Advanced Intermediate Temperature Na-$FeCl_2$ Batteries

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Energy Storage Program

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Project Overview

- **Batteries consisting of *molten sodium anode* and *β"-Al_2O_3 solid electrolyte* (BASE)**
  - Use of low-cost, abundant sodium
  - High specific energy density (120~240 Wh/kg)
  - Good specific power (150-230 W/kg)
  - Good candidate as a large-scale energy storage device for renewable energy
  - Operated at relatively high temperature (300~350°C)
- **Sodium-nickel chloride battery**
  - $2Na + NiCl_2$ (charged) → $2NaCl + Ni$ (discharged)
    - E = 2.58 V at 300°C
    - Use of catholyte ($NaAlCl_4$)
  - **Merits**
    - Safer cell failure mode
    - Easiness of assembly in discharged state
    - Less corrosive nature of cathode materials
- **Energy Storage Challenge**
  - Na-metal based battery systems have been demonstrated as a viable technology for stationary energy storage, however, challenges with operational lifetime and manufacturing costs limit wider scale deployment.

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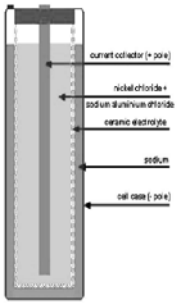
Project Overview

❑Project Objective

Develop lower temperature (< 200°C) chemistries and cell architecture that enable lower cost systems and improved manufacturing.

Tubular type



Planar type

	Tubular (Conventional)	IT Planar
Energy capacity	√	√
Power		√
β" Solid Electrolyte (BASE)	High cost	Low cost
Temperature	≥300˚C	≤200˚C
Packaging	Difficult	Easy

❑Accomplishments

- Demonstrated > 100°C decrease in battery operating temperature with improved durability
- Reduced operating temperature enabling use of polymer seals replacing expensive glass seals and thermal compression bonding.
- New sintering process for β″-alumina electrolyte
- **Fe based chemistry to replace Ni and reduce baseline costs**.
- 15 publications, 6 patents/applications (to date)

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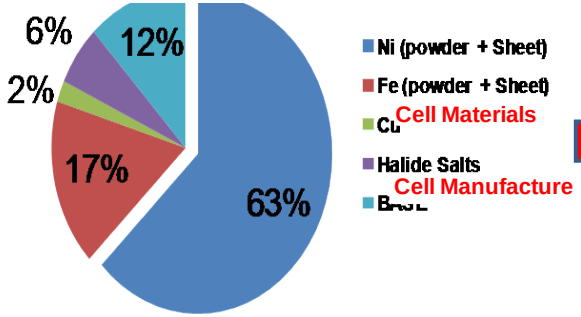
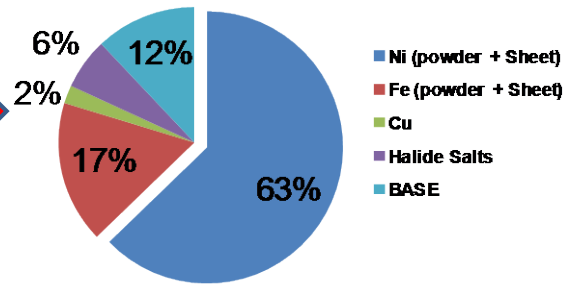
Materials Cost Analysis (Ni vs Fe Cathode)

Battery cost breakdown



Cell material cost



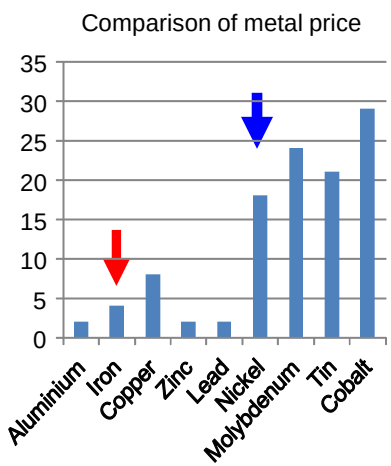
* R.C. Galloway, C.-H. Dustmann, "ZEBRA Battery - Material Cost, Availability and Recycling", MES-DEA GmbH, EVS 20, 2003.

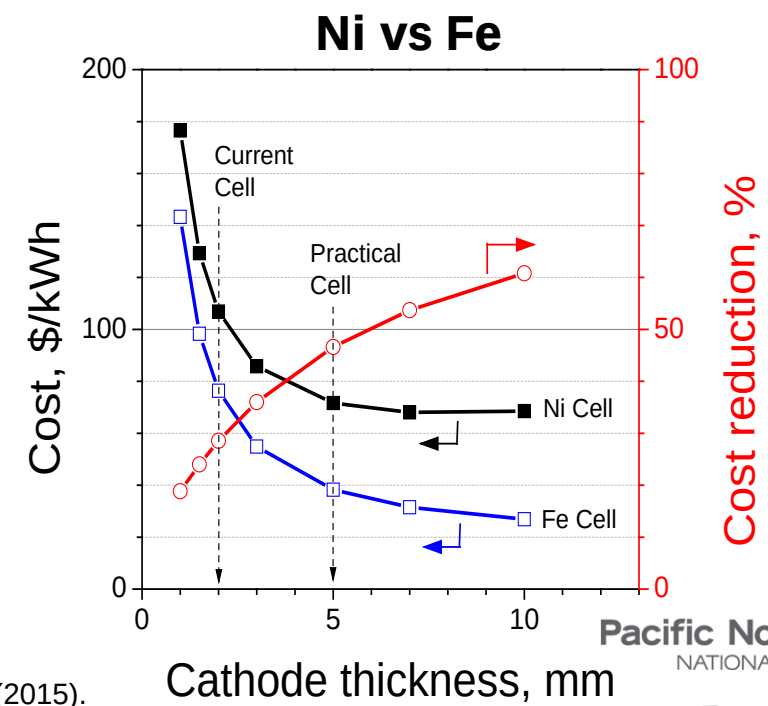
World production and reserves

	2005 World Production	World Reserves[a]
Aluminum	31,900,000	Large
Iron	1.38E+09	7.2E+10
Copper	15,000,000	430,000,000
Zinc	10,000,000	200,000,000
Lead	3,300,000	61,000,000
Nickel	1,400,000	56,000,000
Molybdenum	180,000	7,800,000
Tin	300,000	5,500,000

Unit:MT

[a]Based on the proven and probable portion of the world reserves.





Li et al. *Adv. Energy Mater.*, 5, 1500357 (2015).

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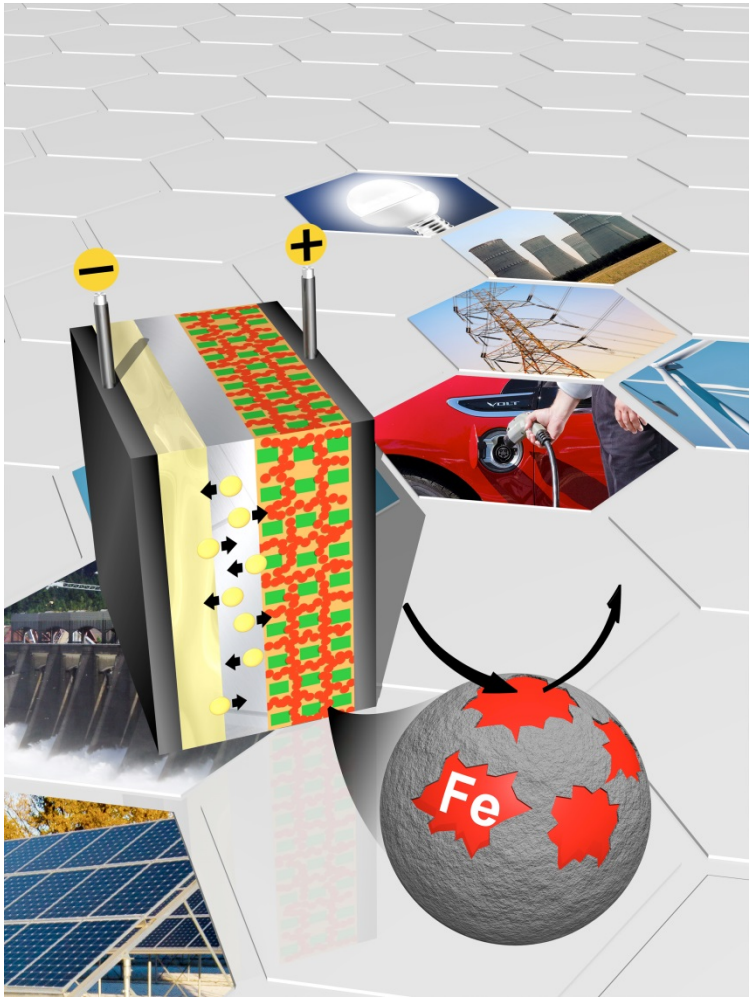
Na-$FeCl_2$ Batteries



Li et al. ***Adv. Energy Mater.***, 5, 1500357 (2015).
Highlighted on the cover page

Battery Redox Reaction:

$$2Na + FeCl_2 \Leftrightarrow 2NaCl + Fe$$

(Charge) $\Leftrightarrow$ (Discharge)

2.38 V at 190°C

Challenge:

- Na-$FeCl_2$ battery assembled in the discharge state (NaCl + Fe) ***can't be charged*** due to the surface oxide layers on Fe particles.
- Needs to be ***reduced*** in hydrogen gas environment (discharge state) or ***chlorinated*** under chlorine gas environment (charged state)

Solution:

- Adding ***sulfur based additives*** to remove oxide layers during battery initial cycles.

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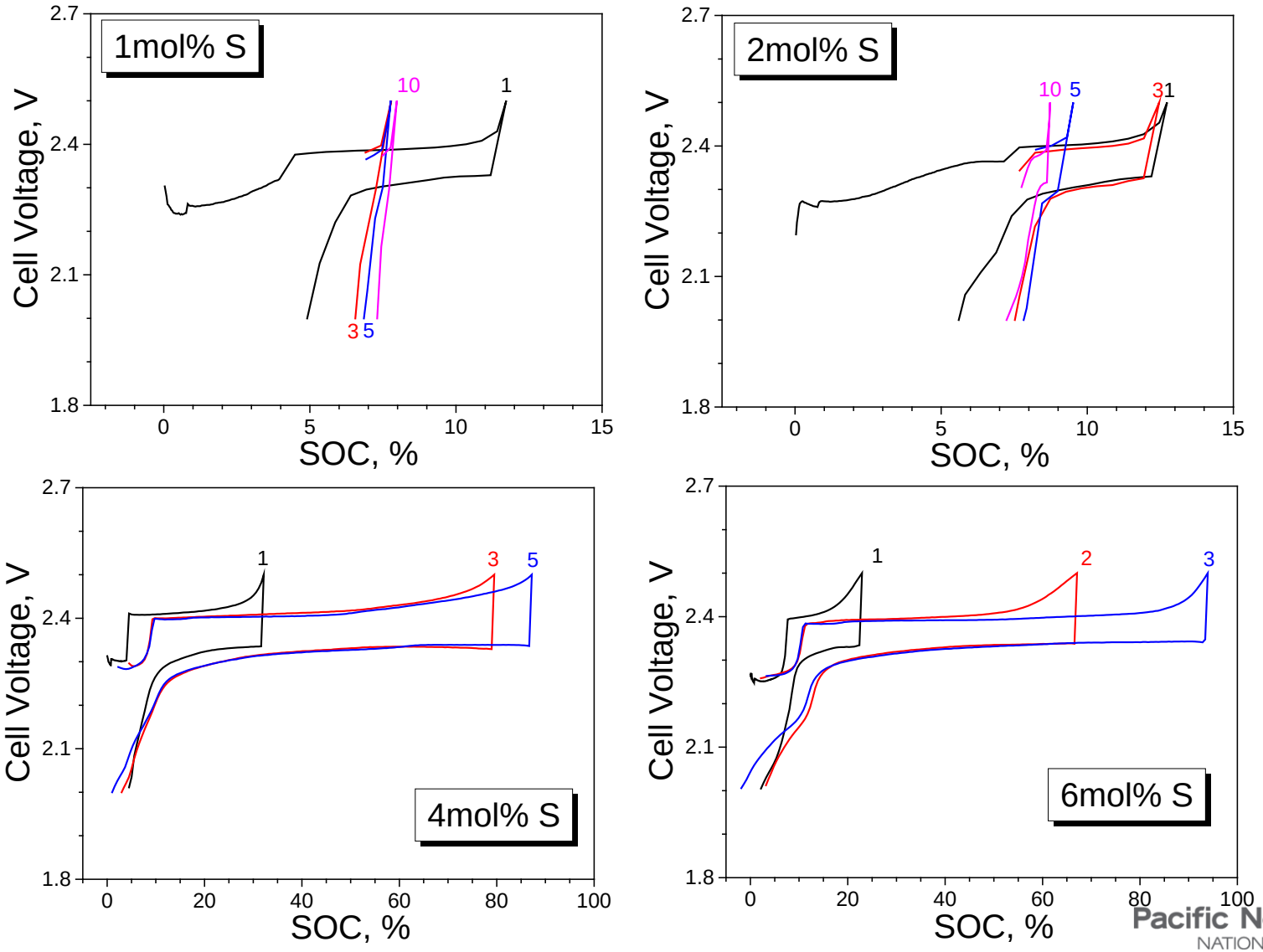
Sulfur as Fe Cathode Additive



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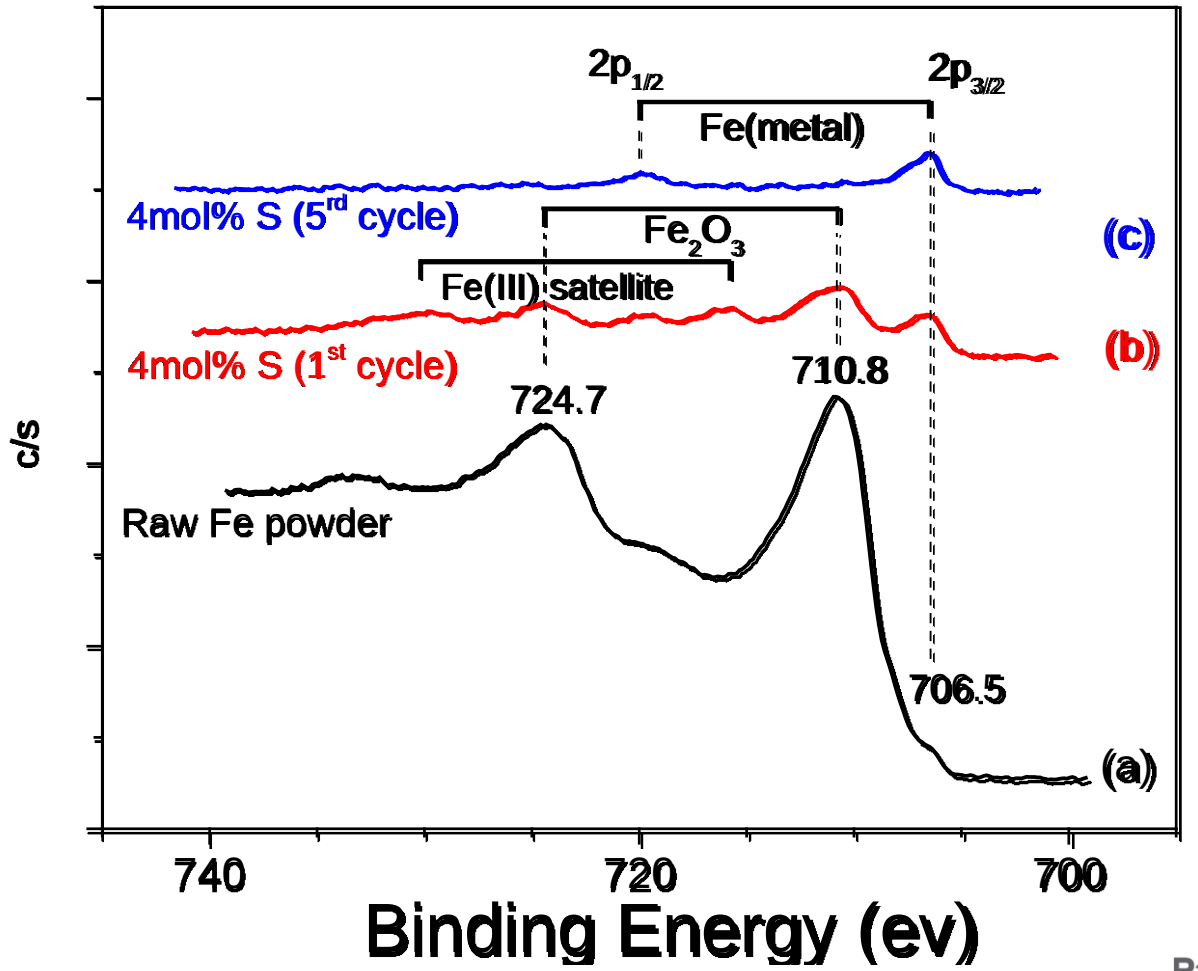
Roles of Sulfur in Fe Cathode

XPS Analysis



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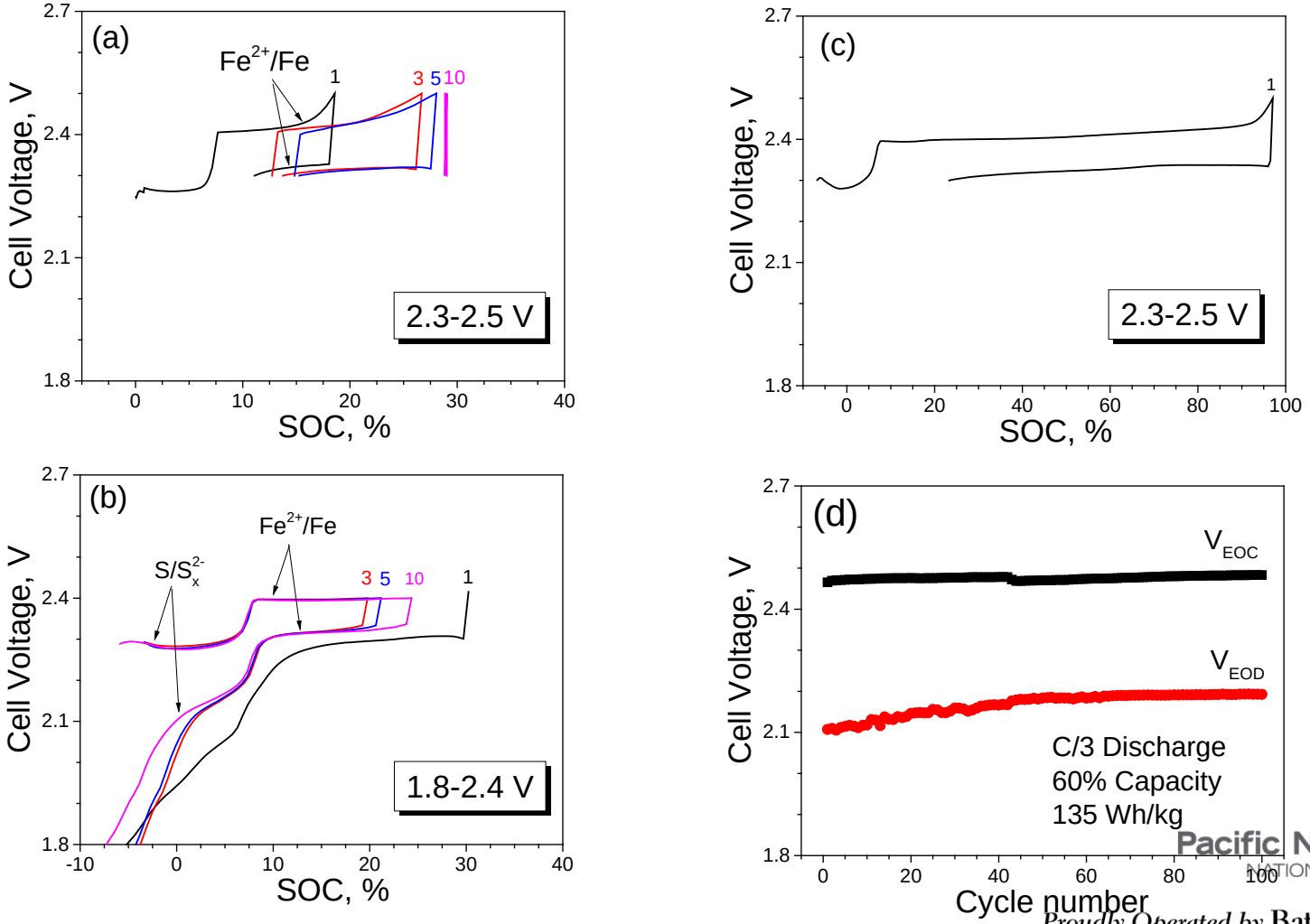
Investigation of Sulfur Additive

Sequential Experiments with 6 mol% S

(a) ⇒ (b) ⇒ (c) ⇒ (d)



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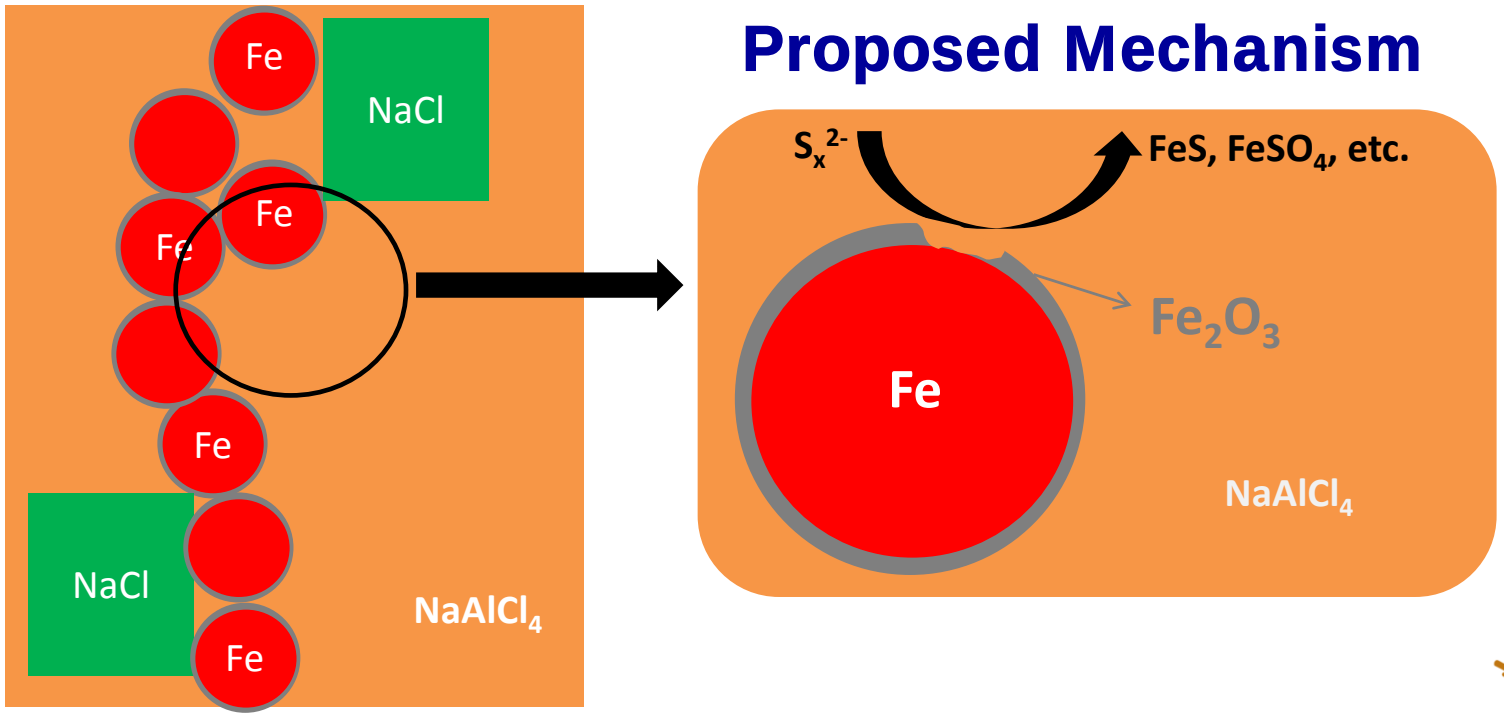
Proposed Activation Mechanism of Fe Cathode

$$E = 1.78 – 2.08\ V$$

$$2Na + xS \Rightarrow Na_2S_x \quad (x>2)\ \text{Discharge}$$



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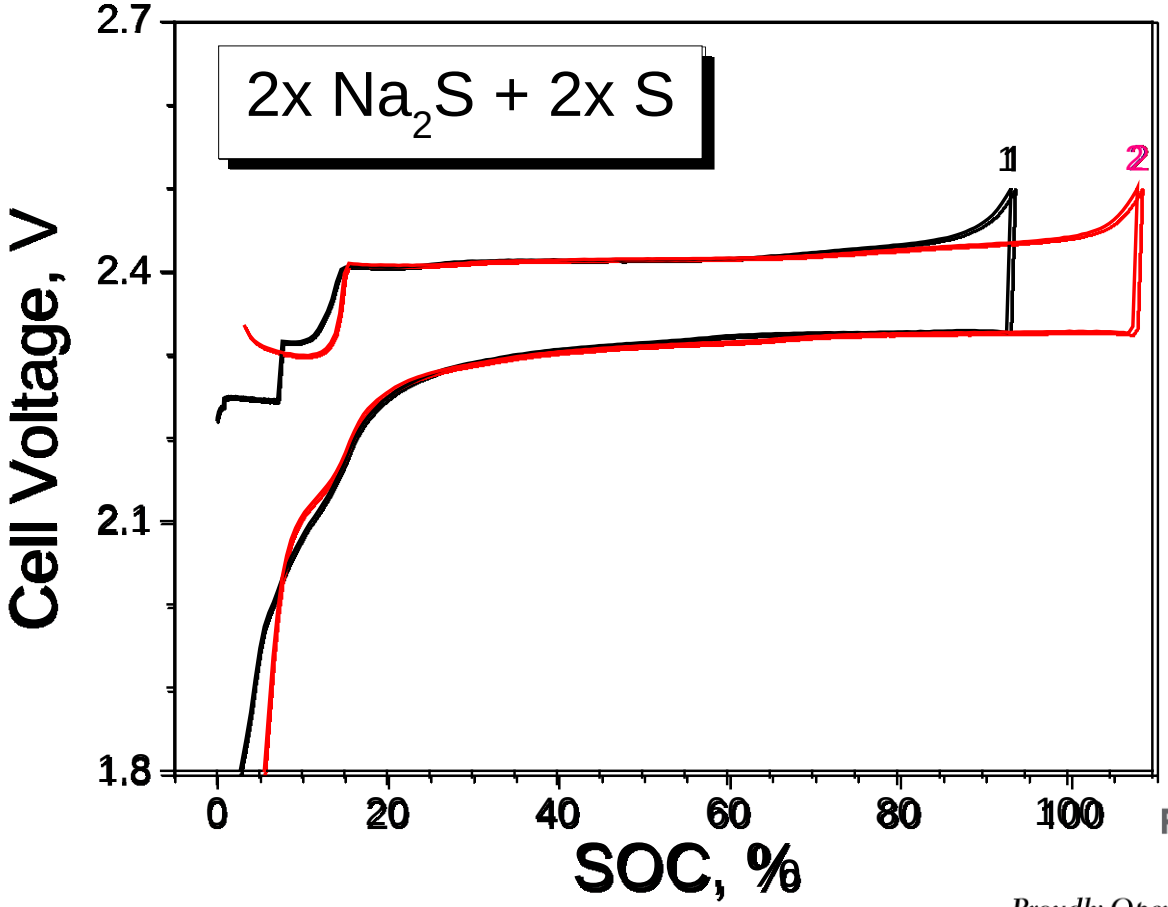
Investigation of Polysulfide for Fe Cathode

Formation of polysulfides:

$Na_2S + (x-1)\ S \rightarrow Na_2S_x,\ X \geq 2$



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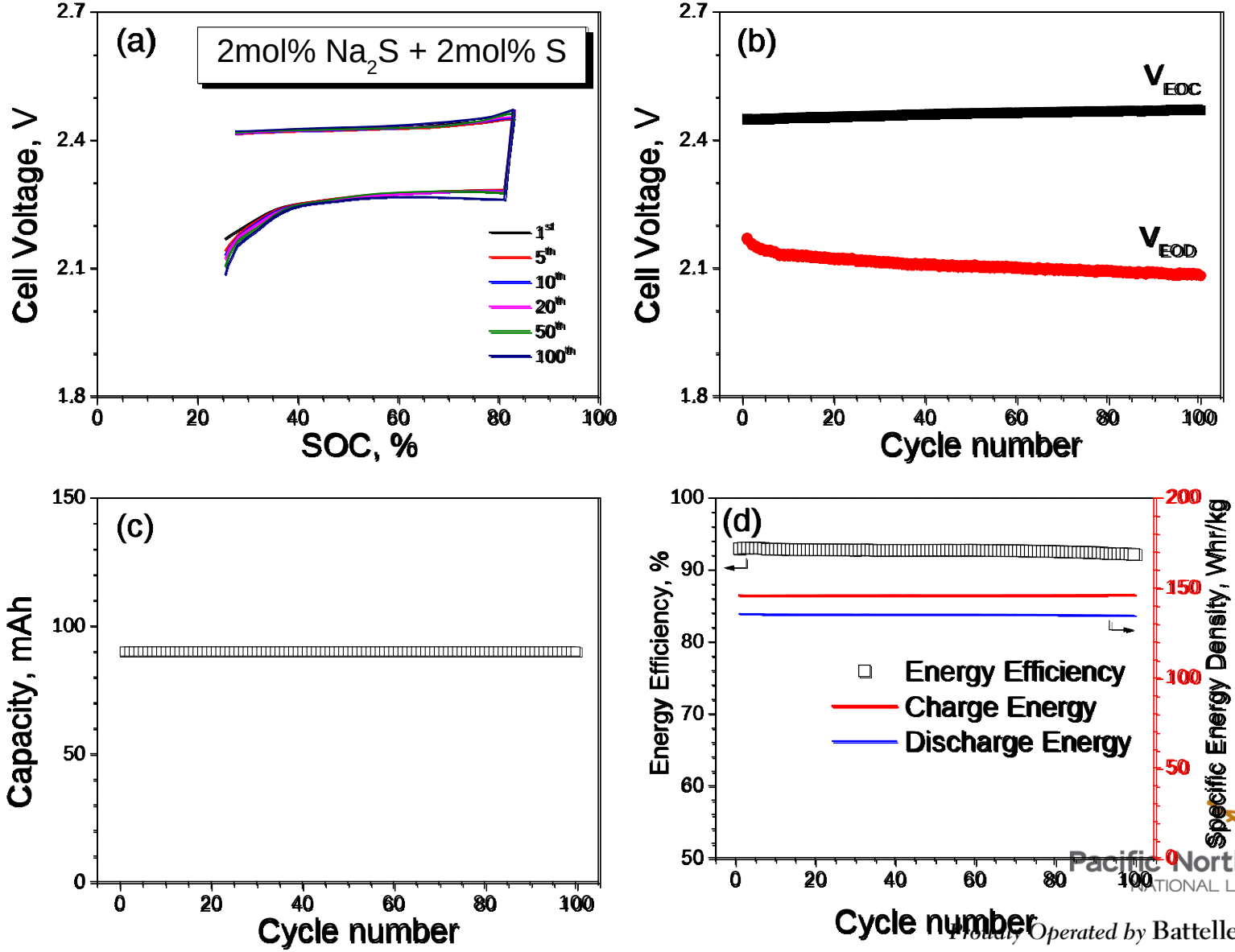
Performances of Na-$FeCl_2$ Batteries



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Summary & Future Works

- In this work, ***for the first time***, we present a novel intermediate-temperature (IT) planar ZEBRA battery based on **Na-$FeCl_2$ redox** couple.
- Owing to unique ***sulfur-based cathode additives*** discovered in this work, the Na-$FeCl_2$ battery was able to be assembled in the ***discharged state*** and then activated at intermediate-temperature (<200°C).
- Initial testing of the battery shows excellent cycling capability with the energy density (discharge) of ***135 Wh/kg*** and high energy efficiency exceeding ***92%*** at an intermediate operating temperature of 190°C.
- Preliminary cost model of ZEBRA batteries indicate that a significant (61%) materials cost reduction is expected through replacing Ni cathode with Fe cathode.

- Study and optimization of Na-$FeCl_2$ batteries for long-term testing.
- Large cell fabrication and testing.

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  Dr. Xiaochuan Lu and Dr. Jin Yong Kim (cell chemistry)
  Dr. Vilayanur V. Viswanathan (cost model)
  Dr. Kerry D. Meinhardt (cell design)
  Mr. Jeff Bonnett, Dr. Nathan L. Canfield (BASE)
  Dr. Vincent L. Sprenkle (PI)

Thanks for your attention!

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