  - 30% ITC
  - Discount Rate – 4.74%
  - Inflation Rate – 2.5%

- TES Systems

Molten Salt Pumped TES

- Storage
  - CAPEX – $108.64 / kWh
- Charge
  - Efficiency – 1.25
  - CAPEX – $934.52 / kW
  - OPEX – $26.85/kW

Concrete Sensible TES

- Storage
  - CAPEX – $32.11 / kWh
- Charge
  - Efficiency – 0.98
  - CAPEX – $125.50 / kW
  - OPEX – $7.35/kW

H2 Electrolyzer + 200 bar GH2

- Storage
  - CAPEX – $122.17 / kWh
- Charge
  - Efficiency – 0.627
  - CAPEX – $1485.3 / kW
  - OPEX – $11.61/kW

*All efficiency numbers are in [kW_t/kW_e]

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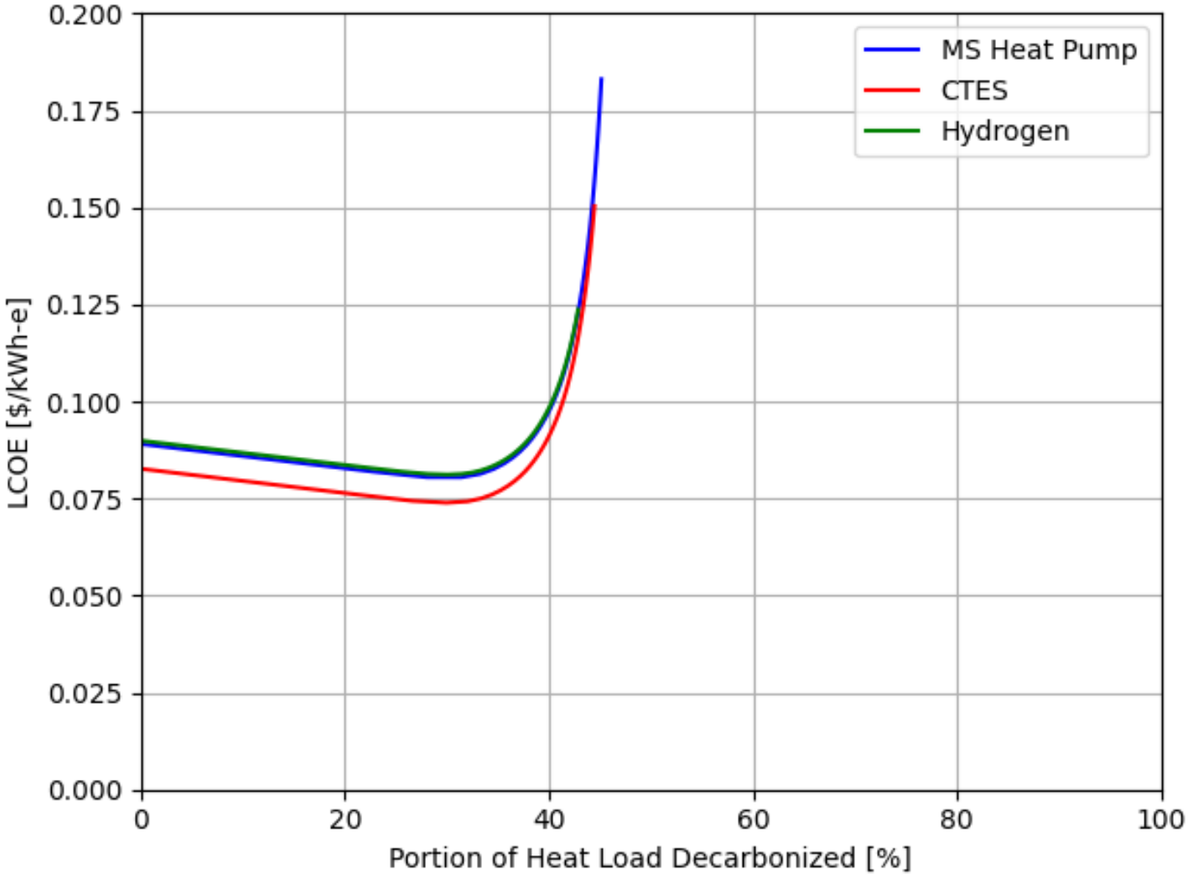
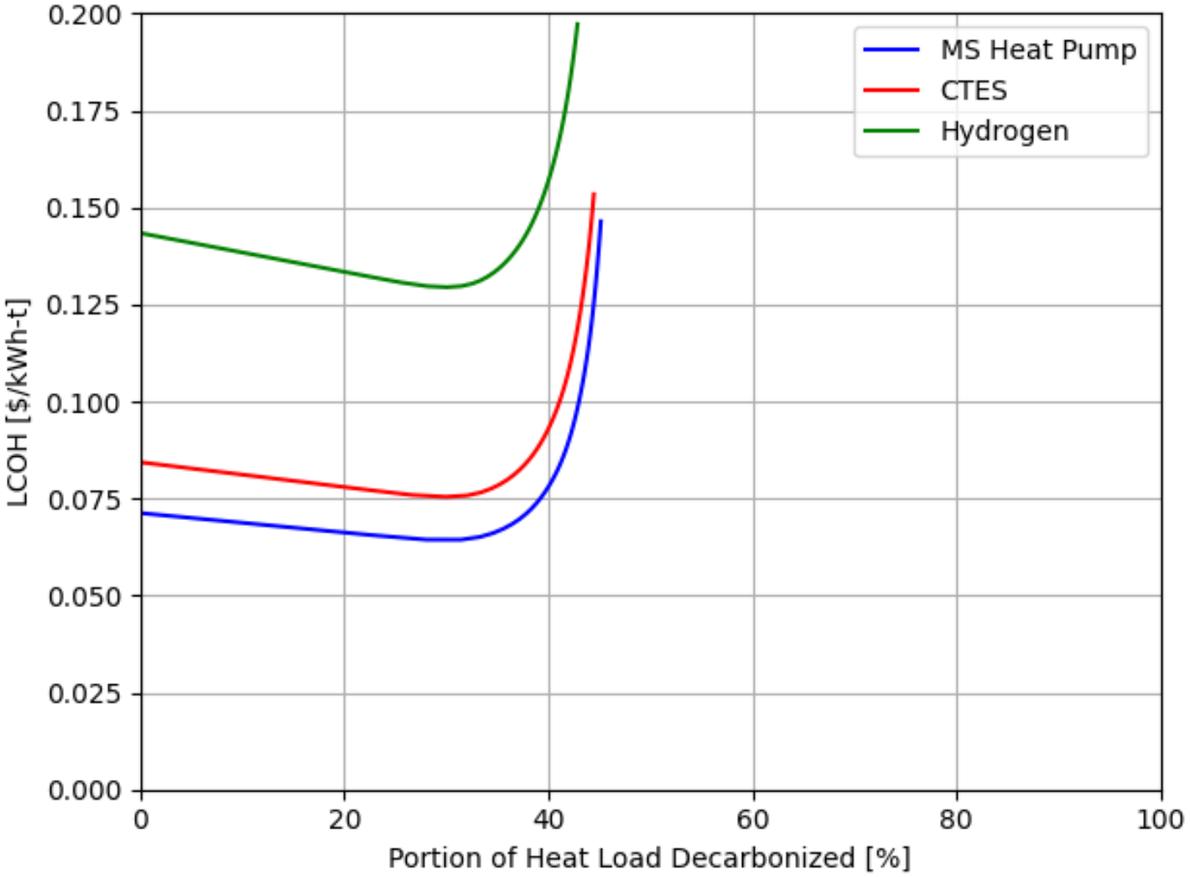
Decarbonization – No Storage





$$LCOE_{real} = \frac{\sum {Costs_i}/{r_{nom,i}}}{\sum {Electricity_i}/{r_{real,i}}} \quad \left[\frac{\$}{kWh_e}\right]$$

$$LCOH_{real} = \frac{\sum {Costs_i}/{r_{nom,i}}}{\sum {Heat_i}/{r_{real,i}}} \quad \left[\frac{\$}{kWh_t}\right]$$

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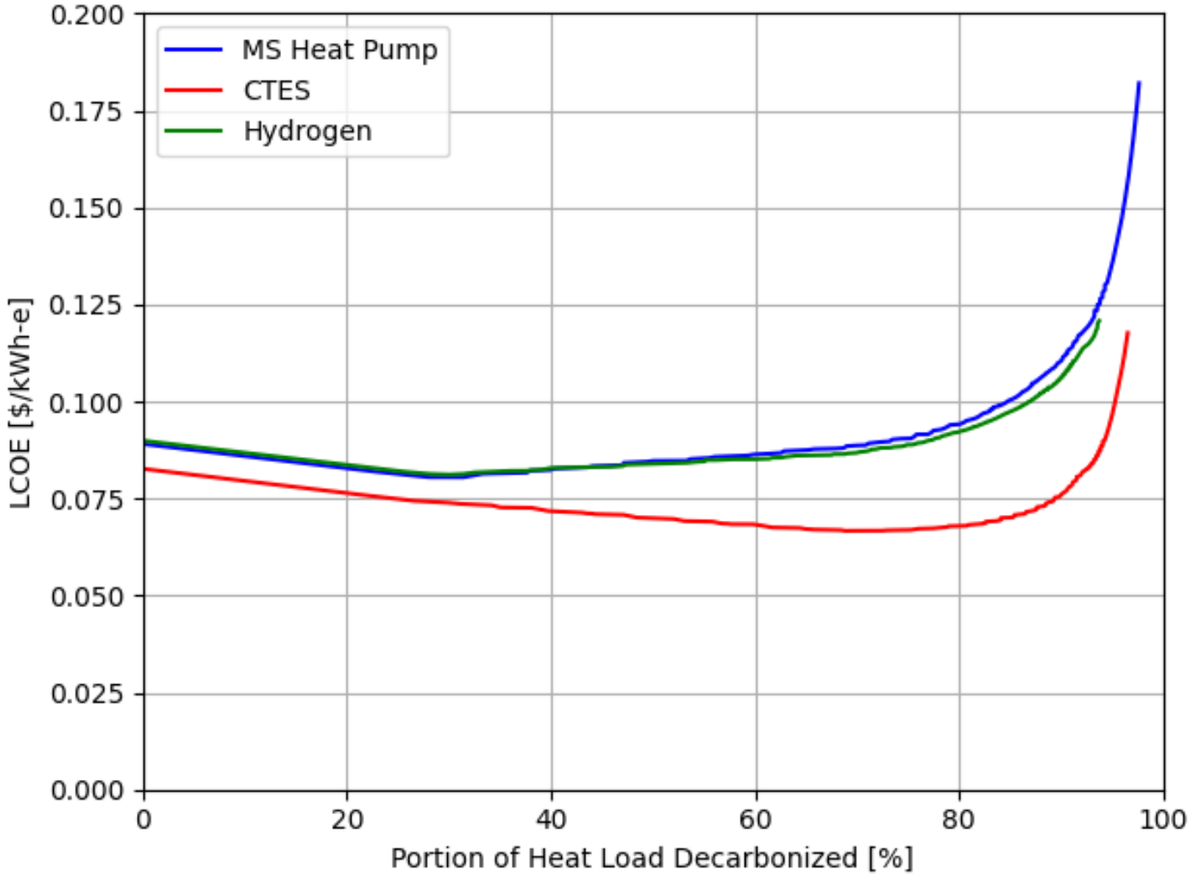
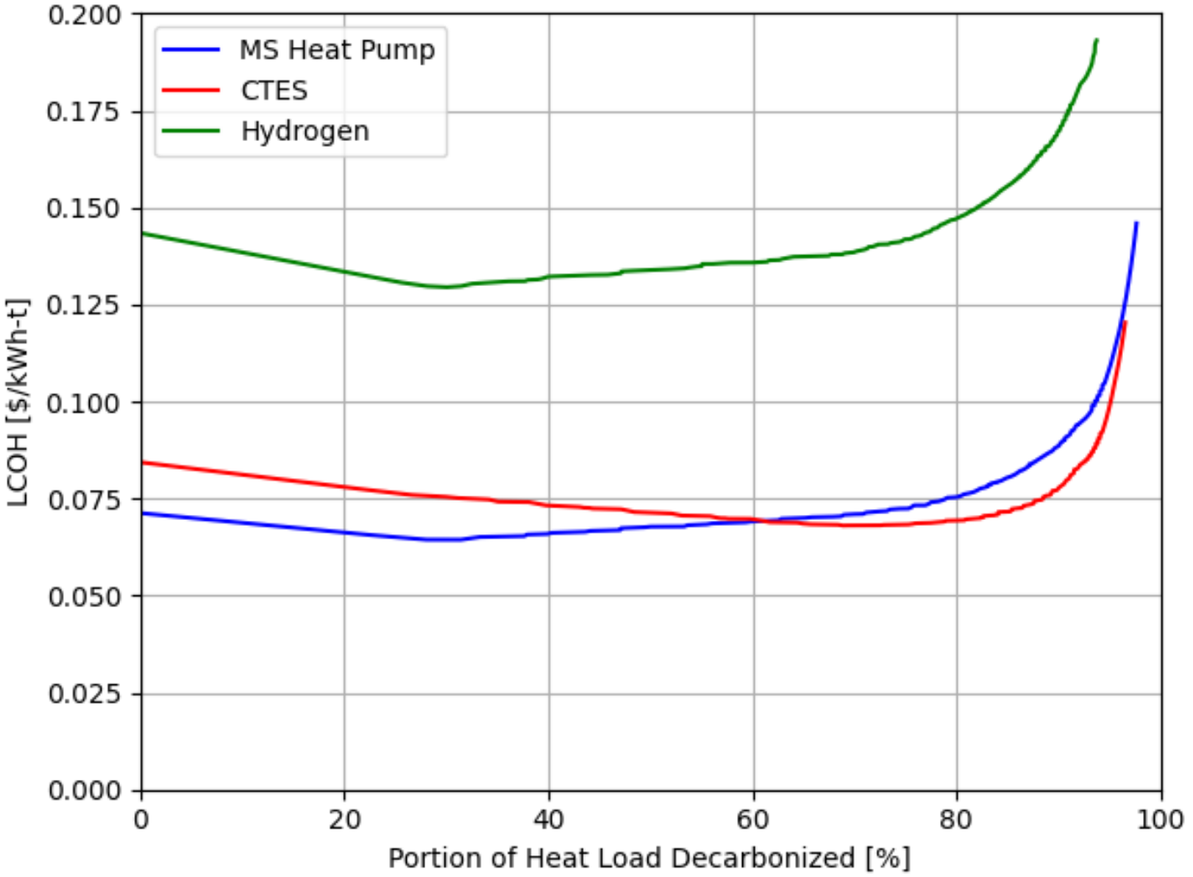
Decarbonization with TES





$$LCOE_{real} = \frac{\sum {Costs_i}/{r_{nom,i}}}{\sum {Electricity_i}/{r_{real,i}}} \quad \left[\frac{\$}{kWh_e}\right]$$

$$LCOH_{real} = \frac{\sum {Costs_i}/{r_{nom,i}}}{\sum {Heat_i}/{r_{real,i}}} \quad \left[\frac{\$}{kWh_t}\right]$$

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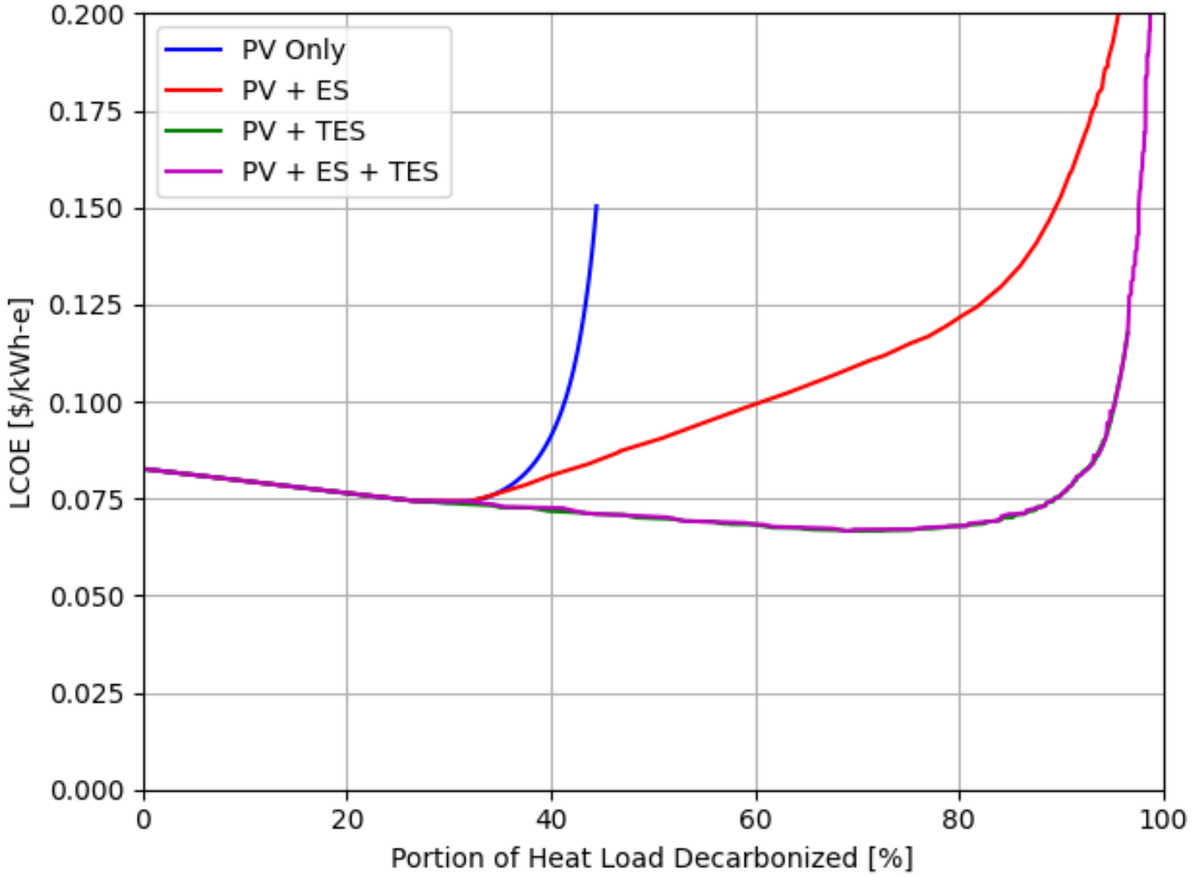
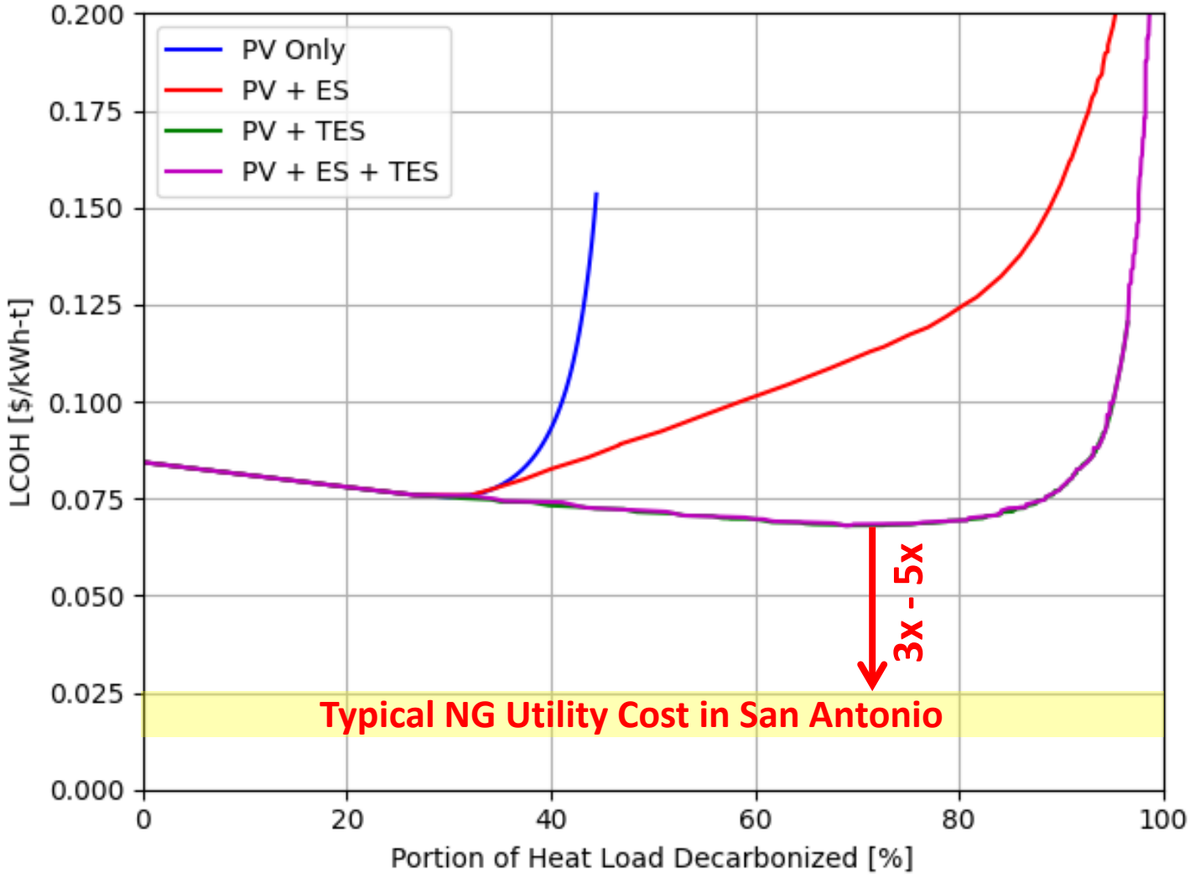
Decarbonization with Battery and Concrete TES





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$$LCOH_{real} = \frac{\sum {Costs_i}/{r_{nom,i}}}{\sum {Heat_i}/{r_{real,i}}} \quad \left[\frac{\$}{kWh_t}\right]$$

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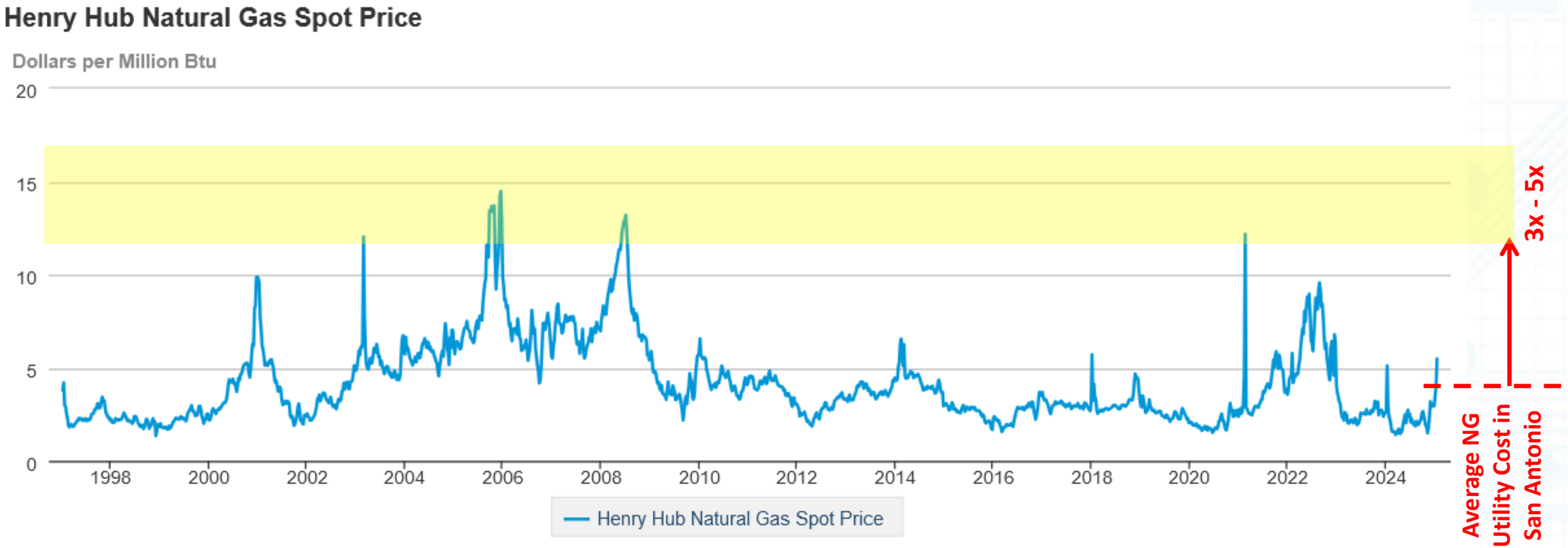
Historical Natural Gas Prices



San Antonio Large User: Average of $4/MMBTU

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Recent Major Awards for Industrial Decarb

- OCED
  - $6 billion, 33 selections
  - Aluminum and Metals
  - Cement and Concrete
  - Chemicals and Refining
  - Food and Beverage
  - Iron and Steel
  - Process Heat
  - Pulp and Paper
- IEDO Cross-cutting
  - $39 million, 16 selections
  - Electrification of Industrial Heat
  - Efficient Energy Use in Industrial Systems
  - Decarbonizing Wastewater Treatment
- IEDO Multi-Topic
  - $171 million, 49 selections
  - Decarbonizing Industrial Heat
  - Low-Carbon Fuels Utilization R&D
  - Exploratory Cross-Sector R&D
    - Enabling Flexible Industrial Energy Use
    - Enhanced Thermal Conductivity Materials
  - Decarbonizing Chemicals
  - Decarbonizing Iron and Steel
  - Decarbonizing Food and Beverage Manufacturing
  - Decarbonizing Cement and Concrete
  - Decarbonizing Forest Products.

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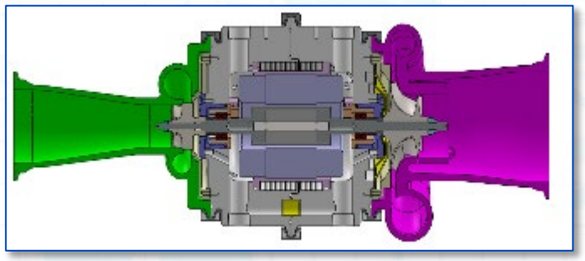
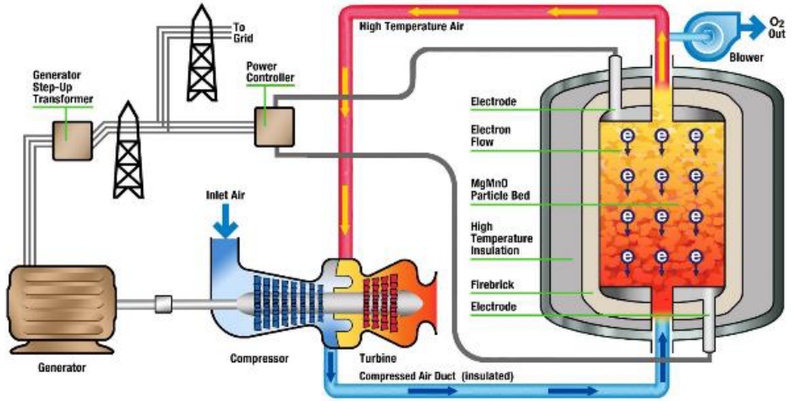
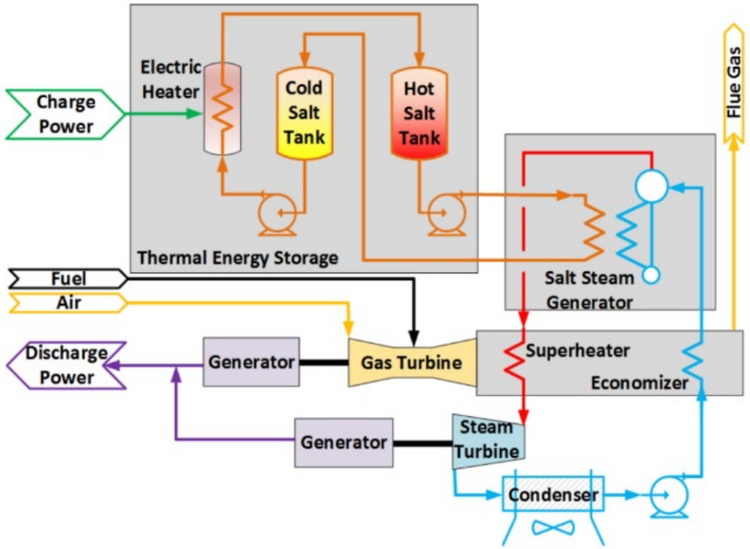
Machinery-Based Energy Storage Technologies

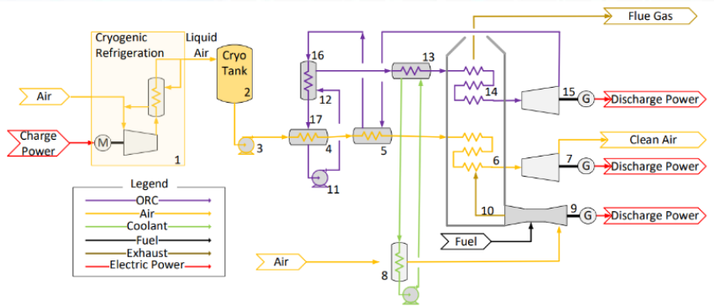


Pumped heat energy storage: Air vs. sCO2, external heat addition, hot (large?) charge compressor, condensing turbine, charge/discharge operation



Electrothermal energy storage: gas turbine integration, sCO2 power, combined heat and power





Hybrid energy storage: Liquid air, molten salt hybridized with gas turbine combined cycles, combined heat and power

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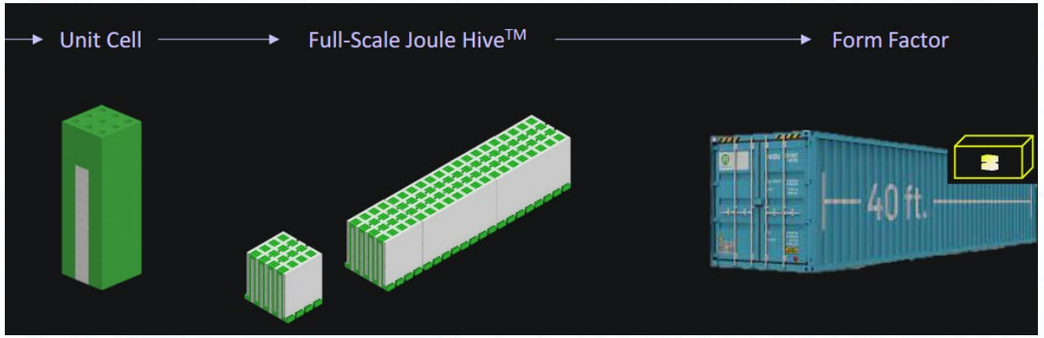
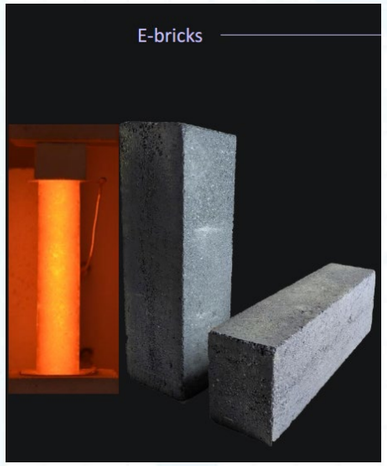
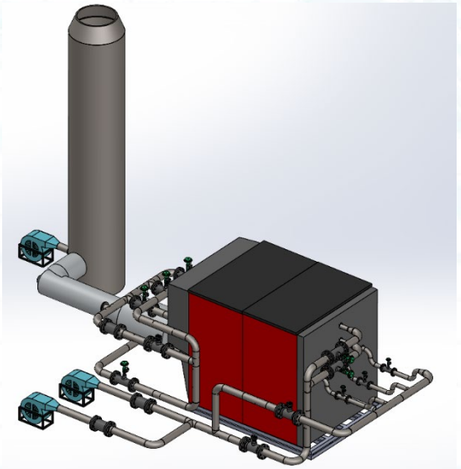
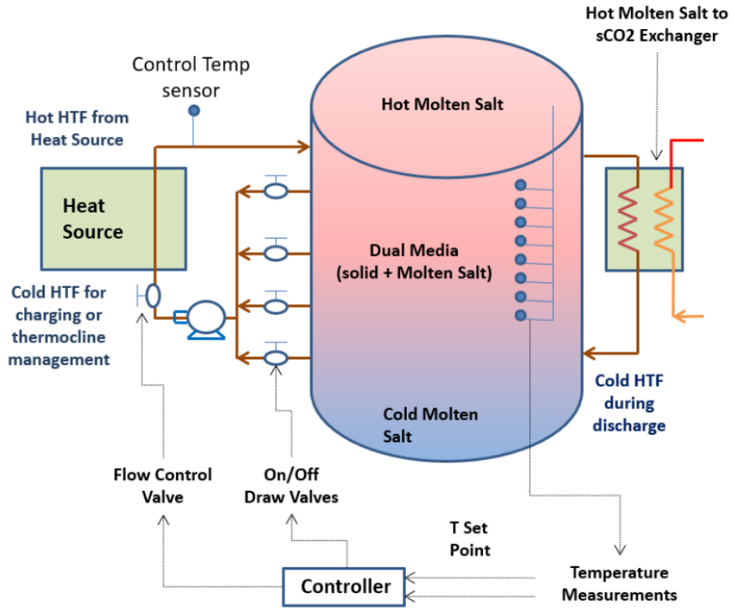
SwRI-Hosted Pilot Tests for TES



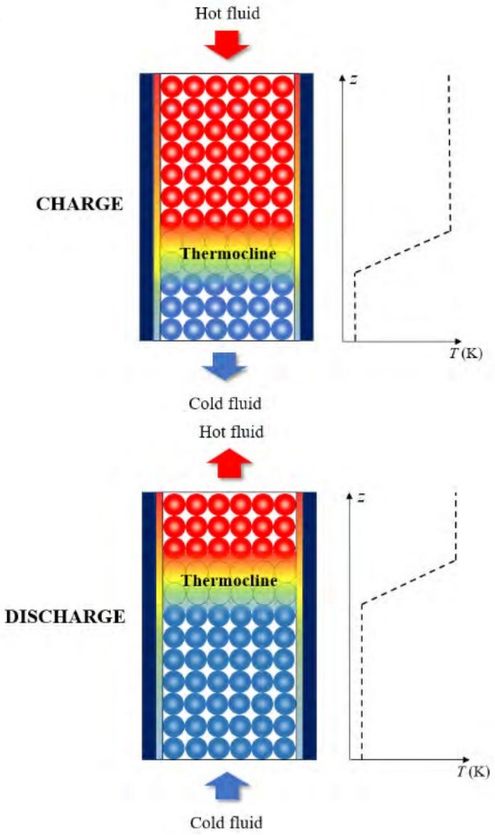
High-Temp Electrified Sensible Heat: Heat stored by temperature change in bricks. Electrically conducting bricks. 1 MW charging test. 20 hours of duration. Planed heat delivery at 900°C







Dual Media TES: Heat stored in molten salt and rocks. Molten salt is the heat transfer fluid. 2 kW discharge with 10 hours of duration. Heat stored at 500°C



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Questions?

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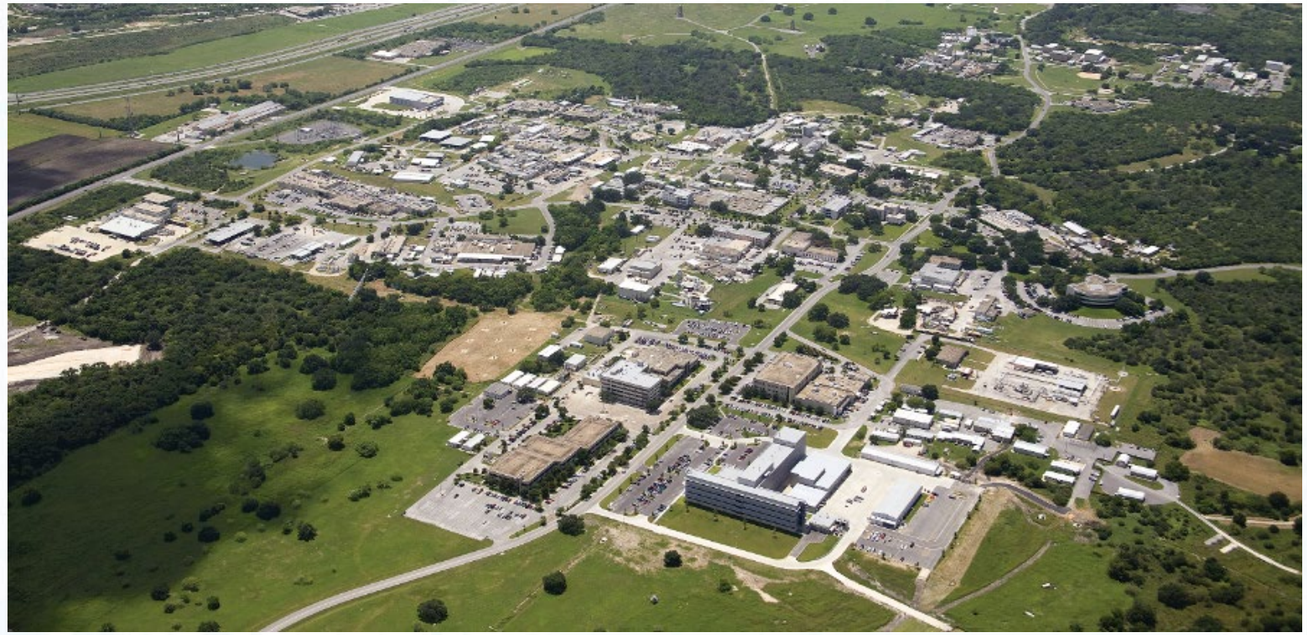

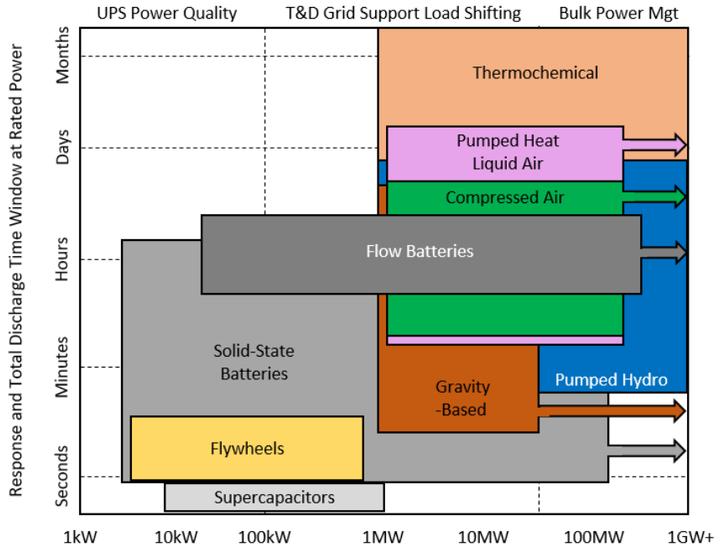

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