Enabling Long Duration Metal Hybrid Redox Flow Batteries

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Project Profile and Problem

Topic: Flow Batteries | Vertical: Materials and Systems Innovation
Strategic Pathway: Grow
Project start and finish: FY25-FY27

Problem:

- **Rising costs of energy and grid instability**
- **Need to improve grid resilience**

- **Limited long duration (>10 hr) energy storage capability**
  - **Expensive battery chemistries [vanadium, lithium]**
  - **Conventional hybrid flow batteries cannot decouple energy and power**

- **Educate the next generation of engineers and scientists in electrochemical energy storage technologies**

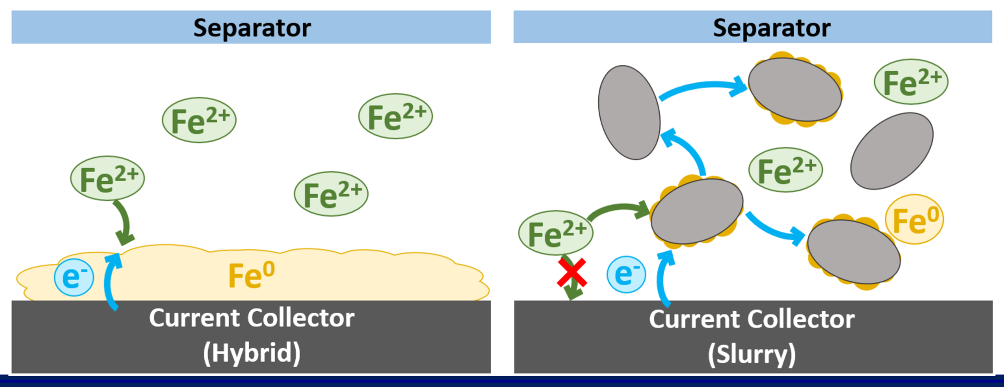
Objectives and Approach

Objectives:

- **Utilize earth abundant, low-cost materials [iron, zinc]**
- **Carbon slurry electrodes to de-couple energy and power**
- **Suppress metal deposition on current collector and hydrogen evolution reaction (HER)**

Approach:

- **Polyethylene glycol co-solvent to aid in carbon black slurry performance**
  - **Enable use of more conductive carbon blacks**
- **Copper plating/striping as proxy for iron and zinc negative couples**

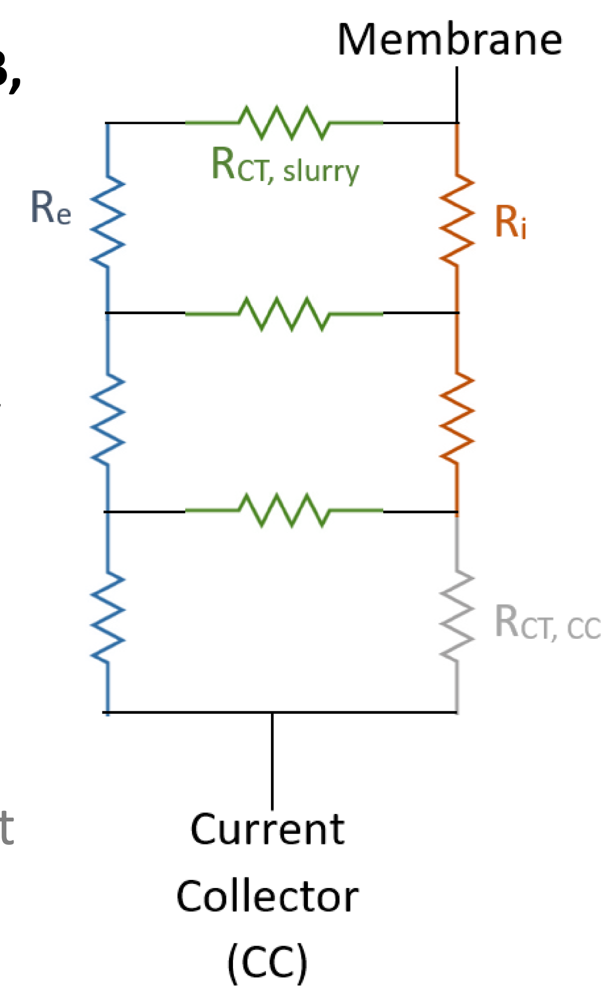


Controlling Current Distribution in Slurry-RFB's

To decouple power and storage capacity in hybrid RFB, the metal deposition current must be on the slurry, rather than on the current collector.

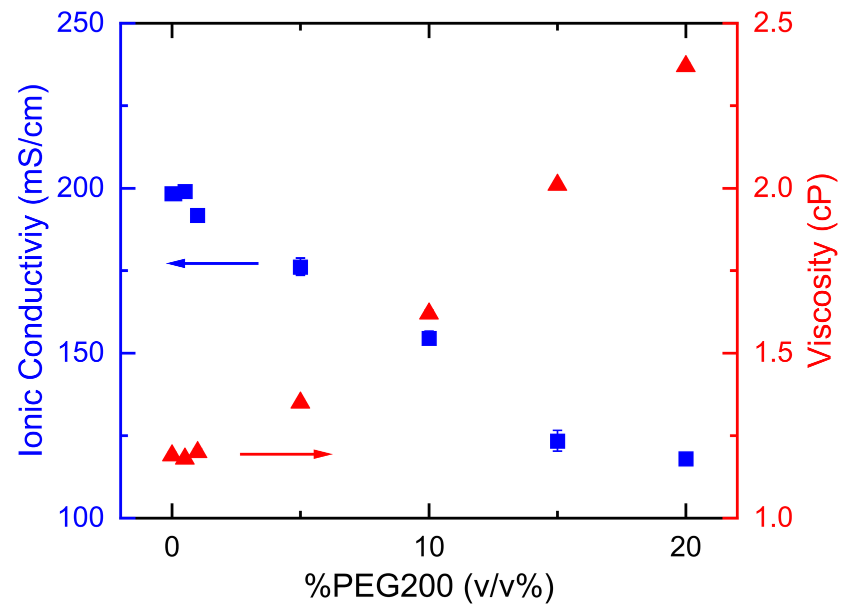
The current distribution for metal deposition in slurry electrodes is dependent on many factors:

- Slurry Electrode Electrical Conductivity
- Electrolyte Ionic Conductivity
- Deposition Kinetics and Mass Transfer on the Slurry
- Deposition Kinetics and Mass Transfer on the Current Collector



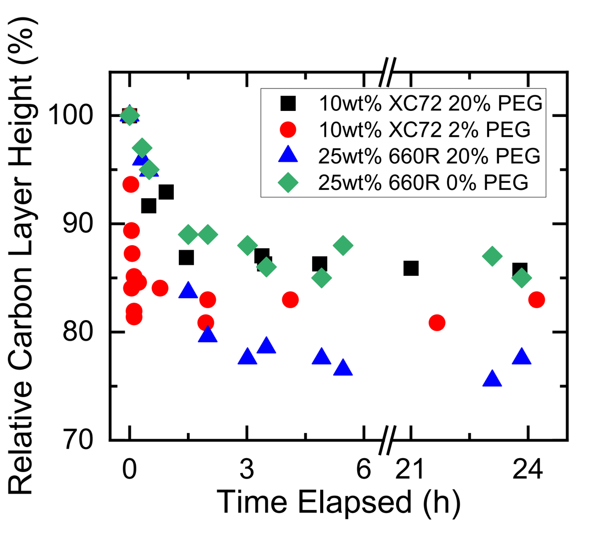
Suppressing Plating and HER via Concentrated PEG

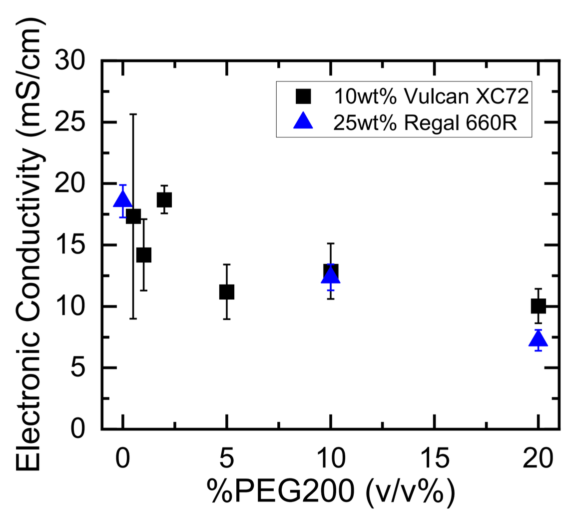
Parameter	0 v/v% PEG200	20 v/v% PEG200
Cu^{2+} diffusion, cm^2/s	6.5E-6	3.5E-6
Cu^{2+}->Cu^0 exchange current density, Log(A/cm^2)	-1.7	-3.7
HER exchange current density on Cu, Log(A/cm^2)	-6.1	-7.0

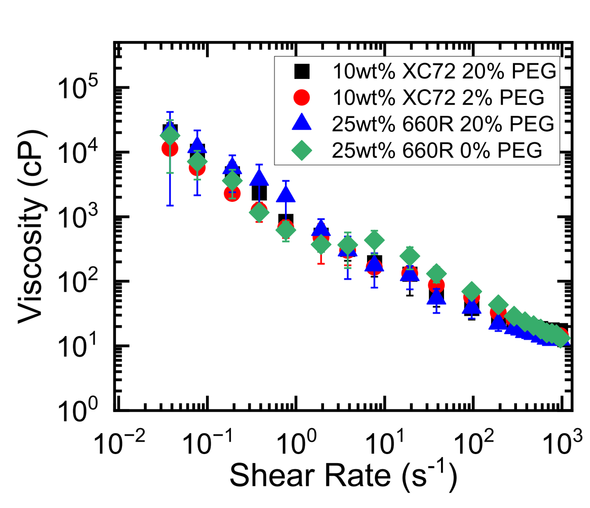


- **Adding low molecular weight polyethylene glycol (PEG) suppresses both plating and hydrogen evolution kinetics**
- **PEG drastically reduces ionic conductivity at slight viscosity penalty**
- **Combination of decreased kinetics and ionic conductivity drive more metal onto slurry versus current collector**

PEG as Co-solvent for Slurry Electrolytes







- **PEG aids in suspension of conductive XC72 carbon black**
  - **2% PEG settles out in minutes, 20% PEG settles in hours**
  - **No effect on 660R because it is a hydrophilic carbon**
- **XC72 achieves same elec. cond. as 660R with less loading (10% vs 25%)**
  - **PEG only slightly hinders electronic conductivity**
- **No significant difference in slurry viscosity with or without PEG**

Plate/Strip Results on Slurry

Carbon	Loading (w/v%)	PEG200 (v/v%)	Elec. Cond. (mS/cm)	Ionic Cond. (mS/cm)	% on Slurry	% on CC
XC72	10	2	19	188	**40±2**	**60±2**
XC72	10	20	10	118	**48±4**	**52±4**
660R	25	0	19	198	**50±3**	**50±3**
660R	25	20	7	118	**58±2**	**42±2**

- **Carbon loadings selected to match electronic conductivity between Vulcan XC72 and Regal 660R**
- **Slurries with 20% PEG have nearly 10% more metal on carbon than slurries with the same carbon and no/low PEG**
  - **Most likely due to decreased ionic conductivity and plating kinetics**
- **660R has 10% more metal on slurry than equivalent XC72 slurry**
  - **Possibly due to increased loading / specific interfacial area (m^2/m^3)**

Future Directions

- **Expand on slurry work by exploring additional conductive carbon blacks for increased loading and specific interfacial area**

- **Improve distribution of metal on slurry vs current collector by increasing electronic conductivity while maintaining flowable slurry**

- **Translate work demonstrated with copper to more valuable hybrid flow battery metals such as iron, zinc, and tin**

References and Acknowledgements

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- V. Tam, R. Savinell, and J. Wainright, "Controlling Current Distribution in Slurry Electrodes for All-Iron Redox Flow Batteries," J. Electrochem. Soc. **172** 070503, (2025). doi: 10.1149/1945-7111/ade745
- Manuscript in progress for current work shown

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