High-Voltage Solid Polymer Batteries for Electric Drive Vehicles

Hany Eitouni, PhD
Seeo, Inc.
May 2013

Project #: ES129

Overview

Timeline

- Start October 2011
- End September 2014
- 30% complete

Barriers

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

Budget

- Total funding
  - DOE share: $4.9M
  - Contractor share: $2.1M
- Funding received in FY12: $1.2M
- Funding for FY13: $2.0M

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

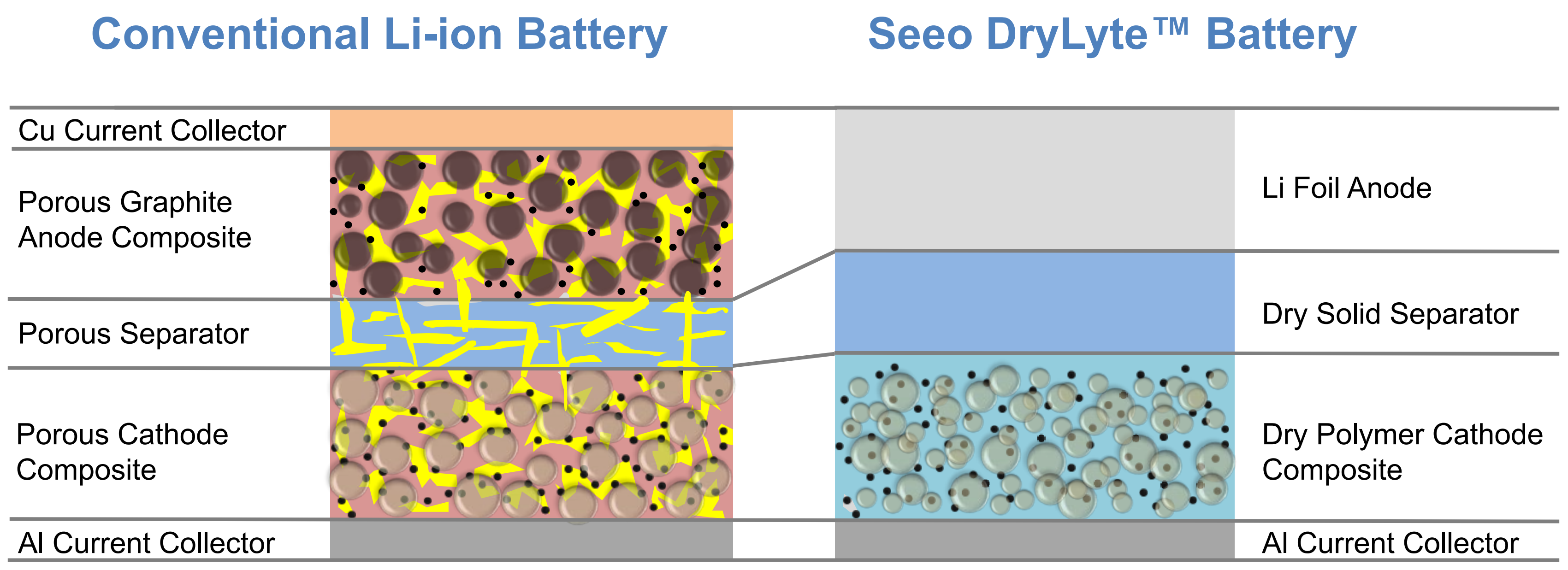
Relevance: Project milestones

Milestone	Planned Completion Date	Actual Completion Date	Comments
Baseline Cells Delivered to DOE	6/30/2012	7/12/2012	Delay in receiving shipping clearance for cells Tested by Argonne National Labs (Ira Bloom)
Active Material Structure Specified	1/15/2013	1/15/2013	
Cathode Batches to Specification	6/30/2013		
Catholyte Polymer to Specification	12/31/2013		
Interim Cells Delivered to DOE	1/15/2014		
Final Cells Testing Completed	9/29/2014		
Final Cells Delivered to DOE	9/29/2014		
Commercialization Plan Completed	9/29/2014		

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



Approach: Project phasing

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												

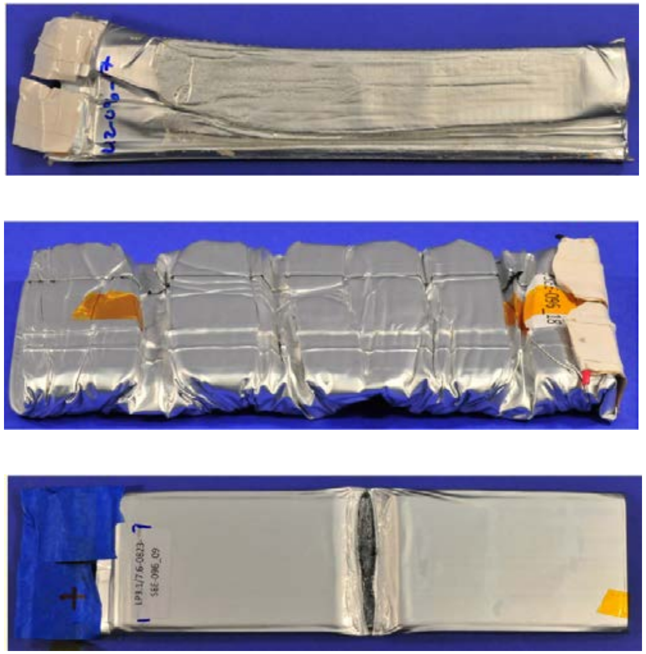
Phase I: Establish a baseline level for project evaluation and commence major research activities. Identify and develop high-voltage polymer and cathode materials.

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

Progress: Baseline cells

X-Axis
Y-Axis
Z-Axis



Seeo LFP cells: post-crush testing, no smoke or flames, avg. 20 C dT

Exponent® 4

1205347.000 A0F0 0912 AA01

Test Summary

All tests unless stated otherwise were performed at an ambient temperature of 80°C

Test Name	Sample #	USABC	Test Results	Cell Temperature Rise (°C)	UL1642 (Pass/Fail)
Short-Circuit Test	1	Apply a hard short (< 5 mΩ) for 10 minutes or until another condition prevents completion of the test	No smoke or flames	20	Pass
	2			21	Pass
	3			19	Pass
Over-Discharge	1	Cell discharged to 150% of rated capacity	No smoke or flames	4	N/A
Over-Charge	1	Charge cell to 200% of rated capacity	No smoke or flames	5	N/A
	2			26	N/A
	3			5	N/A

DRAFT – Privileged & Confidential

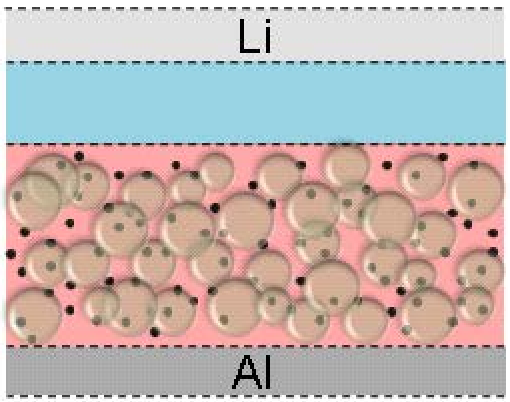
E^x(40)

Example Test Report: Short Circuit, Overdischarge, Overcharge

- Safety testing conducted on large-format Li-LFP cells
- Safety tested by 3rd party labs (independent of DOE VT contract)
- Safety testing for high-voltage cells scheduled for Phase 3

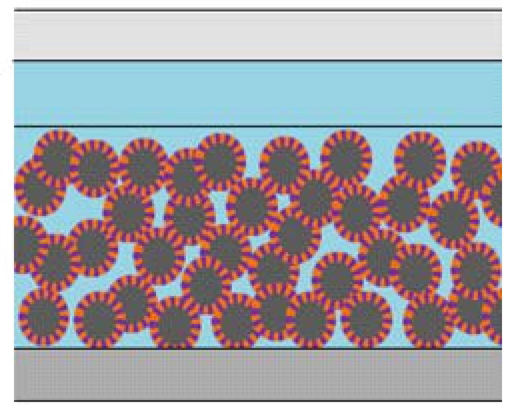
Progress: Decoupling through solid-state

#1: Bi-layer



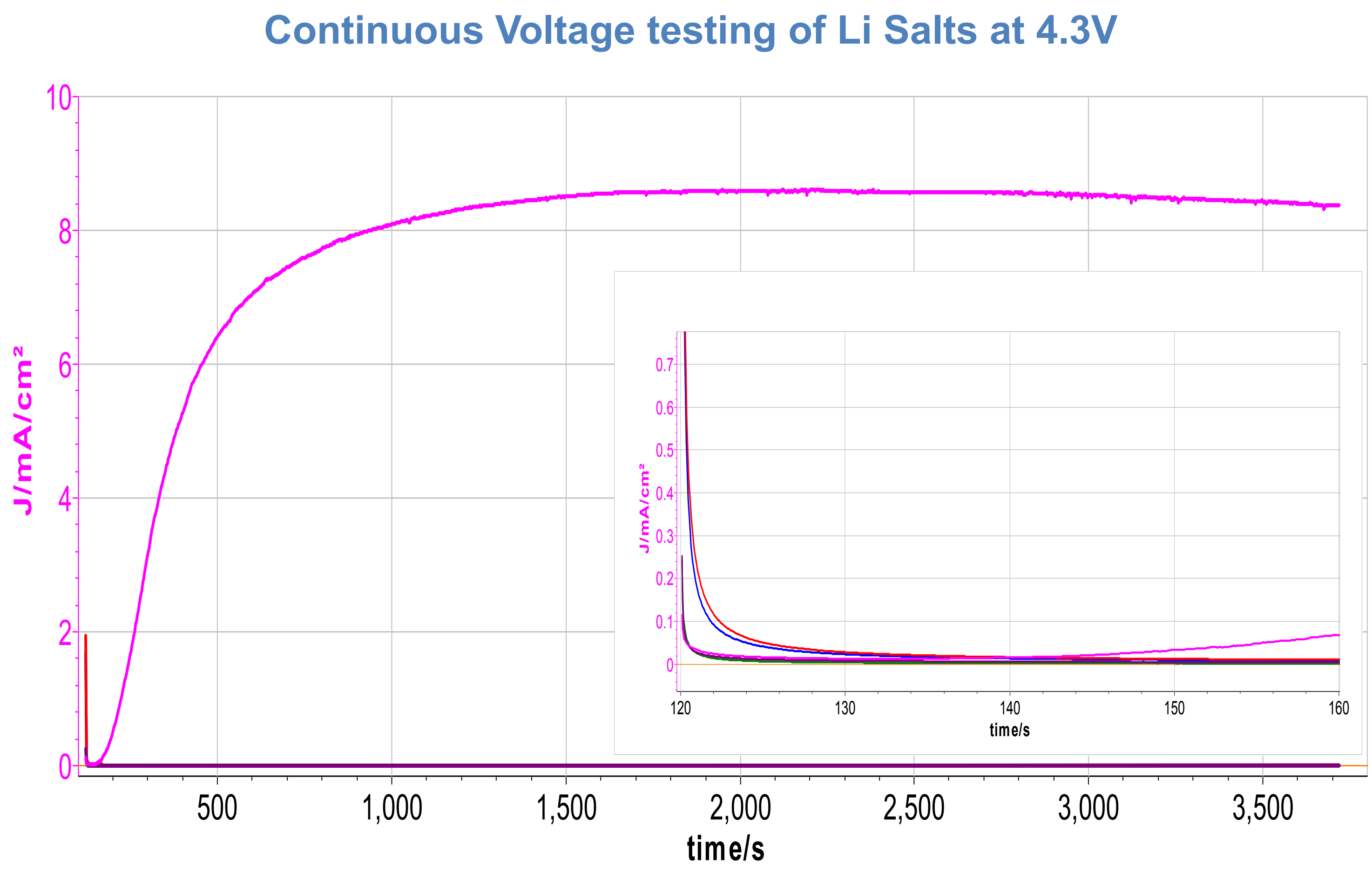
- High-voltage stable polymer used as a binder (catholyte)
- Baseline polymer used for Li anode stabilization
- Tuned copolymer structure to minimize interfacial resistance between electrolyte layers

#2 Coated Particle



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

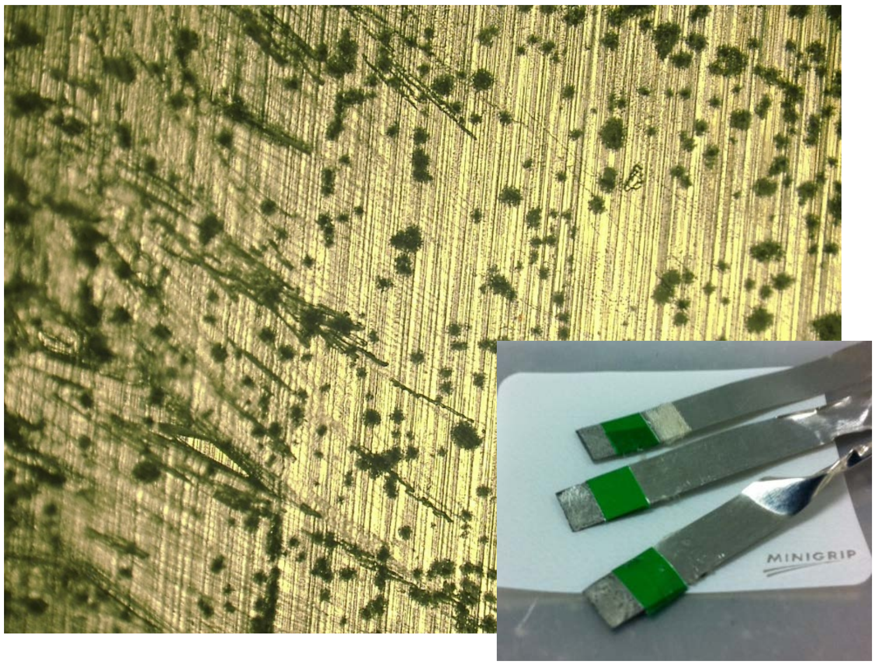
Progress: Conductive salts for catholyte



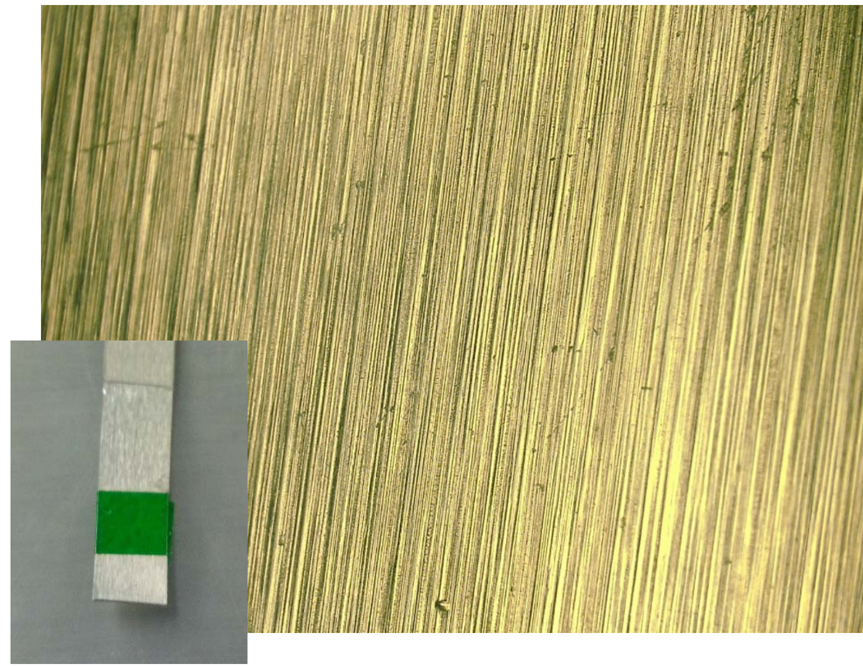
Salts with higher voltage stability than the salt used in baseline cells are being evaluated with candidate HV polymers

Progress: Conductive salts for catholyte

Salt solutions exposed to 4.3V (Li counter electrode, EC/DMC electrolyte)



Corroded Al electrode using Baseline salt

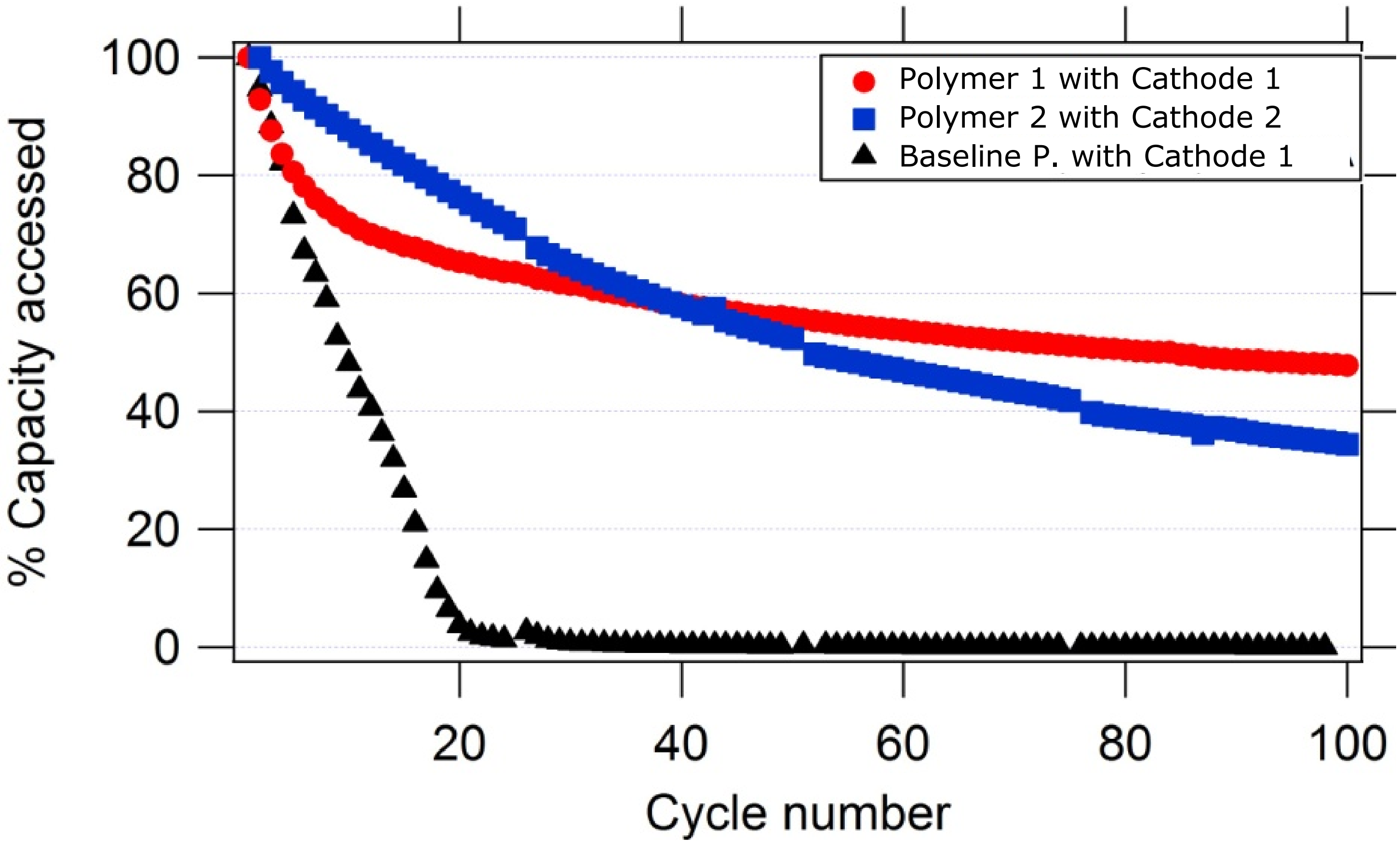


Pristine Al electrode using HV salt

Electrode corrosion demonstrates HV salt stability in cells

Progress: Catholyte stability exceeds baseline

Approach #1: Bi-layer system with HV catholyte



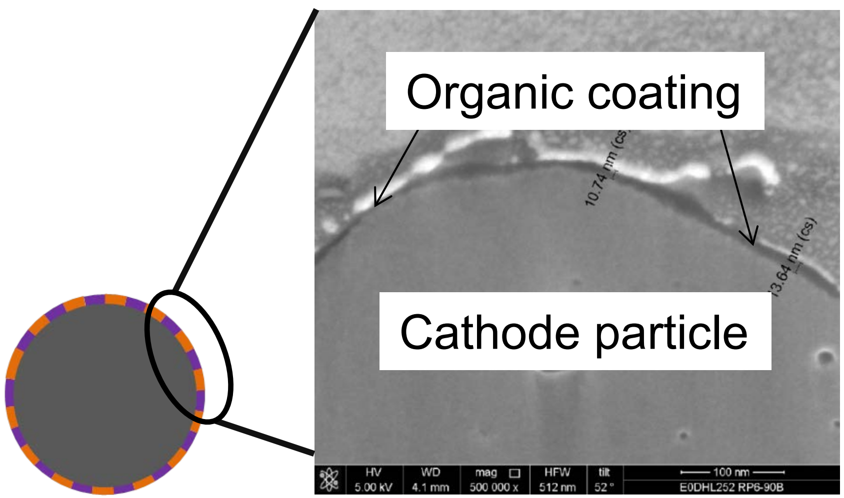
HV polymers show stability over the baseline when paired with HV cathodes

Additional development to achieve stability targets is required

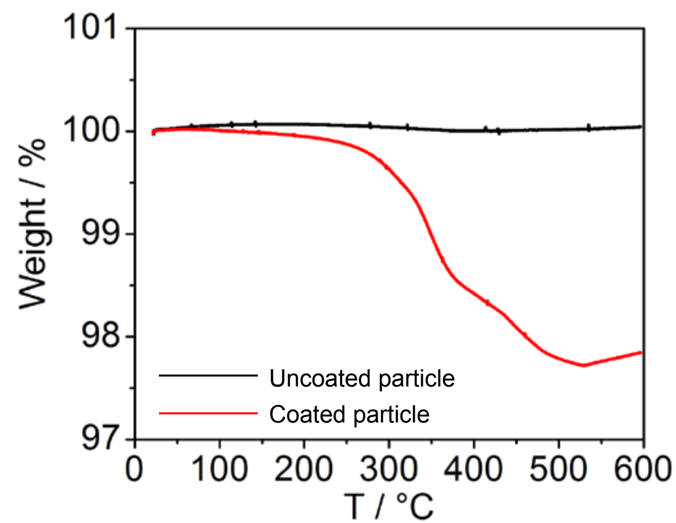
Progress: Organic coatings on particles

Approach #2: Coatings on HV cathode particles

SEM of coated particle



TGA of coated cathode particle



SEM of coated particles shows conformal polymer-coating

TGA of "coated and washed" particles shows weight loss, indicating adherent polymer coatings

Organic coatings appear to adhere to the cathode particles' surface

Collaborations: Technical partners

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

Future work: Phase II Focus

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**	**Lead**												
1	Baseline Cell Delivery	Seeo												
2	Cathode Sourcing and Characterization	Seeo												
3	Mechanical Stabilization of HV Catholyte	Seeo												
4	Anolyte-Catholyte Interfacial Stability	Seeo												
Phase II	**Material Formulation and Scale-Up**													
5	Small-Area Cell Validation	Seeo												
6	Polymer Scale-Up	Seeo												
Phase III	**Cell Fabrication and Testing**													
7	Large-Area Cell Validation	Seeo/HQ												
8	Stacked Cell Design Iterations	Seeo												
9	Cell Fabrication & Manufacturability Assessment	Seeo												
10	Safety and Performance Testing	HQ												

Phase II Workstream Focus

5: Evaluate cathode, polymer and salt combinations in small-area full-cells. Investigate techniques for stabilization of cathode, salt and polymer composites

4: Develop block copolymers based on candidate materials and tune mechanical and electrochemical properties to minimize interfacial resistance with Seeo anolyte

6: Develop, test and evaluate scale-up methods for high-voltage catholyte block copolymers

Future work: Upcoming milestones

Milestone	Planned Completion Date
Cathode Batches to Specification	6/30/2013
Catholyte Polymer to Specification	12/31/2013
Interim Cells Delivered to DOE	1/15/2014

Summary

- Seeo has developed a proprietary nanostructured polymer electrolyte (NPE) that is stable against high capacity anodes
  - Seeo has delivered baseline cells demonstrating this stability to Argonne National Labs with support from the Vehicle Technologies program
- In FY12, Seeo focused on evaluating two approaches for developing a NPE-based platform for high-voltage materials
  - First approach focused on developing high-voltage stable polymers that function as the binder in the cathode, and has shown promising results
  - Second approach uses polymer and ceramic coatings to provide voltage stability while minimizing the reduction in ionic conductivity
- 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

SEEO

Thank you