ZĒLOS

R&D Activity in Zinc-Manganese Alkaline Batteries

Dec 1, 2023

NAATBatt
SODIUM-ZINC
BATTERY WORKSHOP

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Technology Motivation – The Dream

Equal Total Capacity

State of the art Li Ion cell

One Zn-Mn AA battery costs less than 10 cents and has total energy up to ~ 4 Wh (when balanced correctly).

If commercial AA cells could cycle, they equal:

- $23 per kWh
- 182 Wh/kg
- 400 Wh/L

If Zn-MnO2 batteries could cycle at full discharge, get lowest cost, low-footprint battery design.

The Highest Energy, Lowest Cost Battery is now Rechargeable

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Introduction: Zelos Energy

- Zn anode and water-based electrolyte
  - Inexpensive;
  - Non-flammable and Safe
  - Environmentally-friendly
- Processability:
  - Powder-based pastes (simple, scalable manufacturing);
  - Water-based coatings;
  - Only commercial off-the-shelf materials in paste formulations
- Compatible with different cathodes:
  - NiZn
  - MnO_2-Zn
  - AgZn
- High energy density
  - 100 Wh/L projected (GEN1 product)
- Long cycle life
  - 1000 cycles
- Low energy cost
  - < $70/kWh (projected)

The Challenge

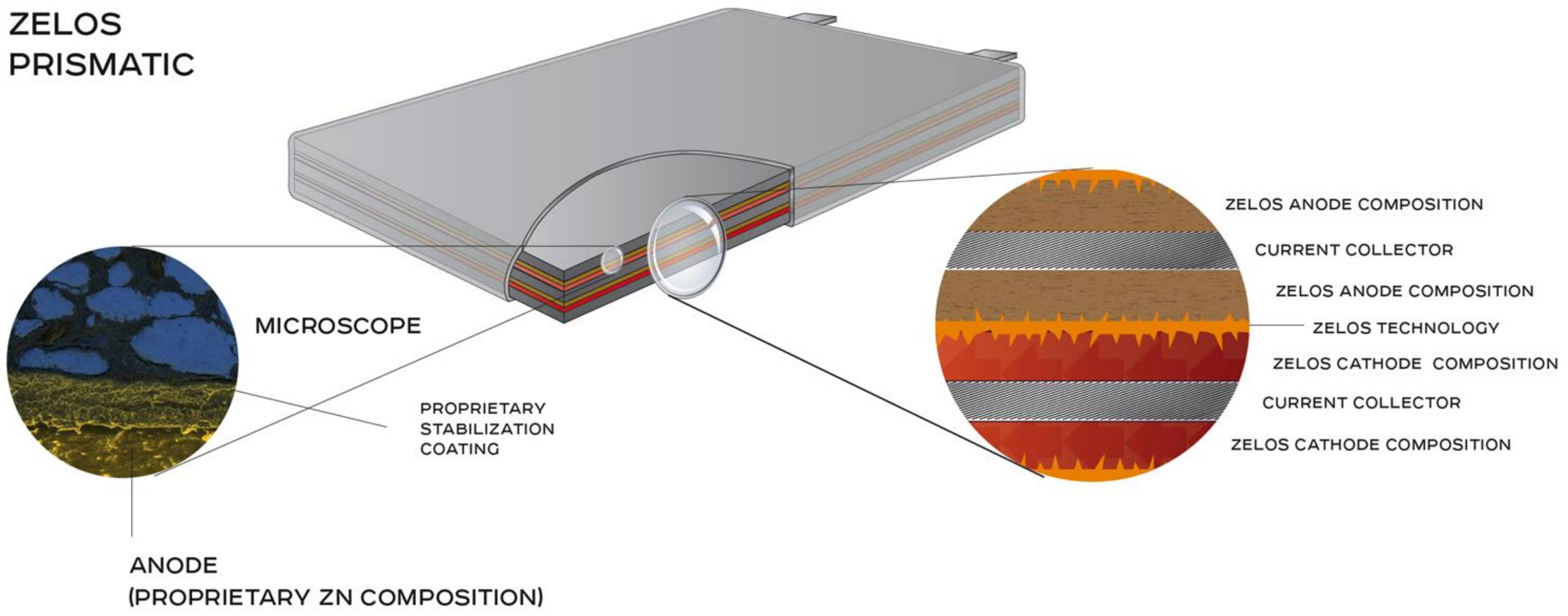
Limited rechargeability of Zn-based batteries due to dendrites growth and shape change when cycling

CALIFORNIA ENERGY COMMISSION

2020 EPIC grant awardee

Zēlos Technology Transforms Alkaline Battery Materials into Rechargeable Batteries for Battery Energy Storage Systems (BESS)

Zēlos proprietary battery architecture and materials with electrode stabilization unlocks the ability to deliver Rechargeable low-cost Zinc-based batteries now

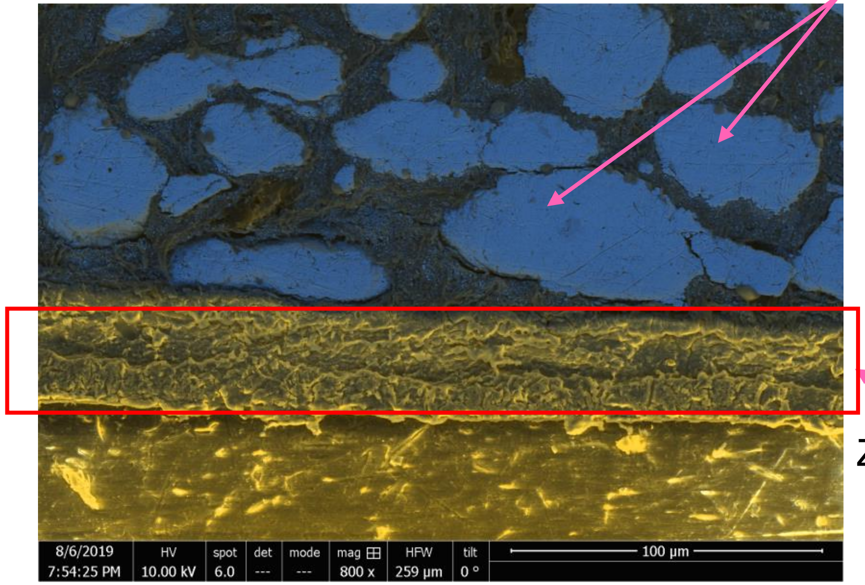


Innovations in Proprietary Electrode Stabilization Technology

- Zēlos batteries - first Technology to successfully demonstrate application of Anion Exchange Layers (AEL) in Zn batteries. It was shown in both Zn alkaline and Zn –air systems
- Zelos patented AEL on the electrode acts as a protective layer to allow ion exchange while completely obscuring the electrode material from the bulk electrolyte. As a result, the electrode stays dry during the life cycling.

Microscope cross-section of Anode

Zinc particles



Zēlos Stabilization Technology

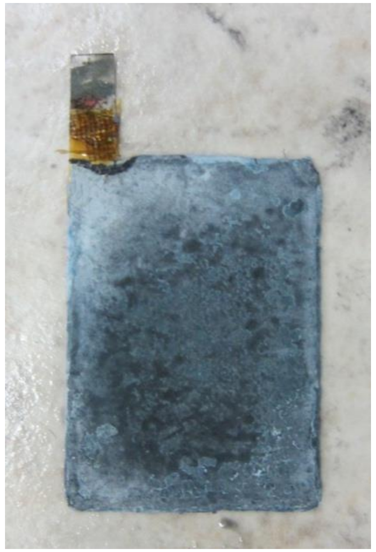
Zēlos Electrode Stabilization Results

Zinc anode failed **after only 2 cycles**

Zinc Shape Change

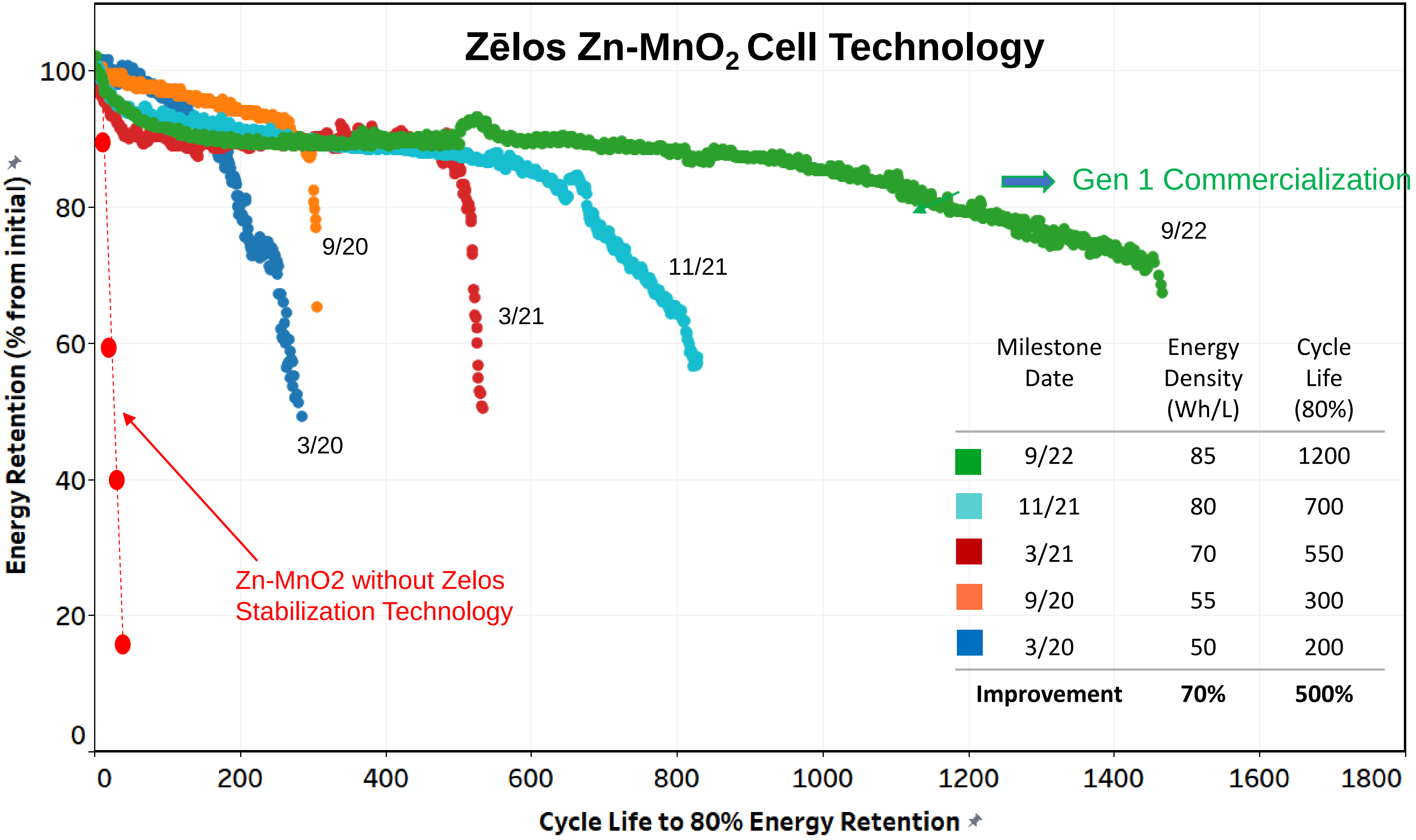
Dendrite formation

Zēlos Zinc anode **1,500 cycles**



Zelos Electrode Stabilization enables Long Duration Energy Storage

Track Record of Rapid Innovation Milestones

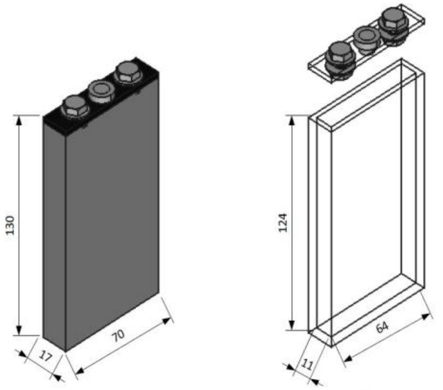


Milestone Date	Energy Density (Wh/L)	Cycle Life (80%)
9/22	85	1200
11/21	80	700
3/21	70	550
9/20	55	300
3/20	50	200
Improvement	**70%**	**500%**

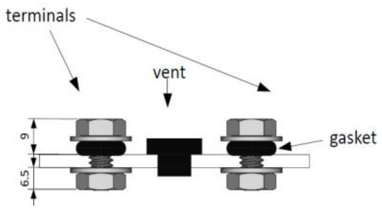
Testing Conditions:
- 10cm2 active area
- 1C Rate Ch/Dch
- KOH electrolyte
- Room Temp

Cycle Life of Li-ion at 1/3 the Cost

Status: Full-Scale Prototypes of two Form-Factors, Ready to Scale Manufacturing



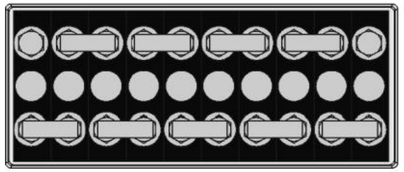
Internal dimensions

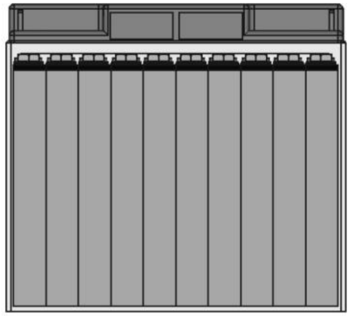


Lid structure

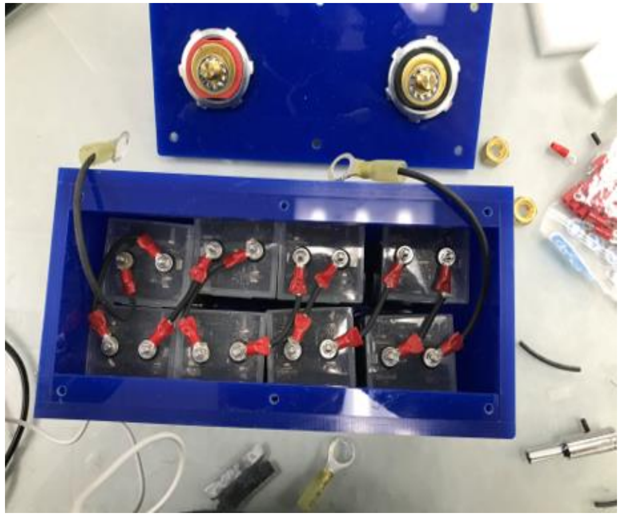
Assembly sequence:
1. Electrode stack is inserted into the can
2. Lid is assembled as shown;
3. Lid is welded to tabs of the electrode stack
4. Lid is mounted on the can with acrylic cement:
https://www.tapplastics.com/product/repair_products/plastic_adhesives/tap_acrylic_cement/130

10 cells per battery (10S1P)
Interconnect: 8 mm Ni strips (spot welded)

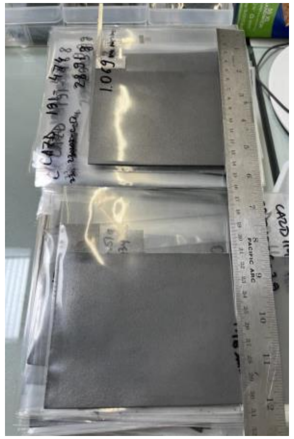


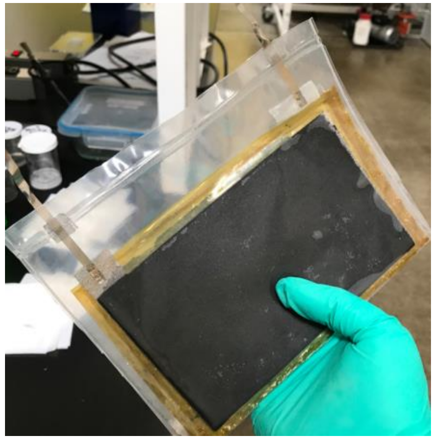


Cells inside the battery enclosure

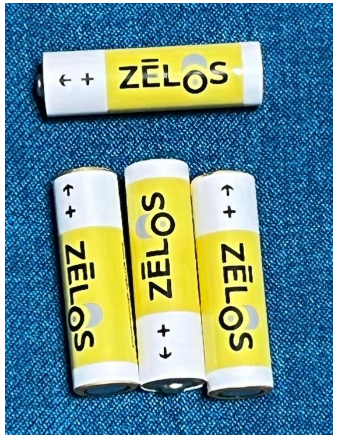


Prototype electrodes and cells built on "for hire" pilot line



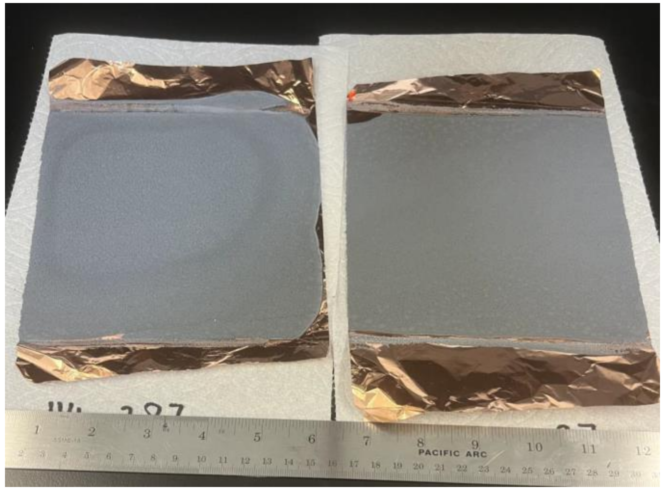


Prototype Cylindrical Cells

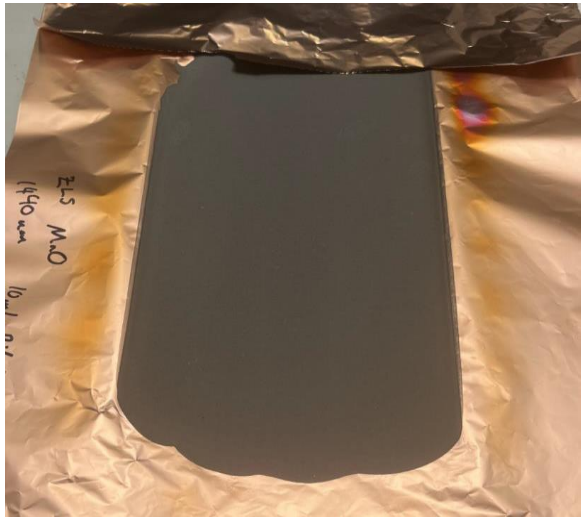


Innovations in Electrode Production for Pouch and Prismatic Cells

Typical Zn Viscosity is not suitable for standard roll-to-rool equipment



Zelos Anode coating on low-cost foil

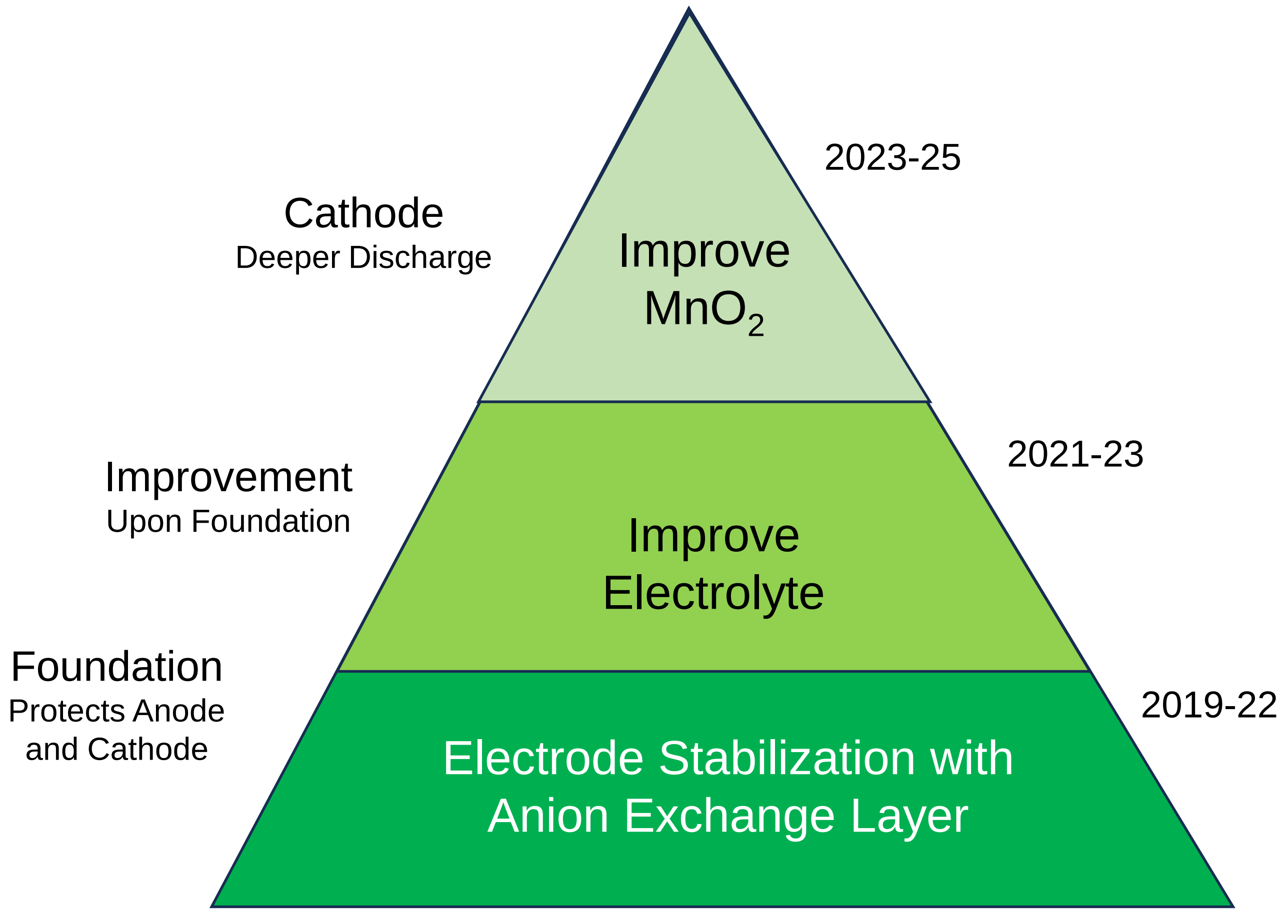


Zelos Cathode coating on low-cost foil

Standard Roll-Roll Coater

- Zinc and MnO2 electrodes are typically a thick paste that is applied to mesh current collectors
  - Expensive but enables thick (>0.5mm) electrodes to adhere to the mesh
- Zelos has developed a proprietary anode and cathode blend and process that to enable coating thick (>0.5mm) electrodes on standard low-cost foil, leveraging standard roll-roll coating equipment

Zelos Technology Foundation and Roadmap

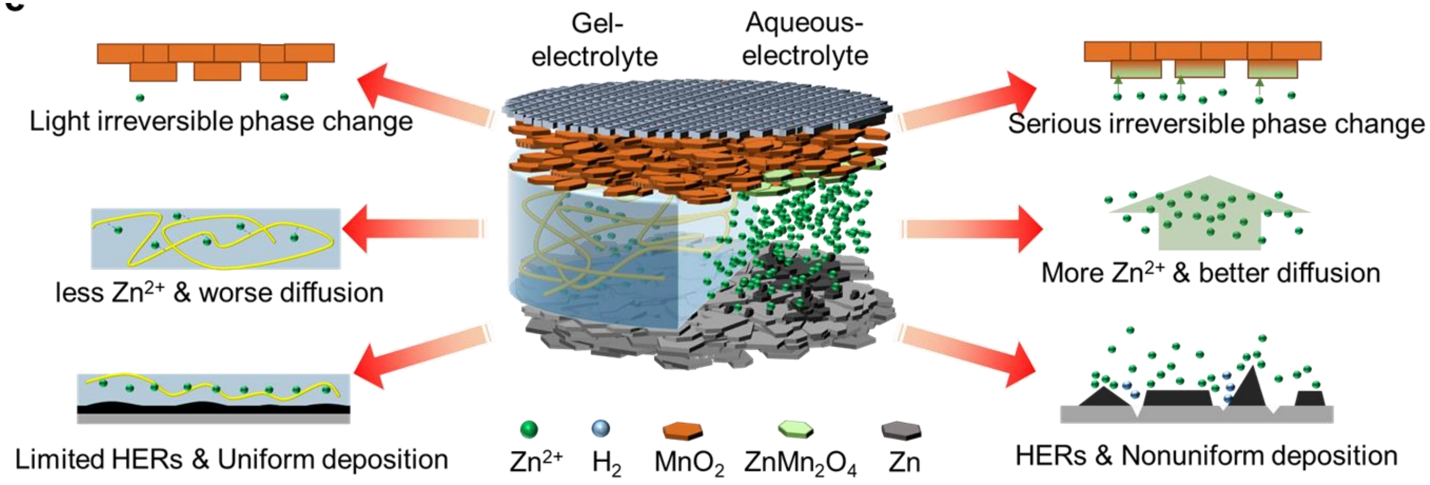


Purpose	Performance	Status	IP
• **Highest ED/Cycle Life** • Improve MnO2 conductivity while maintaining energy density • Uniform utilization • Suppress Mn dissolution	• 200 Wh/L • >1500 cycles	• Development Ongoing • Gen2 Introduction planned 2025	Patents filed
• **Higher ED** • Minimize side reactions	• 140 Wh/L • >1500 cycles	• Research Completed • Introduction in Gen 2	Patents filed

• **Long Cycle Life**
• Mitigates:
  • Zn dissolution,
  • Dendrite formation
  • Crossover to cathode
	• 85Wh/L
	• 1200 cycles
		• Complete, Use for Gen1
		• Scaling Up
			Patented

Electrolyte Modification

- Next Gen of Zelos products will use modified electrolyte!
- Modification of the electrolyte is needed since the nature of aqueous electrolyte has certain limitations: water decomposition (HER) outside of relatively narrow voltage window, dissolution of species, diffusion resulting in aggressive cross-over which can't be limited by AEM.



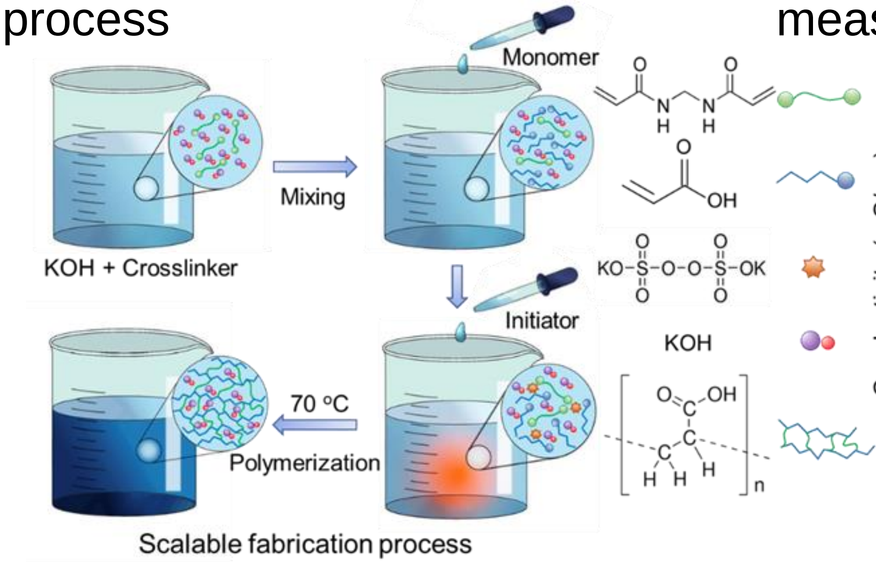
Comparison of KOH with Gel Electrolyte System

- Gel-Electrolyte + Zelos anode stabilization technology further reduces mobility of zinc ions in the electrolyte, restricts re-distribution of zinc ions, and further reduces dendrite formation due to more uniform plating and reduces mobility of zinc as compared to current Zelos technology

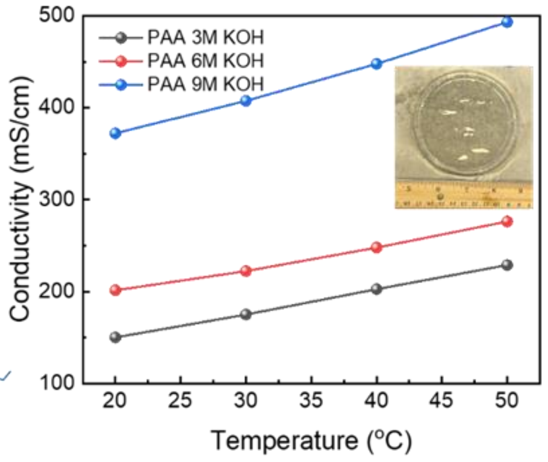
Electrolyte Modification

- Gel-polymer electrolytes in Zn/Mn systems can reduce HER at anode and irreversible phase transition at cathode, though their influence on the degradation mechanisms was largely unknown
- Zelos has investigated the effect of a gel system on the degradation mechanisms of alkaline Zn-MnO_2 batteries, and was able to reduce parasitic side reactions, such as the hydrogen evolution reaction
- Additional reduction of the Zinc crossover and irreversible phase transitions of MnO_2 were also observed.

We have used a scalable process



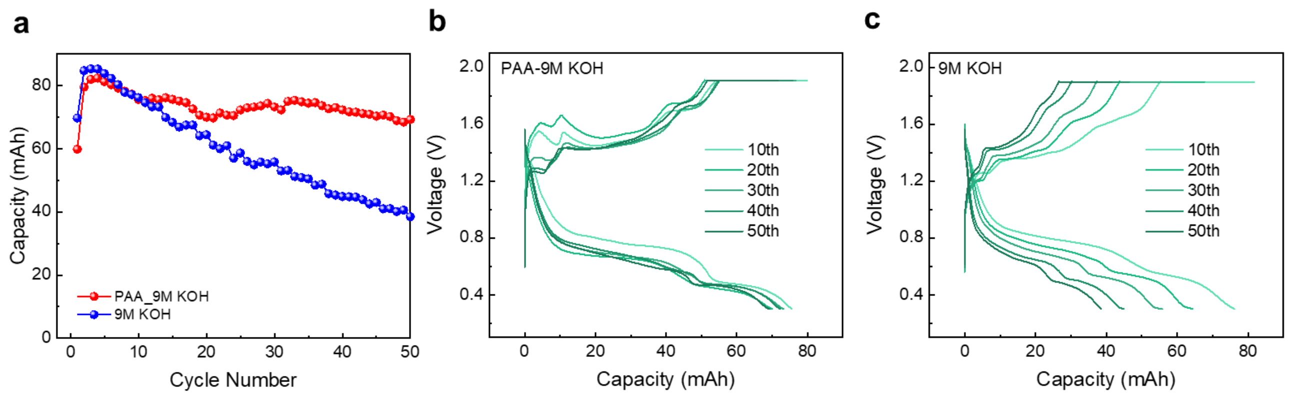
Ionic conductivity measurements



Electrolyte Modification

Can we remove this slide or reduce the specifics

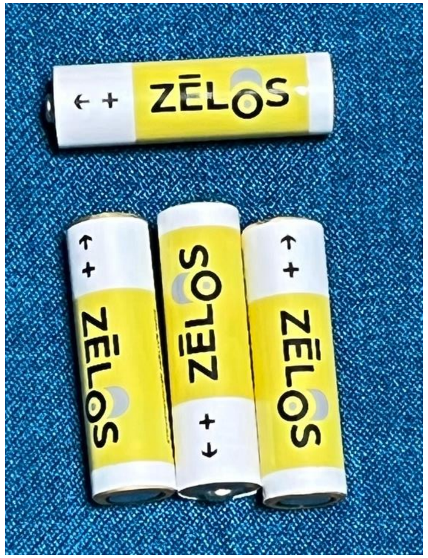
- We have investigated the effect of a polyacrylic acid (PAA) gel system on the degradation mechanisms of alkaline Zn-MnO_2 batteries. Inhibition of the Zinc crossover and irreversible phase transitions of MnO_2 were also observed.
- Application of sol-gel electrolyte supports cycling at 100% DOE

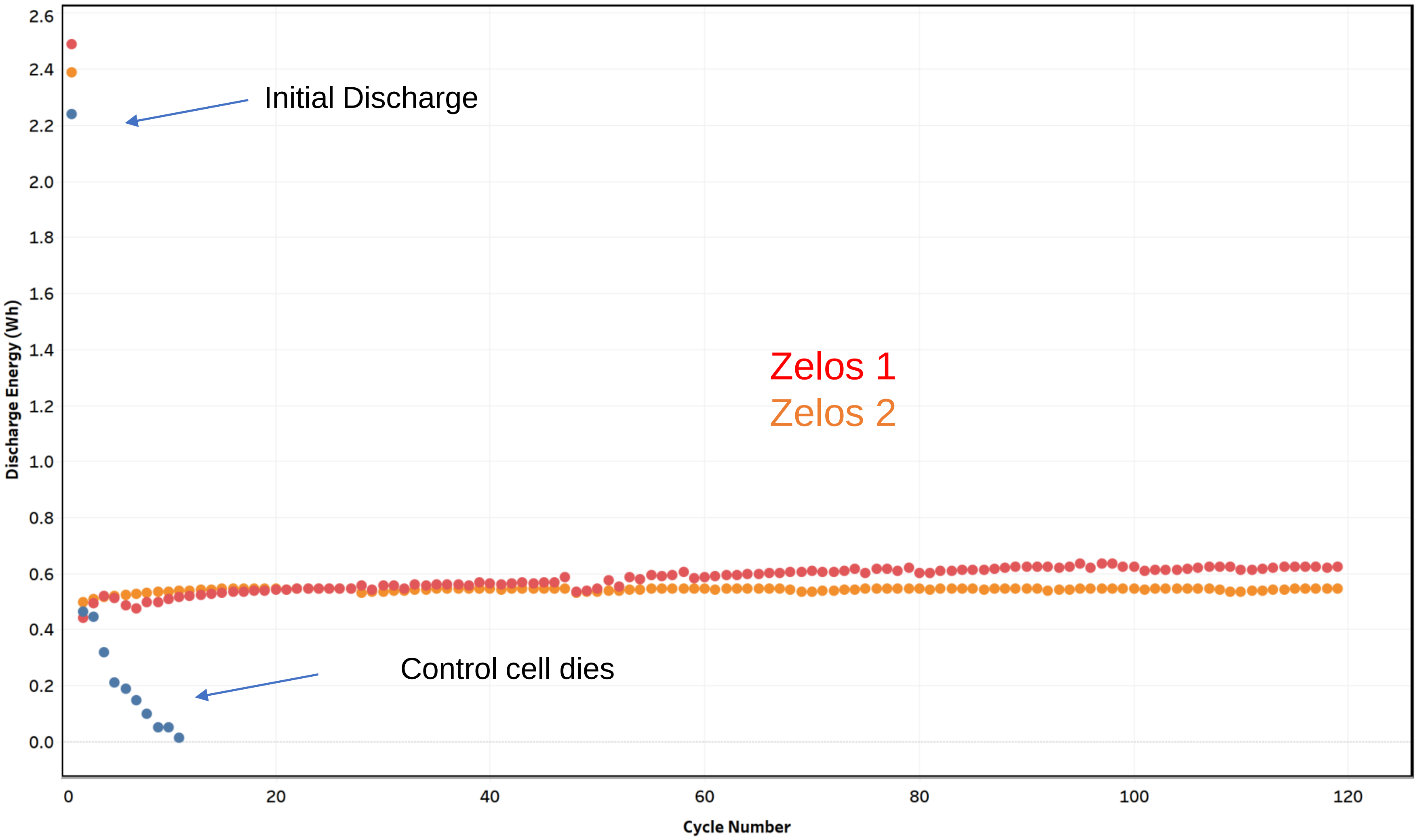


Cycling performance comparison of gel-electrolyte to alkaline cell at 100 DoD. The areal loading is ~30 mg/cm^2. Charge/discharge curves of cells using b) gel-electrolyte and c) 9M KOH aqueous electrolyte

Stable Cycling of Zn/Mn Cylindrical AA Cells

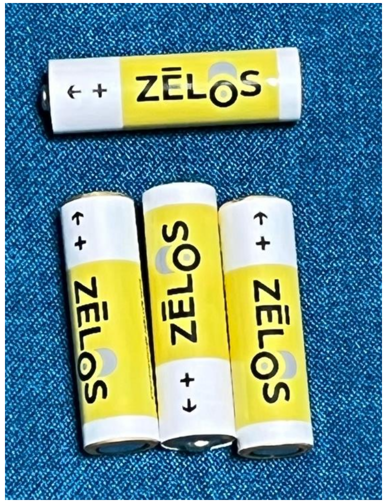
- Zelos applied proprietary electrode stabilization technology to standard AA cells
- Fully discharged in the beginning (~2.3Ah)
- Cycling 500 mAh (~630 mWh) at 50 mA discharge rate
- 85 Wh/L
- Room Temperature
- Achieved >140 cycles as of 11/26/23
- Multiple cells show similar performance, with cycle testing continuing

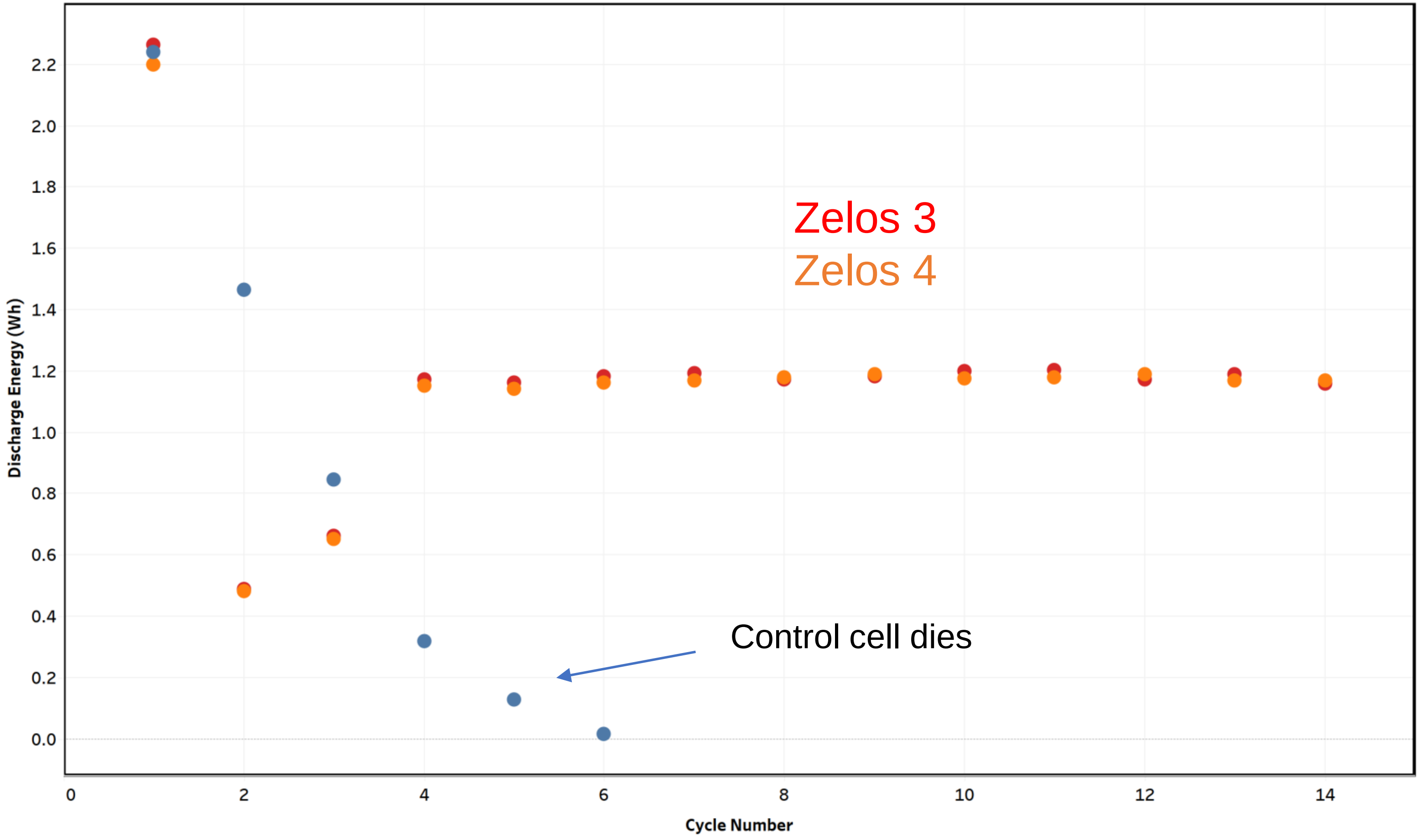




Stable High Energy Cycling After First Full Discharge

- Fully discharged in the beginning (~2.3Ah)
- Cycling at 156 Wh/L
- Room Temperature
- Achieved ~15 cycles as of 10/31/23
- Multiple cells show similar performance, with cycle testing continuing
- Not all cells from the “same family” are identical in performance, due to differences in hand building cells





Final Remarks

- We see a great potential in Zn-Mn technology for long cycle life energy storage systems
- Standard Zn-MnO2 chemistry is simple but not rechargeable as we know it
- Zelos was able to achieve a good cycle life at ~90 Wh/L
- The further improvements in the battery performance will require modification of electrolyte combined with new cathodes materials
- Zelos has made great progress in the manufacturability of pouch and prismatic cells by coating on low-cost foils using standard roll-roll coating equipment
- Zelos has also demonstrated this technology using standard AA bobbin cell manufacturing processes – and can also be an efficient way for mass production of this technology