Xerion
ADVANCED BATTERY CORP

Development Of Advanced High-performance Batteries For Plug-in Hybrid Vehicle Applications

2015 DOE Vehicle Technologies Program
Annual Merit Review and Peer Evaluation Meeting
June 10, 2015

Project ID: ES248

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Overview

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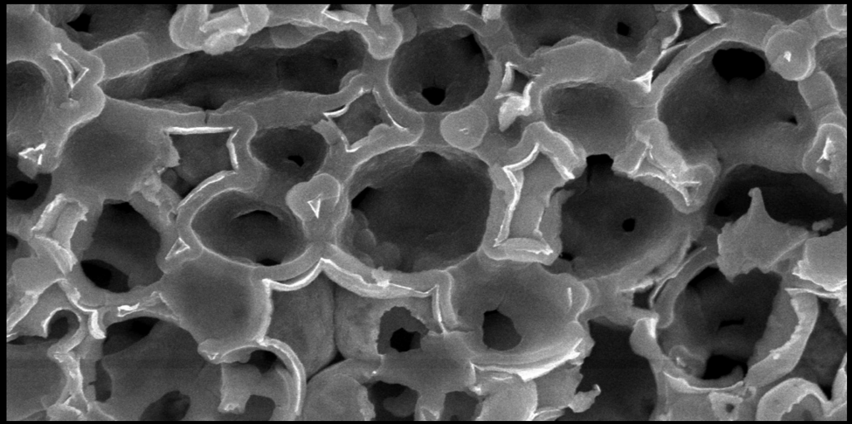
Period of Performance:

- 15 month total duration
- 23 July 2014 start date
- 23 Oct 2015 end date

Contract Total: $667,454

- XABC Costs: $333,727
- USABC Costs: $333,727



Barriers Addressed:

- **Costs:** New manufacturing method reduces cell raw material costs (projected cell costs below $250/KWh)
- **Performance:** New high-rate electrode architecture improves cell power to energy and charge acceptance performance (30,000 W/Kg, 200 Wh/kg)
- **Life:** 3D, co-continuous electrode architecture reduces internal resistance and internal stresses during cycling

Relevance & Objectives

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- **Overall Objective:** Develop and produce commercial pouch cell prototypes optimized for PHEV use to:
  - Demonstrate significant power/energy and charge acceptance improvements using StructurePore^{TM} architecture
  - Demonstrate architecture utilizing currently commercial chemistries for baseline comparisons
  - Produce sufficient materials and process data to project cost reduction at commercial scales

- **Previous Year's Objectives:**
  - Demonstrate through detailed characterization the ability to produce commercial phases of lithium manganese oxide
  - Optimization of carbon current collector for mechanical robustness and high electrical conductivity

Milestones

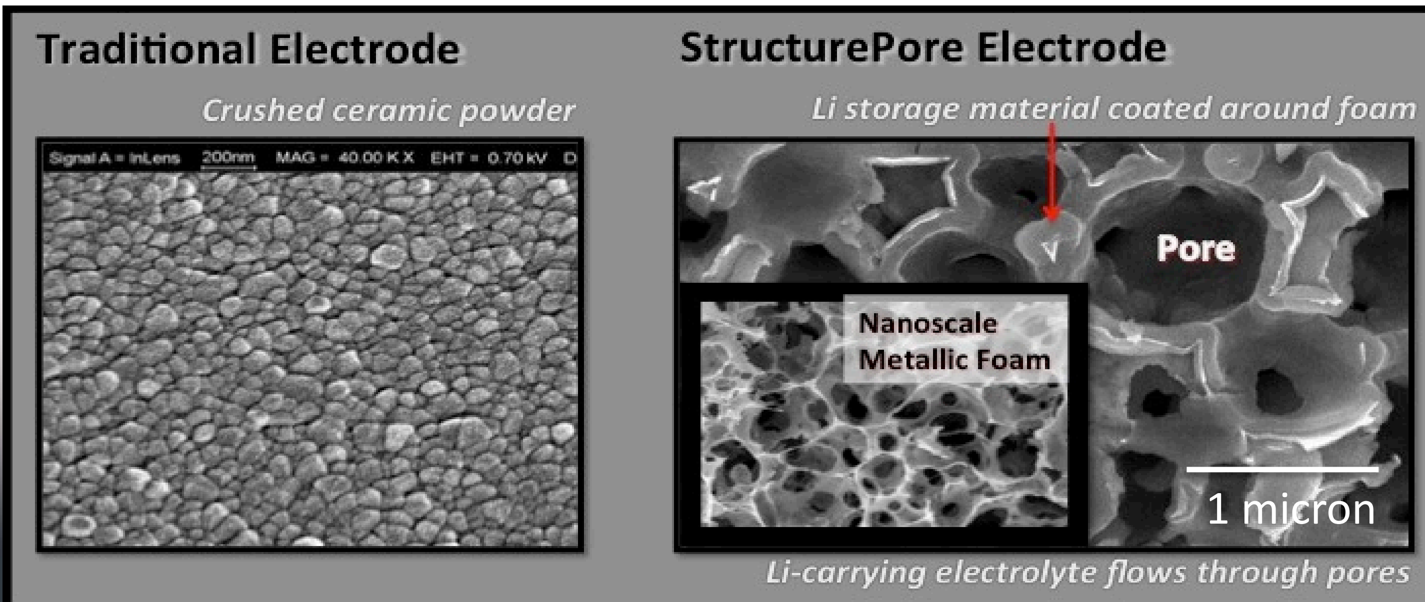
Date	Milestones and Decision Points	Status
July 2014	Milestone: Provide Nanostructured Layered LMO, LCO, and carbon anode cycle data	Complete
Oct 2014	Decision Point: Select LMO or LCO as cathode chemistry	LMO Selected
Jan 2015	Milestone: Demonstrate cylability of Spinel LMO half-cell	Complete
Jun 2015	Milestone: Demonstrate single-layer pouch cell (100 mAh)	On Track

Approach/Strategy

Replace traditional electrodes with StructurePore™ nanostructured, porous electrodes

- Co-continuous electronic and ionic pathways allow fast diffusion of reactants throughout the bulk of the electrode, reducing internal resistance
- Fast diffusion allows achievement of power goals using thicker electrodes, reducing weight and volume of the balance of cell components
- Conductive foam acts as current collector, allowing the removal of metal foils, further increasing packing efficiency
- Reduce raw material costs by directly electroplating active materials

From: To:



Approach/Strategy-Technology

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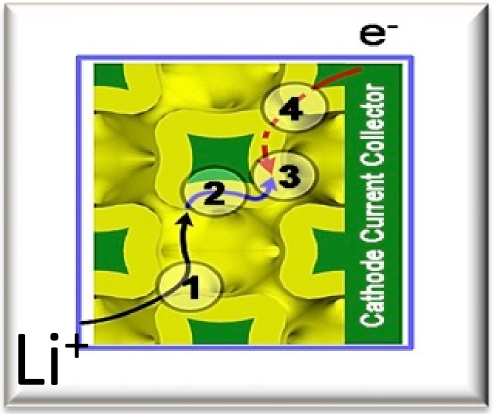


High Energy Density

3D Architecture
+
Nanoscale pores
+
No metal foil
=
Active material high % of total weight

Enhanced Cycle Life

Reduced Heating
=
Slower parasitic chemical reactions

Porous Structure
=
Reduced mechanical cracking due to swelling

High Power Density

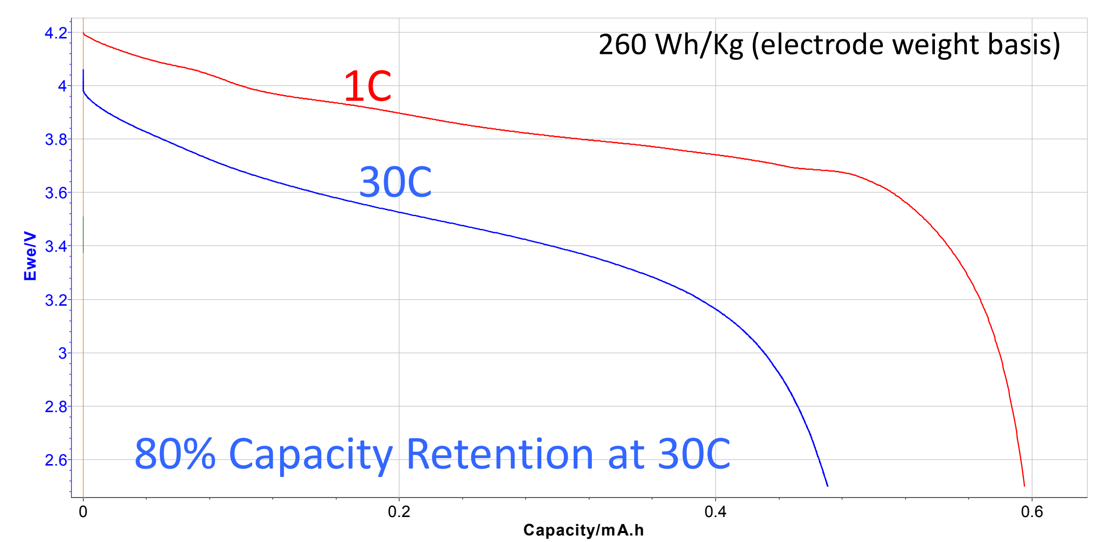
Fast movement of Li^+ through the pores
+
Fast movement of e^- through the lattice
+
Thin active material
=
Fast Reaction

Enhanced Safety

Thin active material
=
Reduced Heating

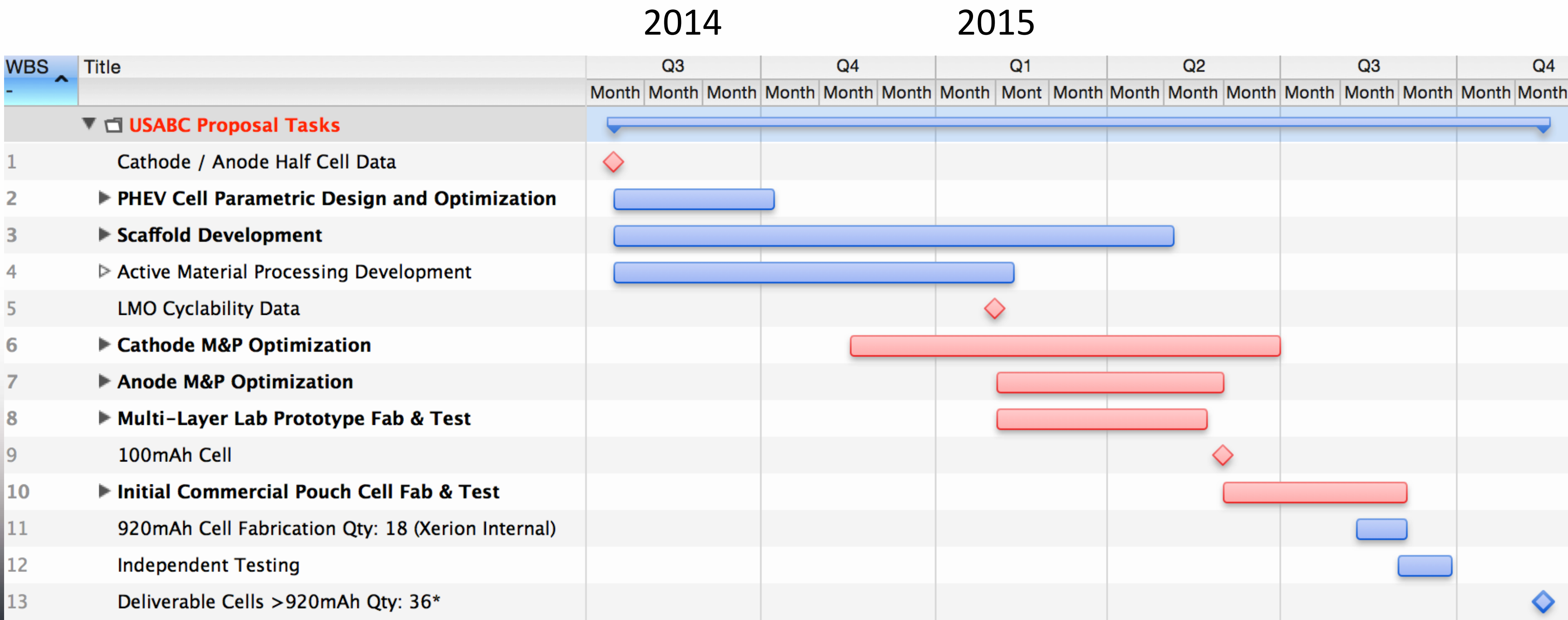
Nanostructured metallic foam
=
Reduced electrical shorts

StructurePore™ LCO Cathode vs composite carbon anode in coin cell



Approach/Strategy-Plan

- Design StructurePore™-based prismatic pouch cells that are parametrically designed to maximize PHEV performance, optimize materials and manufacturing processes, and build for delivery and evaluation by Argonne
- Utilize commercial chemistries so that structure can be evaluated with respect to commercial cells



Technical Accomplishments and Progress

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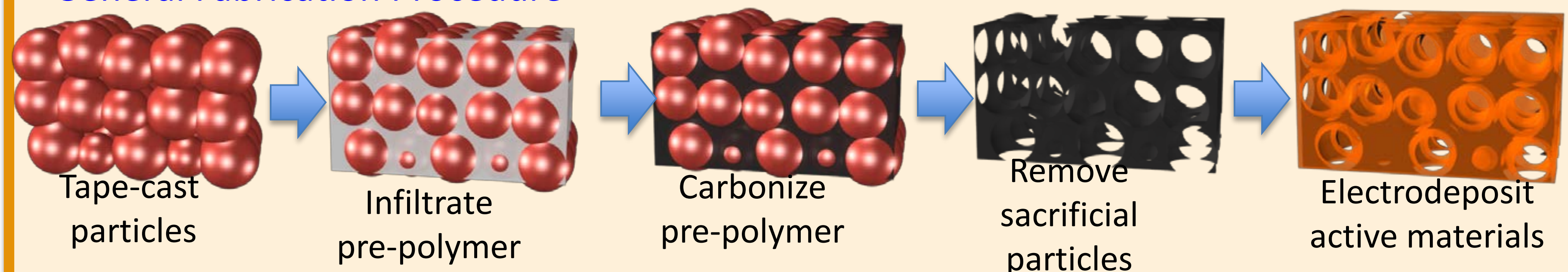
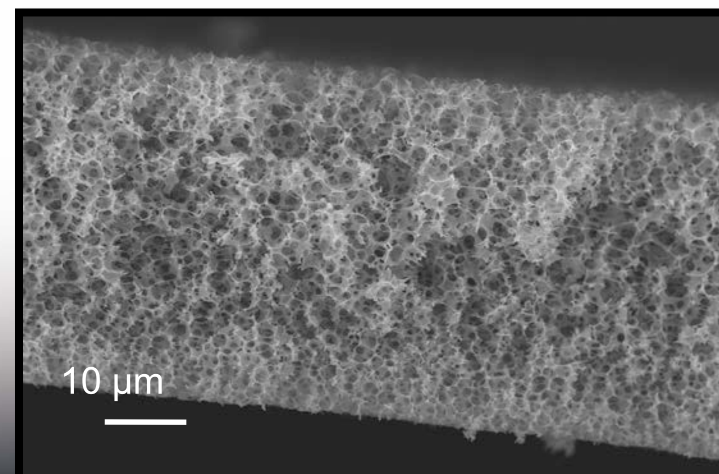
- **Created robust nanostructured, open-cell carbon foam scaffold to act as integrated current collector**

General Fabrication Procedure



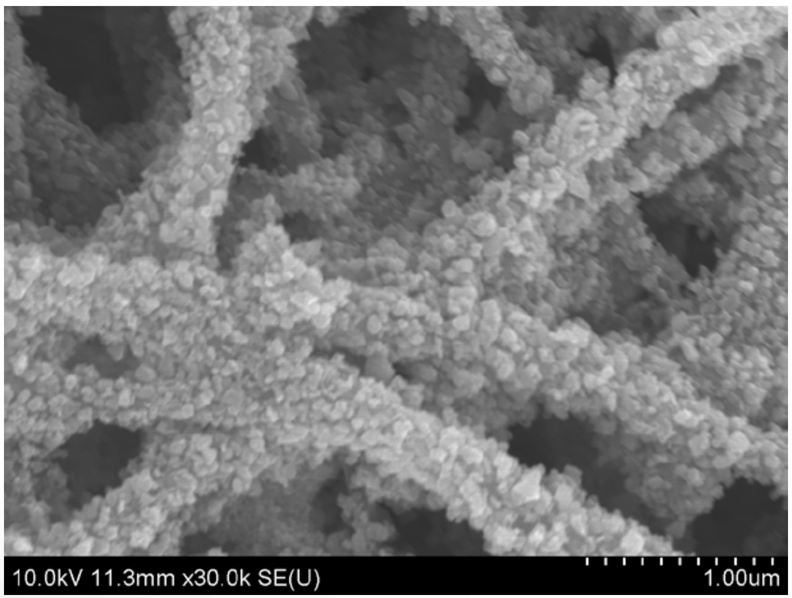
Nanostructured carbon foam



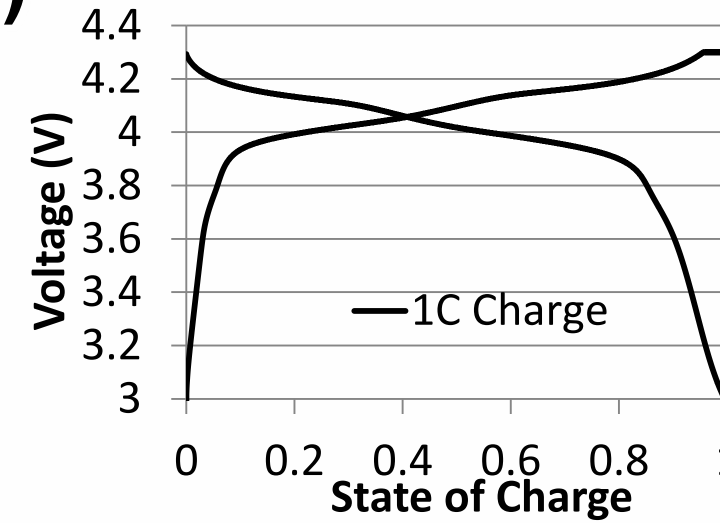
Cross sectional SEM

Technical Accomplishments and Progress (Cont'd)

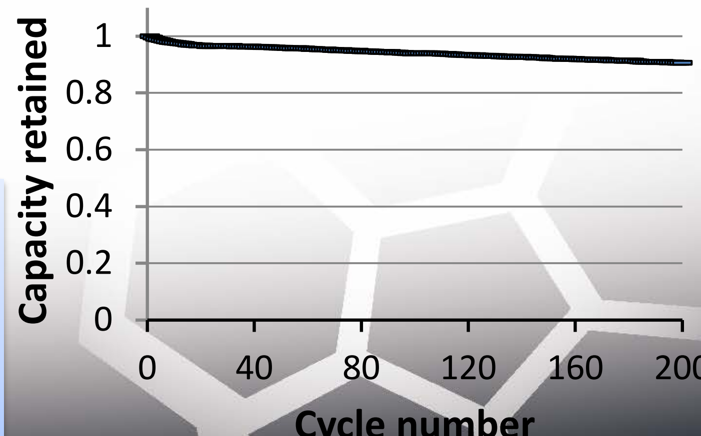
- **Demonstrated conformal electrodeposition of spinel lithium manganese oxide on carbon scaffolds.**



- **Conformal electrodeposition of spinel LMO**
- **Active material based capacity: 80~ 105 mAh/g for standard cycling voltage window (3 – 4.3 V)**
- **Reduced capacity due to the presence of impurity/stabilization phase**

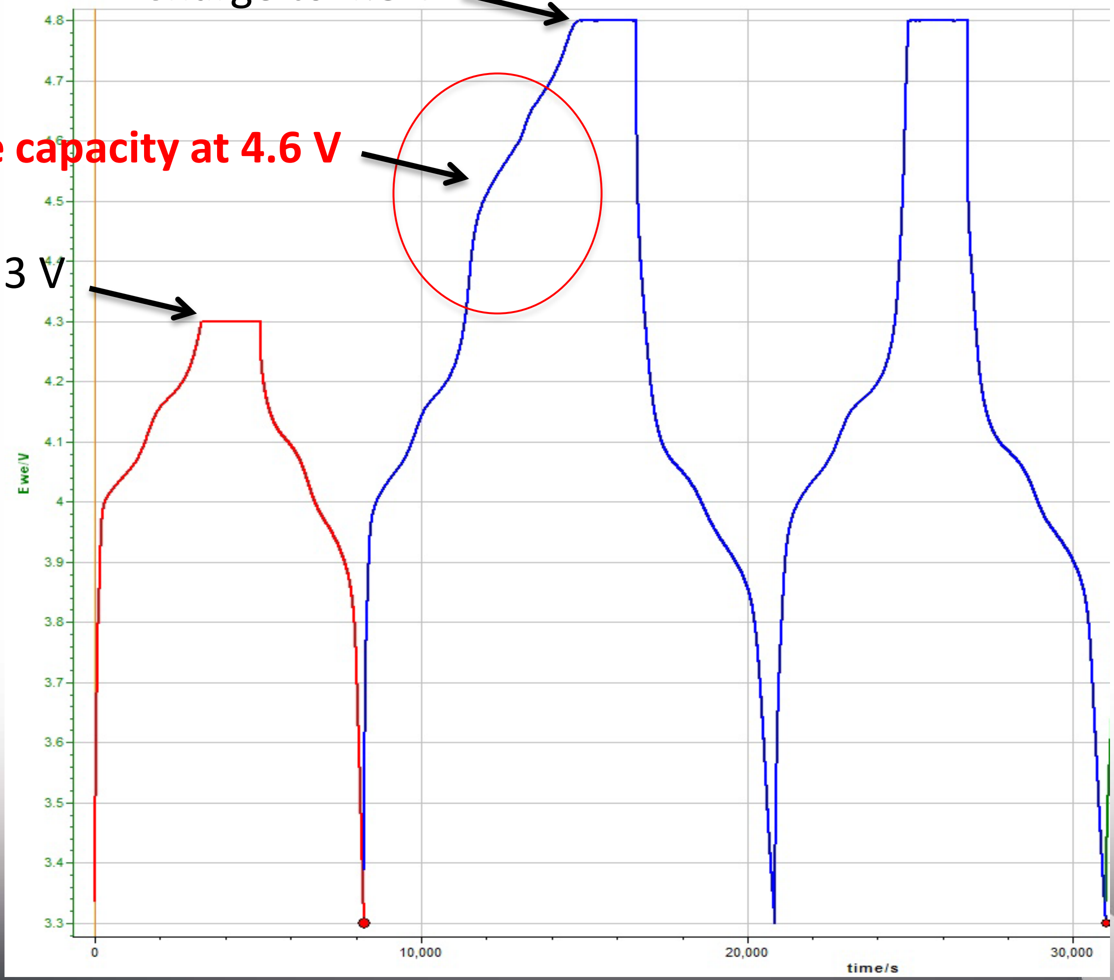


Spinel LMO with Li_2MnO_3 (1.5 mAh/cm^2 cell) cycle life-Half cell vs. lithium



Technical Accomplishments and Progress (Cont'd)

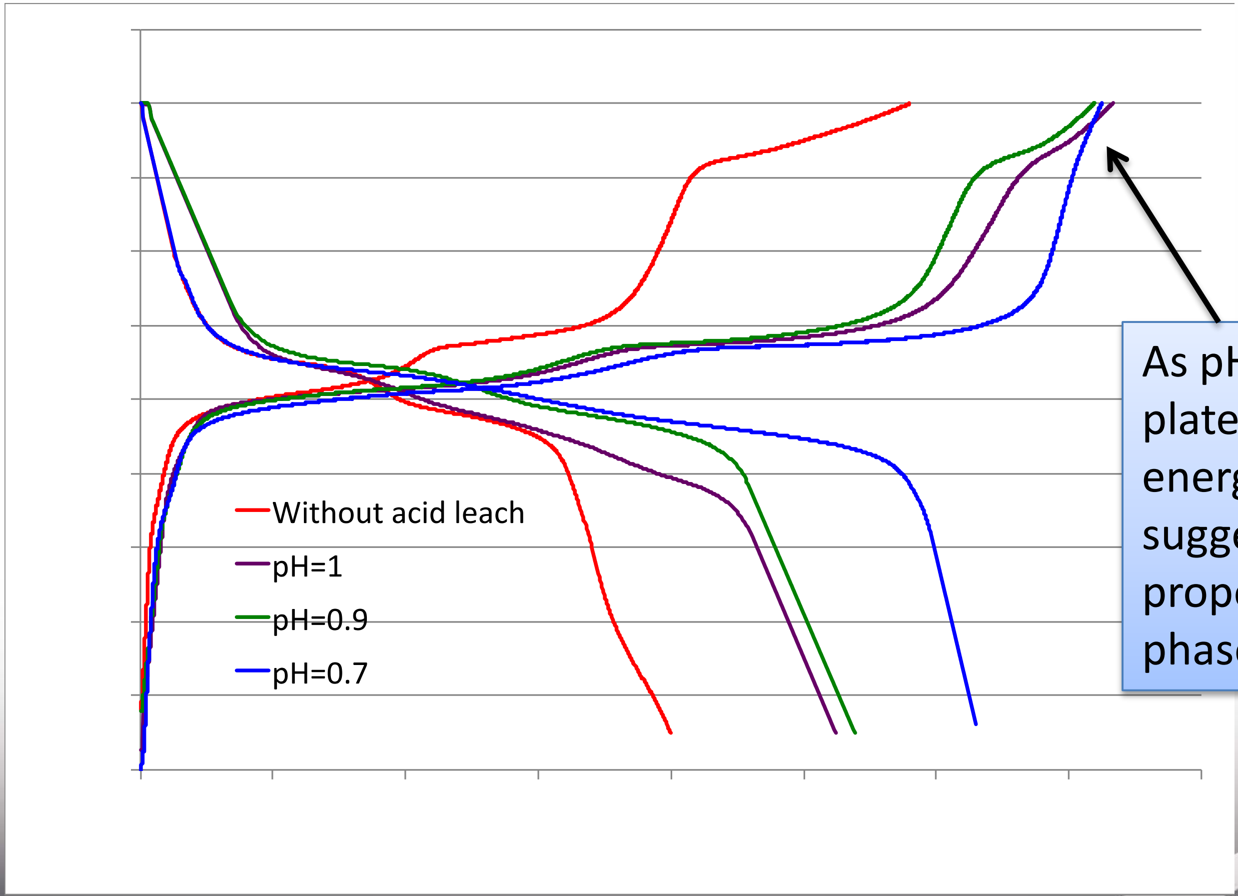
- **Identified secondary phase**



- Active material based (reversible) capacity: **89 mAh/g**
- Irreversible capacity: **89 mAh/g**
- 4.6 V plateau indicates the impurity phase is **Li_2MnO_3**
- The composition of our material based on capacity ratio is most likely to be **$2LiMn_2O_4 \bullet Li_2MnO_3$**
- Consistent with ICP result.
- **Li_2MnO_3** can act as a stabilization phase for spinel

Technical Accomplishments and Progress (Cont'd)

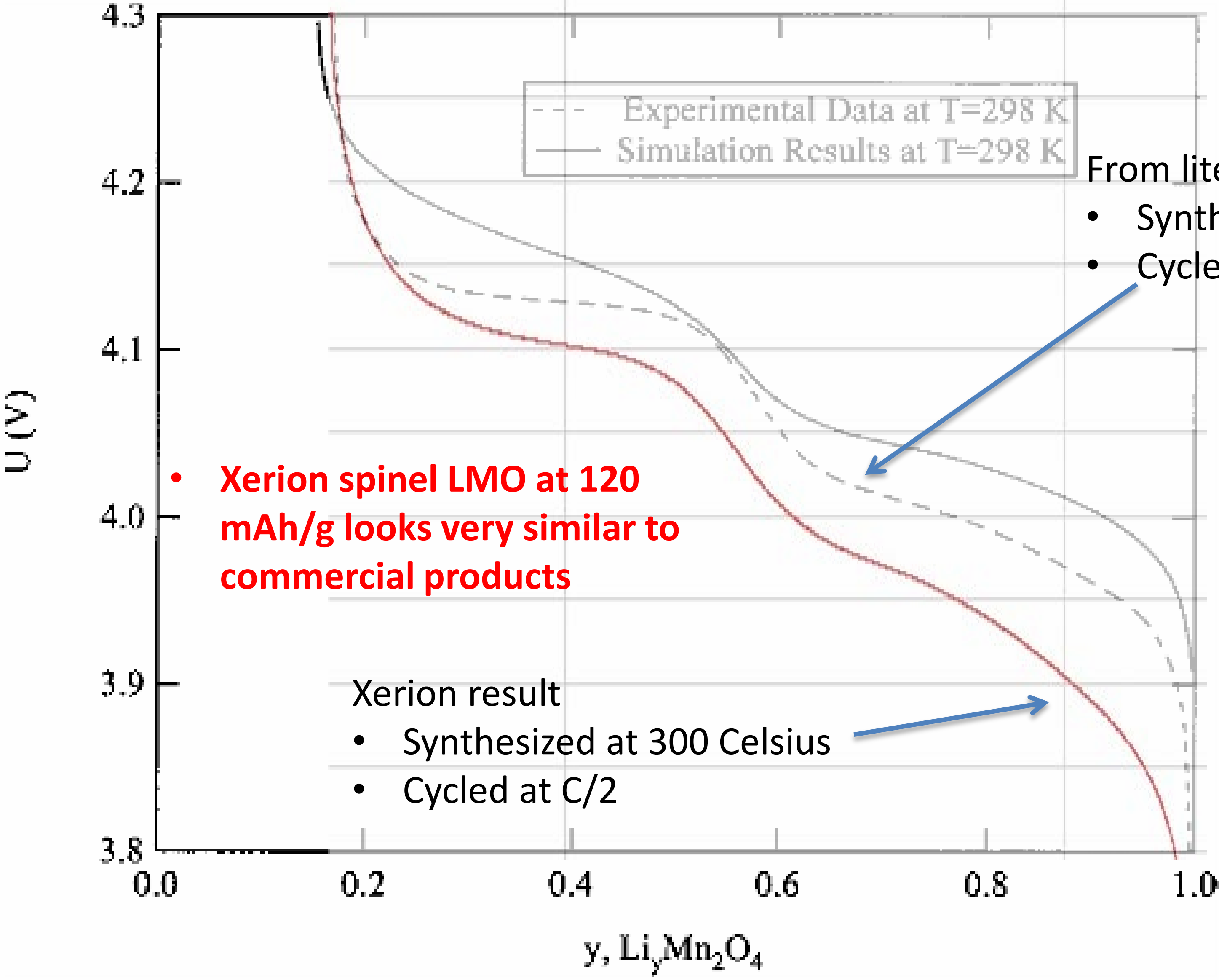
- **Demonstrated ability to controllable remove secondary phase**



As pH decreases, 4.6 V plateau decreases and energy density increases, suggesting higher proportion of spinel phase.

First charge-discharge cycle of spinel LMO leached with different pH

Technical Accomplishments and Progress (Cont'd)



From literature:

- Synthesized at 750 Celsius
- Cycled at C/25

- **Xerion spinel LMO at 120 mAh/g looks very similar to commercial products**

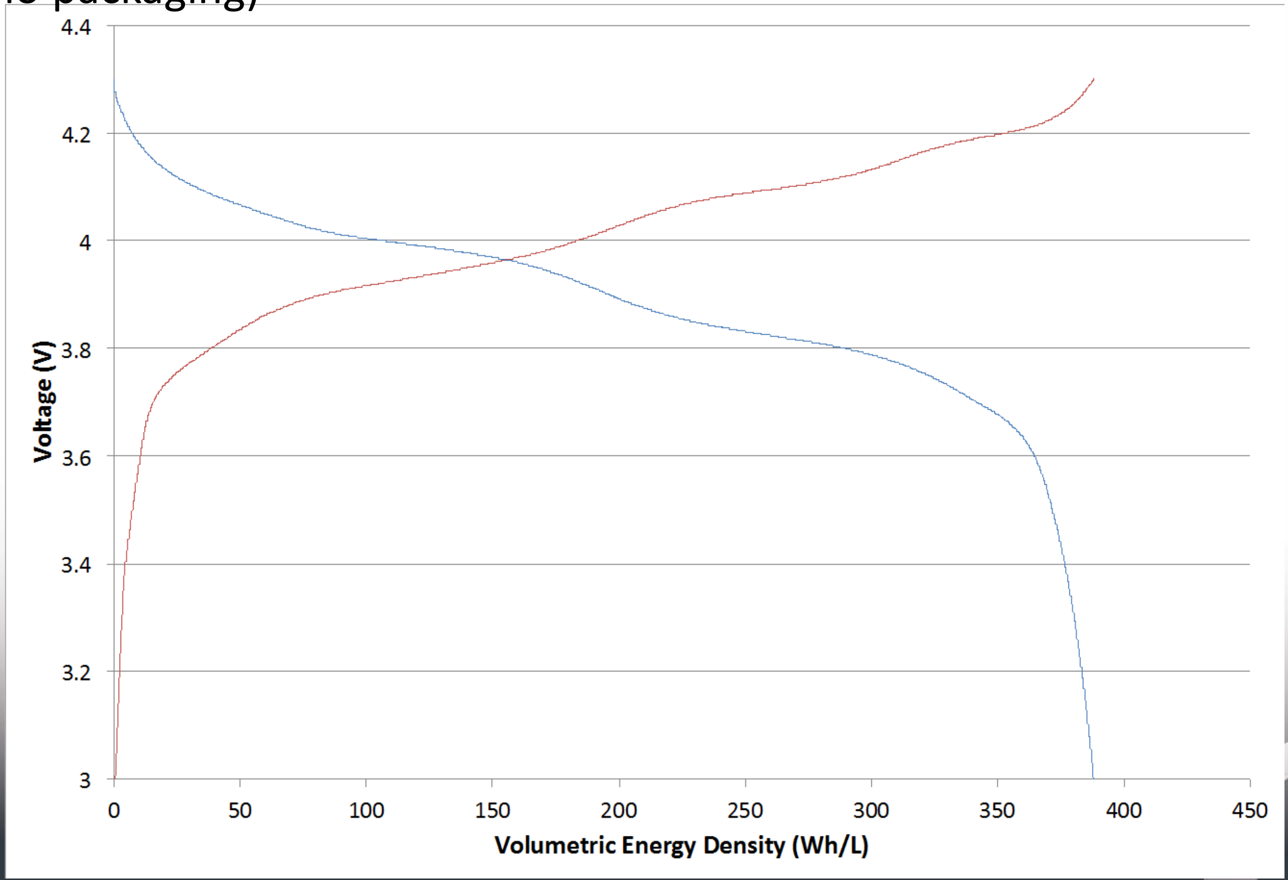
Xerion result

- Synthesized at 300 Celsius
- Cycled at C/2

Technical Accomplishments and Progress (Cont'd)

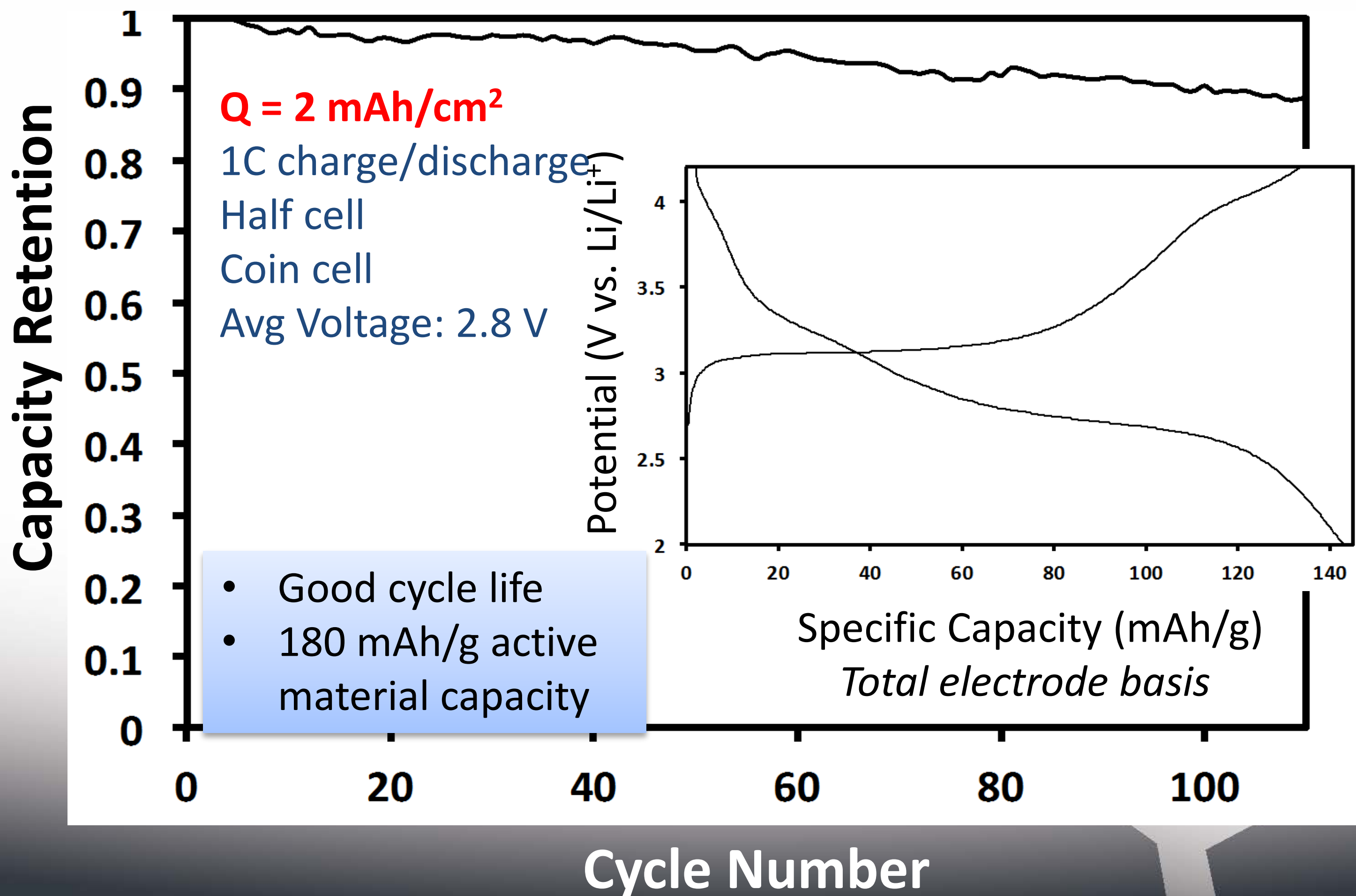
- **Demonstrated full-cell, single layer pair of spinel LMO versus carbon**

Full cell includes LMO cathode, separator, and porous carbon anode (no packaging)



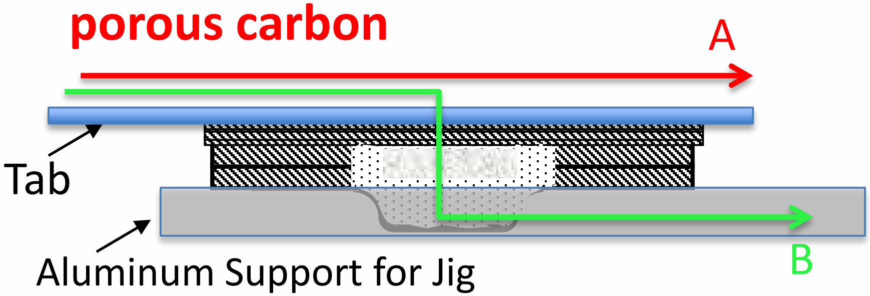
Technical Accomplishments and Progress (Cont'd)

- **Demonstrated direct deposition of γ – MnO_2—must be lithiated after deposition**



Technical Accomplishments and Progress (Cont'd)

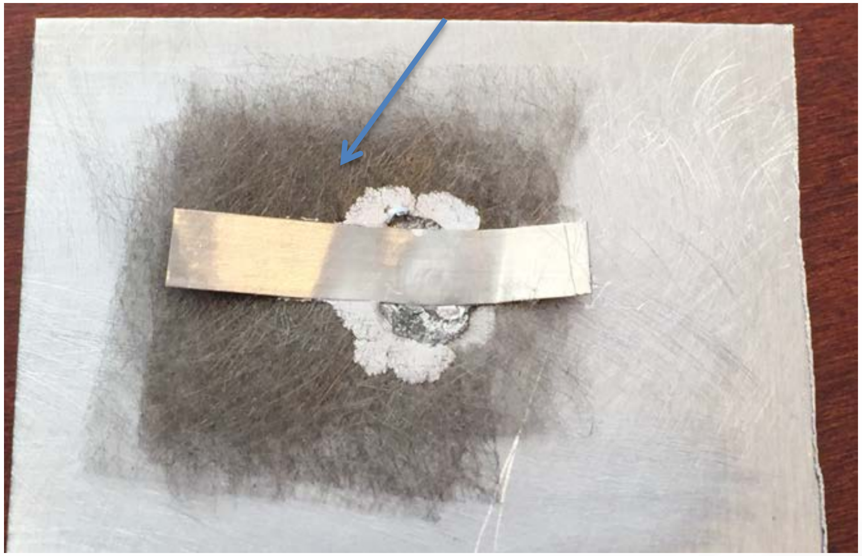
- **Initial demonstration of securely welding aluminum tab to multi-layer porous carbon**



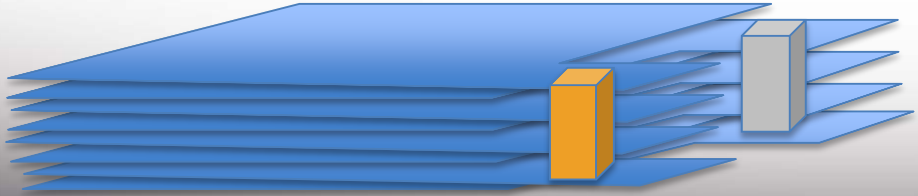
Resistance of Path A=Resistance of Path B

(Resistance of Weld is not measurable with milliohm meter)

Eight Layers of Carbon (microfiber mesh demo)



Envisioned Standard Configuration:



Partners/Collaborations

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Polaris Battery Labs, LLC
Guiding your product to commercialization

Intertek

Subcontract Purpose:

Commercial Pouch Cell Assembly

Environmental Testing

Microstructural Characterization and Process Optimization

Remaining Challenges and Barriers

- Demonstrate robustness of tab welding
- Determine cycle-life and cold weather performance in pouch cell format
- Produce multi-layer pouch cells with spinel LMO vs Porous carbon
- Demonstrate enhanced P/E ratios in pouch cell
- Demonstrate enhanced charge acceptance in pouch cell format
- Validate performance enhancement for USABC Gap Chart
- Deliver prototypes to USABC/Argonne for testing