Vehicles Technology Office
2016 Annual Merit Review

Electrodeposition for Low-Cost, Water-Based Electrode Manufacturing

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June 9, 2016

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Navitas – Mike Wixom, Pu Zhang

Project ID: ES263

Overview

Timeline

- January 1, 2016
- December 31, 2018
- Eight Percent Complete

Barriers

- High material processing costs
- High manufacturing costs

Budget

- Total Funding: $3,999,034
- DOE Share: $1,399,275
- FFRDC: $1,600,000
- Cost Share: $999,759
- 2015 DOE Funding: $0
- 2016 DOE Funding: $437,430

Partners

- Argonne National Lab
- Oak Ridge National Lab
- Navitas Systems

Relevance

Advances in Electrode and Cell Fabrication Mfg.

Current: NMP-based slot-die coating system

Proposed: Efficient water-based electrocoat system

Project Objectives

- Utilize Advanced Electrodeposition Coating Materials and Application Process to Produce Battery Electrodes

Materials

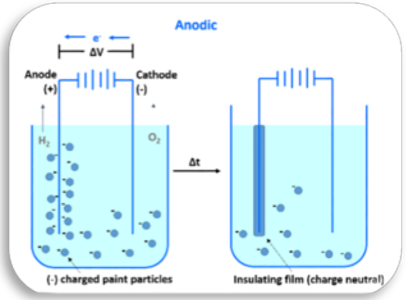
- Novel binders and cathode active materials

Electrocoat Application

- Improve battery performance
- Reduce cell costs by at least 20%

Supply Chain Model

- Mirror traditional automotive OEM supply chain
- Reduce risk and increases adoption



Relevance

Leveraging the Advantages of Electrocoat

Formulation

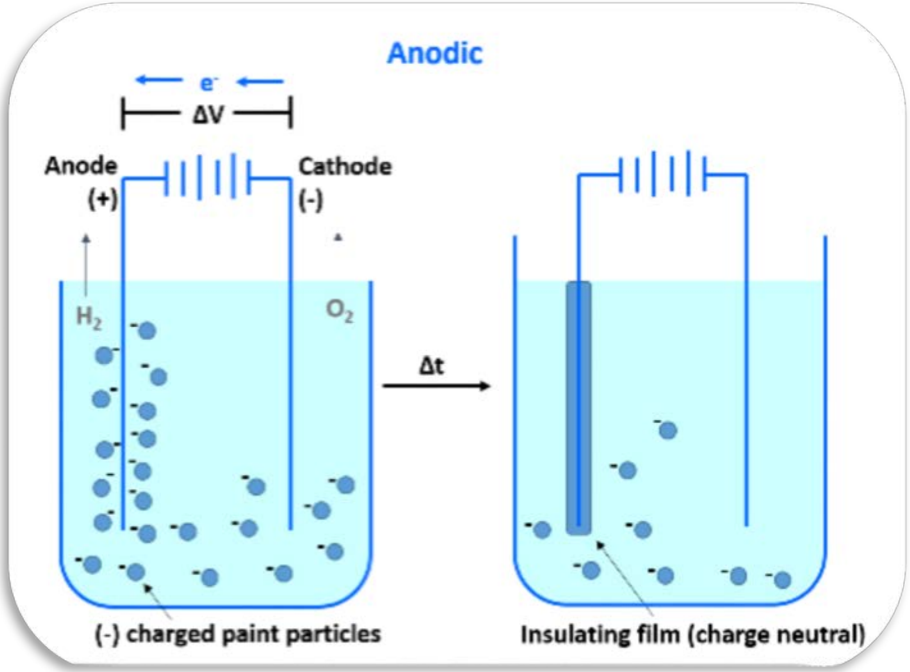
- Low solids, low viscosity bath
- Waterborne, NMP-free

Coating

- Uniform film build
- High density film
- Additives stay in bath

Process

- Coat both sides simultaneously
- High transfer efficiency
- Highly automated
- Scalable, High throughput
- Low cost, low emissions

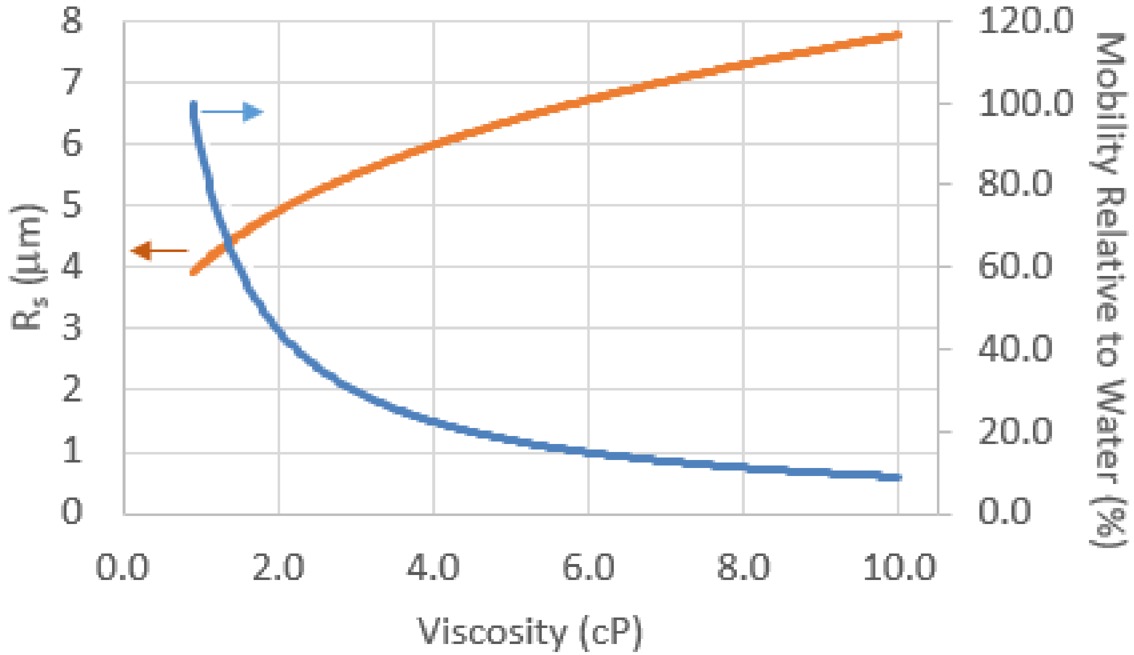


Project Milestones

Budget Period	Task	Description	Finish
1. Materials Development	1	Electrochemical Performance Demonstrated	3/31/16
	1	Active Material Identified	9/30/16
	1	Candidate Resin Identified	12/30/16
	2	Development Process Established	6/30/16
2. Process Development	3	Parameters optimized	6/30/17
	3	Cell Testing Complete	9/29/17
	4	Mini-Coater Built	12/29/17
	5	Cost Estimate Updated	3/31/17
3. Scale-up and Demo.	6	Electrodes Produced	3/30/18
	7	Build 1 Complete	6/29/18
	7	Build 2 Complete	9/28/18
	7	Failure Mechanisms Identified	12/31/18

Approach/Strategy

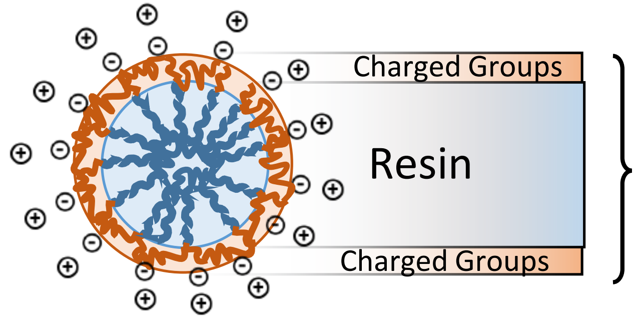
Active material particle size will matter



A theoretical plot of particle electrophoretic mobility relative to water (blue) and the radius of sedimentation (orange) for idealized monodisperse particles that do not aggregate or agglomerate shows that a stable suspension can be obtained with a low-viscosity bath for particles < 5µm.

Approach/Strategy

Formulation will matter

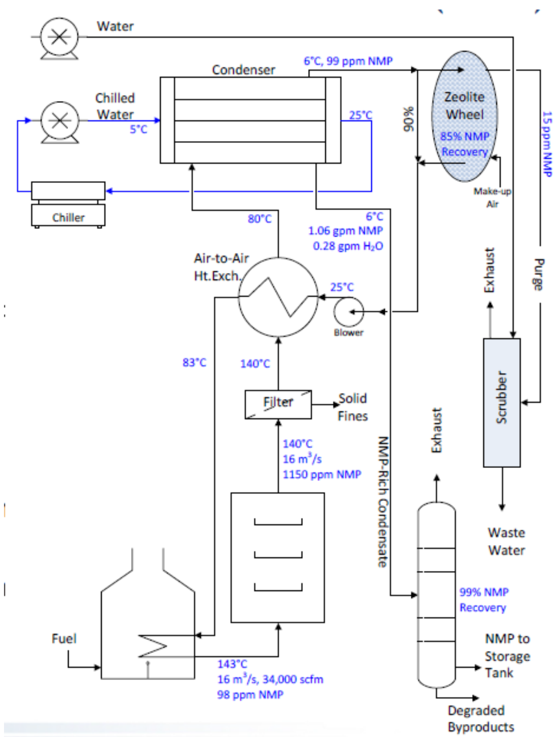


Binder

- Holds it all together
- Effects mobility
- Deposition rate
- Hygroscopic nature of dry film

Water

- Lithium dissolution
- Transition metal dissolution
- Permanent damage

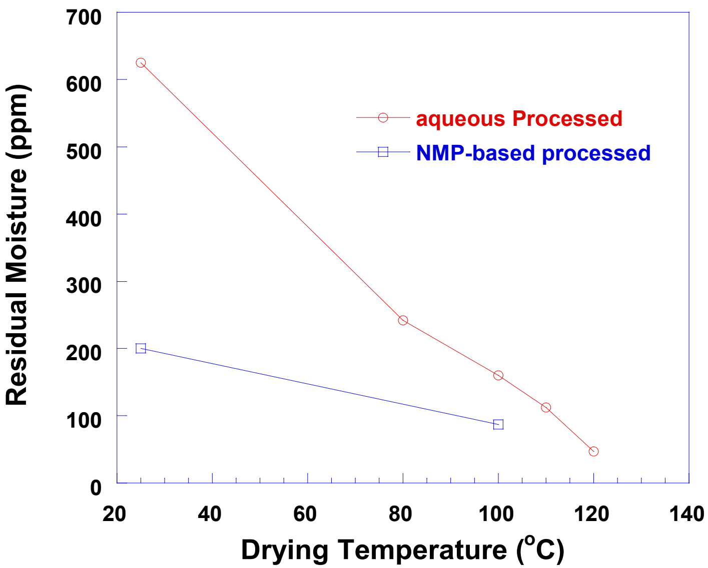


NMP Recovery Process
Shabbir Ahmed, ANL
2015 VTO AMR ES228

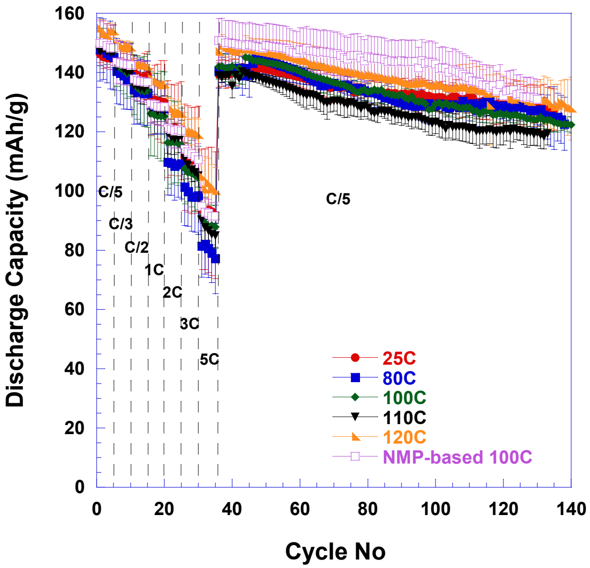
Approach/Strategy

Post-deposition processing will matter

Karl Fischer Titration Results



Half Coin Cell Results

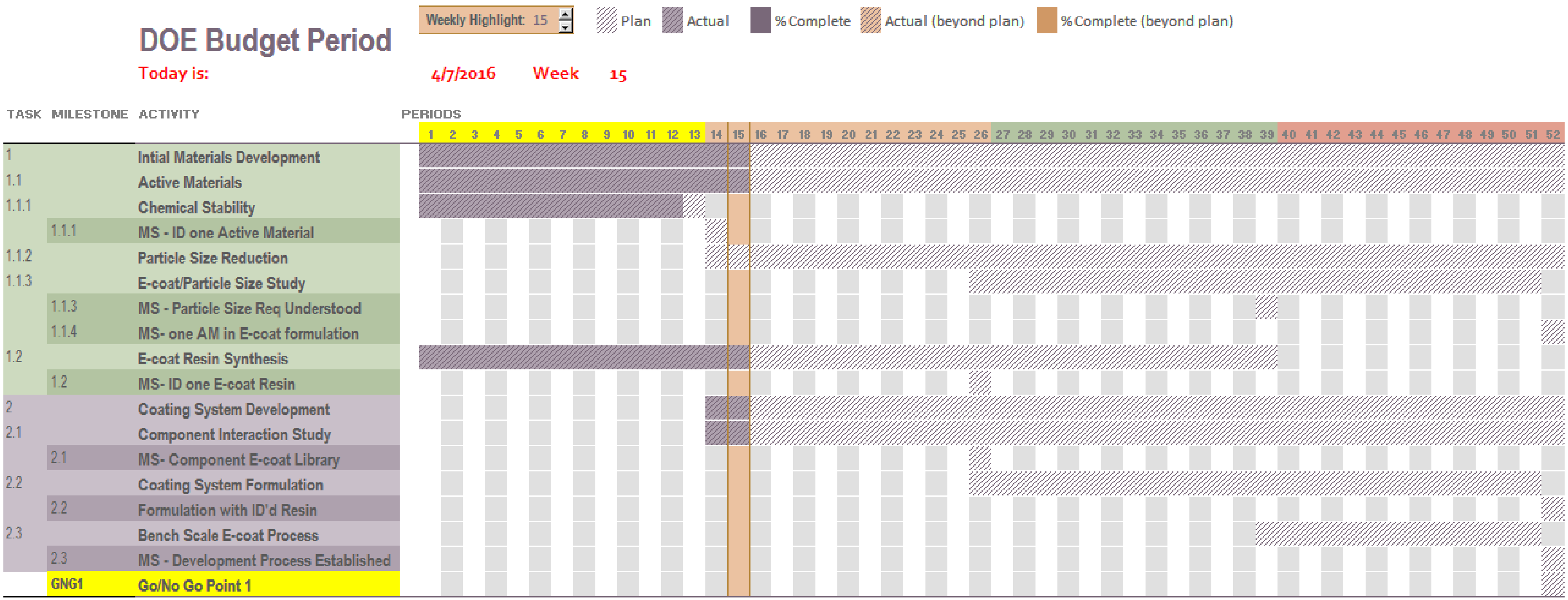


Secondary drying to reduce adsorbed water content

J. Li, C. Daniel, S.J. An, D. Wood, *MRS Advances*, DOI: 10.1557/adv.2016.6 (2016).

Technical Accomplishments

Budget Period 1 Plan



Technical Accomplishments

Small Cathode Particle Synthesis

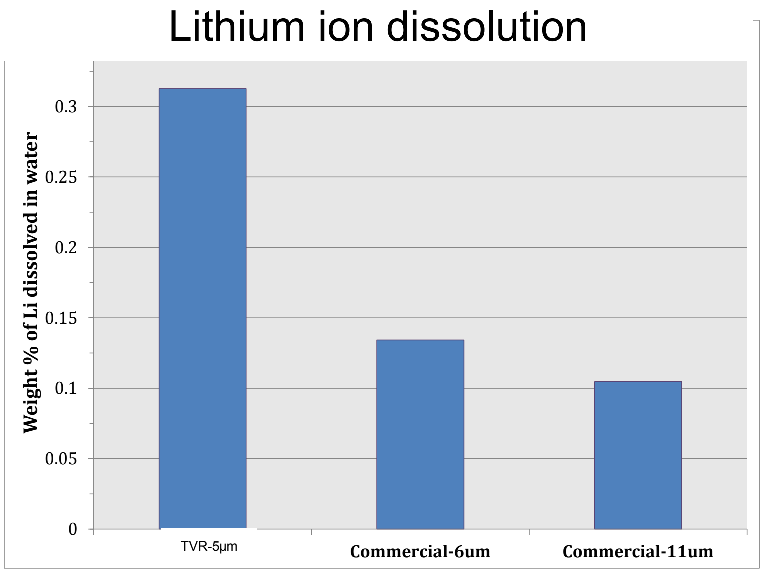
		TVR-5 µm	Commercial-6 µm	Commercial-11 µm
Composition by ICP	P*	$Li_{1.0199}Ni_{0.48}Mn_{0.31}Co_{0.21}O_x$	$Li_{1.0668}Ni_{0.47}Mn_{0.34}Co_{0.19}O_x$	$Li_{1.0139}Ni_{0.51}Mn_{0.29}Co_{0.20}O_x$
	W-T**	$Li_{1.0076}Ni_{0.48}Mn_{0.31}Co_{0.21}O_x$	$Li_{1.0562}Ni_{0.47}Mn_{0.34}Co_{0.19}O_x$	$Li_{1.0005}Ni_{0.51}Mn_{0.29}Co_{0.20}O_x$
Tap density, g/cc	P*	2.083	1.852	2.592
	W-T**	2.370	2.007	2.641
D_{10} / D_{50} / D_{90}, µm	P*	3.12 / 5.09 / 8.58 (Mean dia.: 5.53µm)	3.26 / 6.08 / 11.34 (Mean dia.: 6.80µm)	6.33 / 10.85 / 18.76 (Mean dia.: 11.85µm)
	W-T**	3.11 / 5.05 / 8.51 (Mean dia.: 5.49µm)	3.19 / 5.78 / 10.44 (Mean dia.: 6.37µm)	6.41 / 10.99 / 18.97 (Mean dia.: 12.00µm)
BET, m^2/g	P*	0.559	0.814	0.217
	W-T**	2.949	1.701	1.018

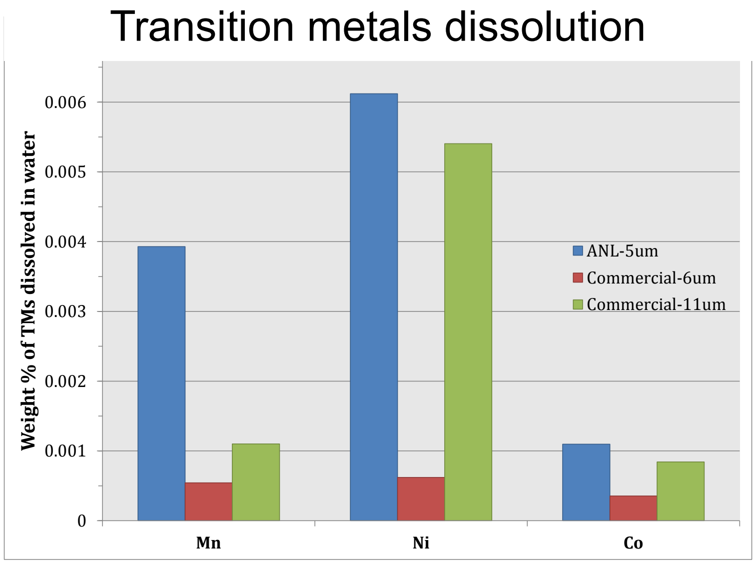
***: P; pristine - untreated cathode sample**
****: W-T; water treated cathode sample**

Technical Accomplishments

Active Particle Soaked in Water

Dissolution behavior and pH trend



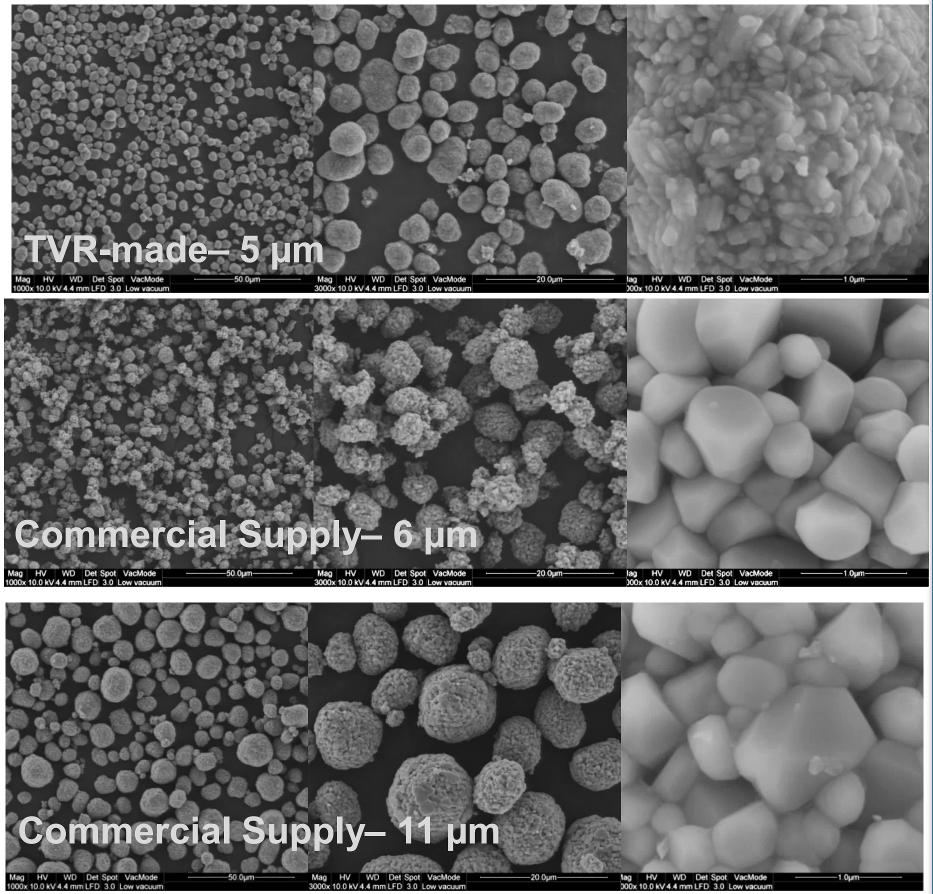


	pH water-only soak			pH water-soak with binder
Soak Time (h)	TVR 5µm	Commercial 6µm	Commercial 6µm	Commercial 6µm
2 min	10.72	10.30	10.30	
1	10.91	11.06	11.06	
2	11.25	11.19	11.19	
24	11.59	11.40	11.40	
48	11.85	11.62	11.62	10.25

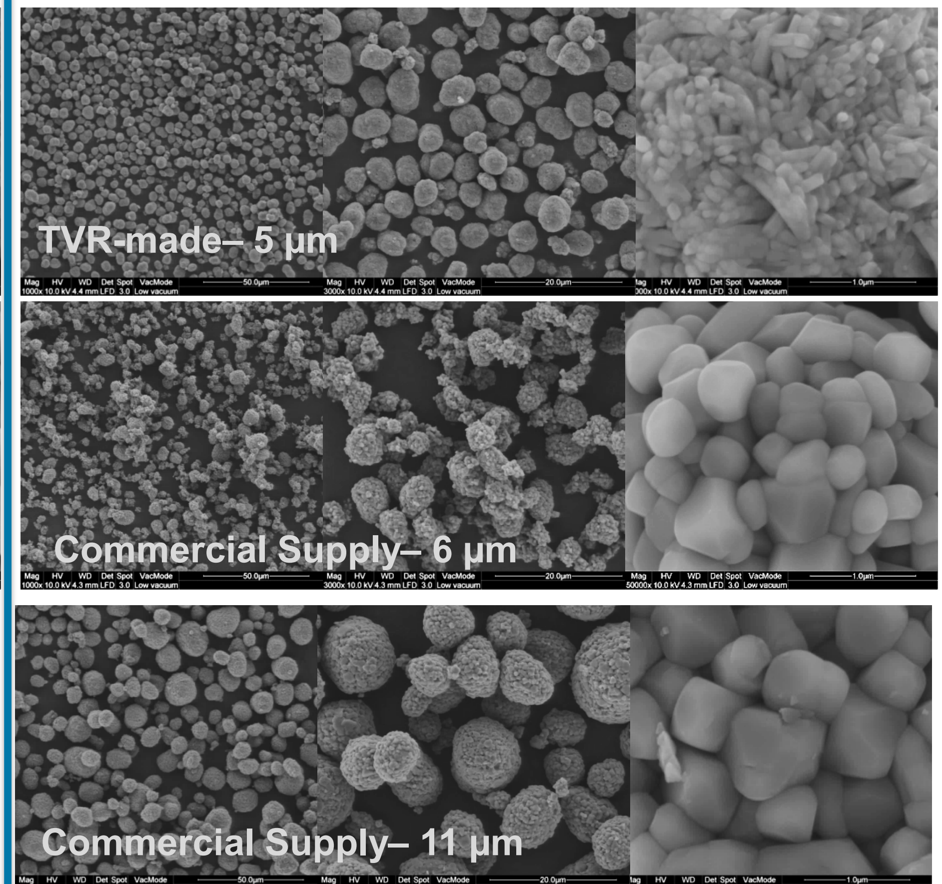
Technical Accomplishments

Material's morphology – no significant changes after water soak

Before Water Soak



After Water Soak



Technical Accomplishments

Resin Synthesis

Binder ID	Relative Properties				
	T_g	Function	MW	Particle Size	Zeta Potential
PPG-072	0.8	0.0	1.4	0.9	-63
PPG-059	0.8	0.0	1.2	1.2	-65
PPG-060	0.8	0.0	1.3	1.1	-68
PPG-042	1.0	1.0	1.0	1.0	-63
PPG-036	0.8	1.0	2.5	0.5	
PPG-063	0.8	0.5	1.5	1.1	-71
PPG-025	0.8	0.3	1.4	1.2	-70

Response to Previous Year Reviewers' Comments

This is the first AMR presentation for this project

Collaboration with Others

Team Member	Role	Significance
PPG	Coating system and manufacturing process development	E-coat commercialization expertise coupled with automotive manufacturing relationships will drive adoption by battery manufacturers
Argonne	Active materials development	Custom active materials enable the development of the coating system as well as optimize the performance of resulting electrodes
ORNL	Aqueous coatings development expertise	Challenges unique to aqueous formulations will be identified and addressed
Navitas	Cell build and testing, manufacturing and commercial insight	Experience in implementing novel technologies to meet specific customer requirements will align technology with battery needs and overcome implementation barriers

Remaining Challenges and Barriers

Materials

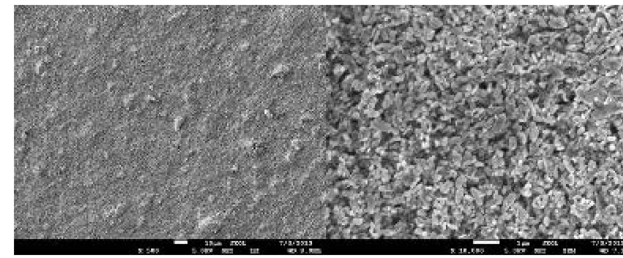
- Active synthesis
- Small Particle Performance

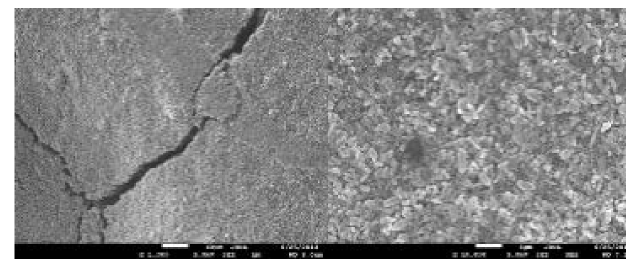
Formulation

- Bath Stability
- Bath vs Coating Composition
- Deposition Rates

Cathode Performance

- Film Quality
- Energy Density
- Battery Performance





Future Work

Budget Periods 2 & 3

Process & Equipment Development

- Refinement & scale-up of active material
- Coatings system formulation optimization
- Impact assessment: Electrode coatings drying process

Design & Build Lab-scale Coater

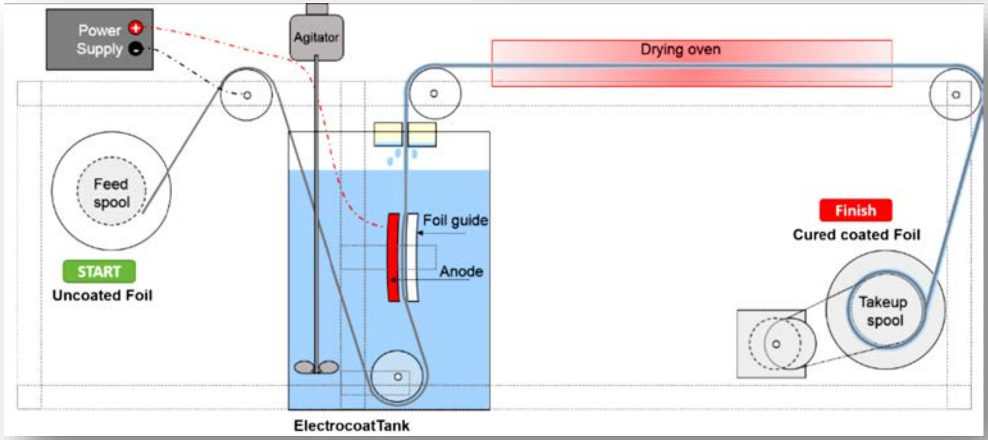
- Continuous two-sided coating
- In-process drying

Other Possible Work

Electrocoat Silicon Anode

Electrocoat Polymer Separator

Binders for Thick Films



Summary Slide

Relevance

- Enable lower-cost production of longer-lasting, reproducible battery electrodes with reduced environmental footprint

Approach

- Utilize Advanced Electrodeposition Coating Materials and Application Process to Produce Battery Electrodes

Technical Accomplishments

- 5 micron NCM-523 synthesized
- Lithium dissolution characterized
- 8 binders synthesized

Partners

- Argonne National Lab, Oak Ridge National Lab, Navitas Systems

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