Dry Process Electrode Fabrication

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Project ID: ES134

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Timeline

- Project start date: Oct. 2011
- Project end date: Oct. 2015
- Percent complete: 56%

Barriers

- Conventional slurry casting processes drive the cost of lithium ion battery electrodes.

Budget

- **Total project funding**: $4,239,879

Government Share: $2,992,744

(DOE Obligations thru 3/01/2016 $2,992,774)

Contract Share: $1,247,135

- **Expenditures of Gov't Funds:**

FY 13: $534,530 (10/1/2012-09/30/2013

FY 14: $821,060 (10/1/2013-09/30/2014)

FY 15: $343,564 (10/1/2014-3/31/2015)

Total: $1,699,154 (3/31/2015)

Partners

- No other funded subcontractors
- Industrial collaborators and consultants listed on slide 17.

Objectives and relevance of this project

- The Phase I objectives of this project are:
  - PTFE binders have been demonstrated for solvent-free cathodes, but PTFE is not electrochemically stable in a lithium battery anode. Therefore phase I will define a binder system for solvent-free anode fabrication that is stable over 500 cycles to full state of charge.
  - Identify the thickness limit for dry process cathodes that can meet EV rate and cycle life criteria
- The Phase II objectives of this project are:
  - Produce a solvent-free anode material that capacity matches the Phase I cathode.
  - Produce free standing dry process cathode that retains 50% capacity at 1C rate.
  - Assess cost saving through modelling and OEM input.
  - Deliver 24 cells in SOA EV cell format.

Project Milestones and Decision Points

Milestone/Decision Point	Metric	Status
1. Acceptance of mgt plan revisions		**met**
2. Down-select LMFP, NMC, and pre-coat		**met**
3. Cathode morphology and mixing conditions specified		**met**
4. High solid loading anode	>40% solids cast to >3 mAh/cm^2	**met**
5. Demo. lab prototype cell w/ dry process blended cathode	>100 µm cathode	**met**
6. Deliver interim cells with dry process blended cathode/wet anode	14 cells, 4 Ah pouch	**met**
7. Demo dry process anode	Rate/capacity match cathode	**met**
8. Down-select low cost anode process	50% vs baseline capex + opex	late Dec 14 → Apr 14
9. Scale cathode film to support task 16	10 m	delayed Apr 15 → July 15
10. Lab prototype cell dry anode/dry cathode	Pass EV life test	**met**
11. Deliver final cells	24 cells, >14 Ah prismatic can	Sep. 15 On track

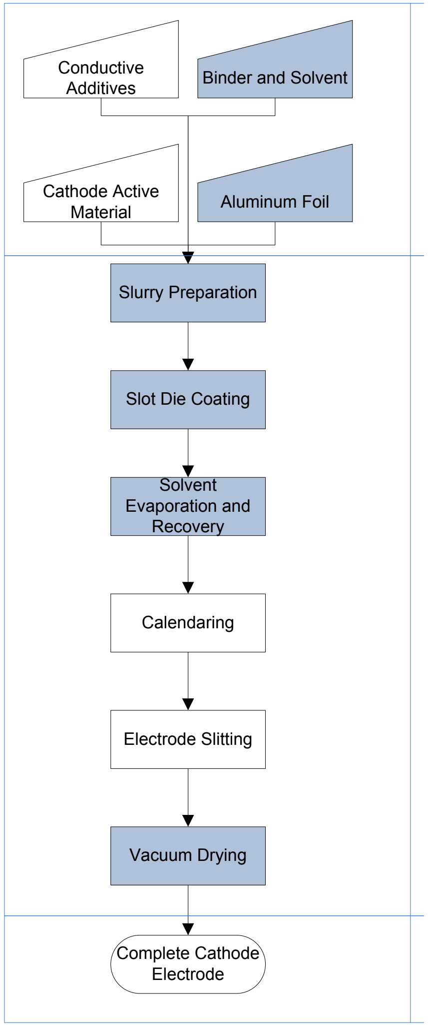
Approach

First, optimize blend of phosphate and oxide cathode powders with respect to energy, safety and compatibility with dry electrode fabrication.

Second, modify low- or zero-solvent binders for anodic compatibility.

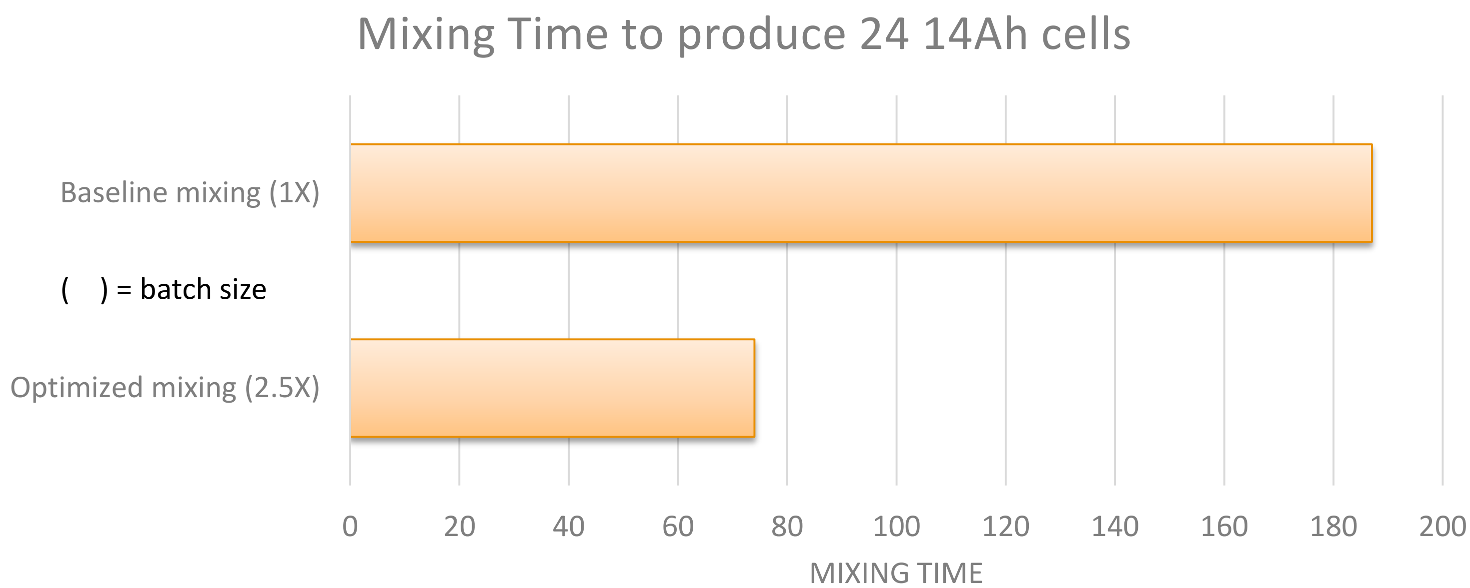
Third, down-select cathode and anode formulations. Scale up processes to support prototype cell assembly and cost model validation.

Validate performance and life in EV-relevant prototype cells.



The dry fabrication process reduces cost by eliminating the shaded steps required in conventional slurry cast electrode fabrication.

Dry process cathode fabrication throughput improved >600%

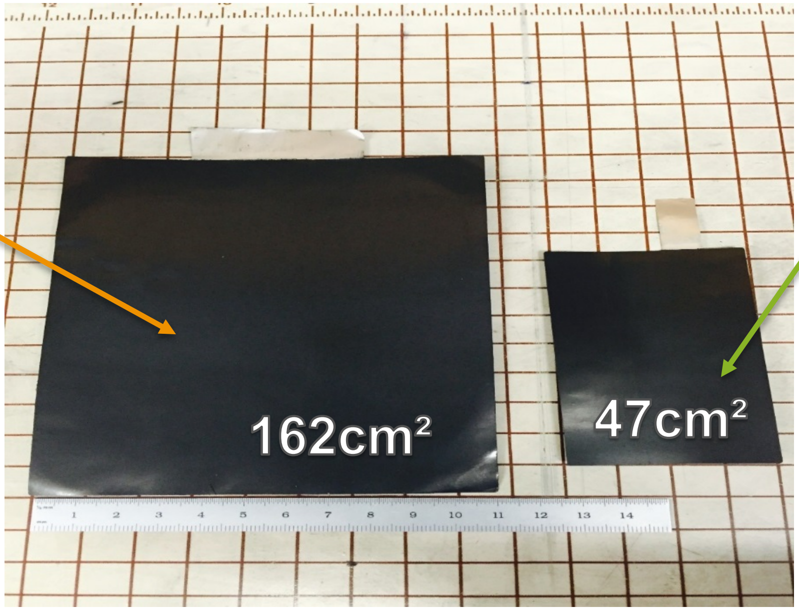


With optimized formulation and mixing, can prepare 1.5kg of electrode material per day. This advance was realized by mixing in larger batch sizes and reducing the cooling time.

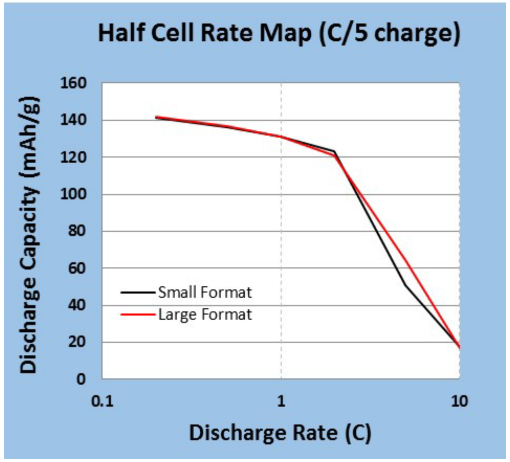
This result addresses a barrier associated with heating from the high shear mixing operation requiring process controls to limit T below a binder phase transition temperature.

Dry process cathode scaled up to EV format

Desired format for final deliverable (14Ah cell)



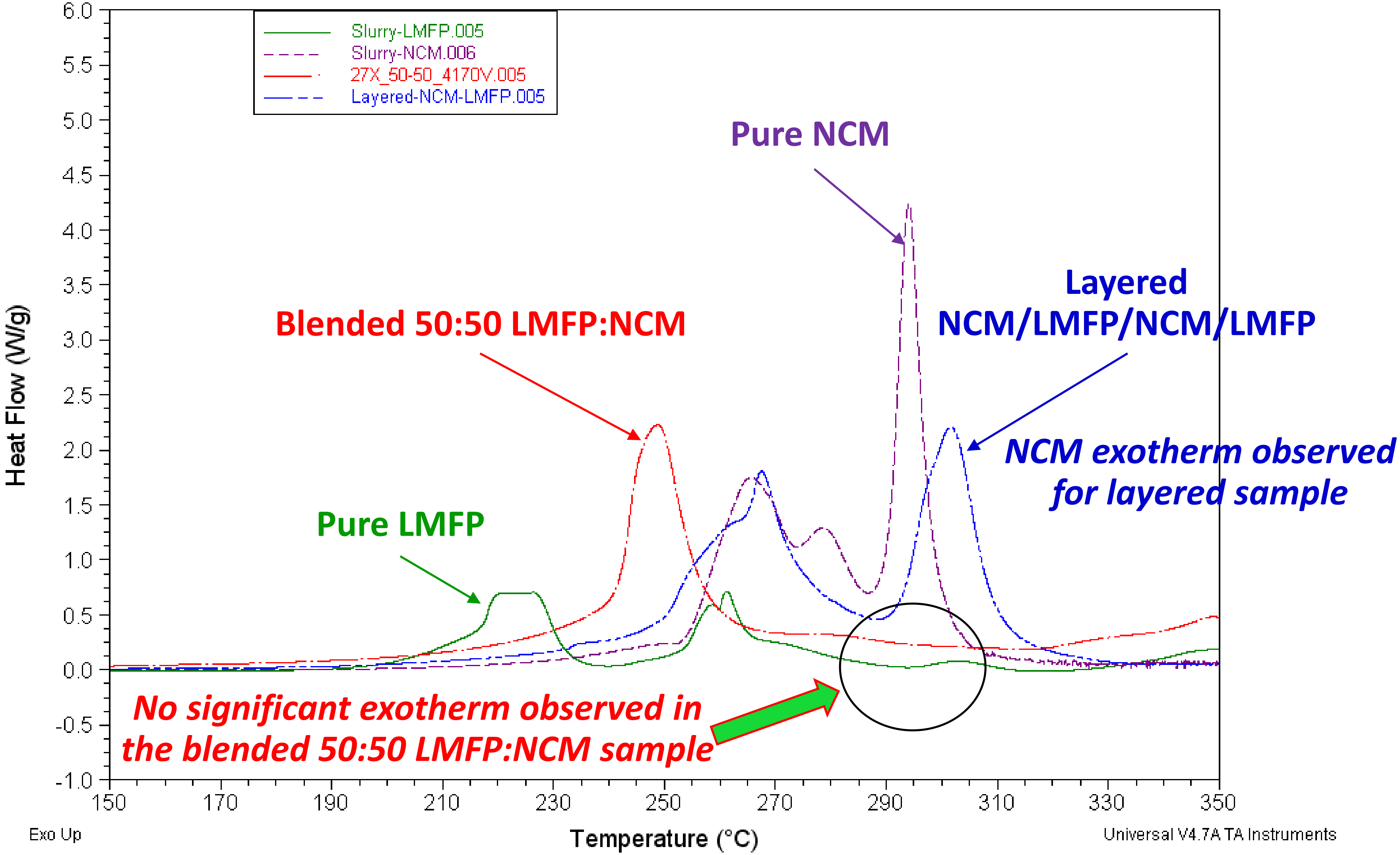
Format used for interim deliverable (4Ah cells)



Large format cells retain same performance as smaller cells.

Progress toward final cell deliverable.

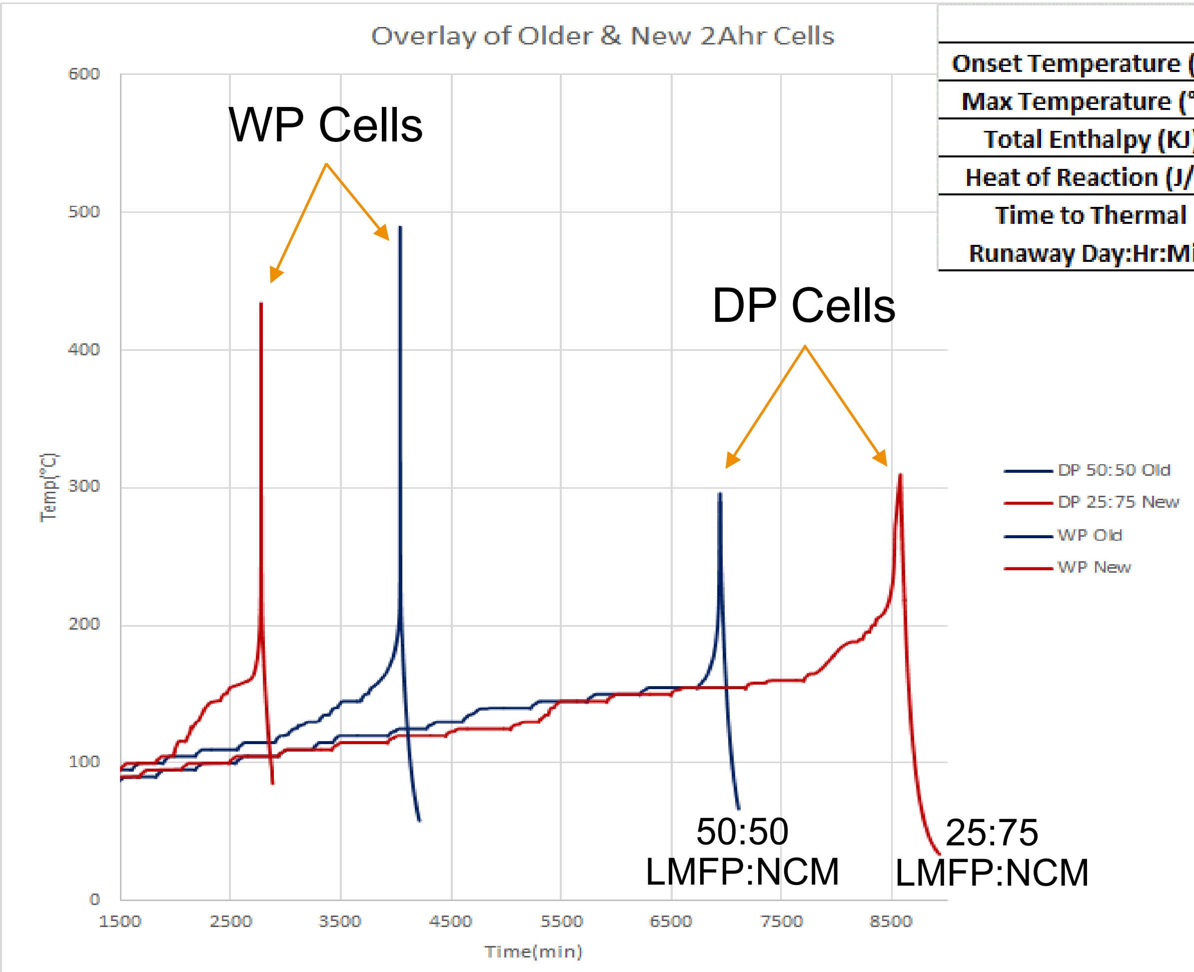
DP blended cathode reduces enthalpy and suppresses the exotherm ~300°C observed for NCM materials.



Improved abuse tolerance is added unexpected benefit of the dry process electrodes

ARC data verify abuse tolerance benefit of Dry Process cathodes in 2Ah cells

NAVITAS SYSTEMS



	DP 50:50 Old	DP 25:75 New	WP Old	WP New
Onset Temperature (°C)	161.4	165.6	155.8	115.4
Max Temperature (°C)	296.1	309.8	489.5	420.5
Total Enthalpy (KJ)	5.8	6.4	14.49	13.3
Heat of Reaction (J/g)	134.7	144.2	333.7	305.1
Time to Thermal Runaway Day:Hr:Min	04:16:48	05:22:58	02:18:40	1:22:16

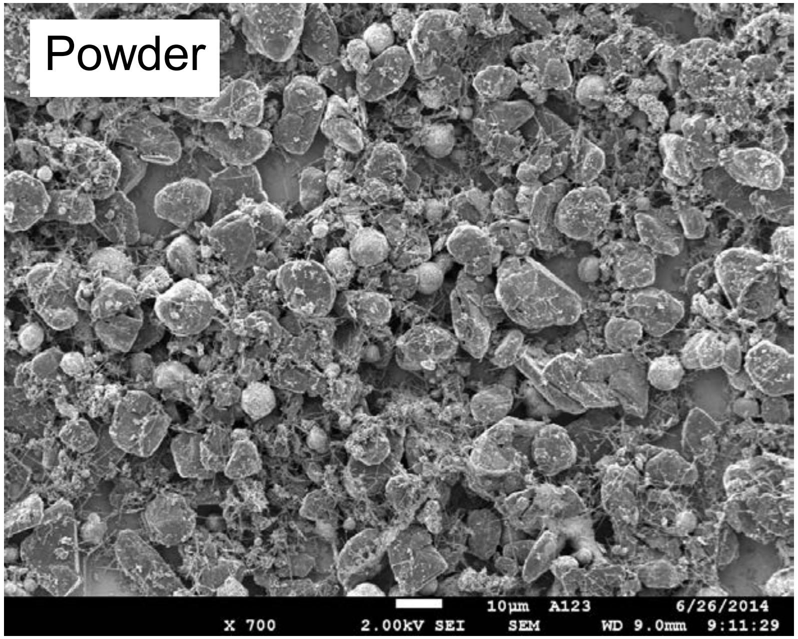
Old refers to cells > 3 month since formed and New refers to cells tested within a week of formation

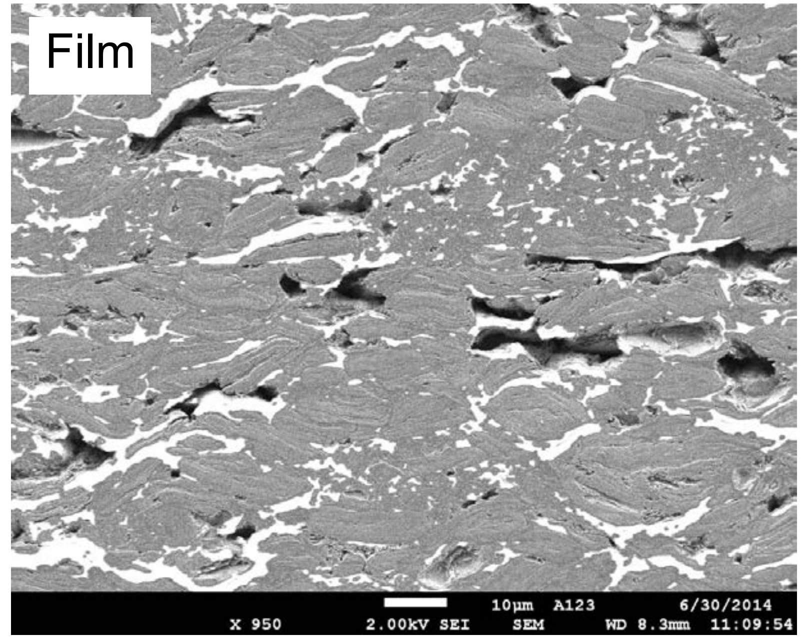
Despite variations observed in pouch cell construction the ARC data clearly shows that the DP cells are more thermally stable than the pure NCM wet process cells even at low (25%) LMFP concentrations.

Anode Development Focus

- Three low-cost options
  - Dry process
    - Validated full cell performance
    - Mechanical properties limit ability to scale to continuous or large format
  - Aqueous natural graphite at high active material content
    - Cost savings may compete with dry
    - Improved energy density
    - Pilot coating demo in progress
  - Aqueous natural graphite + advanced drying process (ADP)
    - ADP feasibility demonstrated at bench scale
    - Further cost saving with 80% reduction in electrode drying time

Dry Processed Anode Characterization





The binder is well dispersed in both dry blended powder mixture before anode fabrication and in the anode film after fabrication

The laminated anode passed both dry adhesion and wet adhesion tests following Navitas production quality standard

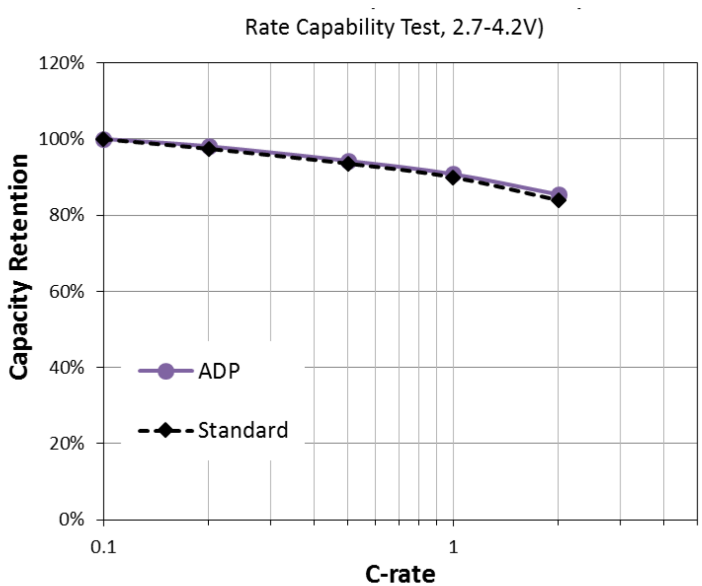
Dry Processed Anode Fabrication and Evaluation

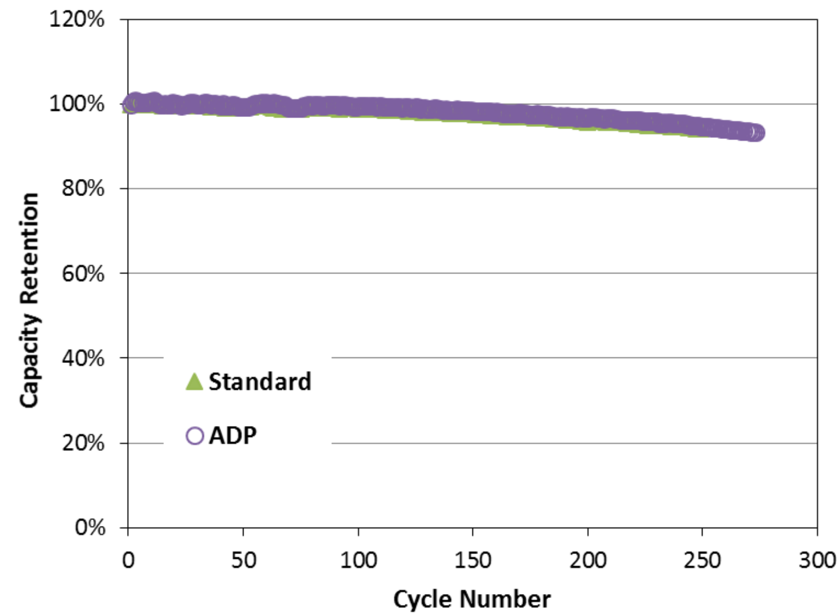
Dry processed anode

Prototype Li ion pouch cell

- Dry blend graphite, carbon, and polymer binder powder to form a homogeneous powder mixture
- Calender the mixture to form a flexible film
- Laminate the film to current collector (with calendering) to form an anode
- Characterize the anode for uniformity and adhesion
- Assemble a Li ion cell with the dry processed anode and dry processed cathode
- See slides 13 and 14 for performance

ADP Anode Demonstration in Li ion Cells

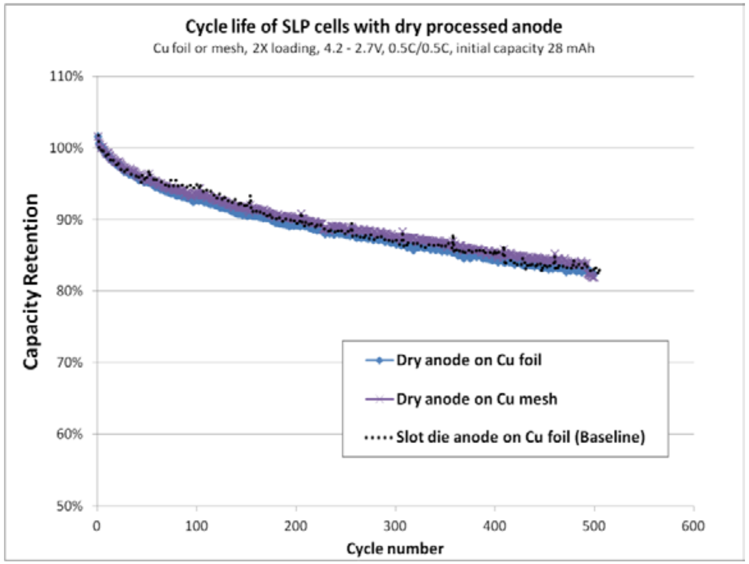




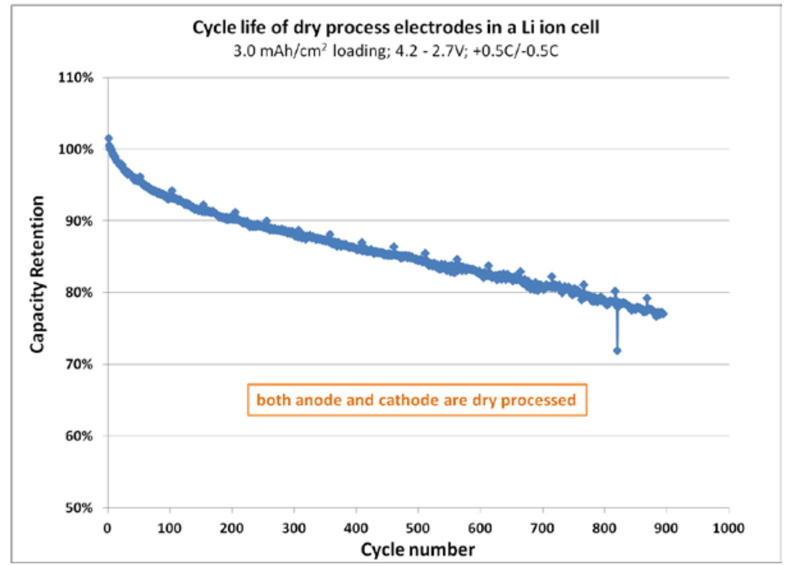
Natural graphite anode and aqueous binder at baseline EV electrode active content and electrode loading.

Full cell tests comparing ADP with conventionally dried anode shows the same rate and cycle life performance at 4X faster drying rate.

Full cell validation of cycle life of dry process anode and cathode



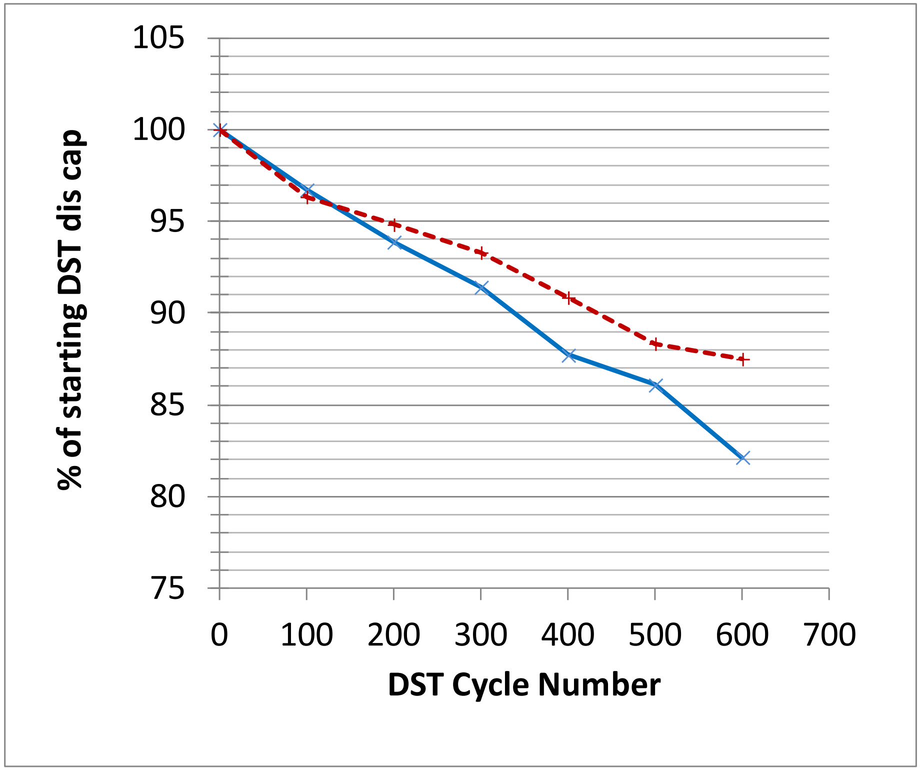
Dry process anodes match cycle life of SOA slot die anodes



800 cycles at 80% capacity at EV electrode loading

DST cycle life evaluation of Interim Deliverable Cells

Cycle protocol: 100 DST cycles to 80% DoD, then DST cycled once to 100% DoD for capacity determination. Repeat until EOL.



- 4 Ah Pouch prismatic stacked cell format (two cells plotted)
- Dry process cathode
- Slot die natural graphite anode
- 3.2 mAh/cm^2 loading

Note: New processing additive in next generation cathode improved cycle life by >40%

DST cycle life >600 before dropping to 80% of their starting capacity.

Response to Reviewer Comments

- … this expert agreed it is important to have proper standards (baseline) for comparison, both in terms of performance and cost; and
- … the reviewer recommended including data from a baseline cell, utilizing traditional processes.

The data in slide 15 and following table compare performance of dry process cell to a baseline cell produced using slurry cast electrodes. No sacrifice in life, capacity or rate are observed in full cells incorporating dry process cathode:

Cell Type	Cathode	Anode	Loading (mAh/cm^2)	Capacity Retention at n^{th} cycle				
				Cycle 200	Cycle 400	Cycle 600	Cycle 800	Cycle 1000
Dry Process EV Cell	LMFP/NCM blend	Natural Graphite	3.0	94%	90%	84%	81%	76%
Baseline EV Cell	LFP	Natural Graphite	2.1	94%	90%	87%	83%	81%

- A realistic cost analysis is required…; and …it is important to make a proper assessment of cost savings with assistance from a commercial EV battery OEM, if possible.

This is included in the workplan. The Navitas team were originally members of A123 Systems and supported scale up of high volume production of Nanophosphate cathodes to support 10K PHEV/year production capacity. We will seek OEM validation of our cost model.

Collaborations

- Navitas is collaborating with process equipment OEM on anode Advanced Drying Process.
- Navitas is collaborating with developer of high loading electrodes that may be synergistic with ADP and enable thicker more robust cathodes.
- Dow Energy Materials has been non-funded collaborator in providing samples and guidance for LMFP cathode material
- DuPont R&D staff have provided samples and consulting on PTFE binder choice and process control.
- Arkema is providing samples and technical guidance on dry process electrode fabrication. This collaboration also involves Ron Turi as consultant. (prior technical lead on extruded electrode production at LTC/Gaia
- Navitas has also reached out to UMass Lowell and Daikin contacts from 2014 AMR

Remaining Barriers and Challenges

- Increase cathode width for EV footprint - limited by calender pressure.
- Reduce number of calender passes and improve cathode yield.
- Improve dry process anode mechanical strength to support larger EV electrode format.
- Capitalize roll-to-roll implementation of anode advance drying process.

Future work

Cathode

Modify calender to demonstrate continuous processing.

Anode

Down-select and scale-up anode process for final deliverable EV cell

Produce >24 14 Ah EV format cells for final deliverable.

Summary slide

- The dry electrode process innovation in this proposal will provide the ability to coat thick *and* fast, while eliminating solvents and saving energy.
- Cathode dry process is scaled to EV cell format demonstration.
- Anode process capability has been validated at EV loading and using low-cost natural graphite.
- The projected readiness level is TRL 6 for the cathodes upon completion of the program, with confidence that the development path will leverage Zn-air or ultracapacitor production technology.

Acknowledgments

- Cathode: Bob Sosik
- Anode: Pu Zhang
- Characterization: Danny King
- Cell Build: Brian Glomski
- Consultants: Ron Turi and Rick Howard

- Brian Cunningham and Ralph Nine, Department of Energy