UV Curable Binder Technology to Reduce Manufacturing Cost and Improve Performance of LIB Electrodes

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June 19, 2017

Project ID # ES265

Project Overview

Timeline:

Start Date: 12/01/2015
End Date: 09/30/2018
Percent Complete: 79%

Budget:

DOE Share	$1,742,560
Cost share	$ 513,640
FY 16	$1,742,560

Barriers to Electric Vehicles addressed in this project :

1. Cost, reducing Electrode Manufacturing Costs, Safety, Energy, …
2. Life, possible advantages, e.g., high temperature life and low temperature stability

Partners:

Argonne National Laboratory
Oak Ridge National Laboratory

OAK RIDGE National Laboratory

Argonne NATIONAL LABORATORY

Relevance

Lowering Cathode Manufacturing Costs vs. NMP process

- ✓ **Miltec cost model shows manufacturing savings in capital and operations of at least 80% and likely 95%.**
- ✓ **Total electrode savings *(including materials)*:**
  - **50% for the two single-sided layers in each cell**
  - **25% for each double-sided layer in each cell**
- ✓ **NMP free UV Process**

Proving It Can Work

- ✓ **Developed (94/3/3) Energy and (90/7/3) Hybrid NMC cathodes with impedance and cycling equal to PVDF**
- ✓ **Proved fast curing (100m/min) with hybrid power cathodes**
- ✓ **Demonstrated layered coating and thicker curing capability for thick, high energy electrodes**
- ✓ **Demonstrate faster coating technology**

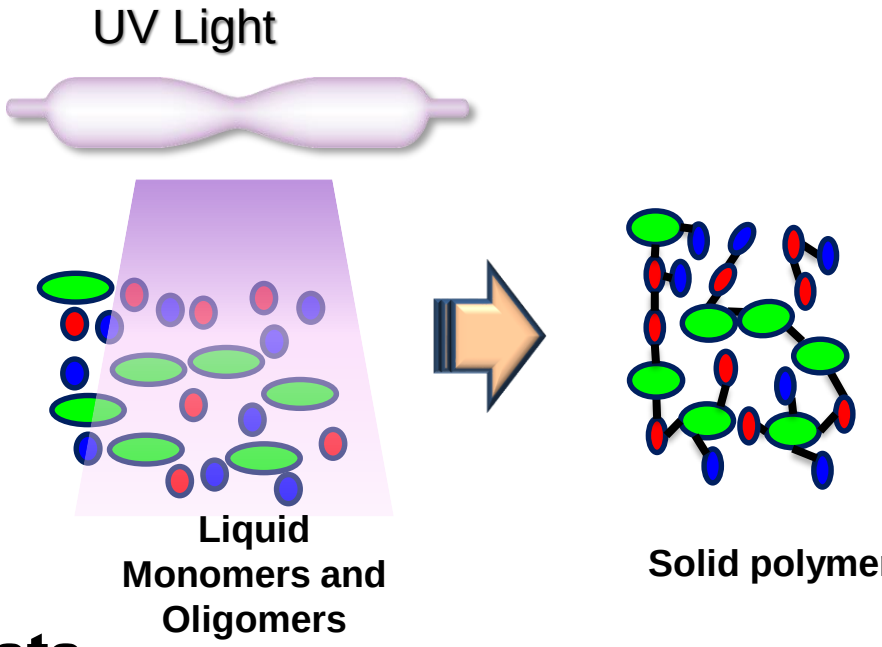
Milestones

Approach and Milestones	Planned Completion	Status
Budget Period 1		
Project Management Plan	12/31/2015	Complete
Confirm binders and coating procedures and testing protocols	12/31/2015	Complete
UV curable Binder Formulation with improved AC Impedance	06/15/2016	Complete
Complete integration and installation of print coating equipment	07/24/2016	Complete
Complete Test to confirm lower AC Impedance and acceptable long term capacity (Go-No Go)	11/30/2016	Complete
Budget Period 2 …		

Milestones

Approach and Milestones	Planned Completion	Status
Budget Period 2		
Demonstration of two-sided electrode coating	03/31/2017	Complete
Determine maximum speed and cathode thickness using a slot-die coater and three-lamp UV curing process	06/30/2017	Progress
Determine maximum speed and cathode thickness using a letterpress and three-lamp UV curing process	09/30/2017	Progress
Determine minimum inactive material (UV curable binder and carbon) loading with either a slot die or letterpress process complete	3/30/2018	Complete
Coating-on-coating cathode evaluation complete with slot die and letterpress processes	2/28/2018	Initiated
Long term cycling evaluation complete	5/31/2018	Initiated
Multilayer pouch cell performance evaluation complete	8/31/2018	

Approach: Why UV?



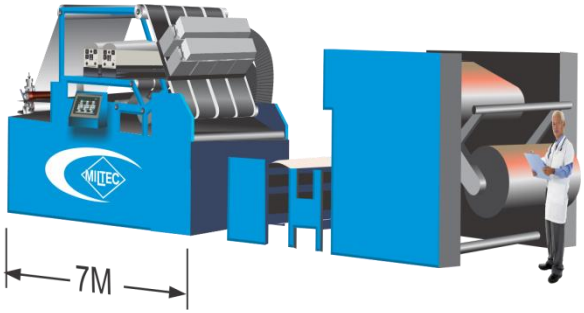
- ✓ **Instant Cure**
- ✓ **Eliminates Drying ovens**
- ✓ **Eliminates NMP**
- ✓ **Consumes less energy *(1/2)***
- ✓ **Very small flexible footprint**
- ✓ **High throughput**
- ✓ **Low capital and operating costs**
- ✓ **Retrofit or greenfield insertion**
- ✓ **Processing speeds limited by coating speed not by drying speed limitations**
- ✓ **A cost model *(for DOE)* shows 85% reduction in electrode manufacturing cost and a 25% reduction in 2-side electrode cost, including the material cost**

Approach: Why UV vs. Conventional Process

Conventional Solvent Drying

- **Instant UV curing reduces space, capital, and operating costs**
- **One two-sided UV system @ 60 m/m has output of four conventional coating lines @ 30 m/m**

UV Curing



Miltec's UV Electrode Coating Process is smaller, simpler, and can reduce manufacturing expenses by 80%

Approach and Strategy

- **Work with battery manufacturers to develop UV electrode products specifically for their applications.**
- **Work with ONRL and ANL for long term 1000 cycle pouch cell data to demonstrate feasibility of hybrid and energy batteries.**
- **Determine if slot die or printing technologies can apply coatings as fast as UV lamps can process the electrode.**
- **Demonstrate feasibility of layered electrode coatings due to the advantages of UV curing and its instant curability.**

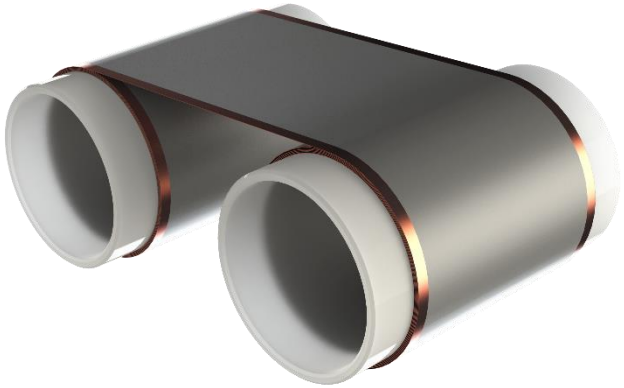
Accomplishment:

Developed UV Curing Chemistry and processes to produce key LIB components

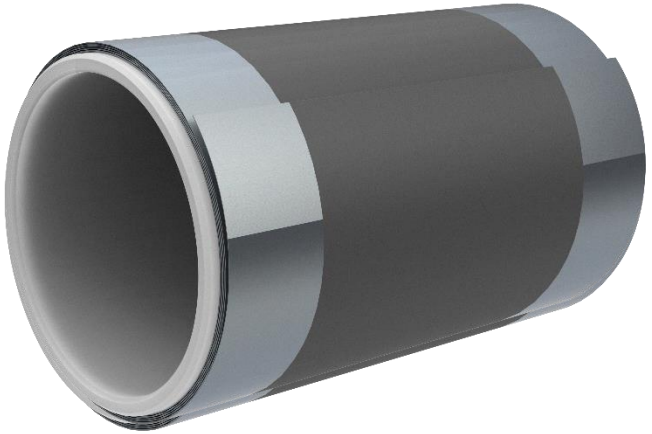
Ceramic Coated Separators

NMC and FEP Cathodes

Ceramic Coated Anodes



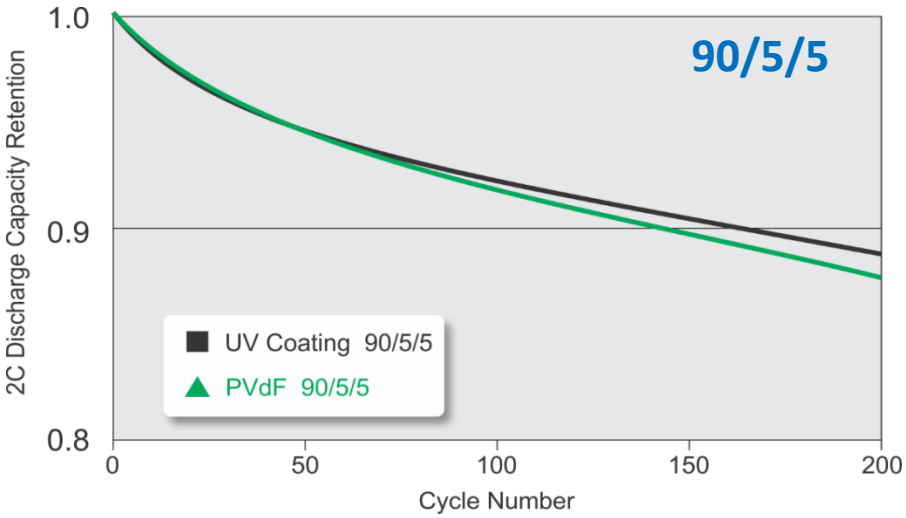
LTO Anodes

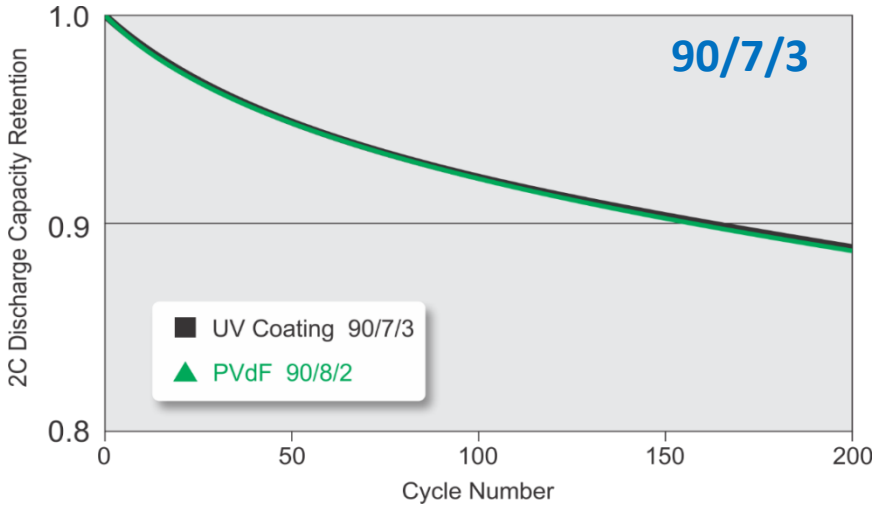


Accomplishment: Developed UV Equipment and Slot Die Process,
Curing to 300 fpm,
Can Coat Layers on Layers
Current Work Focusing on Determining How Fast Can It Coat

Accomplishment:

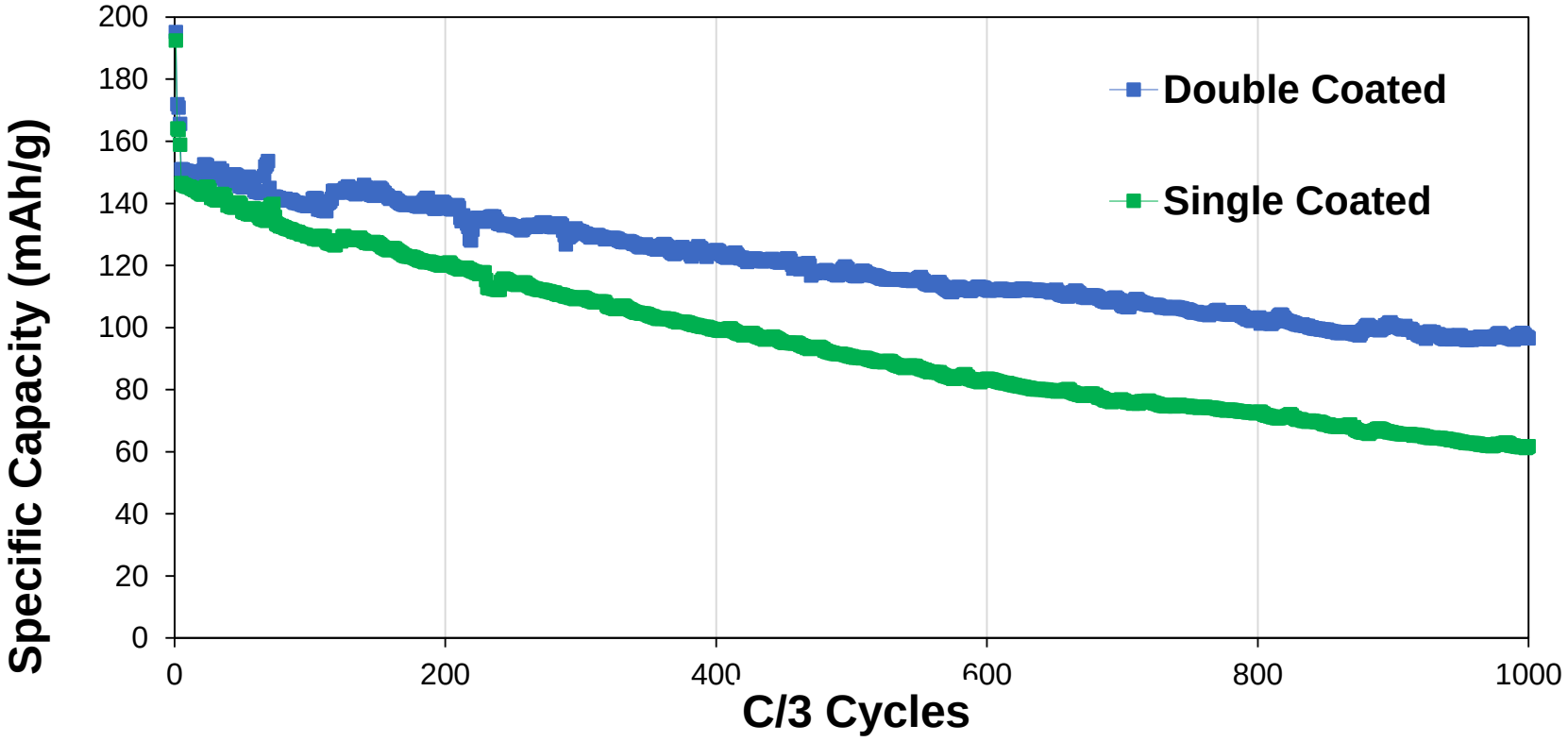
UV Cathodes Have Equivalent Accelerated 60°C Cycling Performance as PVDF Cathodes with Similar Loading in Single Layer Pouch Cells





Accomplishment: Layered Coating

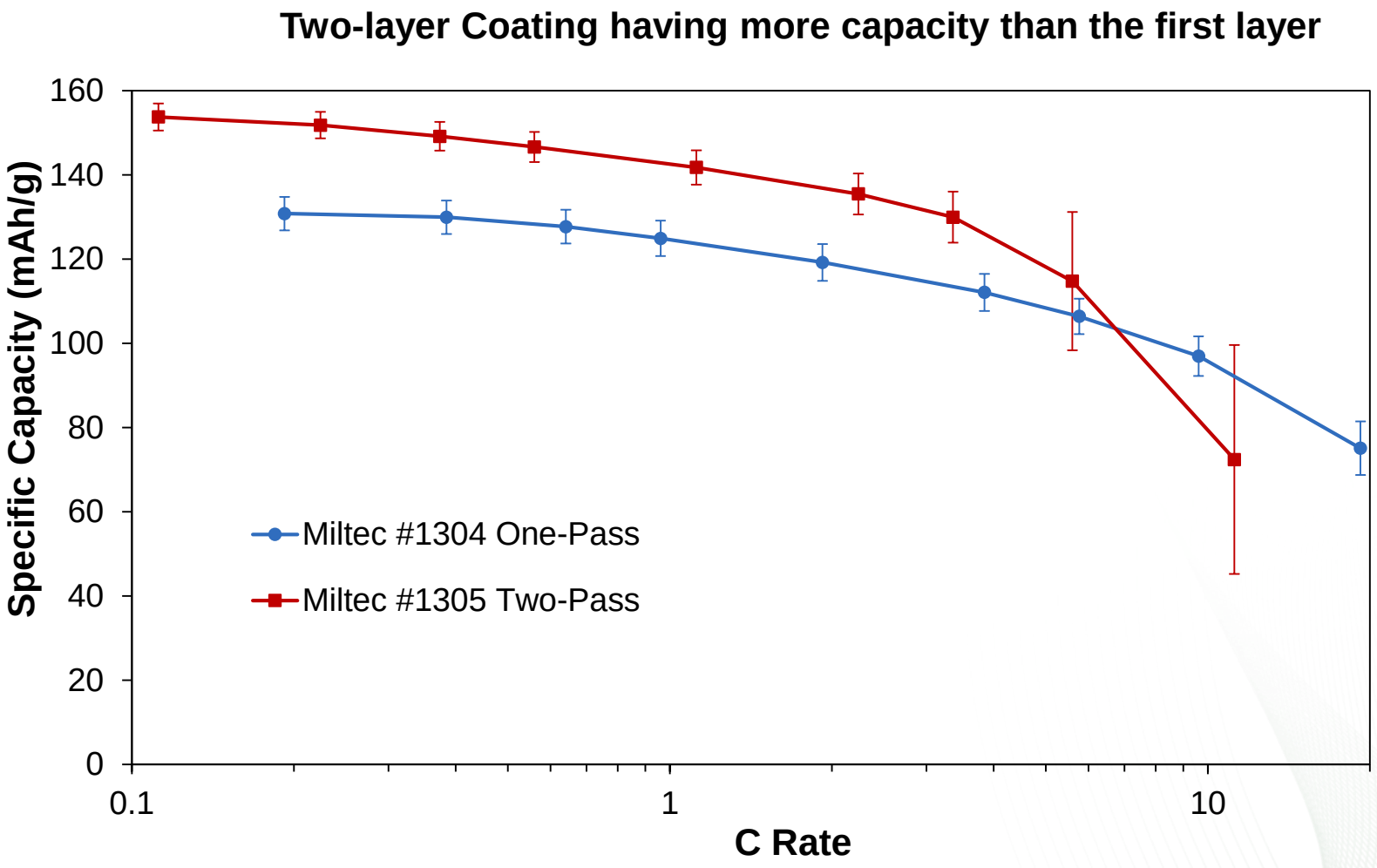
Double layer coatings works, often better than single layer



Slot die applied, each layer is ~ 3 mg/cm^2
Single layer is ~ 3 mg/cm^2
Double layer is ~ 6 mg/cm^2

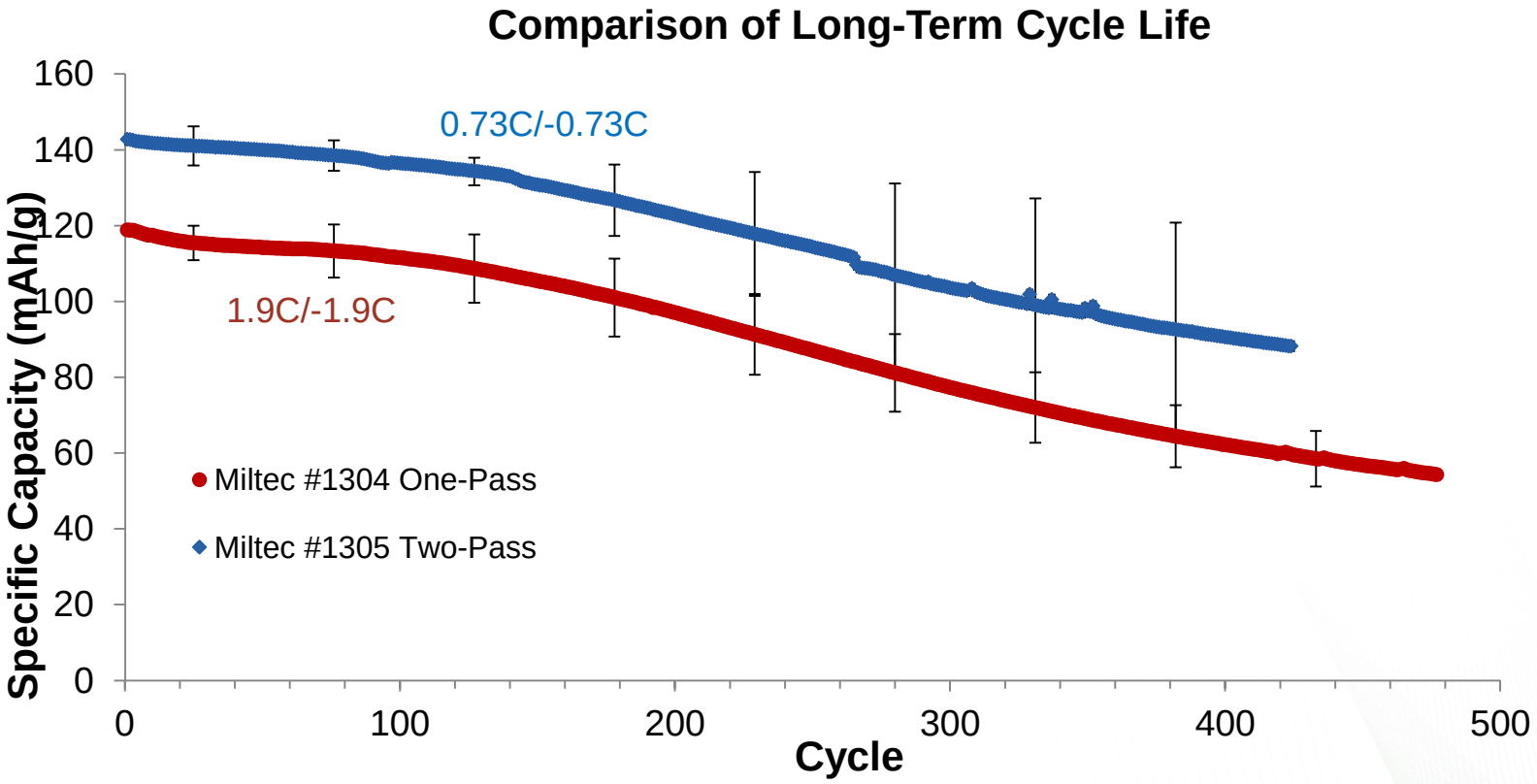
Counter electrode, Electrolyte	Lithium, 1:1 EC:DMC
Cure speed (fpm)	60
Hand, slot, or 3-roll coater	Cathode: Slot die, Anode: Hand
Formula	X-31AS-128 + PVdF-Gr-29
Target customer/project	
NMC:C:UV Binder	NMC 532 90-5-5
Lamps: MPI-HPI-HPI	HPI 30 HPI 29, 50% power each
Foil, pretreated	Yes
related formula/Binder number	Modified Binder 24
Calendered	Cathode, 6,000 psi, anode, 4000 psi

Layered Coatings Do Not Have Barrier Layers, Pouch Cells 90_{532}-5-5



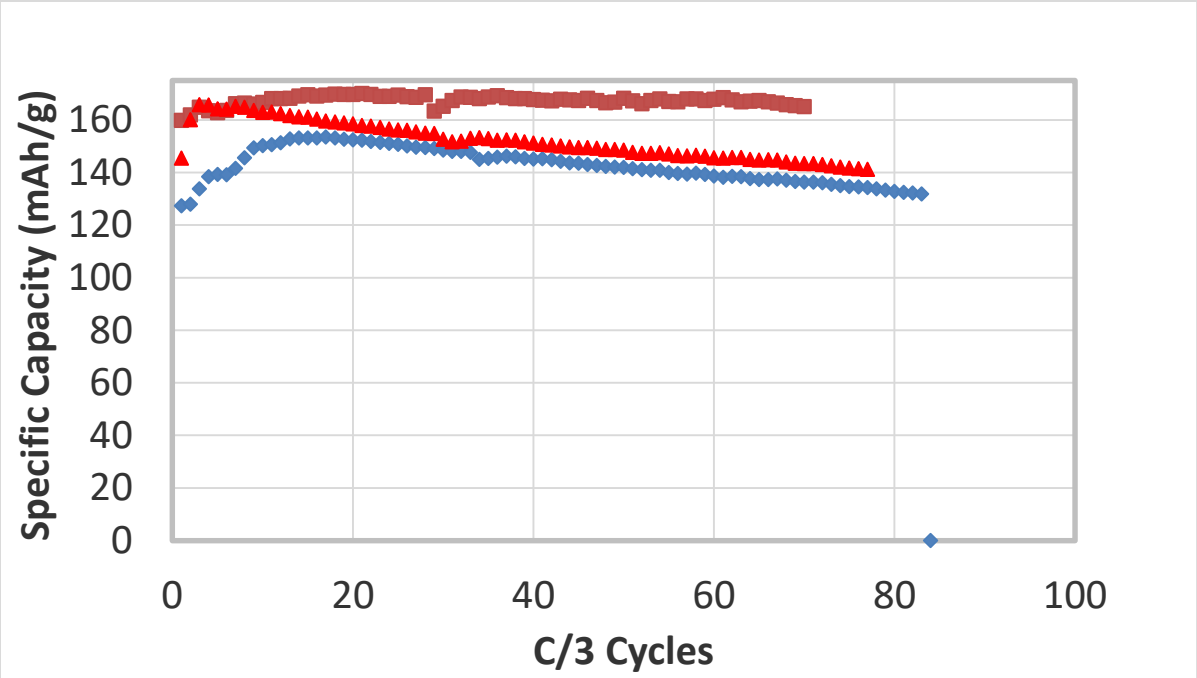
Accomplishment: Layered Coating

Pouch Cell Accelerated Life Following Rate Test, Rerunning with standard formations and cycle



Accomplishment: Layered Coating

Stable Full Cell, Slot Die applied, 94-3-3, NMC 532-C-UV
Single Layer, 7 mg/cm^2



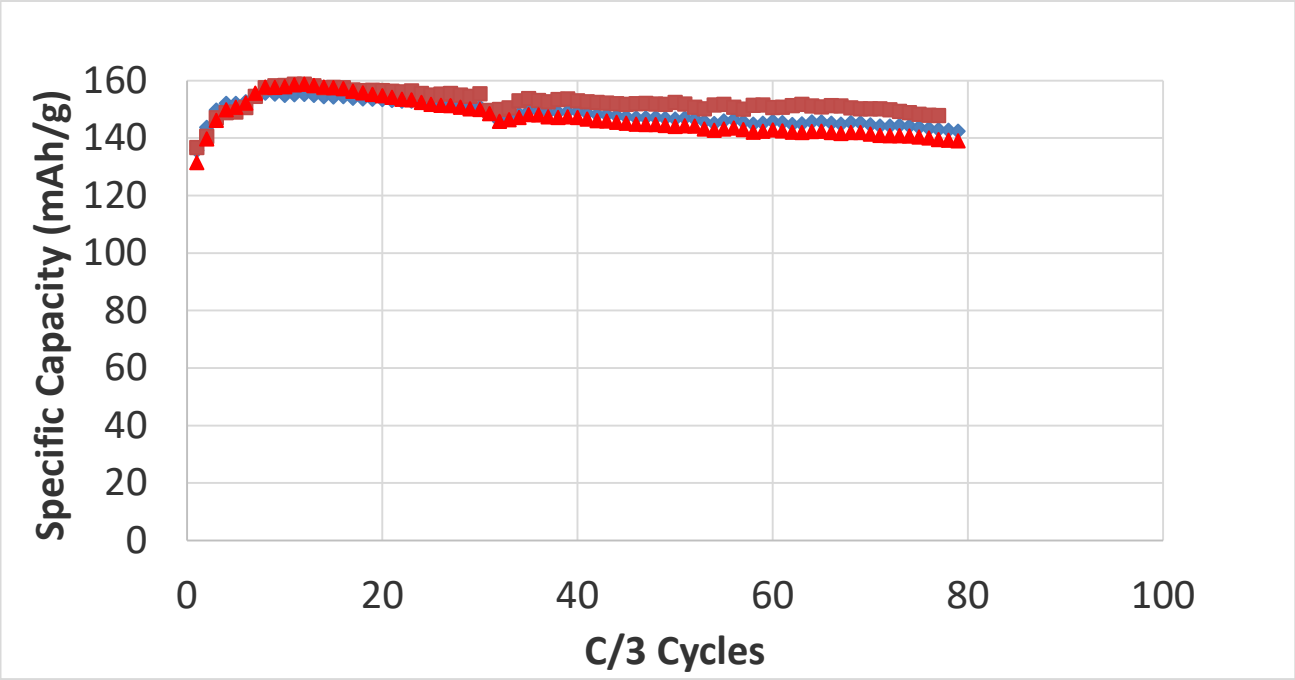
94-3-3

NMC(532)-C-UV Binder

Testing ongoing and sent Oak Ridge for Pouch Cell Testing

Accomplishment: Layered Coating

Stable Full Cell testing of Slot Die Produced, 94-3-3, NMC 532-C-UV Double Layer Cathode, 1+2 layers = ~14 mg/cm²



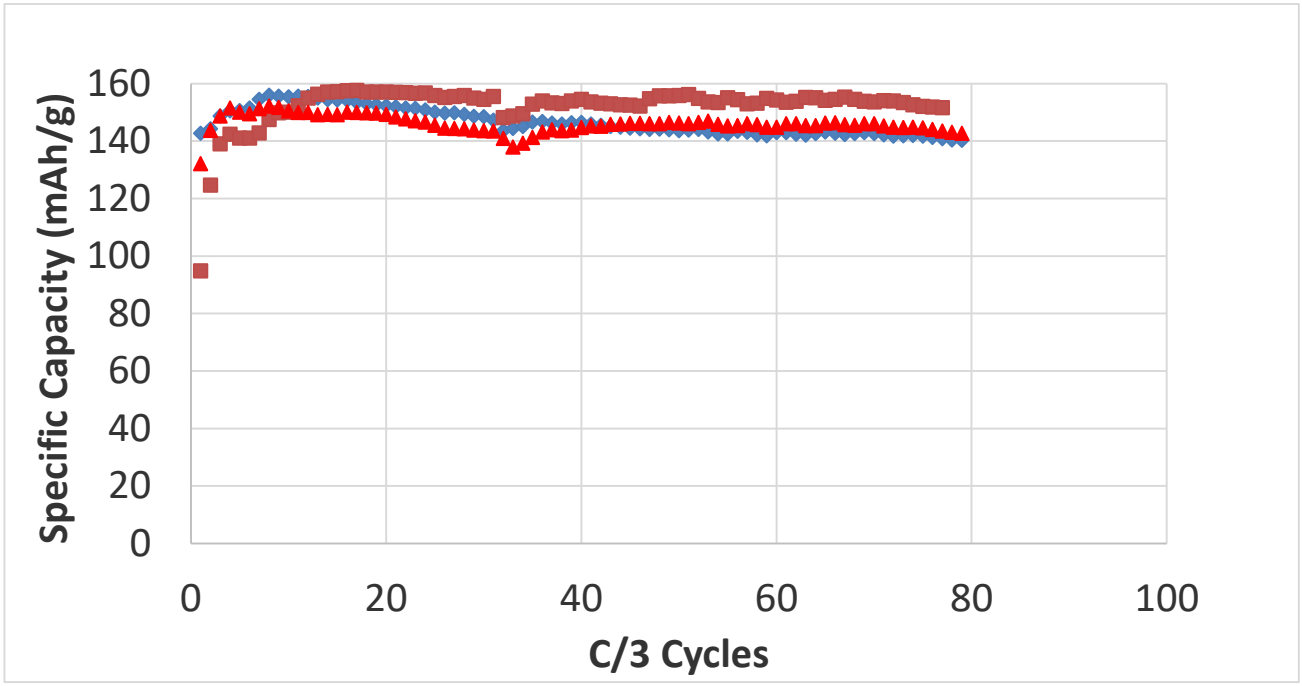
94-3-3

NMC(532)-C-UV Binder

Testing ongoing and sent Oak Ridge for Pouch Cell Testing

Accomplishment: Layered Coating

Stable Full Cell testing of Slot Die Produced, 94-3-3, NMC 532-C-UV Triple Layer Cathode, 1+2+3 layers = ~21 mg/cm²



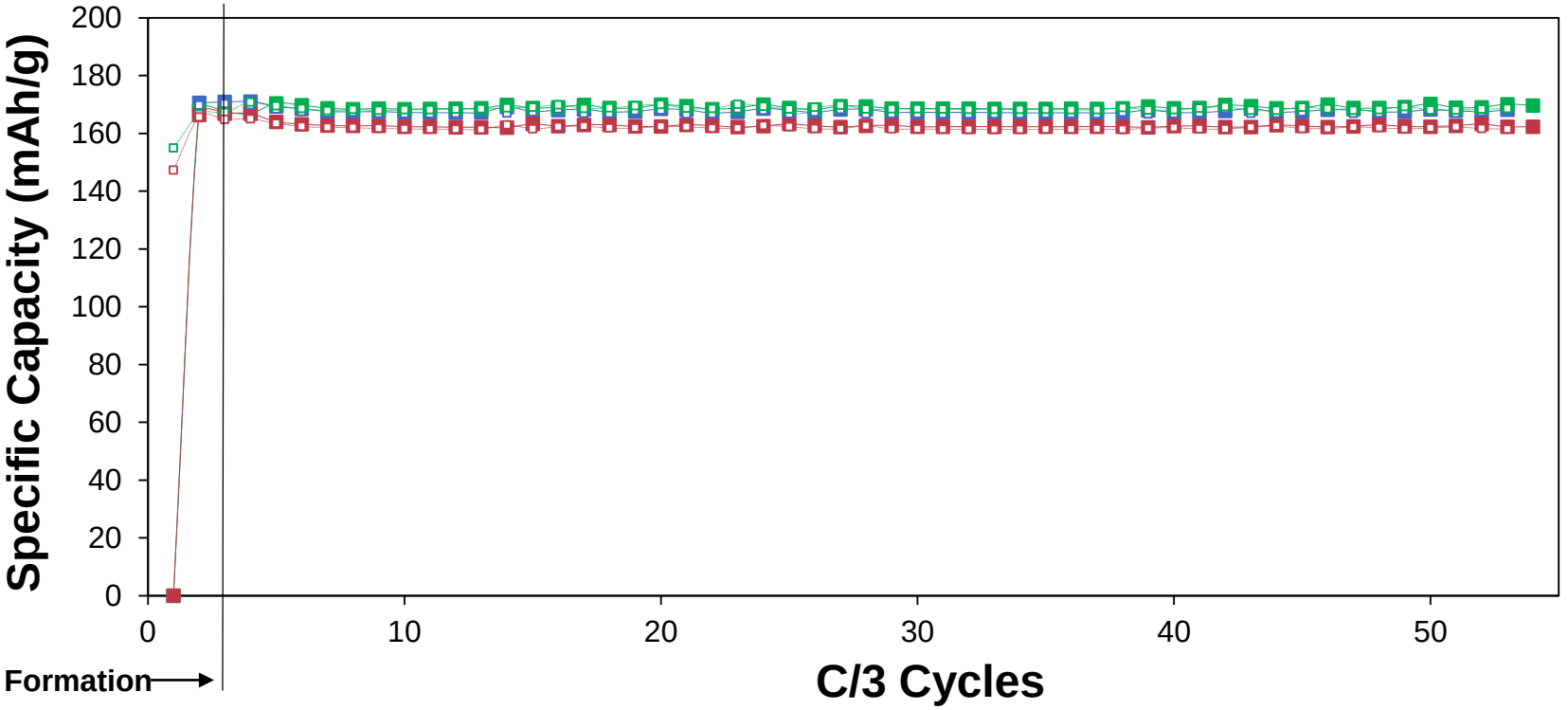
94-3-3

NMC(532)-C-UV Binder

Testing ongoing and sent to Oak Ridge for Pouch Cell Testing

Accomplishment: UV Anode

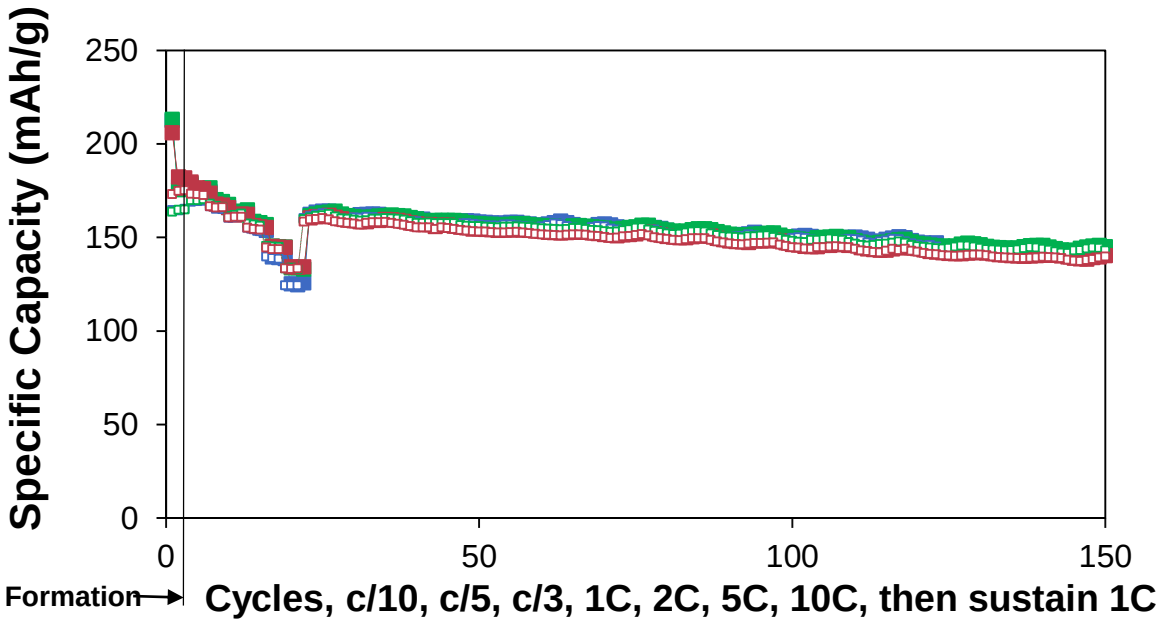
LTO Anodes (93-4-3) made with a UV Binder and Process



Three Coin Cells	143-3
Active Material Loading (mg/cm^2)	2.8-3.1
Composition (LTO:Carbon:Binder)	93-4-3
Cure Speed	60 fpm
Calendering pressure	n/a
Application method	Hand draw-down

Accomplishment: Performance

UV Power Cathode shows 75% capacity retention at 10C Rate
UV Cathode also withstands High Temperatures (>120°C)



82-12-6

$NMC_{(111)}$-C-UV Binder

4 mg/cm^2

Prepared for a U.S. Battery Manufacturer

Slot die applied. Shows tight consistency for all 3 cells.

Partners and Collaboration

Pouch Cell Testing of multilayered UV cathode with goals of higher energy density and developing a UV process at Oak Ridge

Dr. David Wood, ORNL

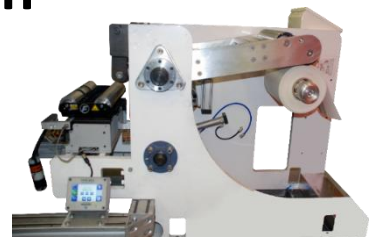
Testing and analysis of UV cured cathodes in pouch cells and compare performance to PVDF baseline

Dr. Khalil Amine, ANL

Proposed Future Research

Remaining Challenges in 2018

- **Special and new compositions always take a few cycles to optimize**
- **Working with Battery Manufacturers, OEMs and Integrators to customize chemistry and processes for their applications**
- **Collecting 1,000 cycle pouch cell data for power and energy batteries**
- **Milestone of working with high speed coating with slot die and printer technology to demonstrate high speed coating, may be limited by equipment**



Beyond Project

Work with OEMs, Battery Manufacturers, and research institutions to develop UV process for next gen higher energy density batteries

Any proposed future work is subject to change based on funding levels

Summary: For a UV electrode process…

- **Major challenges of capacity, impedance, and long term cycling have been overcome for cathodes with a UV process**

- **Cost model:**
  - **UV Manufacturing Cost 80-90% less than PVDF-NMP.**
  - **24% total cost reduction including materials for 2-side cathodes.**

- **UV Process with power batteries has the performance to compete with PVDF-NMP (90/5/5, 90/7/3, 82-12-6, NMC compositions) and LTO.**

- **UV Multilayer cathode process can be used to produce Energy batteries (94-3-3, > 21 mg/cm^2). The concept of barriers between layers is false.**

- **UV is a fast, flexible electrode manufacturing process that is useful to today's batteries and with research could easily integrate into next generation batteries.**