Progress in Aqueous Zn-based Batteries

PRESENTED BY

Timothy N. Lambert

DOE-OE Peer Review, Santa Fe, New Mexico,
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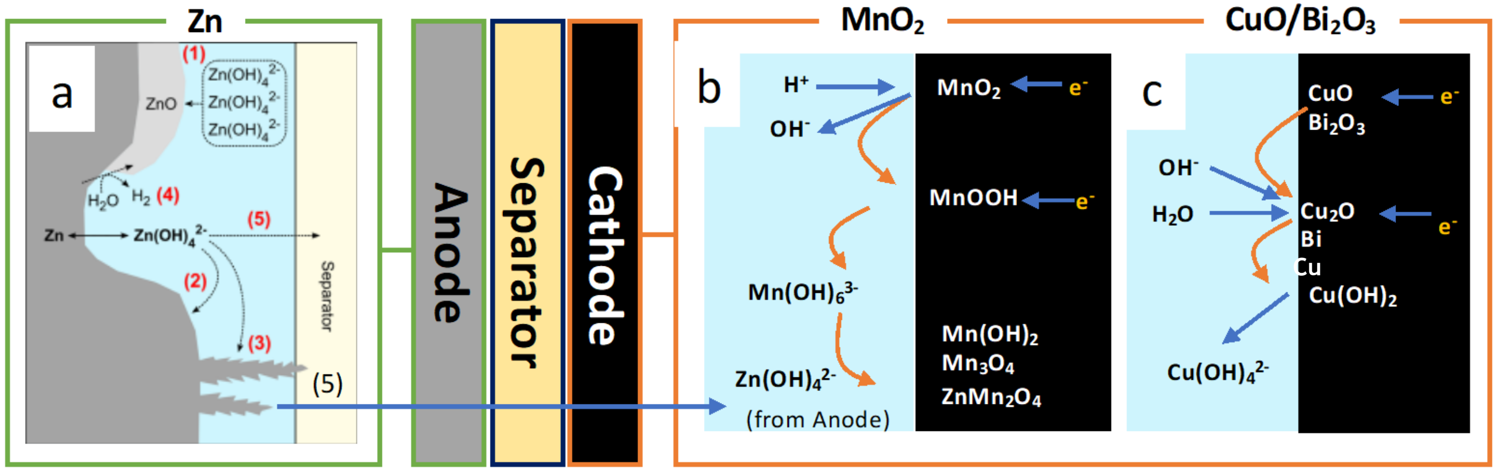
Presentation ID # 701

SAND2023-113670

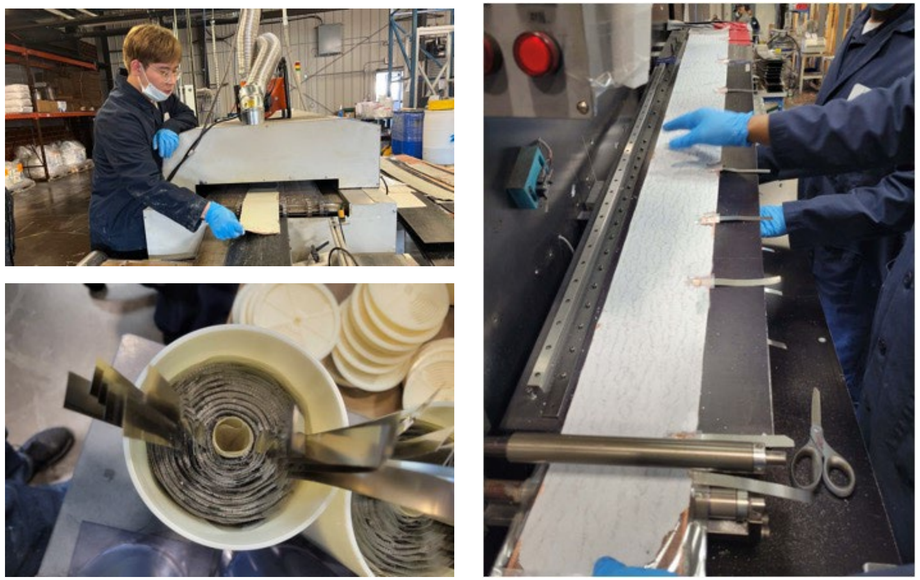
Low Cost Aqueous Batteries based on Zinc

Program Objective: Develop the understanding, materials, methods, components & technologies to enable low cost Zn-based batteries for grid and long duration energy storage

- Zinc-based batteries offer an energy dense, safe and readily manufacturable technology
- OE Funded Project collaboratively investigates new materials and chemistries while supporting technology maturation and US manufacturing
- Zn/(1e-)MnO_2, Zn/(2e-)Bi,Cu-MnO_2, Zn/(2e-)Bi-CuO, Zn/Ni……………… Zn/air, Zn-ion, Zn/S



Adapted from "*A Critical Comparison of Mildly Acidic versus Alkaline Zinc Batteries*"
Acc. Mater. Res. 2023 4, 4, 299-306.

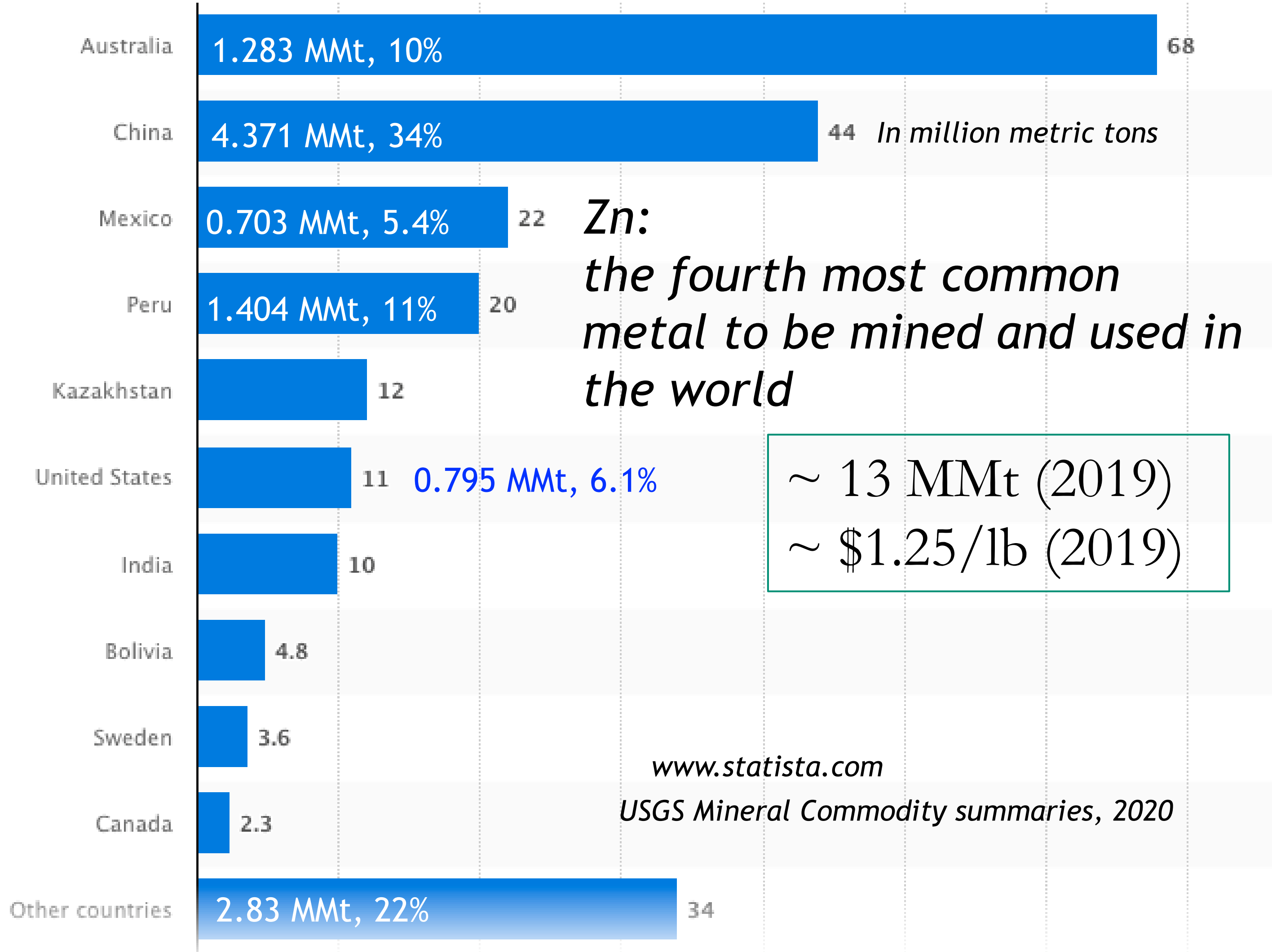


Photos provided by UEP

Sandia National Laboratories
CUNY The City University of New York Energy Institute
NM State University
Lawrence Livermore National Laboratory
URBAN ELECTRIC POWER
U.S. DEPARTMENT OF ENERGY

A case for Zn-based batteries

(2019 Production) 2020 Global Reserves of Zinc



Zn: the fourth most common metal to be mined and used in the world

~ 13 MMt (2019)
~ $1.25/lb (2019)

www.statista.com

USGS Mineral Commodity summaries, 2020

https://www.usgs.gov/centers/nmic/zinc-statistics-and-information

Zn

1° Alkaline Zn/MnO$_2$ as an exemplar

Wikipedia, user Aney, 2005

- Existing supply chain
- > 10B units Zn/MnO$_2$ produced (2019)
- $7.5B global market (2019)
- Affordable ~ $20/kWh
- Aqueous w/long shelf life
- EPA certified for disposal (safe)
- High achievable energy density
  - Zn/MnO$_2$ ~ 400 Wh/L
  - Zn/Air ~ 1400 Wh/L
  - Zn/Ni ~ 300 Wh/L
  - Zn/CuO ~ 400 Wh/L

Low Cost, readily available ~ Energy Equity

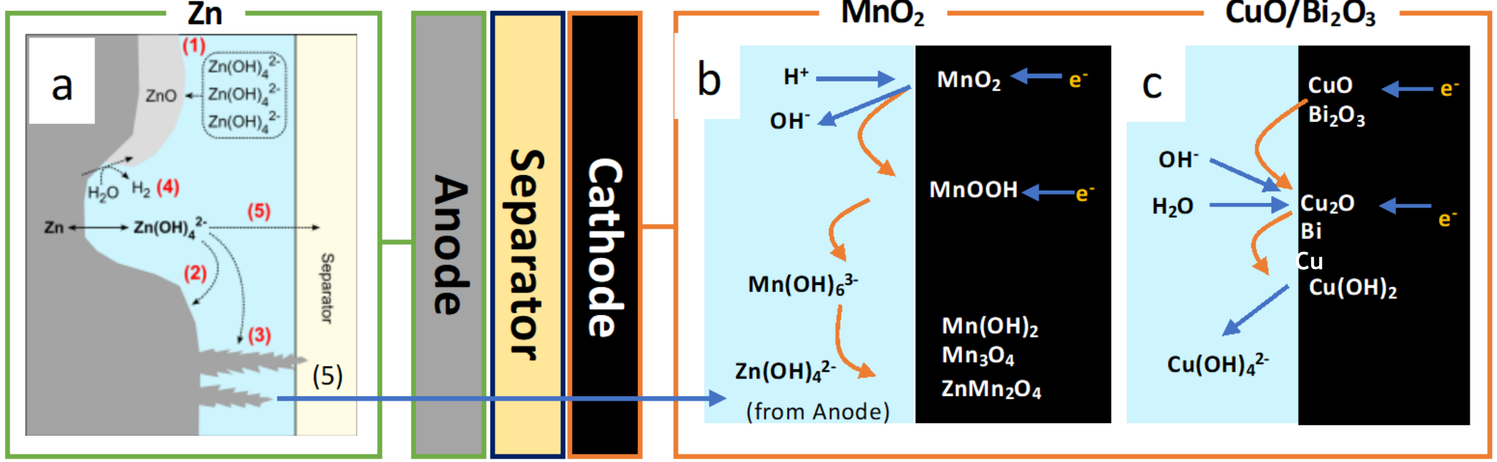
High Energy Density ~ Long Duration Energy Storage

Low Cost Aqueous Batteries based on Zinc

How does one obtain reliable high capacity conversion chemistry in aqueous Zn batteries ?

Obtaining High DOD at both electrodes for thousands of cycles remains a challenge

Schematic for Alkaline Zn Battery



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Cathode - conversion electrode

(1) **MnO$_2$** crystal structure breakdown, Mn(OH)$_6^{3-}$, irreversible phases, susceptible to Zn poisoning, soluble Cu(OH)$_4^{2-}$,Bi(OH)$_3^-$ in 2e- electrode

(2) **CuO** Cu$_2$O reversibility, soluble Cu(OH)$_4^{2-}$

(3) High Capacity is at lower Voltage

What is the mechanism, intermediates, more efficient use of additives?

Zn Anode - conversion electrode

(1) passivation, (2) shape change (3) dendrite formation, (4) H$_2$ evolution (5) Zn(OH)$_4^{2-}$ crossover

How to control zincate and interfacial interactions for maximum capacity?
High DOD w/out complicated 3D architectures?

Separators

Crossover of soluble “ate” complexes

How does one control ion selectivity, migration?

Electrolyte

High voltage and non-spillable

How to engineer electrolyte to enable safe, long cycle life, higher voltage?

Sandia National Laboratories

CUNY The City University of New York Energy Institute

NM STATE UNIVERSITY

Lawrence Livermore National Laboratory

URBAN ELECTRIC POWER

Low Cost Aqueous Batteries based on Zinc

How does one obtain reliable high capacity conversion chemistry in aqueous Zn batteries ?

Obtaining High DOD at both electrodes for thousands of cycles remains a challenge

Zn Anode

J. Electrochem. Soc. 2020, DOI:10.1149/1945-7111/ab7e90.
Small Structures 2022, DOI:10.1002/sstr.202200323.
ACS Appl. Energy Mater. 2023, DOI:10.1021/acsaem.3c00572.

Separators and Polymer Gel Electrolytes

Adv. Energ. Mater. DOI:10.1002/aenm.202101594. (*high Zn DOD*)
ACS Applied Energy Mater. 2022, DOI:10.1021/acsaem.2c01605.
ACS Appl. Polym. Mater. 2022, 10.1021/acsapm.1c01798.
ACS Appl. Mater & Interface 2020, DOI:10.1021/acsami.0c14143.
J. Power Sources 2018, DOI: 10.1016/j.jpowsour.2018.05.072.
Mater. Horiz. 2022 DOI:10.1039/D2MH00280A. (*high voltage*)
Polymer 2022, DOI: 10.3390/polym140304417.

ASV Analysis of Zn, Cu or Bi in Alkaline conditions

Electroanalysis 2020, DOI: 10.1002/elan.202060412.
Electroanalysis 2017, DOI:10.1002/elan.201700337.
Electroanalysis 2017, DOI:10.1002/elan.201700526.

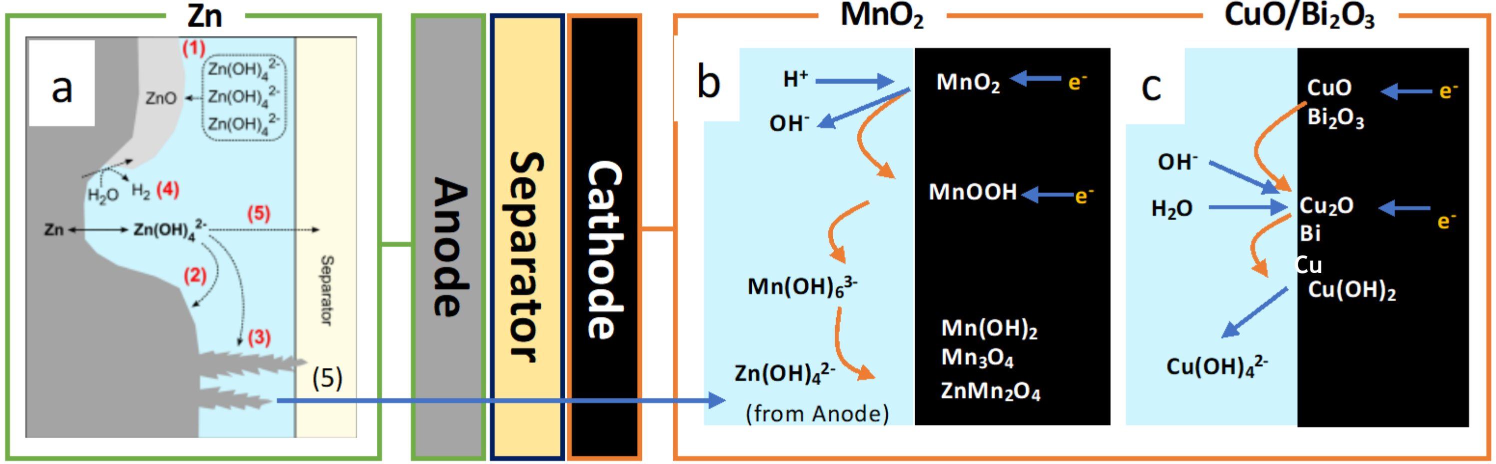
Air Cathodes

ACS Catalysis 2023, DOI:10.1021/acscatal.3c01348.

Select Reviews

Acc. Mater. Res. 2023 DOI:10.1021/accountsmr.2c00221.
J. Electrochem. Soc. 2020, DOI:10.1149/1945-7111/ab9406.
Frontiers in Chemistry 2022. DOI:10.3389/fchem.2021.809535.
MRS Energy Sustain. 2021, DOI:10.1557/s43581-021-00018-4.
Mater. Sci. Eng. R Rep. 2021, DOI:10.1016/j.mser.2020.100593.
DOE Energy Storage Handbook 2021,
https://www.sandia.gov/ess-ssl/eshb/

Schematic for Alkaline Zn Battery



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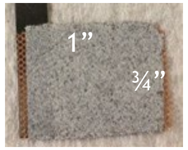
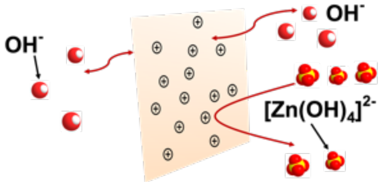
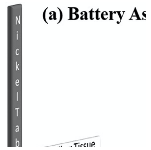
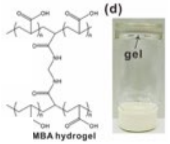


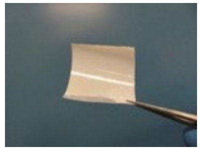


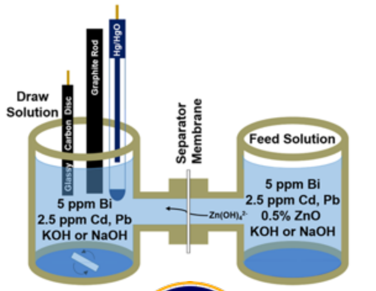


Polymer Gel Electrolyte (PGE)



NC-Celgard





FY 23 PROJECT TEAM – Sandia National Laboratories&Collaborators

OE supports RESEARCH & DEVELOPMENT, MANUFACTURING and DEMONSTRATION of Potentially Wide Impact, Low Cost Energy Storage Technologies

FY 23 Collaborative Efforts on Zn-batteries

Sandia National Laboratories

URBAN ELECTRIC POWER

CUNY The City University of New York
Energy Institute

Northeastern University
Boston, Massachusetts

Industrial R&D
and Deployment

2023 OE Peer Review Team Presentations

Timothy Lambert (SNL):
Progress in Aqueous Zn-based batteries

Gautam Yadav (UEP):
Zinc-Manganese Dioxide Batteries for Long Duration Energy Storage Systems

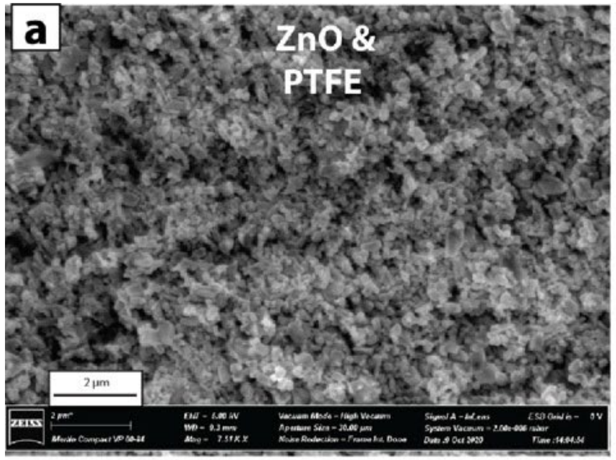
Sanjoy Banerjee (UEP)
Progress with Manufacturing and Deploying Zn-MnO_2 Batteries

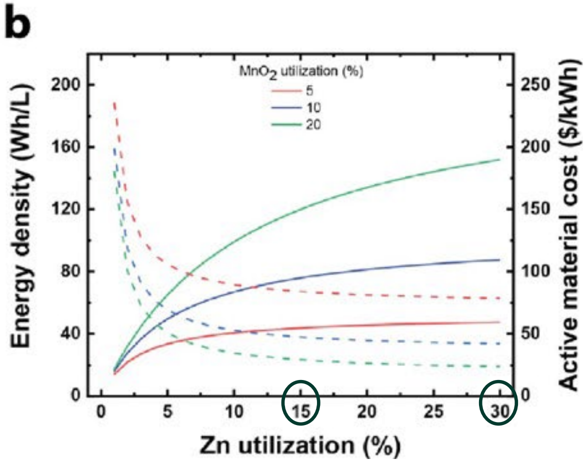
Eight Poster Presentations (5 PIs):
S. Banerjee (CUNY-EI/UEP), A. Frischknecht (SNL), J. Gallaway (NU), T. Lambert (SNL), B. Wygant (SNL)

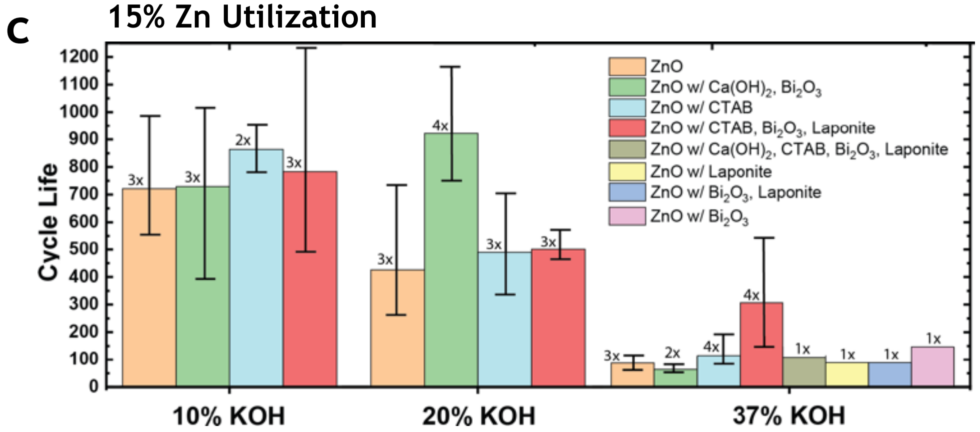
FY 23 Accomplishments:
5 publications (+5 in Preparation), 8 Invited Presentations, 7 Contributed Presentations

FY 23: Zn Anode Highlights

Objective: Evaluate additives/KOH electrolyte to enable high capacity Zn anodes to be realized with low-cost roll to roll pasted electrodes







- Manufacturability: Pasted electrodes compatible with industrial manufacturing: 9.1-14 mAh/cm^2
- Type of Zn: ZnO > Zn (@15 or 30% Zn DOD)
- Cycle Life: 10%, 20% KOH >>37% KOH
- Additives: CTAB, [$Ca(OH)_2$:Bi_2O_3], Laponite
- Bi appears to 'open pores' in the microstructure of the electrode
- In situ XRD = zincate 'capture' upon cycling w/ $Ca(OH)_2$ – less shape change
- Performance comes at the slight cost of volume and weight – *best cumulative Ah/mL and (7x) Ah/g for pasted electrodes*

$$Zn + 4\,OH^- = Zn(OH)_4^{2-} + 2e^-$$

$$Zn(OH)_4^{2-} = ZnO + 2OH^- + H_2O$$

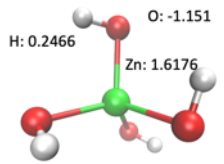
Publication: M. J. D'Ambrose et al. "Performance Advances of Industrial-Design Rechargeable Zinc Alkaline Anodes via Low-Cost Additives" ACS Appl. Energy Mater. 2023, 6, 11, 6091-6103.

Poster: P. Yang et al. "Understanding the Role of Calcium Zincate ($Ca[Zn(OH)_3]_2\cdot 2H_2O$) in Improving Cycle Life and Performance in Rechargeable Alkaline Zinc Batteries" *Manuscript in Preparation: P. Yang et al.*

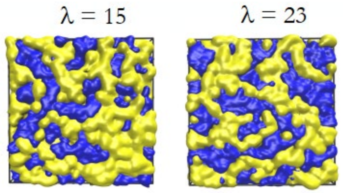
FY 23: Modeling Highlights

Objective: Develop computational models to understand ion transport mechanisms

Zincate

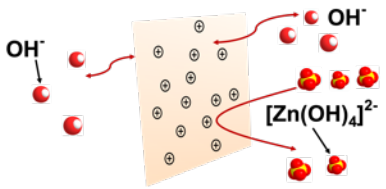


PSU-membranes



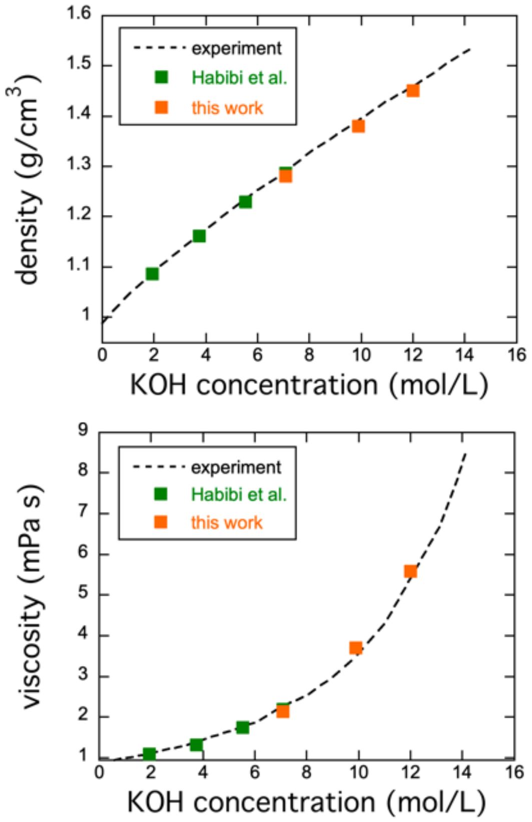
ACS Appl. Mater & Interface DOI:10.1021/acsami.0c14143

Zincate blocking NC-Celgard



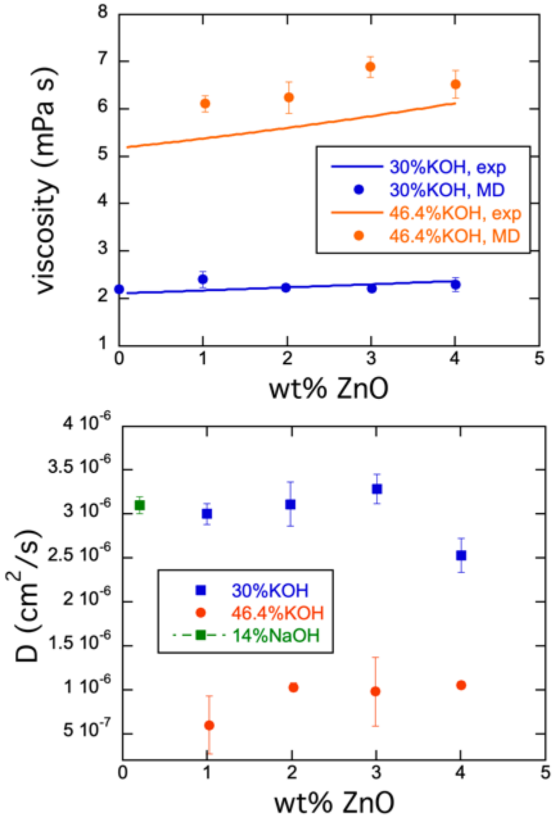
Adv. Energ. Mater. DOI:10.1002/aenm.202101594.

KOH in water



KOH data: Sipos, P. M., Hefter, G. & May, P. M. *J Chem & Eng Data* **2000**, 45, 613-617.

Zincate in KOH

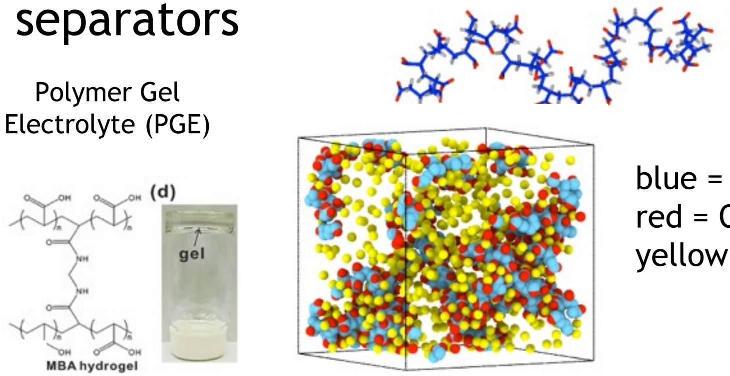


Zincate data: Siu, S. & Evans, J. W. *J Electrochem Soc* **1997**, 144, 1278

Pessine, E. J., Agostinho, S. M. L. & Chagas, H. C. *Canadian J. of Chemistry* **1986**, 64, 523-527.

1) Zinc batteries use high concentration KOH. Showed that MD can capture behavior up to 12M
2) Zincate $[Zn(OH)_4]^{2-}$ forms in zinc batteries. New model agrees with experiment
3) New model enables simulations of zincate/KOH in PGE and separators

Polymer Gel Electrolyte (PGE)



blue = C
red = O
yellow = K^+

4) KOH/Zincate/H_2 in PGE underway

Result: Zincate 1st ever, new computational models could impact whole family of alkaline Zn-batteries

Poster: A. Frischknecht “Enabling simulations of Alkaline electrolytes in Zinc Batteries”

In Preparation: A. Frischknecht et al. “Force Fields for High Concentration Aqueous KOH and Zincate”

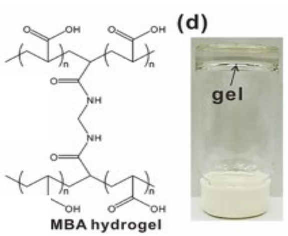
FY 23: Polymer Gel Electrolyte Results

Objective: Develop/understand polymer gel electrolytes for optimized Zn/high-capacity conversion cathode batteries

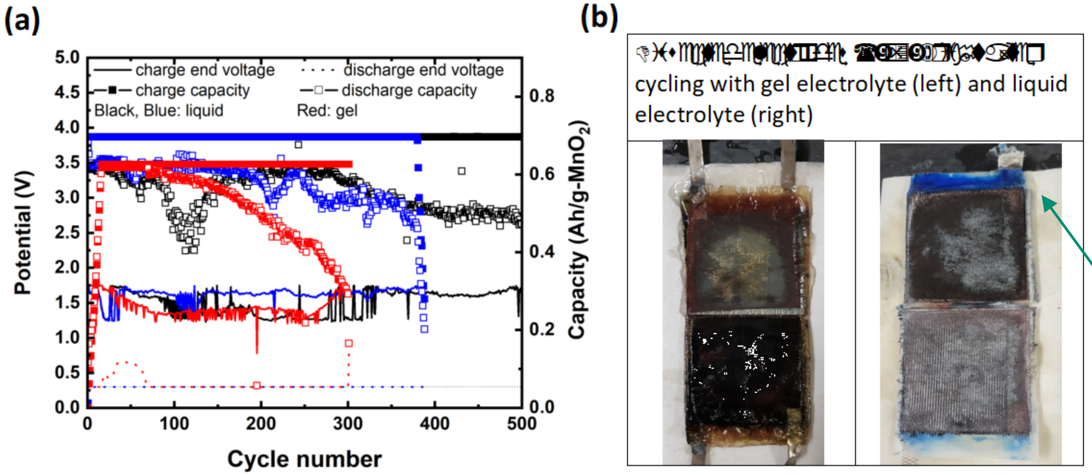
High Capacity Bi,Cu-MnO_2 cathodes requires excess Bi and Copper for long cycle life

Soluble bismuthate [$Bi(OH)_3^-$] and cuprate [$Cu(OH)_4^{2-}$] can lead to capacity loss and shorting (Cu)

Polymer Gel Electrolyte (PGE)



Comparison of liquid versus gel electrolyte

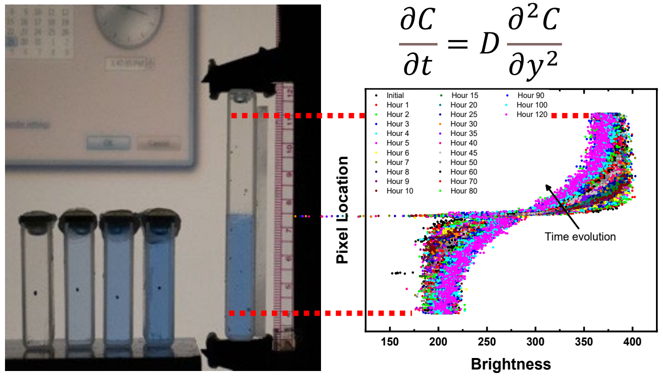


cycling with gel electrolyte (left) and liquid electrolyte (right)

gel liquid

Empirically determine diffusion coefficients

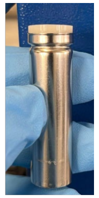
$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial y^2}$$



PGE/$Cu(OH)_x$ reference cells

C: concentration as a function of C(y,t)
D: diffusion coefficient

PGE: J. Cho et al 2022 *Polymers* 14 (3), 417.
2e- Cu,Bi-MnO_2: G. Yadav et al 2017 *Nature Commun.* 8, 14424.



Development of Bobbin-type Cells including w/PGE
Low cost manufacturing.
UEP: Gabe Cowles and Dr. Gautam Yadav

Combining modeling of "ate" species with experimental data should enable improved cells

Poster: J. Cho et al. "Ionic Diffusion in Hydrogel Electrolytes for Two-electron Zn-MnO_2 Batteries"

Manuscript In Preparation: J. Cho et al. "The incorporation of hydrogels into Zn|MnO_2 rechargeable batteries allowing for the transportability and ion diffusion for the 2nd electron reaction of MnO_2"

Development of CuO Cathode (674 mAh/g) – Zn/CuO Batteries

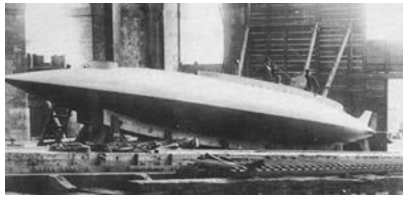
CuO - High Capacity, low voltage primary battery

Anode: $Zn^0 + 4OH^- \rightarrow [Zn(OH_4)]^{2-} + 2e^-$ $E^o = 1.285$ V

Cathode: $CuO + H_2O + 2e^- \rightarrow Cu^0 + 2OH^-$ $E^o = -0.29$ V

$Zn^0 + CuO + H_2O + 2\ OH^- \rightarrow [Zn(OH_4)]^{2-} + Cu^0$ Cell Voltage: 0.995 V

Edison-LaLande Battery.
PAT. Mar. 20, 1883.
OTHER PATENTS APPLIED FOR

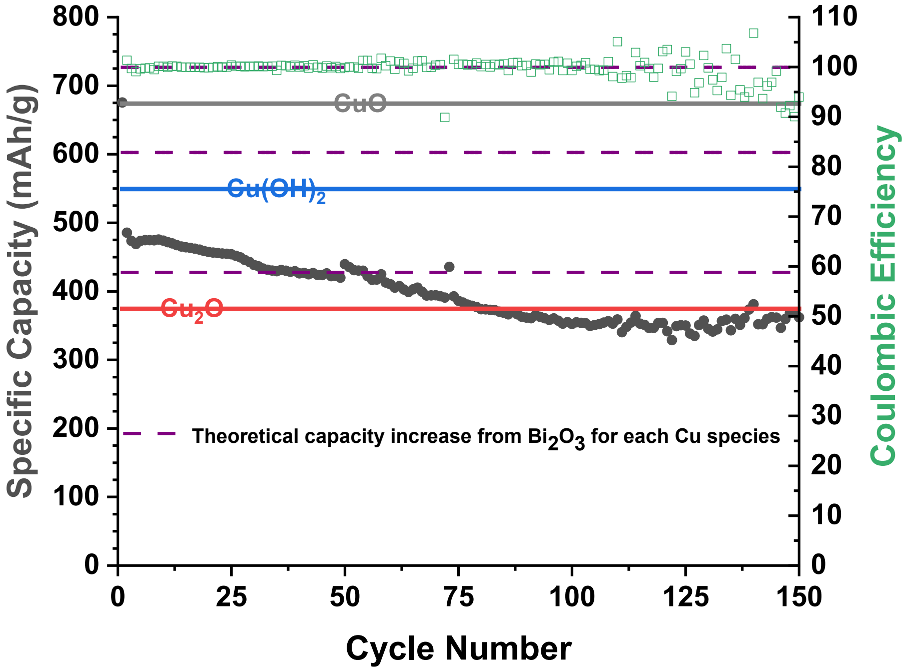


Gymnote in 1889

- 1st electric submarine with torpedoes – 2 x 355 mm (14 in)
- 55 horsepower (41 kW) at 200V and 200A
- 564 Primary Alkaline Zn/CuO Cells (LaLande-Chaperon Patent)

Zn/CuO in use until ~ 1960s

Bi/CuO - High Capacity, moderate voltage secondary battery



N. Schorr et al. *ACS Appl. Energy Mater*. 2021, 4,7,7073-7082.

Average energy densities
157 Wh/L for cycles 2-75
124 Wh/L for cycles 75-150
Limited DOD ~ 140-260 Wh/L

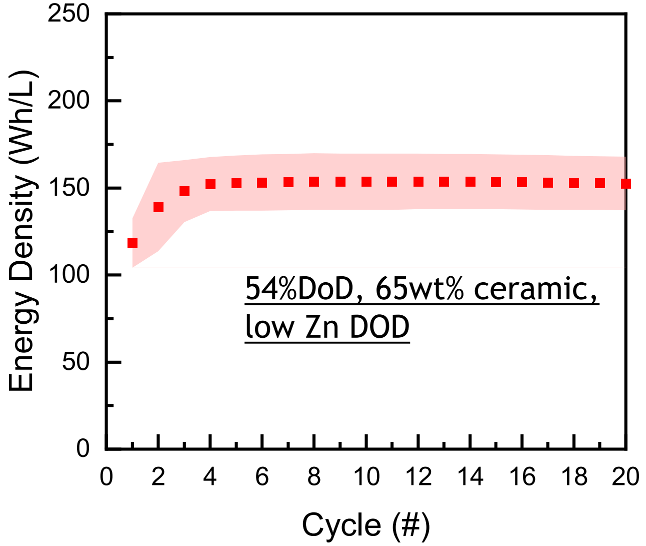
~ 140 years of no reported rechargeable CuO cathode

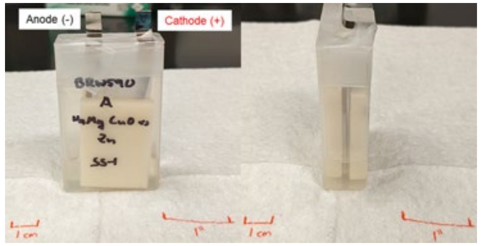
1883 → 2021

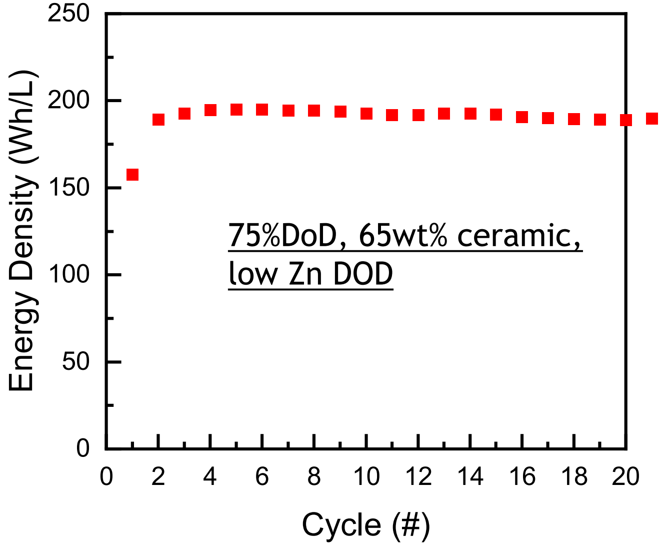
Mixing Bi_2O_3 into the cathode formulation promotes cycle-ability

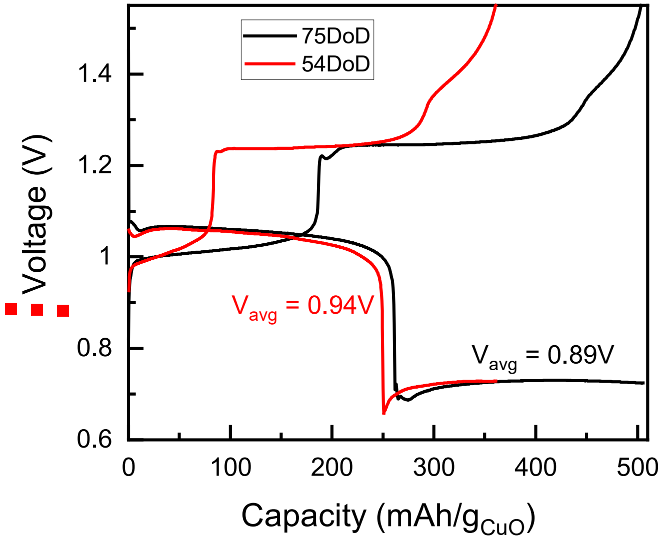
Zn/CuO batteries are the focus of a DOE OTT-TCF Office of Technology Transitions - Technology Commercialization Fund Award

Optimizing Cathode Performance







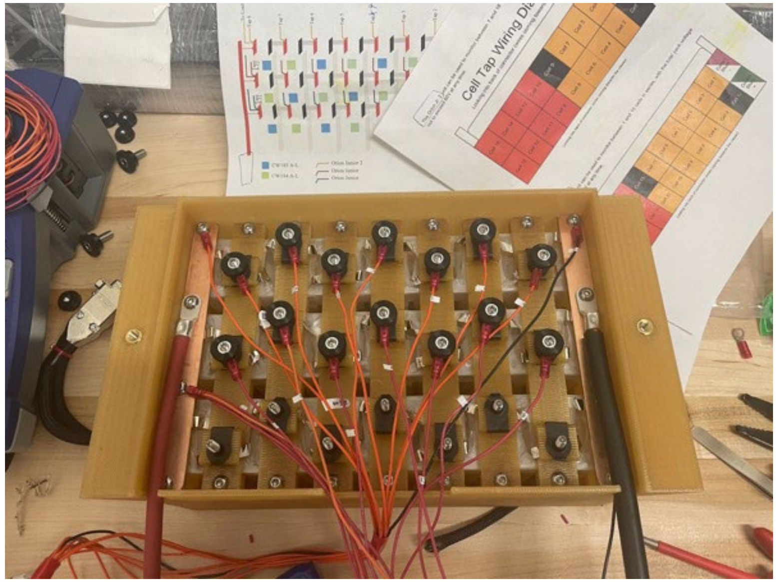


(SNL) Poster: O. Dutta et al. Uses an open-source software-hardware integration platform that is battery agnostic, modular and can operate with any system configuration.

FY 23 results

- **> 200 Ah of CuO electrodes (w/UEP)**
- **Demonstrated ~8V, 2.88Ah Zn/CuO Battery module**
- **Demonstarted power converter compatibility**
- **Target: 200 Wh/L, 100 cycles**

8.2V, 2.88 Ah Zn/CuO Battery Module



V. DeAngelis, J. Mueller, O. Dutta (SNL)

Commercial Partner for: Manufacturing larger Ah, polymer gel electrolyte, higher capacity Zn

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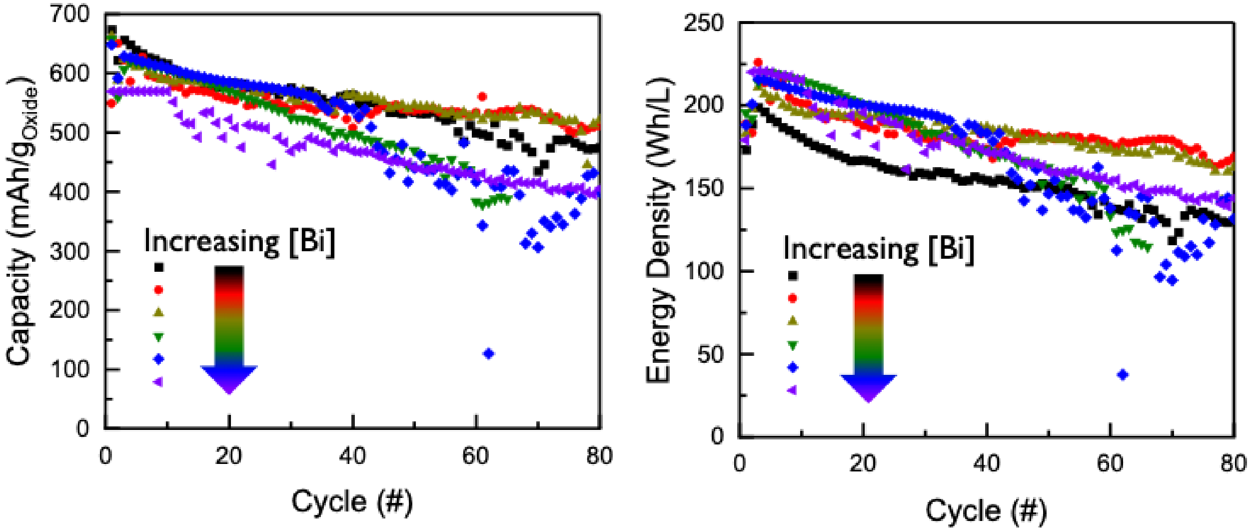
FY 23: Bi, Additives, Electrolytes Highlight

Impact of Bi content



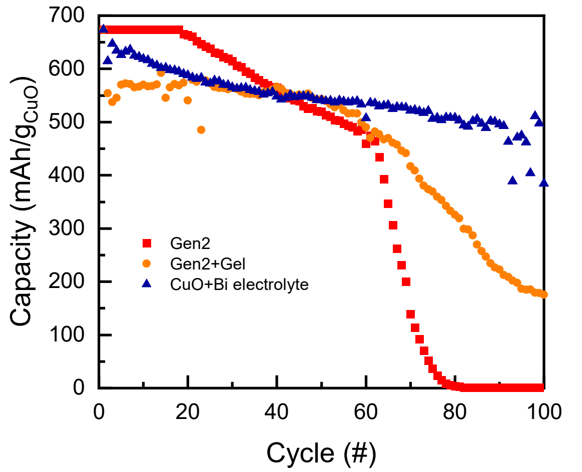
Capacity per total oxide

Energy Density

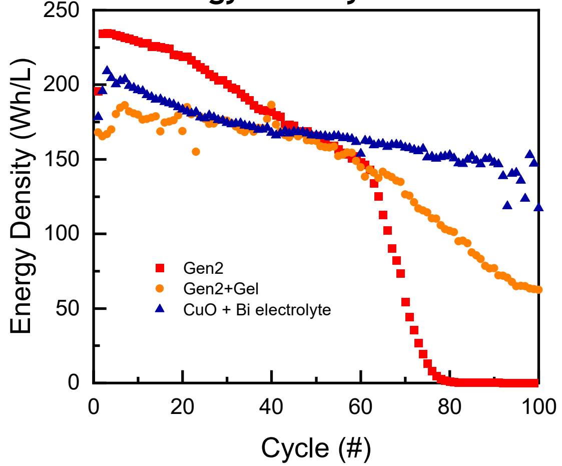
Limited Zn DOD

Impact of Additive/Electrolyte Choice

Capacity Effects



Energy Density Effects

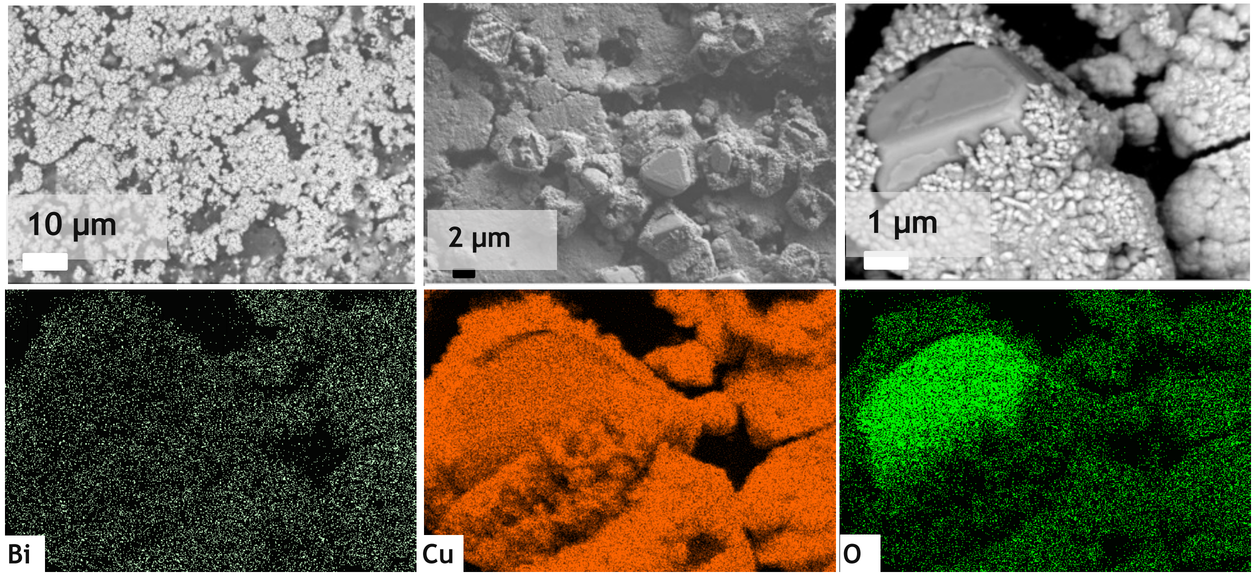


1. Reducing Bi quantity improves energy density while retaining capacity benefits
2. Both soluble and solid Bi play a role in mediating Zn-CuO battery cycling
3. Other additives, the use of coatings, and electrolyte modifications can also impact/improve battery performance
4. Understanding capacity decay and improving battery lifetimes are important next steps

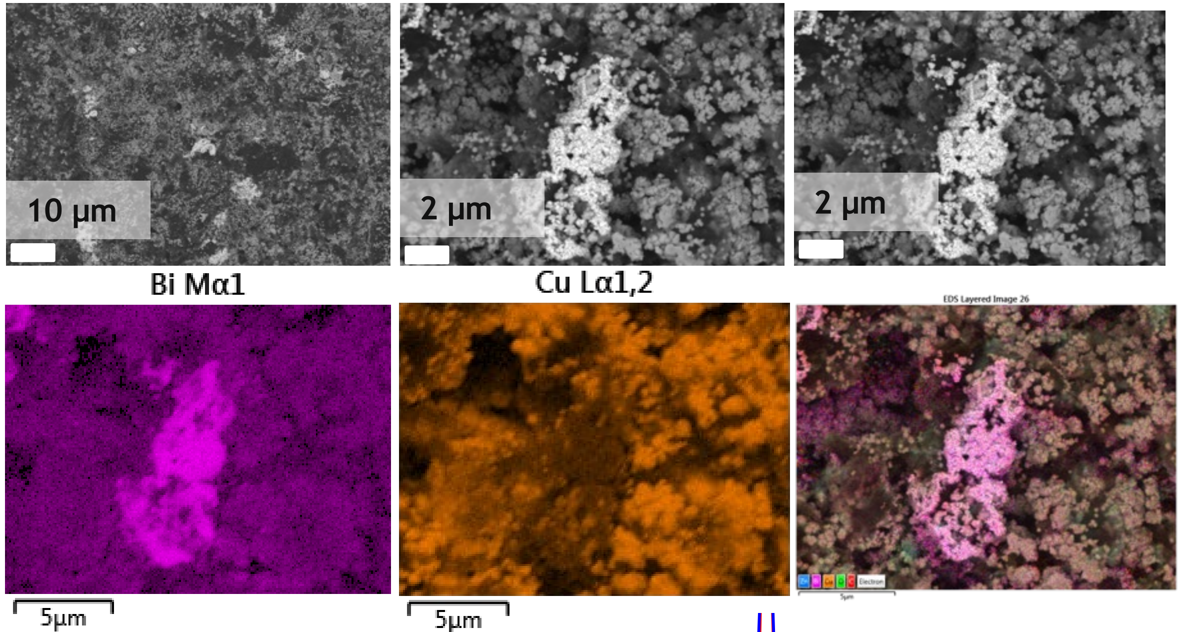
Poster: B. Wygant et al. “Improving Alkaline Zinc-Copper Oxide Batteries through Chemical Modifications”

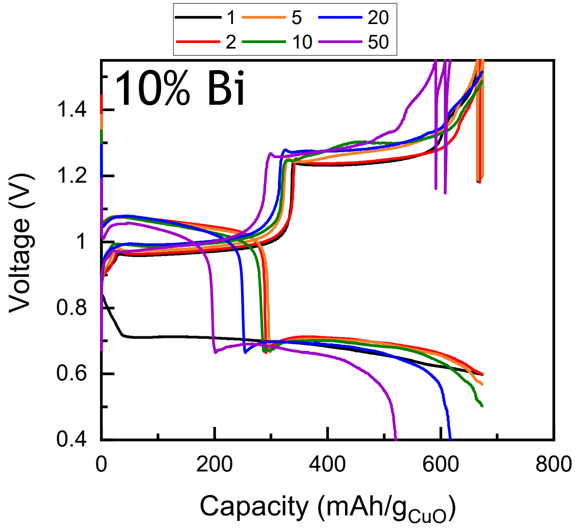
FY 23: Optimizing Cathode Formulations - Highlights

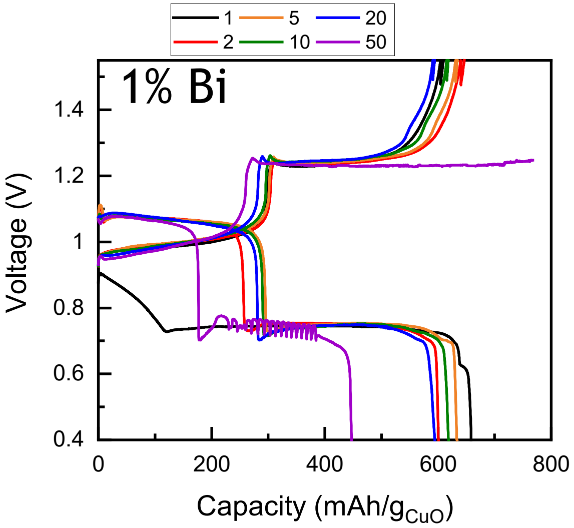
Original CuO/Bi_2O_3 10x Discharge

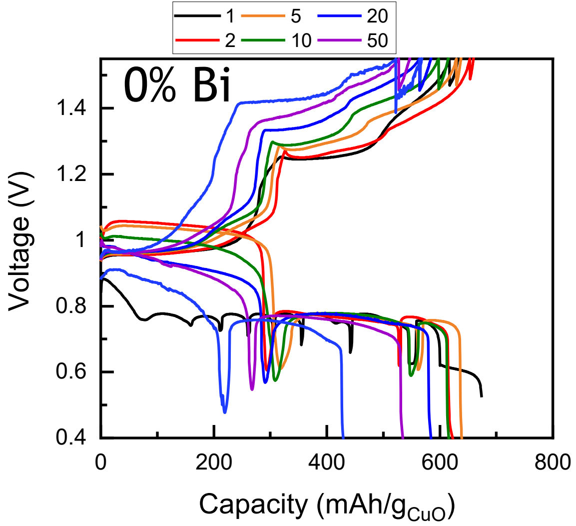


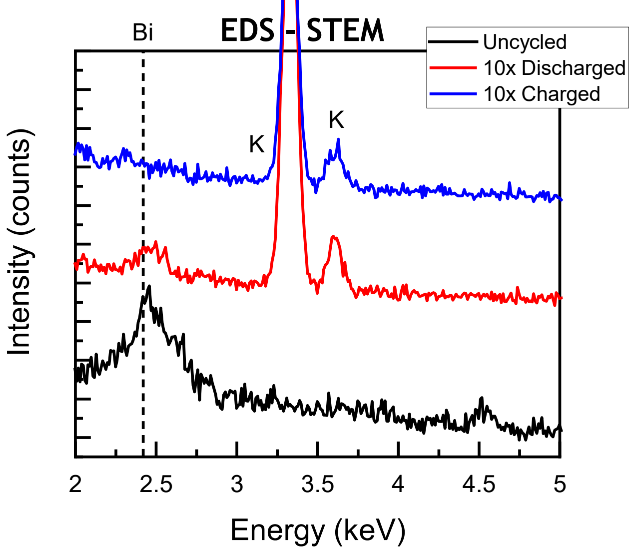
'Improved' CuO/Bi_2O_3 10x Discharge







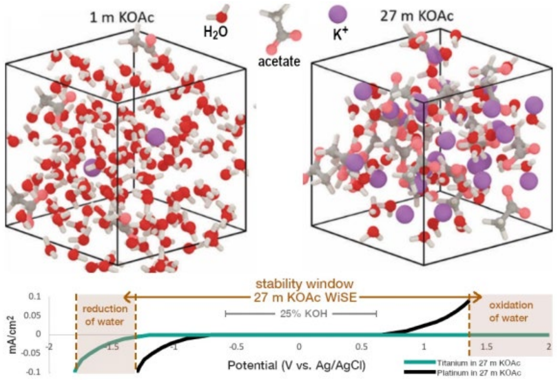




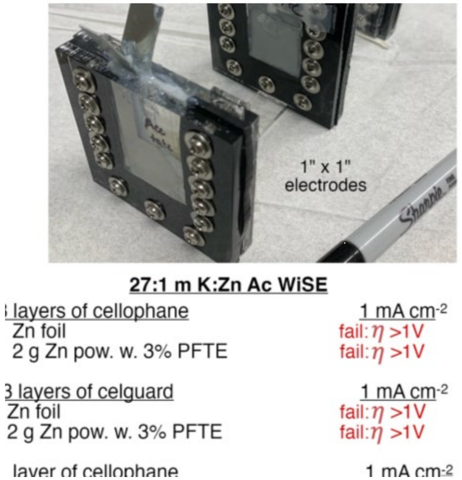
Poster: B. Wygant et al. "Improving Alkaline Zinc-Copper Oxide Batteries through Chemical Modifications"

FY23: Water-in-Salt-Electrolytes for Zn Batteries - Highlights

Water-In-Salt Electrolytes (WiSE)

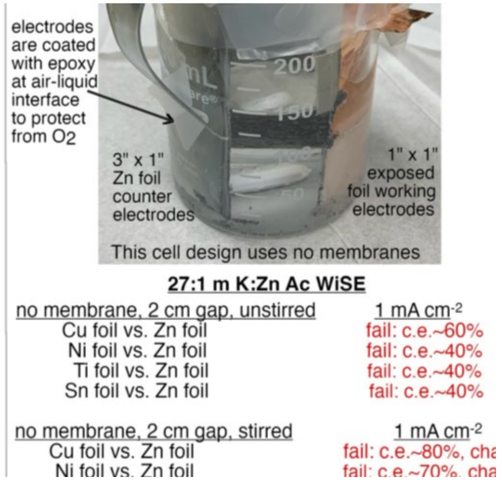


Adapted from: Lukatskaya et al. Energy. Environ. Sci 2018, (11 (10), 2876-2883.



27:1 m K:Zn Ac WiSE

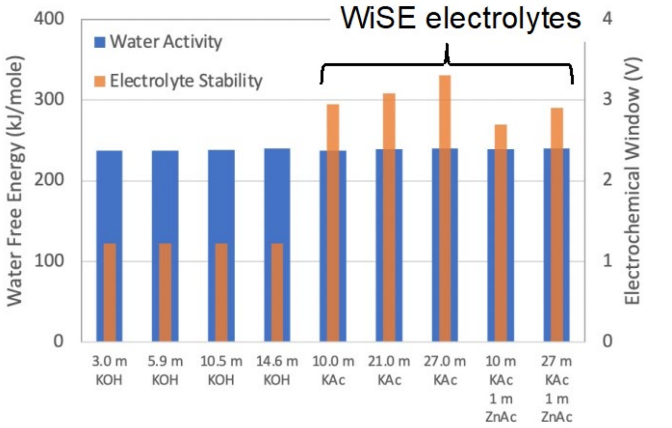
layers of cellophane	1 mA cm-2
Zn foil	fail: η >1V
2 g Zn pow. w. 3% PFTE	fail: η >1V
3 layers of celguard	1 mA cm-2
Zn foil	fail: η >1V
2 g Zn pow. w. 3% PFTE	fail: η >1V
layer of cellophane	1 mA cm-2



This cell design uses no membranes

27:1 m K:Zn Ac WiSE

no membrane, 2 cm gap, unstirred	1 mA cm-2
Cu foil vs. Zn foil	fail: c.e.~60%
Ni foil vs. Zn foil	fail: c.e.~40%
Ti foil vs. Zn foil	fail: c.e.~40%
Sn foil vs. Zn foil	fail: c.e.~40%
no membrane, 2 cm gap, stirred	1 mA cm-2
Cu foil vs. Zn foil	fail: c.e.~80%, cha
Ni foil vs. Zn foil	fail: c.e.~70%, cha



No connection between water activity and WiSE stability

- Voltage Window is improved but not due to H_2O activity (reaction kinetics and SEI layers)
- Zn dendrites are reduced in WiSE
- Lower HER in WiSE than KOH
- Ion mass transfer is too slow for ‘commercially relevant’ cells in WiSE
- Dilution improves mass transfer but at cost of voltage window

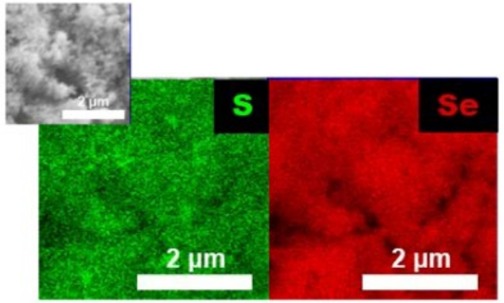
Poster: D. Turney et al. “Practicality and electrochemistry of acetate water-in-salt electrolyte (WiSE) for zinc battery cycling” *Poster:* D. Dutta et al. “Comparing Hydrogen Evolution Rates in Potassium Acetate and Potassium Hydroxide based Electrolytes for Zinc Aqueous Batteries” *Manuscript in prep:* D. Turney et al.

FY 23: Zn/air – New Electrocatalysts (SNL LDRD/CINT/OE funding)

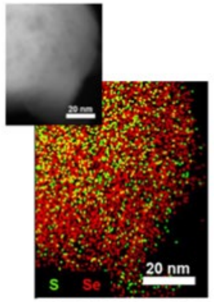
Objective: Demonstrate Bi-directional Oxygen electrocatalysis with Nickel sulfo-selenides and determine optimum formulation

Synthesis of NiS_xSe_y

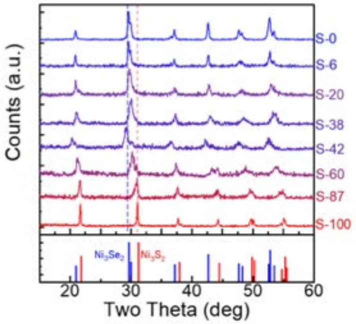
- Hydrothermal reaction to produce series of $Ni_3S_{2-x}Se_x$ (NiSSe) powders



SEM/EDX



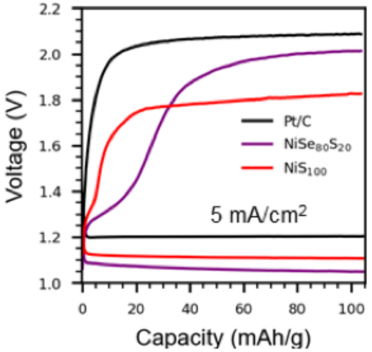
STEM/EDX

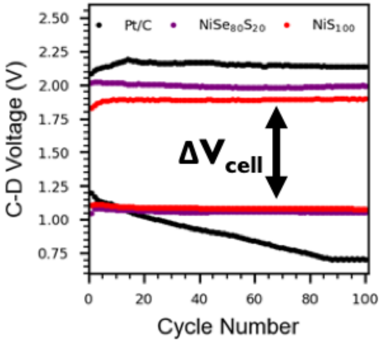


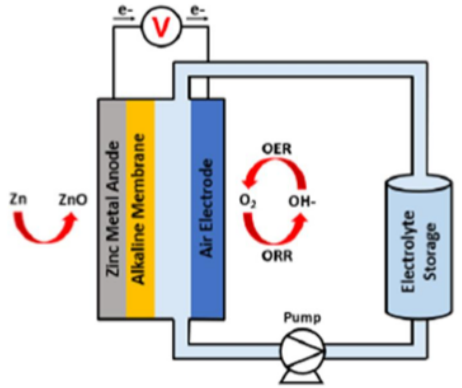
- Characterization shows that the materials show a transition from Ni_3S_2 to Ni_3Se_2, but that the S/Se in the material is evenly distributed within discreet particles

Zn/air demonstration with NiS_xSe_y

- Testing in a flow Zn-air battery shows improved BOE performance for NiSSe compared to commercial Pt/C







w/ T. Zawodzinski (ORNL)

1. Hydrothermal synthesis is a simple, tunable method for producing mixed metal chalcogenides
2. Electrocatalytic performance of NiSSe materials is promising, and suggests that Se-rich materials may be suitable BOEs for Zn-air batteries
3. Exploration of more earth-abundant metals (e.g., Fe, Mn) will help further improve costs for developing and building Zn-air batteries

New FY 24 OE Effort in Zn-air started

Publication: B. R. Wygant et al. "The Effects of Compositional Tuning on the Bifunctional Oxygen Electrocatalytic Behavior of Nickel Sulfoselenides" ACS Catalysis 2023 13, 13, 9245-9253.

Poster: B. Wygant et al. "Transition Metal Multi-chalcogenides as Bifunctional Oxygen Electrodes for Zinc-air Batteries"

PROJECT TEAM - RESULTS

8 Posters

RESULTS: Zn Project Battery Posters - DOE OE Energy Storage Virtual Peer Review 2023

OE Peer Review 2023 Posters:

1. A. Frischknecht “Enabling Simulations of Alkaline Electrolytes in Zinc Batteries”
2. D. Dutya et al. “Comparing Hydrogen Evolution Rates in Potassium Acetate and Potassium Hydroxide based Electrolytes for Zinc Aqueous Batteries”
3. J. Cho et al. “Ionic Diffusion in Hydrogel Electrolytes for Two-electron Zn-MnO_2 Batteries”
4. D. Turney et al. “Practicality and electrochemistry of acetate water-in-salt electrolyte (WiSE) for zinc battery cycling”
5. P. Yang et al. “Understanding the Role of Calcium Zincate ($Ca[Zn(OH)_3]_2 \cdot 2H_2O$) in Improving Cycle Life and Performance in Rechargeable Alkaline Zinc Batteries”
6. B. Wygant et al. “Improving Alkaline Zinc-Copper Oxide Batteries through Chemical Modifications”
7. B. Wygant et al. “Transition Metal Multi-chalcogenides as Bifunctional Oxygen Electrodes for Zinc-air Batteries”
8. Erik K. Zimmerer “Spectroscopic Characterization of Rechargeable Alkaline Batteries for the Grid”

PROJECT - RESULTS

5 Publications w/5 in preparation

RESULTS: Zn Project Battery Publications - DOE OE Energy Storage Virtual Peer Review 2023

Publications:

1. C. Zhu, N. B. Schorr, Z. Qi, B. R. Wygant, D. E. Turney, G. G. Yadav, M. A. Worsley, E. B. Duoss, S. Banerjee, E. D. Spoerke, A. van Buuren, T. N. Lambert "Direct Ink Writing Of 3D Zn Structures as High Capacity Anodes For Rechargeable Alkaline Batteries" Small Structures 2022, 4, 4, 2200323.
2. *Invited Review:* M. Vind, N. B. Schorr, B. Sambandam, S. Kim, S. Lee, T. N. Lambert, J. Kim "A Critical Comparison of Mildly Acidic versus Alkaline Zinc Batteries" Acc. Mater. Res. 2023 4, 4, 299-306.
3. M. J. D'Ambrose, D. E. Turney, M. N. Nyce, T. N. Lambert, S. Banerjee, G. G. Yadav "Performance Advances of Industrial-Design Rechargeable Zinc Alkaline Anodes via Low-Cost Additives" ACS Appl. Energy Mater. 2023, 6, 11, 6091-6103.
4. M. A. Kim, E. K. Zimmerer, Z. T. Piontkowski, M. A. Rodriguez, N. B. Schorr, B. R. Wygant, J. S. Okasinski, A. C. Chuang, T. N. Lambert, J. W. Gallaway "Li-ion and Na-ion intercalation in layered MnO_2 cathodes enabled by using bismuth as a cation pillar" J. Mater. Chem. 2023 11, 11272-11287.
5. B. R. Wygant, B. A. Washington, C. N. Wright, G. A. Goenaga-Jiménez, T. A. Zawodzinski, T. N. Lambert "The Effects of Compositional Tuning on the Bifunctional Oxygen Electrocatalytic Behavior of Nickel Sulfoselenides" ACS Catalysis 2023 13, 13, 9245-9253. 10.1021/acscatal.3c01348.

Five additional manuscripts in preparation

PROJECT - RESULTS

8 Invited Presentations

RESULTS: Zn Project Battery Presentations - DOE OE Energy Storage Virtual Peer Review 2023

Invited Presentations:

1. A. L. Frischknecht, “Using Molecular Dynamics Simulations to Relate Morphology to Water and Ion Dynamics in Hydrated Polymers,” 243rd Electrochemical Society (ECS) Meeting, Boston, MA, May 29, 2023.
2. A. L. Frischknecht, “Insights into Hydrated Ion-Conducting Polymers from Molecular Dynamics Simulations,” Complex Fluids Design Consortium Annual Meeting, University of California, Santa Barbara, January 27, 2023.
3. A. L. Frischknecht, “Insights into Hydrated Ion-Conducting Polymers from MD Simulations,” Departmental Seminar, Chemical Engineering Department, University of New Mexico, Albuquerque, NM, October 26, 2022.
4. A. L. Frischknecht, “Insights into Hydrated Ion-Conducting Polymers from MD Simulations,” Departmental Seminar, Chemical and Biological Engineering Department, Princeton University, Princeton, NJ, October 5, 2022.
5. T. N. Lambert, B. R. Wygant, C. Wright, J. Gallaway, A. Stavola, E. Zimmerer, V. DeAngelis, J. Mueller, O. Dutta, I. Vasiliev, K. Acharya, N. Paudel, B. A. Magar, G. G. Yadav, G. Cowles, S. Banerjee “Energy Dense Rechargeable Cu-based Cathodes for Alkaline Zn/Cu Batteries” ACS Fall 2022, San Francisco, CA, August 13-17, 2023.
6. T. N. Lambert, B. R. Wygant, C. Wright, J. Gallaway, A. Stavola, E. Zimmerer, V. DeAngelis, J. Mueller, O. Dutta, I. Vasiliev, K. Acharya, N. Paudel, B. A. Magar “Progress Towards the Development and Understanding of Energy Dense Rechargeable Batteries Utilizing Zn and Cu” 243rd ECS Meeting, Boston, MA, May 28-June 2, 2023.
7. S. Banerjee “Development of Commercial-Scale High Energy Density Aqueous Zinc Manganese Dioxide Alkaline Batteries for Long Duration Storage” 243rd ECS Meeting, Boston, MA, May 28-June 2, 2023.
8. S. Banerjee “Development of Rechargeable Zinc Manganese Dioxide Batteries From Concept through Product to Market”

PROJECT - RESULTS

7 Contributed Presentations

RESULTS: Zn Project Battery Presentations - DOE OE Energy Storage Virtual Peer Review 2023

Contributed Presentations:

1. T. N. Lambert, B. R. Wygant, C. Wright, J. Gallaway, A. Stavola, E. Zimmerer, V. DeAngelis, J. Mueller, O. Dutta, I. Vasiliev, K. Acharya, N. Paudel, B. A. Magar, G. G. Yadav, G. Cowles, S. Banerjee “The Development of Energy Dense Rechargeable Zn/CuO Batteries” 3rd International Zinc-air and other Zinc batteries workshop (IZABW), Ulm, Germany, September 18-19, 2023.
2. T. N. Lambert, B. R. Wygant, C. Wright, J. Gallaway, A. Stavola, E. Zimmerer, V. DeAngelis, J. Mueller, O. Dutta, I. Vasiliev, K. Acharya, N. Paudel, B. A. Magar “Progress Towards the Development and Understanding of Energy Dense Rechargeable Batteries Utilizing Zn and Cu” TechConnect World Innovation Conference and Exposition” Washington, DC, June 19-21, 2023.
3. B.R. Wygant, C. N. Wright, B. A. Washington, G. A. Goenaga-Jiménez, T. A. Zawodzinski, T. N. Lambert “Compositional Tuning of Nickel Sulfoselenides for Use as Bifunctional Oxygen Electrocatalysts in Aqueous Electrochemical Energy Storage” 243rd Electrochemical Society (ECS) Meeting, Boston, MA, May 28 – June 2, 2023.
4. P. Yang, D. E. Turney, T. N. Lambert, S. O’Brien and S. Banerjee “Studying the Addition of Metallic Zinc (Zn) to Rechargeable Alkaline Calcium Zincate (CaZn2(OH)6·2H2O) Anodes” AIChE 4th Battery and Energy Storage Conference, The City College of New York, New York City, United States, October 26-28, 2022.
5. J. Cho P. Yang, D. E. Turney, G. G. Yadav, M. Nyce, T. N. Lambert and S. Banerjee “Understanding of ion diffusion for non-spillable Zn|MnO2 rechargeable batteries allowing for 2nd electron MnO_2 cycling in hydrogel electrolytes” AIChE 4th Battery and Energy Storage Conference, The City College of New York, New York City, United States, October 26-28, 2022.
6. D. Dutta, D. E. Turney, R. Messinger, T. N. Lambert and S. Banerjee “Koutecky-Levich Study of the Hydrogen Evolution Reaction on a Zinc Rotating Disk Electrode in Traditional Alkaline and Acetate-Based Water-in-Salt (WiSE) Electrolytes” AIChE 4th Battery and Energy Storage Conference, The City College of New York, New York City, United States, October 26-28, 2022.
7. J.W. Gallaway, M.A. Kim, E.K. Zimmerer, T.N. Lambert, and N.B. Schorr "Li-Ion and Na-Ion Intercalation in Layered MnO2 Cathodes Enabled by Using Bismuth as a Cation Pillar" Symposium A03: Large Scale Energy Storage 14, The Electrochemical Society 243rd Meeting, Boston MA, May 2023.

PROJECT CONTACTS


Tim Lambert

Timothy N. Lambert
tnlambe@sandia.gov


Ray Byrne

Ray Byrne
rhbyrne@sandia.gov

FY 21 Sandia Team


Bryan Wygant


Rachel Habing


Ciara Wright


Nelson Bell


Erik Spoerke

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Sandia National Laboratories

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Laboratory Directed Research and Development


Imre Gyuk

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