FY21 DOE OE Energy Storage Program Annual Peer Review Meeting
Oct. 26-28
Na Battery Session

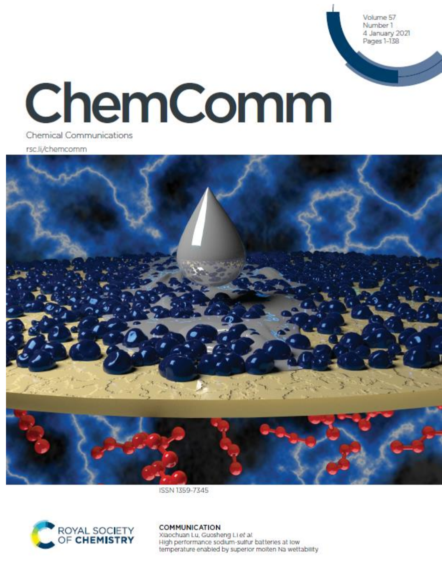
(I) Intermediate Temperature Na Battery Technologies

(II) Long Duration/Seasonal Battery Development

Guosheng Li

Battery Chem & Electrochem Group
Pacific Northwest National Laboratory

FY21 Milestones and Plans for FY 22



- **Project Team:**

  Dr. Mark Weller (new postdoc), Dr. Miller Li,
  Dr. Eugene Polikarpov, Dr. Keesung Han
  Dr. David Reed, Dr. Vince Sprenkle, and Dr. Guosheng Li

FY21	
Journal publications (2) & Milestone	1. "High Performance Sodium-Sulfur Batteries at Low Temperature Enabled by Superior Molten Na Wettability" *Chem. Comm.* 57, 45 (2021). (Front Cover) 2. "A High-Performance Na-Al Battery Based on Reversible $NaAlCl_4$ Catholyte" *Adv. Energy Mater.* 10, 2001378 (2020). 3. "Recent Progress in Cathode Materials for Sodium-Metal Halide Batteries" *Materials.* 14, 3260 (2021). (review article) 4. 19 Wh 2-cell stack testing (Achieved).
IP& Invention Reports	Licensing US patent 10,615,407 (Na-$FeCl_2$ battery) Provisional IP application (Na wetting agent, in preparation)
Collaboration	RIST (Dr. Keeyoung Jung), etc

FY22:

1. High performance and low-cost Na based battery for long duration application.
2. Large cell demonstration & OE/KETEP project (phase 2)

Pacific Northwest
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Challenges for High Temperature Na Batteries

Batteries	Temp. (°C)	OCV (V)	Energy density (Wh/kg)	SSE	Cycle life	Safety	Cost ($/kWh)
Na-S	350	~2.0	~150	β″-alumina	> 3,000	Thermal runaway, limited thermal cycle	500
$Na\text{-}NiCl_2$	280	2.58	~120	β″-alumina	>1,000	No thermal runaway	1,000

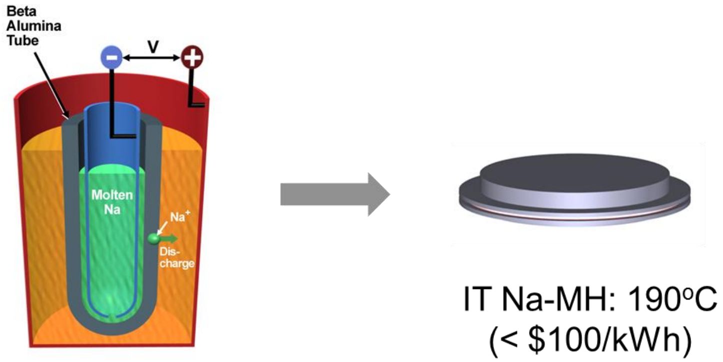
❑ Challenges for high temperature $Na\text{-}NiCl_2$ batteries:

- Manufacturing process of β″-alumina tube: dimension, microstructure, mechanical robust, etc.
- Cell Assembly for high temperature operation: Glass sealing, TCB, EBW, etc.
- Materials degradation at the high temperature: Corrosion, particle growth, etc.

❑ PNNL strategies

- Develop intermediate temperature (<200°C) chemistries
- Planar-cell architecture enables lower materials cost and manufacturing cost.

Tubular type | Planar type



IT Na-MH: 190°C (< $100/kWh)

NaS: 350°C (~$500/kWh)

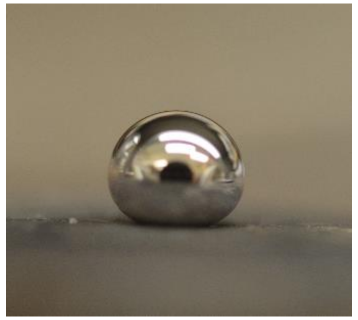
ZEBRA: 280°C (~$1,000/kWh)

Na Wetting on BASE (Miller Li)

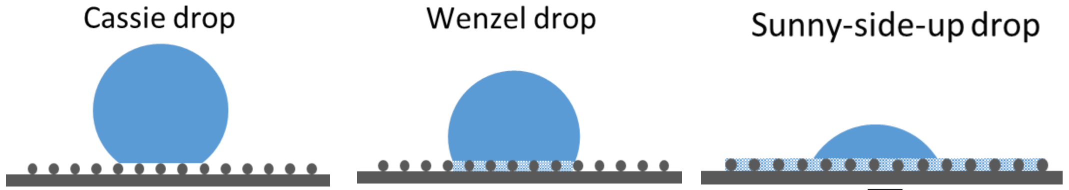
Na wetting on smooth surface

$W_{adh}=\gamma_m (1+\cos\theta)$

γ_m of Na = 200 mN/m
(3X higher than water)

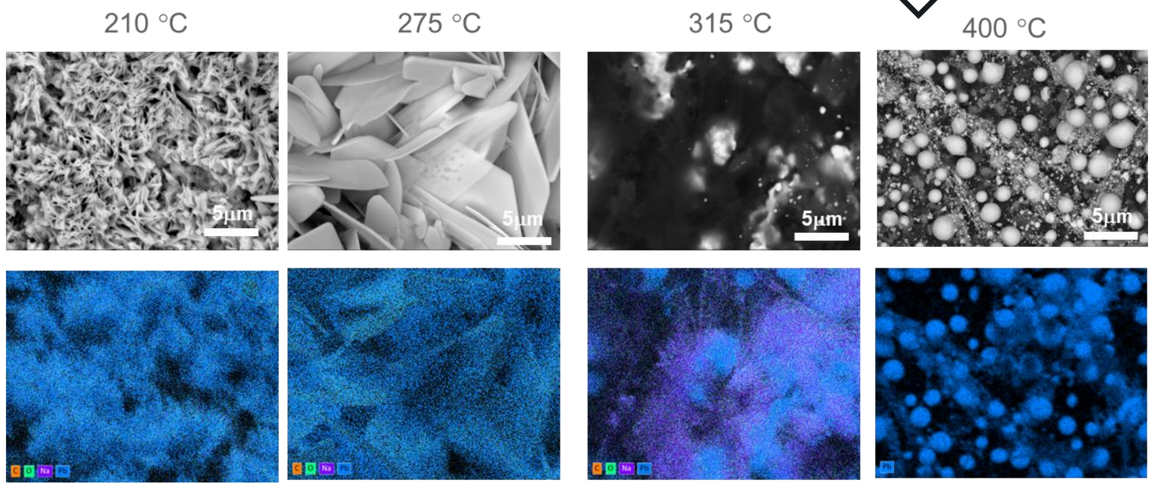


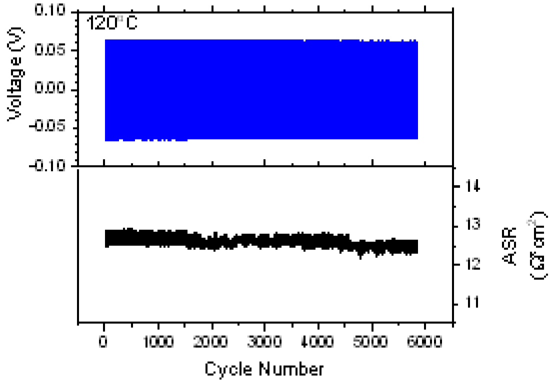
Na wetting on rough surface

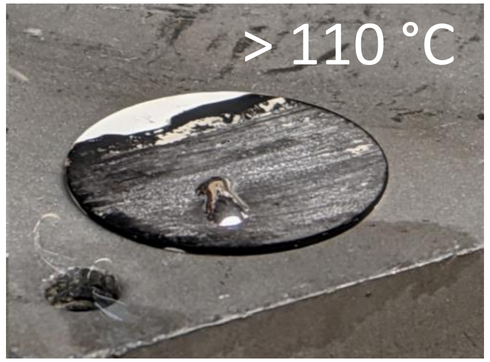


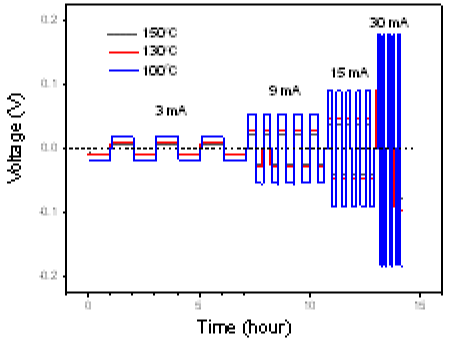
LAT

J. Mater. Chem. A 6, 19703 (2018).





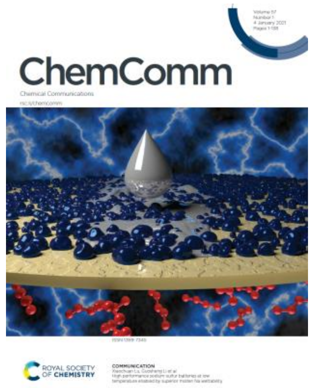


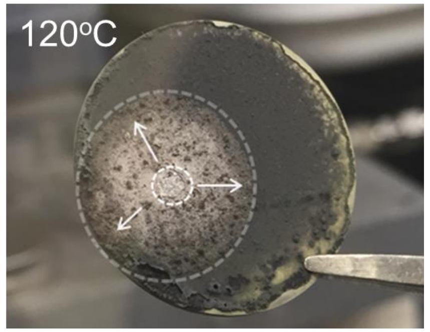


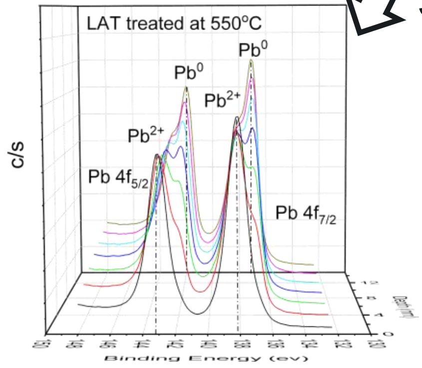
New Na wetting agent (Manuscript in preparation)

Chem. Comm. 57, 45 (2021).

550°C





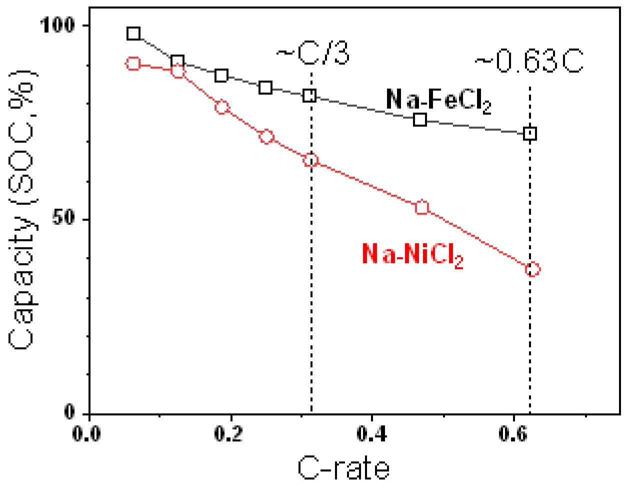


Low-Cost Na-MH Batteries for LDES

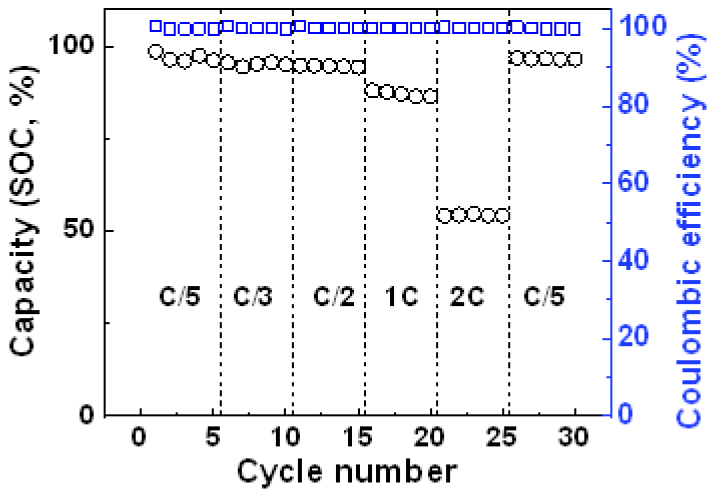
1. Lower cost materials/system
2. Fast kinetics/high-capacity loading
3. Safety
4. Reliability/long cycle life

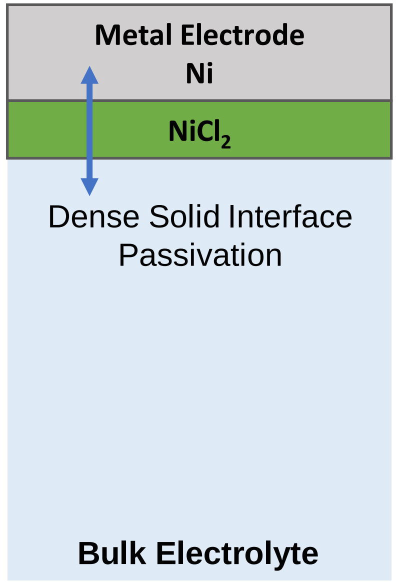
	$Na\text{-}NiCl_2$	$Na\text{-}FeCl_2$	Na-Al
Cathode	Ni/NaCl	Fe/NaCl	Al
S.E.	$NaAlCl_4$	$NaAlCl_4$	$NaAlCl_4$
E (V)	2.58	2.35	1.6
Capacity (mAh/g)	305	310	308
Price ($/lb)	**20**	**0.5**	**0.8**
Materials cost ($/kWh)	**<100**	**<5**	**<5**
Duration (Hours)	**6-8**	**~15**	**>15**

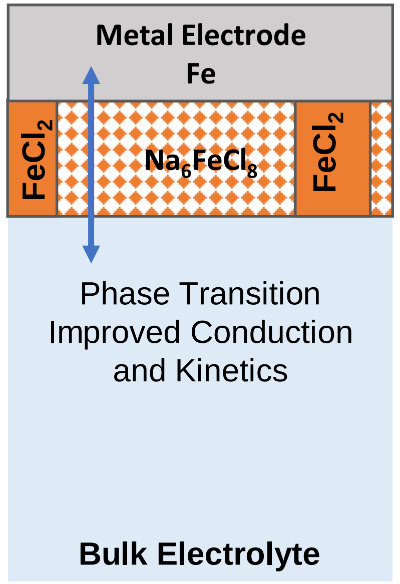
Poster by Eugene Polikarpov

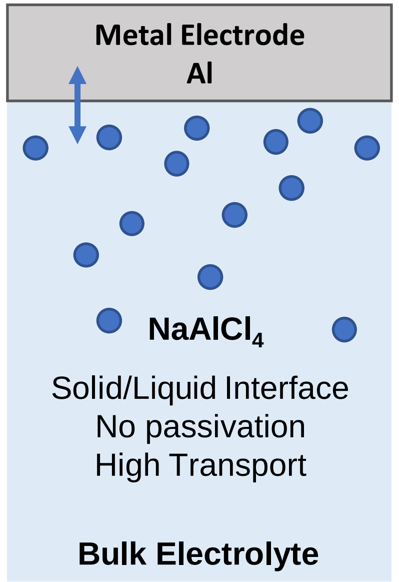


Poster by Mark Weller









Nature Commun.. 7, 10683 (2016).

Ni ⇳ $NiCl_2$

Adv. Energy Mater. 10, 1903472 (2020).

Fe ⇳ Na_6FeCl_8 ⇳ $FeCl_2$

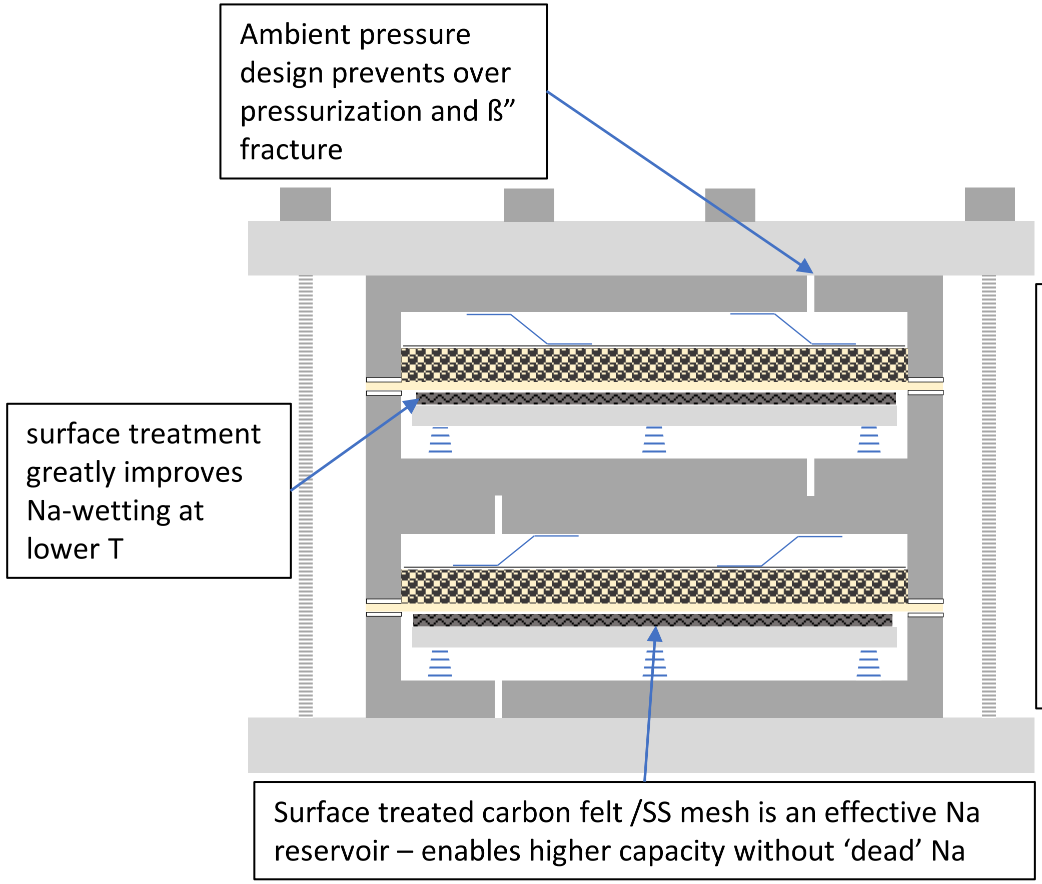
Adv. Energy Mater. 10, 2001378 (2020).

Al ⇳ $NaAlCl_4$

Large Cell Test (OE/KETEP Project, Mark Weller)

Major Challenges Addressed:

- Pressure buildup in sealed cell design (potential BASE fracture)
  - Pressure release holes & hermetic sealing *via* a secondary vessel (PNNL)
  - Assembly under partial vacuum (RIST)
- Na-reservoir (~9 g sodium in each cell at the full charge) and 'dead' Na
  - Good/consistent Na wick (surface treated carbon felts/SS mesh)

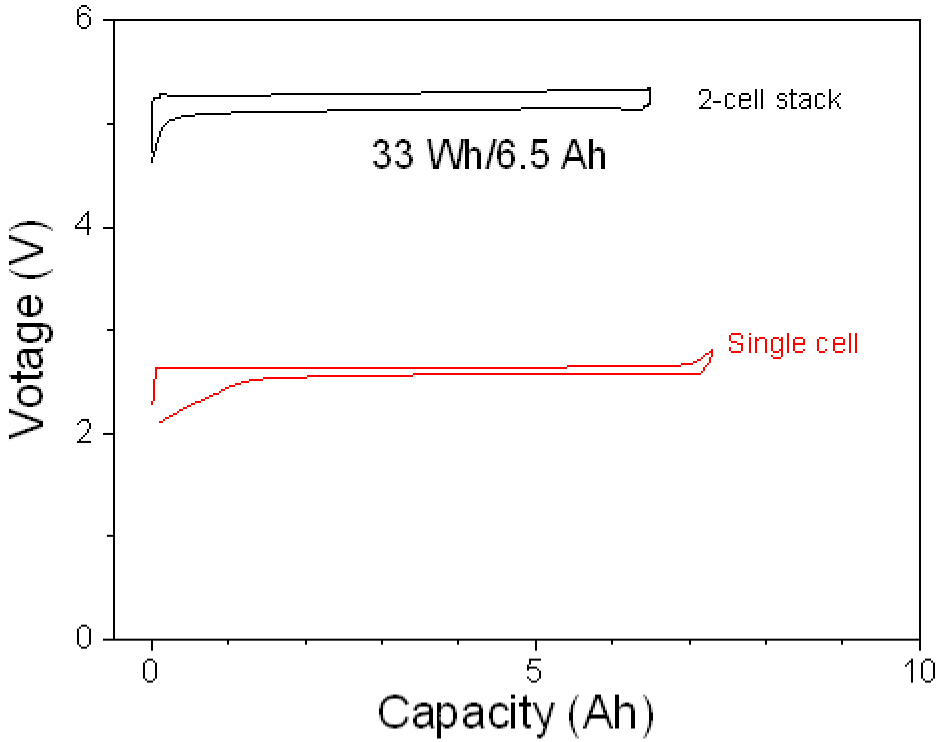


Cell Pressure:

$\sigma_{max} = \frac{3\,\Delta p\, r^2_{plate}}{t} \propto r^2$

Small pressure difference can produce large stresses

For Δp of 2.3 PSI (approximation for our cells), σ_{max} ~ 735.6 PSI ~ 5 MPa



Long Duration/Seasonal Energy Storage Technologies

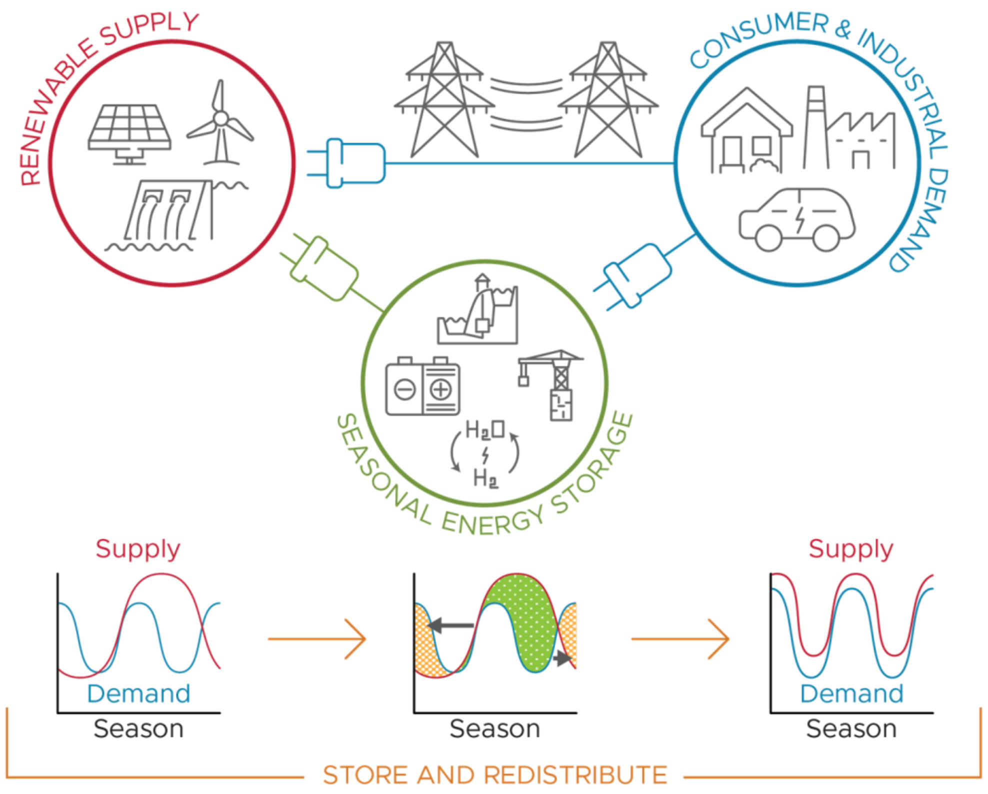
- Project team:

Dr. Miller Li (postdoc), Dr. Aaron Hollas, Dr. Fred Park (postdoc),

Dr. Qian Huang, Dr. David Reed, Dr. Vince Sprenkle, and Dr. Guosheng Li

FY21	
Journal publications (PNNL lead)	1. “Let Energy Freeze: A Thermal-Cycling Molten-Salt Battery for Seasonal Storage” (under review) 2. “Concepts for All-Iron Redox Flow Batteries at Moderate pH” (manuscript in preparation)
IP& Invention Reports	Non-provisional IP application (Seasonal energy storage; Miller Li) Provisional IP application (Long duration technology; Aaron Hollas)

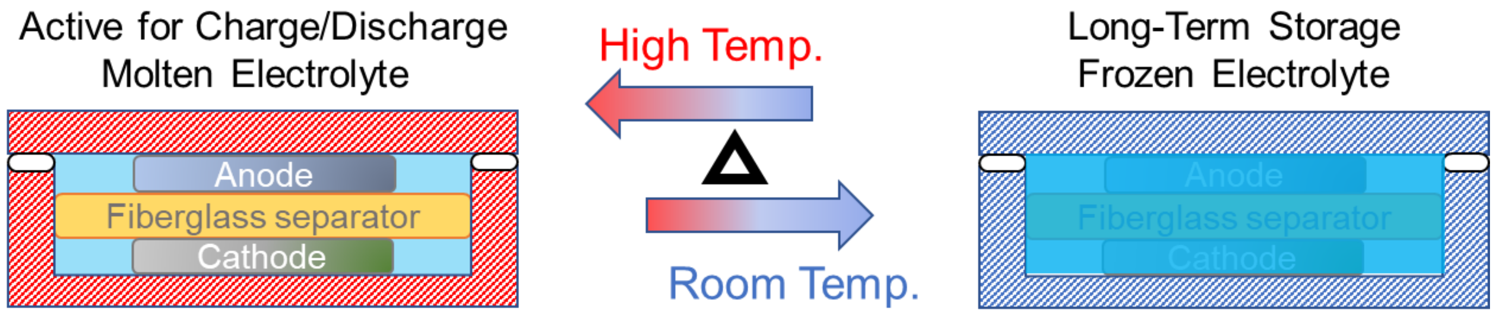
Thermocycling Battery Technologies for Seasonal Storage Application (Miller Li)

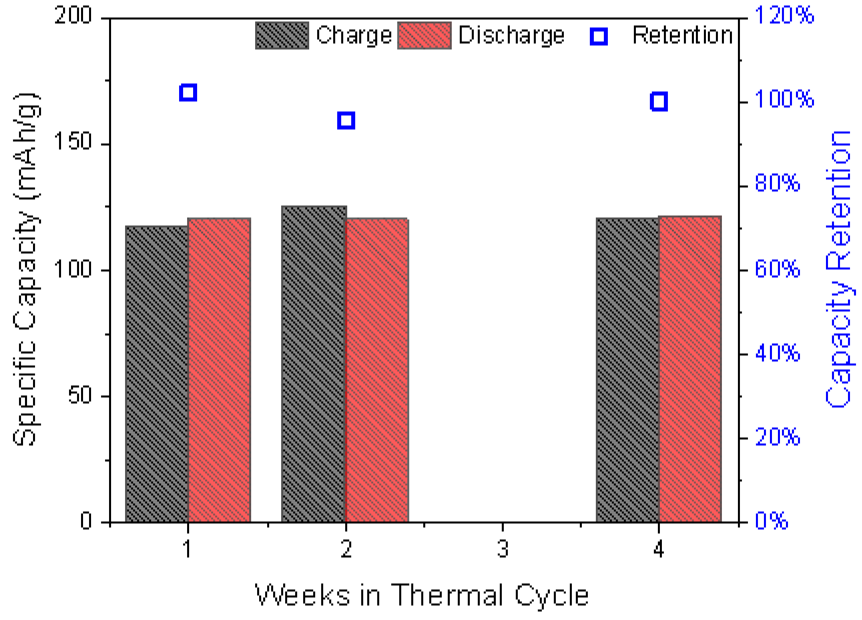


Challenges of Battery Technologies for Seasonal Storage:

- High cost
- Self-discharge via electrolytes

Schematic of Thermocycling Battery

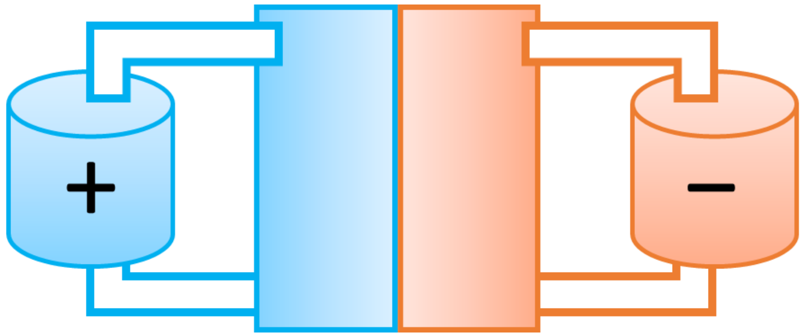




- Low materials cost (~$20/kWh)
- Low battery manufacturing cost
- High-capacity retention after long storage time

Li et al. (under review)

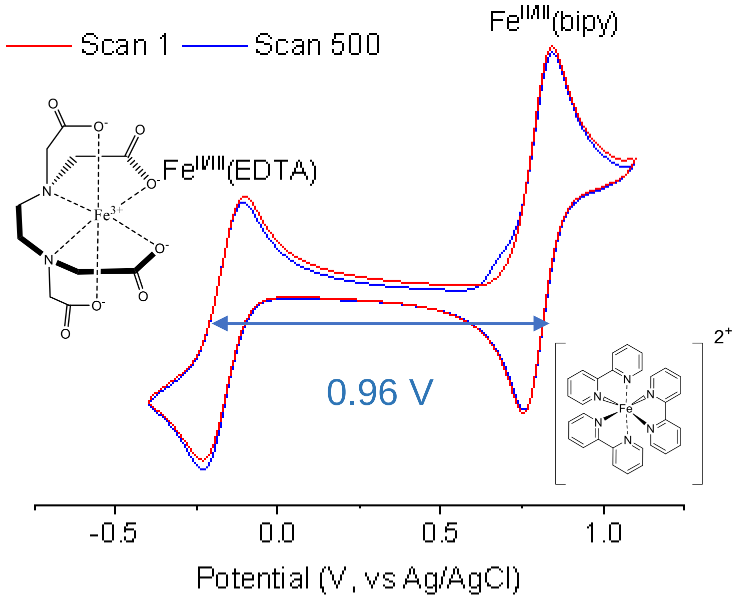
Low-Cost RFB for LDES (Miller Li, Qian Huang & Aaron Hollas)



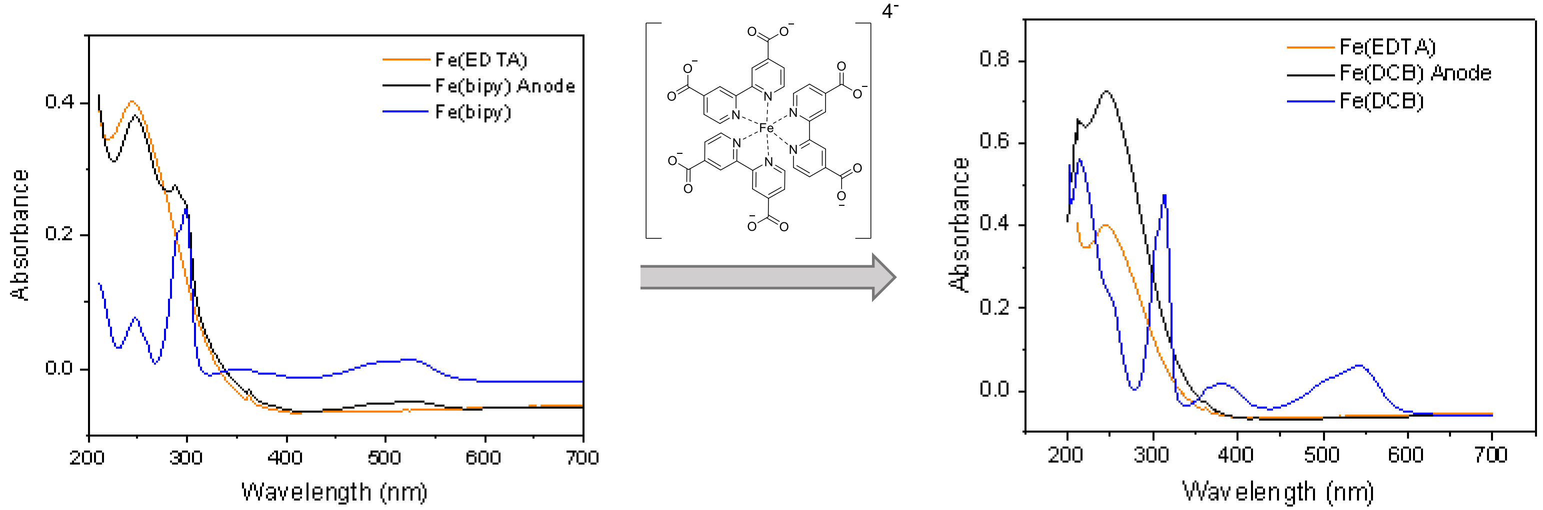
- ❑ Decoupling of power and energy capacity is suitable for LDES
- ❑ High cost of VRFB is the main obstacle for wider market penetration
- ❑ Corrosive electrolytes with low pH

Vanadium ⇨ **Iron**

~$13/lb ~$0.5/lb



- Electrochemically reversible $[Fe(bipy)_3]^{+2/3}$ and $[Fe(EDTA)]^{-1/2}$ have simple ligand designs, suitable for large-scale implementation
- However, crossover causes fast self-discharge.



- Modifying bipy ligand can make partially anionic complex, which aligns the polarity of active molecules and stops crossover.

Office of Electricity
(Dr. Imre Gyuk)

Thank You!

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