2012 DOE Vehicle Technologies Program Review Presentation

Miltec UV International, LLC

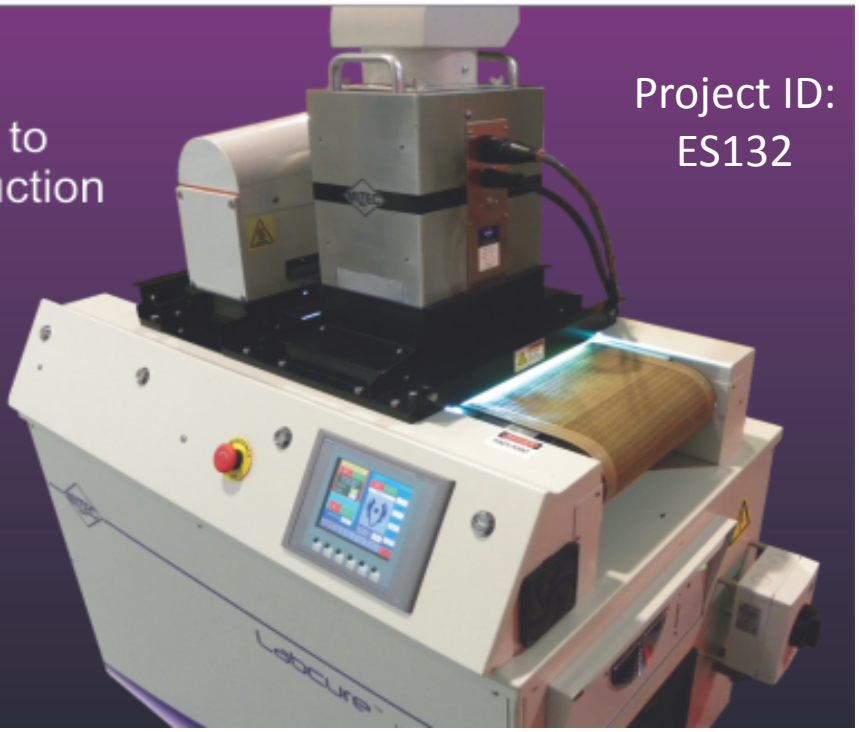
Utilization of UV or EB Curing Technology to Significantly Reduce Costs and VOCs in the Manufacture of Lithium-ion Battery Electrodes

A revolutionary high speed approach to manufacturing cost reduction

May 14th, 2012

Principal Investigator:
Dr. John Arnold

Presented by:
Gary Voelker,
Project Director



Project ID:
ES132

Overview

Project Timeline:

- Start Date:10/01/2011
- End Date: 09/30/2014
- Percent Complete: 20%

Project Barriers:

- Battery Manufacturing Knowledge
- Coating optimization
- Calendering optimization

Project Budget	
DOE Share:	$4,572,709.00
Miltec Share:	$1,143,299.00
Total Project Funding:	$5,716,008.00
FY11 Funding:	$381,086.80
FY12 Funding:	$1,524,347.20

Partners:

A123 SYSTEMS

Argonne NATIONAL LABORATORY

OAK RIDGE National Laboratory

ACTEGA Coatings & Sealants

Project Objectives

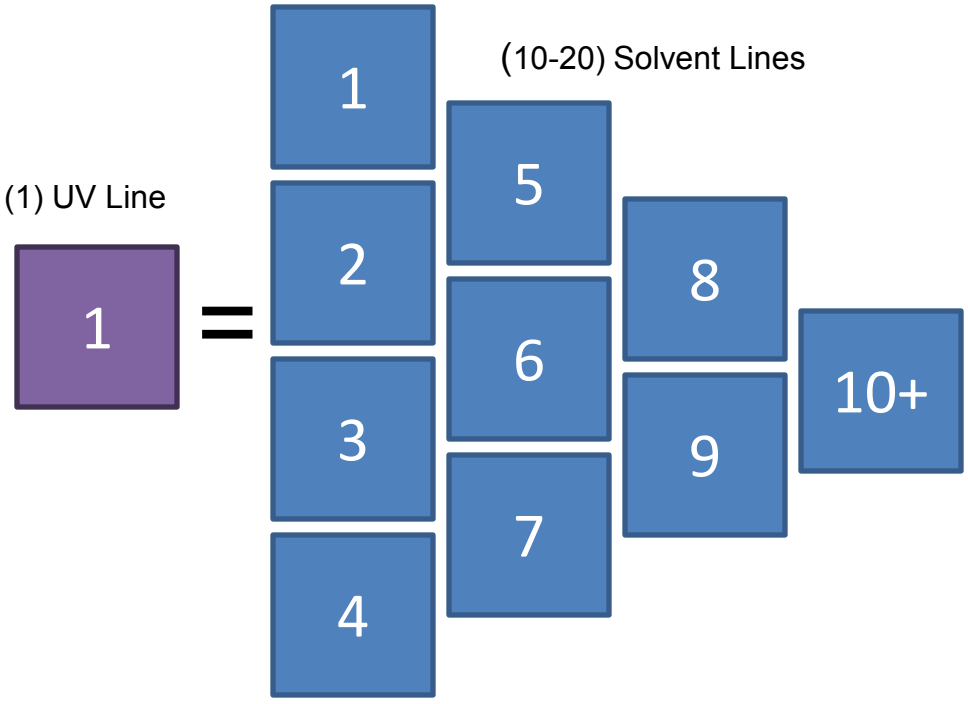
The objective of this project is to further develop and demonstrate the use of Ultraviolet (UV) and Electron Beam (EB) curing technology to significantly reduce the cost of manufacturing Lithium-ion battery electrodes by more than 50%.

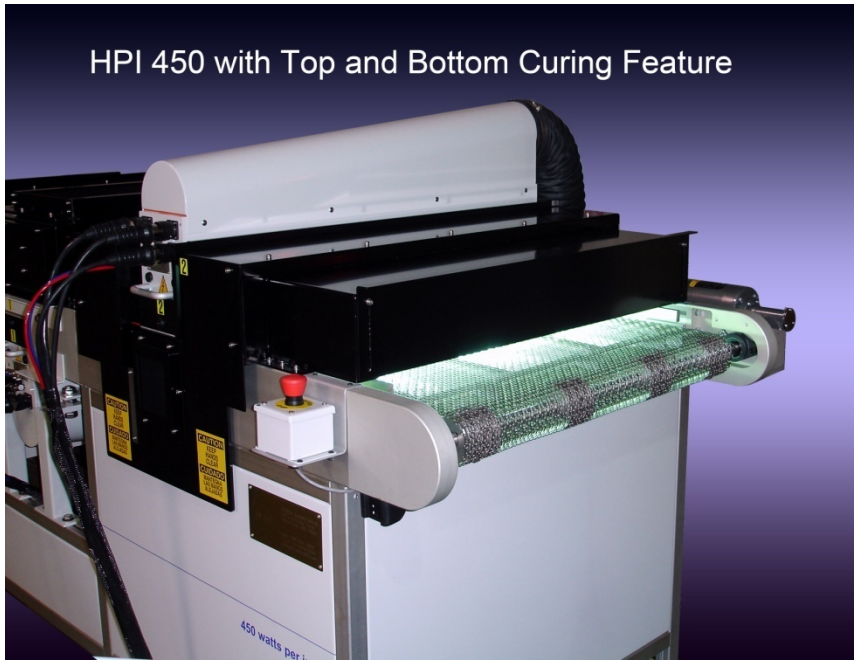
Additional Objectives:

Increase Process Speeds
Reduce Energy Requirements
Eliminate Solvent Recovery and VOCs
Double-sided Coating

Increase Process Speeds & Double Sided Curing

Current curing speeds for solvent based systems are approximately 15-25 fpm. With the introduction of a UV Curing System, these speeds would increase 10-20 times, to 100-200 fpm





Solvent based curing systems only have the capability to cure one side. UV Curing systems, Miltec specifically, is introducing technology that will allow for double-sided curing. Increased curing speeds and double sided coating offer huge reductions in capital cost and operating expenses.

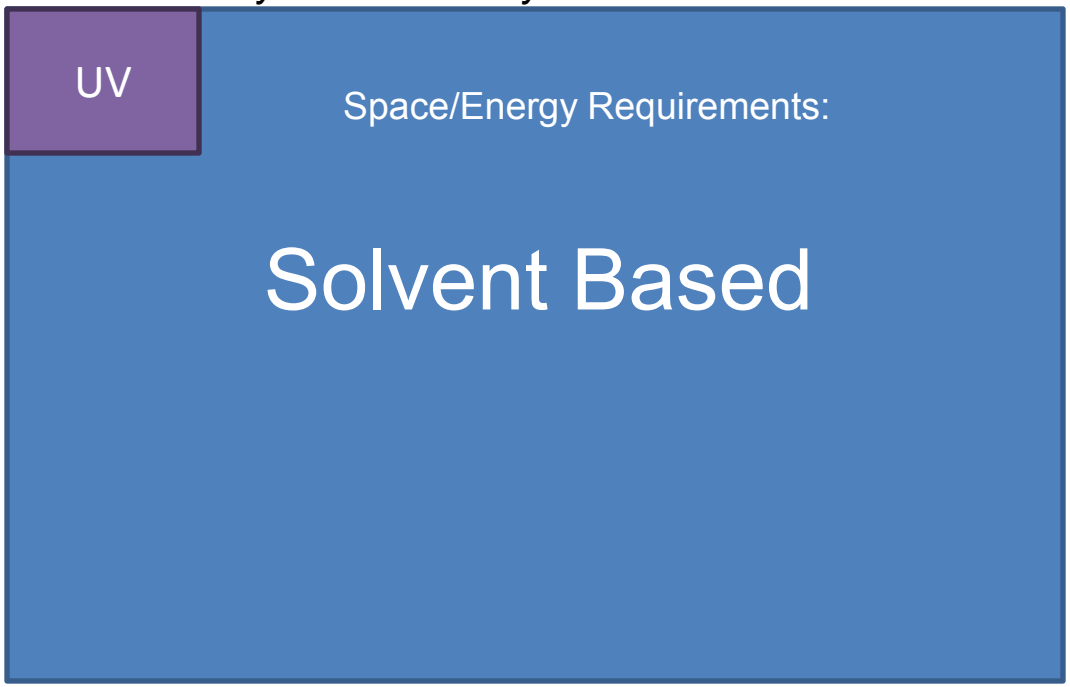
Reducing Capital, Energy, VOC and Space Requirements

Current energy requirements for solvent based systems are large. The major contributor is fuel for the drying ovens plus Humidity Control, Heating & Cooling.

Capital cost for a UV curing system per unit of electrode area produced can be 1/20th to 1/100th a solvent based system.

Space requirements for a UV system are 1/10th to 1/20th a solvent based system.

A UV System essentially eliminates VOCs.



Project Milestones

(FY11 & FY12)

FY2011	Milestone or Go/No-Go Decision
Oct-11	Milestone: Initiate formulation of cathode binder for Interim Cells using ANL and Miltec/ACTEGA binder and Lithium iron phosphate and NMC
Oct-11	Milestone: Initiate formulation of anode binder for Interim Cells using ANL and Miltec/ACTEGA binder
Oct-11	Milestone: Initiate Baseline Cell Design

FY2012	Milestone or Go/No-Go Decision
Feb-12	Milestone: Initiate Baseline Cell Fabrication
Feb-12	Milestone: Initiate Baseline Cell Test Plan
Mar-12	Milestone: Complete Baseline Cell Test Plan (Deliverable)
Mar-12	Milestone: Complete Baseline Cell Design (Deliverable)
Mar-12	Milestone: Complete Fabrication Baseline Cells for DOE Testing (Deliverable)
Aug-12	Milestone: Finalize UV Curable Binder for Cathode, Interim Cells

Qualifying UV Curable Binders

Binder Constituents

- Monomers
- Oligomers
- Photoinitiators
- Dispersants

Miltec UV & ACTEGA Kelstar

Qualify = Testing

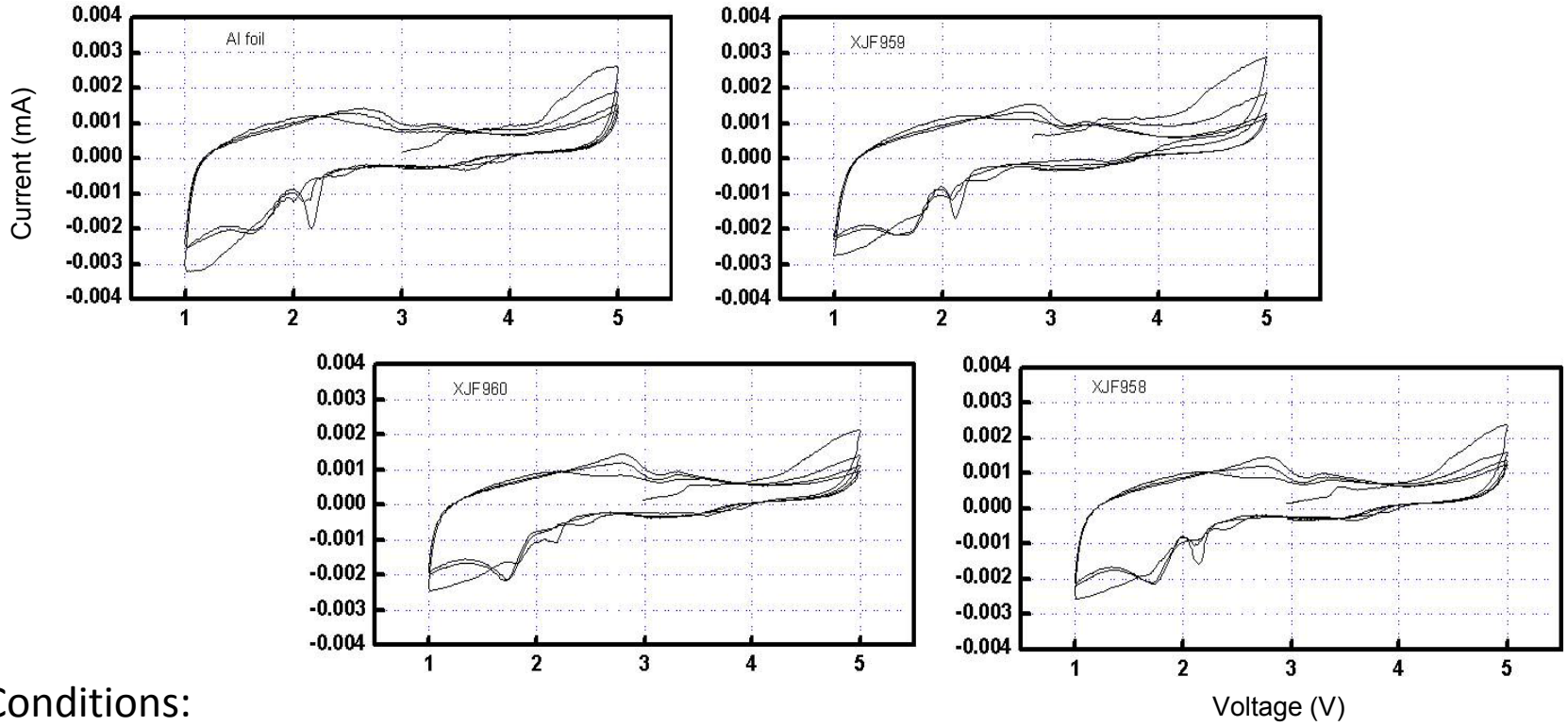
- Electrolyte Immersion
- Cyclic Voltammetry

Electrolyte Immersion:
Two grams, of varying formulas, are cured under a standard UV lamp system at 100 (fpm). After curing, the two gram 'pucks' are placed in dishes filled with a mixture of 60% dimethyl carbonate and 40% propylene carbonate, and placed in oven at 140°F for two weeks.

Cyclic Voltammetry (CV) :
An electrochemical technique which measures the current that develops in an electrochemical cell under conditions where voltage is in excess of an electrodes predicted potential. CV is performed by cycling the potential of a working electrode, and measuring the resulting current.

Cyclic Voltammetry: Passing the Test

The CV tests shows UV binder chemistry can resist electrochemical degradation



Test Conditions:

Coin cell: CR 2032
Lithium metal as counter electrode
Electrolyte: 1.2 M $LiPF_6$ in EC: EMC (3:7 in weight)
CV: 0.1 mV/s between 1-5 V at room temperature for 3 cycles
Instrument: Solartron Analytical 1400 cell test system

Mix, Cure & Fabricate

Miltec UV

Mixing and Curing

- Baseline Loading Parameters
- Adhesion
- High Conductivity

A123 Systems & ANL

Baseline Cells

- Fabricate
- Test
- Submit

Baseline Loading:
87% NMC
8% Binder
5% Carbon

Fabrication
•18 Baseline Cells
•9 NCM (ANL)
•9 Nano-phosphate (A123)

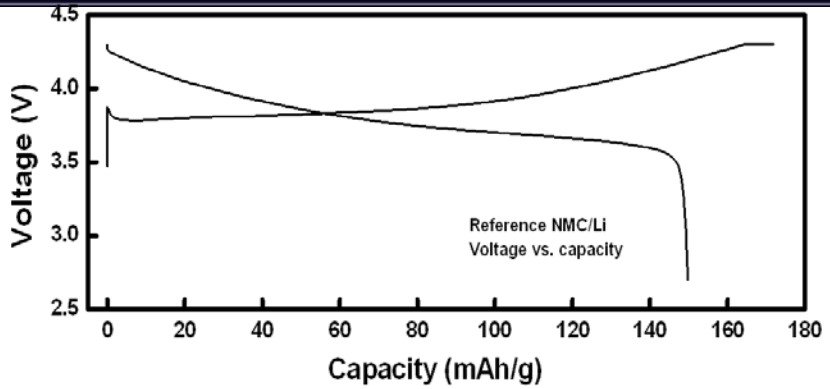
Adhesion:
Tape/Pull Test
Poor = Moderate Flaking
Good = Minimal Flaking
Excellent = No Flaking

Conductivity/Resistance:
Measured in Ohms:
0.1 = Achieved
0.2 = Target
0.35 = Acceptable

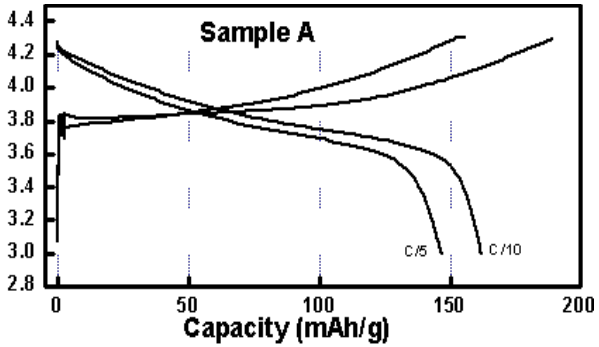
Coin Cell Test Conditions

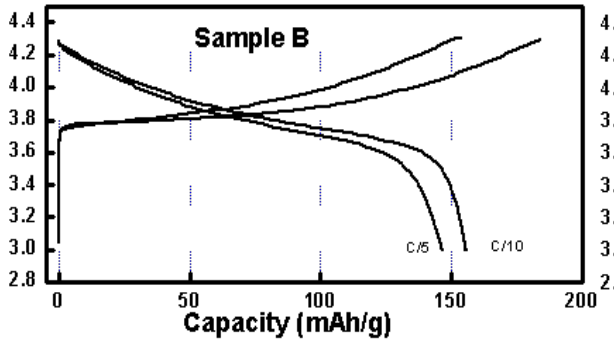
- Room temperature (about 20^{O}C)
- Half cell (Li metal as anode) Coin cell 2032
- Electrolyte: 1.2 M LiPF6 in EC:EMC (3:7 in weight)
- Separator: Celgard 2325
- Assemble in He-glove box
- Electrochemical equipment: Maccor 4400

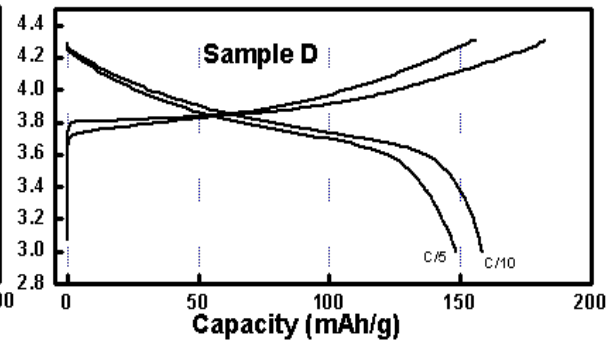
Electro-chemical Testing: Charge and Discharge

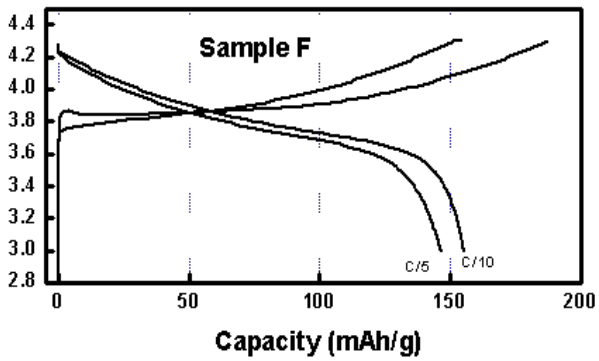


Sample	Charge (C/10)	Discharge (C/10)	C/5	Thickness (Al foil 25 um)	Loading (87%:5% carbon:8%binder)
Sample A	189	161	146	15	1.91 mg/cm2
Sample B	184	155	145	14	1.94 mg/cm2
Sample D	183	158	149	17	2.41 mg/cm2
Sample F	187	155	147	15	2.01 mg/cm2

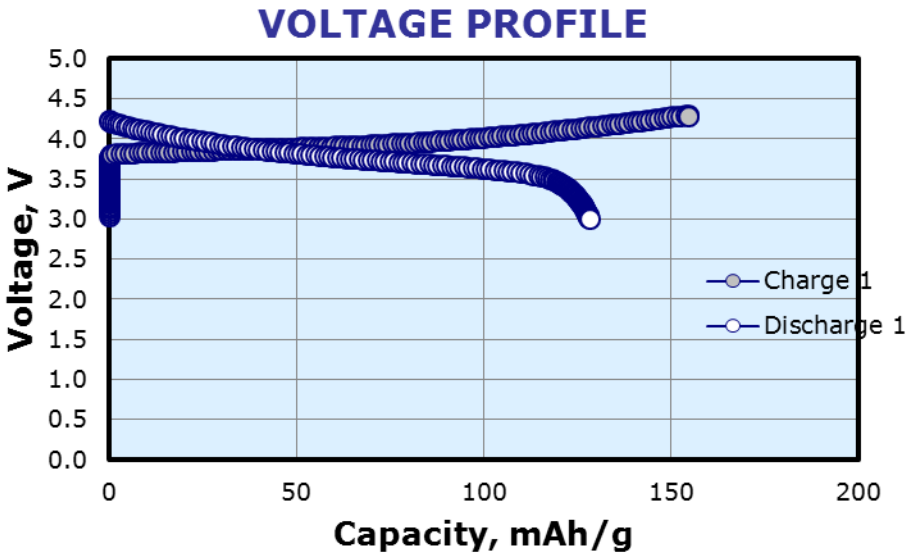


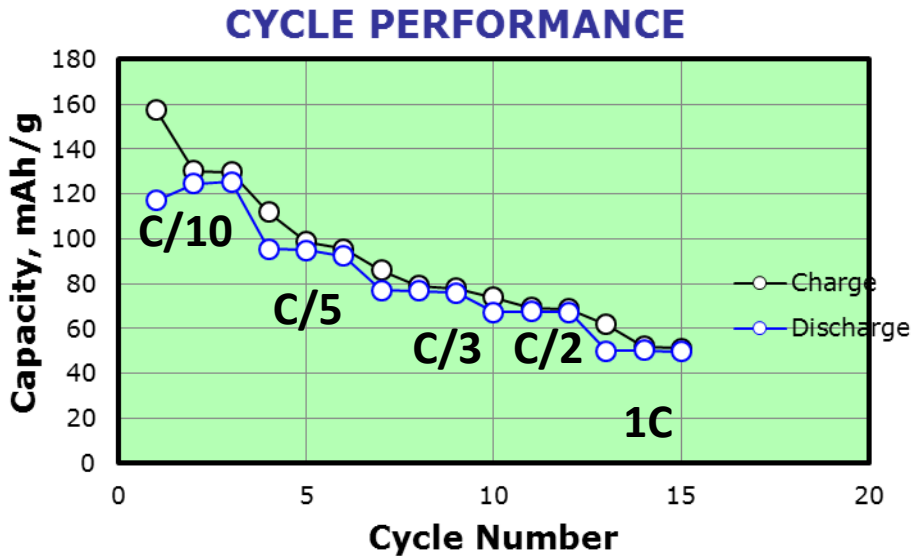




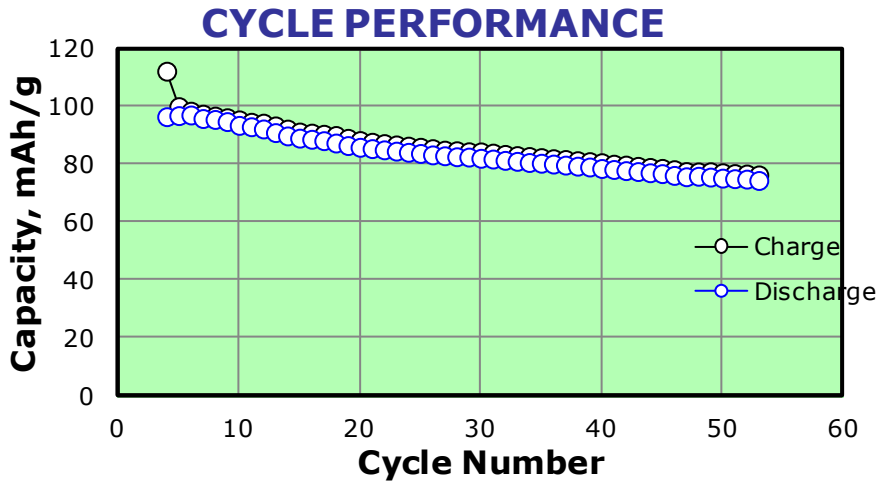


Profiles, Performance and Curves – Single Layer

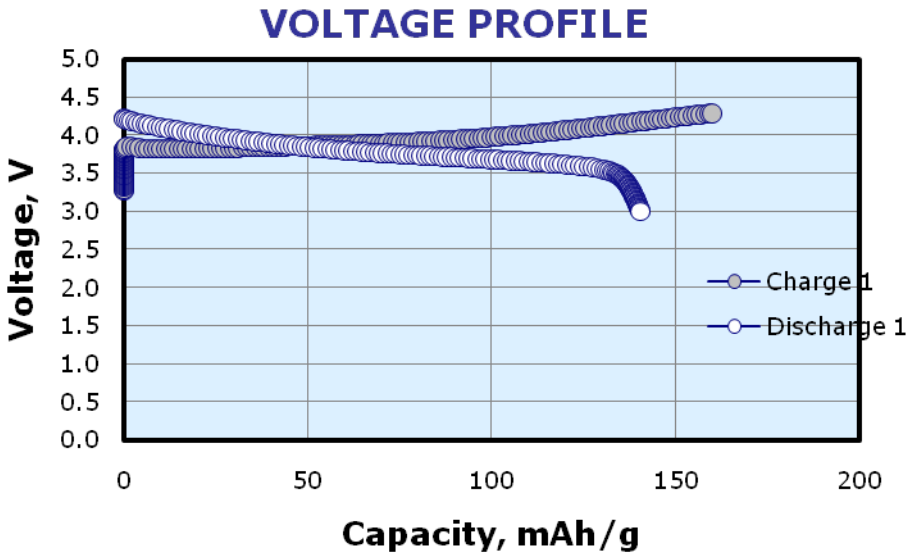


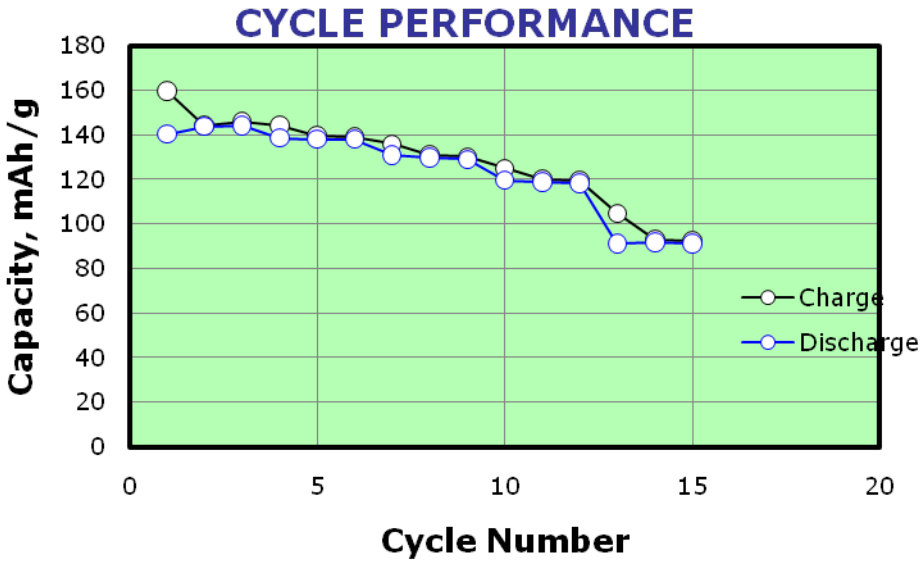


Coating: Single Layer
Thickness: 50 microns, Not calendered
Composition: 87% NMC, 8% Binder, 5% Carbon
Curing Speed: 100 fpm
UV Lamps: HPI Lamps, 2 @ 550 wpi
Initial Charge/Discharge: 154/128 mAh /g
Void = 32%

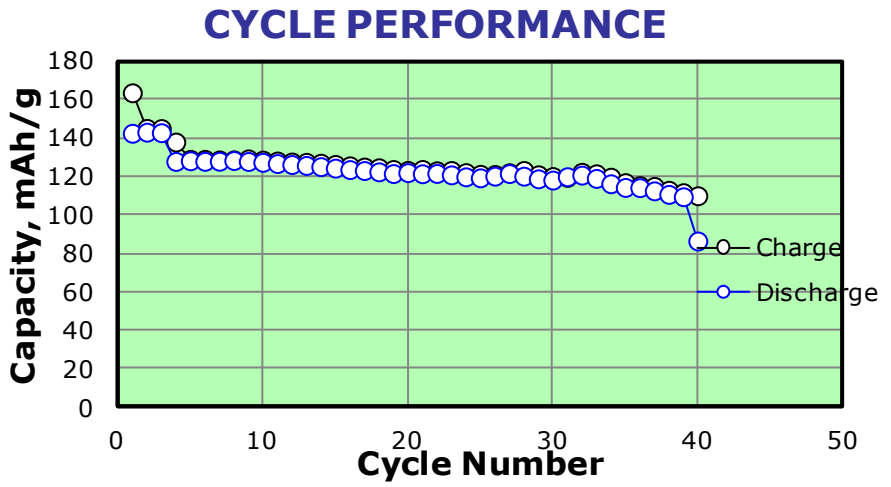


Profiles, Performance and Curves – Double Layer





Coating: Two Layers
Thickness: 20 microns, calendered,
Composition: 87% NMC, 8% Binder, 5% Carbon
Curing Speed: 100 fpm
UV Lamps: HPI Lamps, 2 @ 550 wpi
Initial Charge/Discharge: 163/142 mAh /g
Void = 30%



Technical Results Summary

Overall Results:

- Successfully qualified 5 oligomers, 4 monomers, 4 photoiniators and 4 dispersants
- Successfully mixed 87% NMC, 8% UV binder, 5% Carbon
  - Coated, cured at 150 fpm
  - Excellent adhesion per scratch test
- Nominal 35% voids
- 14 mg/cm2 NMC loading
- 0.15-0.36 ohm resistance
- Initial charge discharge nominal 150/135 mAh/g

Technical Results Summary

Coin Cell Test Results Significance:

- Coin cell tests show thin coatings with UV binders and NMC show promise for handling charge and discharge for power applications

- Coin cell tests show thicker coatings with UV binders and NMC show promise for handling charge and discharge for energy applications

- Coin cell tests show thin and thick coatings with UV binders and NMC show promise for multiple charge and discharge cycles

Collaboration and Coordination

ACTEGA Kelstar, Inc. – Innovation Laboratory

- Subcontractor to Miltec UV
- 30% cost share in all efforts
- ACTEGA Kelstar provides a representative to the Advisory Team and will provide input to the Cell Design Reports with regard to binder description and testing.
- ACTEGA effort managed by Jim Wittig, VP Innovation Laboratory

A123 Systems - Advanced Research & Government Solutions Group

- Cost Sharing Partner
- The total A123 systems effort includes 44% cost share.
- A123 efforts are conducted at A123's headquarters and Lithium-ion battery research facilities in Watertown, MA, and Ann Arbor, MI.
- A123 Systems serves a consultant role to Miltec UV as a member of the Advisory Team ensuring Miltec UV approaches to electrode and cell design and manufacturing will be compatible with a typical battery manufacturing process in either a new or retrofit application
- A123 effort managed by Mike Wixom, Senior Technical Director

Collaboration and Coordination

Argonne National Laboratory – Chemical Sciences and Engineering Division

- Subcontractor to Miltec UV
- Performs analytical and electrochemical testing efforts
- Cell fabrication efforts
- ANL has world class laboratory facilities for the fabrication and testing of Lithium-ion cells.
- The ANL effort is managed by Dr. Khalil Amine, Senior Scientist

Oak Ridge National Laboratory – Materials Science and Technology Division

- Subcontractor to Miltec UV
- Acts in a consultant role to Miltec UV in the technical areas of electrochemical performance and coating technology
- Provides specific analytical testing of selected electrode samples prepared by Miltec UV
- Provides technical review support as needed to Miltec UV for Cell Test Plans and Cell Design Reports
- ORNL effort is managed by Dr. Claus Daniel, Staff Scientist

Proposed Future Work – FY12 and FY13

FY12:

- Baseline Cell Test Plan
- Baseline Cell Design
- 18 Baseline Cells for DOE validation testing
  - (9) NCM Cells prepared by ANL
  - (9) Nano-Phosphate cell prepared by A123
- Finalize UV Curable Binder for Cathode, Interim Cells

FY13:

- Initiate Interim Cell Fabrication
- Initiate Interim Cell Test Plan
- Complete Interim Cell Test Plan (Deliverable)
- Complete Fabrication Interim Cells for DOE Testing (Deliverable)
- Initiate UV/EB Curable Binder Formulation for final Cells
- Complete Interim Cell Performance Milestone Report
- Go-No-Go Decision Point Based on Interim Cell Performance (Deliverable)
- Initiate UV/EB Curable Binder Formulation for Final Cells

Summary

- Foundations in place: During the first quarter of the contract award, Miltec UV acquired personnel, equipment, materials, and a new facility to initiate the program
- Since October 2011, Miltec UV has successfully qualified candidate UV Curable constituents including: 5 Oligomers, 4 Monomers, 4 Photoinitiators, and 4 Dispersants

- ANL and A123 Systems continue to report successful CV and Electrochemical testing on cathode samples
- In March 2012, Miltec UV delivered 18 Baseline Cells prepared by ANL & A123
- Anode Preparation Work for Budgetary Period 2 Initiated for Interim Cells
- With initial success in only the first two quarters, the Interim Cell milestones are ahead of schedule with a Go/No- Go decision due 11/22/2013