Sandia National Laboratories

# MECHANICAL COMPRESSION EFFECTS RECHARGEABLITY OF ALKALINE Zn-MnO₂ BATTERIES

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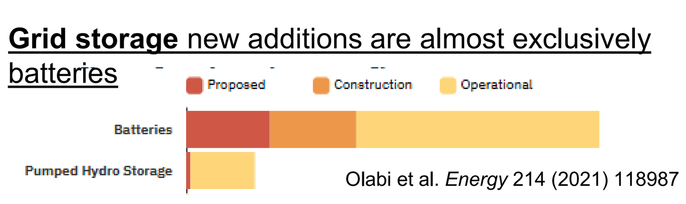
## PROJECT PROFILE

Topic: Zinc & Lead Batteries
Vertical: Materials and Systems Innovation

Strategic Pathway: Grow: Long-term expansion by enabling innovation, advancing new technologies, and building capacity for a future-ready electricity system

Project start and finish: FY26-FY27, Storage Innovations - 2030

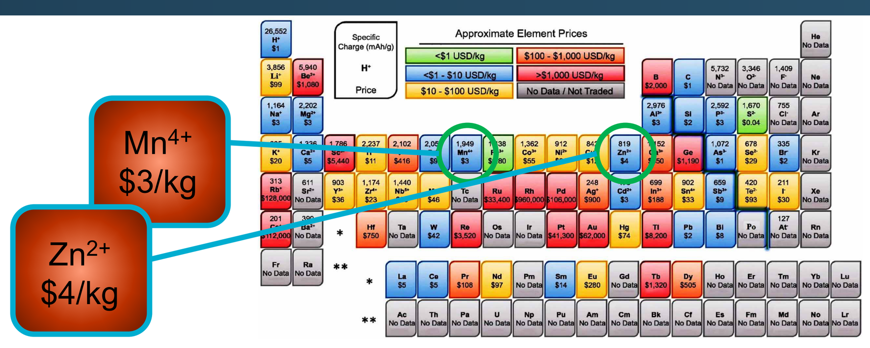
## PROBLEM




Moss Landing battery fire
January 16, 2025
Credit: Anadolu via Getty Images

Li-ion batteries are inherently flammable

A Li-ion battery bank triggered a fire on Air Busan plane (Photo: Yonhap News Agency)




Banerjee, Arghya Narayan, and Sang Woo Joo. "Beyond Li-ion technology"—a status review." Nanotechnology 35.47 (2024): 472001.

**Limitations of Li-ion**

- **High cost** – Li is scarce and expensive to mine
- **Flammable electrolyte** – Safety concerns, high thermal runaway risk
- **Potentially toxic metals** – Also fluorinated compounds
- **Supply chain risk** – Geographically concentrated raw materials

**Alkaline Zn-MnO$_2$**

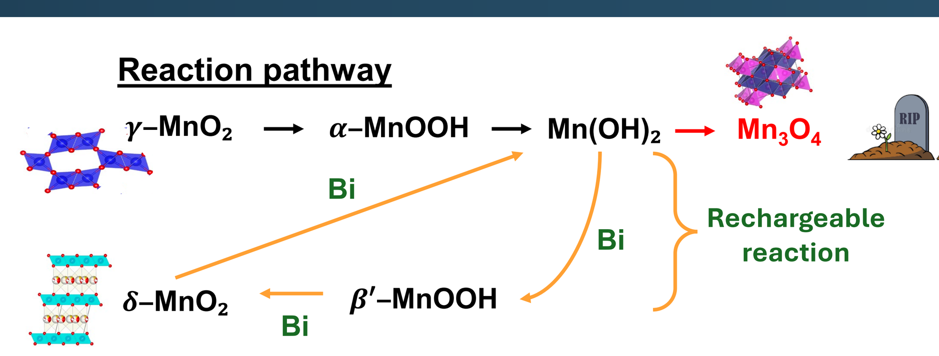
- **Low cost** – Mn and Mn are abundant and significantly cheaper
- **Aqueous electrolyte** – Inherently safe, low thermal runaway risk
- **Non-toxic materials** – Zn and Mn pose no health risk
- **Domestic supply chain** – Widely available, stable supply chain

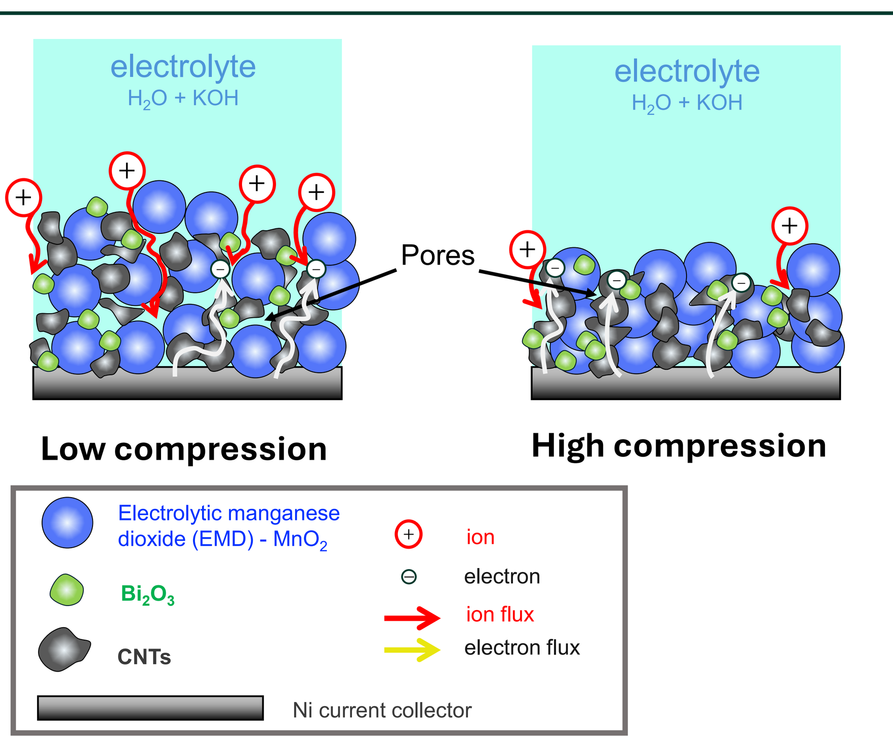
## APPROACH

Controlling mechanical compression in rechargeable Zn-(Bi)MnO$_2$ batteries.[1]

- **Hypothesis**: There exists an optimal mechanical compression that improves cycle life and stability

**Reaction pathway**




**Effect of Compression on MDB Electrode**

**Benefits**

- Improves inter-particle contact → lower contact resistance, faster e⁻ transport
- Promotes Mn$^{3+}$ deposition onto CNT surface
- Shortens Bi$^{3+}$ diffusion distance to MnO$_2$

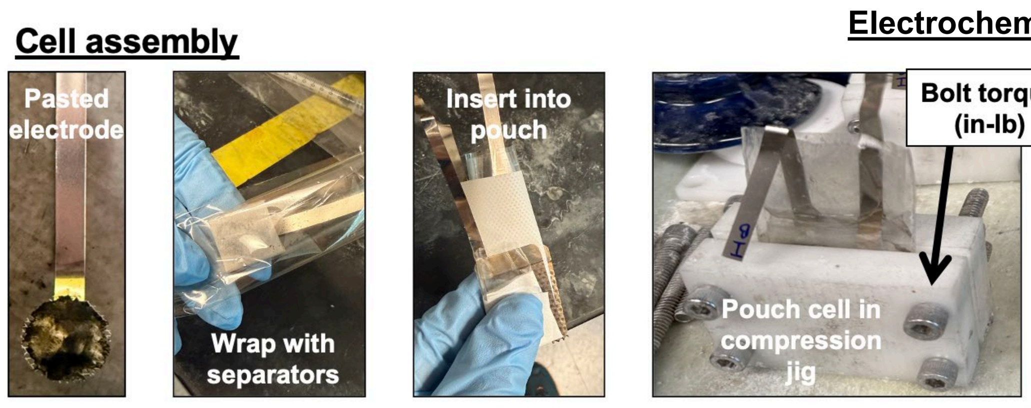
**Trade-offs**

- Reduces porosity → limits OH⁻ access to electrode
- Increases tortuosity ($\tau$) → ionic transport

**Mechanical compression** has a significant impact on rechargeability

- What is the optimal compression?
- What is the mechanism?
- Can compression can help increase the MnO$_2$ loading?

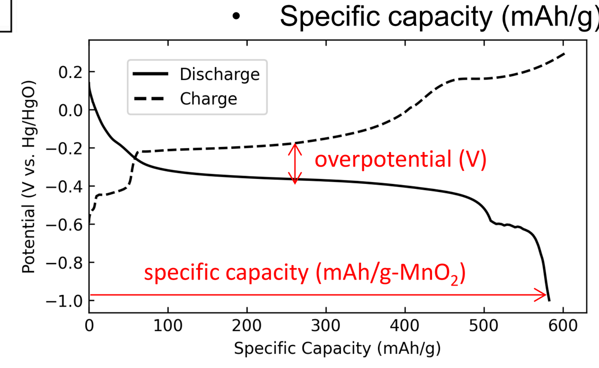
**Cell assembly**



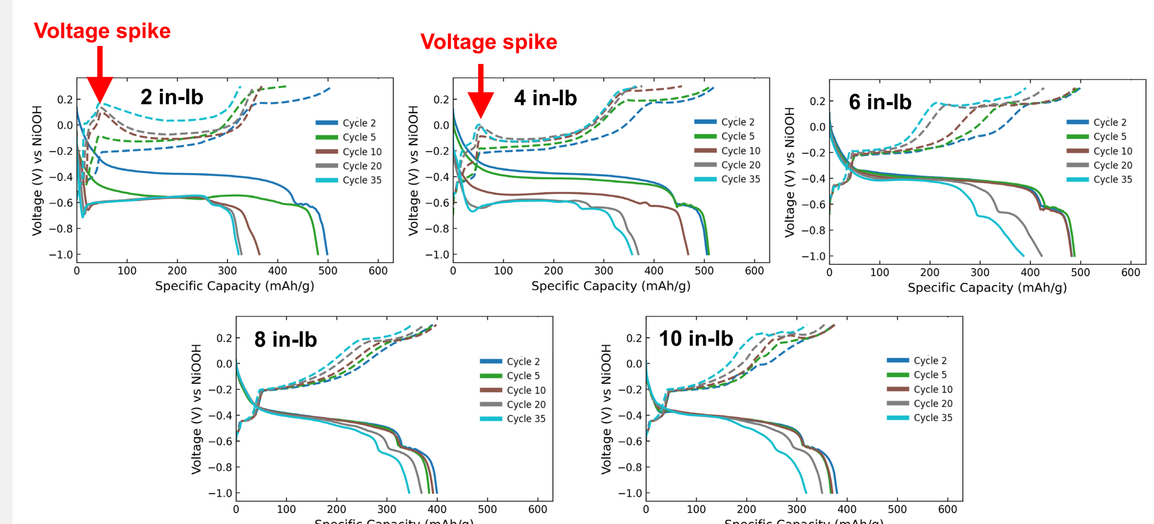

**Electrochemical analysis**

Figures of merit for assessing compression effect

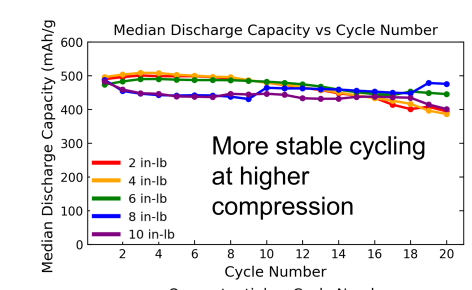
- Overpotentials (V)
- Specific capacity (mAh/g)

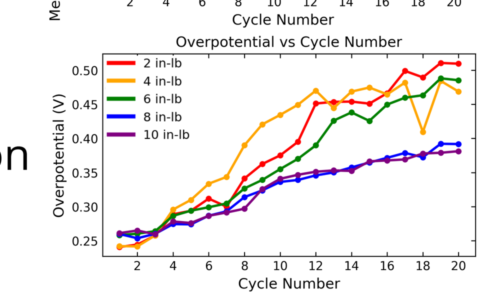



## RESULTS



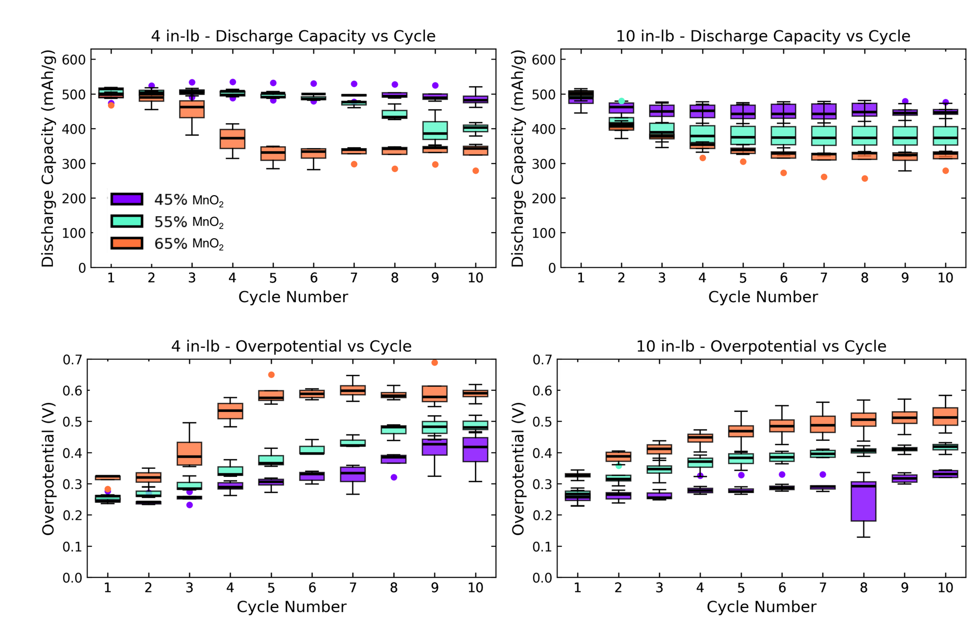

| Torque value (in-lb) | Pressure (psi) | Pressure (kPa) |
|---|---|---|
| 2 | 245 | 1692 |
| 4 | 499 | 3440 |
| 6 | 696 | 4800 |
| 8 | 881 | 6076 |
| 10 | 1046 | 7214 |




1. Compression (stack pressure) greatly affects cell voltage and performance.
2. Higher compression cells have better capacity retention and a slower overpotential increase

4. In a study of MnO$_2$ loading, higher loadings of MnO$_2$ caused more rapid degradation in capacity.
5. However, compression affected this. Higher compression lowered overpotential growth




## CONCLUSIONS & IMPACT

- Bi is added to improve reversibility
- Compression enhances inter-particle contact, promotes Mn$^{3+}$ deposition on CNTs, and shortens Bi$^{3+}$ diffusion distance to MnO$_2$
- A trade-off exists between electronic and ionic transport under compression
- Higher compression improves capacity retention and reduces overpotential, indicating more efficient electrochemical reactions

## FUTURE DIRECTIONS

- Work is ongoing to quantify the interdependent effects of compression, MnO$_2$ loading, and electrode performance.
- This will feed into a technoeconomic model to identify technical targets to minimize cost (USD/kWh/cycle) and maximize energy density (Wh/L).
- The goal is design of practical rechargeable Zn-MnO$_2$ batteries for the grid.

**References**

1. C Nguyen, E Zimmerer, JR Mulligan, TN Lambert, and JW Gallaway, A Study of Mechanical Compression Effects on the Reversibility of Rechargeable Alkaline Zn-MnO₂ Batteries, 249th ECS Meeting (May 24-28, 2026).

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