Progress in the Development and Deployment of Zinc Manganese Dioxide Batteries

Sanjoy Banerjee

Distinguished Professor of Chemical Engineering,

Director, the CUNY Energy Institute,

The City College of New York,

Founder & Chairman

Urban Electric Power Inc., NY

banerjee@ccny.cuny.edu

DOE Energy Storage Program, Peer Review
October 2022
Presentation # 703

CUNY ENERGY INSTITUTE

the City College of New York

URBAN ELECTRIC POWER

Objective and Topics

Discuss developments and deployments of energy storage systems powered by zinc manganese dioxide batteries and lessons learned

Main Topics

01 Rechargeable zinc manganese batteries as a low-cost option for decarbonizing the grid

02 Zinc-manganese dioxide developments –

- Improving active materials utilization for proton insertion (Gen 1) cells
- Cost reductions related to "conversion reaction" two-electron (Gen 2) cells

03 Manufacturing, supply chain and path to scale up.

04 Deployment of $Zn\text{-}MnO_2$ stationary energy storage systems: lessons learned

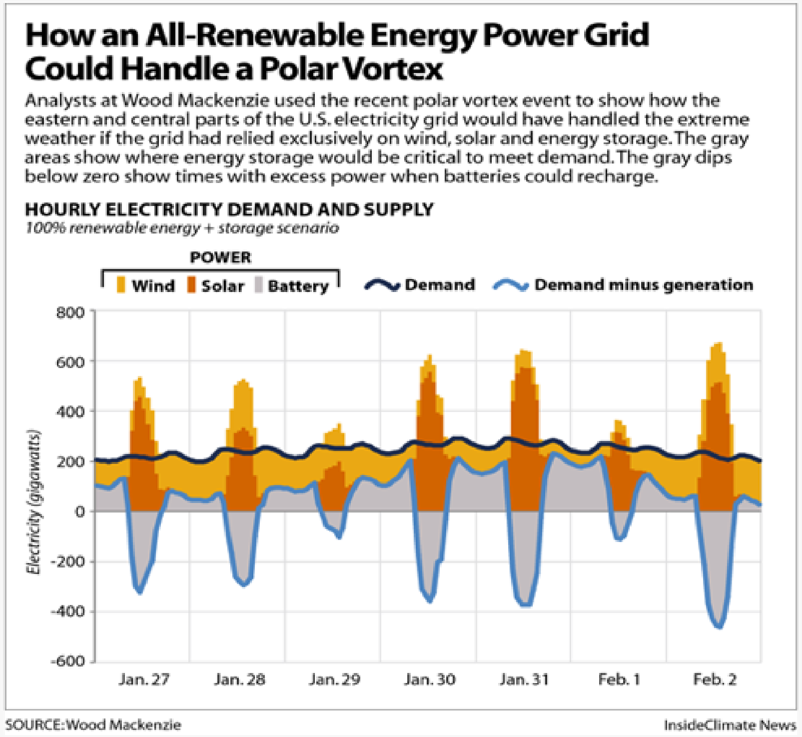
the City College of New York

CUNY ENERGY INSTITUTE

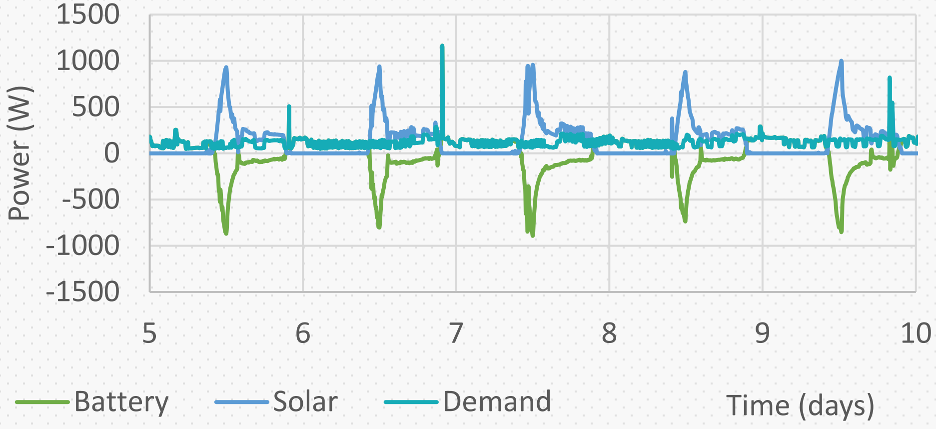
URBAN ELECTRIC POWER

Energy storage for a renewables based decarbonized grid: an example

- Peak energy generation does not necessarily align with peak energy consumption on a renewable powered grid.
- Estimating about 30% of renewable energy generated needs to be stored for a renewable powered electricity grid.
- The US will need 4 quads/year (~900 TWh/year) of energy storage to meet 2050 GHG emissions targets.



Example – Microgrid Power Demand and Supply (a UEP installation)



The City College of New York

CUNY ENERGY INSTITUTE

URBAN ELECTRIC POWER

Why Zinc Batteries?

How much material is theoretically needed to store electricity produced by Niagara Falls in a day?

Niagara Falls: 60,000 MWh/day

Anode (*)	**Cost $M**	GHG Produced Mt CO_2	Volume (m^3)	Mass (tonnes)
Zinc	**93**	1.5	6,200	44,000
Lithium	**370**	6	10,200	5,300
Lead	**230**	4	12,000	120,000

Zinc Lithium Lead

(*) Based on the anode theoretical capacity against a hypothetical air cathode

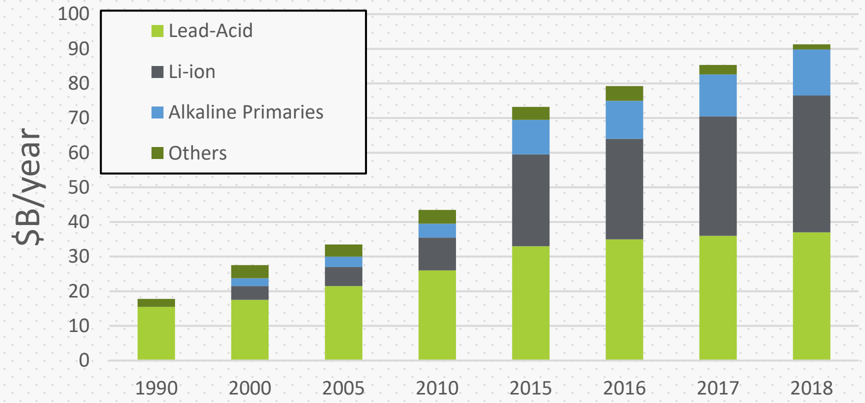
The City College of New York · CUNY Energy Institute · Urban Electric Power

Robust Existing Zinc Battery Supply Chain

Zinc Production	Mine	Thousand Tons/Year
Location		**Zinc**
Tlemcen, Algeria	Ghazaouet Mine	869
Alaska, United States	Red Dog Mine	491
Rajasthan, India	Rampura Agucha Mine	369

Manganese Production	Metric Tons/Year Manganese	Reserves MT
Location		
Mexico	225.7 thousand	1.5 million
Canada	2 thousand	9 million
India	2.8 million	52 million
South Africa	5.2 million	360 million
Australia	3.3 million	91 million
Gabon	2.8 million	250 million

Global Battery Sales



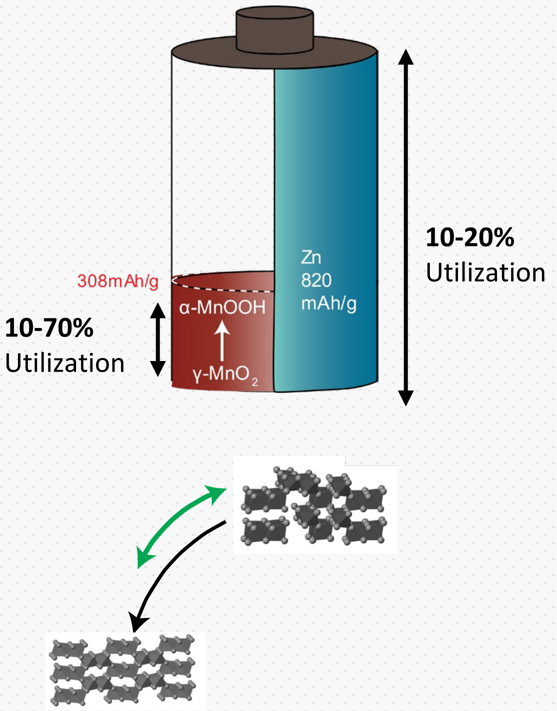
Zinc and manganese dioxide have established supply chains to meet demands of $13Bn/year of Zn0MnO2 alkaline (primary) cells.

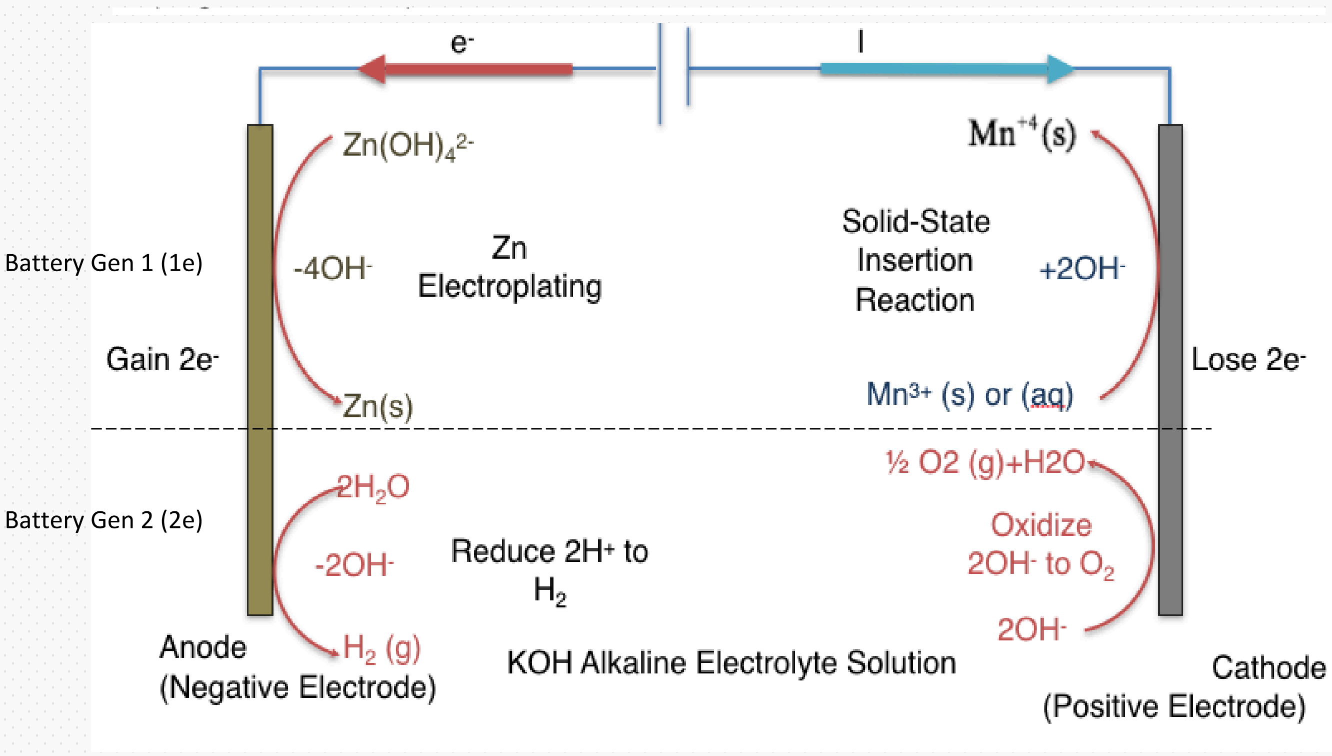
https://www.statista.com/statistics/751255/mexico-manganese-production/#:~:text=Mexico's%20manganese%20mine%20production%20amounted,236%20thousand%20metric%20tons%20produced.
https://novascotia.ca/natr/meb/data/pubs/74egs01/74egs01_Chapter01.pdf

Rechargeable Zinc-Manganese Dioxide Battery Chemistry:

Gen 1

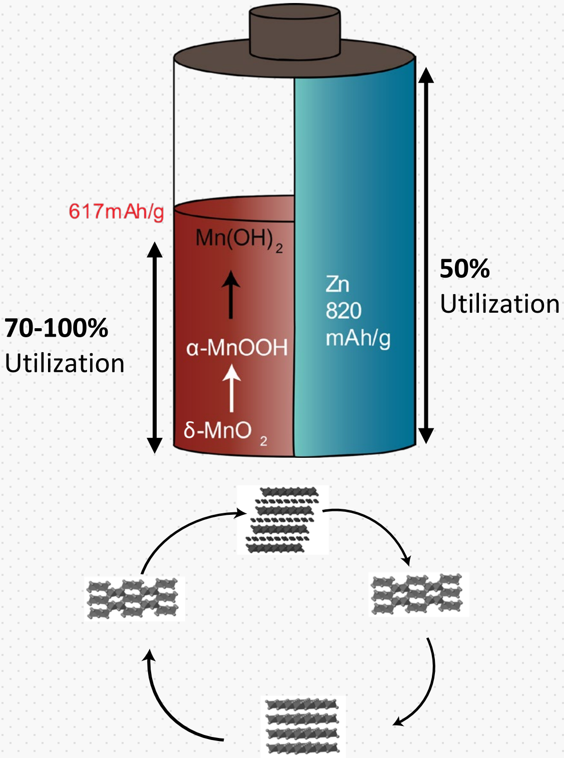
Proton Insertion Battery





Gen 2

Conversion Battery



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

- 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.

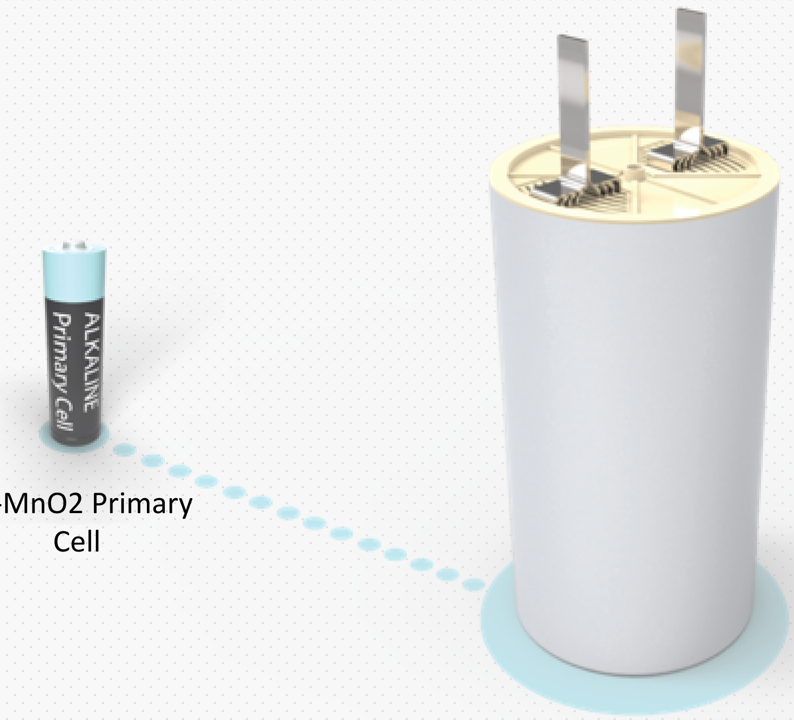
the City College of New York

CUNY ENERGY INSTITUTE

URBAN ELECTRIC POWER

An Evolution in Zn-MnO2 Alkaline Cells:

From Primary to UEP's Rechargeable Cell



Zn-MnO2 Primary Cell

UEP Rechargeable Zn-MnO2 Cell

- The CUNY Energy Institute and it's spinout, Urban Electric Power (UEP), develop rechargeable Zn-MnO2 alkaline cells.
- Evolves the familiar alkaline battery (e.g, double AA) into a rechargeable Zn-MnO2 alkaline battery to enable decarbonization goals.

Zinc Manganese Dioxide

($Zn\text{-}MnO_2$)

Alkaline batteries are recyclable and non-toxic.

UL 1973/9540A safety certification confirms no fire risk.

Modular solution utilized from residential to grid.

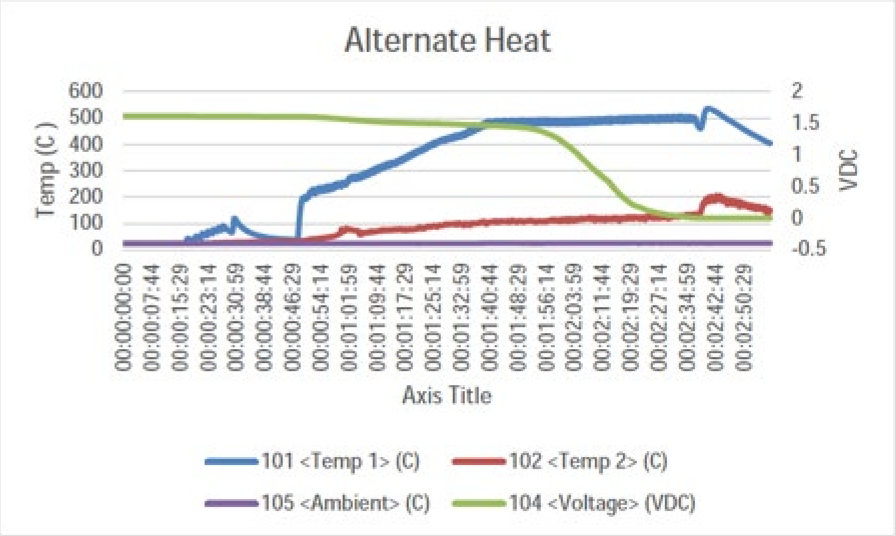
The City College of New York | CUNY Energy Institute | Urban Electric Power

Safety

Certifications of UEP’s Rechargeable Zinc-Manganese Batteries

- UL 9540A testing demonstrated UEP batteries do not reach thermal runaway when subjected to abuse tests
- Abuse testing performed by DNV-GL produced similar results and determined that “Unlike lithium-ion batteries, UEP’s cell is essentially nonflammable"
- FDNY Certificate of Approval and CE marking efforts currently in process

UEP Zn-MnO2 batteries after 9540A testing (above) and temperature data captured during the test (below).

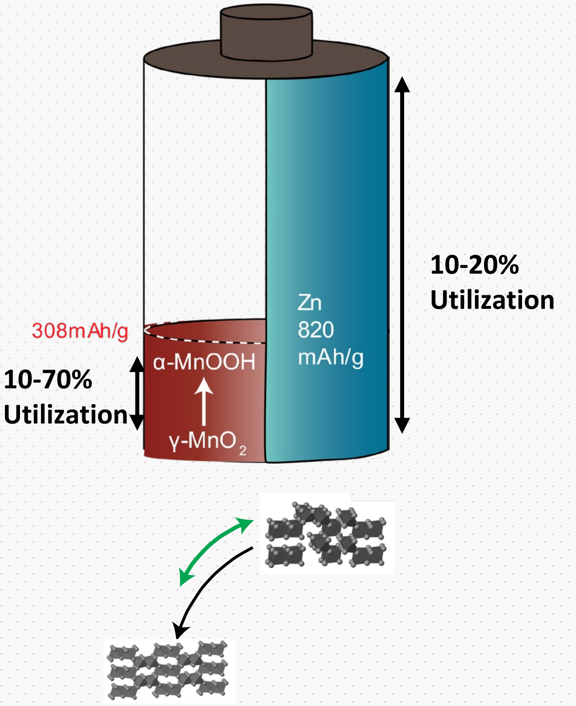


UL 9540A Tests for Fire Hazard

Test	Test Method	Thermal Runaway Time	Thermal Runaway Time
1	Film Heater	Not observed	N/A
2	Pipe Heater	Not observed	N/A
3	Nail Penetration	Not observed	N/A
4	Overcharge	Not observed	N/A
5	Overdischarge	Not observed	N/A

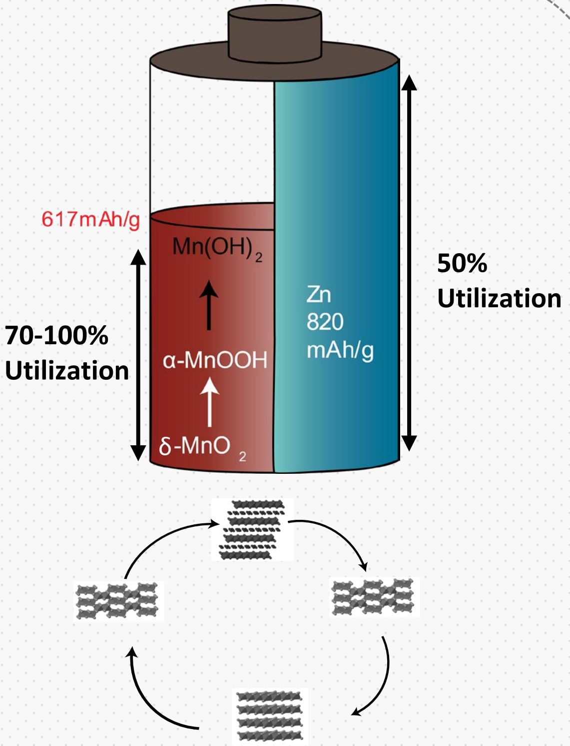
Development Stages For Zn-MNo$_2$ Batteries

Gen 1
Battery 1 and 2
Proton Insertion Battery



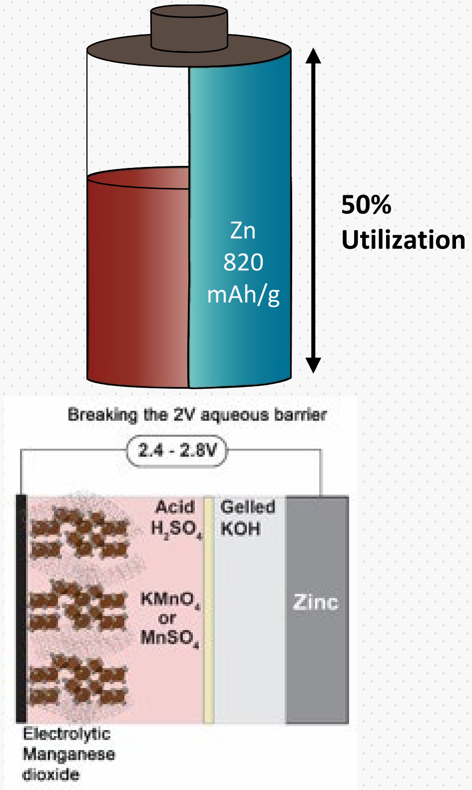
- Analogous to the Li-ion intercalation chemistry.
- Rechargeable utilization till 70% of proton insertion chemistry.
- Inactive spinel formation beyond 70% utilizations.

Gen 2
Battery 3
Conversion Battery



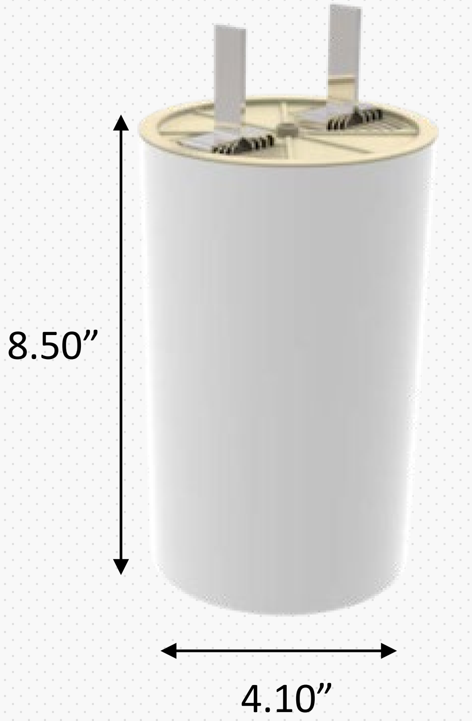
- Analogous to the Li-ion's Silicon conversion anodes that promise higher energy density.
- UEP's conversion battery can access energy densities comparable to Li-ion.

Gen 2+
Battery 4
The Li-ion Competitor
High Voltage 2.45-2.8V Zn-MnO$_2$



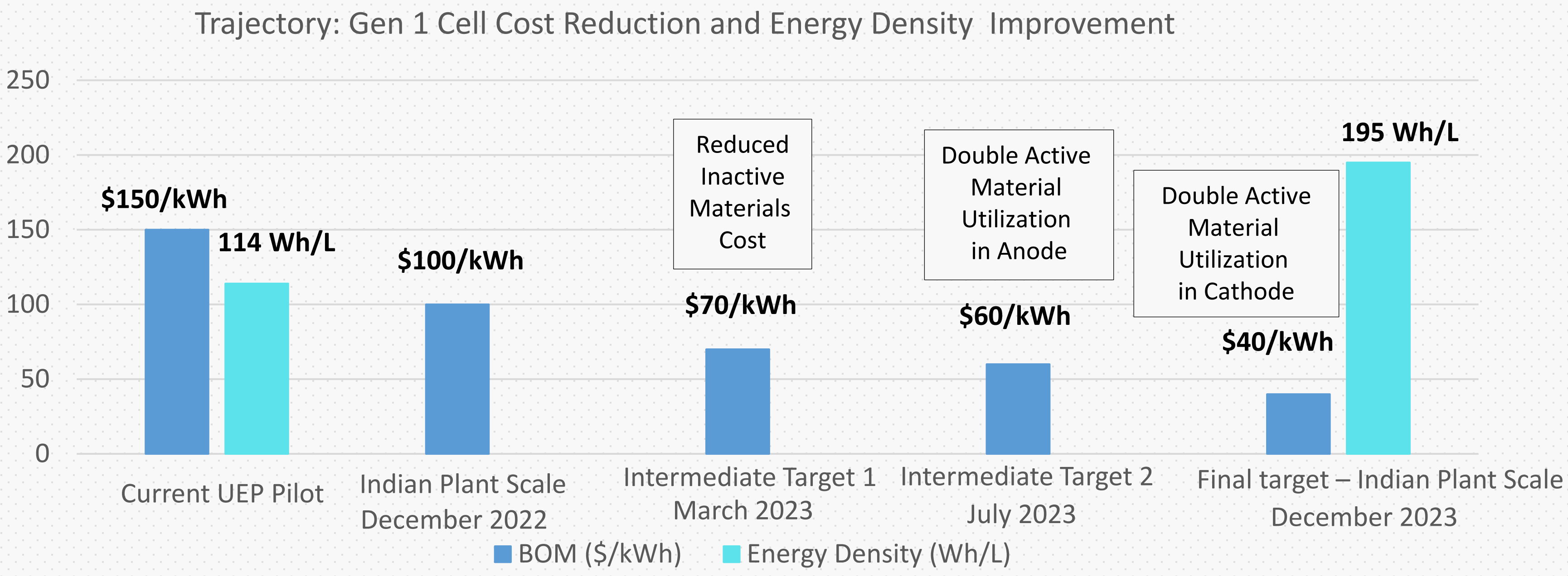
- Breakthrough accessibility in >2.4-2.8V & 100% utilization of 308mAh/g of MnO$_2$ allows higher energy density than Li-ion.

Product Roadmap: UEP Zn-MnO2 Gen 1 Cell Development



Current Gen 1 Cell

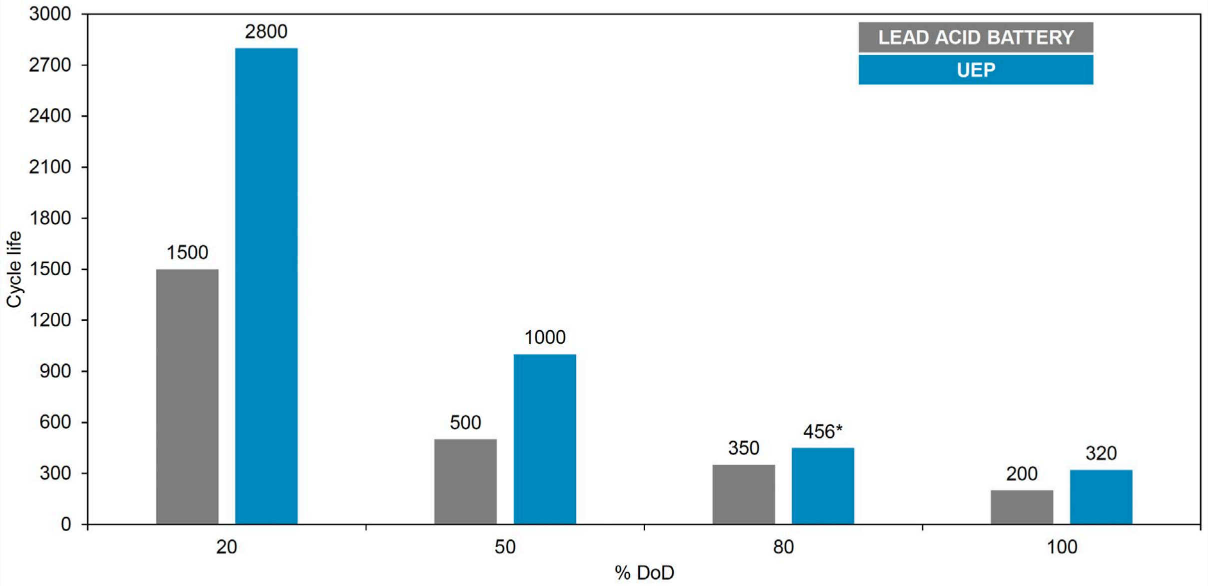
2022	December 2022	December 2023
Current Cost UEP-Pilot Scale: BOM: $150/kWh	Intermediate Cost Indian Plant Scale: BOM: $100/kWh	Target Cost Indian Plant Scale: BOM: $40/kWh

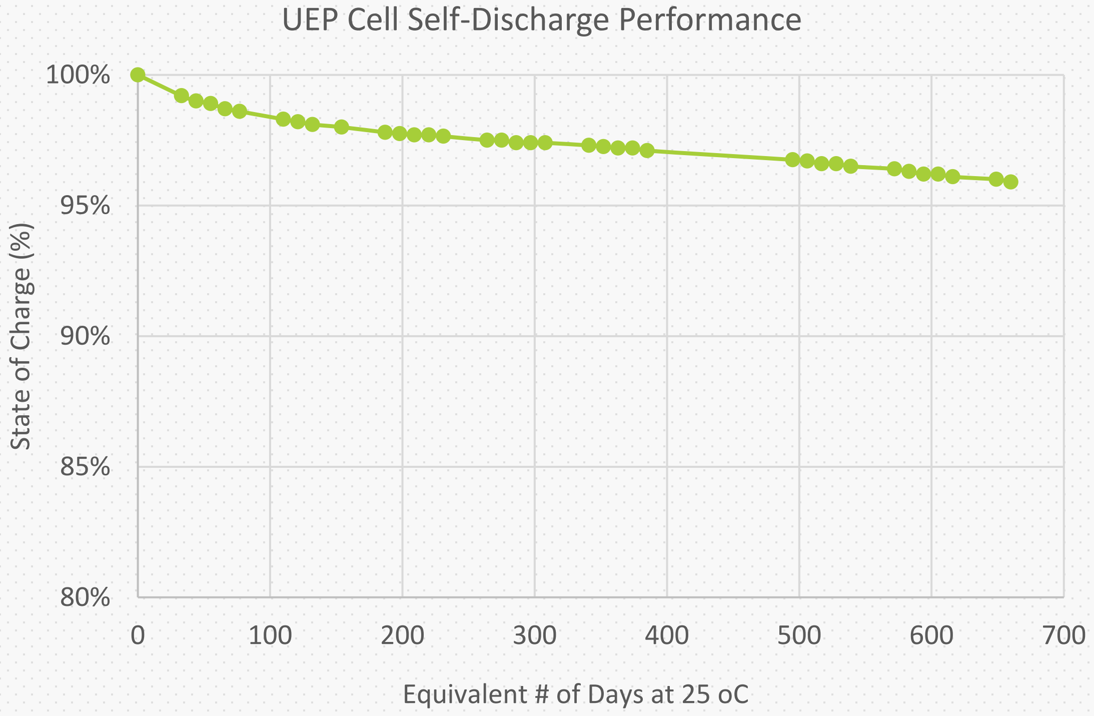


** All costs based on solar microgrid application with 5-year warranty conforming to IEC Solar Standard 61427-1. The standard simulates daily cycling in microgrids under representative varying solar insolation conditions. By ‘Indian Plant Scale’ is meant a plant being built in India for completion by end 2022*

Gen 1 Battery 1:
Comparison to Pb acid batteries

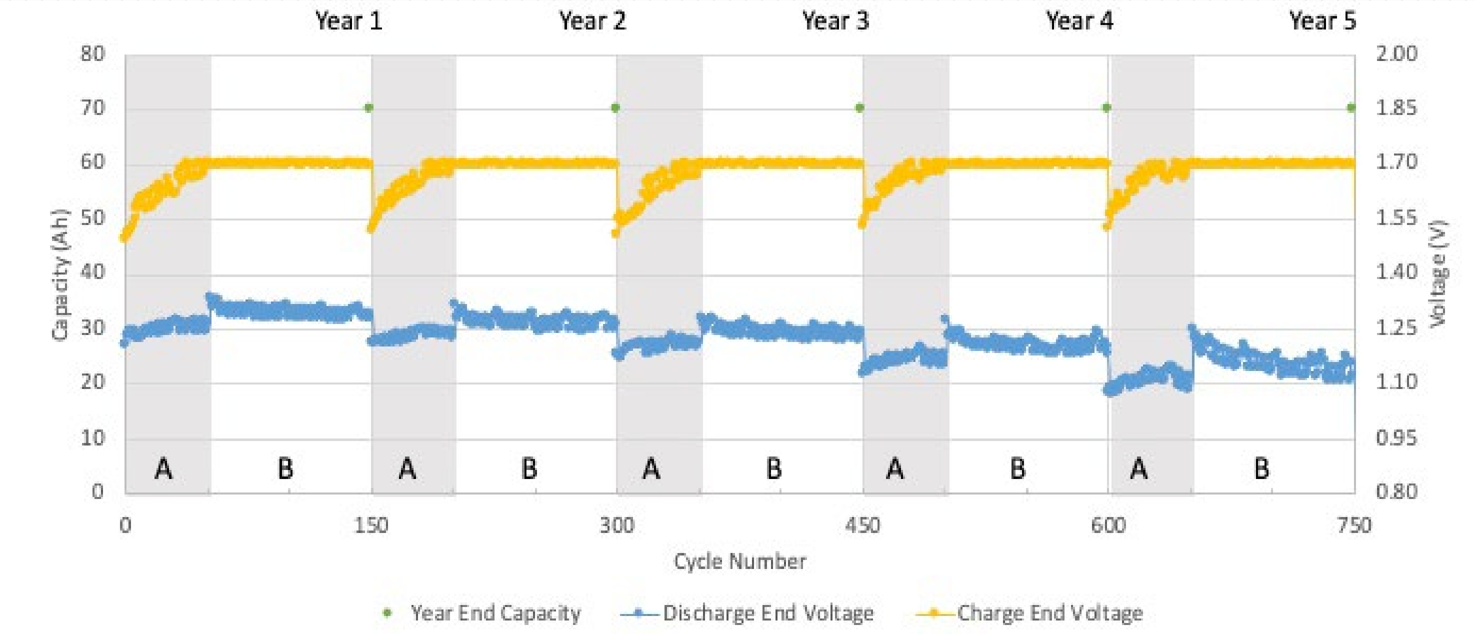
Zinc Manganese Dioxide compared to Lead Acid

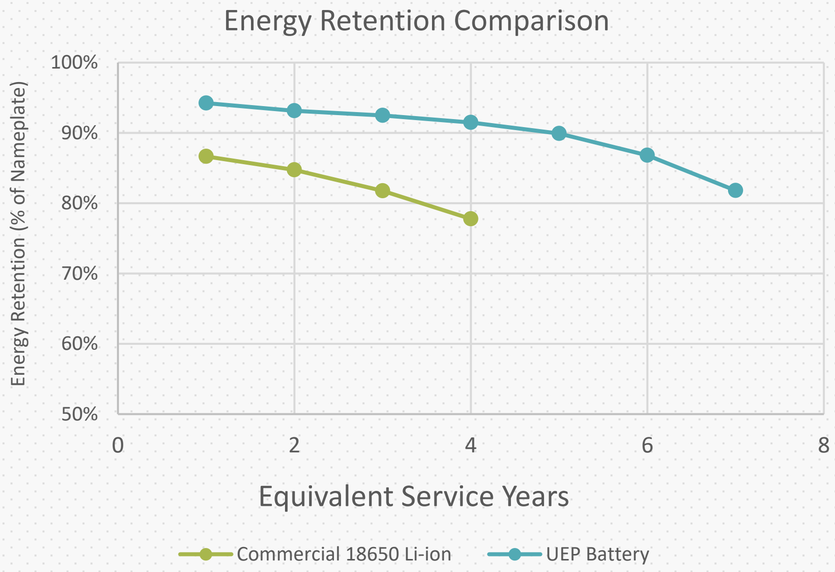




UEP Zn-MnO2 Gen 1 battery 1 tests: Solar Microgrid Protocol

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.



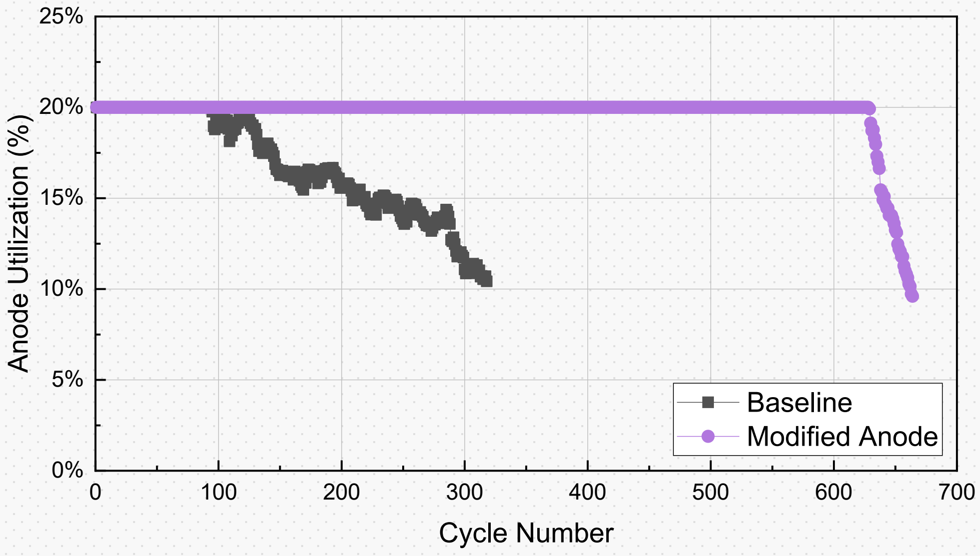


Phase A: 3h C/10 charge and 3h C/10 discharge cycling at low state of charge for 50 cycles.
Phase B: 6h charge and 2h C/8 discharge cycling at high state of charge for 100 cycles.
A 9-hour C/10 discharge is done between phases B and A at the end of each year.

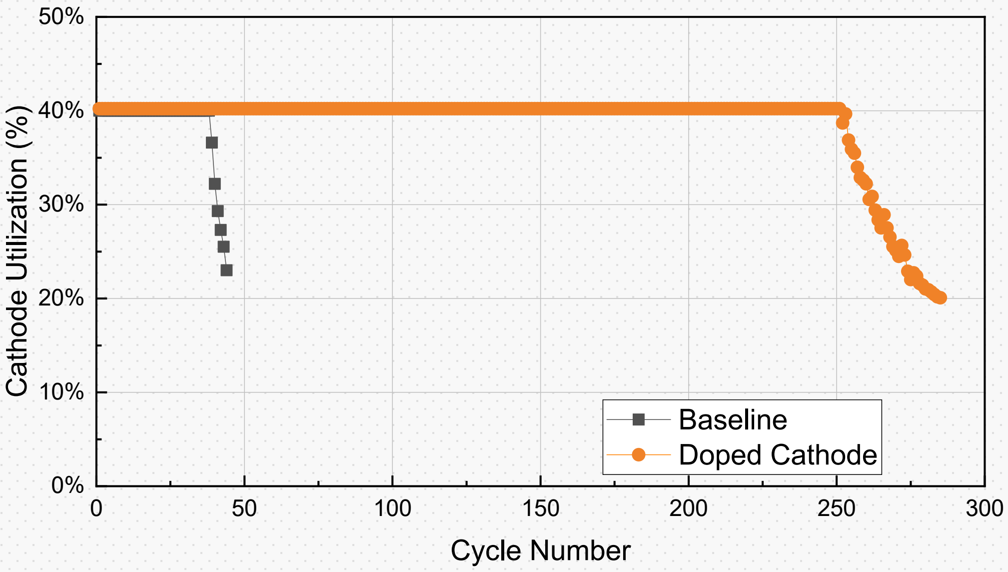
UEP Gen 1 shows an energy retention above 80% of its nameplate after 7 years of service life.

Gen 1 Battery 2 Progress

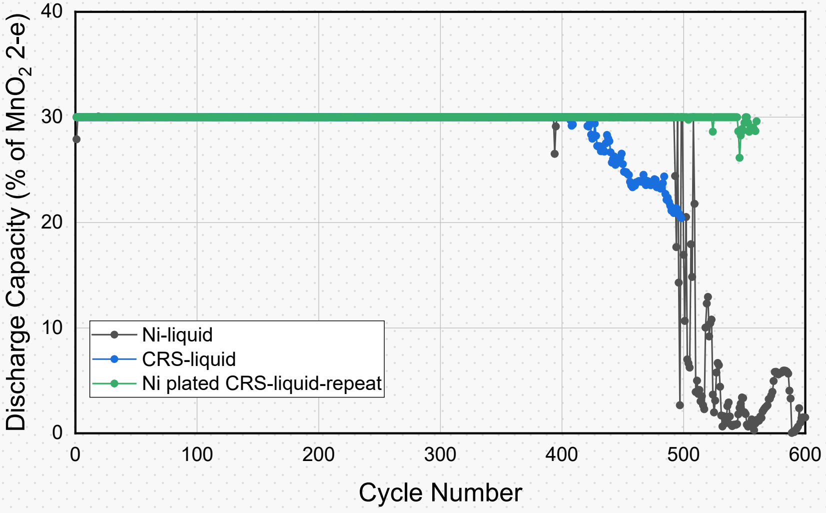
Developed improved Zn anodes with 20% utilization >600 cycles



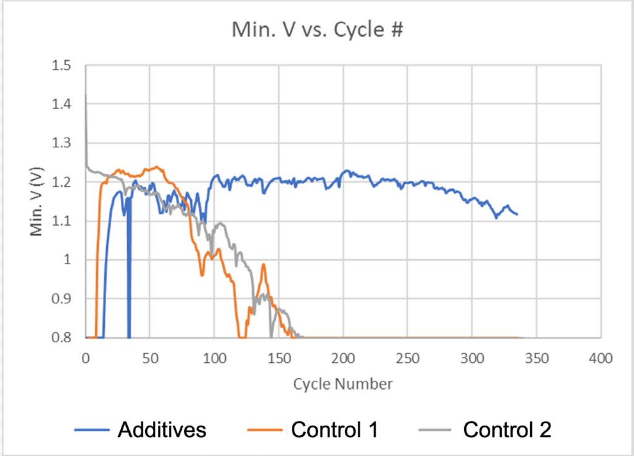
Developed improved MnO2 cathodes with 40% utilization >250 cycles



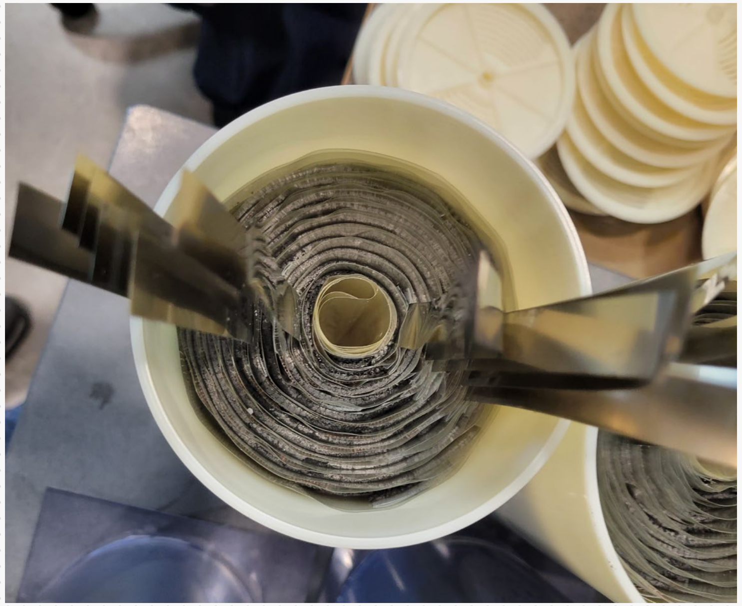
Developed cheaper current collectors to reduce overall cost



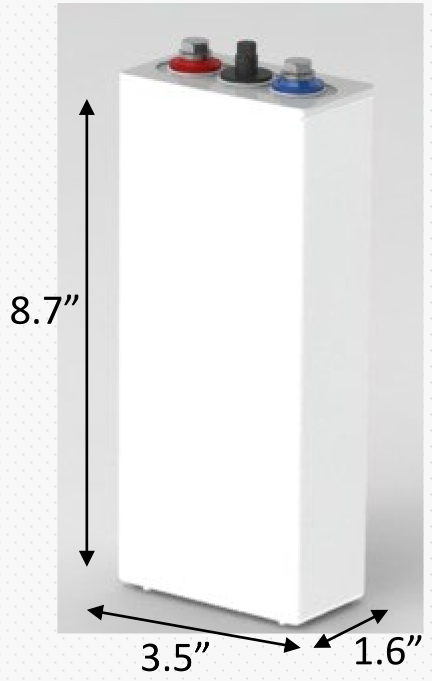
Performance of improved electrodes manufactured on the line



Scaling up laboratory made improved electrodes to the manufacturing side



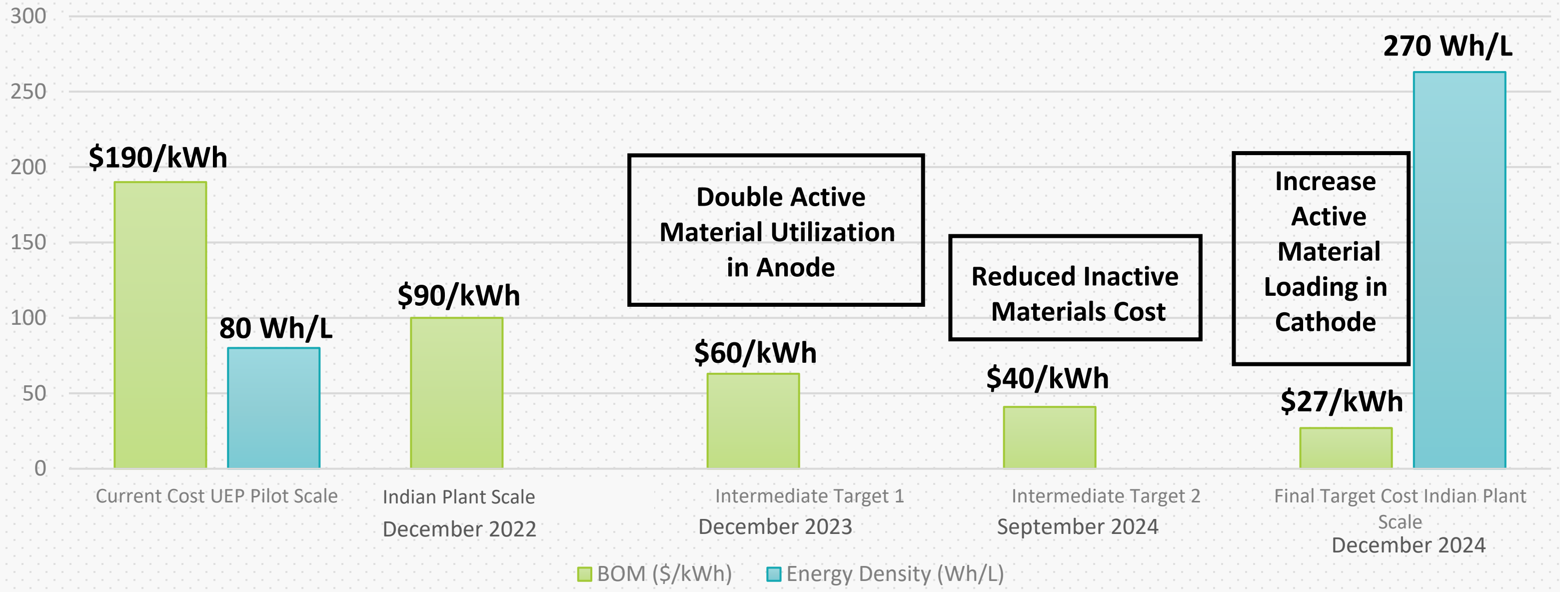
Product Roadmap: UEP Zn-MnO_2 Gen 2 Cell Development



Current Gen 2 Cell

2022	December 2023	December 2024
Current Cost UEP-Pilot Scale: BOM: $190/kWh	Intermediate Cost Indian Plant Scale: BOM: $90/kWh	Target Cost Indian Plant Scale: BOM: $27/kWh

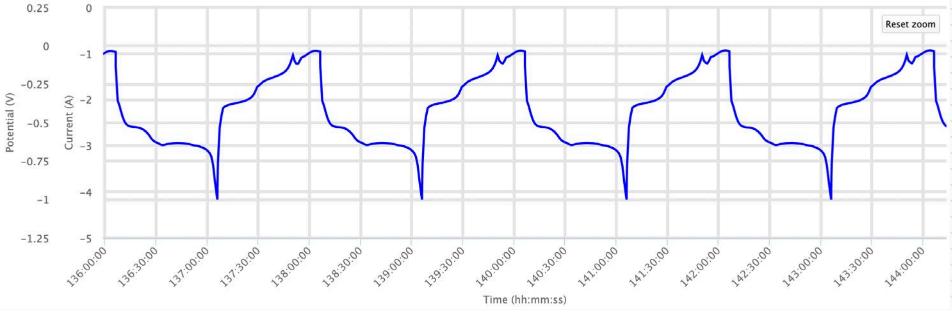
Trajectory: Gen 2 Cell Cost Reduction and Energy Density Improvement

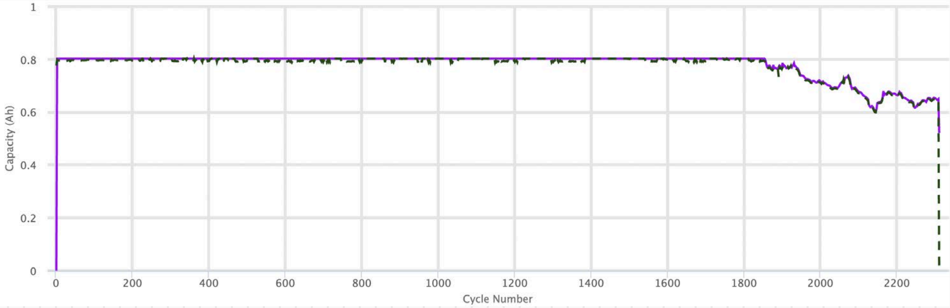


** All costs based on solar microgrid application with 10-year warranty conforming to IEC Solar Standard 61427-1. The standard simulates daily cycling in microgrids under representative varying solar insolation conditions.*

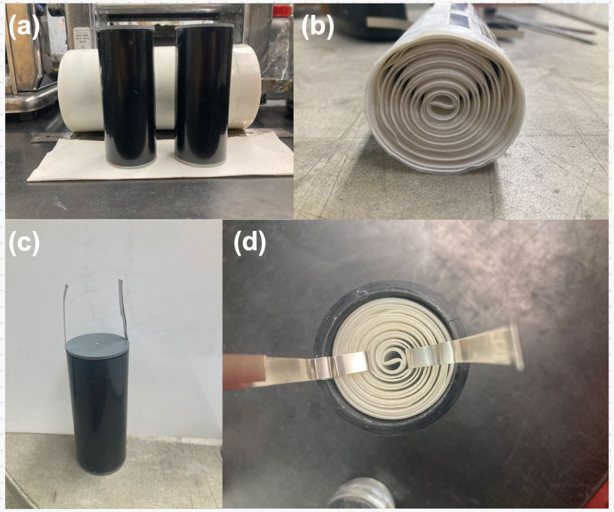
Gen 2 Battery 3 Progress

Prismatic Battery 3 cathodes cross >2000 cycles

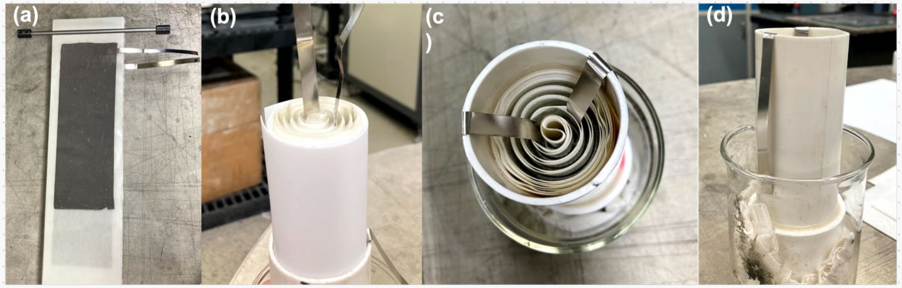


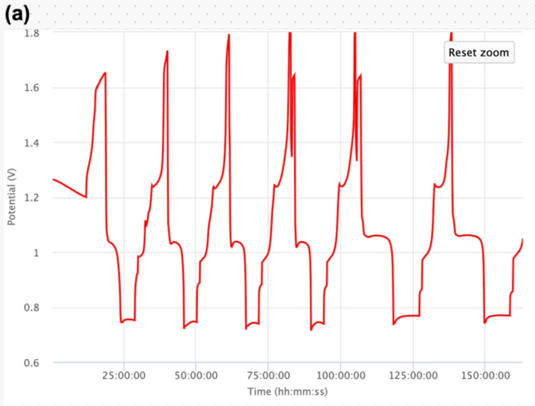


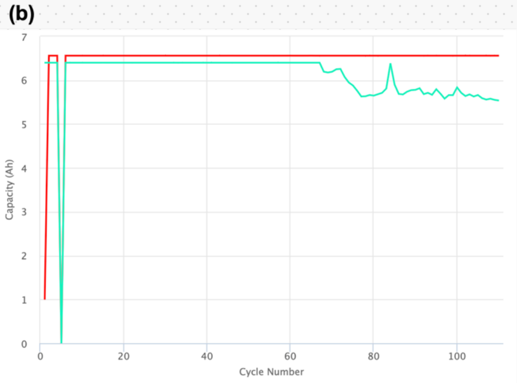
Scaling Cylindrical Cell to 16Ah

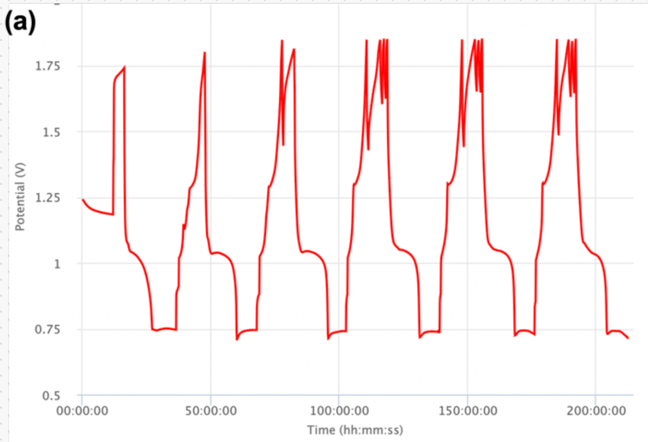


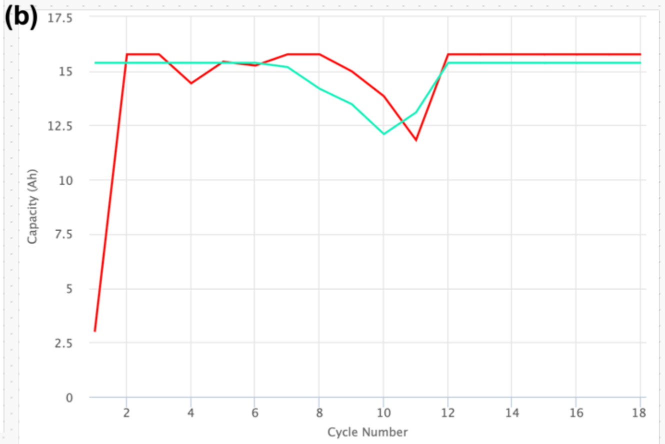
Translating Prismatic Performance to Cylindrical Form Factor (6.5Ah)



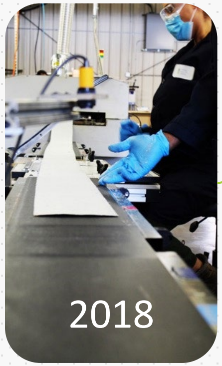




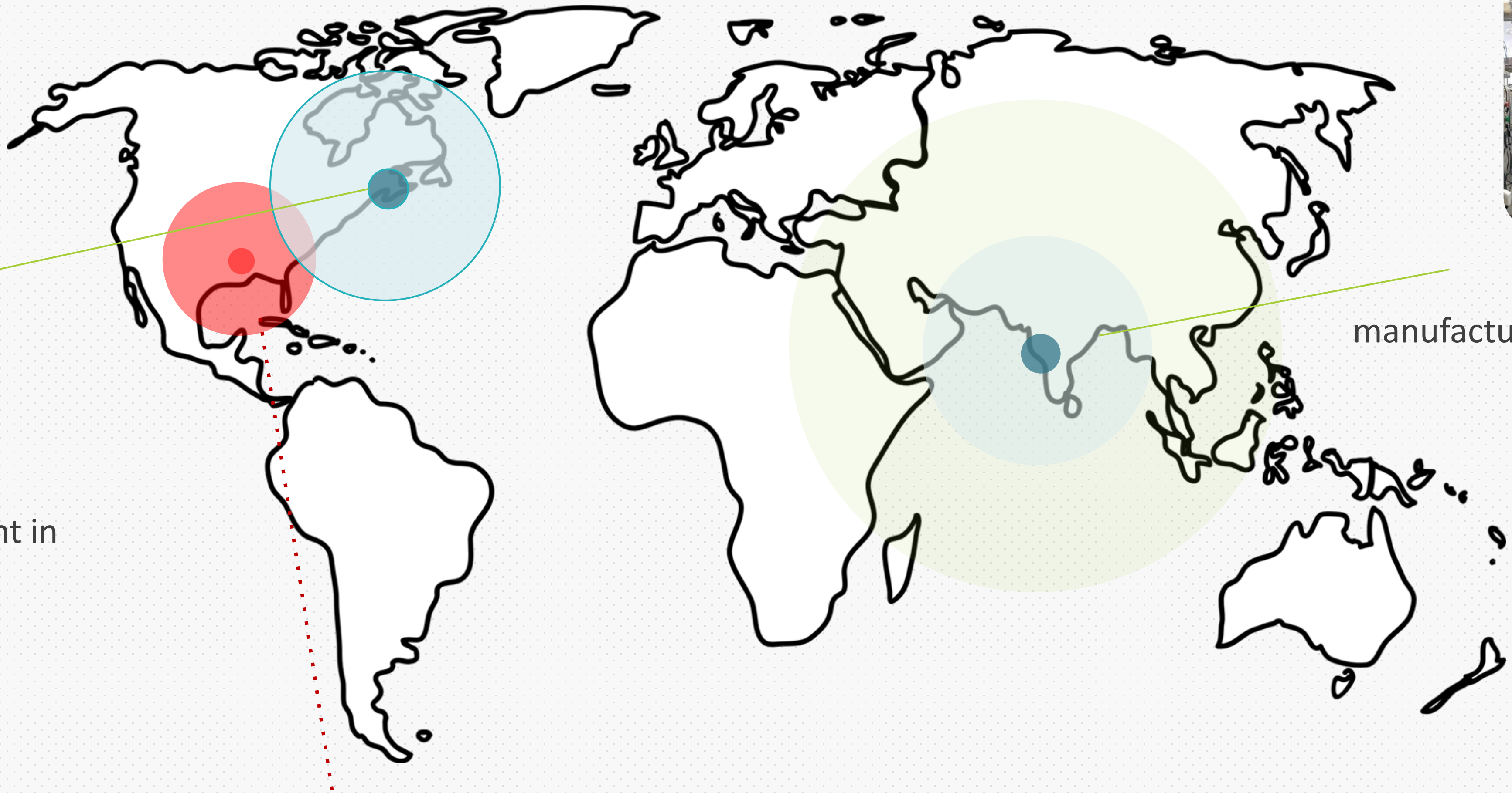




Current Manufacturing: Rechargeable aqueous Zn/MnO2 batteries



30 MWh pilot manufacturing plant in Pearl River, New York.



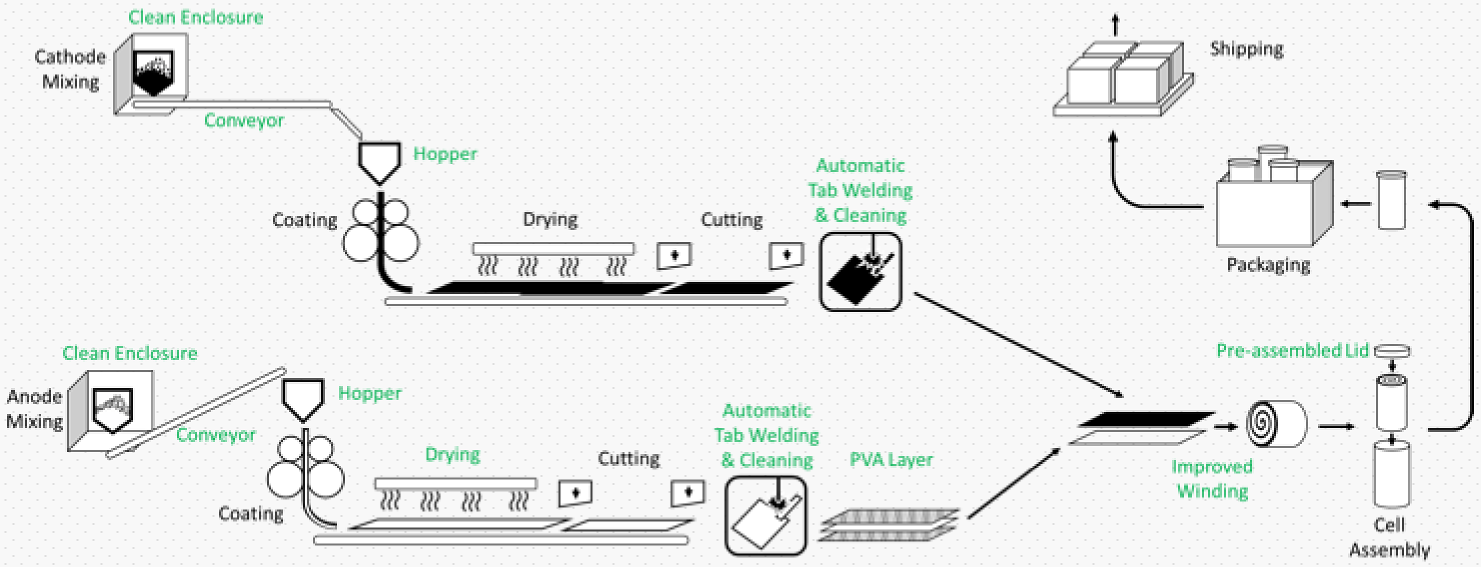
100 MWh manufacturing plant in Mumbai, India.

PUBLIC-PRIVATE PARTNERSHIPS

UEP has submitted to the US Dept of Energy for $50M in funding for a total $150M investment to scale a GWh scale factory potentially in Houston, Texas.

Manufacturing

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



Potential Houston, Texas GWh Scale Factory

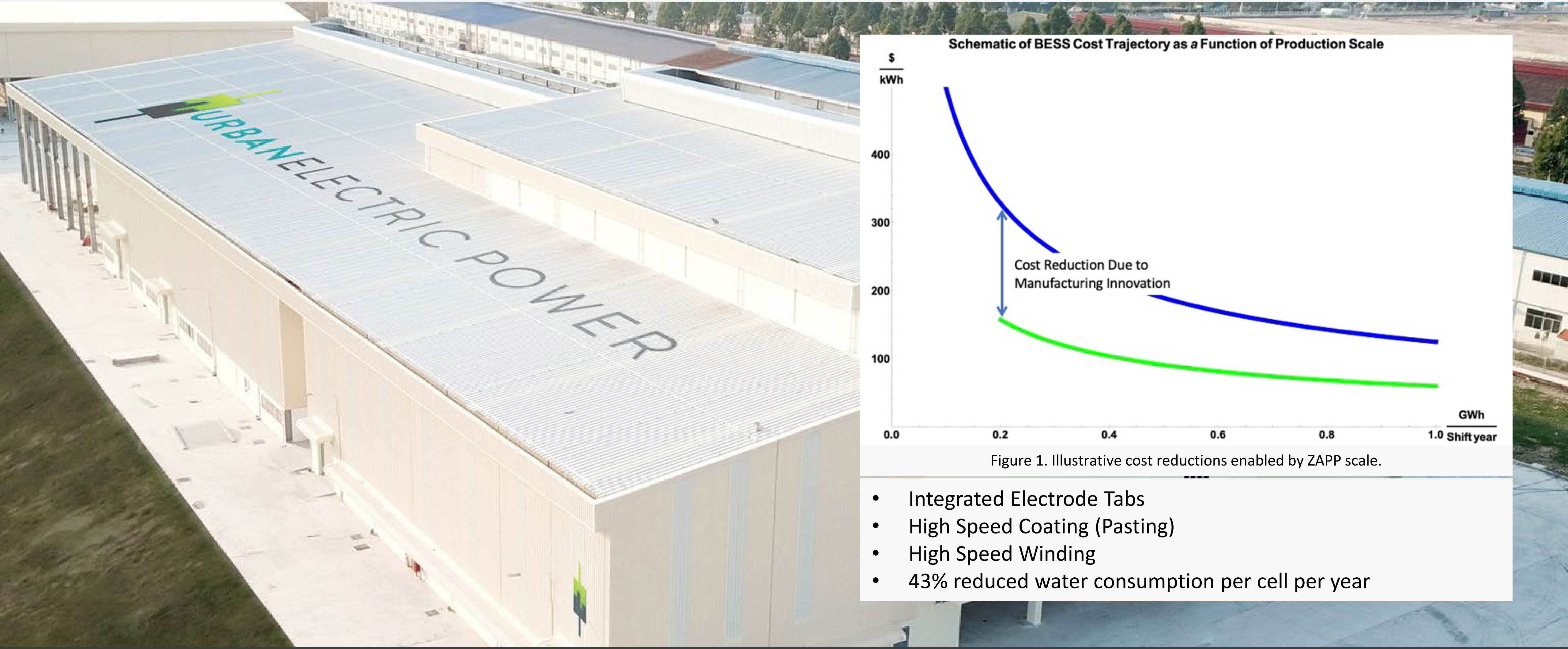
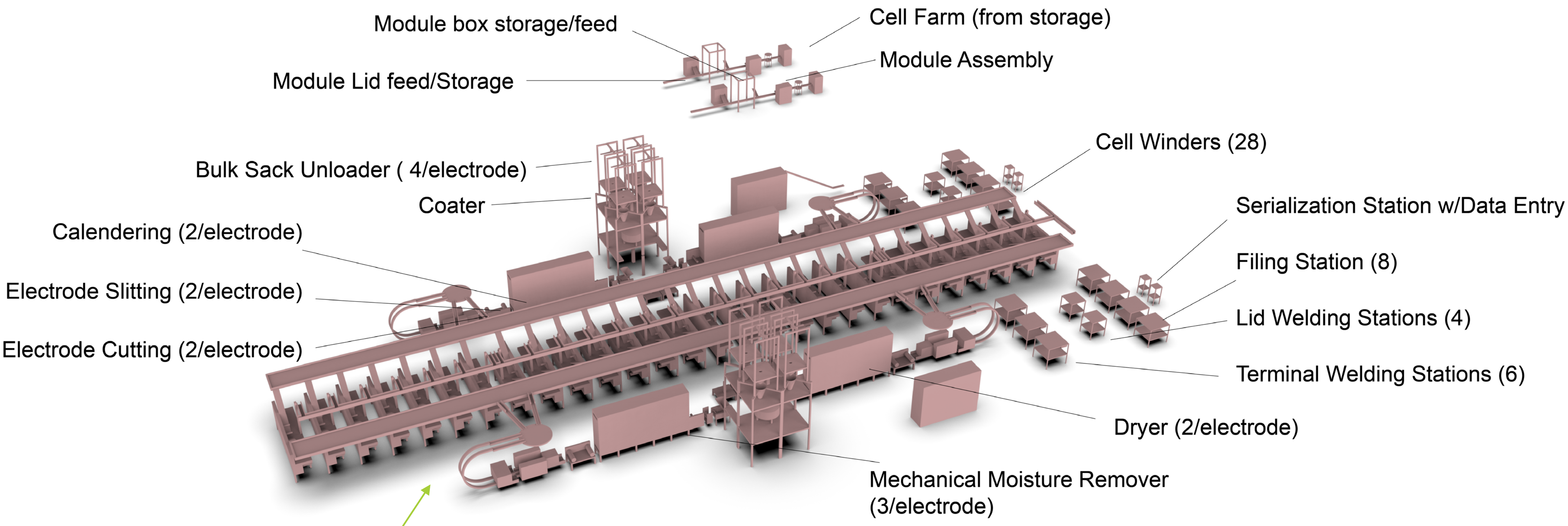
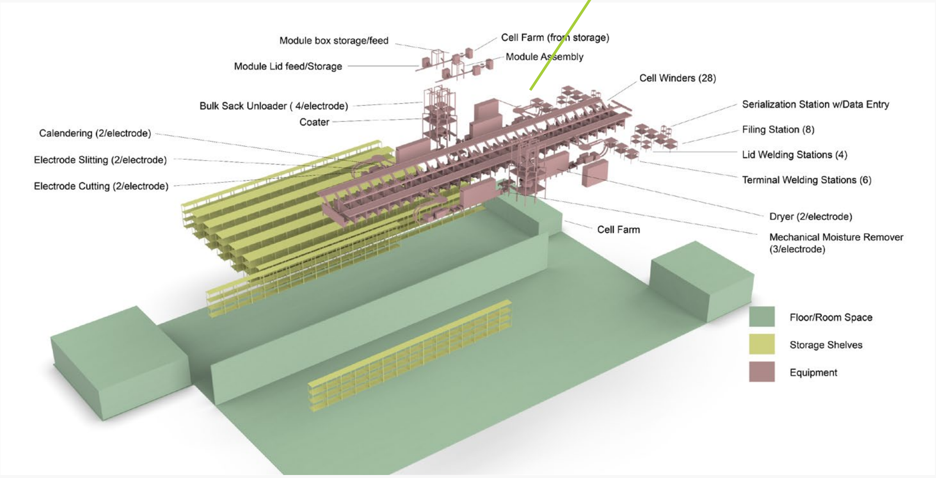


Figure 1. Illustrative cost reductions enabled by ZAPP scale.

- Integrated Electrode Tabs
- High Speed Coating (Pasting)
- High Speed Winding
- 43% reduced water consumption per cell per year

UEP is submitting to the US Dept of Energy for $50M in funding for a total $150M investment to scale a GWh scale factory in America. Of the $150M, $75M will be capital equipment expenditures.





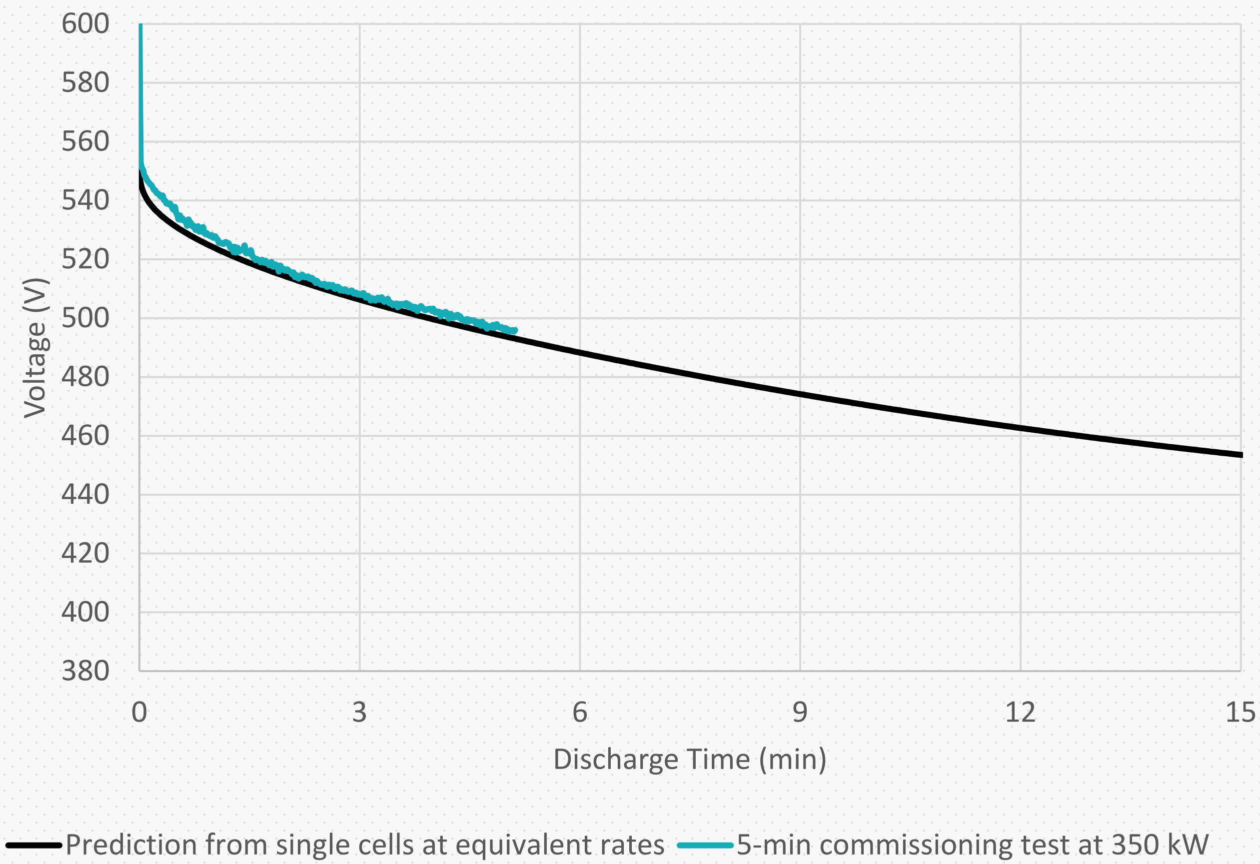
ZAPP Proposed Layout in DAC Facility Identified potentially in Houston, TX.

Ongoing and Recently Completed Gen 1 System Deployments

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

Installation Highlights:

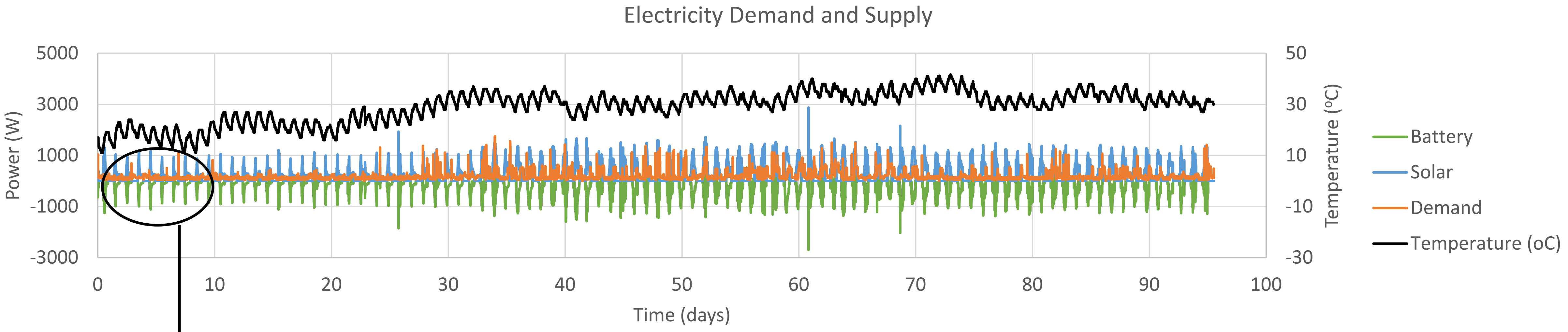
Backup System for the San Diego Supercomputer Center (SDSC)

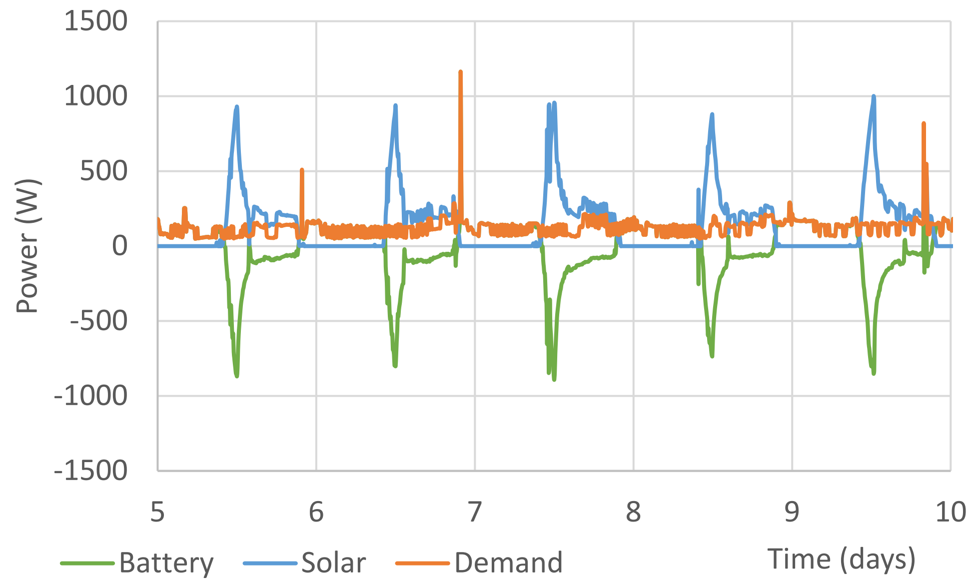


- At the 15-min cutoff, which is the max backup time that the lead acid batteries can provide, the voltage of the UEP system is about 453 V, well above the 380 V inverter limit.

Navajo Tribal Utility Authority (NTUA) Solar Microgrid

Data on Cycling at -4°C (performed by Sandia)





- 13 kWh solar microgrid system deployed in Q1 2021
- System uses a standard Outback inverter and seats on a self-contained pod

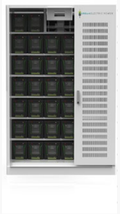
Ongoing Project:
CCNY Grid Modernization Center

Mitsubishi: 100kW/400kWh UPS unit

- Short and long duration emergency UPS
- 100 kW of demand response

Vertiv Inverter

- 100 kW of demand response peak shaving

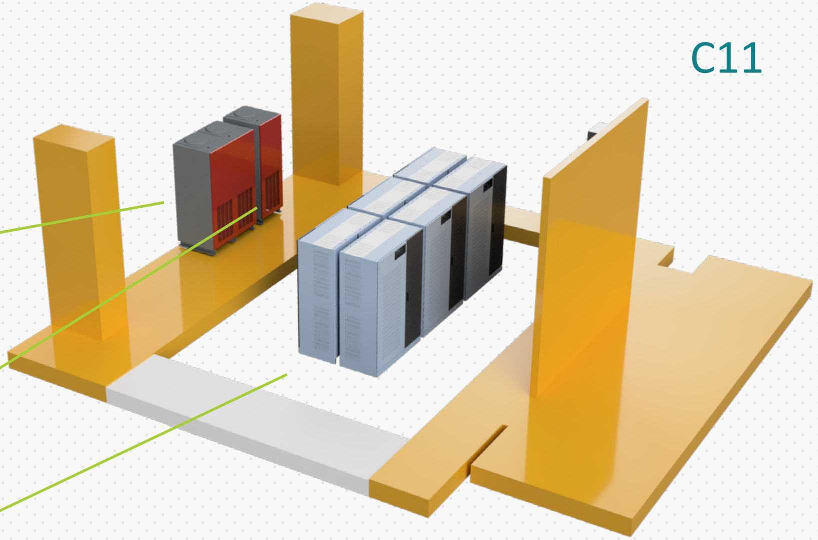


UEP 4D Commercial Battery Rack

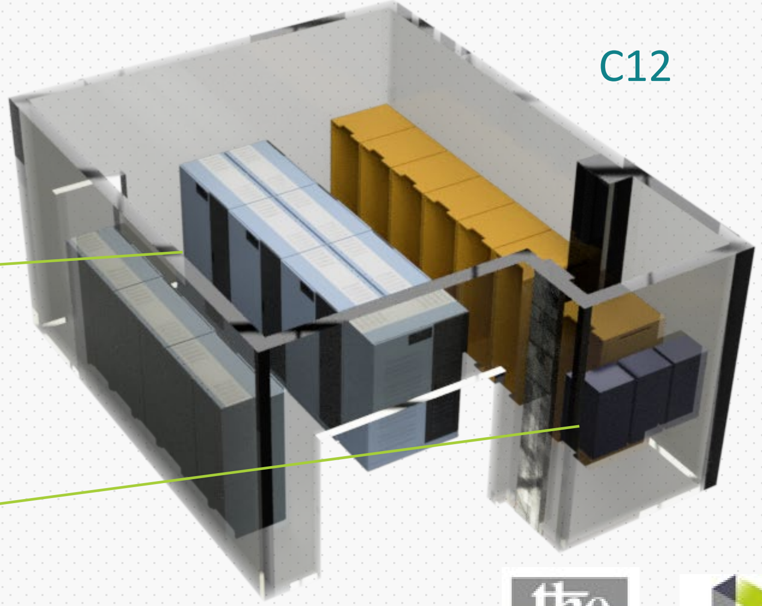
- 6 Racks in C11
- 10 Racks in C12

(3)Ideal Power 30 kW

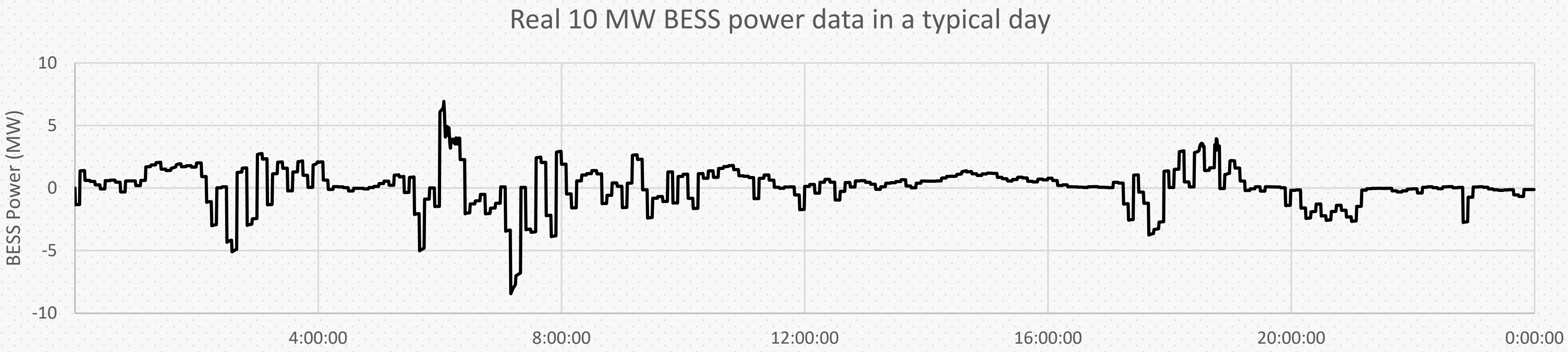
C11

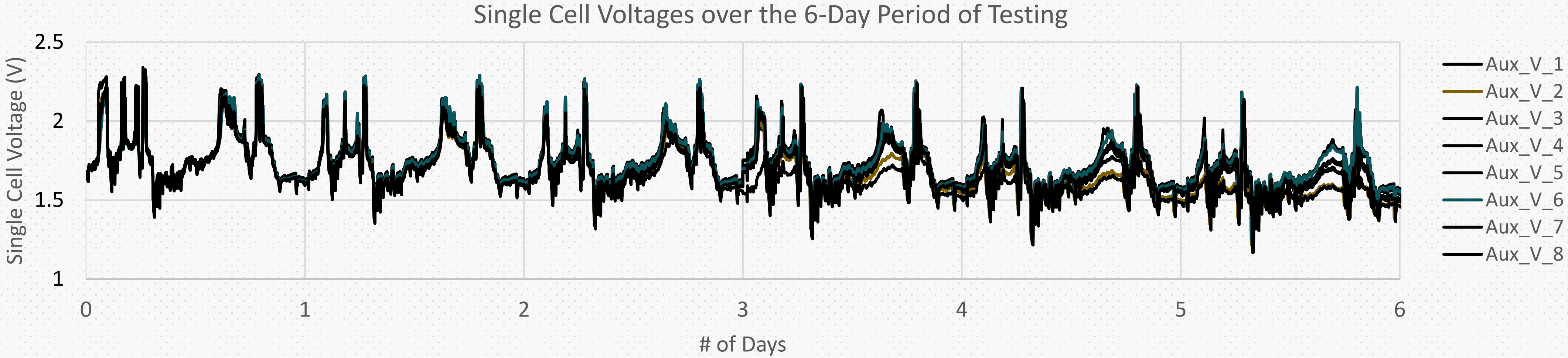


C12

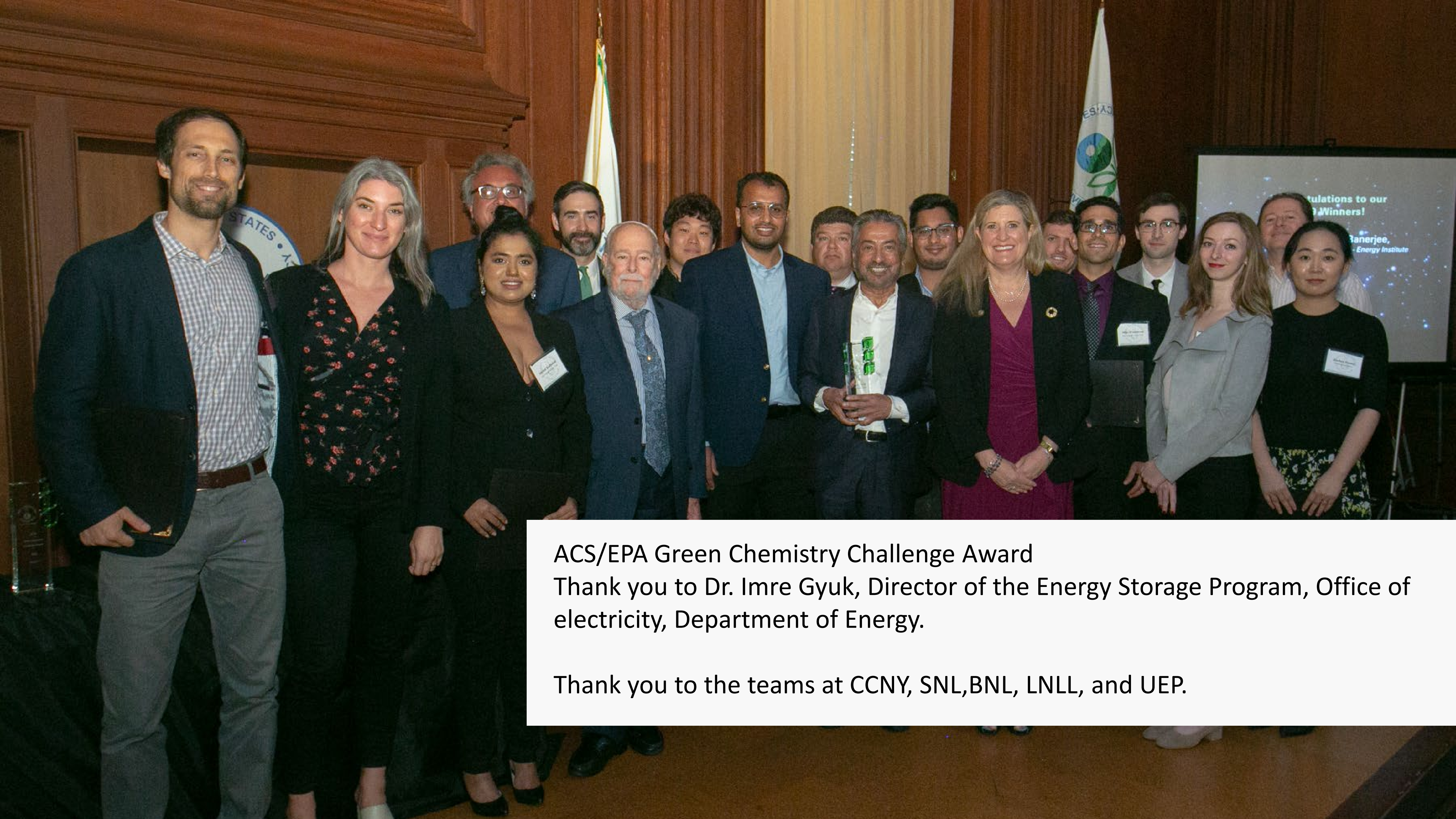


UEP Modules for Energy Reliability





- UEP modules were tested under a protocol simulating a real utility-scale 10 MW BESS.
- Each module was tested at 1,000 W nameplate. 10,000 module (100,000 cells) will be needed for a 10MW system.
- Under this protocol, the module has a coulombic efficiency of ~93% and energy efficiency ~82%.
- The voltage of the single cells were monitored throughout testing.



ACS/EPA Green Chemistry Challenge Award
Thank you to Dr. Imre Gyuk, Director of the Energy Storage Program, Office of electricity, Department of Energy.

Thank you to the teams at CCNY, SNL,BNL, LNLL, and UEP.