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Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

AMMTO & IEDO JOINT PEER REVIEW

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Roll-to-Roll Manufacturing of Low Cost and Safer Lithium Ion Batteries | AMMTO

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Project Overview

- To develop sustainable, low-cost electrodes by eliminating NMP in production without compromising performance:
  - Synthesizing novel water-based (WB) PVDF binder for cathode; and novel WB-acrylics for anode
  - Developing stable aqueous slurry for high energy densities NMC-622 cathode and graphite anode

➢ ***Impact:*** Reduces manufacturing cost; improves safety of manufacturing lines; and sustainable

- To develop water-based composite in-situ separator (CIS) to replace/eliminate free-standing polyolefin separator in cell assembly.
  - Developing novel formulation & processing using only alumina and binder

➢ ***Impact:*** Improves battery safety at elevated temp.; increases energy and power densities due to reduced thickness; decreases scrap rate (two instead of three-layer assembly)

Energy, Emissions, & Environment: Smaller carbon footprint, sustainable	**Cost & Competitiveness:** Lower cell cost (>10%), higher safety
Technical & Scientific: Patents expected (Materials /processes)	**Other Impacts:** Advances competitiveness of USA

Project Outline

Innovation: WB-PVDF, WB-acrylics, WB stable slurries for high energy cathode and anode, composite in-situ separator

Project Lead: Arkema Inc.

Project Partners: Cabot Corporation, Saft USA, ORNL

Timeline: Oct. 1, 2020 to Dec. 31, 2024; 61% progress

Budget: Cost shares BP1 (Oct. 2020 to Dec. 2022): 24.99%; BP2 (Jan. 2023 to Dec 2023): 24.68%; BP3 (Jan. 2024 to Dec. 2024): 24.29%. ***Total cost share: 24.64%***

	FY21 Costs	FY22 Costs	FY23 Costs	Total Planned Funding
DOE Funded	$719,799	$504,151	$1,329,344	$3,937,888
Project Cost Share	$229,348	$179,341	$435,510	$1,287,416

End Project Goal: Demonstrate at pilot scale that production cost will be reduced to $92-$97.5/kWh, volumetric energy density increased to > 635 kWh/L, WB process can produce high quality electrodes with >4.1 mAh/cm^2, and separator shrinkage reduced to 0% at 150 °C.

Background & Strategic Approach

Roll-to-Roll Manufacturing of Low Cost and Safer Lithium-Ion Batteries

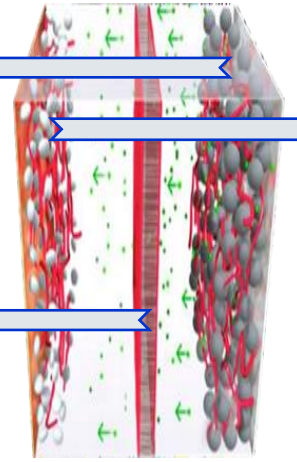
Sustainable and low carbon emission electrode and separator fabrication

High Energy WB Cathode

Needs: water-processable ***conductive carbon, NMC /LCO /LFP, WB-PVDF-binder,*** and ***formulation***

Composite In-situ Separator (CIS): WB in-situ composite (higher safety)

Needs: ***fumed alumina, WB Binder, formulation*** and ***casting process***

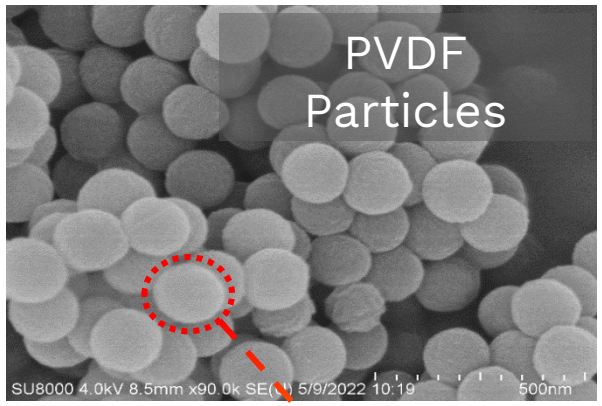


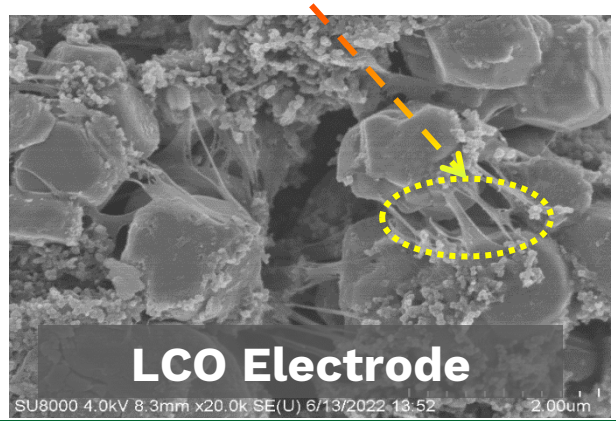
High Energy WB Anode

Needs: water-processable ***conductive carbon, graphite, WB-binder*** and ***formulation***

WB Binders:

WB-PVDF
WB-Acrylics (Si)
Standard SBR (G)





Arkema:

- Synthesize ***WB-PVDF binder***, develop ***WB-formulations*** for electrodes

Cabot:

- Materials, ***formulation, and process*** development for **CIS**
- Screening/developing ***carbon*** & ***alumina*** suitable for WB formulation
- Developing ***coated NMC*** to protect against water attack

Saft:

- ***Cell fabrication*** & verification BP2
- ***Pilot scale R2R production***, cell fabrication and validation BP3

ORNL:

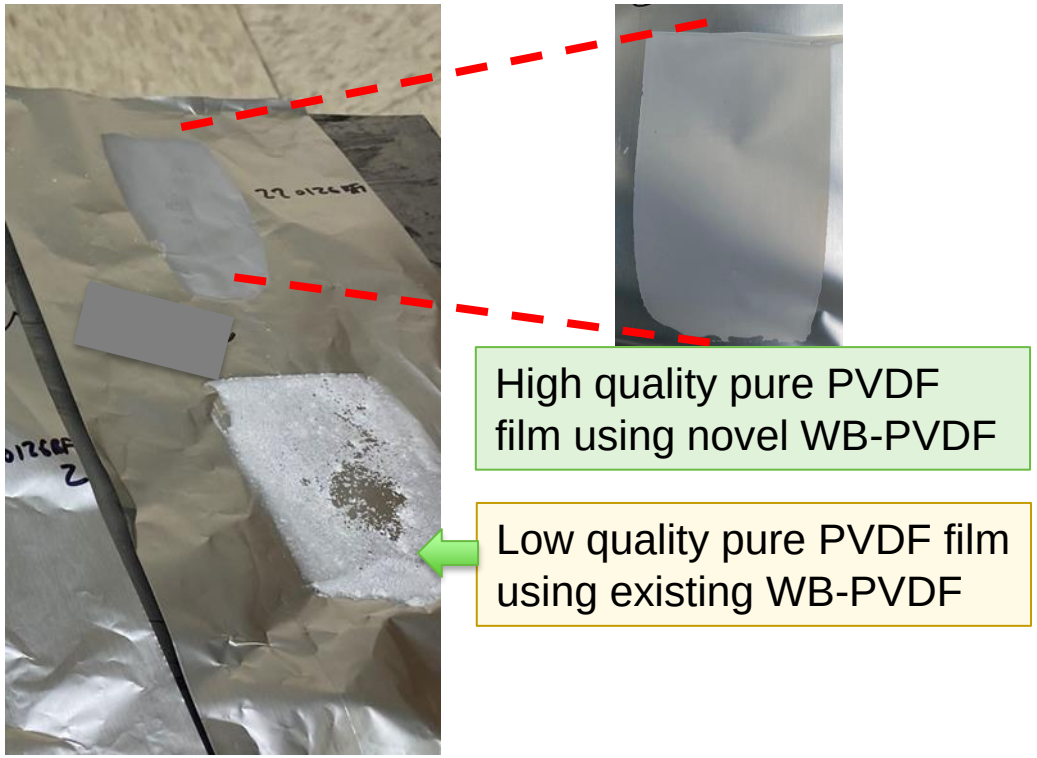
- Material analysis
- Validating formulations and processes

Results and Achievements in BP1

	Task or Subtask Title	Milestone Description	Current Progress to Milestone
1.0	**Material Developments**		
1.1	Carbon and alumina surface modification	Dispersions of carbon & alumina in water without any settling after 2 hrs	Stable dispersion overnight ✓
1.2	WB-PVDF synthesis ☆☆	WB-PVDF latex with solids > 25%, shear stability > 20 min	Solids >26%, Stability > 30 min ✓
1.3	Water-resistant NMC622 development ☆☆	Water-resistant NMC that retains >80% specific energy after 2 hrs	Retains >90% specific energy ✓ ☆☆
2.0	**WB slurry formulation development and electrode fabrication**		
2.1a	WB anode formulation development	WB slurry with solids >35%, easy to cast	Solids > 45%, stable, easy to cast ✓
2.1b	WB cathode formulation development	WB slurry with solids >40%, easy to cast	Solids ~36%, stable, easy to cast ✓
2.2	Composite in-situ separator (CIS) ☆☆	CIS with > 35% porosity, shrinking < 10%	Porosity >40%, shrinks <5% ✓
2.3	Integrating separator electrode fabrication + CIS in one step ☆☆	Fabricating anode/cathode having CIS on it	CIS fabricated, stand alone, on anode and on cathode ✓ ☆☆
3.0	**Coin cell assembly and testing**		
3.1	Cell assembly using the state-of-the-art electrode made with NMP process	Working cells made with electrodes using a typical NMP process/fabrication	800 cycles @C/2 & >80% capacity ✓
3.2	Cell assembly using electrode of task 2.0	Working cells made with WB-electrodes	WB-anode & WB-cathode tested ✓
	Go/No-Go Decision Point	Fabricate coin cells using WB anode, Wb cathode and WB-CIS structures	Demonstrate rate capability (0.5C/0.2C) > 0.8, fade rate < 10% ✓

Novel WB-PVDF

- → The most challenging aspect of WB-PVDF binder is to coalesce particles and form an interconnected network
- → Binder should be able to make a continuous film (i.e. transparent and crack-free) upon drying
- → Developed formulation/processing for continuous solid film out of WB-PVDF having zero VOC (Innovative)

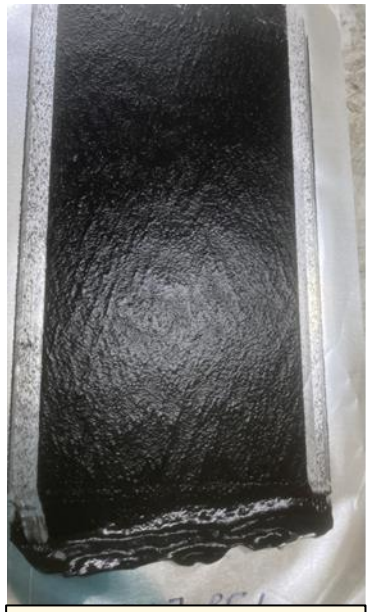


High quality pure PVDF film using novel WB-PVDF

Low quality pure PVDF film using existing WB-PVDF

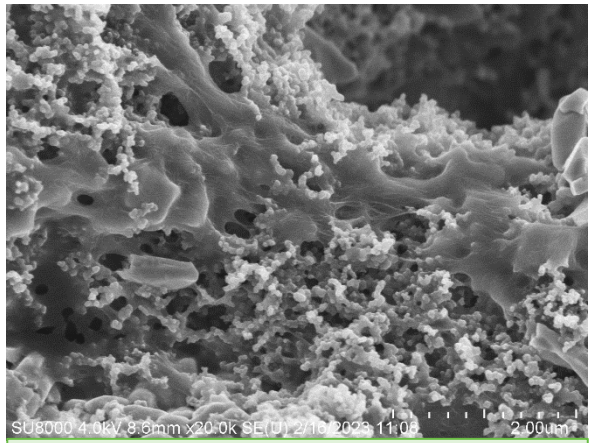
WB-NMC cathode

- → Stable and manageable pH is the most challenging aspect of NMC slurry; i.e NMC in water has pH ~12
- → ORNL showed water does not alter the main structure, just washes off residual impurities at the surface.
- → Developed high quality electrode formulation having zero VOC; (balanced formulation and suitable processing)



Low quality WB-NMC, pH >10

High quality WB-NMC, pH <9

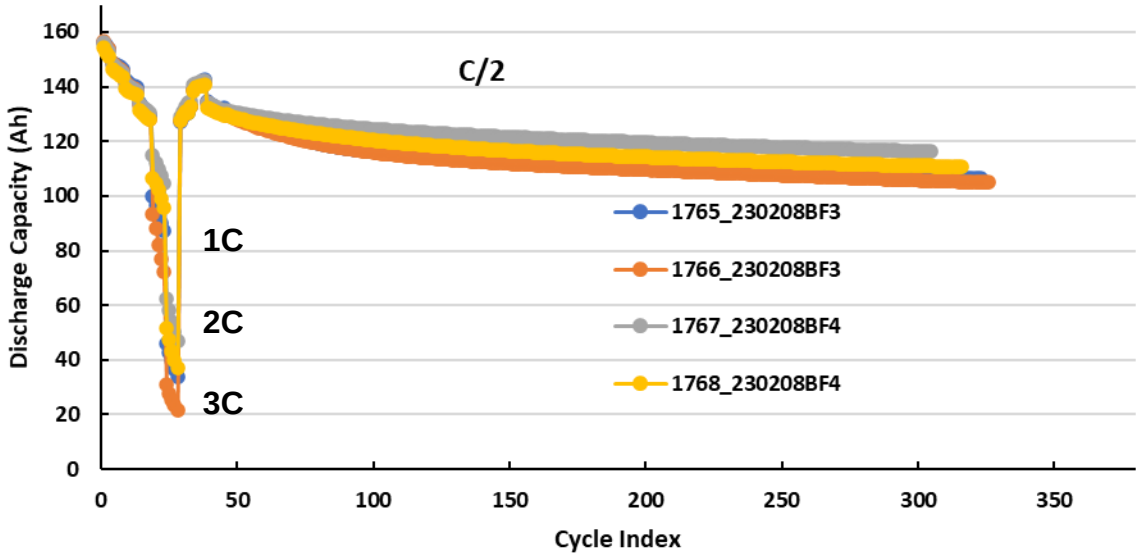


High resolution SEM
Well interconnected network WB-NMC cathode;

WB-NMC 622 cathode performance

Characteristics & Cell Performance of WB-NMC-622 Cathode

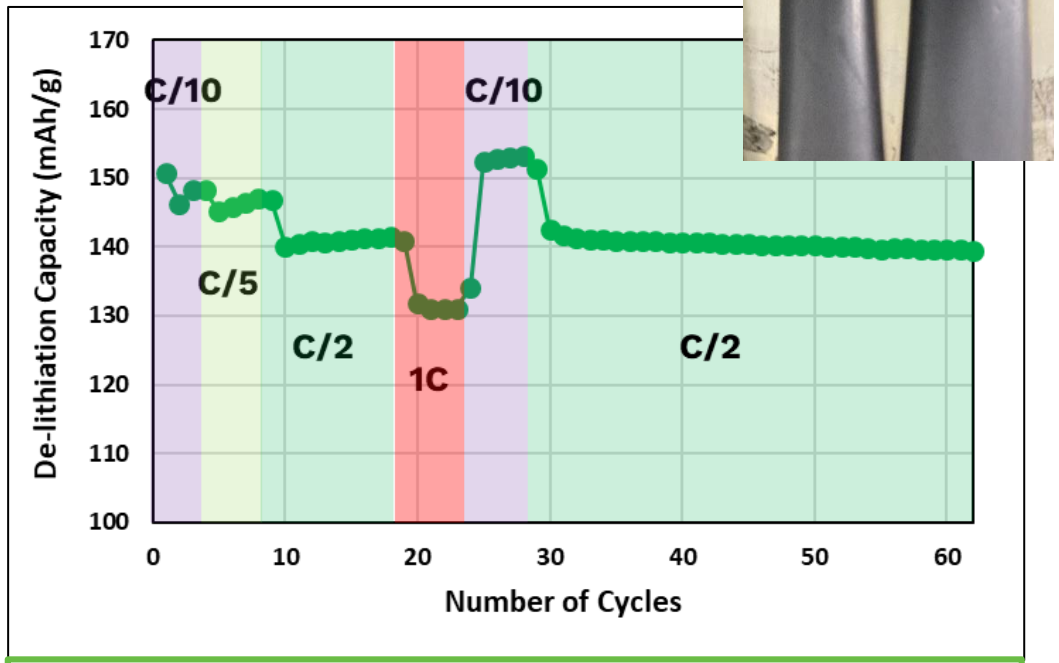
Cell #	Adhesion (N/m)	Mass Loading (mg /cm²)	Porosity (%)	N/P	1st Cycle CE (%)
1765	**59**	11.0	27.0	**1.24**	83.21
1766	Duplicate				83.04
1767	**40**	10.5	26.1	**1.27**	82.37
1768	Duplicate				82.73



High-energy-density WB-NMC cathode (94% AM) cycles well at C/2, and can tolerate high c-rates in coin cell

WB-LFP cathode (extension)

Developed high quality WB-LFP cathode using balanced formulation



High-energy-density WB-LFP cathode (93% AM) cycles well at C/2, operating at specific capacity of 140 mAh/g (no noticeable losses) after C-rate testing

Composite In-situ Separator (CIS) Development & Testing

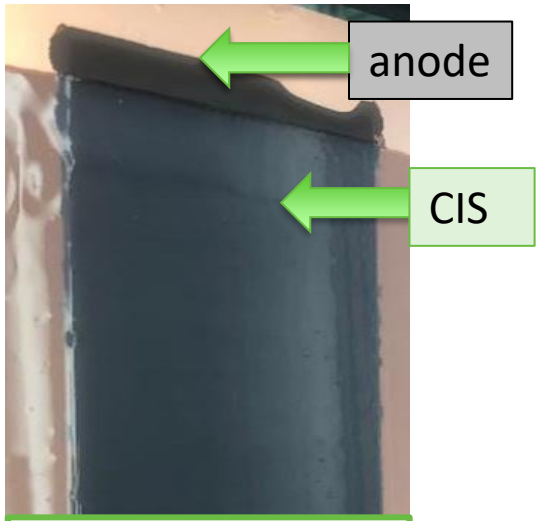
- Developed adhesive & highly resistive separator
- Composite in-situ separator cast on copper

Cast CIS on Copper

Thickness: ~20 µm

Porosity > 40%

Resistivity >> MΩ

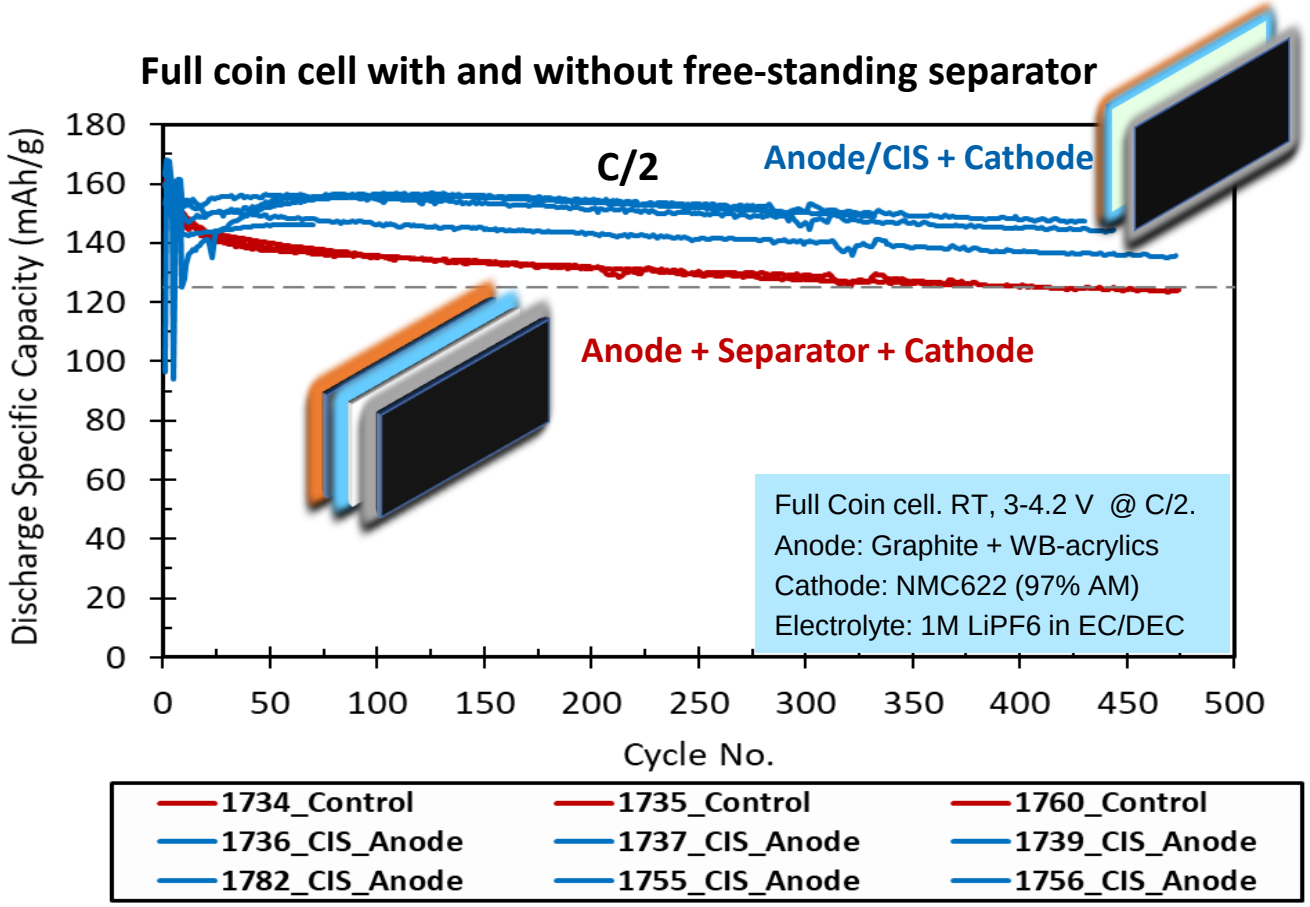


Cast Smooth & defect-free wet CIS on top of anode:

Thickness: ~15 µm

Porosity > 40%

Resistivity >> MΩ



Cell without free-standing separator operational; and offers:

- **Lower component cost by about 10%**
- **Thermal stability, tunable porosity, superb wettability,**
- **Improved cycle life! other advantages??**

Future Work, Technology Transfer, & Impact

Future Work:

- Formulation optimization for WB-NMC-622 to achieve high loading (> 20 mg/cm^2)
- Formulation optimization of CIS to achieve thinner separator (< 15 µm) & pinhole-free
- Test CIS in pouch cell and map advantages

Technology Transfer:

- Scale up production of WB-acrylics & validate performance at industrial partner
  - Upon positive results accelerate market introduction of WB-acrylic binder to NA (Arkema)
- Produce novel WB-PVDF binder at pilot scale
  - Validate performance at industrial partner for continuous R-2-R production of WB-cathode and CIS
  - Upon positive results accelerate market introduction of WB-PVDF binder to NA (Arkema)
- Secure partners for commercialization of WB-cathode and CIS (technology leap)

Impact:

- Process improvement → Lower cost, sustainability, smaller carbon footprint, safer production line, higher energy and power densities, and safer cells operation → advancing the AMMTO/IEDO mission towards electrification of transportation

Questions?

- **Roll-to-Roll Manufacturing of Low Cost and Safer Lithium Ion Batteries | AMMTO**

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