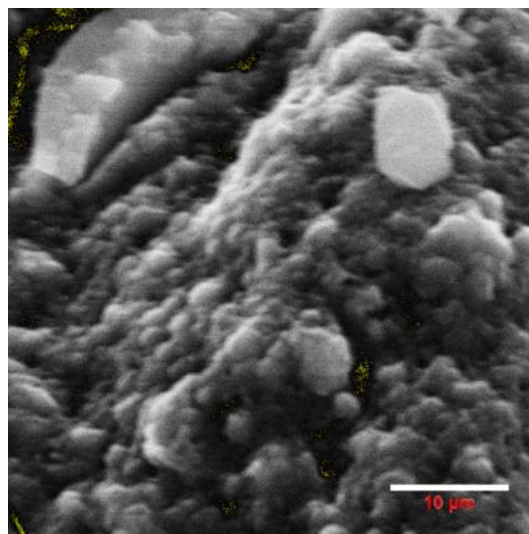
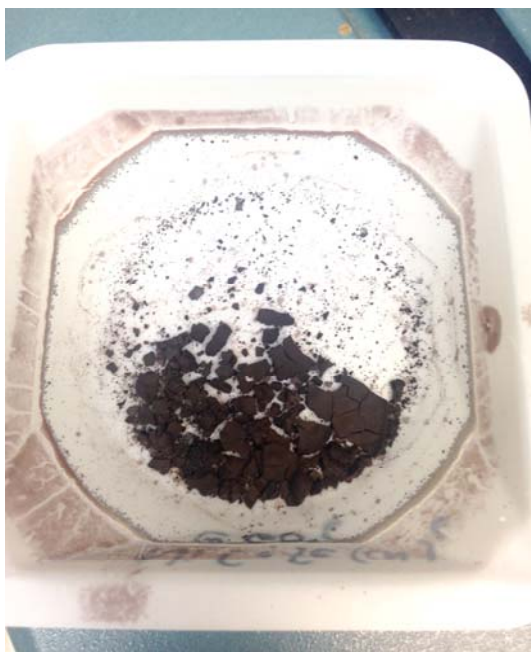


# Mixed metal Prussian blue analogues as working electrodes for rechargeable batteries and their electrochemical properties

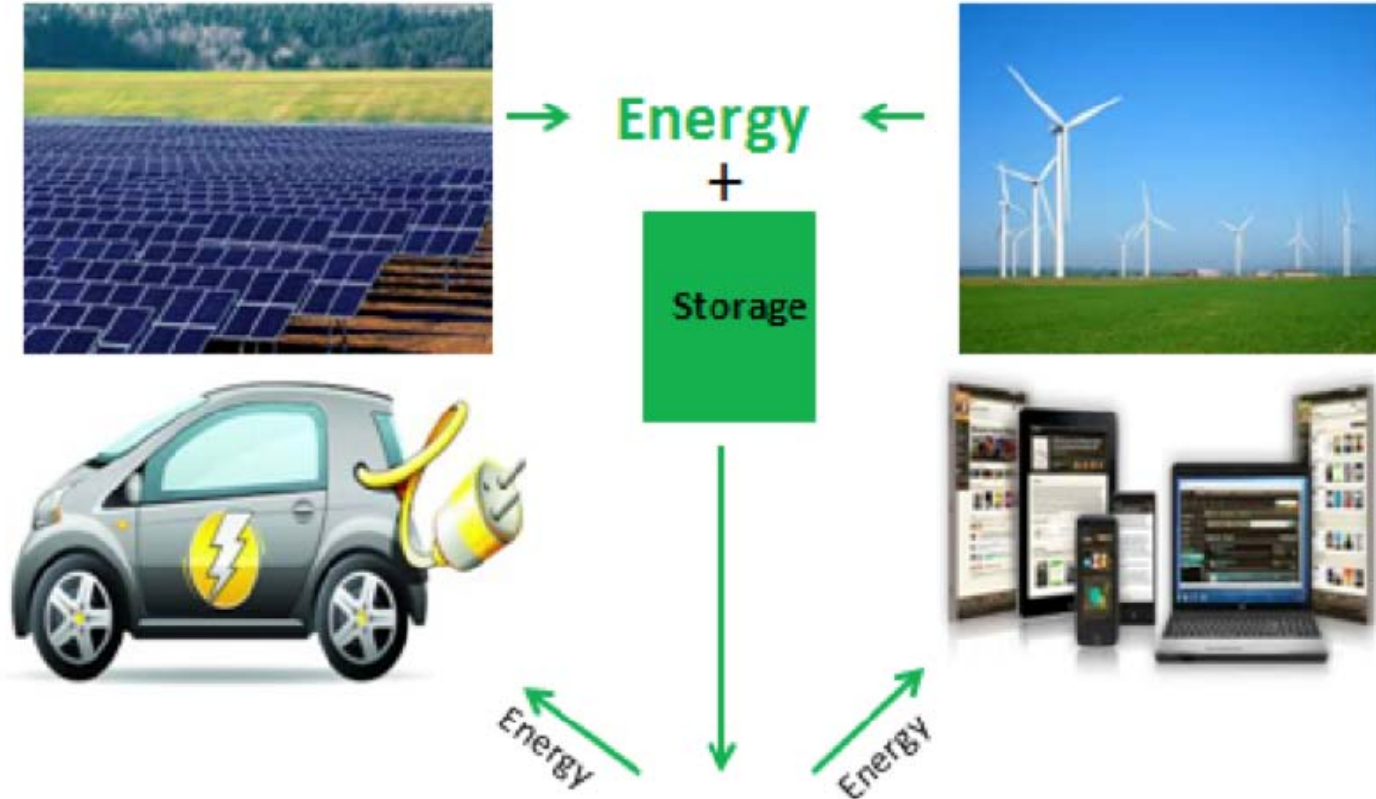


Madeline Mackey

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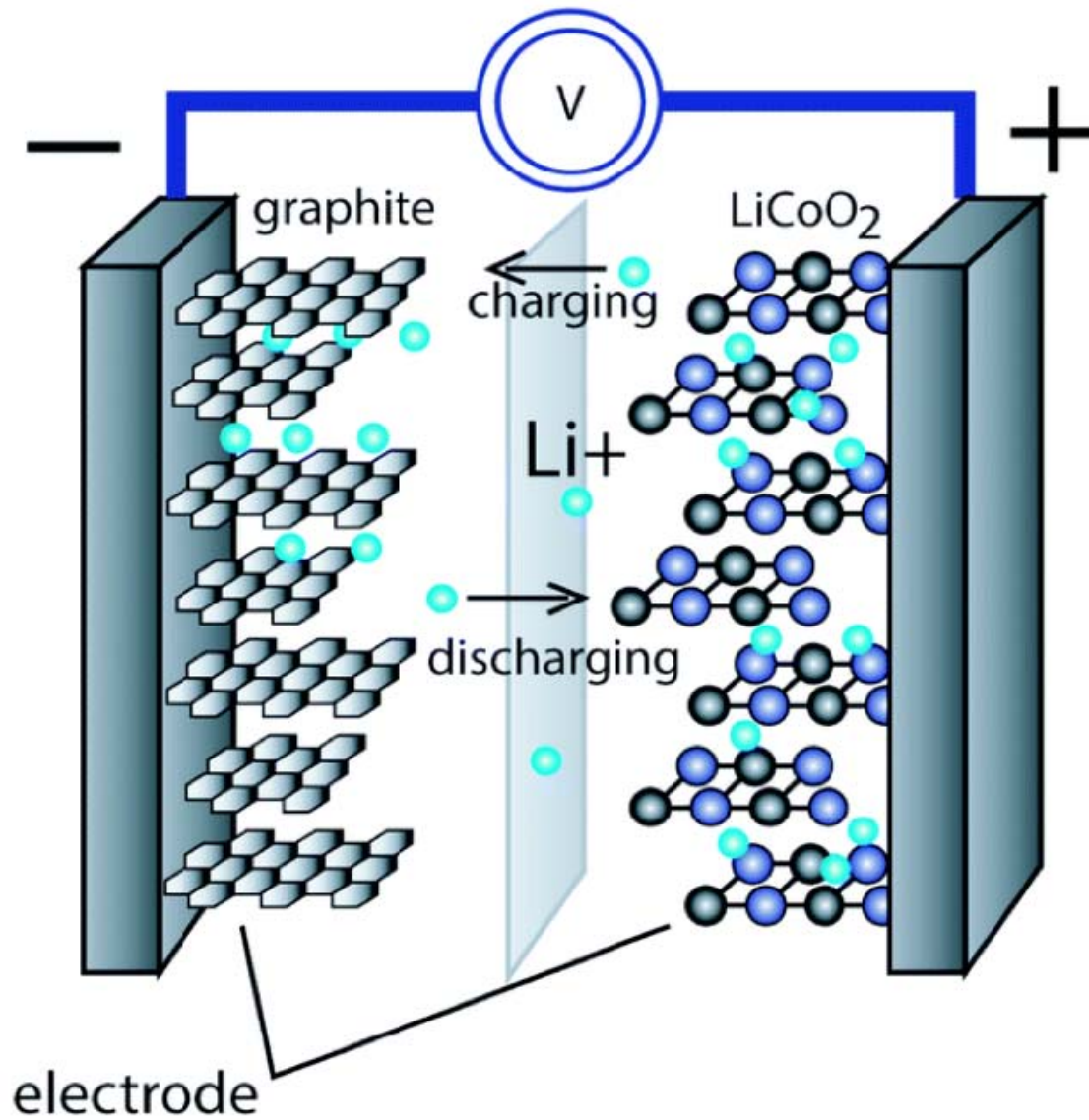
# What are we doing?

- Need for high-energy storage for rechargeable batteries



Energy Storage: Energy Sources

# Battery



# How?

- Mixing metals with Prussian blue analogues (PBAs)
  - Analogue: “a compound with a molecular structure similar to that of another”
  - Hexacyanoferrate (HCF) & hexacyanocobaltate (HCC)

# What is Prussian blue

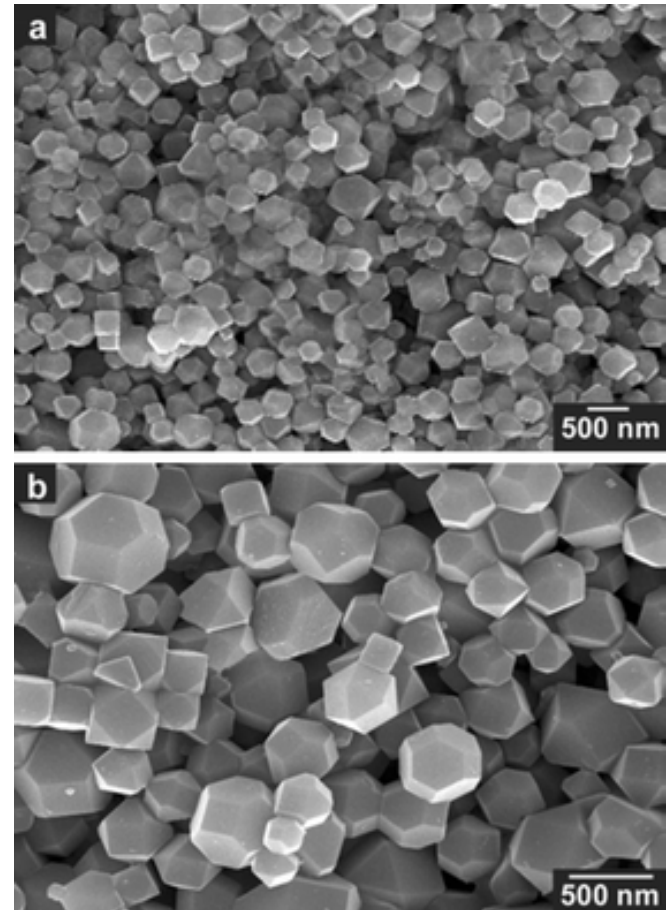
- A dark blue pigment
- Used in medicine as an antidote for heavy metal poisoning
- Work as efficient electrodes due to redox properties



Van Gogh's Starry Night  
-prussian blue color

# Prussian blue composition

- Open framework crystal structure
- Properties:
  - Stores counteranions
  - Ion-exchange selectivity
  - Ability to catalyze electrochemical reactions



Prussian blue SEM image,  
Cao et al.

# Materials and Methods

- Nickel Cobalt hexacyanoferrate. NiCoHCF.
- NiCoHCF @ 60 degrees Celsius.
- Iron Manganese hexacyanocobaltate.  
FeMnHCC.
- Tin hexacyanocobaltate. SnHCC.

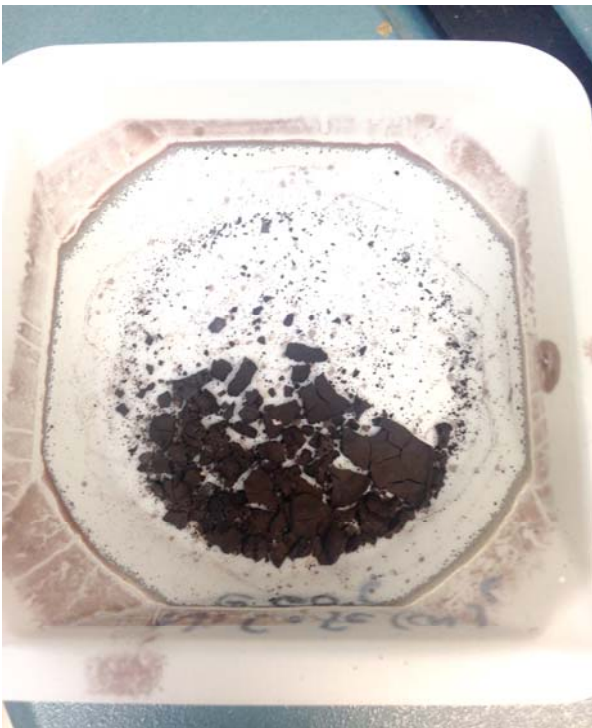
# Materials and Methods

- Facile method
  - Mixed metals in deionized water, mixed PBA with DI water
  - Add mixed metals drop-wise to PBA
  - Constant stirring 1 hr.
  - Sit for 1 day
- Centrifuged and washed with ethanol



# Materials and Methods

- Dried in oven
- annealed at 150 degrees Celsius (16 hrs.)



Dried NiCoHCF



Annealed NiCoHCF

# Materials and Methods

- Paste created
- Painted onto carbon tape (electrodes)
- Carbon tape electrodes annealed at 150 degrees for 2 hrs.

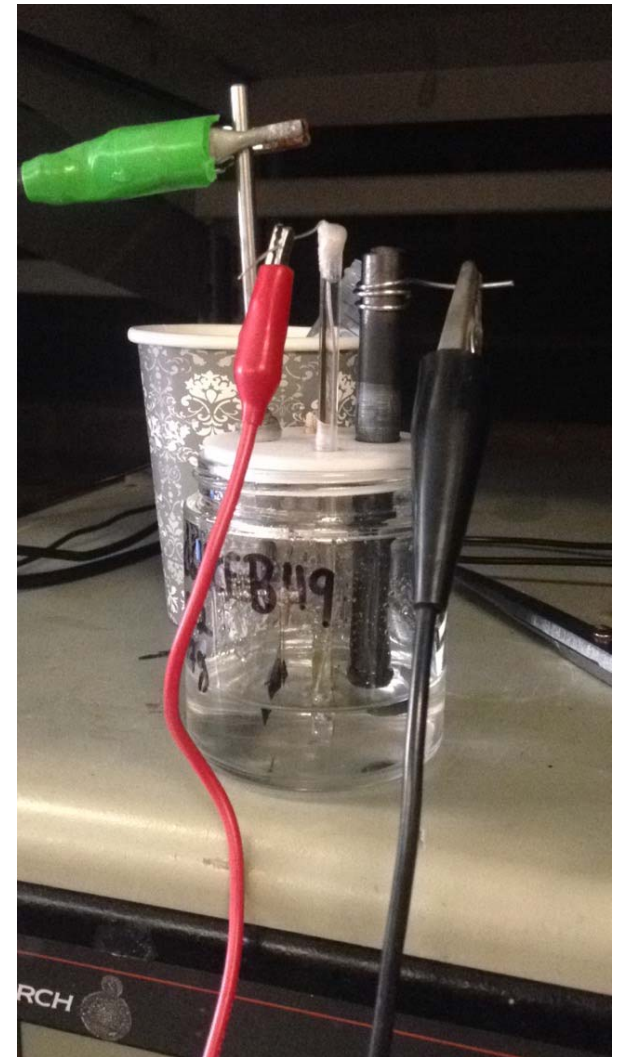


# Testing

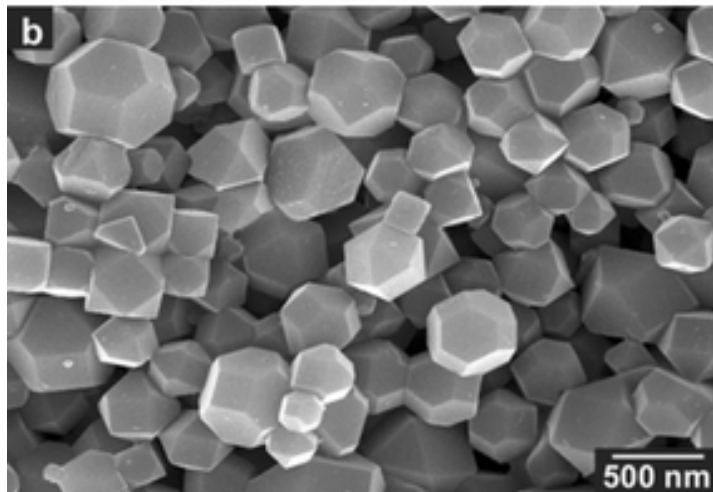
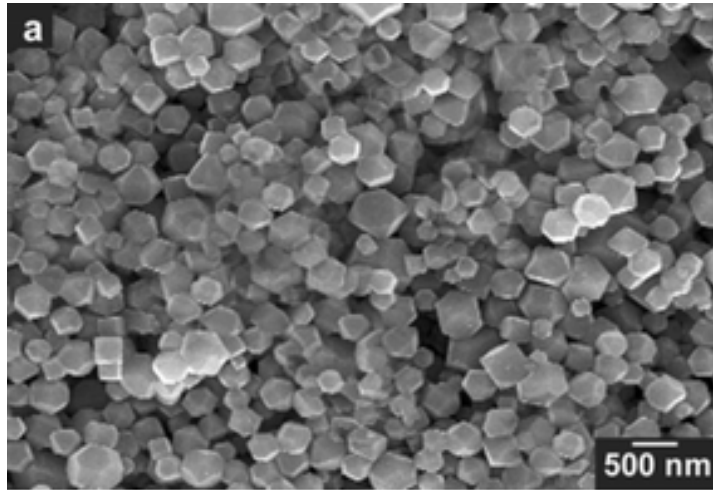
- Set up in three-electrode battery
- Scanning electron microscope (SEM)
- Cyclic voltammetry
- Galvanic cycling

# Three-electrode Battery

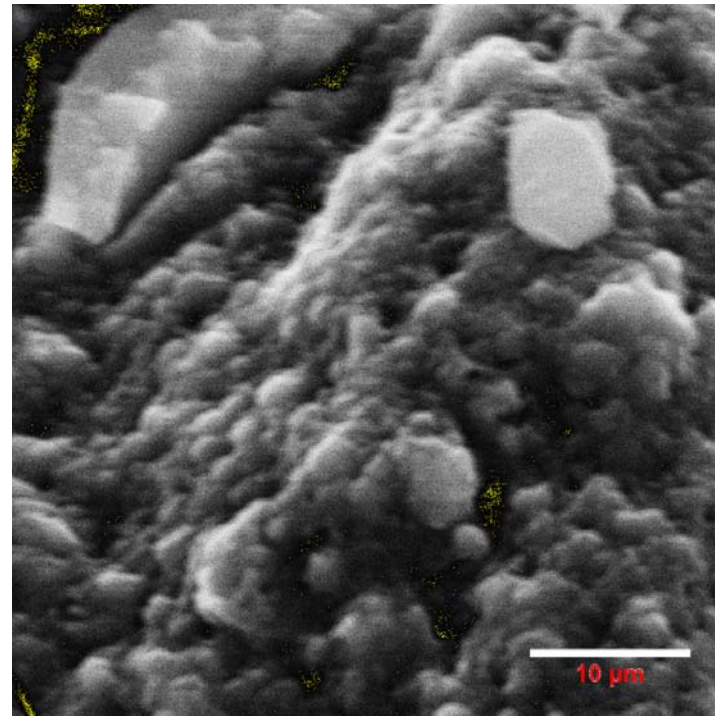
- Working electrode – painted carbon tape
- Reference electrode – glass tube with silver nitrate and small silver metal rod
- Anode/Negative electrode – graphite rod
- Placed in electrolyte.



# Results – SEM NiCoHCF vs. PB

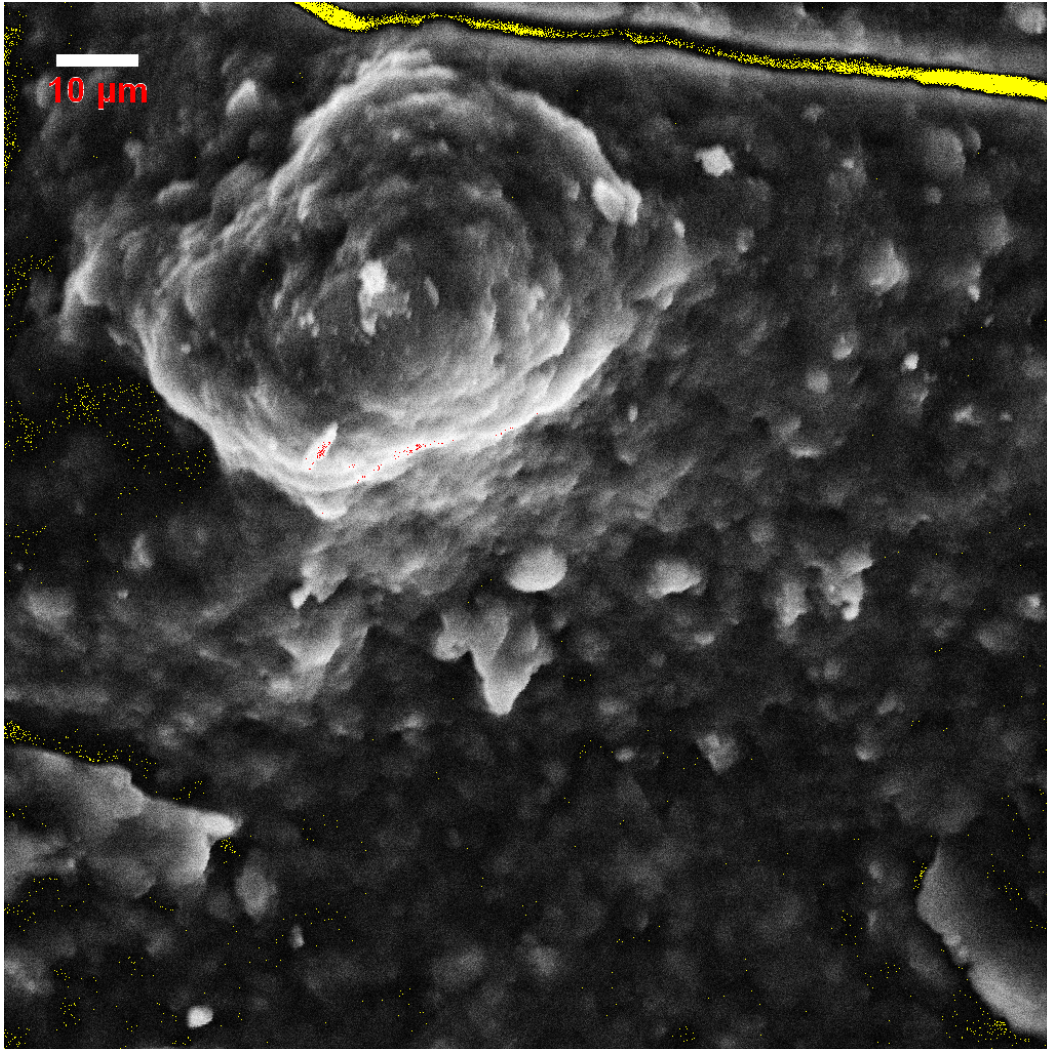


Prussian blue SEM image, cubical



NiCoHCF SEM image

# SEM – NiCoHCF

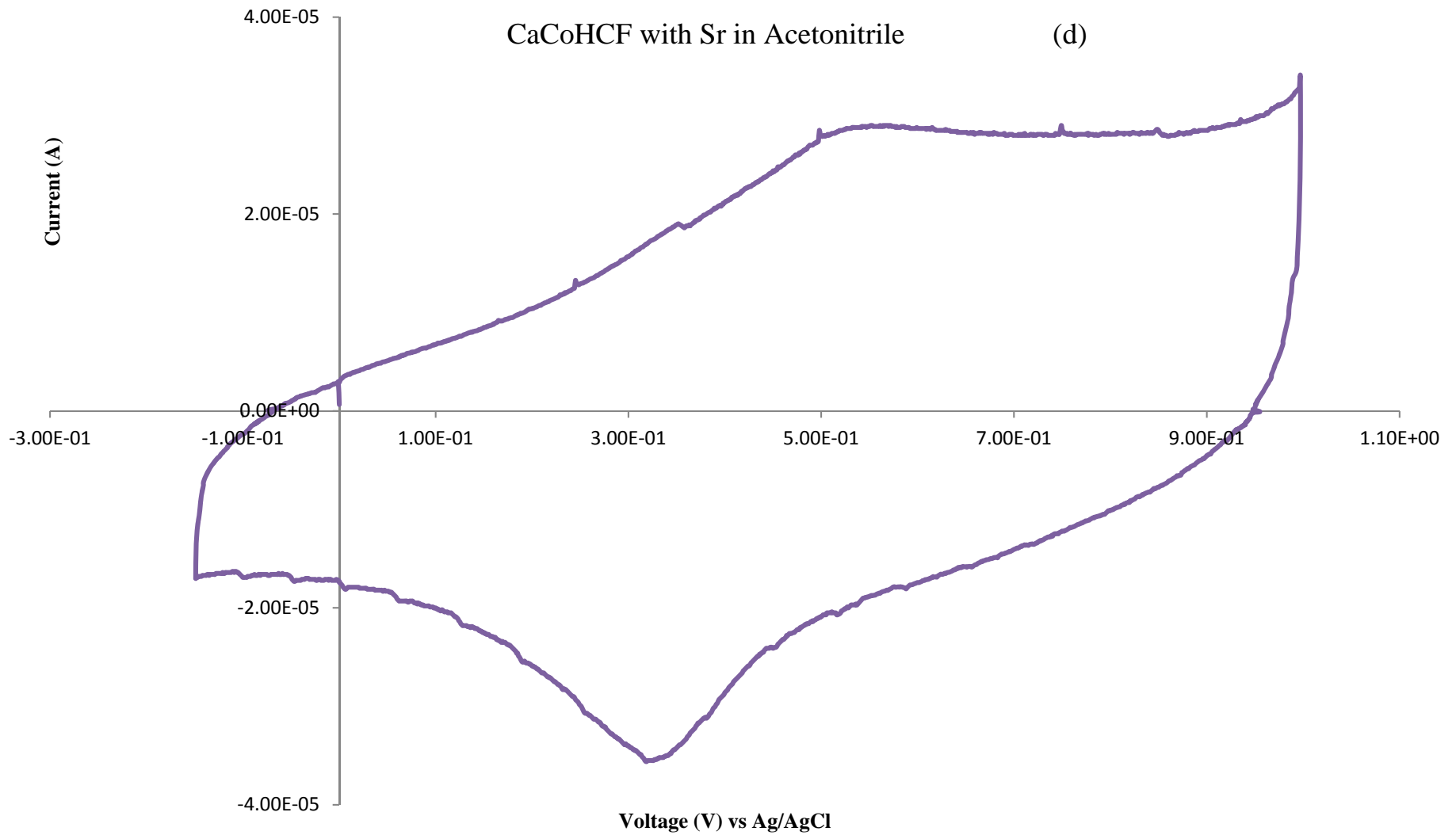


NiCoHCF stacked particle SEM image

# Cyclic Voltammetry

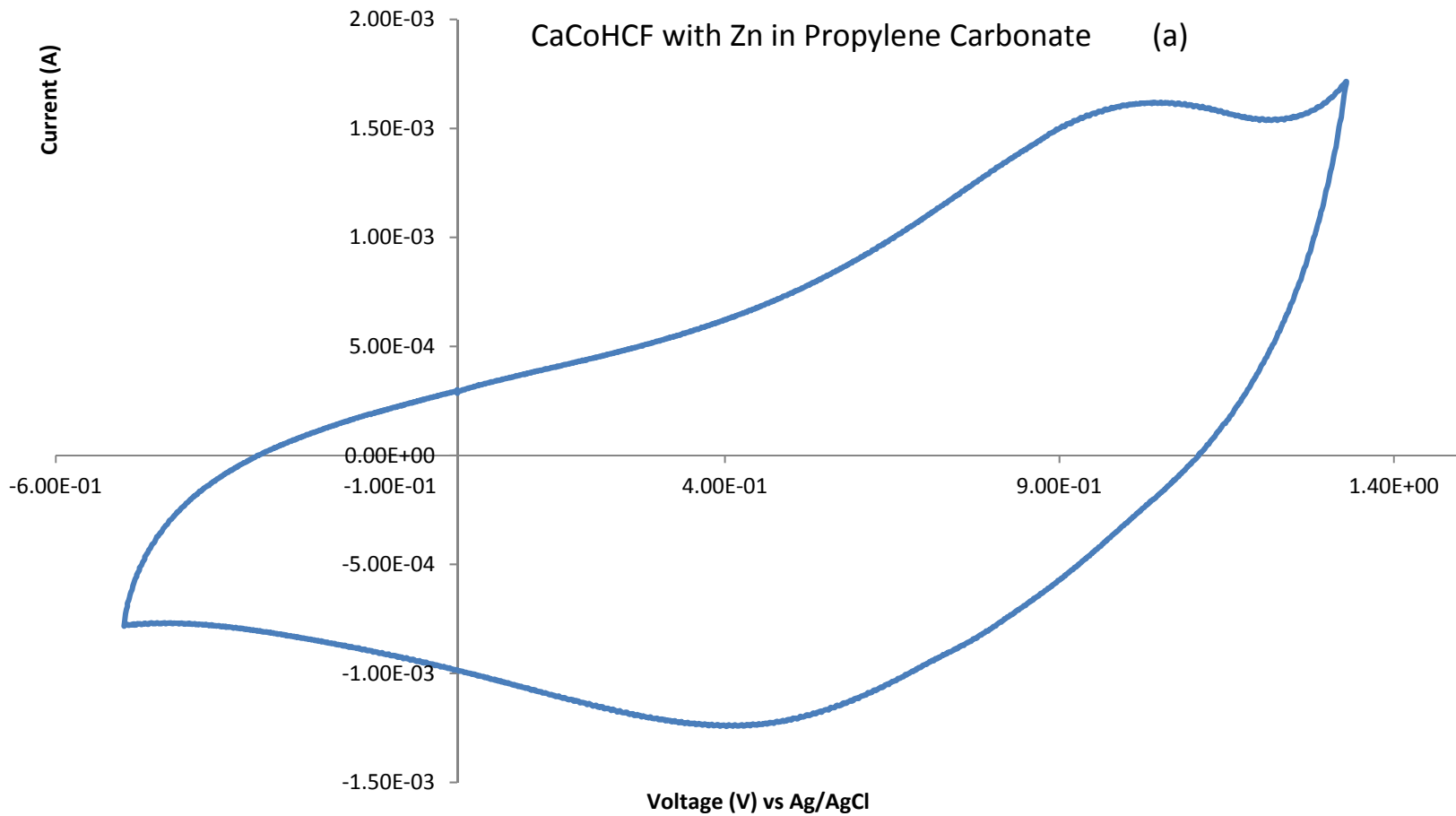
- Applying voltage to the battery and observing the current.
- Plot of Current versus applied Voltage
- Looking for multiple peaks in graph.

# Cyclic Voltammetry example



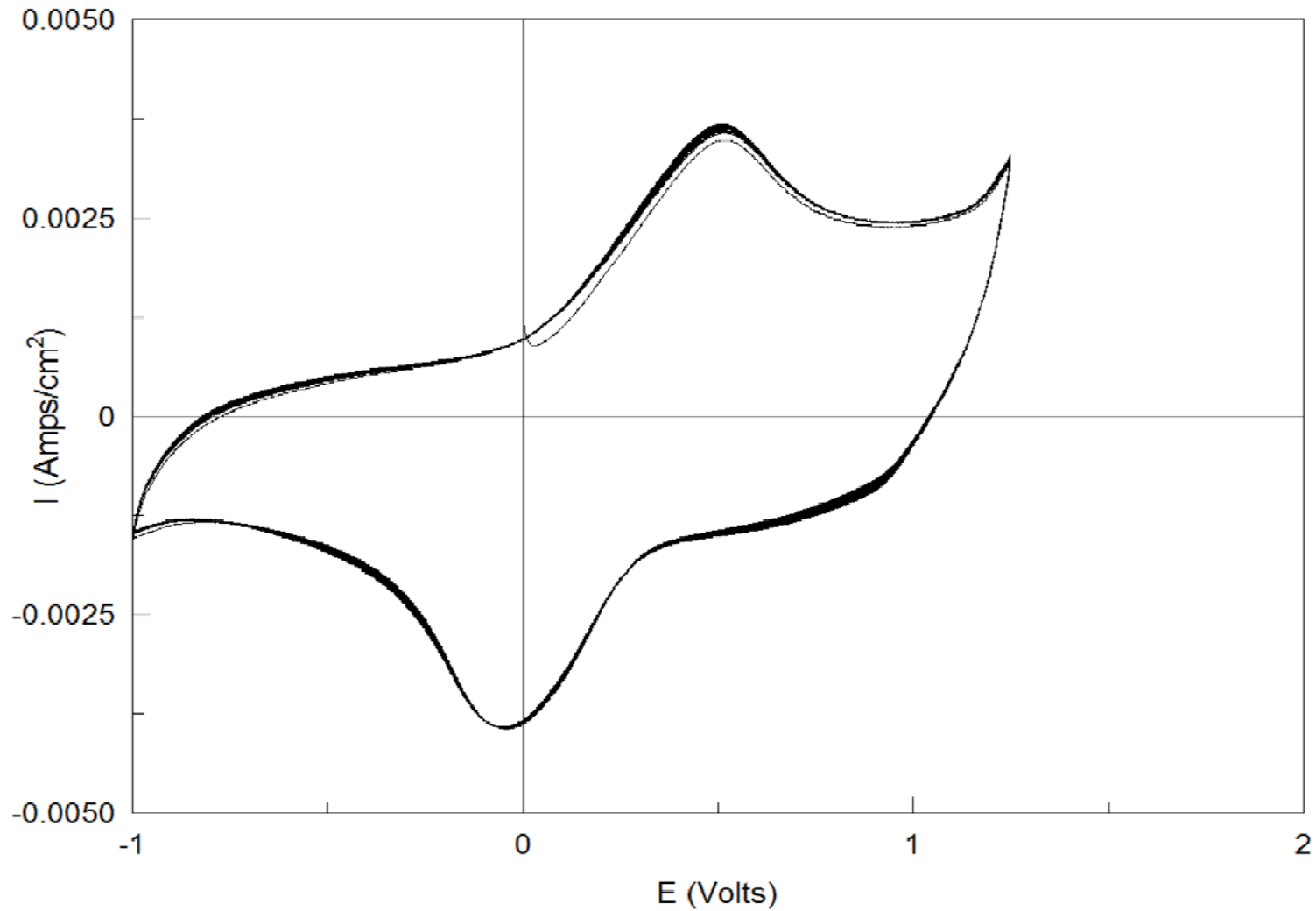


# Cyclic Voltammetry



# Cyclic Voltammetry – NiCoHCF

NaCoHCF with Na Perchlorate in PC-EC



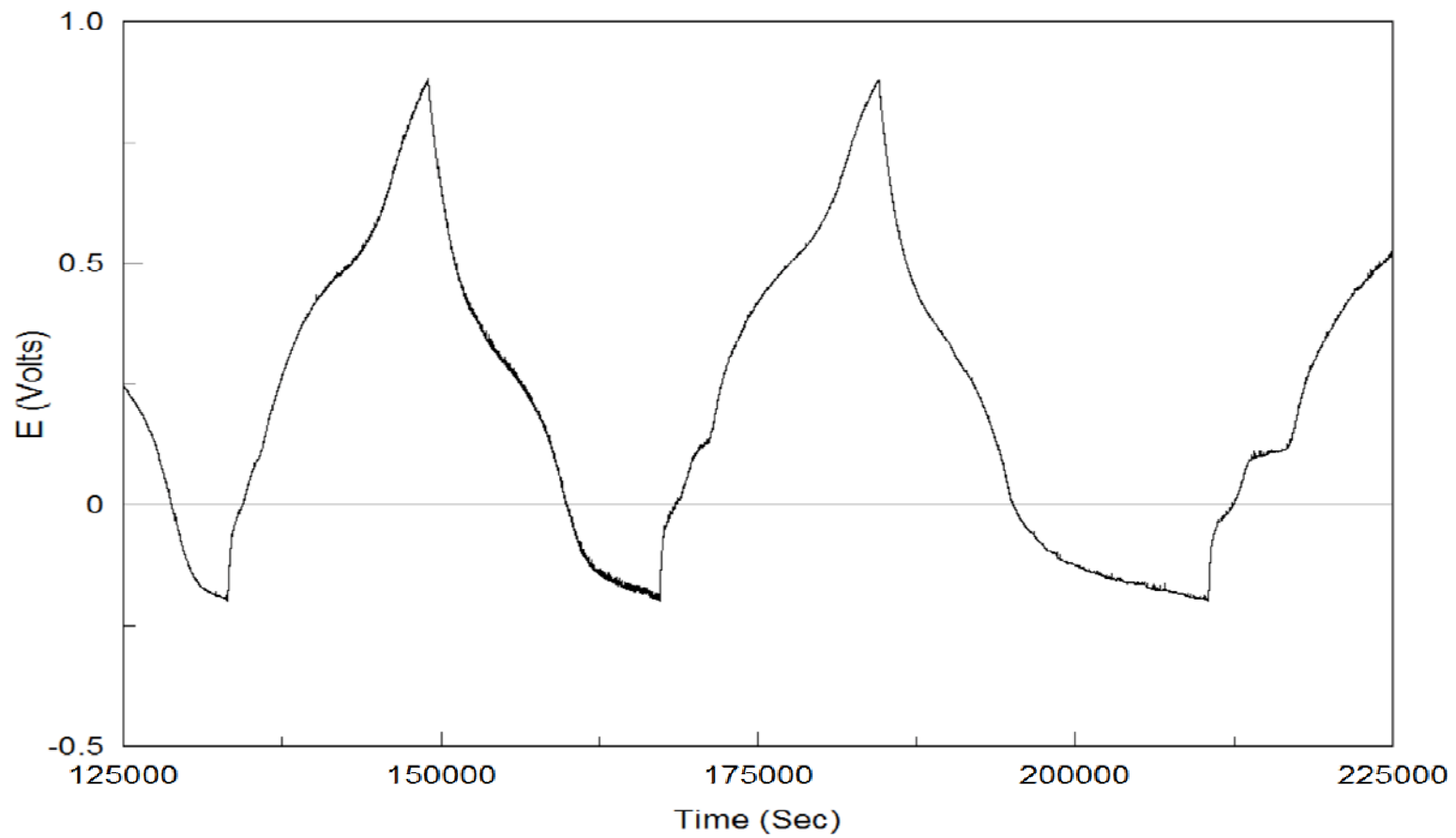
# Galvanic Cycling

- Testing charge/discharge
- Voltage vs. Time
- Provides quantitative and electrochemical information about battery

# Galvanic Cycling – NiCoHCF

NiCoHCF with Na Perchlorate in PC:EC

Electrode 2 (.7mg) Counter Electrode 12 with Na Perchlorate in PC-EC (1-to-1) (1molar) Dried with sieves 25mA per g (17.5microAmps) 20 cycles



# Discussion/Future applications

- Continue testing mixed metal hexacyanoferrate and hexacyanocobaltates
- Attempt to understand the framework and further understand the electrochemical properties.
- Exciting new properties to explore that may create efficient batteries.

# Acknowledgments

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