Polymer Electrolyte-Based Zinc-Air Batteries with Earth-Abundant Bifunctional Electrocatalysts

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PROJECT PROFILE

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

Strategic Pathway: Grow & Optimize

Project start and finish: FY25-FY26

PROBLEM

Zinc-air batteries (ZABs) are promising candidates for grid-scale energy storage, but several critical challenges continue to hinder their commercialization, including:

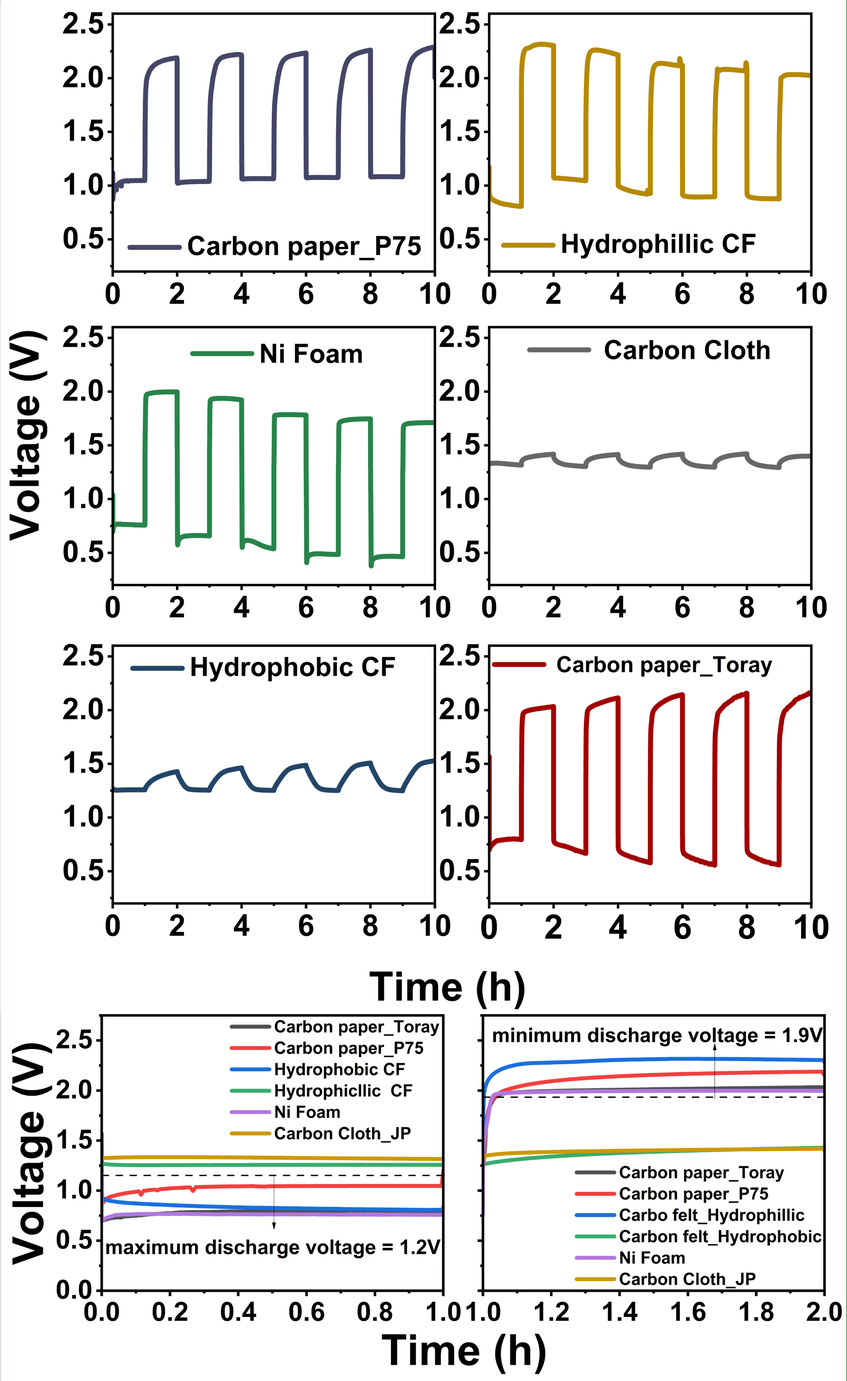
- Low and poorly reproducible cell voltages
- Parasitic reactions at the air cathode
- Limitations associated with liquid electrolytes
- Sluggish oxygen electrocatalytic reaction kinetics

Performance Target: Charge voltage of ~1.9 V and discharge voltage of ~1.2 V with high reproducibility and stable cycling performance.

APPROACH

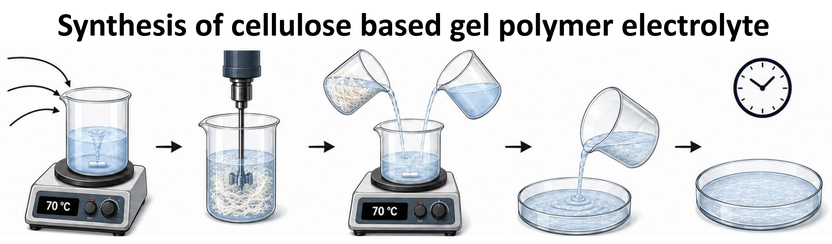
- **Gas Diffusion Electrode (GDE) Screening**
  Six different GDE materials systematically investigated.
- **Cellulose-Based Gel Polymer Electrolyte (GPE)**
  Modified cellulose-based GPE developed as a solid-state electrolyte.
- **Bifunctional Catalyst Evaluation**
  Two catalyst configurations evaluated during full-cell cycling.

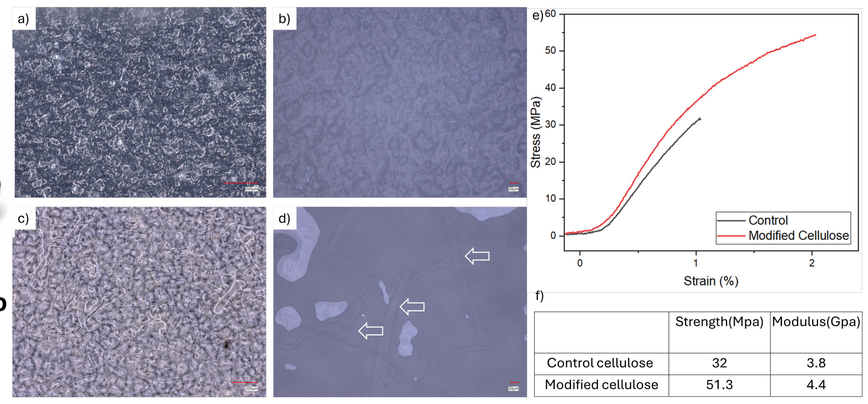
RESULTS



R1. GDE Material Screening: Of six GDEs tested, Carbon paper P75, Carbon paper Toray, Ni foam, and Carbon felt hydrophilic showed thermodynamically correct charge/discharge voltages.

RESULTS

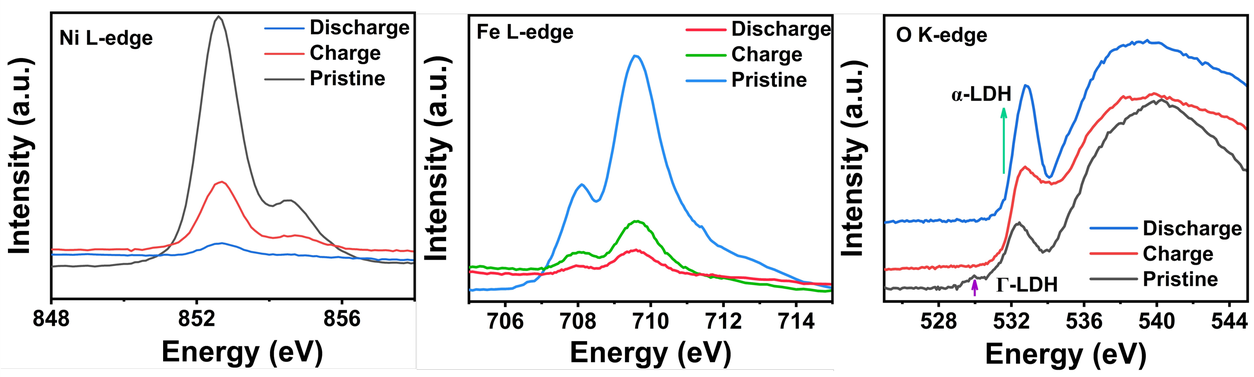




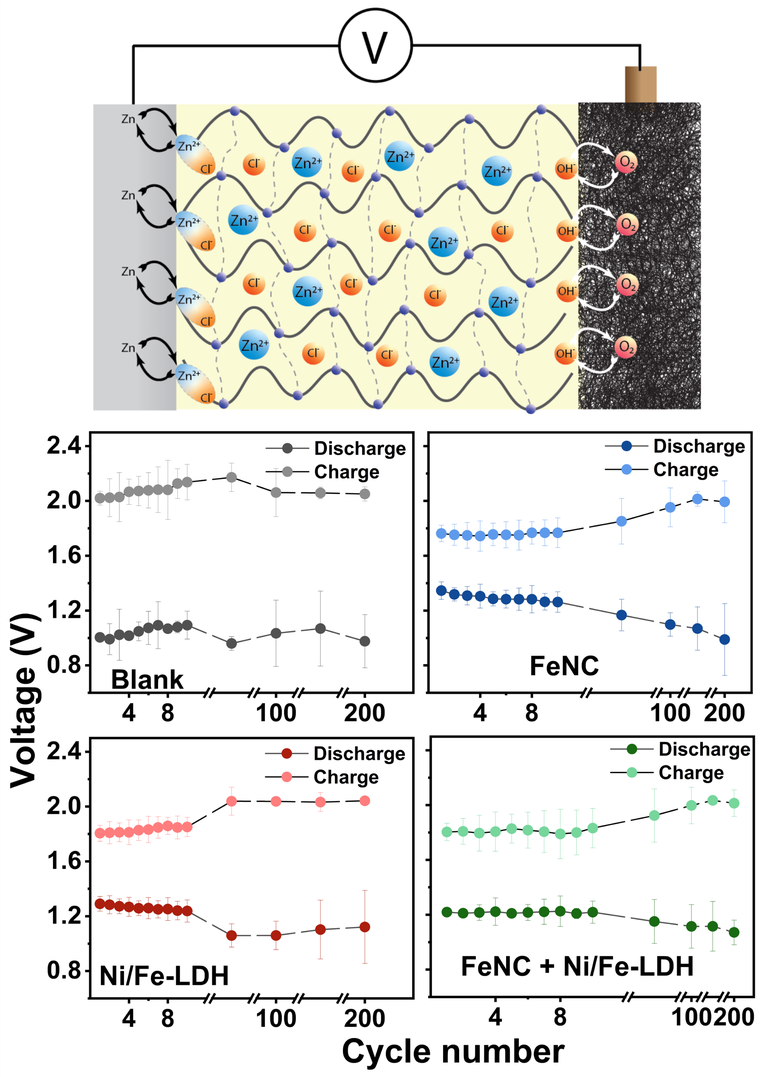
	Strength(Mpa)	Modulus(Gpa)
Control cellulose	32	3.8
Modified cellulose	51.3	4.4

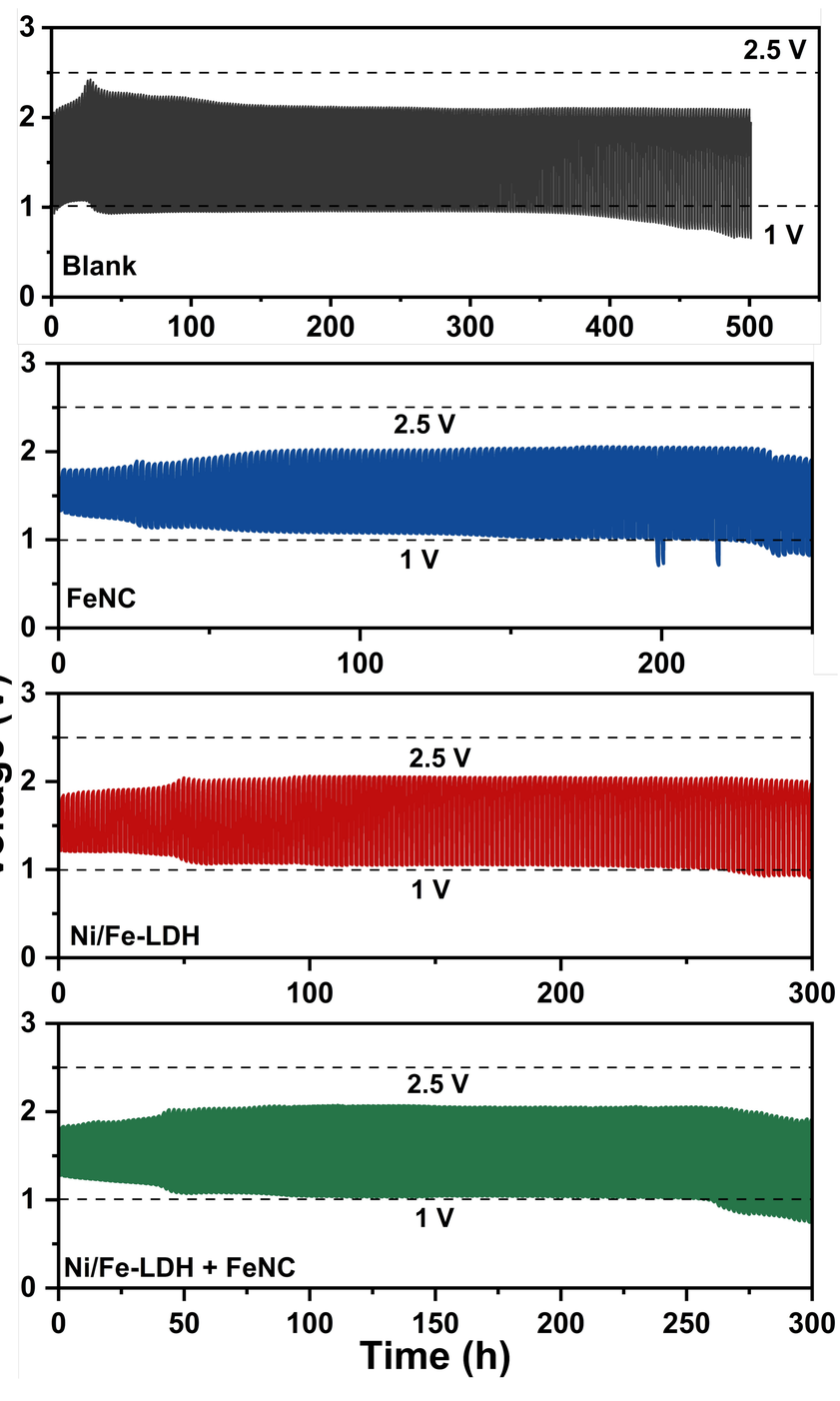
R2. Cellulose GPE Synthesis and Characterization: Schematic process showing the synthesis process of cellulose based GPE. Modified cellulose shows 60% higher strength (51.3 vs 32 MPa) and improved modulus (4.4 vs 3.8 GPa) vs. control.

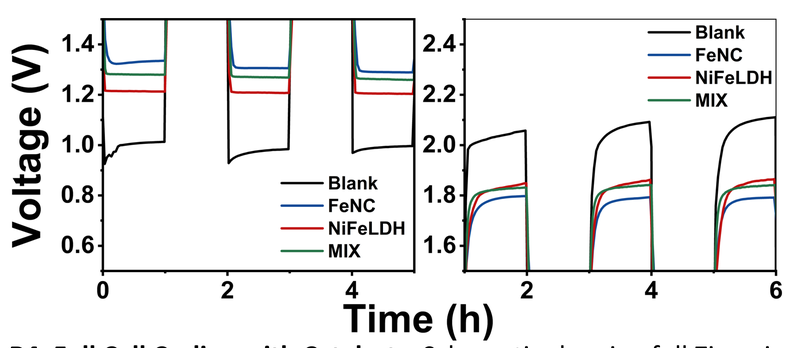
RESULTS



R3. Ni/Fe-LDH catalyst mechanism: Uncovering the catalytic mechanism of the Ni/Fe-LDH catalyst. (b) Ni L3-edge, (c) Fe L3-edge, and (d) O K-edge spectra in the total electron yield (TEY) mode of the catalyst at different states of charge.







R4. Full Cell Cycling with Catalysts: Schematic showing full Zinc-air cell**.** Ni/Fe-LDH showed most stable long-term charge voltage (~2 V) over 300 h. FeNC reduced overpotential but showed early failure. Mixed catalyst achieved best balance. Zoomed in first 3 cycles of charge and discharge for different catalyst based zinc air battery. All catalyst formulations maintain discharge voltage ~1.0-1.3 V over 200 cycles.

ARTIFACTS

Articles published or under review:

- V. Raj, R. Amin et.al., Journal of power sources, Manuscript accepted, ***2026***
- R. Amin, V. Raj et.al., Small, doi.org/10.1002/smll.202512733, ***2026***
- M. Rahman, R. Amin et al., Electrochem. Energy Review, DOI: 10.1007/s41918-025-00249-w, ***2025***
- R. Amin et al., J. Mater. Chem. A, DOI: 10.1039/d4ta01061b. Selected as a Hot Article, ***2024***

Presentations and Conferences

- Oral presentation at ACS Atlanta 2026
- Oral and Poster presentation at OE Washington 2025
- Oral presentation at ECS Chicago 2025
- Oral presentations at MRS fall 2024
- Oral presentation at ECS Prime 2024

CONCLUSIONS, IMPACT & FUTURE WORK

Carbon paper P75, Toray carbon paper, Ni foam, and hydrophilic carbon felt emerged as the most promising GDE candidates with thermodynamically consistent voltage profiles. The modified cellulose-based GPE showed improved mechanical strength (+60%) and elastic modulus (+16%), supporting stable cycling for 330+ hours without a catalyst. Ni/Fe-LDH maintained the most stable charge voltage (~2 V) over 200+ cycles, FeNC showed the lowest ORR overpotential, and their combination improved overall voltage stability.

Future work will focus on XPS characterization of carbon cathodes, full-cell integration of the cellulose GPE with FeNC + Ni/Fe-LDH, and extended cycling beyond 500 cycles to probe degradation mechanisms.

Impact: This work provides a systematic framework for optimizing polymer-based ZAB components, advancing their viability as a safe, low-cost alternative for grid storage.

ACKNOWLEDGEMENT

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