Earth Abundant Multivalent Materials for Metal-Air Batteries: Al-Air Battery

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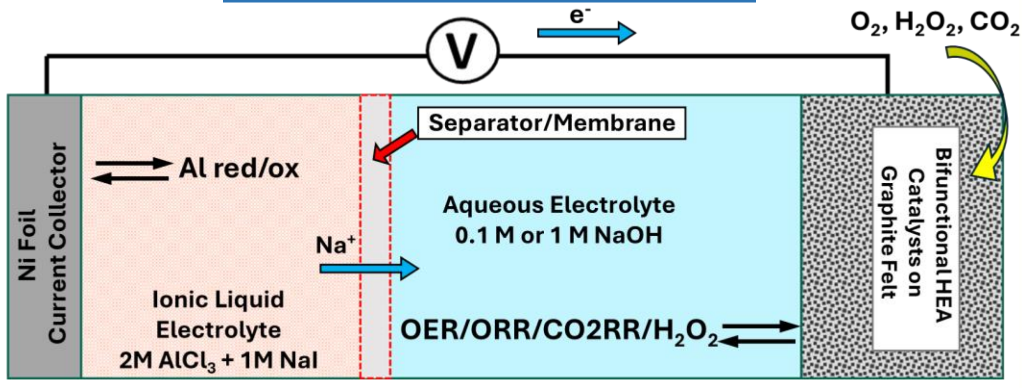
Project Motivation and Overview:

Scalable, energy storage, utilizing earth abundant elements such as aluminum, is desirable because of the high theoretical energy density. Aluminum represents an abundant resource with established domestic supply chains, needed for grid resilience and reliability.

The project goal is to develop new stable, rechargeable aluminum-air based batteries with efficient cycling behavior consisting of a stable aluminum containing electrolyte and bifunctional electrocatalysts.

- ***This year's research was focused on Al containing electrolyte development and non-noble metal based bifunctional catalyst evaluation for use in full battery cells.***

Al-Air Battery Schematic



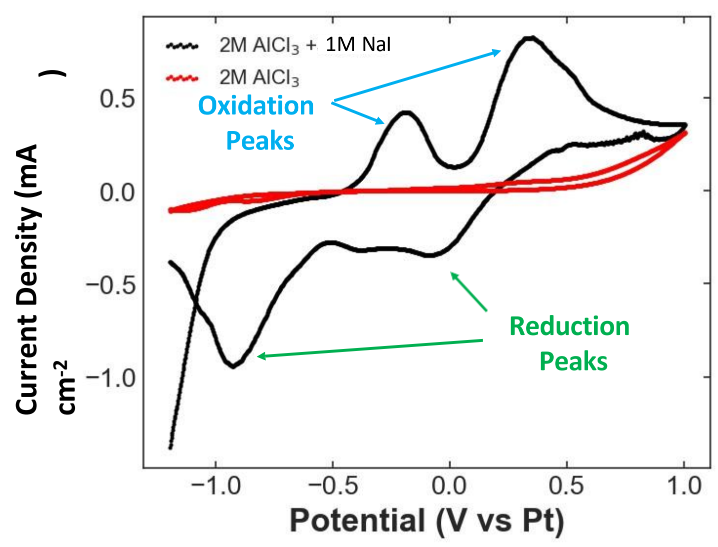
Stable Al Based Ionic Liquid Electrolyte

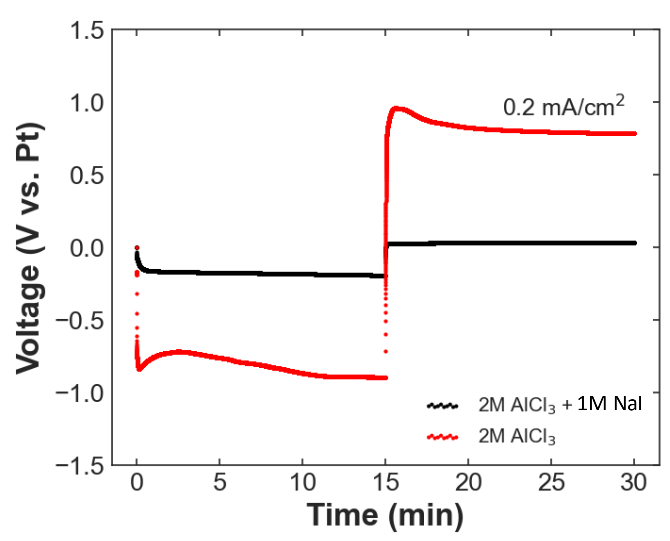
Goal of this FY Research:

- **Deposition 1-10 µm thick Al metal at ambient conditions**

*Initially, Al deposition from new electrolytes and Al based salts investigated electrochemically, but **new Al compound electrolyte system developed eliminating need to deposit/strip solid Al materials,** shifting scope of research.*

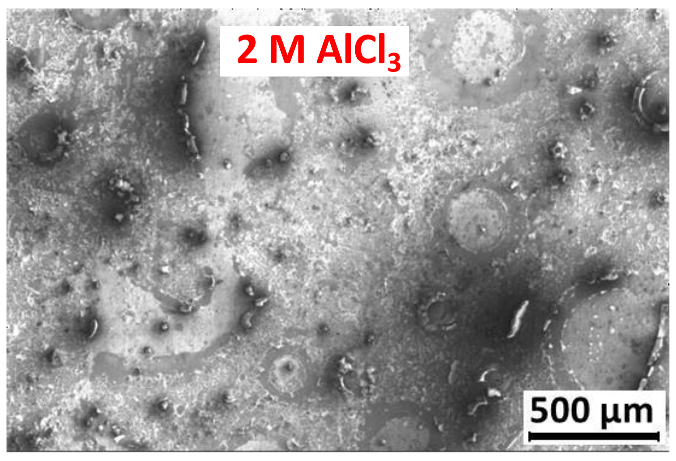
Redox peaks are seen in the ionic liquid electrolytes with the molecular additive (NaI), indicating increased reversibility of the electrochemistry.

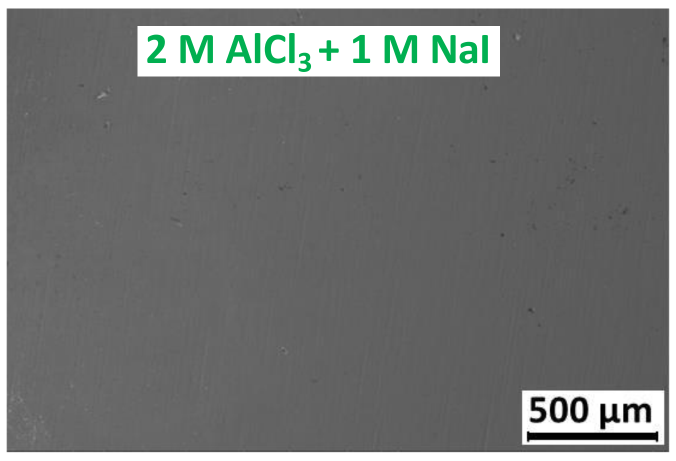




Without the added NaI, undesirable, large potentials are seen at a constant current draw for "charge" and "discharge", but the ***2 M $AlCl_3$ + 1 M NaI ionic liquid system exhibits stable electrochemistry and a low voltage difference.***

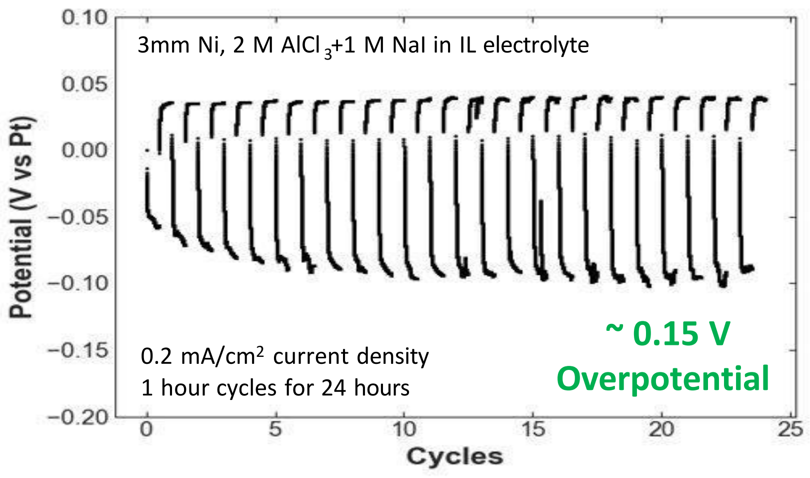
Redox Species Remain Soluble





Solid deposits seen on Ni foils after reduction of the Al without NaI additive

***No deposits are seen with NaI added** - eliminating phase changes that could hinder energy efficiency and showing reversible charge storage is possible.*



Half Cell Cycling

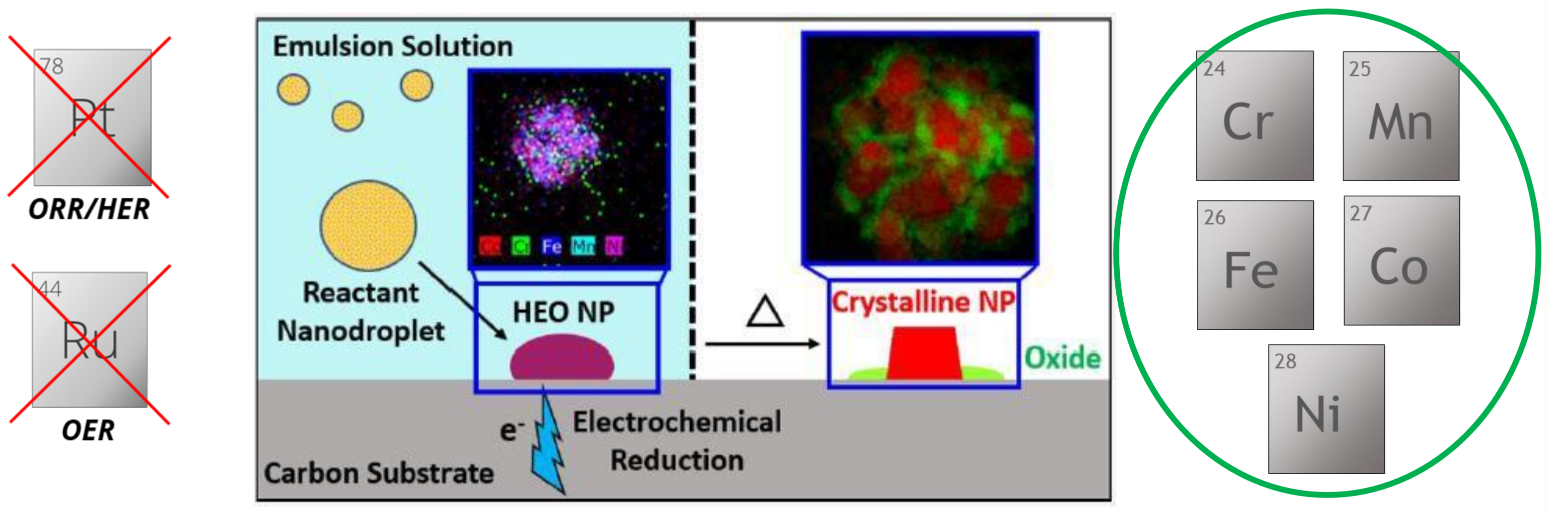
Preliminary half cell cycling of aluminum complex containing ionic liquid electrolyte show good redox stability with a relatively low overpotential!

Non-Noble Bifunctional Electrocatalysts

Goal of this FY Research:

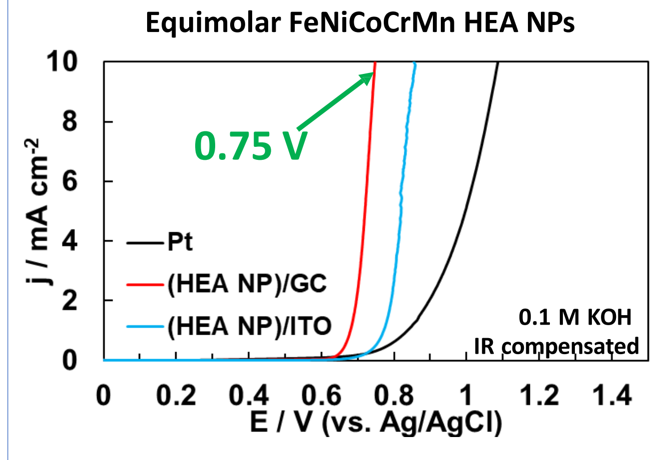
- **Demonstrate OER at 10 mA/cm² with η<500mV**
- **Demonstrate ORR (or equivalent red. rxn) at 0.5 mA/cm² with η<500mV**

Need for efficient, abundant electrocatalyst materials that eliminate noble metals that can perform Oxygen Evolution Reaction (OER) and Oxygen Reduction Reaction (ORR)



High Entropy Alloy Nanoparticles (HEA NPs) deposited with an emulsion based electrochemical deposition method followed by low temperature annealing. **Forms FeNiCo metallic particles with a $CrMnO_x$ stabilizing phase.**

Bifunctional Oxidation Reaction (Charge)



Oxygen evolution reaction (OER) will be used during charge, efficient/stable catalyst needed

HEA NPs show lower OER overpotential compared to Pt with η<500mV

- Typically measured as the potential to reach the current density of 10 mA/cm²

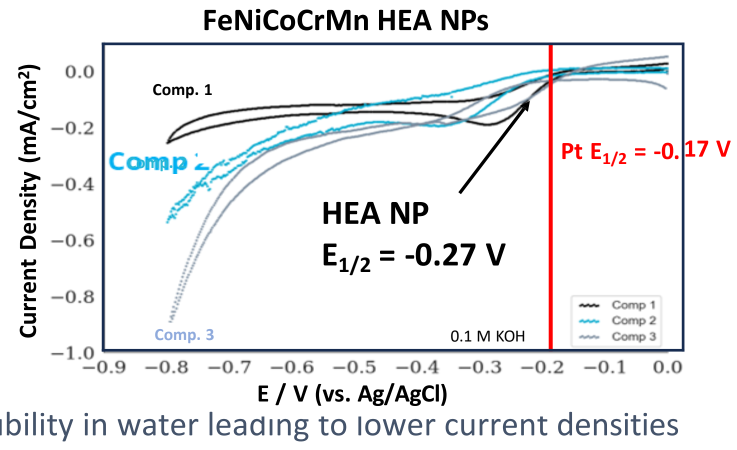
Bifunctional Reduction Reaction (Discharge)

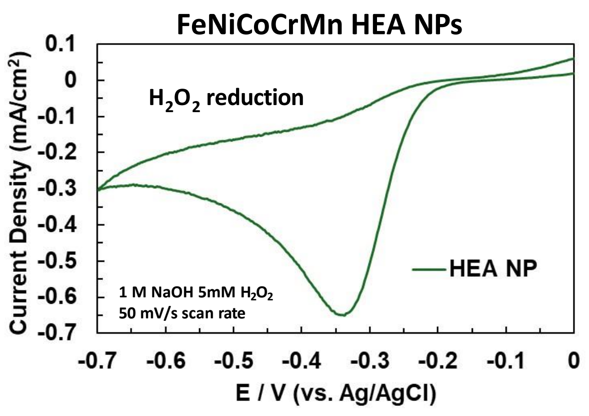
HEA NPs show composition dependent ORR $E_{1/2}$ potential similar to Pt with η<500mV

HEA NP ORR $E_{1/2}$ = -0.27 V (vs Ag/AgCl) **in 0.1 M KOH**

ORR thermodynamic potential:

- 2 e- mechanism = -0.265 V (vs Ag/AgCl @ pH 13)





O_2 has low solubility in water leading to lower current densities than desired.

- Targeted 0.5 mA/cm² current density achieved only at more cathodic potentials
- Switching to H_2O_2 reduction is an option to increase current density, but will suffer from reactant instability

Will need to increase O_2 concentration and HEA NP mass loading to increase current density to desired levels

Summary and Next Steps

- A new aluminum containing, air-stable electrolyte, was demonstrated through the addition of a molecular additive (NaI), enabling the electrochemical reversibility of the Al complex redox species, where the Al species can be cycled while remaining dissolved in the electrolyte.
- Bifunctional HEA NP electrocatalysts have shown great activity for OER and ORR/H_2O_2 with lower OER overpotentials compared to Pt and similar ORR/H_2O_2 overpotentials and current densities compared to Pt.

Next Steps: Membrane/separator testing will find suitable polymeric or ceramic ion conducting membranes/separators that are compatible with the IL and aqueous electrolyte. Increase HEA NP loading and O_2 concentration. Full battery cell cycling will begin to determine and improve efficiency of the Al-air battery system

Membrane Test Cell

- **Project Accomplishments: 1 paper published, 2 patent applications filed, 1 paper in review and 1 paper in preparation to be submitted**

References:
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