Rechargeable Zinc Manganese Dioxide Batteries for Stationary Energy Storage

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NAATBatt Zinc Workshop

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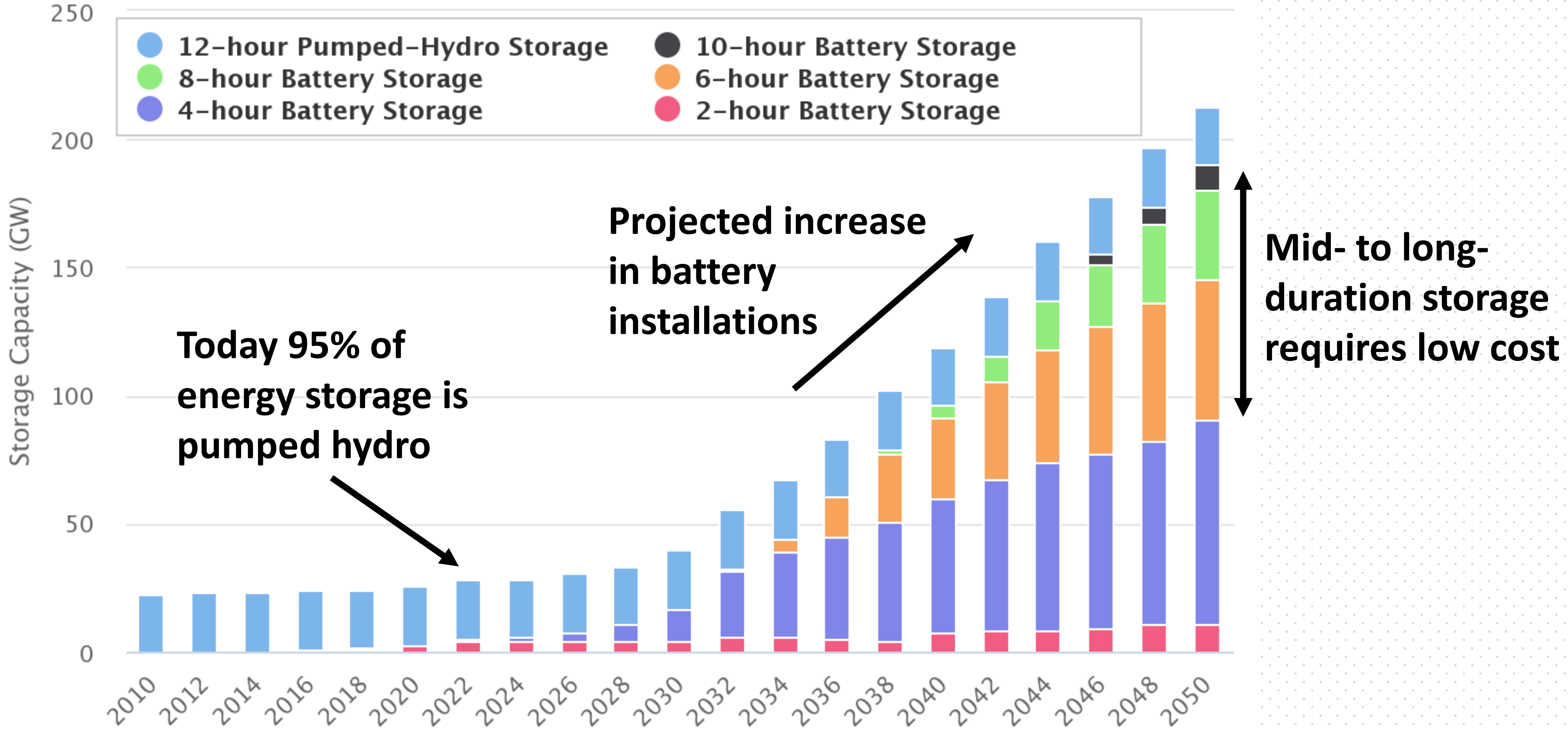
Need for Renewable Energy

Undergoing a global transition from fossil fuels to renewable energy to mitigate effects of climate change.

https://www.noaa.gov/education/resource-collections/climate/climate-change-impacts

Batteries for Renewable Energy Storage

Projected Energy Storage Installations – National Renewable Energy Lab (NREL)



NREL estimates 3,000x more battery capacity in 2050 than today.

Frazier, A. Will , Wesley Cole, Paul Denholm, Scott Machen, Nathaniel Gates, and Nate Blair. 2021. Storage Futures Study: Economic Potential of Diurnal Storage in the U.S. Power Sector. Golden, CO: National Renewable Energy Laboratory.

Growing and Existing Demands for Stationary Storage

Applications:

- Renewable energy storage
- Uninterruptible power supplies
- Demand response, peak shaving, load shifting

Zinc batteries have an opportunity to displace existing technologies for these applications

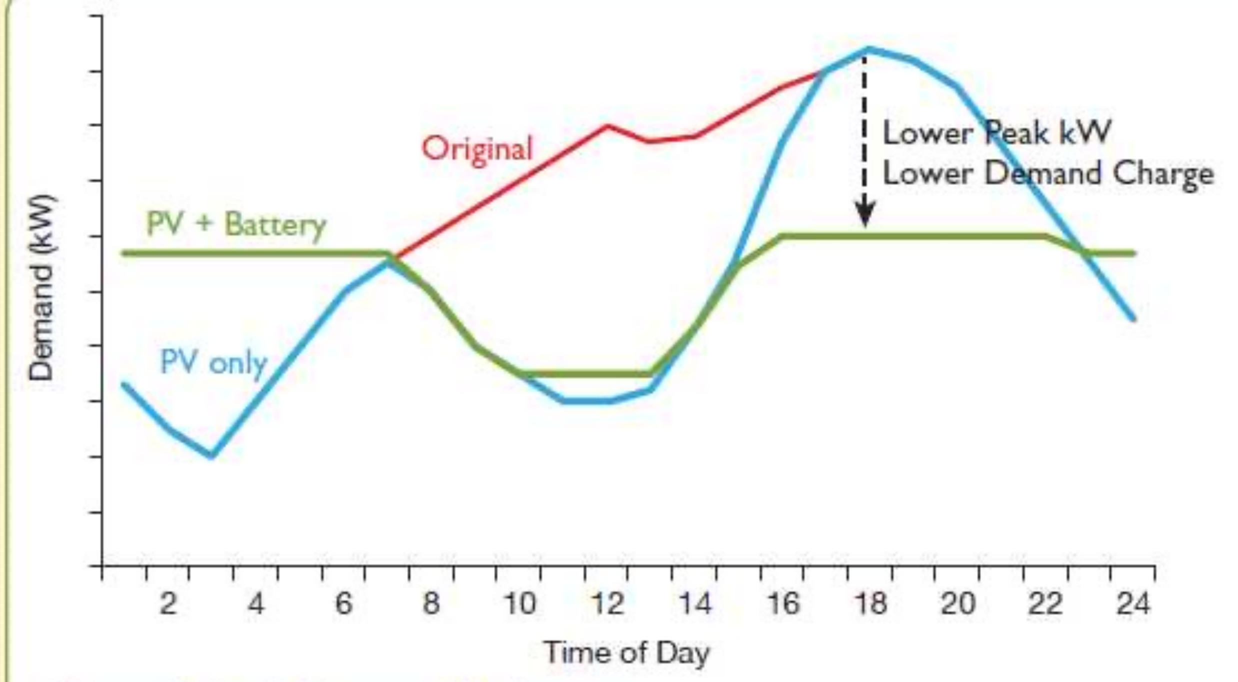
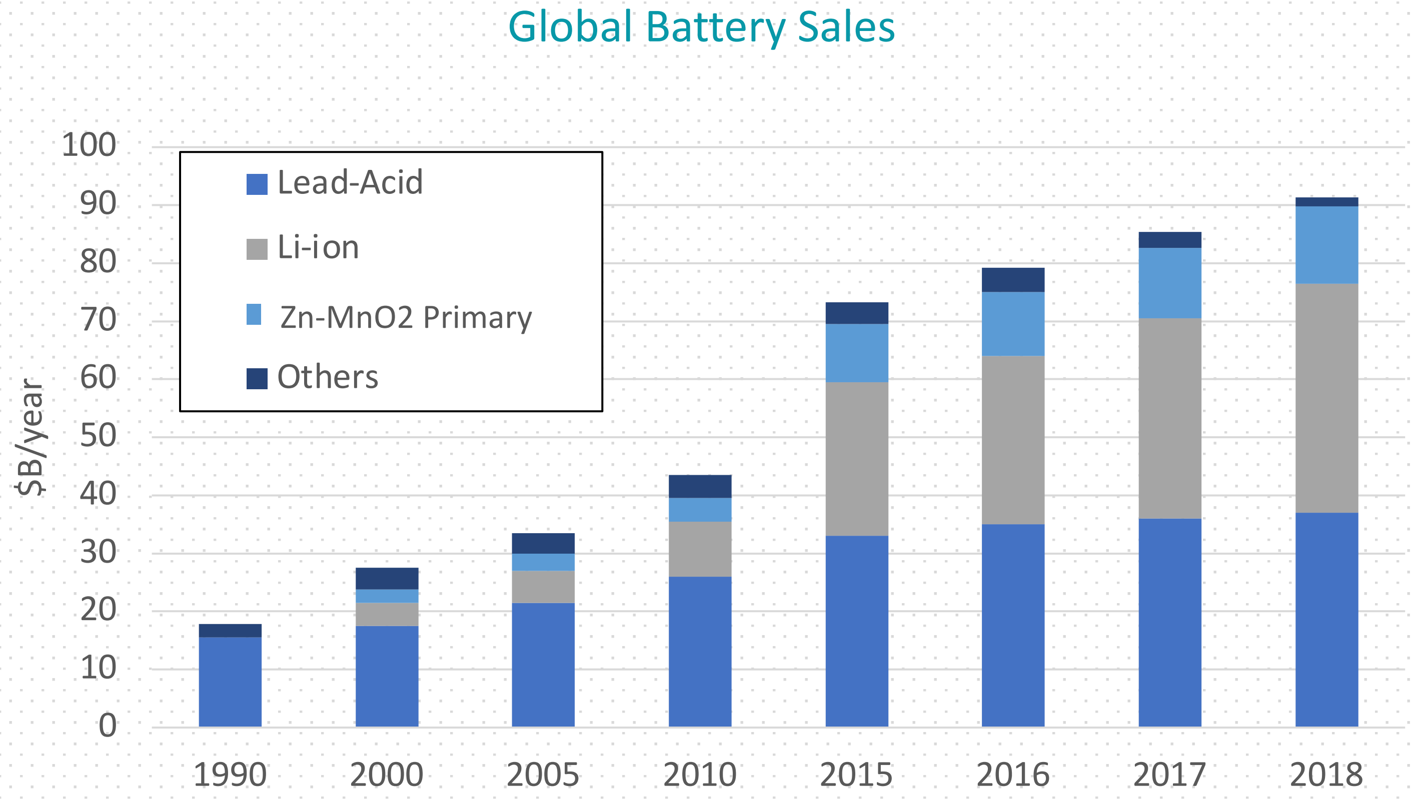


Figure 2. Peak Demand Reduction

https://www.solarpowerworldonline.com/2013/02/solar-white-paper-peak-demand-reduction-using-battery-storage/

Existing Global Battery Market



Where are we today?

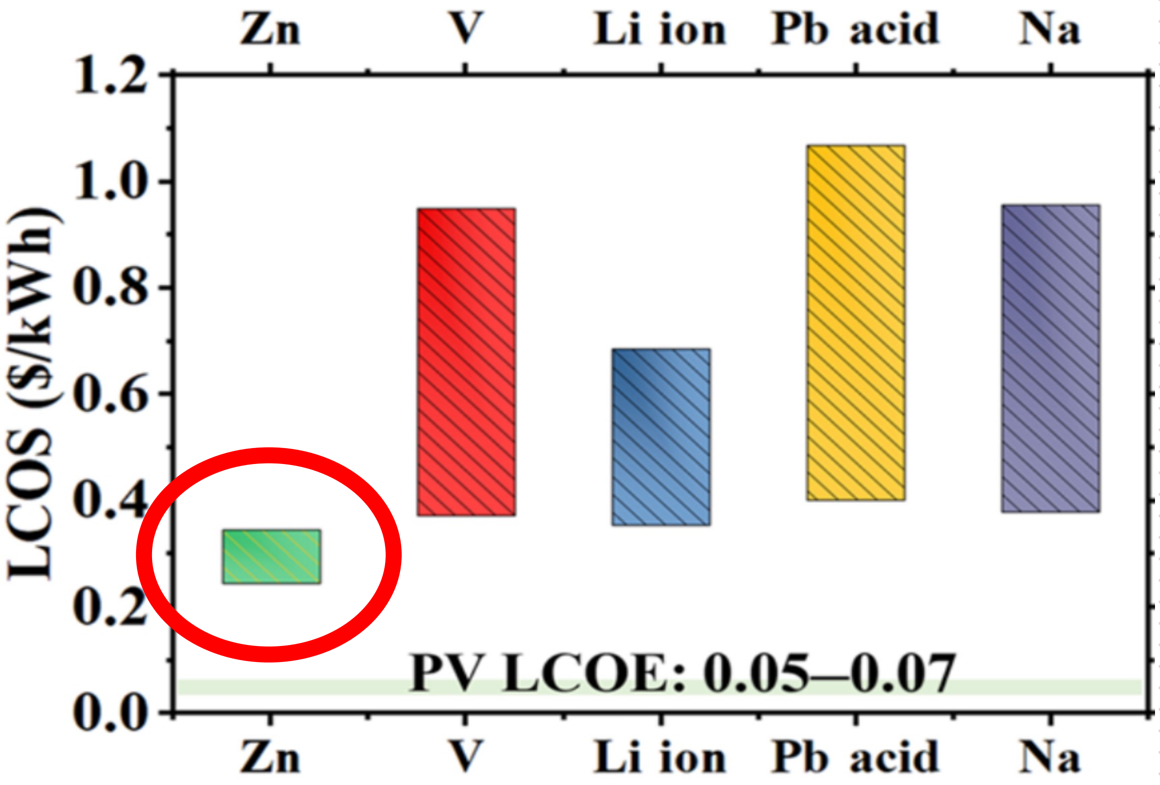
- Li-ion sales ~$40B/yr growing
- Lead-Acid sales~$38B/yr stable
- Zn-MnO2 primary cell sales ~ $13B/yr growing
- Other battery sales (NiCd, NiMH, Flow batteries, NAS, …) ~$1.5B/yr decreasing

Zinc and manganese dioxide have established supply chains to meet demands of $13Bn/year of Zn0MnO2 alkaline (primary) cells.

Why Zn over Pb and Li?

- Zinc is inherently low cost
- Lithium-ion has inherently high cost and safety concerns
  - Unsuitable for applications with limited budget
  - Unsuitable for installation near occupied spaces or in populated areas

Estimated Levelized Cost of Storage



Zheng, Jingxu, and Lynden A. Archer. "Controlling electrochemical growth of metallic zinc electrodes: Toward affordable rechargeable energy storage systems." *Science Advances* 7.2 (2021): eabe0219.

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- Lead-acid is extremely toxic
  - 26 million people at higher risk of disease worldwide
  - Lead recycling is #1 worst polluting industry rated by Green Cross

- Lead
  Population at risk: 26m
  DALYs: 9m
- Radionuclides
  Population at risk: 22m*
  DALYs: N/A
- Mercury
  Population at risk: 19m
  DALYs: 1.5m
- Chromium
  Population at risk: 16m
  DALYs: 3m
- Pesticides
  Population at risk: 7m
  DALYs: 1m
- Cadmium
  Population at risk: 5m
  DALYs: 250,000
- **Total**
  Population at risk: 95m
  DALYs: 14,750,000 years of lost life

Earth, Pure, and Green Cross. "World's Worst Pollution Problems. The New Top Six Toxic Threats: A Priority List for Remediation." (2016).

Why Manganese Dioxide?

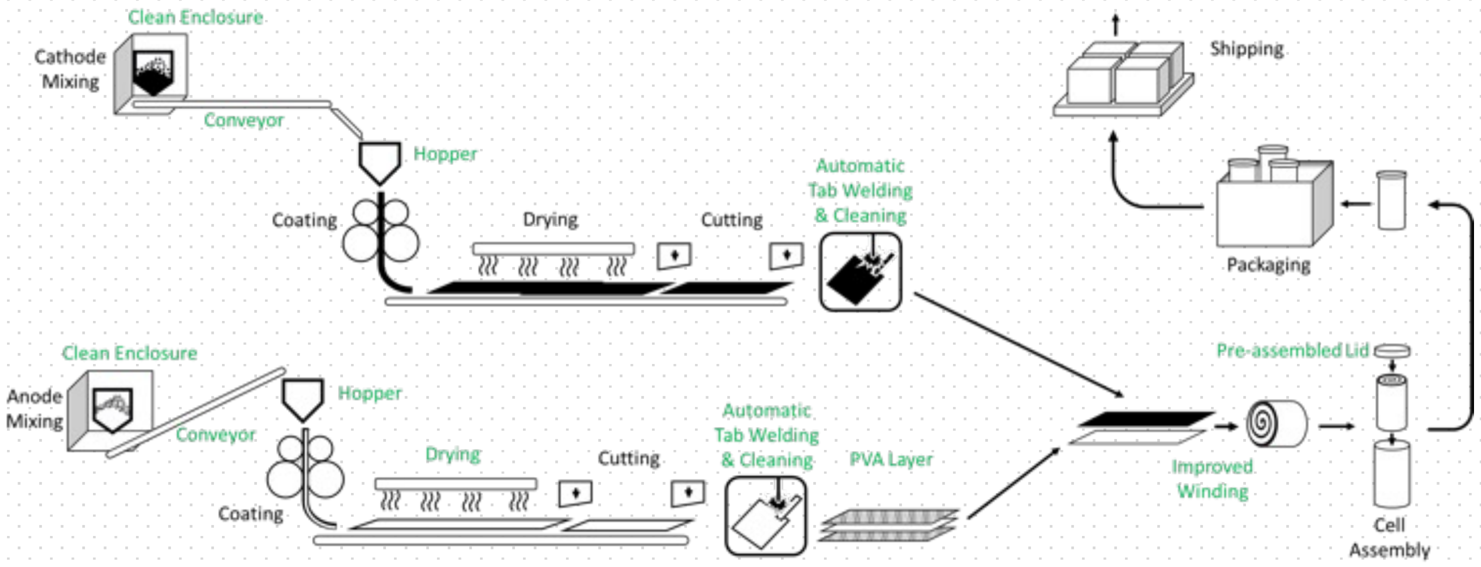
Common cathodes paired against zinc:

Silver oxide, nickel oxyhydroxide, air, manganese dioxide

- Silver – too expensive
- Nickel – great performance, but high/volatile cost
- Air – currently poor stability and energy efficiency
- **Manganese dioxide**:
  - Abundant: 5th most abundant metal in earth's crust
    World reserves of manganese are ~630 M metric tons. Annual global consumption is ~16 M metric tons (USGS)
  - Low-cost:
    - Nickel trades at ~$30k/ton
    - Manganese trades at ~$2k/ton
  - Robust supply chains: used in Li-ion, primary Zn, steel production

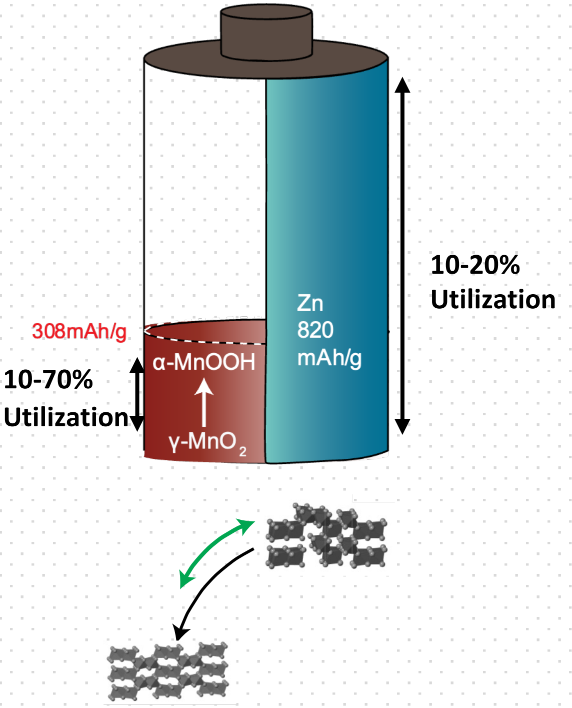
Manufacturing

UEP's Rechargeable Zn-MnO2 Battery Manufacturing Process:
Concept to Product



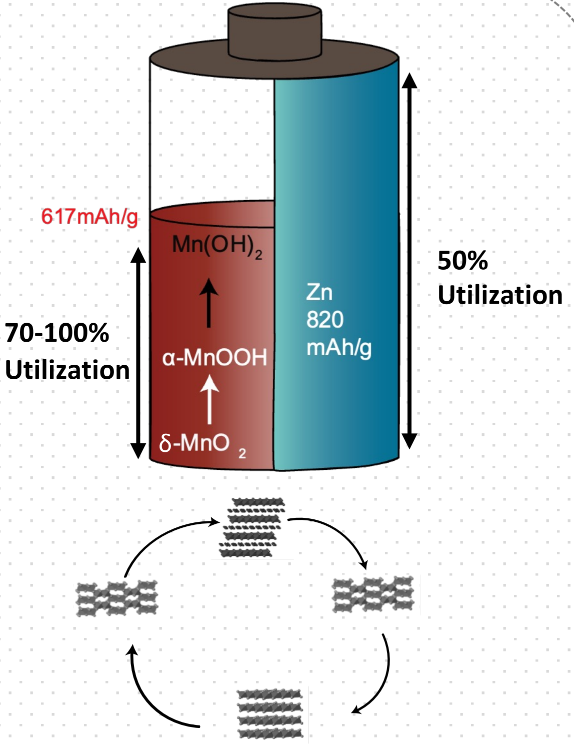
Development Stages For Zn-MnO$_2$ Batteries

Gen 1
Proton Insertion Battery



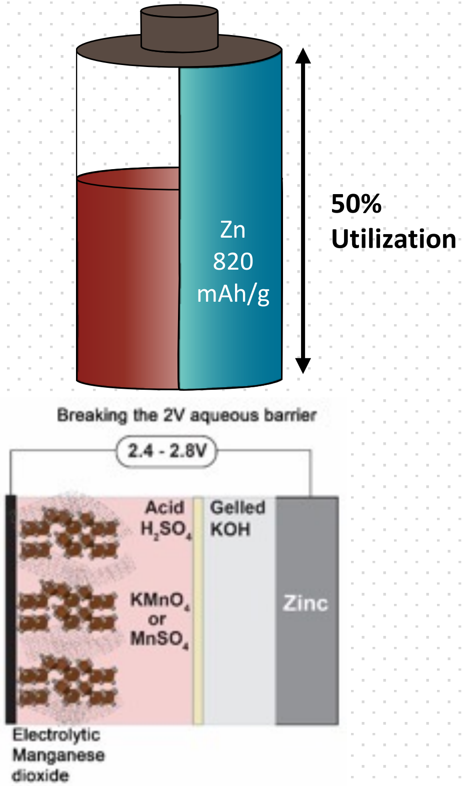
- Analogous to the Li-ion intercalation chemistry.
- Rechargeable utilization till 70% of proton insertion chemistry.
- Inactive spinel formation beyond 70% utilizations.

Gen 2
Conversion Battery



- Analogous to the Li-ion's Silicon conversion anodes that promise higher energy density.
- UEP's conversion battery can access energy densities comparable to Li-ion.

Gen 2+
The Li-ion Competitor
High Voltage 2.45-2.8V Zn-MnO$_2$



- Breakthrough accessibility in >2.4-2.8V & 100% utilization of 308mAh/g of MnO$_2$ allows higher energy density than Li-ion.

Ongoing and Recently Completed Deployments

Ongoing and Recently Completed Gen 1 System Deployments

Project	Use Case	Timeline
San Diego Supercomputer Center backup (San Diego, California)	1MW / 2 MWh High-Rate UPS	½ - Quarter 1, 2022 ½ - Quarter 4, 2022
CCNY Grid Modernization Center (Manhattan, New York)	1 MWh Grid Storage (demand response/ demand charge) Solar Microgrid High-Rate UPS	Quarter 4, 2022
BMCC Energy Storage System (Manhattan, New York)	200kWh Grid Storage (demand response / demand charge)	Quarter 1, 2023
Five Spoke Creamery Power Backup System (New York)	200 kWh Long Duration UPS	Quarter 1, 2022
Navajo Nation Microgrid (New Mexico)	Multiple 10 KW Solar Microgrids	Quarter 2, 2022
Electrical Power Research Institute	40 kWh scalable utility modules for demand response and renewables	Quarter 4, 2021

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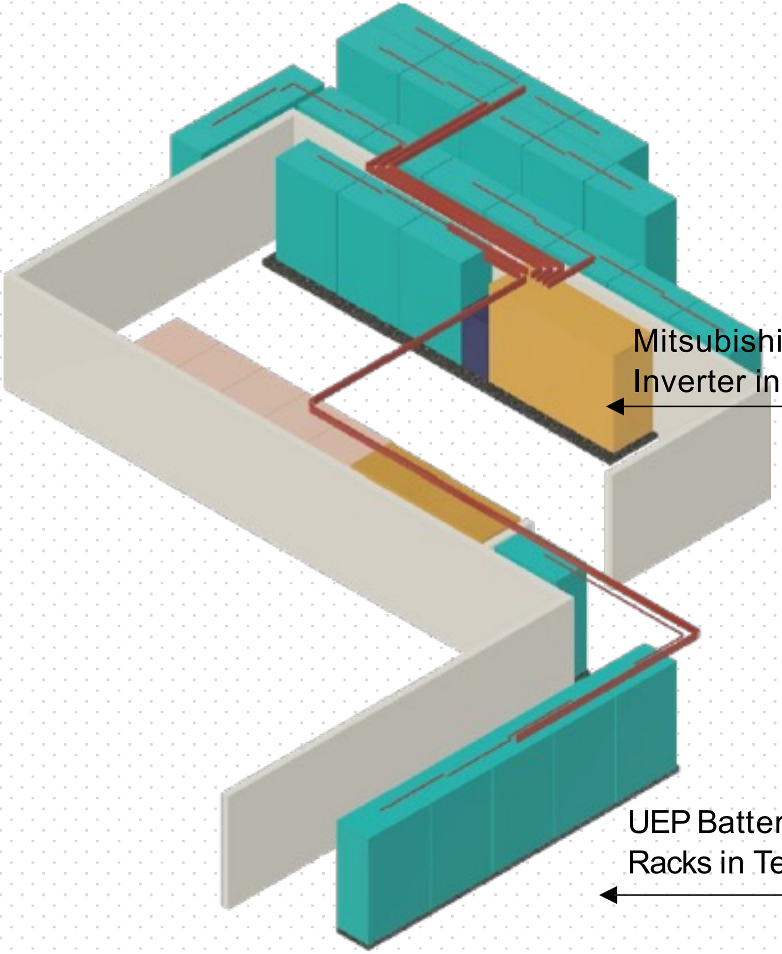
Installation Highlights:

Backup System for the San Diego Supercomputer Center (SDSC)



- UEP received a purchase order for a 1 MW data-center UPS installation at SDSC to provide 2-hour backup

- UEP is proposing 27 standard 4D (BCI) battery racks (see Slide 11) for the installation.

- For comparison, the VRLA lead acid system currently installed would require 60 racks and twice the cost for the same duration as Urban Electric Power.

Layout for the San Diego Supercomputer Center 1MW/2MWh Backup System

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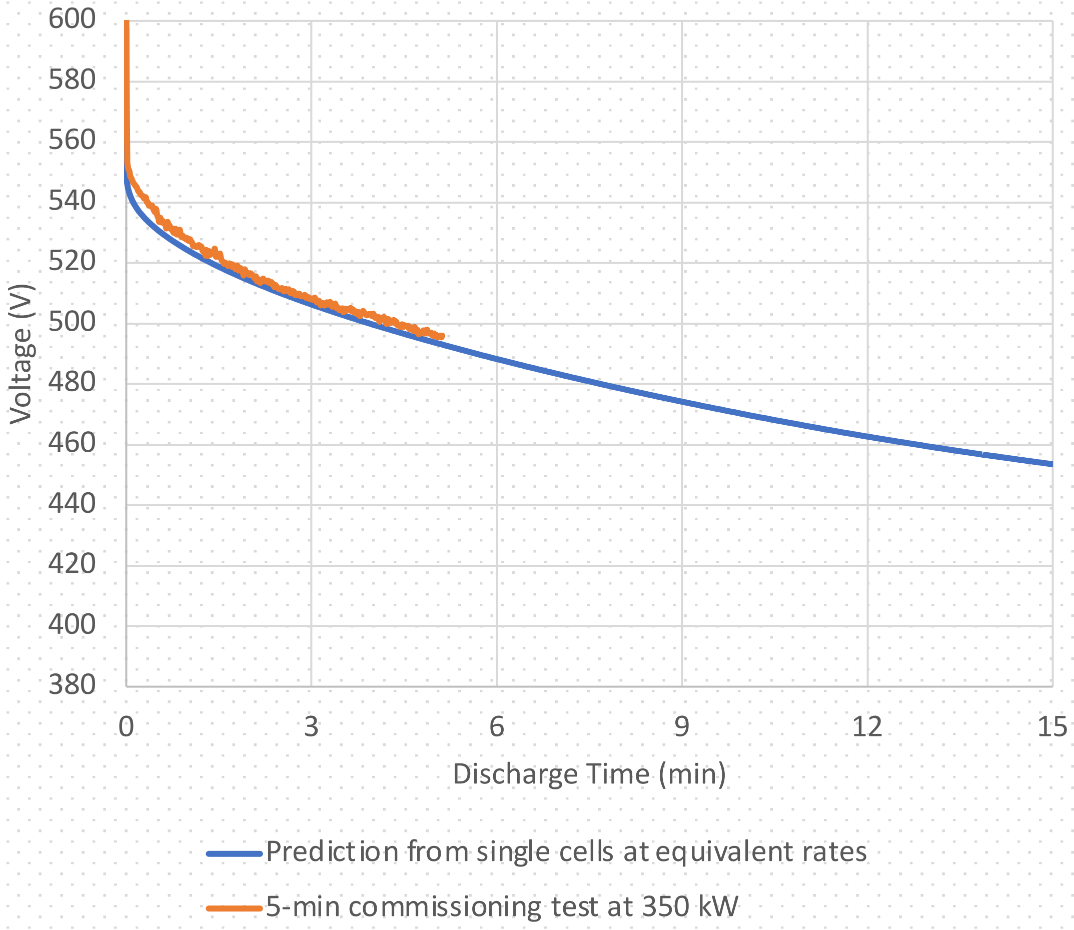
Predicting the rack discharge by single cell performance



- The orange curve is the average discharge voltage curve of 13 racks during the commissioning test. The commissioning test ran for 5 minutes at 350 kW (equivalent to 75W per cell) as requested by the customer.
- The blue curve is the discharge voltage curve of a single cell tested in UEP at 75W. The single cell voltage is multiplied by 360 to be compared to the rack voltage.
- The average voltage of the racks falls on top of the single cell discharge curve under equivalent discharging conditions.
- At the 15-min cutoff, which is the max backup time that the lead acid batteries can provide, the voltage of the UEP system is 453 V, exceeding the 380 V inverter limit.

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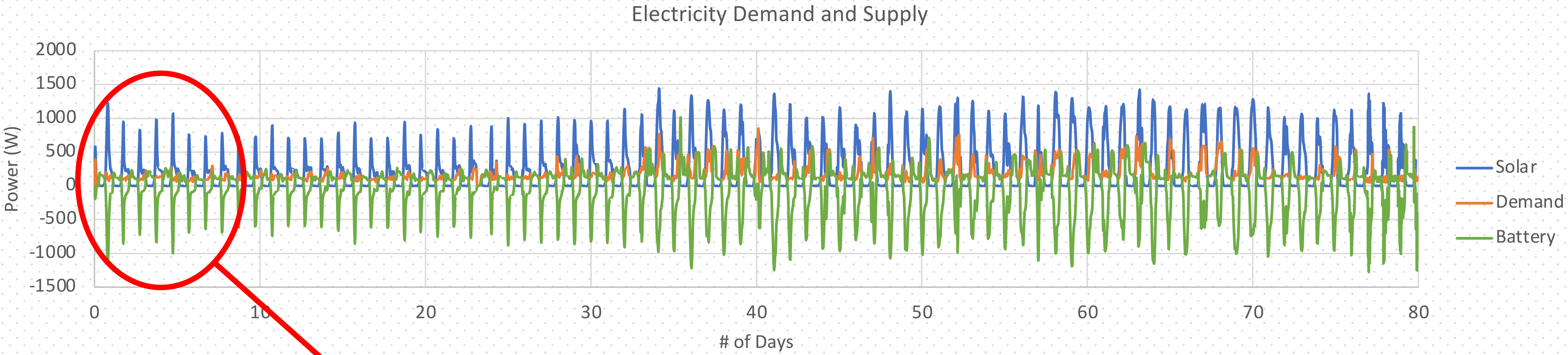
Installation Highlights:

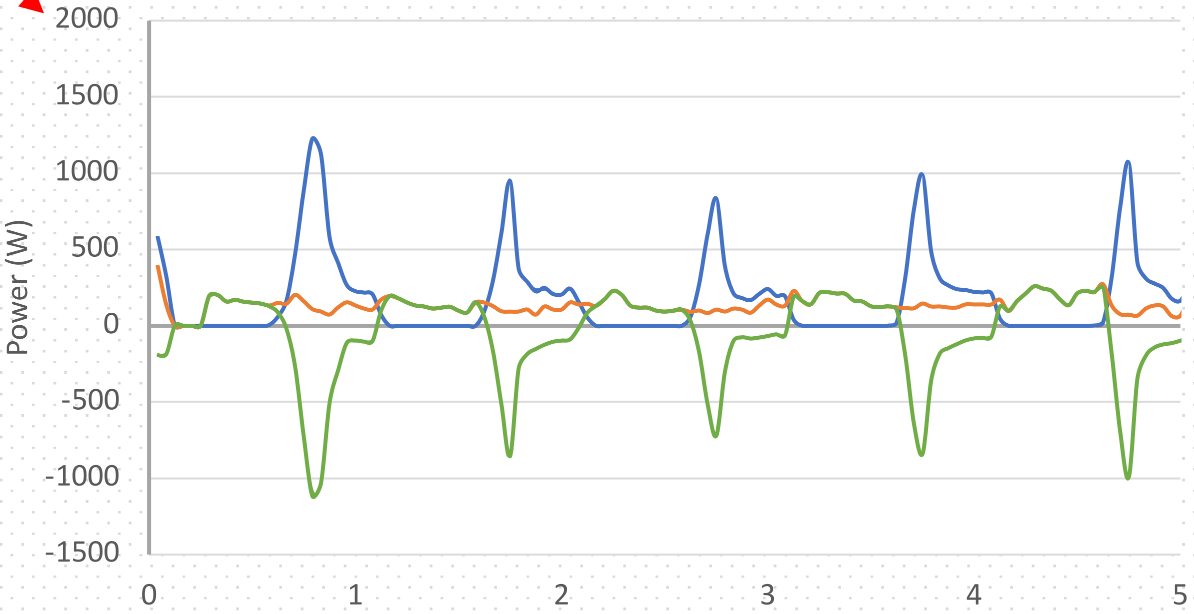
Navajo Tribal Utility Authority (NTUA)

Solar Microgrid

- 13 kWh solar microgrid system deployed in 2022
- System uses a standard Outback inverter and seats on a self-contained pod

Navajo Tribal Utility Authority (NTUA) Solar Microgrid: Power Curves





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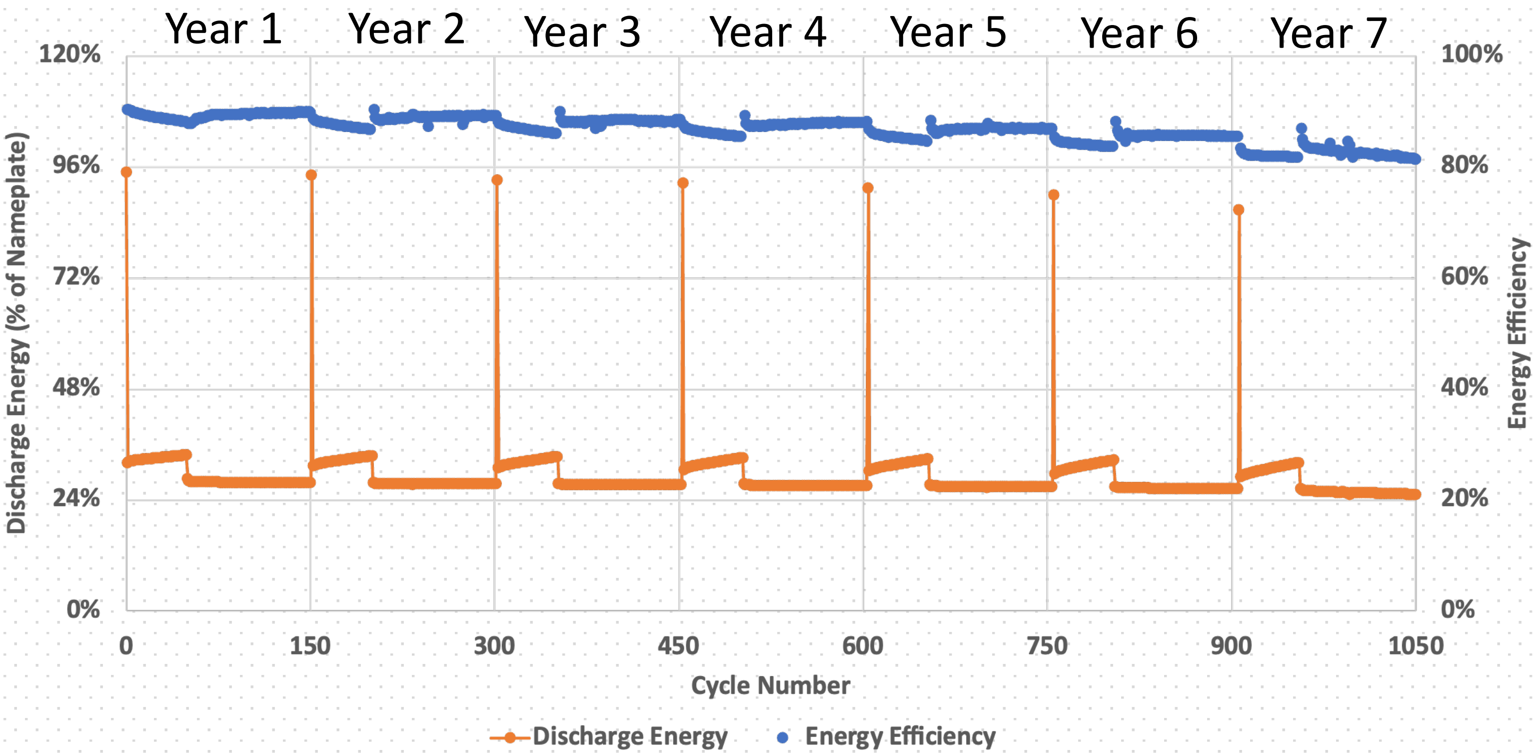
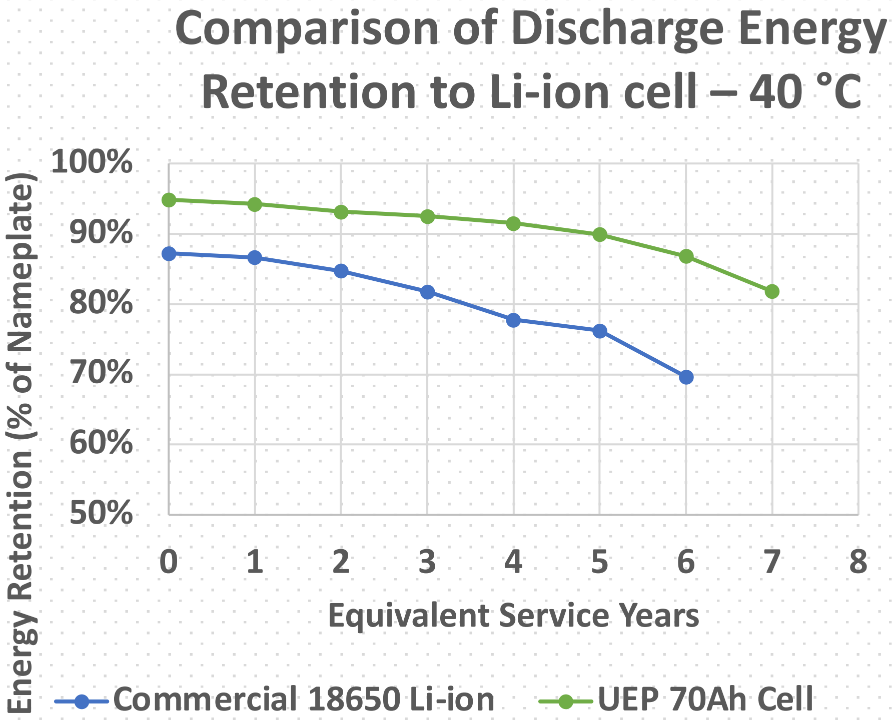
Provided Solar Microgrid Performance

UEP Zn-MnO2 Gen 1 Cell Tests: Solar Microgrid Protocol

UEP Battery cell 70 Ah nameplate capacity, completed 5 years and still running under IEC 61427-1 testing protocol, defined below, for solar microgrid use case.





Phase A: 3h C/10 charge and 3h C/10 discharge cycling at low state of charge for 50 cycles.
Phase B: 6h charge and 2h C/8 discharge cycling at high state of charge for 100 cycles.
A 9-hour C/10 discharge is done between phases B and A at the end of each year.

Conclusions

- Zinc manganese dioxide batteries are attractive replacements for lead-acid and lithium-ion for mid- to large-scale stationary storage
  - Solar microgrids
  - Demand response
  - Uninterruptible power supply
- Demonstrated utility in systems up to 2 MWh
- Planned improvements to formulations, design, and manufacturing will drop cost of cells to ~$30/kWh

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Thank you!

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