Final Report

DOE Contract Award: DE-EE0007287

Development of Ultraviolet Curable Binder Technology to Reduce Manufacturing Cost and Improve Performance of Lithium ion Battery Electrodes

Miltec UV International

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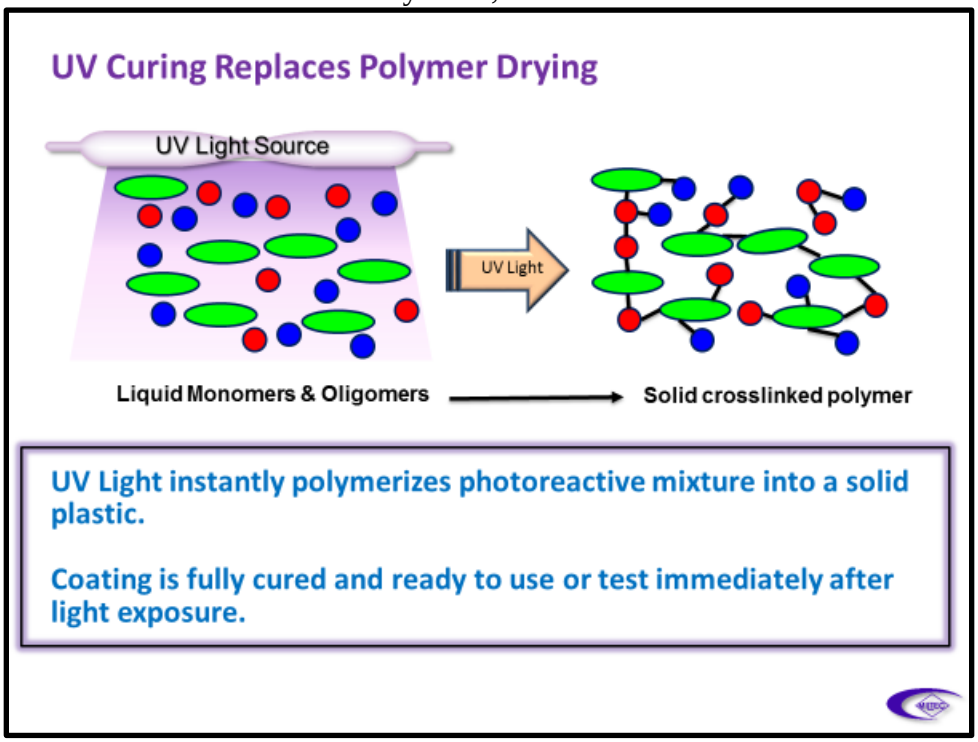
EXECUTIVE SUMMARY

Miltec UV International and its partners, Oak Ridge National Laboratory (ORNL) and Argonne National Laboratory (ANL) undertook this project to demonstrate the use of UV curable binder to replace conventional solvent based binders such as PVDF as a means of reducing the manufacturing cost of Lithium ion battery (LIB) electrodes. The project involved an iterative Research and Development (R&D) effort: making coin cells and pouch cells from electrodes made with varying UV chemistries and active materials, followed by testing and analyses, then by adjustments in UV chemistry, mixing, coating, and UV curing to produce layered pouch cells at high processing speeds with performance equal or greater than that of a conventional PVDF cell. The effort focused on cathodes made with UV curable binders and multiple active cathode materials such as NMC, NCA, Sulfur, and LMO and anodes made with LTO. A primary objective of the project is to provide performance data sufficient for Lithium ion battery manufacturers to commit to the first steps of making their own HEV, PHEV and/or EV Lithium ion batteries with a UV process. In addition, the project successfully demonstrated coating

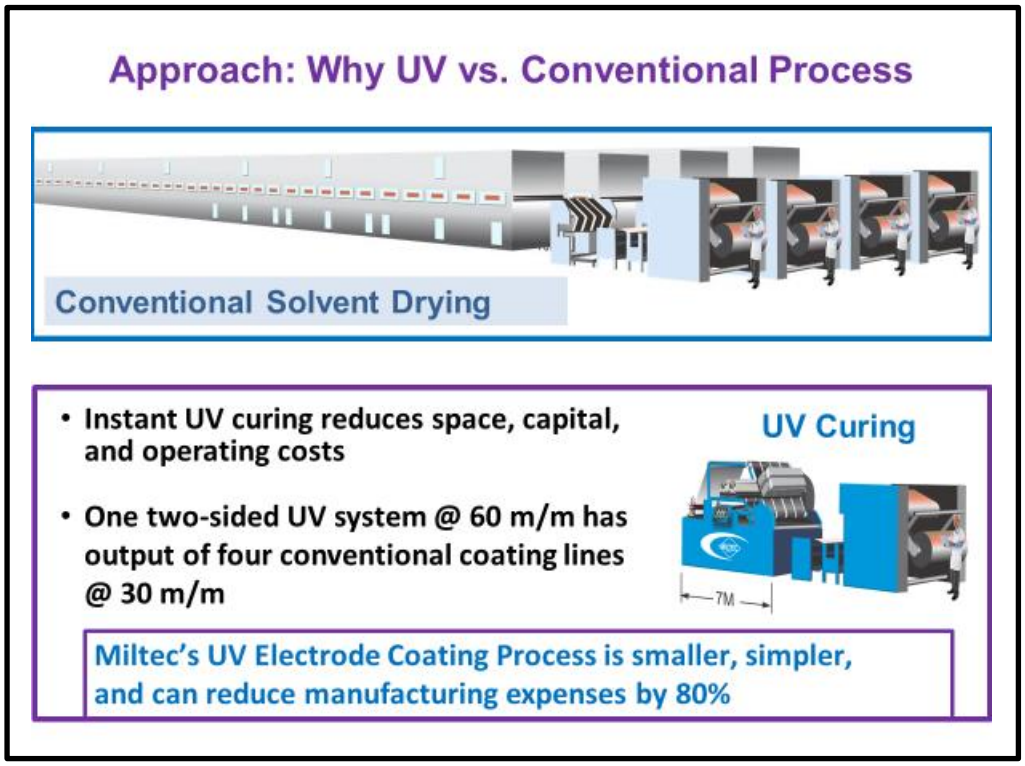
and UV curing a cathode layer on top of an existing UV cathode layer to produce a thicker high energy cathode with good porosity and no discontinuity between layers. It also demonstrated the potential advantages of one layer of a power loading with a second layer of an energy loading.

As shown in the graphic below, a UV process allows for near instantaneous solidification of the binder thus eliminating the need for a drying oven and solvent recovery as needed in conventional solvent based binder systems,



A cost model developed by Miltec UV under a previous DOE contract estimated that the manufacturing cost of an electrode could be reduced 80-85% by the use of UV and the total cost of the electrode including the material costs could be reduced 25% by the use of UV. These cost reductions are made possible by the dramatic increases in process speeds as well as significantly reduced capital cost, operating cost, reduced energy consumption and reduced environmental concerns and costs due to the elimination of volatile organic solvents.

The project was very successful in meeting its objectives. 0.5 and 1.0 Ahr multilayer pouch cells were fabricated and demonstrated performance equal to a conventional PVDF cathode and LTO anode performance was also demonstrated equal to LTO anodes prepared with a PVDF binder. The cathode and anode electrode coating samples were prepared on a continuous roll to roll UV system with 3 UV lamps and a slot die coater. The successful completion of this project has enabled Miltec UV to take the final steps leading to the commercialization of an innovative technology that will result in UV electrodes being manufactured and sold from the U.S., with increased production capacity, reduced cost, and improved battery safety.



ACCOMPLISHMENTS

This project employed an iterative process of technology selection, implementation, testing, and resulting optimization. Miltec initially focused on screening potential UV binders with chemical screening tests, formation and impedance measurements, and < 50 cycle, half-cell charge capacity tests. ANL and ORNL and potential battery manufacturer customers ran longer term cycle tests (50-1,000 cycles) with full coin cells and pouch cells as well as offering world class analytical testing to evaluate coating chemistry and morphology as it relates to battery performance.

Another innovation of the use of UV curable binders in LIB is the potential for much higher processing speeds. Miltec and its partners have shown that once a condition for complete UV curing is determined (speed, thickness, number of lamps, etc.) then there is a linear correlation between process speed and number of UV lamps. For example, it has been shown that if UV curable coating completely cures at a cathode coating thickness of 20 µm with 1 lamp (600 W/in lamp) at a speed of 50 fpm, then that same 20 µm coating will completely cure at a speed of 150 fpm with 3 lamps.

Another potentially important innovation made possible with UV curable binders is the ability to make cathodes with multiple layers of coating. This is made possible by the fact that, unlike a solvent based system, the second or subsequent layers can be applied without the solvent in the second layer dissolving material in the layer below. Miltec has demonstrated this innovative capability in both hand drawn and slot die coated samples. Multilayered coating

introduces the ability to make thicker, higher active material loading cathodes for EV applications. It also introduces the ability to change porosities and other characteristics such as material composition (active material and carbon) between layers.

The accomplishments of this project are highlighted in the ensuing sections.

Cells with UV Binder Demonstrate Performance Equal to PVDF

An early, recurring and constant objective of the project was to confirm that cells made with a UV curable binder would demonstrate performance equal to or greater than a cell made with PVDF with the same loadings and other conditions. Figure 1 is the cycling data from single layer pouch cells fabricated by a cooperating battery manufacturer. The cells were to represent a typical loading for a HEV application of 5.8 mg/cm^2 NMC 111 active cathode material. As can be seen the UV cells were equal or better at a temperature of 60ºC. The higher operation temperature accelerates the degradation of the battery.

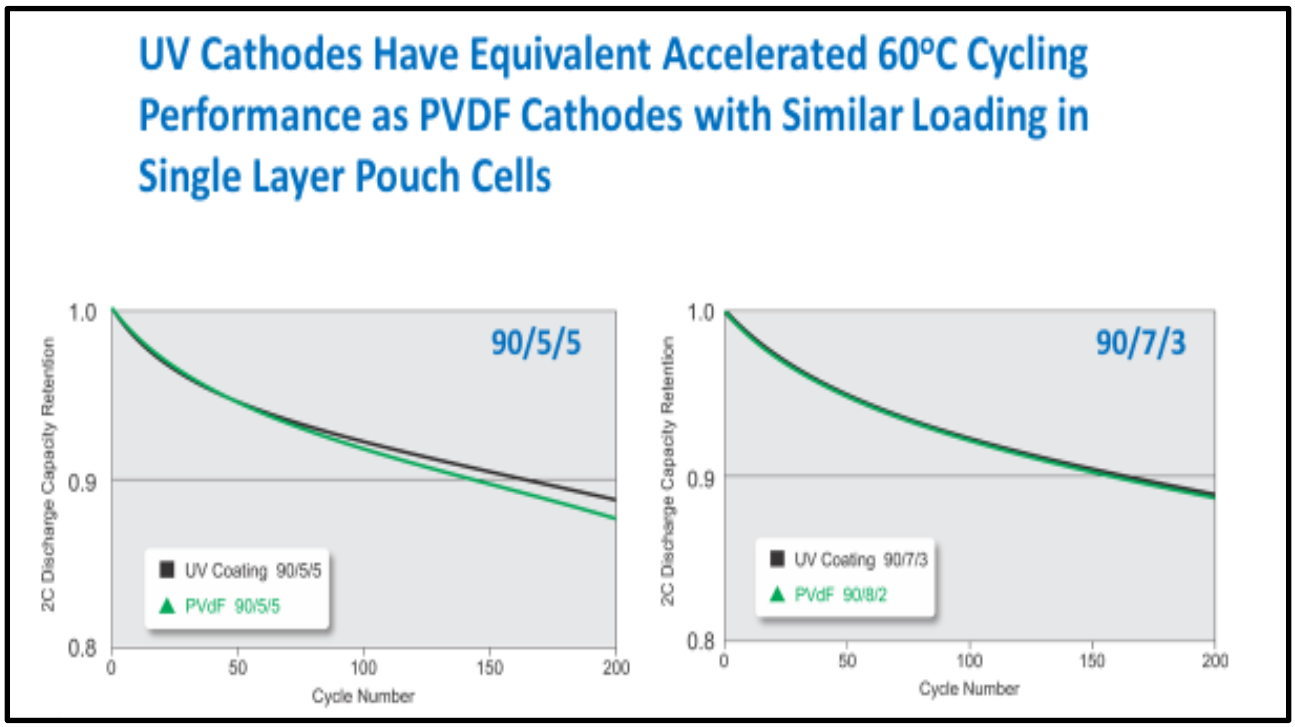


Figure 1. UV binder at least equal to PVDF binder for 5.8 mg/cm^2 NMC (111) cathodes and the same graphite anode.

Figure 2 is the reactive impedance of the same cells as shown in Figure 1. It can be seen that the UV cells began with impedance slightly higher, but they did not increase in impedance with cycling as did the PVDF cells.

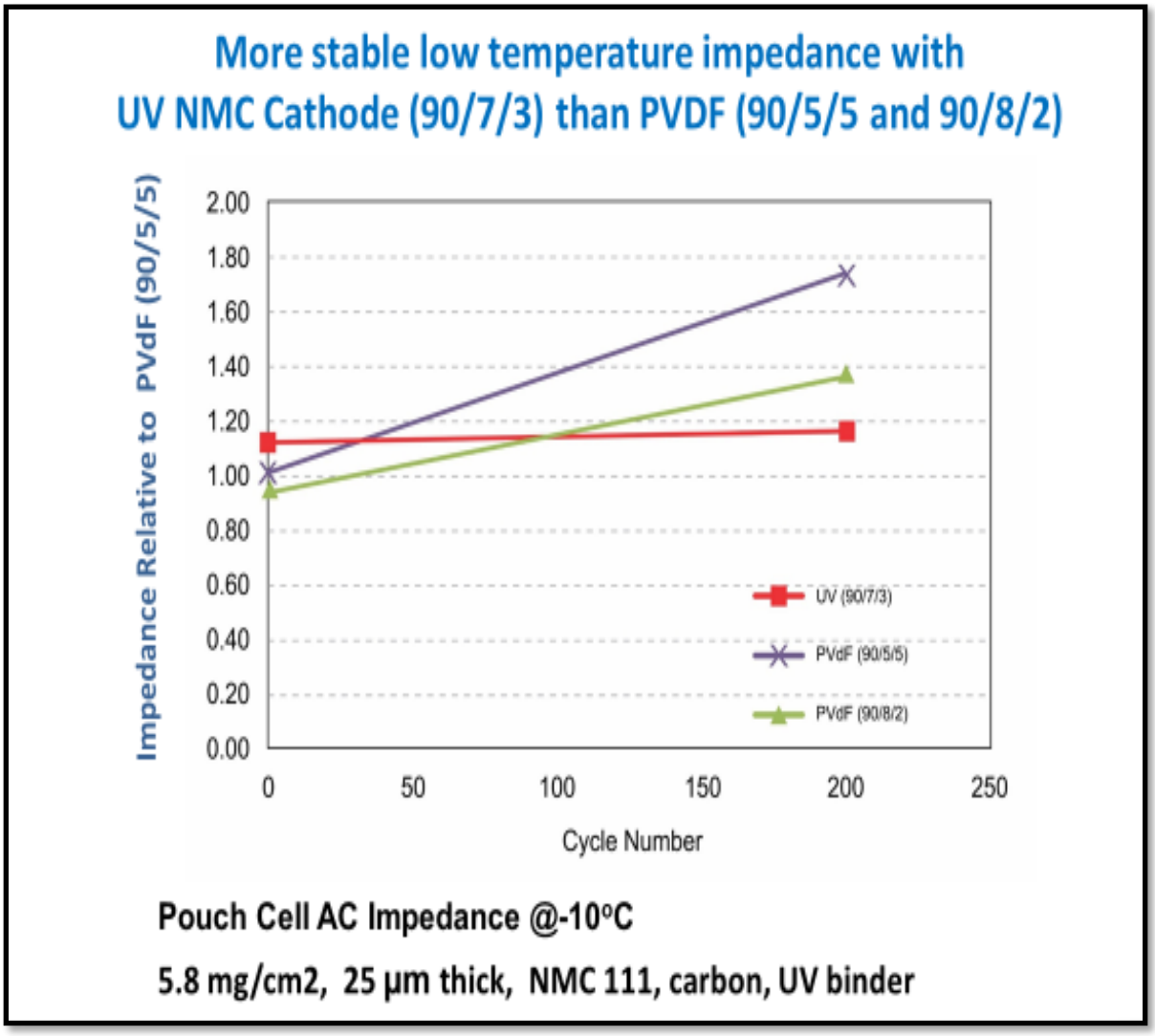


Figure 2. Reactive Impedance of UV pouch cells near equivalent to PVDF baseline and showing better stability.

Multilayer Pouch Cell Rate and Long-Term Cycling Tests

The culminating accomplishment and final milestone of the project was the successful fabrication and performance testing of multilayer pouch cells (0.5–1.0 Ahr) fabricated using UV curable binder cathodes to demonstrate capacity, long term cycling, rate capacity, impedance, and repeatability equal to or Cathode samples using NMC 532 at 94/3/3 by weight of NMC/carbon and UV binder were prepared using the Miltec UV coating and curing system described in the next section. The two-side total loading and double layer coatings of 29.2 mg/cm^2 two-side total loading. Combined with matching graphite anodes, ORNL assembled multilayered pouch cells 0.5 Ahr using the single layer cathodes and 1.0 Ahr using the double layer cathodes. Each pouch cells contained 6 double-sided anodes and cathodes and 1 each single-sided anode and cathode.

Figure 3 shows charge-discharge capacity for the full rate capability test of C/10 to 10C for the single layer cathode coating cells. These are good charge rates for a 94-3-3 coating.

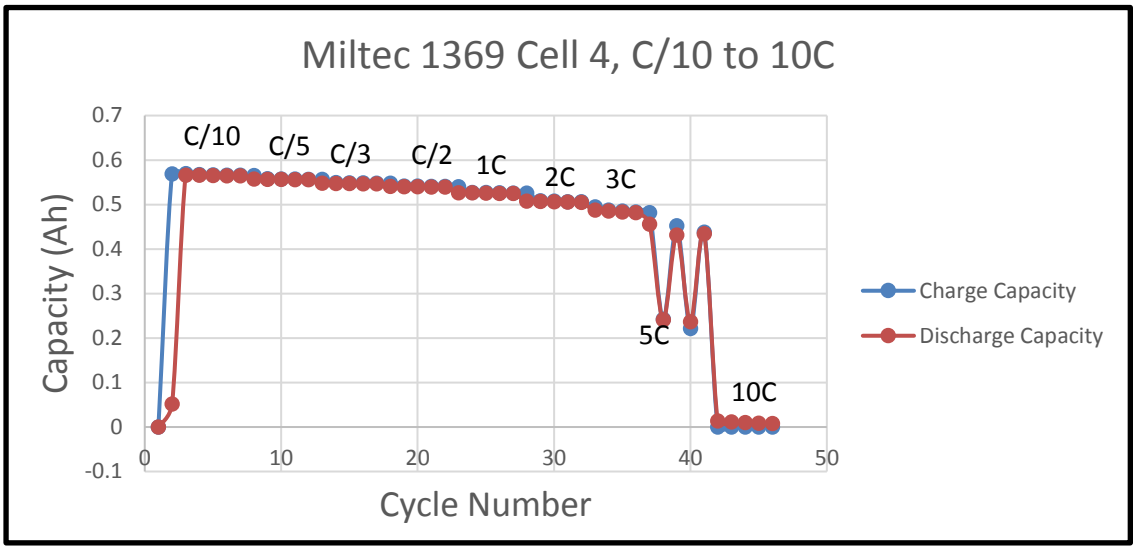


Figure 3. UV Pouch Cells (0.5 Ah) Rate capability from C/10 to 10C Ah for single layer 17.75 mg/cm^2 (two sides total) NMC 532

After the capacity cascade, the same the cells were cycled for at c/2 30 equal charge and discharge cycles showing that the 0.5 Ah cells were not stressed by the rapid charging cycles (Figure 4).

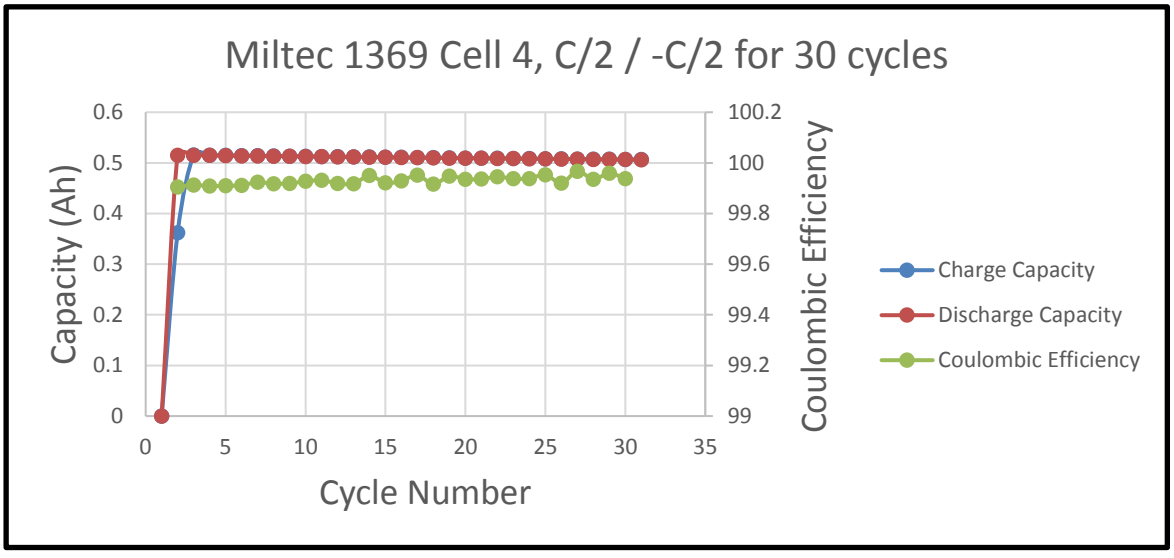


Figure 4. UV Pouch Cells (0.5 Ah) recover with after capacity cascade. Equal C/2 charge discharge capacity. Single layer 17.75 mg/cm^2 (2 side total) NMC 532

Similarly, good results are shown for the 1.0 Ah pouch cells. As expected the thicker coatings in Figure 5 do not cycle as fast as the thinner electrodes of Figure 3.

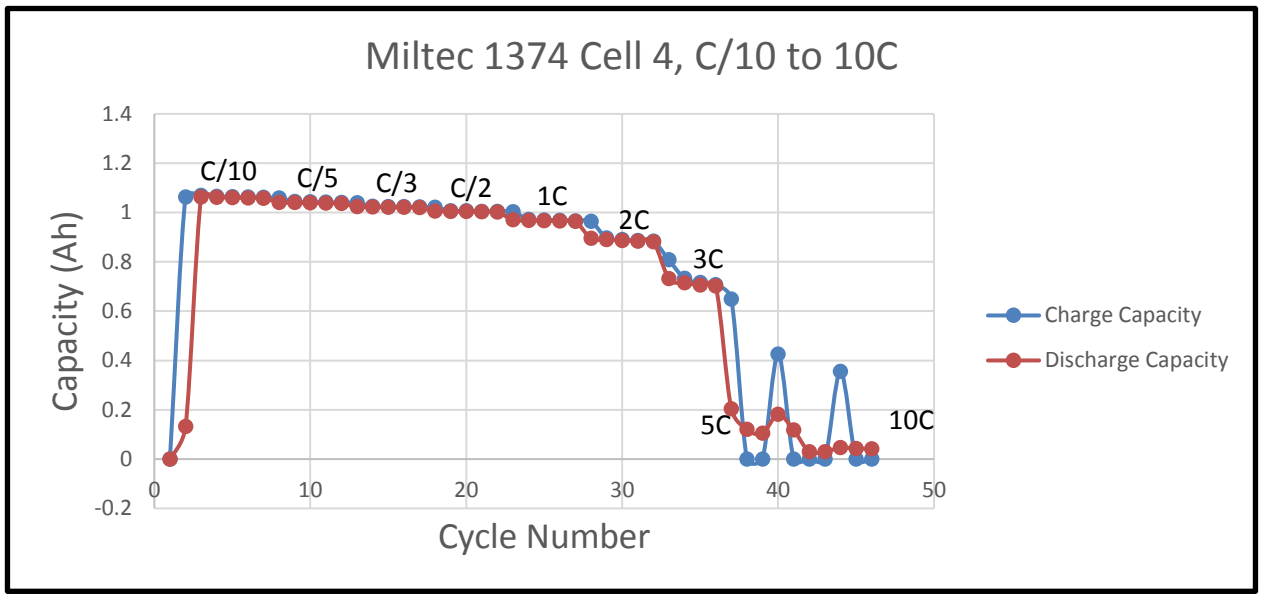


Figure 5. UV Pouch Cells (1.0 Ah) Rate capability from C/10 to 10C. Double layer 29.2 mg/cm^2 (two side total) NMC 532 with UV binder.

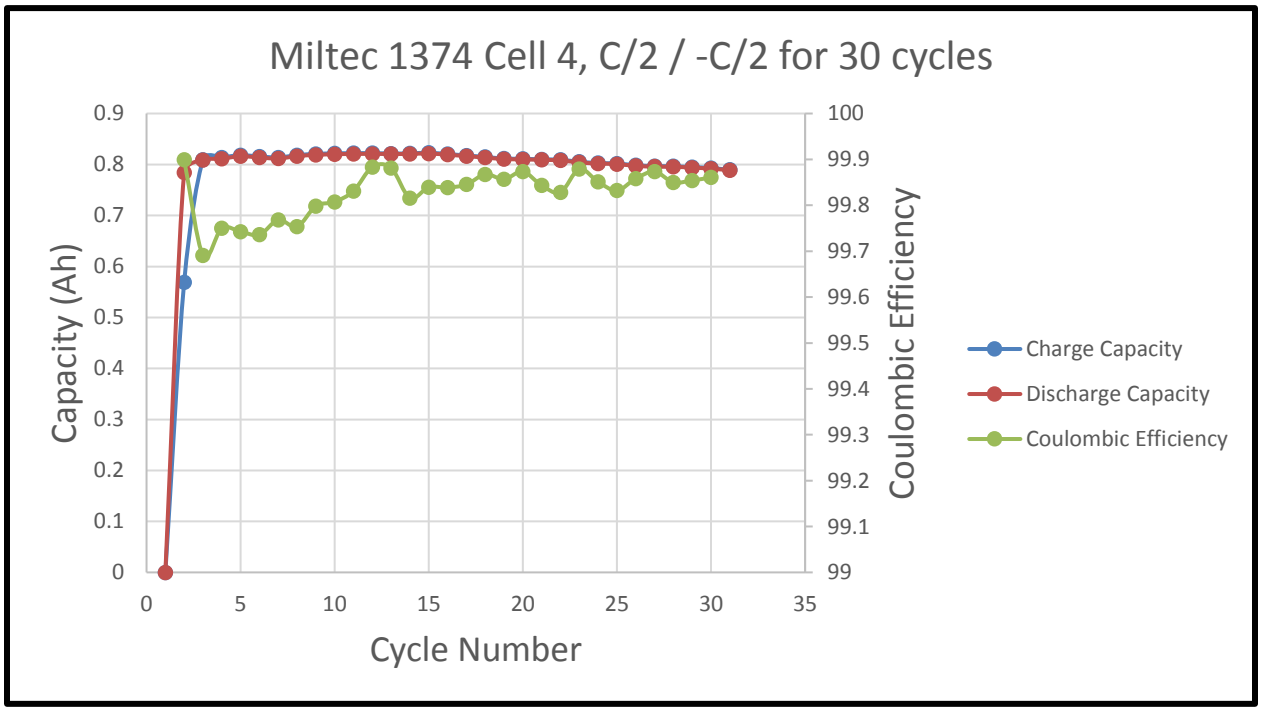


Figure 6. UV Pouch Cells (1.0 Ah) recover with after the capacity cascade. Equal C/2 charge discharge capacity. Double layer 29.2 mg/cm^2 (two side total) NMC 532 with UV binder.

Six of the 16 multilayer pouch cells prepared by ORNL were tested for the rate characterization shown in Figures 3, 4, 5 and 6. The remaining 10 cells (5 each 0.5 Ahr and 5 each 1.0 Ahr) are to be tested to 1,000 cycles at C/3 charge/ discharge rate. The 0.5 Ahr cells were fabricated from the single layer UV cathodes and the 1.0 Ahr cells were fabricated from the double layer UV cathodes. Figure 7 shows an average discharge capacity of the five 0.5 Ahr Miltec 1369 cells. The Coulombic efficiency is also graphed based on the average discharge capacity over the average charge capacity. Figure 8 shows the average discharge capacity and Coulombic efficiency for the five 1.0 Ahr Miltec 1374 cells. Both of the discharge capacities are plotted with error bars based on the standard deviation.

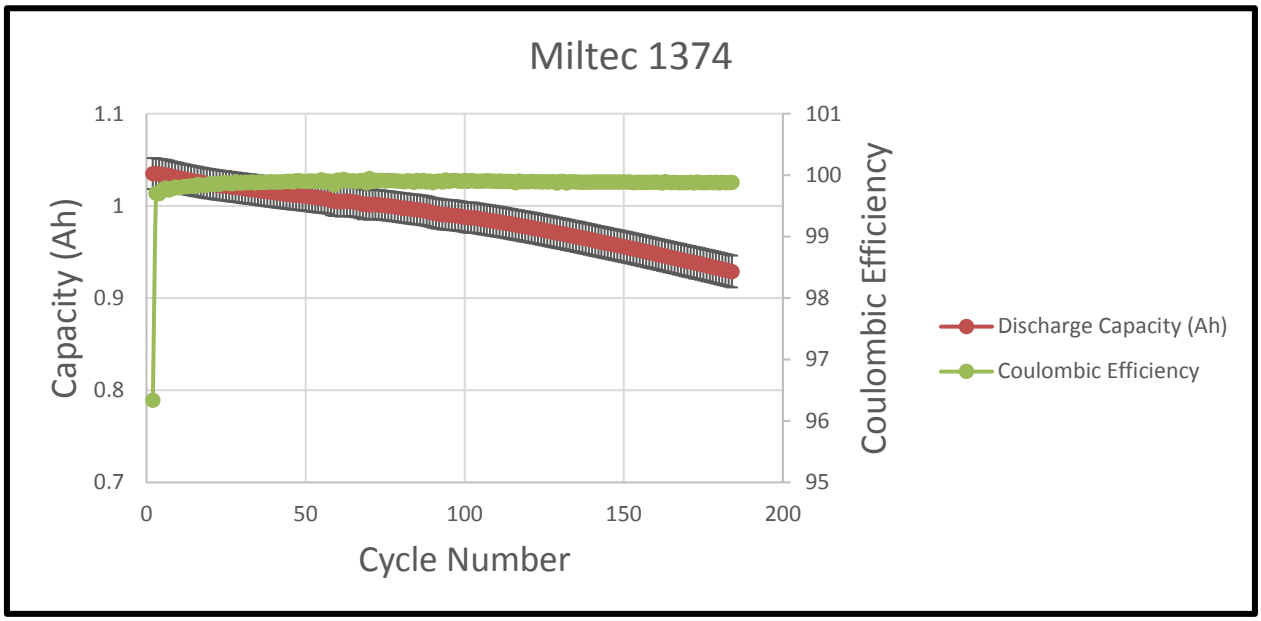


Figure 7. Long term cycling results of double layer cathode cells

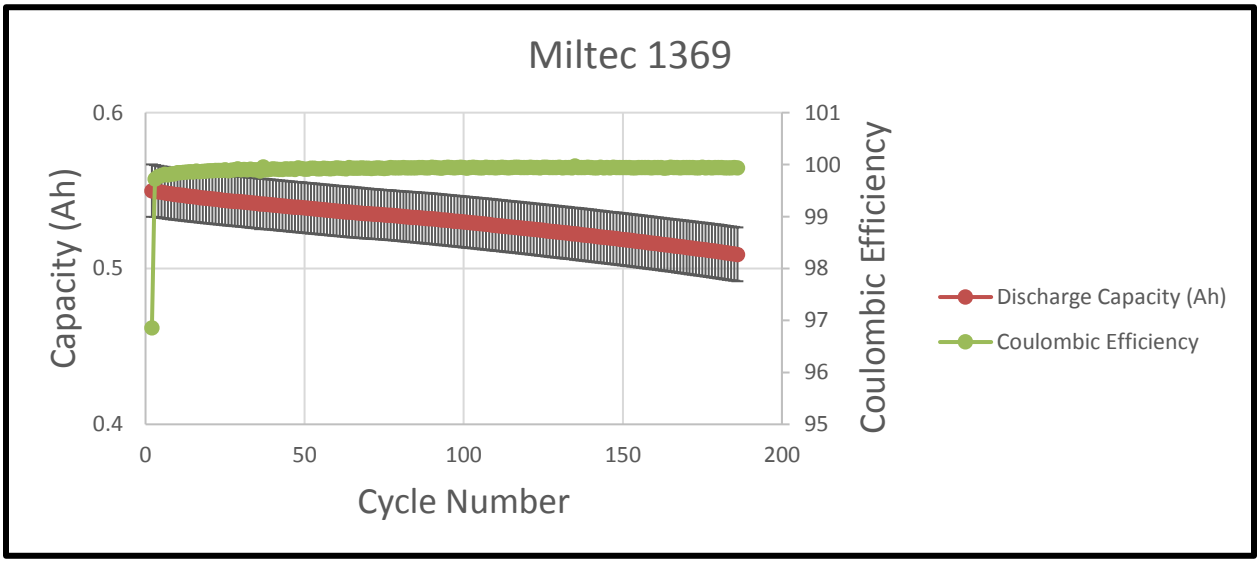


Figure 8. Long term cycling results of single layer cathode cells

Roll to Roll UV Coating and Curing System

Miltec made modifications to an existing web conveyor with a 3 lamp UV curing system to interchangeably use either slot die or letterpress coating technology (Figure 7). This machine coupled with a hand-drawn sample fabrication capability allowed Miltec to generate extensive design data on a future commercial UV curing system. The UV binder contains a small amount of liquid carrier in addition to the monomers, oligomers and photoinitiator in order to make an acceptable viscosity for coating. This carrier, typically an alcohol or acetate, is removed very quickly by an IR dryer before the UV curing step. The original design of the UV system had a very limited space (about 2 feet) for the IR dryer and we confirmed that to achieve the processing speed goal of 100 meters/minute a longer IR drying section would be required in a commercial unit. The IR dryer is the rectangular box just to the left hand of the operator in Figure 9. The additional space required is less than 3 meters compared to the 80 meters of drying oven that would be required for a 60 meters/minute NMP solvent based system.

Figure 9. Miltec roll to roll, slot die coater and 3 UV lamp laboratory system

Extensive testing has determined that the maximum practical loading is about 10 mg/cm^2 or about 50 um thickness coating at any speed. This is because of the limits of even very high-powered UV to penetrate beyond that depth for a cathode coating. We also learned that thinner coatings such as a power coating of 7 mg/cm^2 can be processed at faster speeds with the same number of UV lamps.

During the last quarter of the project, Miltec successfully demonstrated the ability to UV cure NMC 532 cathodes at 9mg/cm2 loading at curing speeds of 300 fpm with 3 UV lamps. This was achieved by first coating and drying the cathode coating without exposure to UV and then passing the coated cathode under the 3 UV lamps at a speed of 300 fpm to polymerize and

crosslink the UV curable binder. It is estimated that the slot die coater and UV curing system shown in Figure 9 would require a drying section of approximately 3 meters to be able to dry samples at 300 fpm instead of the approximate ½ meter presently available. This process was required because the roll to roll slot die coater and UV system shown in Figure 9 does not have an adequate drying section to dry a coated sample at 300 fpm.

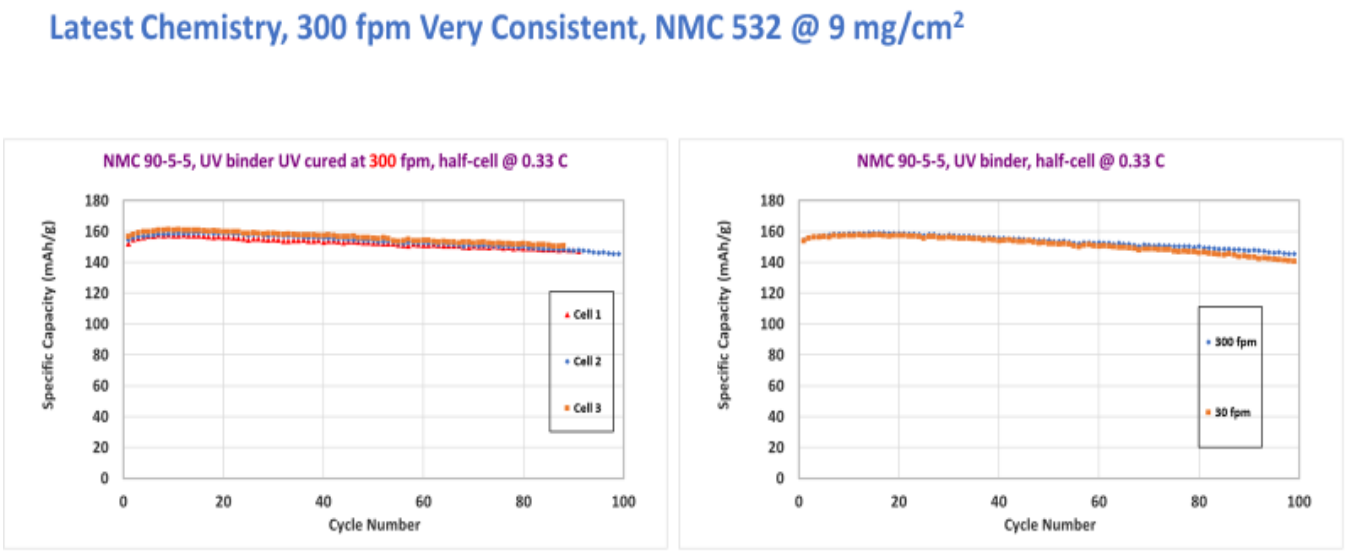


Figure 10 Coin cell cycling results for 9 mg/cm2 cathode cured at 300 fpm with 3 UV lamps

This project has provided Miltec with the design data needed to design and manufacture a commercial cathode UV coating and curing system based upon the customers electrode specifications in terms of loadings and sizes and a desired processing speed. Miltec is in contact with battery manufacturers and it is our belief that they will take the next steps once we demonstrate equivalent pouch cell performance. The most likely next step after the completion of this project would be the addition of a UV curing system to an existing cathode manufacturing line as a demonstration project; or a stand-alone demonstration unit because of the relatively low capital and operating cost of a UV curing system.

Layered Coatings

One of the milestones of the project was to demonstrate the ability to achieve higher energy loadings beyond the approximate 10 mg/cm^2 or 50 um thickness practical limit by layering cathode coatings.

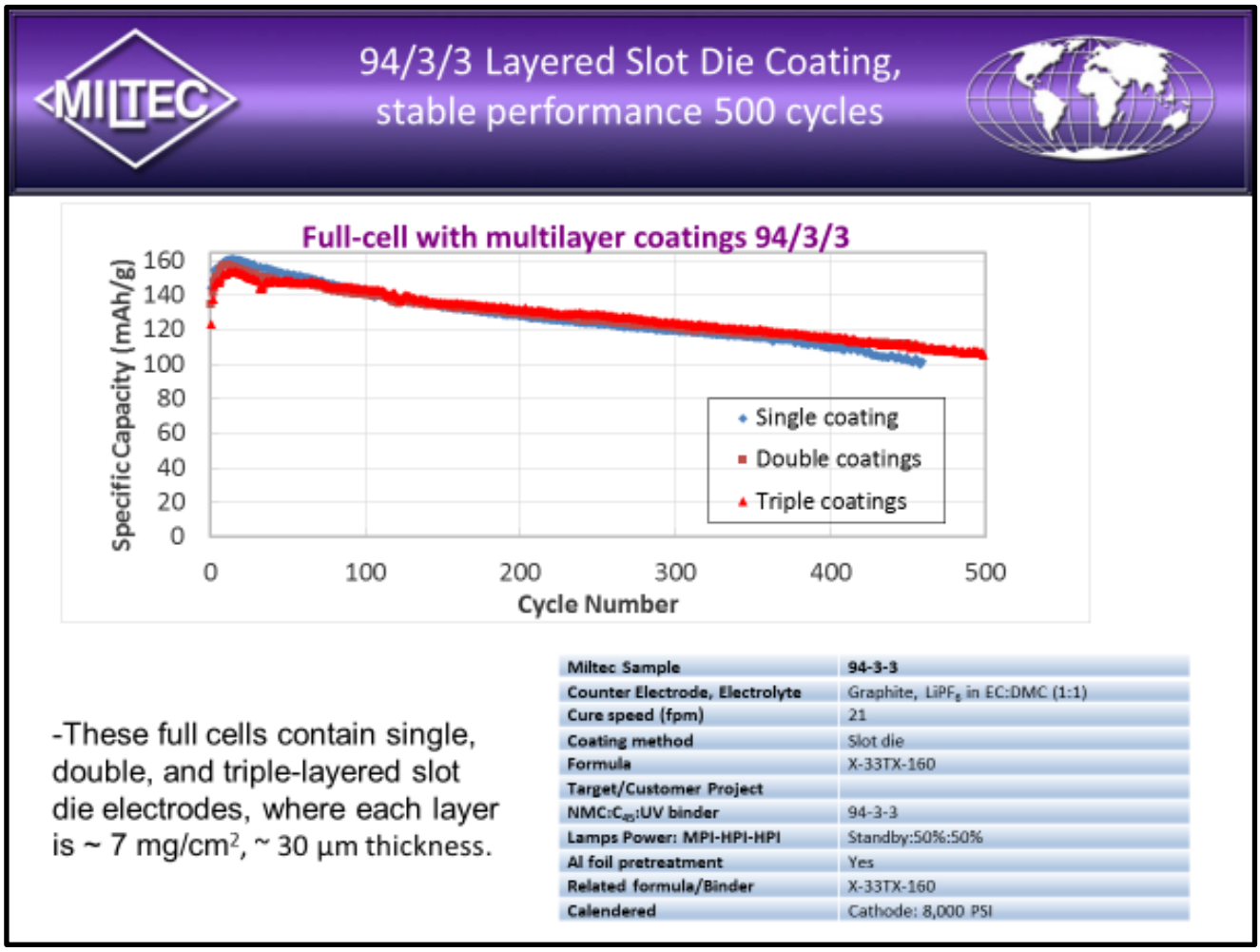


Figure 11. Multilayered cathode coatings stable to 500 cycles.

Double and triple layered coatings were successfully demonstrated using the slot die coater (Figure 10) and the 3 UV lamp curing system in Figure 9. The coin cell tests demonstrate the multilayer coatings perform in most cases better than a single layer coating.

Layered Coatings with Composition Variations

One of the accomplishments of the project was the successful demonstration of the use of UV binder for a wide range of loadings for LIB cathodes. These range from the 94/3/3 loadings for

high energy batteries and 90/7/3 for high power batteries shown in the previous Figures. We also demonstrated for a battery manufacturer a very high-power loading of 82/12/6 (Figure 11).

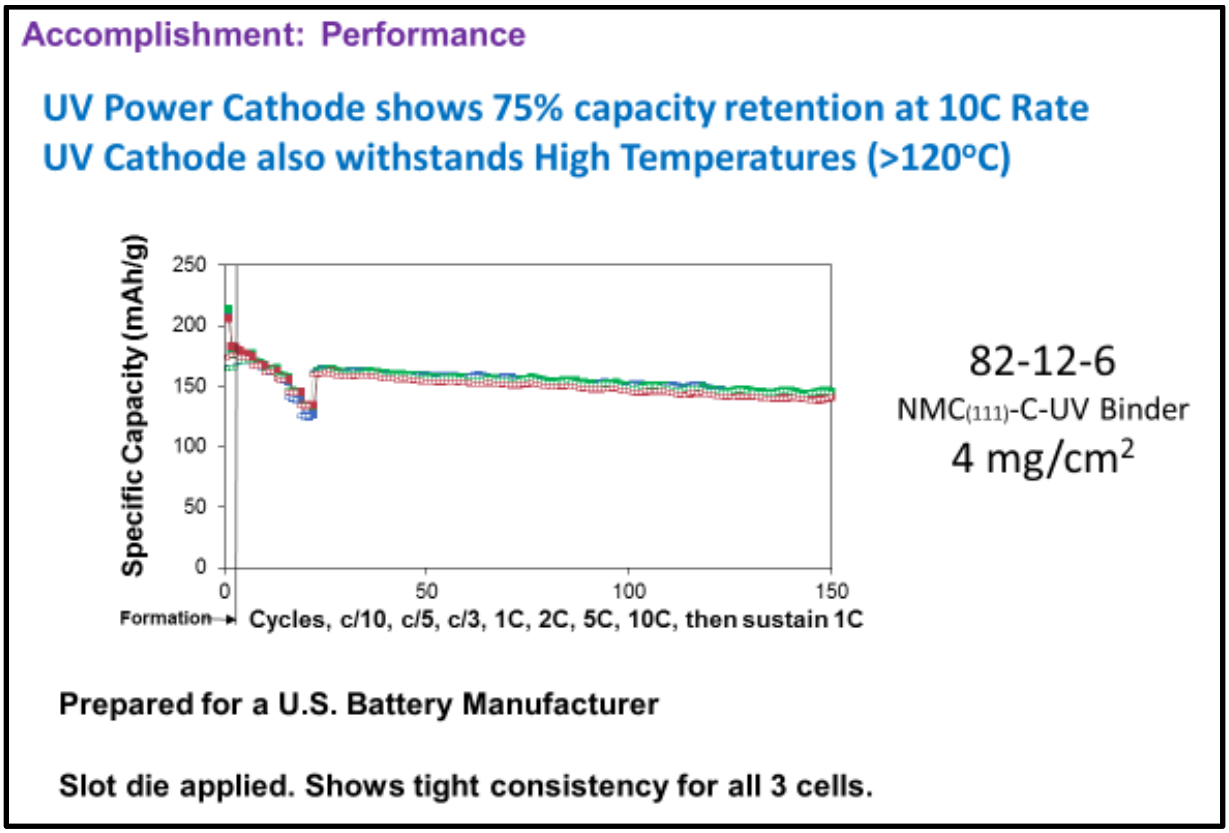


Figure 12. 10C rate capability for very high-power cell.

It has also been suggested that performance could be improved if the characteristics of the layers were varied. For example, it was suggested that the overall rate performance and capacity retention could be improved if one layer was of a power loading and the other was a layer with a higher energy loading. Figure 12 is a side by side comparison of 2-layer cathodes tested in coin cells. The overall performance is significantly improved with the power layer on the bottom (next to the current collector) and the energy layer on top. The results favor placing a power layer beneath an energy layer. This opens a huge door for future research to determine the benefits different ratios and compositions in each layer.

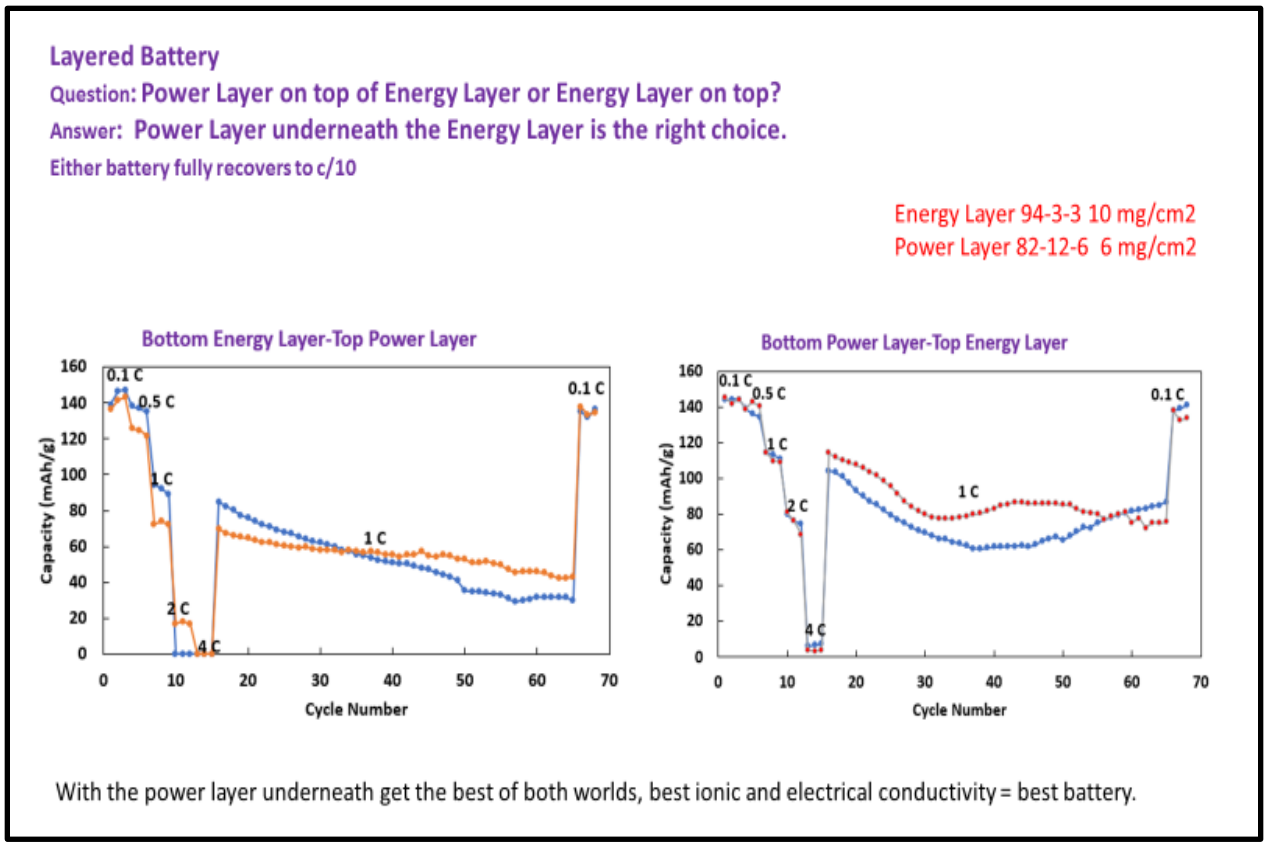
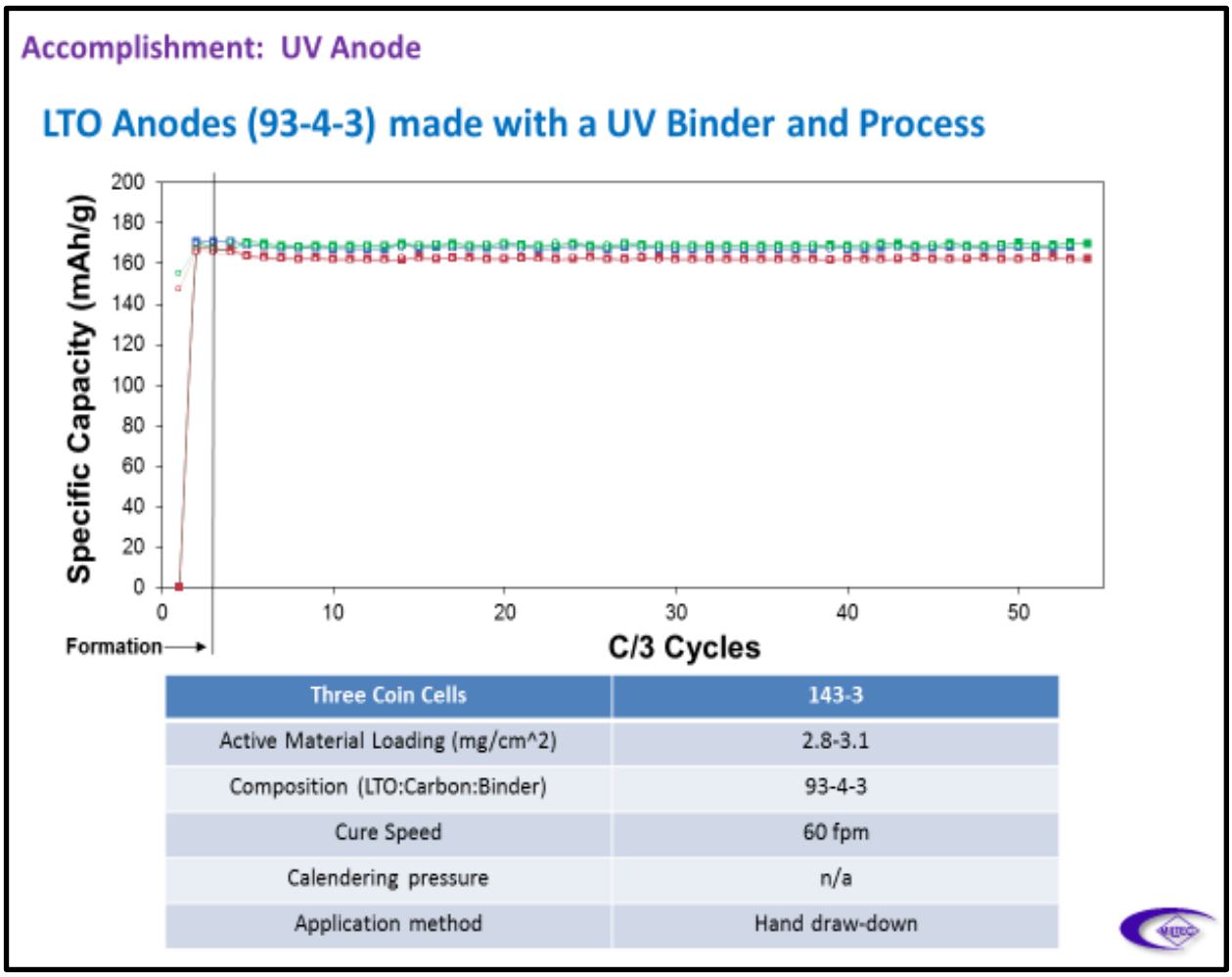


Figure 13. Comparison of layered coatings with power layer and energy layer. The power layer should be on the bottom.

LTO Anodes

Graphite is the anode material used for a vast majority of manufactured LIBs. Miltec experimentation determined that the use of a UV binder for binding the particles to themselves and to the current collector was not an effective alternative to the conventional PVDF or water-based binders in use commercially today. The liquid monomers and oligomers that are the building blocks for a UV curable binder are very small in size and molecular weight compared to the eventual polymerized and cross-linked polymers that make up the solid UV cured binder. Graphite is a very absorbent material. It absorbs into the graphite particle such a large proportion of the liquid monomers and oligomers that much of the monomers and oligomers are not polymerized (connected). Another way of thinking is that the monomer and oligomers that make up the polymer precursors just never become physically allowed to connect when exposed to the UV light. Far too much UV curable binder is required to make up this shortcoming to result in a practical binder content. However, Lithium Titanate (LTO), an active anode material used for very high-power applications in many LIB products, does not present this problem. LTO is very similar in mixing and coating and UV binder compatibility properties as the usual active cathode materials of LCO, LMO, NMC, NCA and $LiFePO_4$. Miltec successfully demonstrated the use of UV curable binder in the fabrication and testing of multiple LTO anodes. Figure 13 below shows the coin cell cycling results for a 93/4/3 (LTO/carbon/UV binder) for an approximate 3

mg/cm2 anode. Cells have also been prepared using the slot die coater and UV curing system in Figure 9 as well.



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

Figure 14. Stable performance of LTO anode.

Sulfur Cathodes for Lithium Sulfur Battery

Miltec has successfully evaluated the use of a UV curable binder with various active cathode materials including LMO, LCO, NMC (111 and 532), NCA, and $LiFePO_4$. Sulfur is also one of the cathode active materials being considered for significantly increased energy density in LIB's; especially when coupled with Lithium metal anodes. Miltec successfully prepared sulfur-carbon mixes of 70/30 by weight with 90/10 sulfur-carbon/UV binder and used a water-based UV binder to make 100 µm thick sulfur cathodes (5 mg/cm^2). The cathode samples were hand drawn and UV cured at 280 fpm under 3 UV lamps. The samples exhibited great adhesion in electrolyte. Coin cells were fabricated, and Figure 14 shows the cycling performance for 3 different cells.

This was not a focus of the project. Since it was our first attempt at a Sulfur electrode it suggests there is a lot of potential in using an NMP-free UV binder with sulfur.

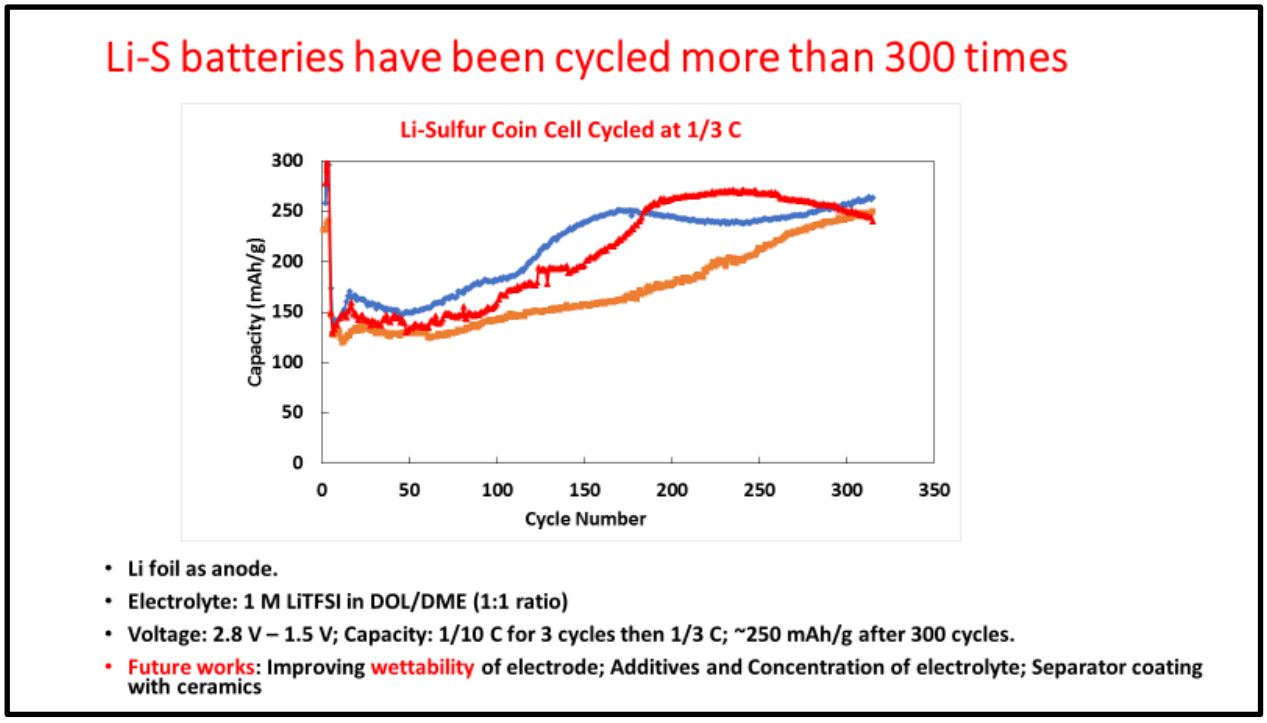


Figure 15. First UV Sulfur cathode cycling performance in lithium half cell.

SUMMARY of SPECIFIC PROJECT ACTIVITIES

The project milestone chart below lists the specific completed milestones during the period of performance of the contract. The accomplishments derived from these milestones were presented in the previous section. Provided in this section is a summary of specific project activities that were not highlighted in the accomplishments section.

Milestone	Planned Completion Date	Status
Budget Period 1		
Complete Project Management Plan	12/31/2015	
1. Confirm candidate binders and coating procedures and testing protocols	12/31/2015	Complete
2. UV curable Binder Formulation with improved AC Impedance Complete	06/15/2016	Complete
3. Complete integration and installation of flexographic and letter press coating equipment.	07/24/2016	Complete
4. Complete Test to confirm lower AC Impedance and acceptable long-term capacity. (Go-No-Go)	11/30/2016	Complete
Budget Period 2 and Budget Period 2 Extended		
5. Demonstration of two-sided electrode coating	03/31/2017	Complete
6. Determine maximum speed and cathode thickness using a slot-die coater and 3 lamp UV curing process.	06/30/2017	Complete
7. Determine minimum inactive material (UV curable binder and carbon) loading with hand drawn samples	09/30/2017	Complete
8. Determine minimum inactive material (UV curable binder and carbon) loading with a slot die.	12/31/2017	Complete
9. Coating on coating cathode evaluation complete with slot die	3/30/2018	Complete
10. Determine maximum speed and cathode thickness using a letterpress and 3 lamp UV curing process.	6/30/2018	Complete
11. Coating on coating cathode evaluation complete with letterpress	9/30/2018	Complete
12. Long term cycling evaluation complete; including multilayer pouch cell performance	12/31/2018	Complete

The first budget period consisting of milestones 1-4, including the Go-No-Go decision associated with milestone 4 were completed successfully and on schedule. Demonstration of a 2-sided coating was successful, and the data needed to determine the relationship between speed, thickness and number of UV lamps was generated. The limitations of the pilot unit discussed in accomplishments (Figure 9) with regard to IR drying were also discovered and defined. During the activities associated with Milestones 7 and 8 it had been established that the practical UV binder content by weight required to achieve acceptable performance was 3% using

conventional active cathode materials and carbon contents from 3 to 7%. In other words, from loadings of 90/7/3 for power cells to 94/3/3 for energy cells.

Miltec also acquired NMC that had been coated with very small amounts of carbon (0.2%) by an outside vendor using a proprietary process to determine if the carbon and UV binder content could be lowered even further.
Miltec prepared samples of NMC 523 with loading of 98.8/0.2/1 (designated below as 99/0/1) to be made into pouch cells by ANL and similar coatings to ORNL for also making pouch cells. The NMC was coated by an outside vendor by a proprietary process (0.2% carbon). In addition, Miltec prepared samples of NMC 111 with the same 0.2% carbon and 1% UV binder to be made into pouch cells. The loading for all of these cells was 5.5-6 mg/cm2. Figure 15 below shows the cycling results of pouch cells prepared by ORNL. The rate tests show current limits and full recovery for these carbon deficient cathodes.

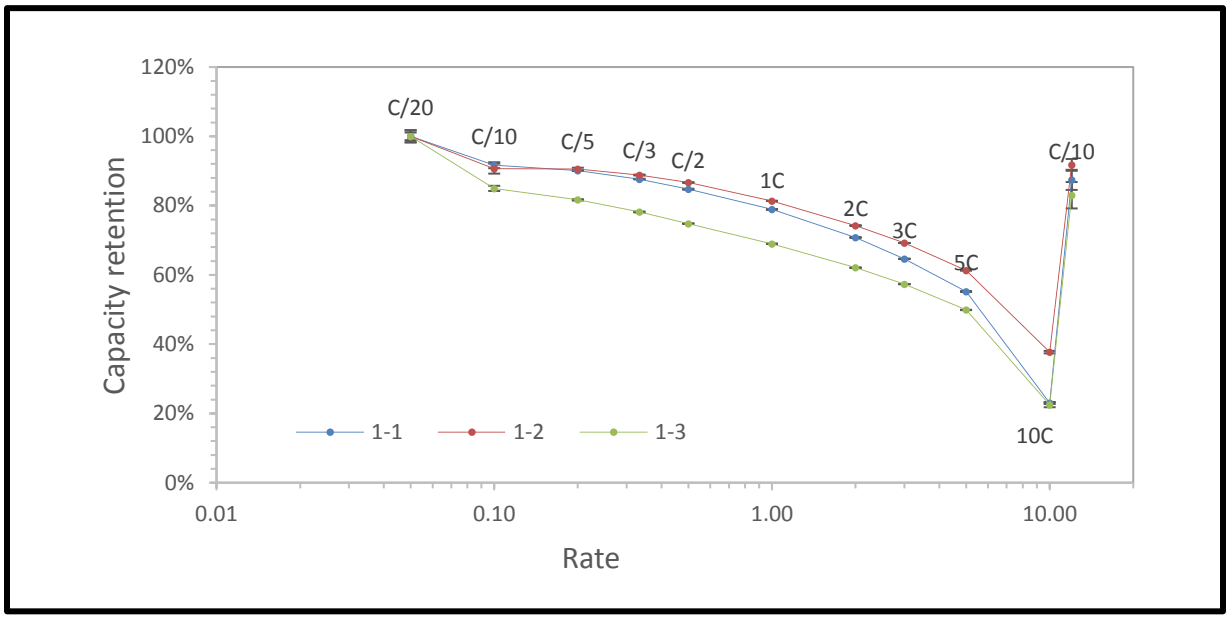


Figure 16. Rate capability results for pouch cells using 1% UV binder and precoated NMC 532.

The test results for ANL and ORNL pouch cells were very similar. Figure 16 below shows the pouch cell impedance measurements from the ANL tests. B32A, B, and C are NMC 523 from an outside vendor and B32D, E, F and NMC 111 prepared by Miltec. The best performing cells designated B32A and B retained capacity out to 2C charge and discharge rates had acceptable ASI even with just 0.2% carbon.

These tests establish the feasibility of making electrodes with only 1% UV curable binder and less than 1% carbon. These cells have higher ASI than appropriate for power cells and inadequate charge and discharge rates for power applications. Unfortunately, there is no substitute for carbon. Energy cells are less limiting, so the next step will be to determine if energy application cell performance can be achieved with minimal increase in the carbon content. With UV processing it is may also possible to put a thin real power layer beneath and Energy layer with very little carbon.

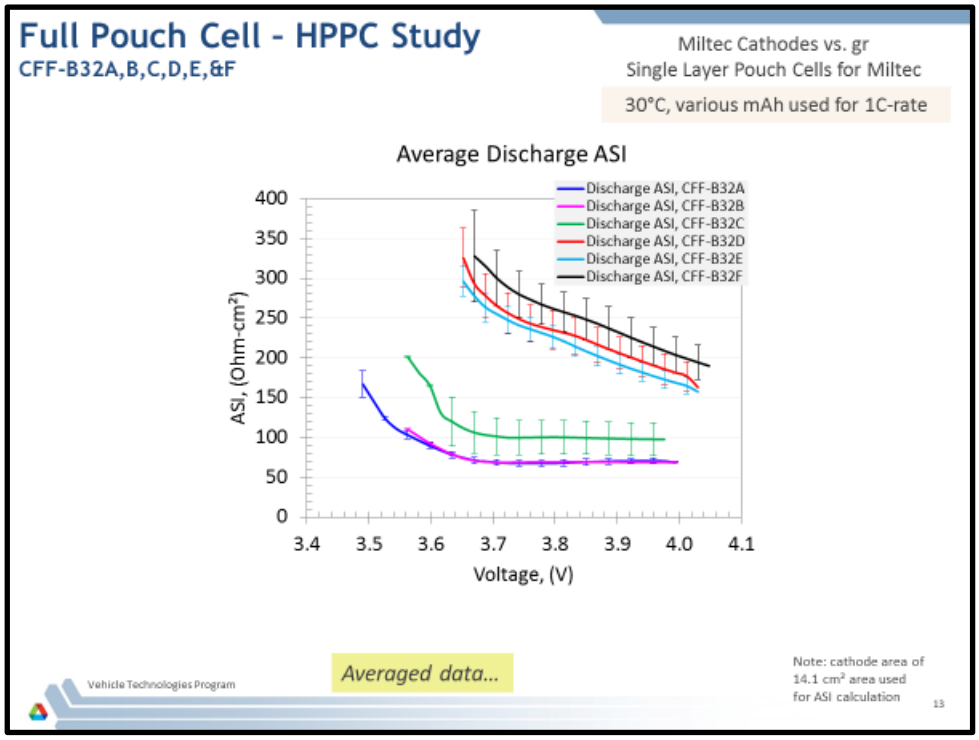


Figure 17. Impedance of cells with 1% UV binder and precoated NMC 532

The coating on coating and long-term cycling objectives of Milestones 9 and 12 were completed and the results highlighted in the Accomplishments section.

Milestones 10 and 11 related to the evaluation of a letterpress coater to achieve higher processing speeds than a slot die coater. It was previously discovered during testing of the speed limitations of the slot die in conjunction with the 3 UV lamp system that to make commercial-quality electrodes, slower evaporation rates than achievable with the limited exposure time IR dryer configuration would be required. To that end, an increased path length of the web between the slot die coater and the dryer will be needed in a commercial system. Therefore, the processing speeds that can be achieved with the existing slot die/IR dryer combination are limited, and these same limitations caused by the inadequate IR drying apply to the letterpress coater. However, we are proceeding to demonstrate slower coating feasibility with the letterpress. Figure 17 is a picture of the letterpress coater installed on our UV coating and curing system.

During slow speed testing of the letterpress coater, it was learned it was learned that low boiling point solvents used in our slot die process dry too quickly and the slurry dries on the letterpress rolls. High boiling point solvents do not dry on the rolls, but we grossly underestimated how much drier capacity would be required to achieve full carrier/solvent removal prior to the UV lamps thus making our coater and UV curing setup unusable for even the slowest speeds. This was an unexpected result and represents a major limitation to letterpress application to LIB electrode manufacturing. Low viscosity slurries appear to be incompatible

with the letterpress coater because the slurry does not have the cohesive strength for good transfer across the multiple rolls of the letterpress. High viscosity, low solvent battery slurries have been too sticky for good flow and transfer. This result was expected but not overcome under this project. These issues may be surmountable to achieve high speed (>300 fpm) cathode coatings but additional equipment and chemistry formulation would be required; specifically:

1. A more powerful, longer dryer. This would allow for running with higher solvent content coatings.
2. A contained letterpress device. The rollers spin rapidly, resulting in high shear and heat generation for high viscosity slurries. A closed device will limit evaporation, but the associated chemistry may still be problematic.
3. New chemistry formulations are needed. Unfortunately, the chemistry historically maximized for letterpress rheology has poor chemical resistance, making this a much more complex task

Today's slot die coating technology is acceptable up to and including 60 meters per minute and higher speeds are most likely possible when incorporated with a UV curing system that is not limited by the economics of a longer/ bigger drying oven for even higher speeds. It is concluded that at this time more development is required to make letterpress a viable competitor.

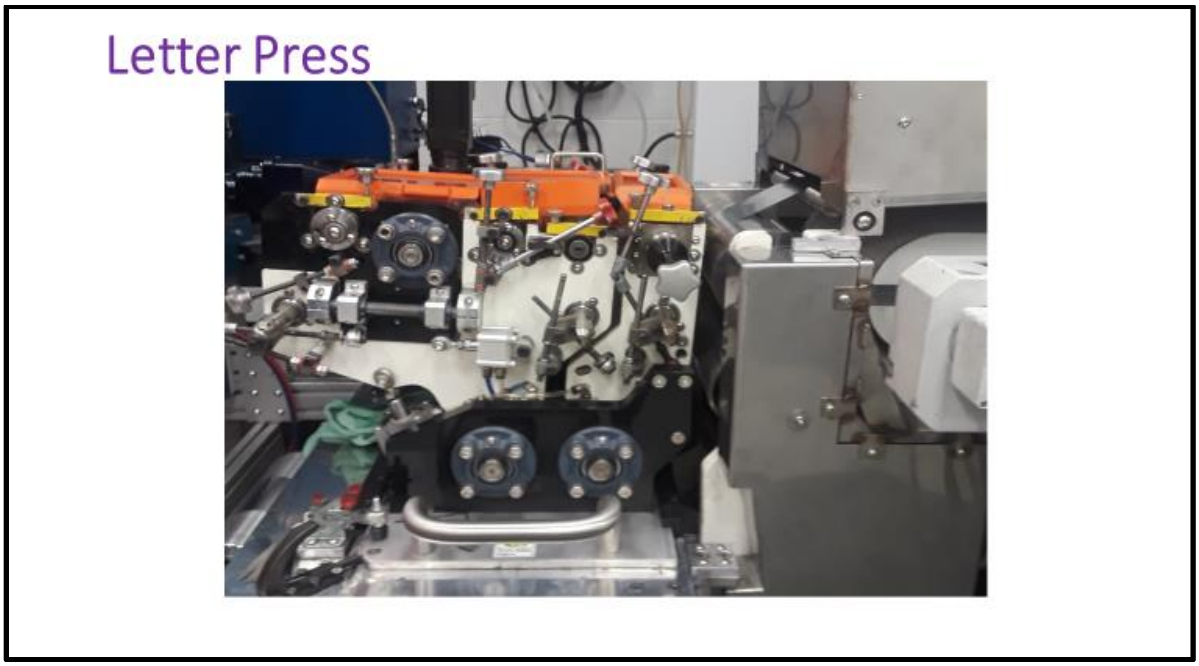


Figure 18. Letterpress coater installed on Miltec roll to roll, 3 UV lamp laboratory system

Milestone 11 was the evaluation of letterpress for coating on coating cathode manufacture. Because of the limitations of letterpress and our specific equipment constraints discovered in Milestone 10, we were unable to evaluate multi-layer coatings using the letterpress.

Milestone 12 is the long-term cycling evaluation; including multilayer pouch cell performance with both single layer and double layer coatings. Multiple cathode samples of 17.75 mg/cm^2 (2 side total) single layer and 29.2 mg/cm2 (2 side total) double layer were delivered to ORNL for fabrication into 0.5 Ahr and 1 Ahr pouch cells, respectively, for rate and long-term

cycling tests. The results were presented in the accomplishments section. This milestone demonstrates the overall objective of this effort and result in having available for industry to consider a new technology with significant opportunities for manufacturing cost reduction and performance improvement for Lithium ion batteries.

RESULTS and PRODUCTS DEVELOPED

Publications

Miltec UV made various public releases of results during the period of performance of the contract. These include:

- Presentations at each of the DOE Annual Merit Reviews sponsored by the Vehicle Technology Office in June of 2015,2016, 2017, and 2018.
- Gary Voelker and Dr. John Arnold gave a presentation on the merits of UV binder for LIB electrode production to the DOE USCAR representatives from Ford, Chrysler, GM and EPRI in Detroit May 17, 2017
- Miltec UV had an exhibit, at Miltec expense, with visuals and a video presenting the progress on UV curable binders for LIB electrode manufacturing at the International Battery Conference, Fort Lauderdale, FL in March 2017 and March 2018.
- Dr. John Arnold, at Miltec expense, gave a presentation titled *UV Coating Processes to Enhance Li Ion Battery Performance and Reduce Costs* to the Electrochemical Society meeting at National Harbor Fall 2017.
- Miltec UV, at Miltec expense, had an exhibit with visuals and a video presenting the progress on UV binder for LIB electrode manufacturing at the Battery Show, Novi, MI September 2017 and September 2018.
- Dr. John Arnold, at Miltec expense, gave a presentation on UV technology applied to Lithium ion batteries at the NAATBatt annual meeting March 22nd in San Antonio, TX.
- On May 24,2018, Gary Voelker, at Miltec expense, presented an overview of the Miltec UV technologies applied to Lithium ion Batteries at the GM Battery Congress in Novi, MI. The presentation resulted in subsequent visits to Miltec facilities by two major battery manufacturers/users.

Web Site

Miltec UV has a fully operating website presenting details on the performance and potential for UV cured binders for LIB electrodes. http://www.miltec.com/technology/battery/

Networks or collaborations fostered

The Miltec UV business model for commercialization of the use of UV curable binder for LIB electrodes is for Miltec UV to sell coating and UV curing equipment based on the design data generated under this contract and to either sell the UV curable binder or license the formulation chemistry to potential customers. In pursuit of this business model Miltec UV fostered multiple collaborations during the course of the contract. These collaborations were primarily with Lithium ion battery manufacturers and automobile manufacturers who provided Miltec with

specifications of their desired electrodes and in some cases, they supplied active material, conducting material and current collector. Miltec UV prepared samples for these potential customers to make into coin cells and pouch cells for evaluation. Some samples were hand drawn but most were prepared on the Miltec UV slot die continuous coater. These samples ranged from HEV applications of 90/7/3 at 6 mg/cm^2 loadings to EV applications of 94/3/3 at 20 mg/cm^2. Most of the samples used NMC 532 and much of the data reported in this final report is from pouch cell testing conducted by those potential customers. These approximately seven collaborations are continuing and involve manufacturers in the United States, Europe and Asia. In addition, Miltec UV is collaborating with potential battery manufacturers regarding the use of an ionically conductive UV curable Gel Polymer Electrolyte for the manufacture of a Solid-State Battery.

Inventions

Miltec UV Patent 10,102,979 B2 Actinic and Electron Beam Radiation Curable Water Based Electrode Binders and Electrodes Incorporating Same covering the invention of using a UV curable binder for using a UV curable binder to make Lithium ion battery electrodes was filed before project award and was granted October 16, 2018.
Previously, Miltec was granted a product patent US 8,906,548 B2 December 9, 2014 covering the basic UV curable binder product. The follow-on divisional process patent US 9,543,565 B2 to this original patent was granted January 10, 2017.

Products Developed

This cost shared project enabled Miltec UV international to successfully develop and demonstrate the advantages of the use of UV binder to manufacture Lithium ion battery electrodes. Miltec now possesses the design criteria to produce a commercial process for manufacturing: single layer LIB cathodes, multiple layer LIB cathodes, and LIB LTO anodes.