High-Voltage Solid Polymer Batteries for Electric Drive Vehicles

Hany Eitouni, PhD

Seeo, Inc.

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Project #: ES129

Overview

Timeline

- Start October 2011
- End September 2014
- 80% complete

Barriers

- Barriers addressed:
  - A. Battery cost
  - C. Performance: Energy Density
  - E. Lifetime
- Targets – prototype cells exhibiting:
  - >515 Wh/l, >325 Wh/kg
  - >1000 cycles, 15 yr calendar life

Budget

- Total funding
  - DOE share: $4.9M
  - Contractor share: $2.1M
- Funding received in FY13: $2.1M
- Funding for FY14: $1.3M

Partners

- Hydro-Québec (IREQ):
  - Li anode development
    - For baseline, interim & final deliverable cells
    - Supports commercialization plan
  - Safety & Abuse Testing

Relevance: Project Objectives

- Delivery of baseline low-voltage cells to demonstrate the safety, stability and performance of Seeo's nanostructured polymer electrolyte (NPE) using high capacity Li anodes
- Delivery of advanced high energy cells utilizing a layered solid electrolyte, Li anode and high-voltage cathode material
- Full performance evaluation and validation of specifications, with results from USABC safety and performance testing
- Analysis of the commercial and manufacturing potential and impact of advanced high energy cells

Relevance: Project Milestones

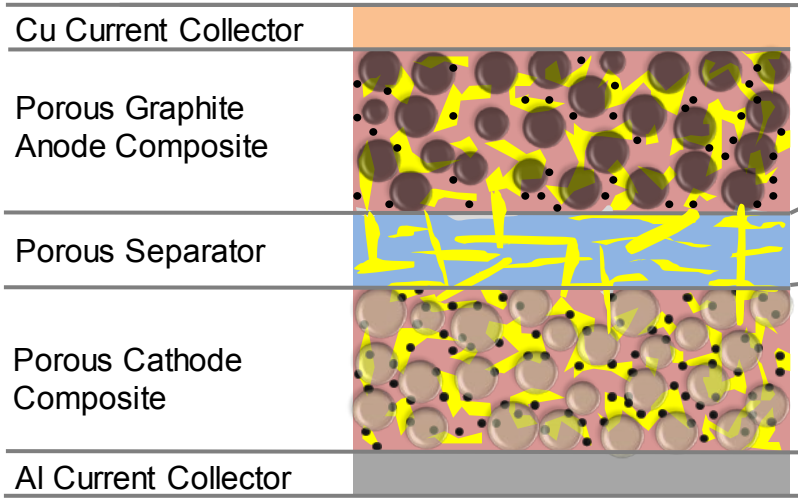
Milestone	Planned Completion Date	Comments	Status
Baseline Cells Delivered to DOE	6/30/2012	Tested by Argonne National Lab (Ira Bloom)	Complete
Active Material Structure Specified	1/15/2013	Internal milestone	Complete
Cathode Batches to Specification	6/30/2013	Internal milestone	Complete
Catholyte Polymer to Specification	12/31/2013	Internal milestone	Complete
Interim Cells Delivered to DOE	1/15/2014	Tested by Argonne National Lab (David Robertson)	Complete
Final Cells Testing Completed	9/29/2014		On Schedule
Final Cells Delivered to DOE	9/29/2014		On Schedule
Commercialization Plan Completed	9/29/2014		On Schedule

Approach: Solid Polymer Batteries

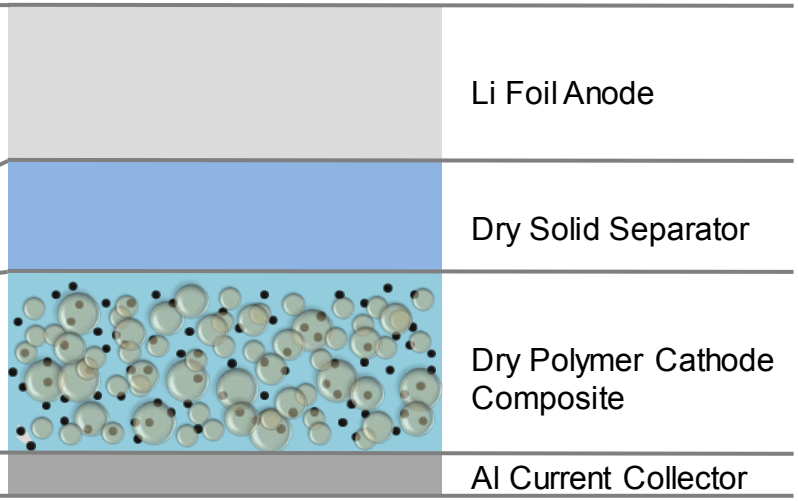
Element	Li-ion	Seeo
Electrolyte	Liquid	Solid
Anode	Porous	Solid
Cathode	Porous	Solid

DryLyte™ Benefits
Safety: Non-flammable and non-volatile
Energy: Superior specific energy (Wh/kg)
Reliability: High temp stability, minimal fade

Conventional Li-ion Battery

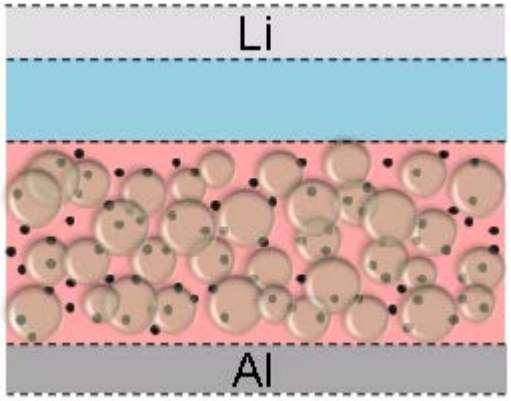


Seeo DryLyte™ Battery



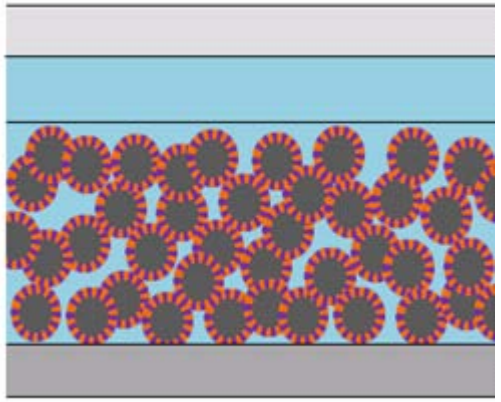
Approach: Decoupling through Solid-state

#1: Bi-layer



- High-voltage stable polymer used as a binder (catholyte)
- Baseline polymer used for Li anode stabilization
- Tuned copolymer structure to minimize interfacial resistance between electrolyte layers

#2 Coated Particle



- Thin layer coatings used on cathode particles
- Baseline polymer used as binder and for Li anode stabilization
- Thin coating layer enables good rate performance

Primary development path

Project plan (high-level)

			2012				2013				2014		
		Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Phase I	**Baseline Evaluation and Material Synthesis**												
1	Baseline Cell Delivery												
2	Cathode Sourcing and Characterization												
3	Mechanical Stabilization of HV Catholyte												
4	Anolyte-Catholyte Interfacial Stability												
Phase II	**Material Formulation and Scale-Up**												
5	Small-Area Cell Validation												
6	Polymer Scale-Up												
Phase III	**Cell Fabrication and Testing**												
7	Large-Area Cell Validation												
8	Stacked Cell Design Iterations												
9	Cell Fabrication & Manufacturability Assessment												
10	Safety and Performance Testing												

Phase I: Establish a baseline level for project evaluation and commence major research activities. Identify and develop high-voltage polymer and cathode materials.

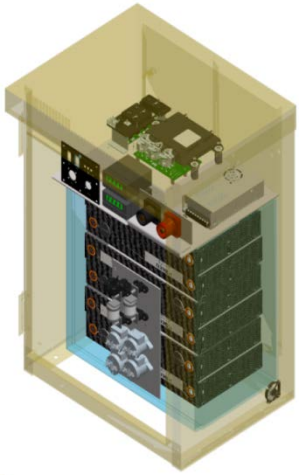
Phase II: Optimize polymer and cathode mechanical and electrochemical properties. Develop volume synthetic techniques, comparing cost and performance.

Phase III: Test and construct prototype cells, validate cell design, establish final specs, and deliver a commercialization plan

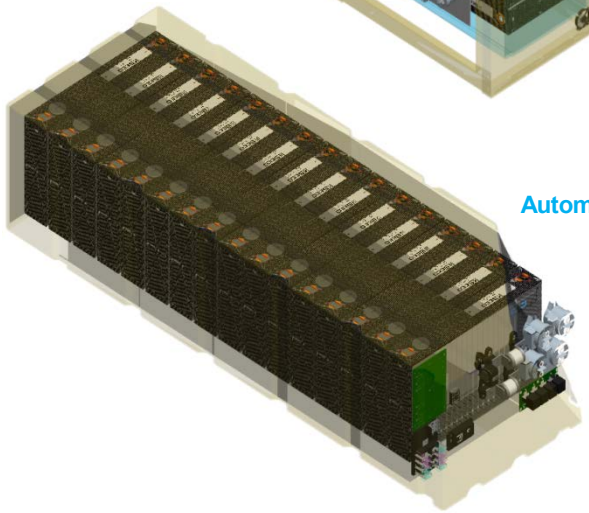
Approach: Build on Baseline Technology

Cell

Alpha3 Module



Stationary energy storage application

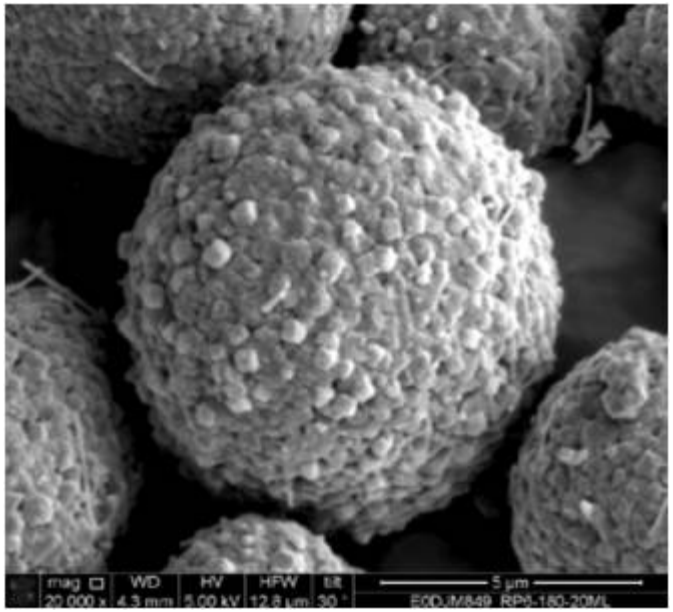


Automotive application

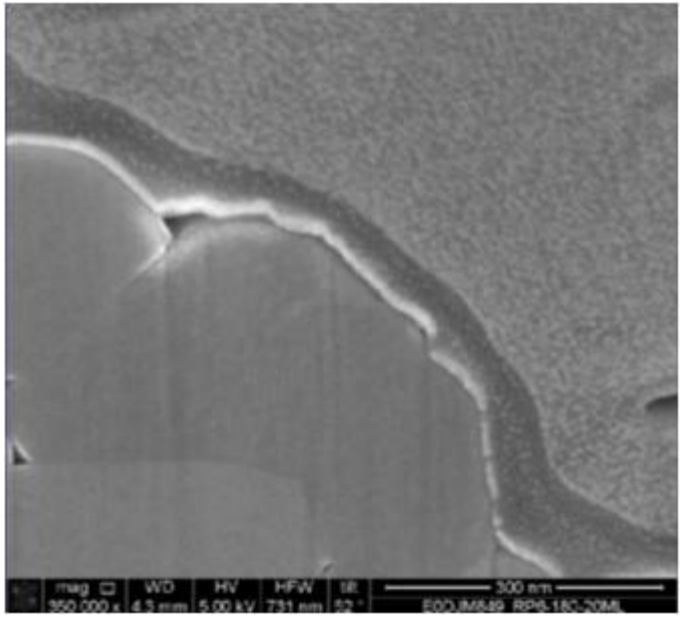
High voltage cells developed w/ support from the VT program will be scaled-up in Seeo's pilot facility & will utilize existing BMS and thermally managed module technologies

Technical Progress: Coatings for Improved Stability

- NCA has been coated and analyzed through microscopy and cell performance



- Coated NCA, 5µm zoom

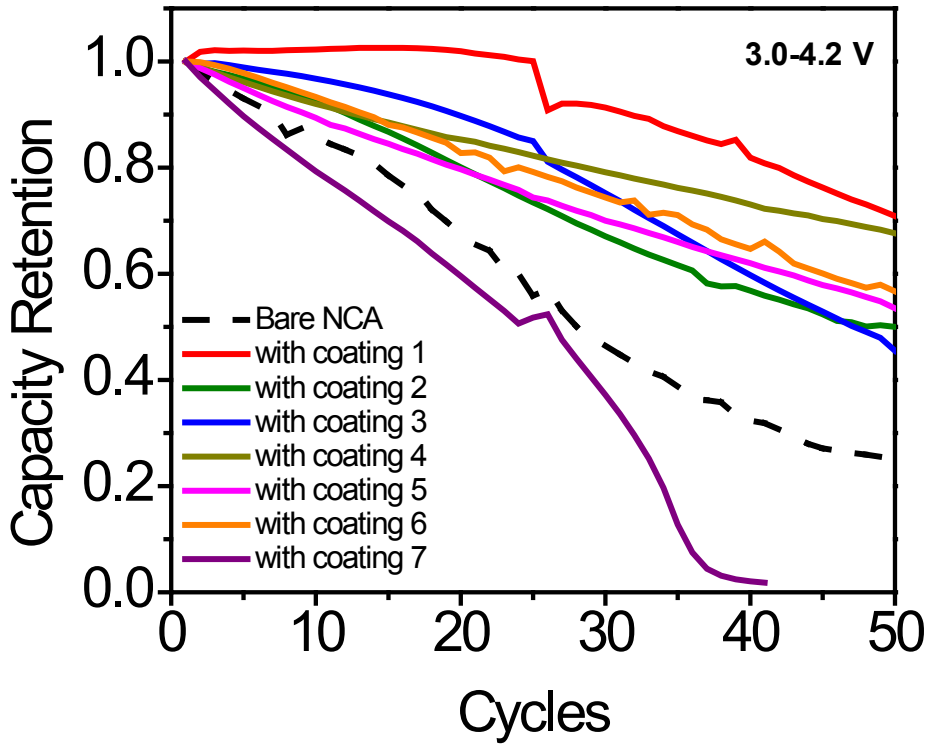


- Coated NCA, 300nm zoom

Numerous coatings on NCA have been evaluated and have shown improved cycling performance compared to uncoated cathodes

Technical Progress: Stability w/ Pre-formed Coatings

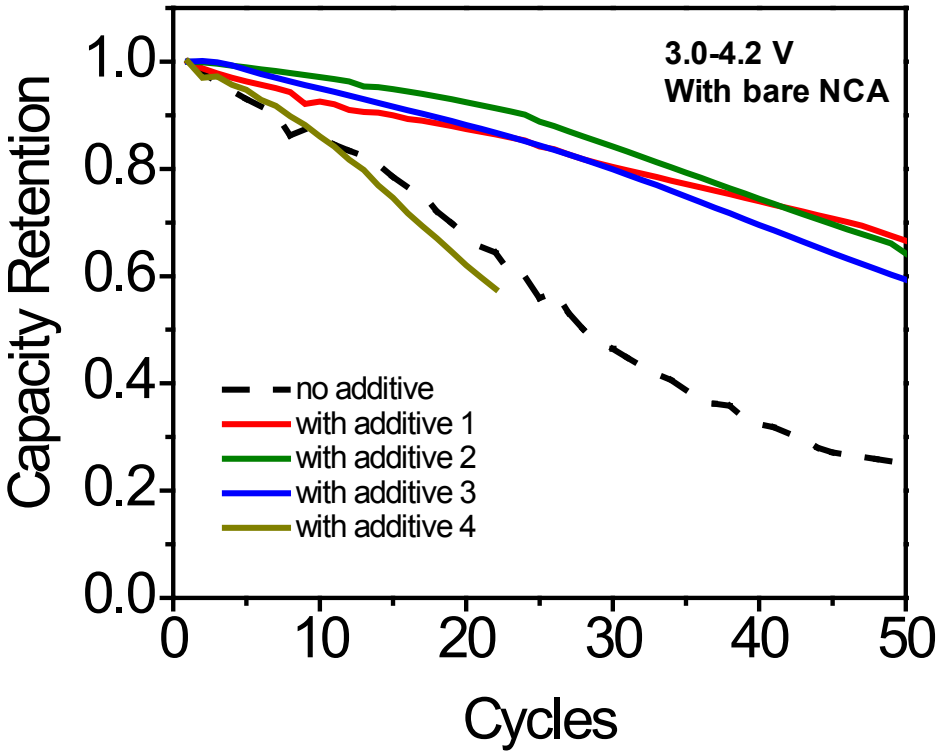
- 7 different pre-formed coatings were tested in Li polymer cells
- 6 coatings improved cycling stability as compared with bare NCA



NCA with Coating 1 showed favorable stability for 25 cycles

Technical Progress: Stability w/ Coating-forming Additives

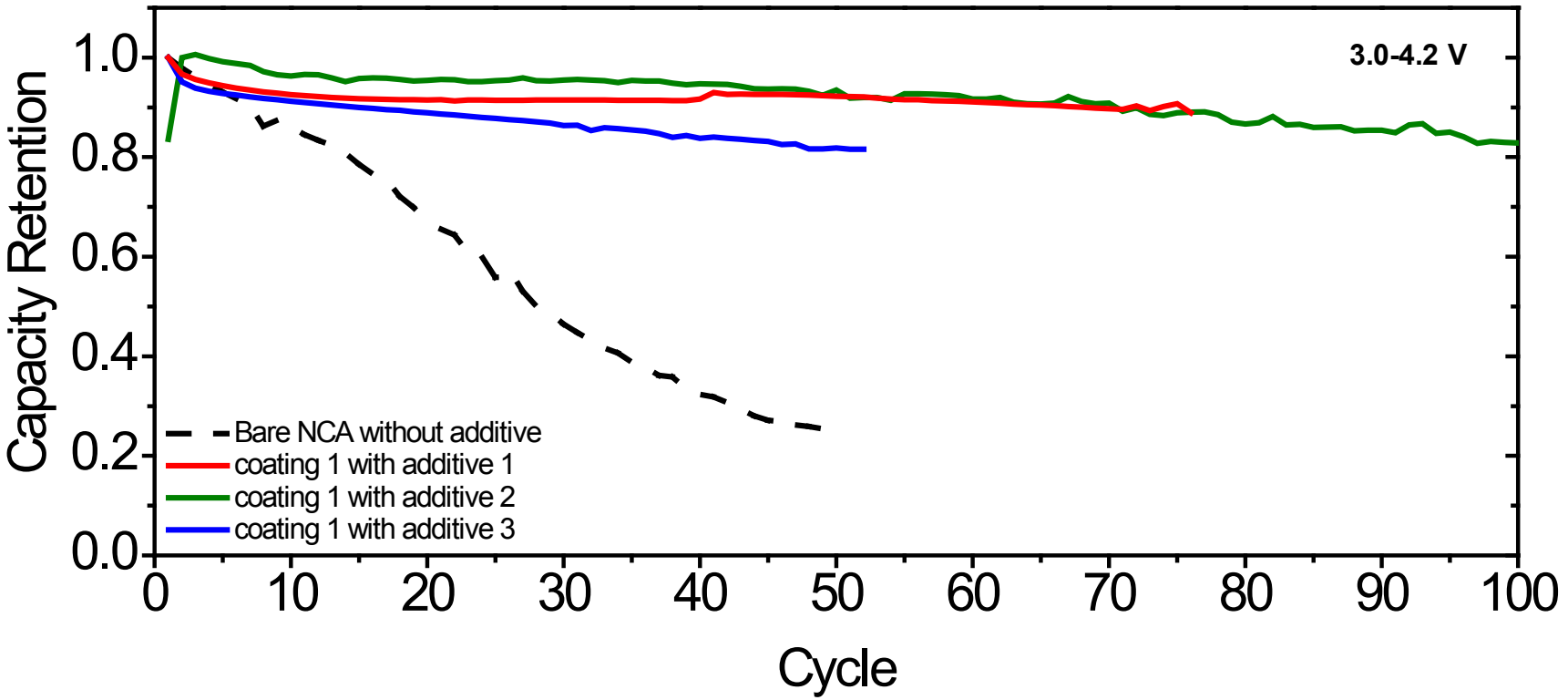
- 4 different additives were tested that could form a coating in-situ during cycling



3 additives improved cycling stability as compared with the bare NCA

Technical Progress: Stability w/ Combined Coating Approach

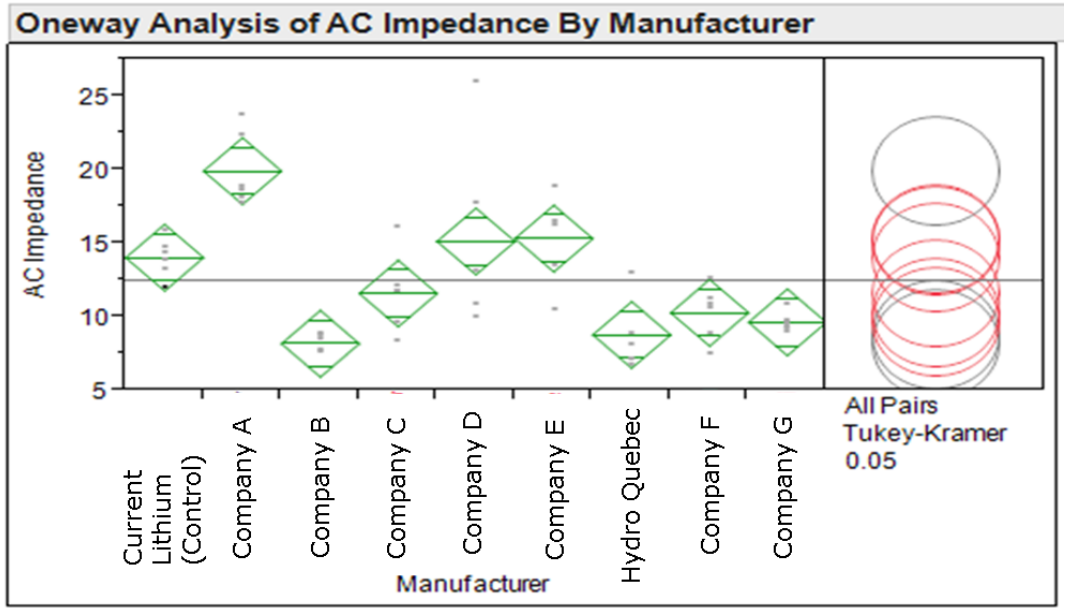
- 3 different coating-forming additives were tested w/ pre-coated NCA



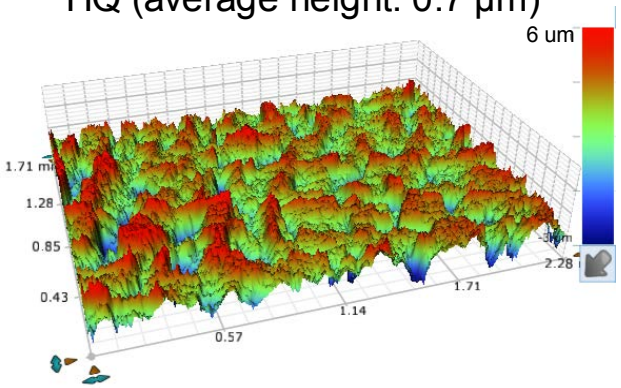
Cells with Additive 1 & 2 combined with the pre-coated NCA show the best stability

Technical Progress: Anode Performance

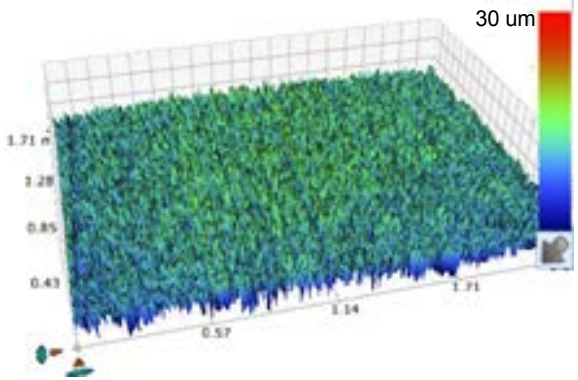
- Studied different lithium foils as a means to improve capacity access and rate capability
- Impedance spectroscopy and white light interferometry were used to measure surface properties



HQ (average height: 0.7 µm)



Control (average height: 1.3 µm)



Hydro-Québec and Company B have statistically lower AC interfacial impedance and surface roughness than the Control Lithium

Response to FY2013 Reviewer Comments

- It was noted by reviewers that the approach of using two solid electrolytes is a novel means to reaching higher voltages, but that it was unclear which of the two presented development paths would be chosen.
  - "two different electrolytes layered this way appears to be a creative and potentially robust solution to the problem of achieving a high voltage lithium-ion cell"
  - "should yield a product that could be used to support the development of a polymer battery that meets the performance requirements"
  - "not clearly stated when the project will decide which approach will be focused on"
  - RESPONSE: Due to conductivity limitations of high-voltage catholytes, Seeo has focused on thin layer coatings on the cathode particles.
- Reviewers suggested that Seeo should have more collaborations, but it was noted that the majority of collaborative work occurs late in the project.
  - "work performed so far shows little if any collaboration with identified partner"
  - "does have work that appears to have more collaboration later on near project end"
  - RESPONSE: Since the last review meeting, Seeo has evaluated Li foils produced by its collaboration partner, and the partner has performed failure analysis of Seeo's R&D cells.
- Multiple reviewers expressed concern with the low temperature polymer conductivity.
  - "some concern that the low temperature performance issue does not appear to have sufficient focus"
  - "solid state electrolyte conductivity is not acceptable at 25C"
  - RESPONSE: Seeo's technology is a high temperature system that is thermally managed at the module level. A slide showing the module and pack has been included in this presentation.

- Institut de recherche d'Hydro-Québec (IREQ):
  - Develop Li foil for interim and final cell deliverables
  - Perform safety and performance testing
  - Assess manufacturing costs for high capacity anodes
- Cathode suppliers
  - Working with 2 commercial suppliers of high-voltage cathode materials for testing with candidate catholyte materials

Future Work: Phase III Focus

Project plan (high-level)

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Phase III Workstream Focus

7: Scale-up material synthesis and optimize design of single-stack, large-area cells

8: Develop stacked cell design and evaluate rate, resistance and cycling stability performance

9: Evaluate high-volume manufacturing costs and risks using data from baseline cell production

10: Conduct performance and safety testing on R&D cells designed to final spec; deliver to DOE

Future Work: Upcoming Milestones

Milestone	Planned Completion Date
Final Cells Testing Completed	9/29/2014
Final Cells Delivered to DOE	9/29/2014
Commercialization Plan Completed	9/29/2014

- Seeo has developed a proprietary nanostructured polymer electrolyte (NPE) that is stable against high capacity anodes
  - Seeo has delivered baseline and interim cells demonstrating this stability to Argonne National Labs with support from the Vehicle Technologies program
- In FY13, Seeo focused on evaluating two approaches for coating and stabilizing high-voltage cathode materials in NPE cells
  - First approach uses pre-coated cathode materials to provide voltage stability
  - Second approach uses additives that react in-situ to form coatings on the cathode particles
- Solid-state, high-energy cells represent a distinct opportunity for the United States to build a viable battery manufacturing industry
- With support from DOE, Seeo has commitment from our private investors for the full duration of this project