POWERGEN SERIES

"Breaking through the Electron Ceiling: Alternatives to Lithium Ion in Stationary Storage"

12/8/21

ZincFive | Invinity Energy Systems | Urban Electric Power

1

ZincFive

Alternatives for Lithium-Ion Stationary Storage

Dan Lambert

zincfive.com

2

Safety

- NiZn batteries have a broad temperature tolerance without significant loss of capacity. The extremes of the operating temperature range are typically in the -20°C to +50°C range. Recommended operating range is +20°C to +35°C.
- Temperature compensated charging is highly recommended.
- There is very little potential for a thermal runaway. The plastics in the case are the most flammable materials.
- Batteries have been punctured, crush tested, and subjected to charge and discharge testing at 80°C without a thermal event.
- The primary metals used in typical NiZn batteries are nickel, zinc, and copper. All of these are commonly used in metallurgy and are highly recyclable.

UL9540A Testing

- UL tested ZincFive's NiZn monobloc battery according to the UL9540 test method and issued a test report dated November 22, 2019.
- ZincFive batteries were tested at the cell level to UL9540A and ZincFive's nickel-zinc batteries did not exhibit thermal runaway in any of the five tests.

Test	Test Method	Venting Time (mm:ss)	Venting Temperature (°C)	Thermal Runway Time (mm:ss)	Thermal Runway Temperature (°C)
1	Overdischarge	Not Observed	N/A	Not Observed	N/A
2	Overcharge	91:30	103.7	Not Observed	N/A
3A	Heating Trial 1	22:30	216	Not Observed	N/A
3B	Heating Trial 2	46:30	180.5	Not Observed	N/A
4	Nail Penetration	00:15	84.5	Not Observed	N/A
5	Short Circuit	00:18	99.6	Not Observed	N/A
6[3]	Gas Composition (Overcharge)	66:40	97.5	Not Observed	N/A

NiZn – Pba Outgas Comparison

- UL over-charging test was at 130A for 4 hours
- For any aqueous electrolyte cell over-charged at 130 A, this will produce 54.33 L of H_2 and 27.16 L of O_2 per hour per cell
- The table below provides a comparison of theoretical and actual values

Gas Production Comparison	NiZn (8 Cells)			PbA (6 Cells)					
				Flooded			VRLA		
	H_2	O_2	Total	H_2	O_2	Total	H_2	O_2	Total
Theoretical Gas Production (L) Outside of Normal Operating Parameters (130A Overcharge for 4 hours)	1738	869	2607	1304	652	1956	~1304	~652	~1956
Actual Gas Production (L) Outside of Normal Operating Parameters (130A Overcharge for 4 hours)	222	0	226*	~1304	~652	~1956	~1304	~652	~1956

Important Notes:
- In normal operation a flooded PbA battery will outgas during discharge and NiZn does not.
- *13% of theoretical hydrogen volume and no oxygen - due to recombination effects within the NiZn battery.

5

Components Measured in Vented Battery Gas

(Excerpt from UL Report)

Gas		Measured %	Component LFL[1]
Carbon Monoxide	CO	<0.02	10.9%
Carbon Dioxide	CO_2	1.99	N/A
Hydrogen	H_2	98.01	4.0%
Methane	CH_4	<0.2	4.4%
Ethylene	C_2H_4	<0.2	2.4%
Ethane	C_2H_6	<0.2	2.4%
Propylene	C_3H_6	<0.2	1.8%
Propane	C_3H_8	<0.2	1.7%
Propadiene	C3H4	<0.04	1.9%
-	C_4 (Total)	<0.04	1.5%[2]
Pentane	n-C_5H_{12}	<0.04	1.1%
Total	-	100	-

Note: All values for gases other than Carbon Dioxide and Hydrogen were below the lowest detectable limit (LDL) of the measurement system and are not included in the total.

6

Recycling

Li-Ion	Lead-Acid	NiZn
50%	90%	>90%

Li-Ion

- ~50% of materials are recoverable
- Expensive recovery effort
- Hazardous materials with air freight restrictions

Lead-Acid

- Highly recyclable
- World's worst pollution problem[2].
- 120M people worldwide lead poisoned[3].
- Transportation restrictions.

NiZn

- Highly recyclable
- Lead-free. All Zinc, Copper, Nickel recaptured and saleable on commodity market
- No air freight restrictions

Climate Impact Metrics Comparison

ZincFive NiZn

- **Six times** or more avoidance of GHG emissions compared to lithium-ion and **four times** more compared to lead-acid chemistries
- **400% greater** carbon payback time for lithium and lead-acid batteries than nickel-zinc batteries

INVINITY
ENERGY SYSTEMS

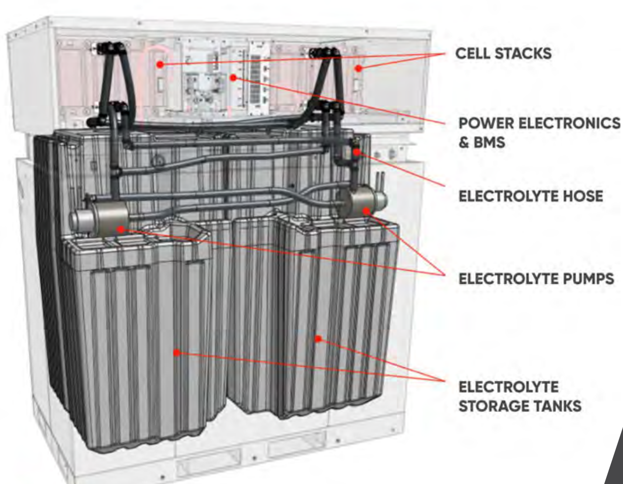
ALTERNATIVES FOR LITHIUM ION STATIONARY STORAGE

8 December 2021

9

Inside a VFB

Durable/Reliable/Economical/Proven

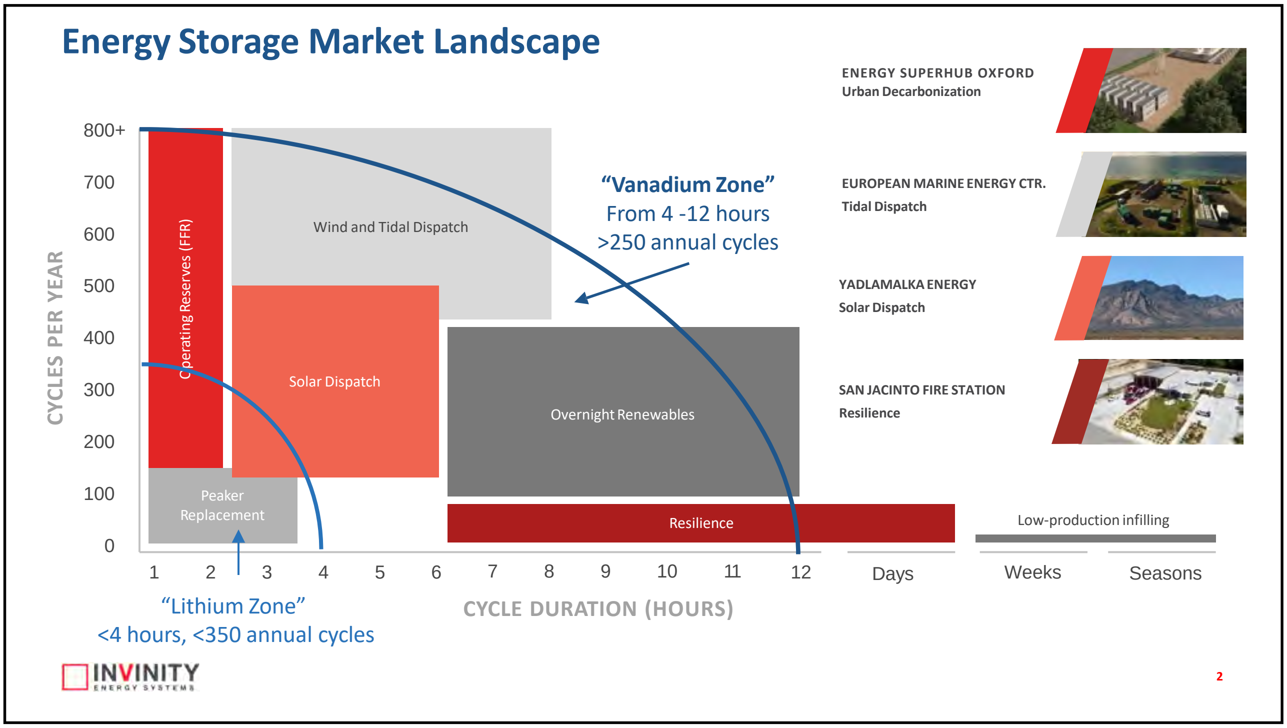


INVINITY
ENERGY SYSTEMS

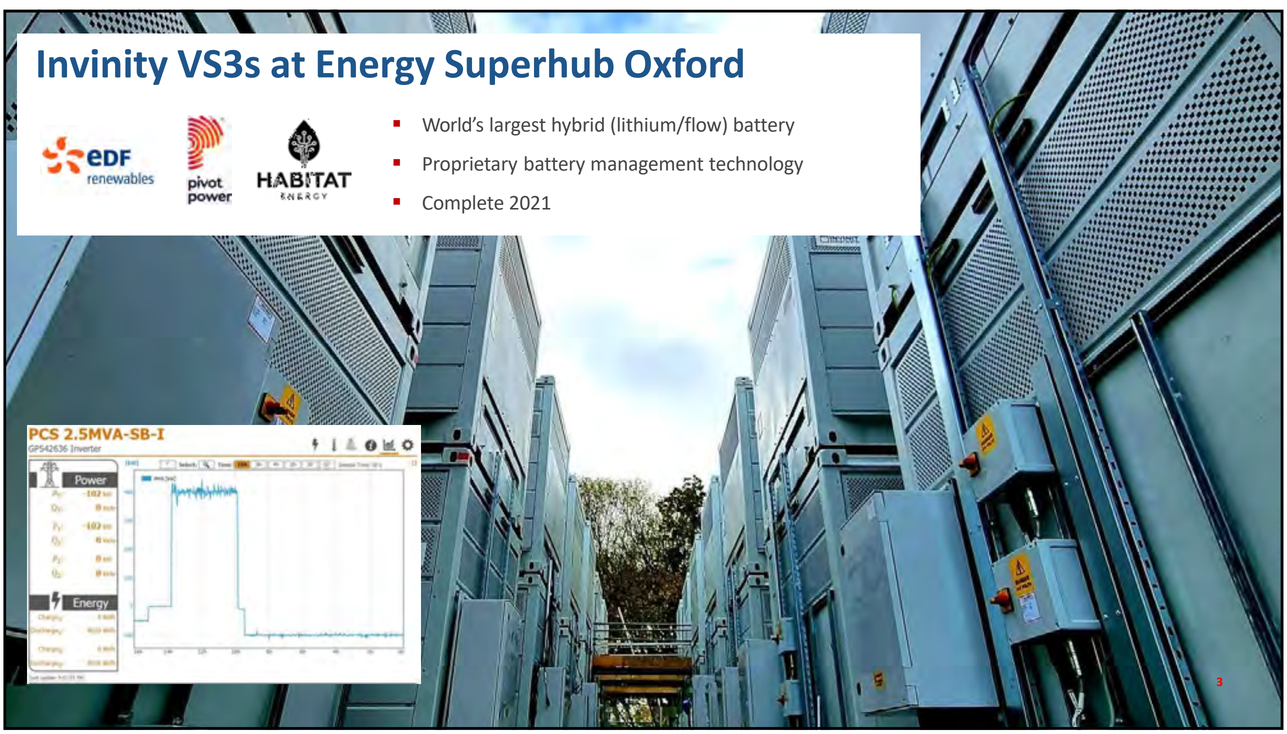
VANADIUM

- **AVAILABLE**
  4 stable states of charge that underpins the functioning of the VFB, no impact on the electrolyte from aggressive cycling and full depth of discharge
- **REUSABLE**
  Virtually unlimited working life. 97% proven recovery rate from used electrolyte
- **SAFE**
  Electrolyte is ~70% water, non-flammable with no risk of thermal runaway

10


Energy Storage Market Landscape
CYCLES PER YEAR
800+
700
600
500
400
300
200
100
0
Operating Reserves (FFR)
Wind and Tidal Dispatch
Solar Dispatch
Overnight Renewables
Peaker Replacement
Resilience
Low-production infilling
"Vanadium Zone"
From 4 -12 hours
>250 annual cycles
1 2 3 4 5 6 7 8 9 10 11 12 Days Weeks Seasons
CYCLE DURATION (HOURS)
"Lithium Zone"
<4 hours, <350 annual cycles
ENERGY SUPERHUB OXFORD
Urban Decarbonization
EUROPEAN MARINE ENERGY CTR.
Tidal Dispatch
YADLAMALKA ENERGY
Solar Dispatch
SAN JACINTO FIRE STATION
Resilience
INVINITY
ENERGY SYSTEMS
2

11


Invinity VS3s at Energy Superhub Oxford
eDF renewables
pivot power
HABITAT ENERGY
World's largest hybrid (lithium/flow) battery
Proprietary battery management technology
Complete 2021
PCS 2.5MVA-SB-I
Power
Energy
3

12

Invinity VS3s at Scottish Water – Perth

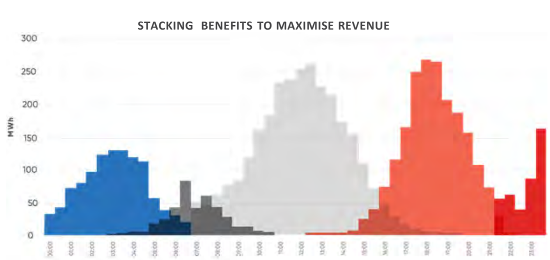
- Solar-plus-storage powering major water treatment plant
- Assists Scottish Water to accelerate net-zero goals
- Will eliminate approximately 160 tons of CO_2 emissions per year
- Currently installed with handover by end of 2021

13

Yadlamalka Solar + Storage

DELIVERING THE WORLD'S LARGEST SOLAR-POWERED VFB

- 8 MWh Invinity Battery System + 6 MWp Solar PV
- Manufacturing underway
- 41 Invinity VS3s
- Will be Australia's largest flow battery
- Delivery scheduled 1H 2022



INVINITY ENERGY SYSTEMS

14

Soboba Fire Station

CALIFORNIA ENERGY COMMISSION-FUNDED

- Delivering clean power to critical infrastructure
- 0.5 MWh flow battery system integrated with onsite solar PV
- 10-hours storage duration, supplying resiliency in a region heavily affected by wildfires

INVINITY ENERGY SYSTEMS GRID

15

INVINITY ENERGY SYSTEMS

QUESTIONS?

16

URBAN ELECTRIC POWER

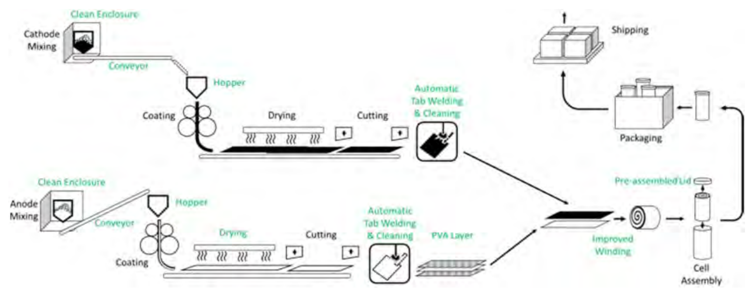
PowerGen+ Talk: Rechargeable and Energy Dense Zinc|Manganese Dioxide Batteries For Application of The Future

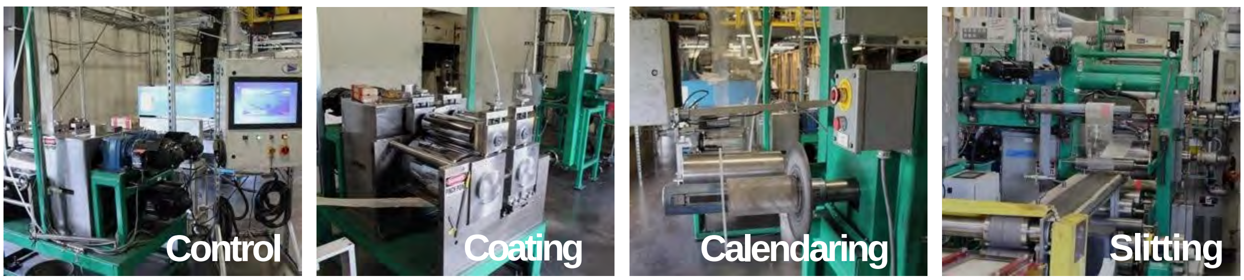
By Gautam G. Yadav, PhD
Director of Advanced Battery Development

17

18

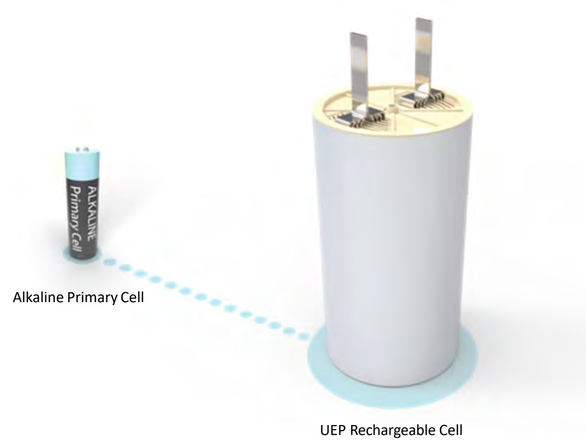
Continuous Manufacturing of Cylindrical Cells





19

Rechargeable Alkaline Batteries



UEP revolutionizes the familiar alkaline battery (e.g., double AA) into a rechargeable alkaline battery to enable decarbonization goals worldwide.

- Recyclable
  Non-toxic
- Modular solution residential to grid
- Low fire risk
  UL 1973/9540A

20

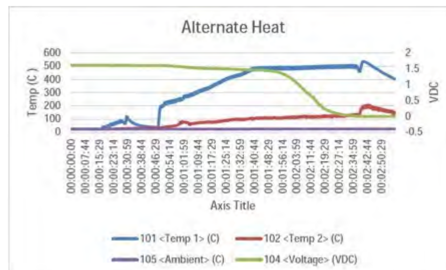
Safety Certifications of Zinc-Manganese Dioxide Batteries

- 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 currently in process

UL 9540A Tests For Fire Hazard

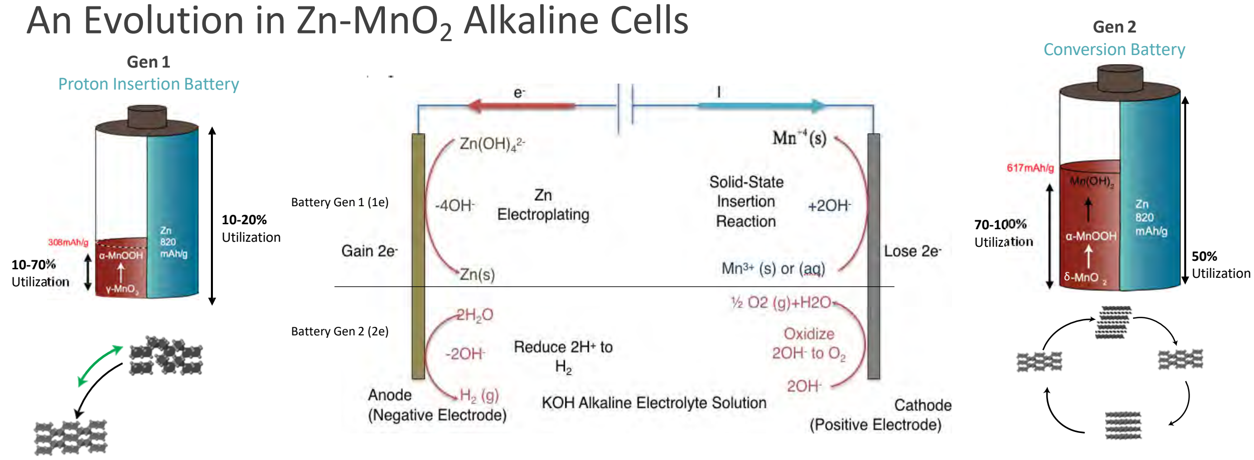
Test	Test Method	Thermal Runaway Time	Thermal Runaway Time
1	Film Heater	Not observed	N/A
2	Pipe Heater	Not observed	N/A
3	Nail Penetration	Not observed	N/A
4	Overcharge	Not observed	N/A
5	Overdischarge	Not observed	N/A


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



21

An Evolution in Zn-MnO$_2$ Alkaline Cells



- Utilizes 50% of the theoretical capacity of the zinc anode.
- Utilizes nearly 50% of the theoretical 1-electron capacity of the MnO$_2$ cathode (250-300 mAh/G), comparable to lithium-ion.
- Analogous to the Li-ion’s Silicon conversion anodes that promise higher energy density.
- Utilizes nearly 100% of the theoretical 2-electron capacity capacity of the MnO2 cathode (550-600 mAh/G), greater than lithium-ion.

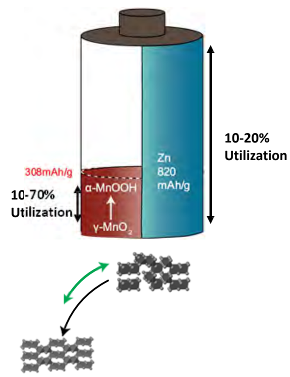
Breakthrough advancements in rechargeable alkaline chemistry enable UEP batteries to utilize the high energy densities of Zn and MnO$_2$ while retaining capacity during cycling.

22

Summary of Generation 1 & Generation 2 Cells

Generation 1

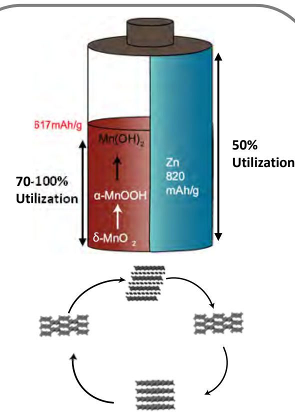
Battery 0, 1 and 2
Proton Insertion Battery



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

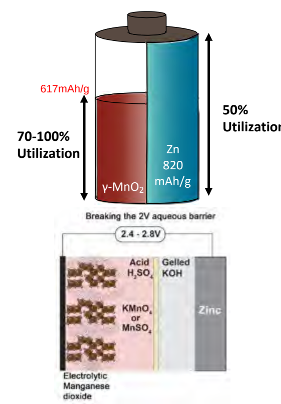
Generation 2

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.

Battery 4
The Li-ion Competitor
High Voltage 2.45-3V Zn-MnO$_2$



- Breakthrough accessibility in >2.4-2.8V & 100% utilization of 617mAh/g of MnO$_2$ allows higher energy density than Li-ion.

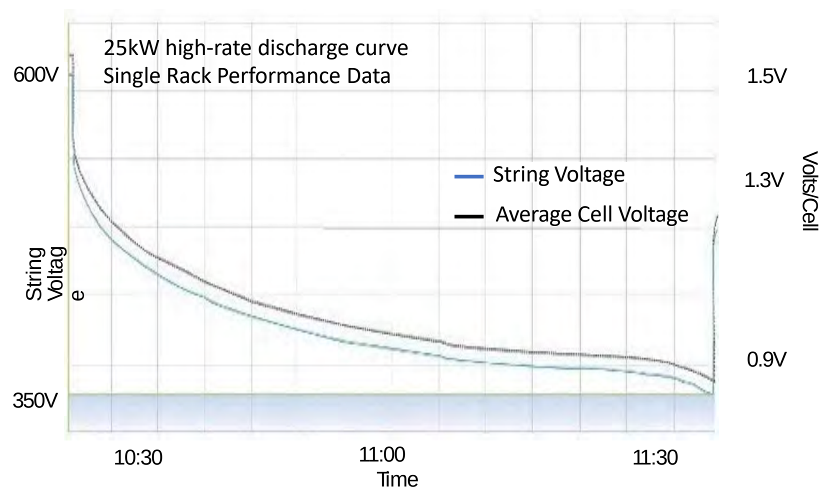
7

23

Generation 1 Commercial Example

Power Backup/UPS for the San Diego Supercomputer Center

- Testing of a constituent rack for the SDSC UPS/backup system
- 26 such racks in parallel will provide 90 minutes of power backup

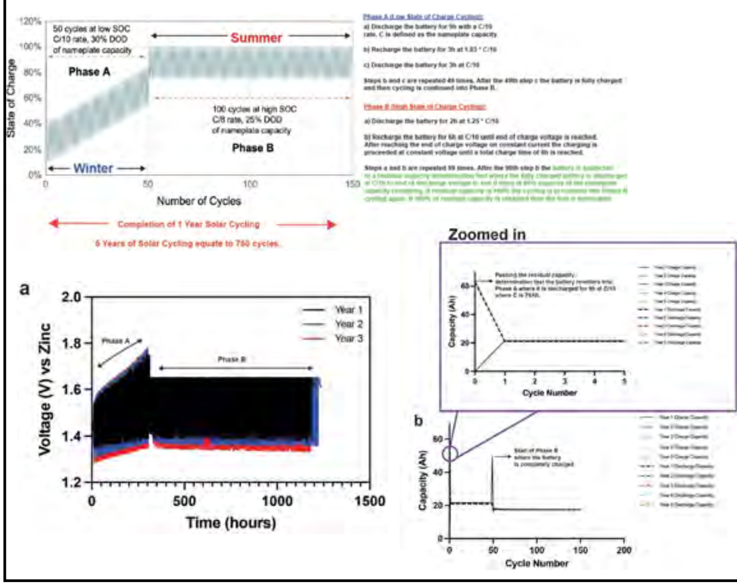


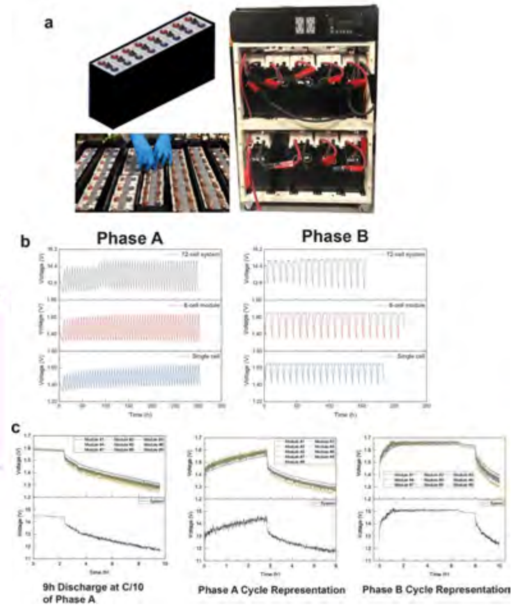
The 400 cell strings in each rack behave similarly to single cells in their discharge characteristics.

24

Generation 1 Solar Microgrid

IEC – 61427-1 protocol



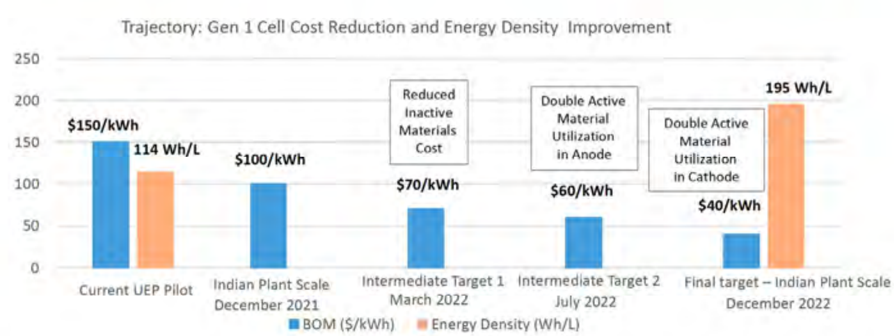


25

Product: UEP Zn-MnO2 Gen 1 Cell Development Roadmap

Current Gen 1 Cell

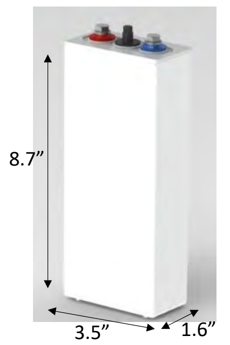
2021	December 2021	December 2022
Current Cost UEP-Pilot Scale: BOM: $150/kWh	Intermediate Cost Indian Plant Scale: BOM: $100/kWh	Target Cost Indian Plant Scale: BOM: $40/kWh



** 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 2021*

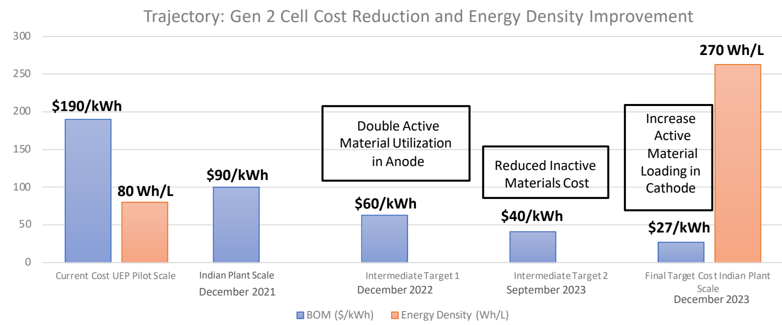
26

Gen 2 Cell Development Roadmap



Current Gen 2 Cell

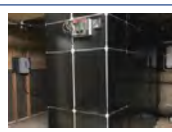
2021	December 2021	December 2023
Current Cost UEP-Pilot Scale: BOM: $190/kWh	Intermediate Cost Indian Plant Scale: BOM: $90/kWh	Target Cost Indian Plant Scale: BOM: $27/kWh



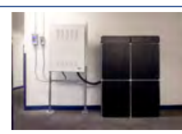
** All costs based on solar microgrid application with 10-year warranty conforming to IEC Solar Standard 61427-1. The standard simulates daily cycling in microgrids under representative varying solar insolation conditions.*

27

Installation Portfolio



Stratatech Power Backup 100kWh



Residential Power Backup 32kWh

San Diego Supercomputer Center 2MWh

2019 2021 2022

Peak Shaving Container 120kWh

U.S Navy Support Backup 15kWh

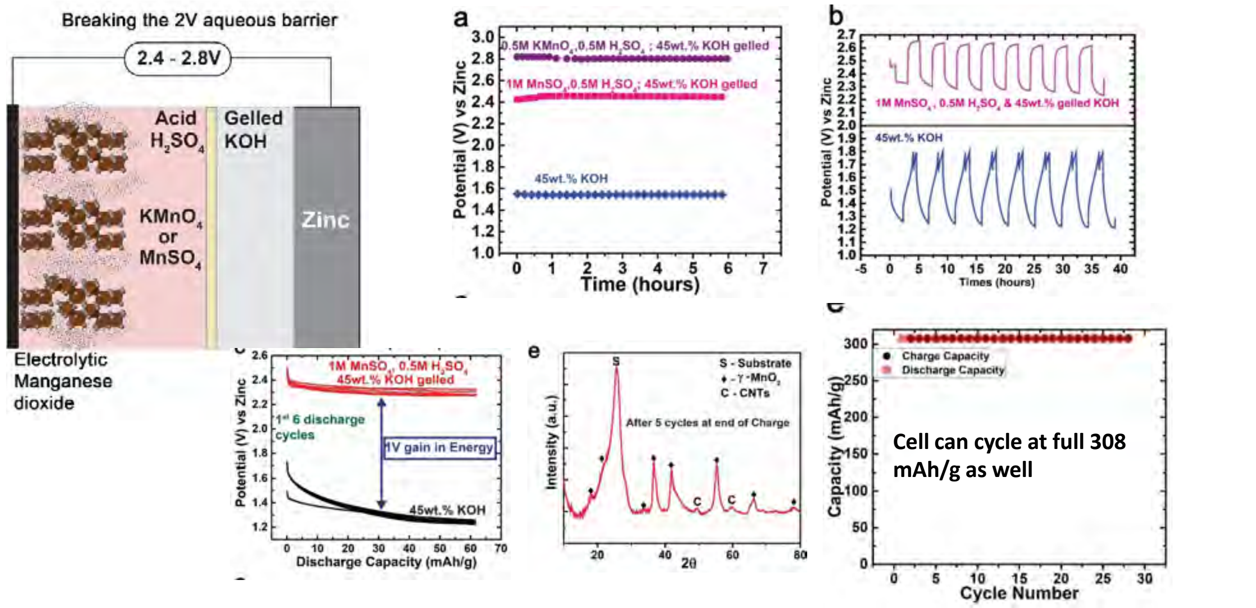
Navajo Nation Solar Microgrid 30kWh

- 8 systems installed at various sites to date
- 5 installations currently in process

12

28

Breaking the 2V Barrier in Zinc Anode Batteries

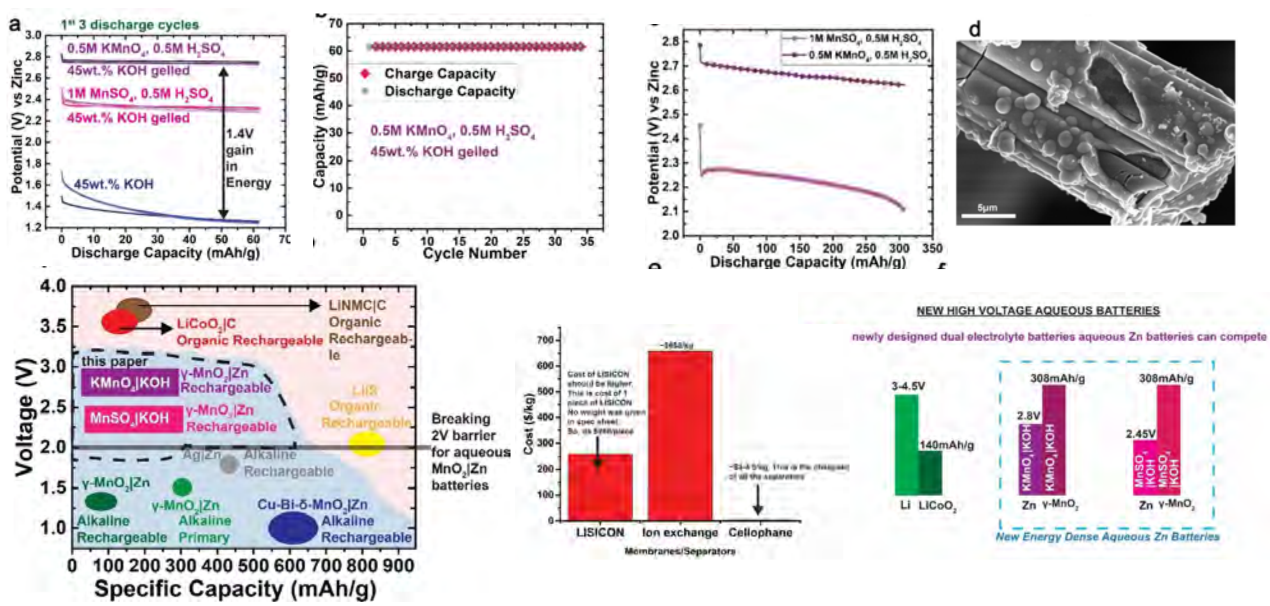


G. G. Yadav et al., ACS Energy Letters (2019)

Urban Electric Power Technical Slides 13

29

Making Zinc the New Lithium

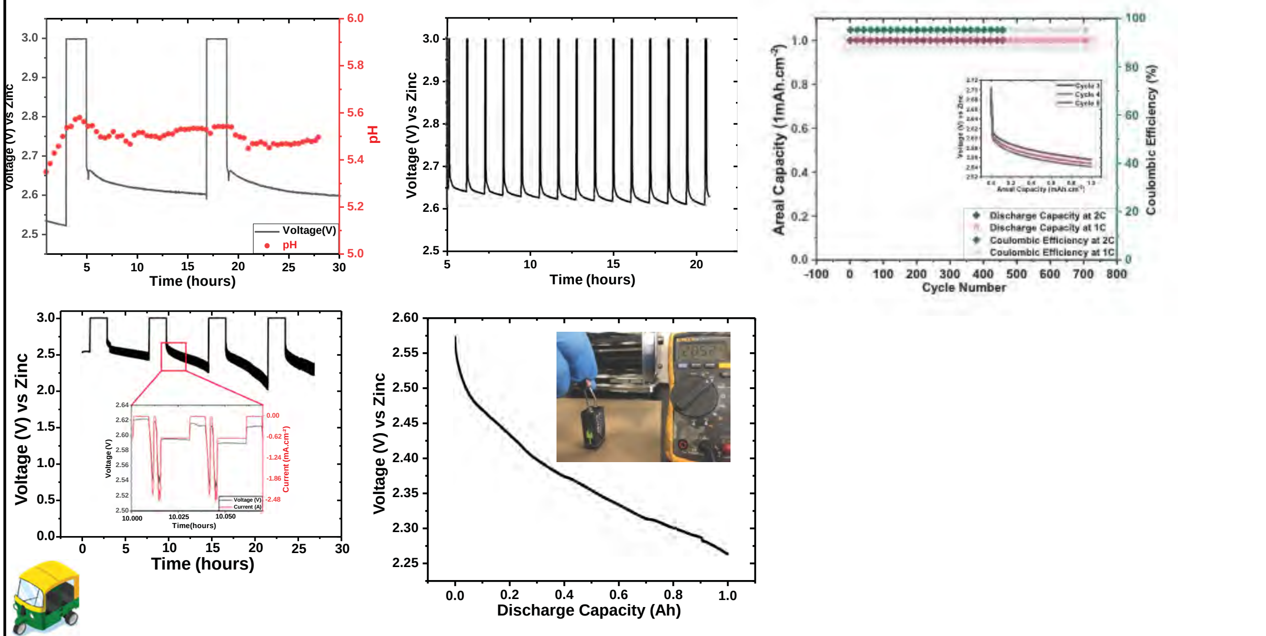


G. G. Yadav et al., ACS Energy Letters (2019)

Urban Electric Power Technical Slides 14

30

Performance of Membrane-less High Voltage Solid-State Zn|MnO_2 Cells



G. G. Yadav et al., In Peer Review (2021)

Urban Electric Power Technical Slides

31

POWERGEN SERIES

energy-cast.com

32