Developing Safe, High-Energy, Fast-Charge Batteries for Automobiles

Wenjuan Mattis (PI)

Bryan Yonemoto, Jianzhao Liu, Karima Lasri

Microvast, Inc.

Annual Merit Review

DOE Vehicle Technologies Program

Washington, DC

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Project ID#: BAT395

Overview

Timeline

- Project Start Date: Jul 2018
- Project End Date: July 2020
- Percent Complete: 85%

Budget

- Total Project Funding
  - DOE Share: 50%, 1.5M USD
  - Contractor Share: 50%, 1.5M USD
- Budget Period 1:
  - DOE: $773,349
  - Contractor: $829,208
- Budget Period 2:
  - DOE: $726,651
  - Contractor: $670,800

Barriers

- Extreme fast charge (XFC) cell cycle life
- Material performance for XFC cells

Partners

- Argonne National Labs
  - Khalil Amine, Tongchao Liu, Jihyeon Gim, Chi Cheung Su, Jiayan Shi
- BMW Group
  - Peter Lamp, Forrest Gittleson
- Interactions/collaborations
  - Argonne Center for Nanomaterials
  - Argonne Advanced Photon Source

Relevance

Project Objective:

- Design, build and test safe, high energy XFC cells using new cathode and electrolyte materials to improve safety and/or impedance rise in high energy XFC cells
- Demonstrate XFC cells using both pouch and prismatic large format automotive cells

Impact to DOE VTO mission:

- Research that improves the understanding of cell failure during XFC cycling, and innovations that may solve the identified issues
- Developing technology that would enable EV cars to recharge at similar rates to gasoline vehicles, improving the convenience for consumers
- XFC capable cells may accelerate adoption of EVs for commercial fleet vehicles that could now run continuously

Milestones & Gantt Chart

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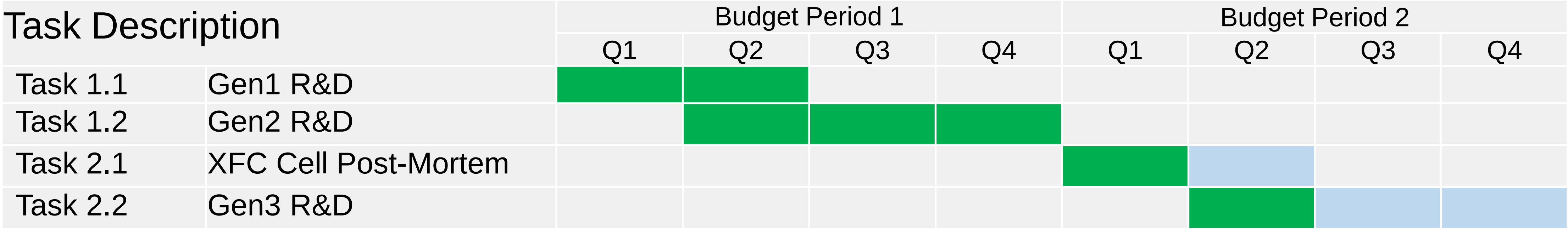


Milestone	Target End Date	Description	Milestone Progress
Gen1 Build Complete	10/3/2018	At the start of project, a baseline cell will be designed by project partners.	Complete
Gen1 Analysis Complete	1/3/2019	The final analysis on Gen1 cell will be complete, and the technology gap will be known to aid additional cell development	Complete
Gen2 FCG-VS Selected	4/3/2019	The cathode material process for use in Gen2 cells is complete	Complete
Deliver 9 cells to DOE	7/3/2019	Upon completion of budget period one 9 cells (Gen1 or Gen2) will be delivered to the DOE for cycle testing	Complete
Go/No Go Decision Point	Go/No Go	Gen-1 cells PASS 500 cycles 6C charge*/1C discharge cycle requirements (see FOA for * details)	Complete
Ageing Study Complete	10/3/2019	The findings of spent cell diagnostics are done for Gen2 cell	In Progress
>10 kg Cathode Scale-up	1/3/2020	The newly designed cathode is scaled to at least 10kg	Complete
Low impedance Additive	4/3/2020	The new additive designed to limit impedance rise in the cell is determined	Complete
Gen3 Build Complete	7/3/2020	The final Gen3 pouch and can cells completed Gen3	In-Progress

Battery Design: High Energy vs. High Power

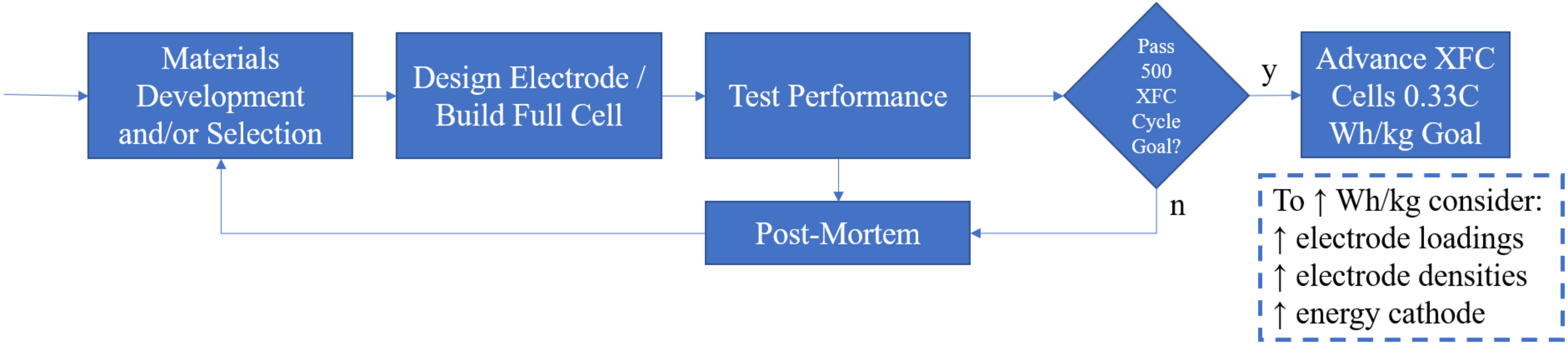
- **High energy battery:** Goal is to maximize *energy density*
  - Want to maximize amount of active material in a given volume of cell, minimize space taken up by inactive materials
  - **Thick layers** of active materials on current collectors, **low porosity**

- **High power battery:** Goal is to maximize *power density*
  - Want to maximize cell voltage at high current (minimize polarization)
  - $V_{cell} = V_{open\ circuit} - \Sigma IR_{internal}$
  - Components of $IR_{internal}$ (polarization) are functions of current density
  - Thus, want to **maximize electrode surface area** (at expense of active material volume)
  - **Thin layers** of active materials on current collectors, **high porosity**, **many windings/layers**

Project Approach

- **Build and test automotive size (>15AH) XFC battery prototypes**
  - Testing occurring in pouch (stacked electrodes) and prismatic (jelly roll) cells during project
  - Postmortem cells following testing for insights on improvement routes
- **Develop new materials (the basic building blocks of a cell) for XFC batteries**
  - High-Ni variable slope concentration gradient cathode
  - Low impedance electrolyte

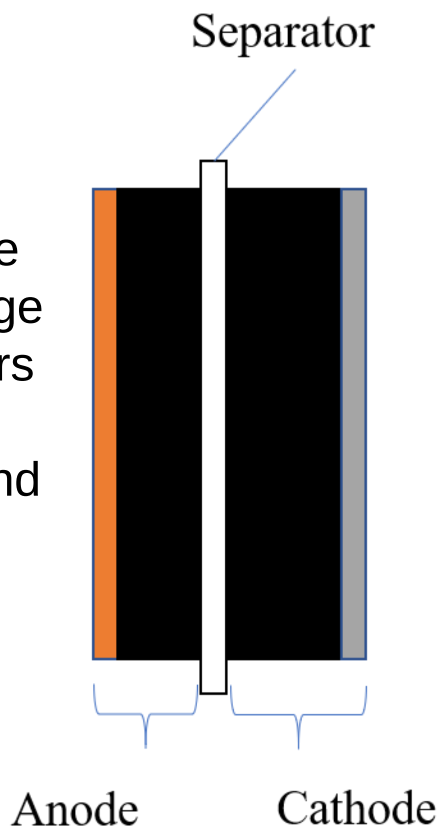
XFC Cell Development Strategy



Technical Approach

- Safety and energy density matter a great deal for all cells, and XFC cells must be developed consider these features concurrently.

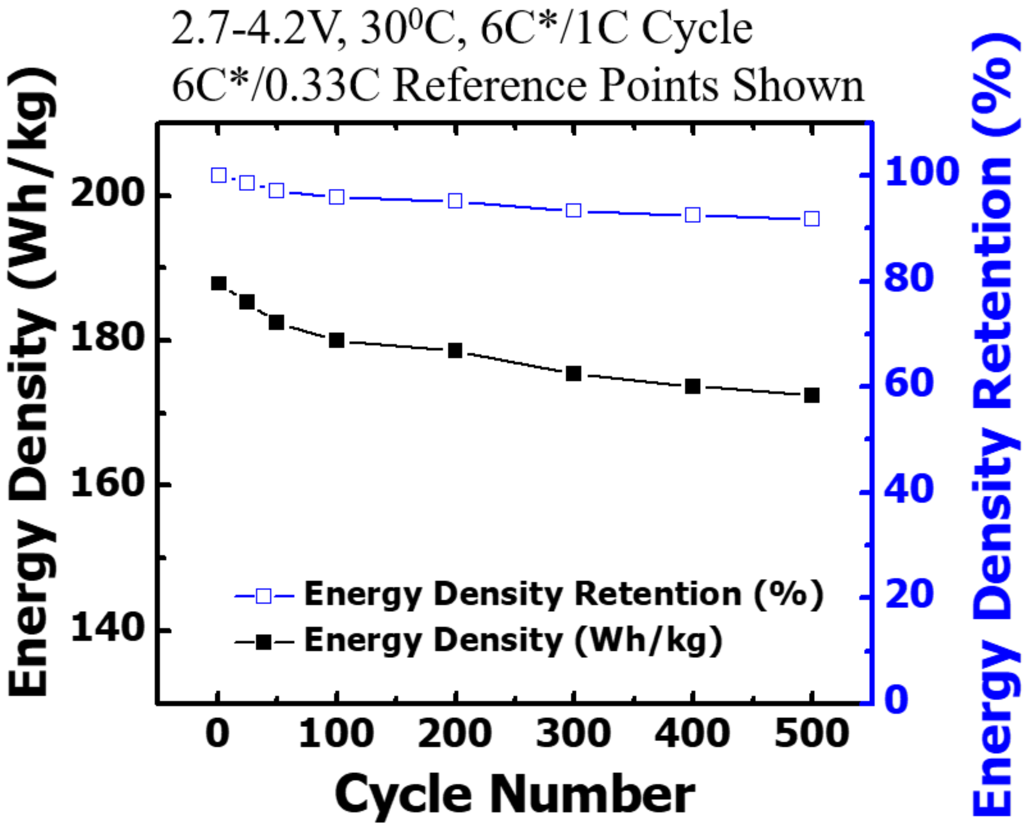
Electrolyte w/ Additives
- Stabilize the SEI to halt li-ion inventory losses
- Should create a low resistance interface to promote fast charge
- Low resistance interface lowers local overpotential, which relates to lithium nucleation and plating onto anode surface



Microvast's High Thermal Stability Separator
- During fast charge temperature "hotspots", which may deform traditional separators are serious concern.
- Microvast's technology will be applied to Gen3 XFC cells to improve safety.

Full Concentration Gradient (FCG) Cathode
- High nickel core that is good for energy density
- Surface stabilized Mn / Al particle exterior for improved safety and cycle stability.
- Nanorod structure orients diffusion pathway for intercalated lithium perpendicular to particle surface, improving high rate performance.

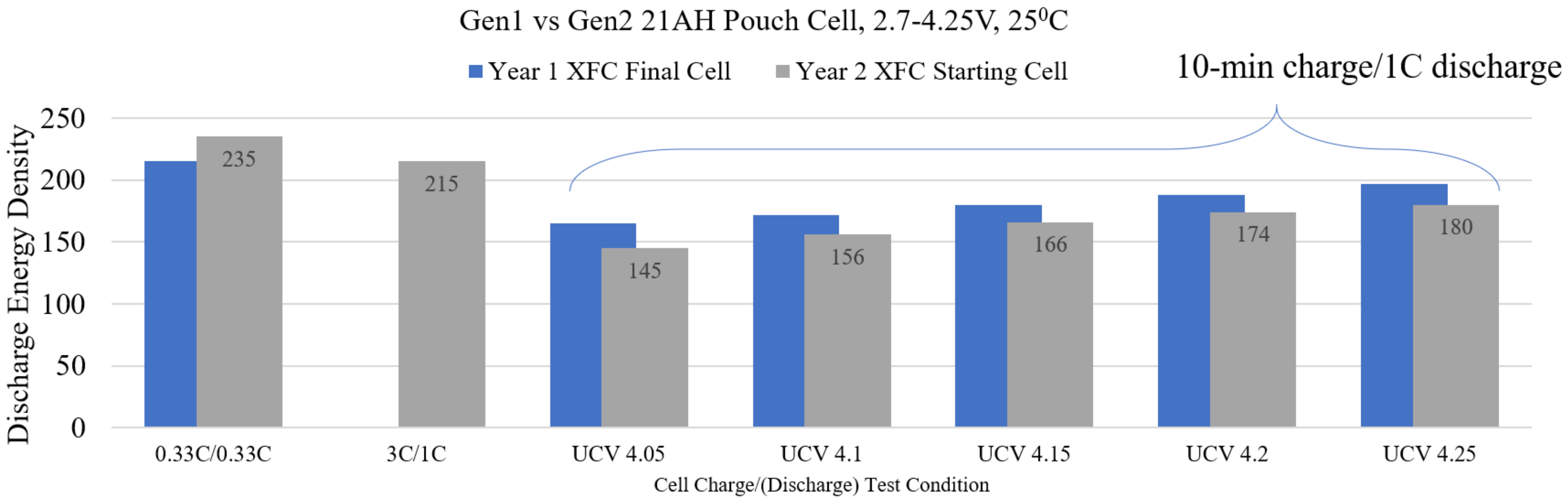
500 XFC Cycles, 21AH Cell



RPT	Capacity (Ah)	Energy Density (Wh/kg)	Energy Density Retention
1	18.33	187.85	100
25	18.09	185.35	98.67
50	17.82	182.44	97.12
100	17.61	180.09	95.87
200	17.47	178.60	95.08
300	17.18	175.36	93.35
400	17.03	173.72	92.48
500	16.90	172.41	91.78

21AH pouch cells developed during year 1 of project show ~91% retention after 500 cycles. The projects testing result is similar and confirmed by deliverable (year 1) XFC cells tested at DOE National Laboratory.

Advancing Energy Density of Cell



- Advanced study to higher energy density cells in year 2
- Despite higher low current energy density, initial XFC tests of higher energy density cells was lower.
- To achieve XFC performance design and materials must improve.

Hard Can Cell Assembly

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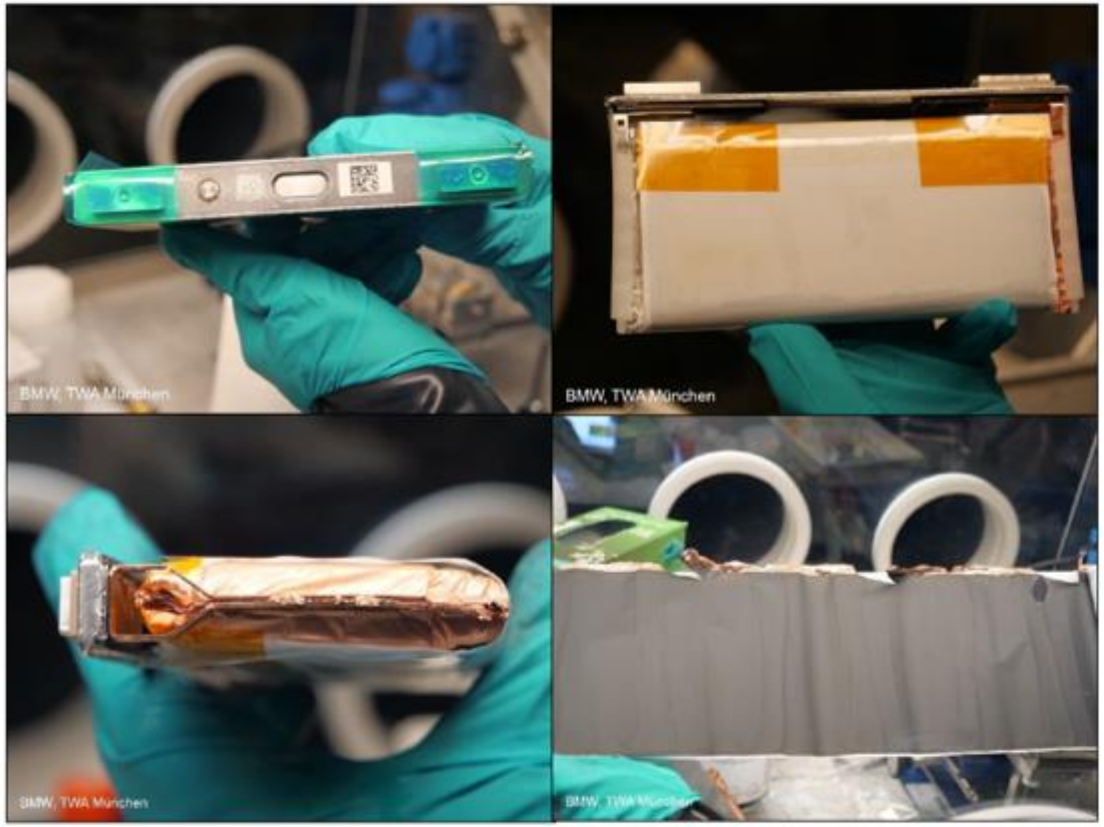
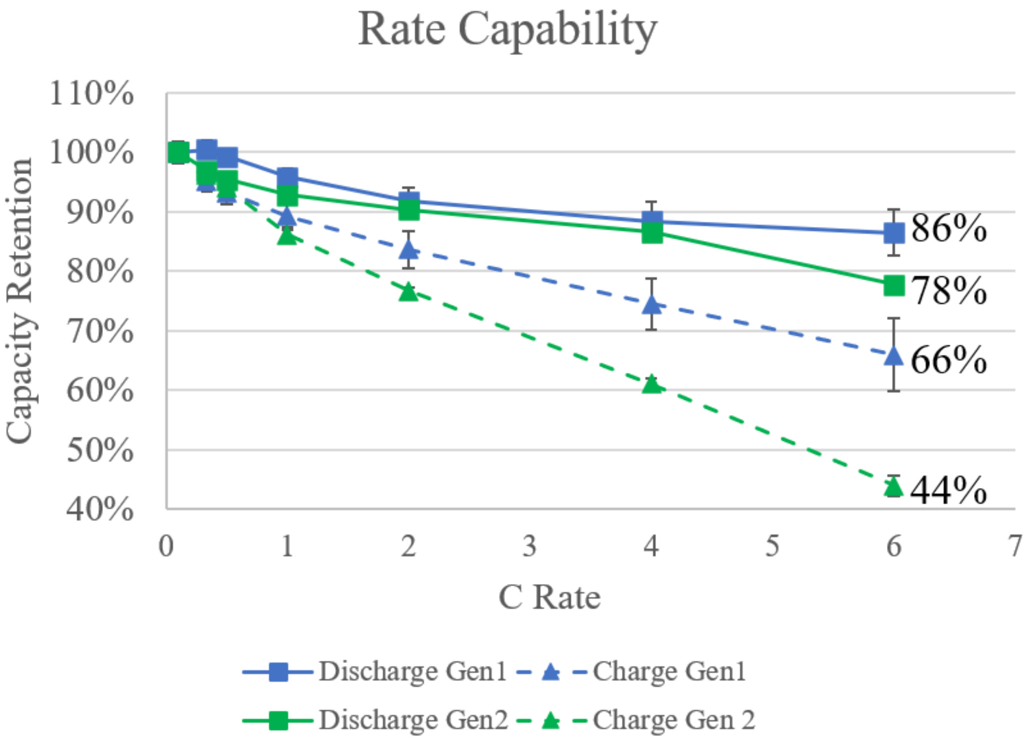


Hard can PHEV1 format with wound jelly rolls

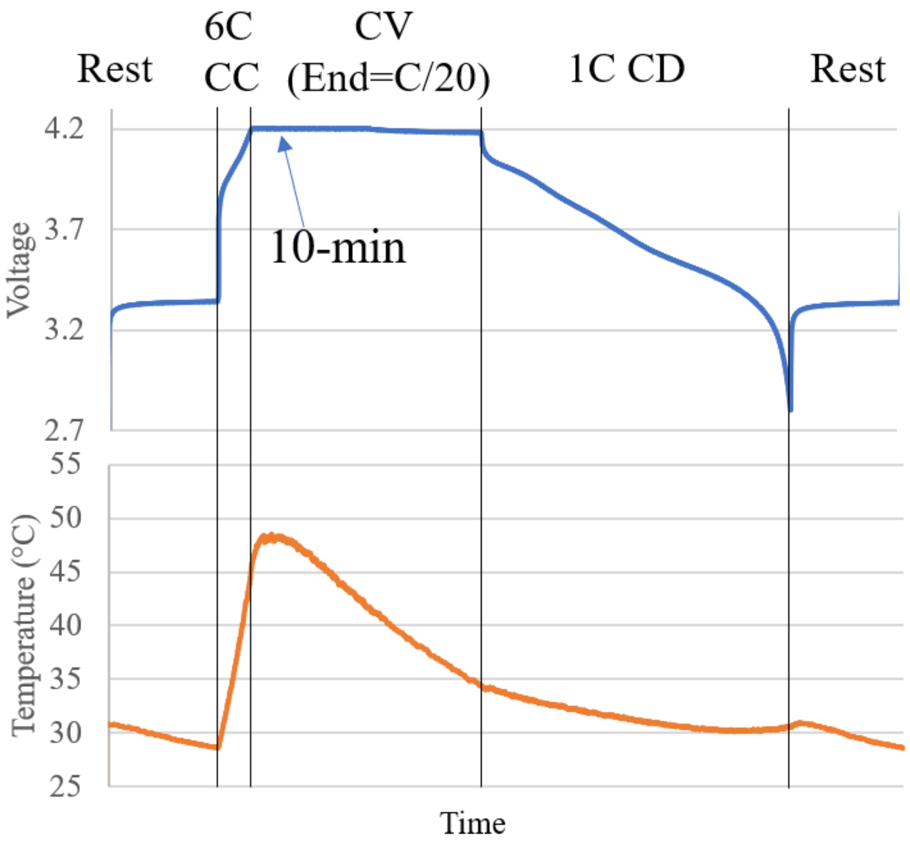
- Gen1: 21.8 Ah
- Gen2: 30.5 Ah

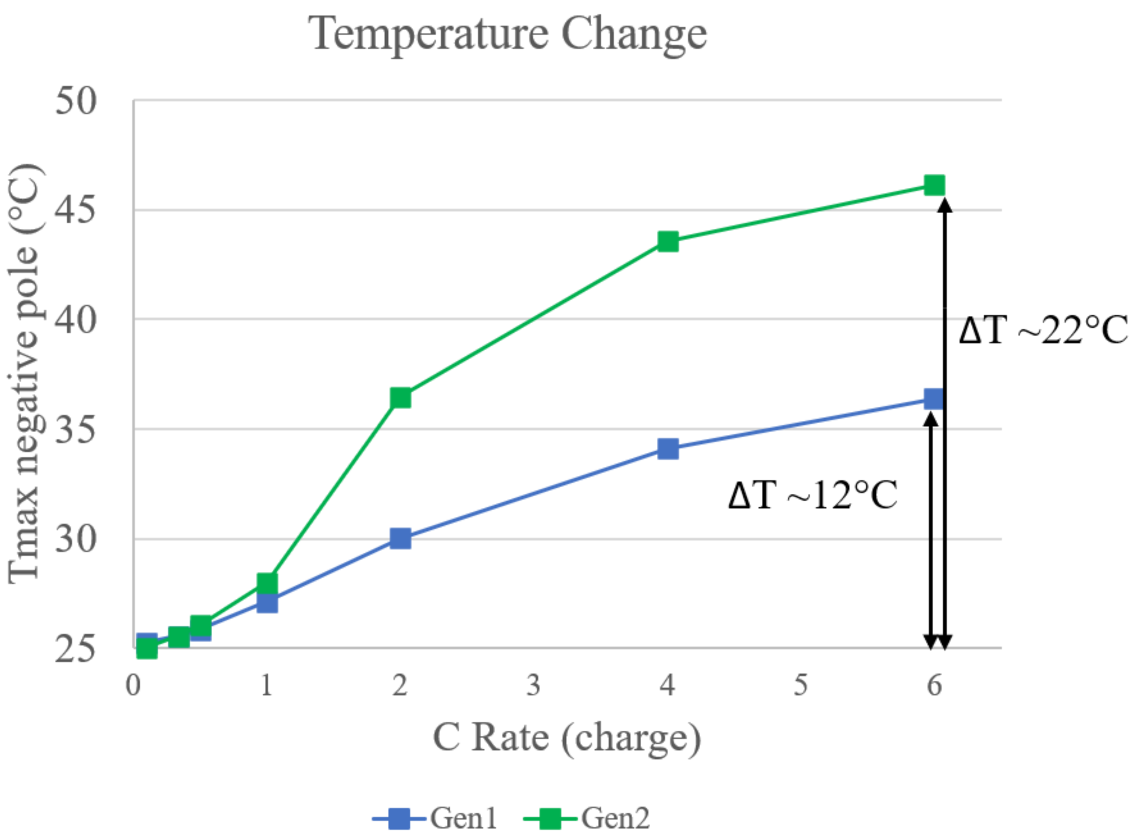
Higher loadings impact rate performance during advance from Gen1 to Gen2



Increased electrode loadings and densities enable higher energies but create additional challenges

Analyzing Hard Can XFC Charge



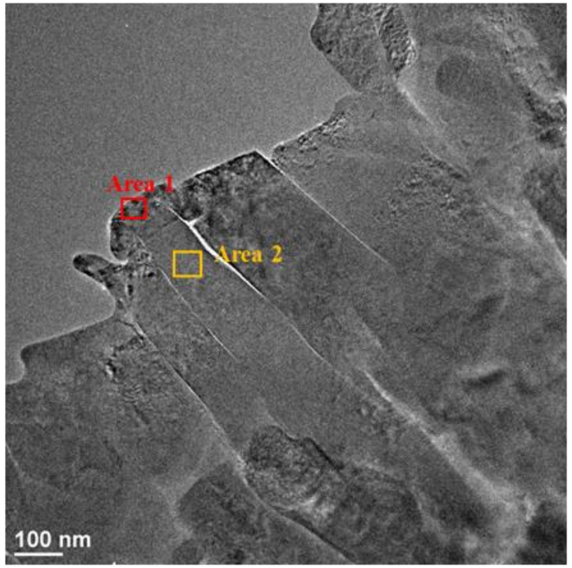


- 85% SoC can be achieved in 10 min (Gen1 and Gen2)
- Gen2 format leads to greater ΔT at highest charging rates
- Cell components (and active materials) can be optimized to reduce ΔT

Cycled Material Study

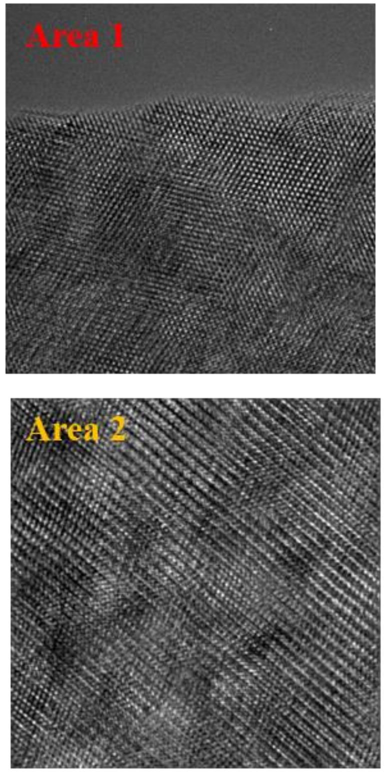
- To improve the XFC cell, characterization was performed to understand the material/cell fade mechanisms.

Transition Electron Microscopy (TEM)

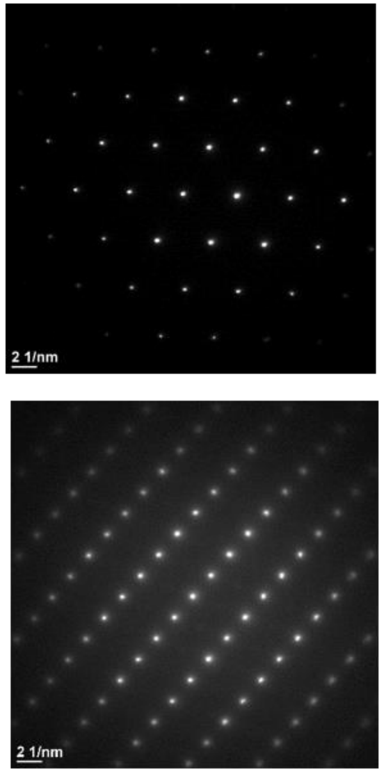


Post cycling evidence of rocksalt (Area 1) to layer (Area 2) is observed in the cathode particle

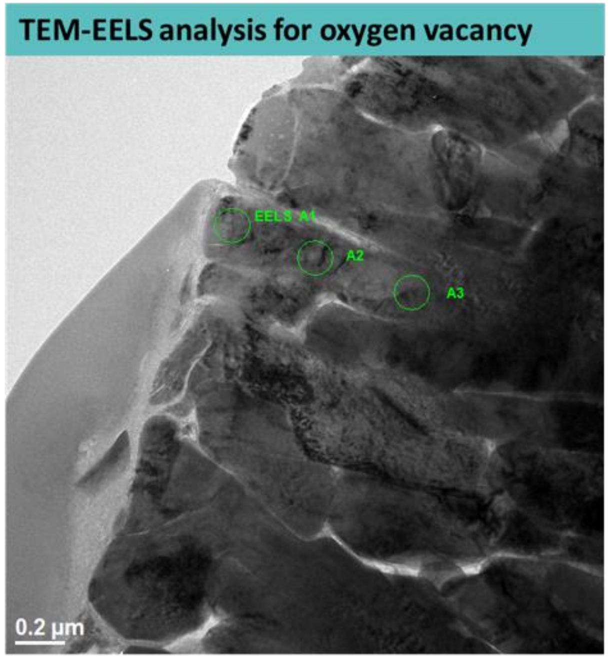
High Res.-TEM

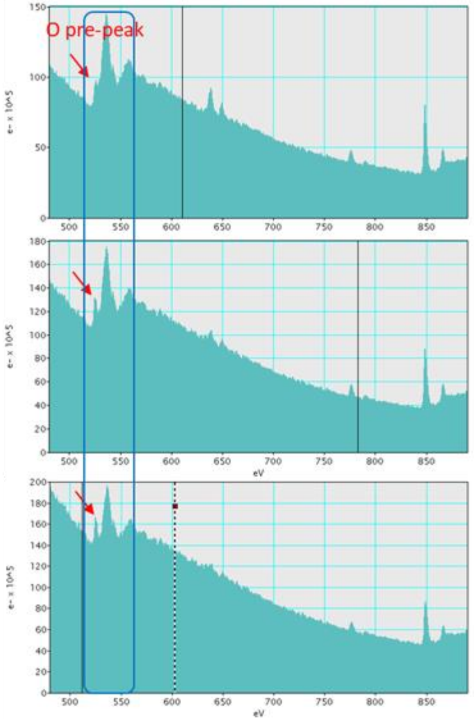


Selected Area Diffraction



Some oxygen loss at surface is observed at particle surface, consistent with HR-TEM & selected area diffraction results.

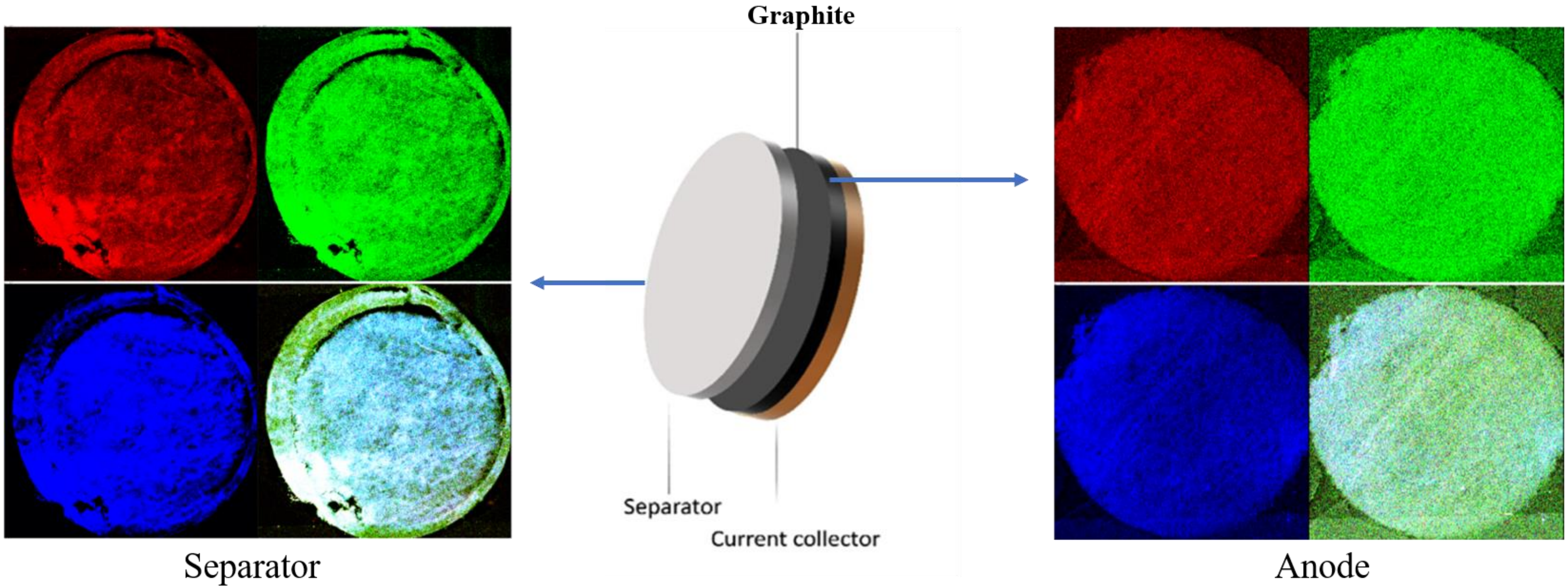




Collaborating with Argonne CNM

Transition Metal Dissolution Study

Synchrotron X-ray Fluorescence: APS beamline 8-BM-B

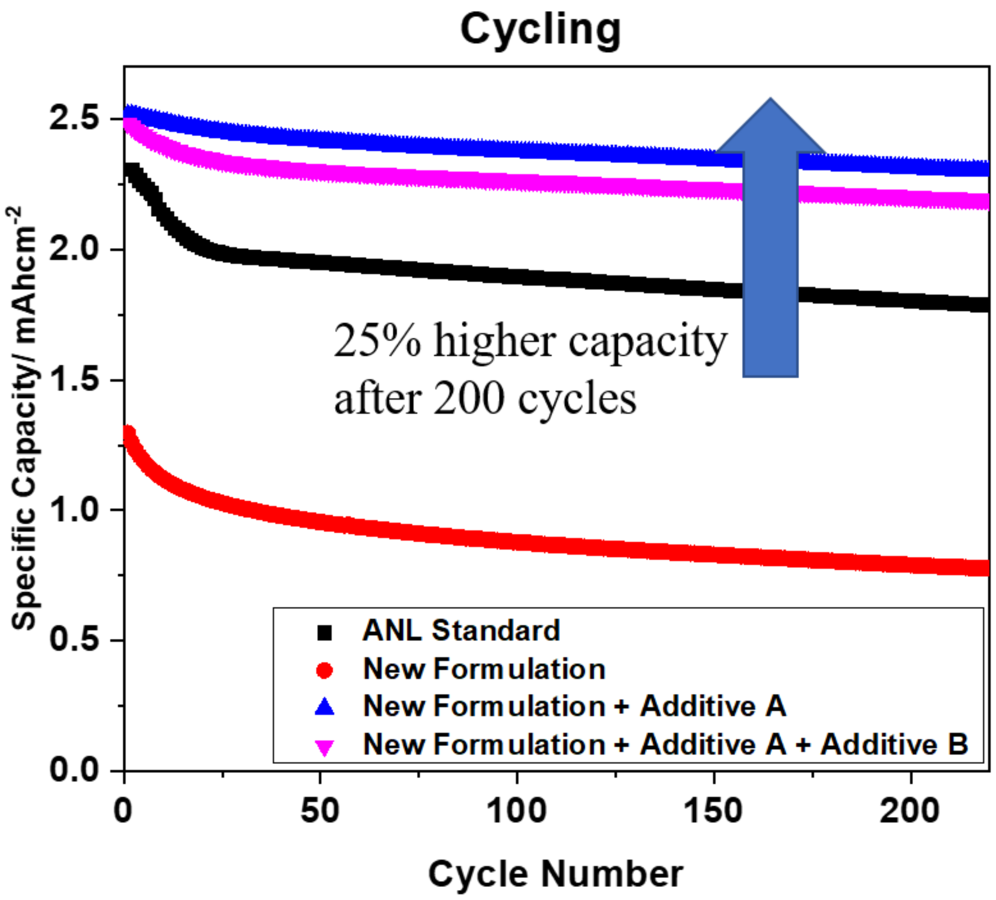


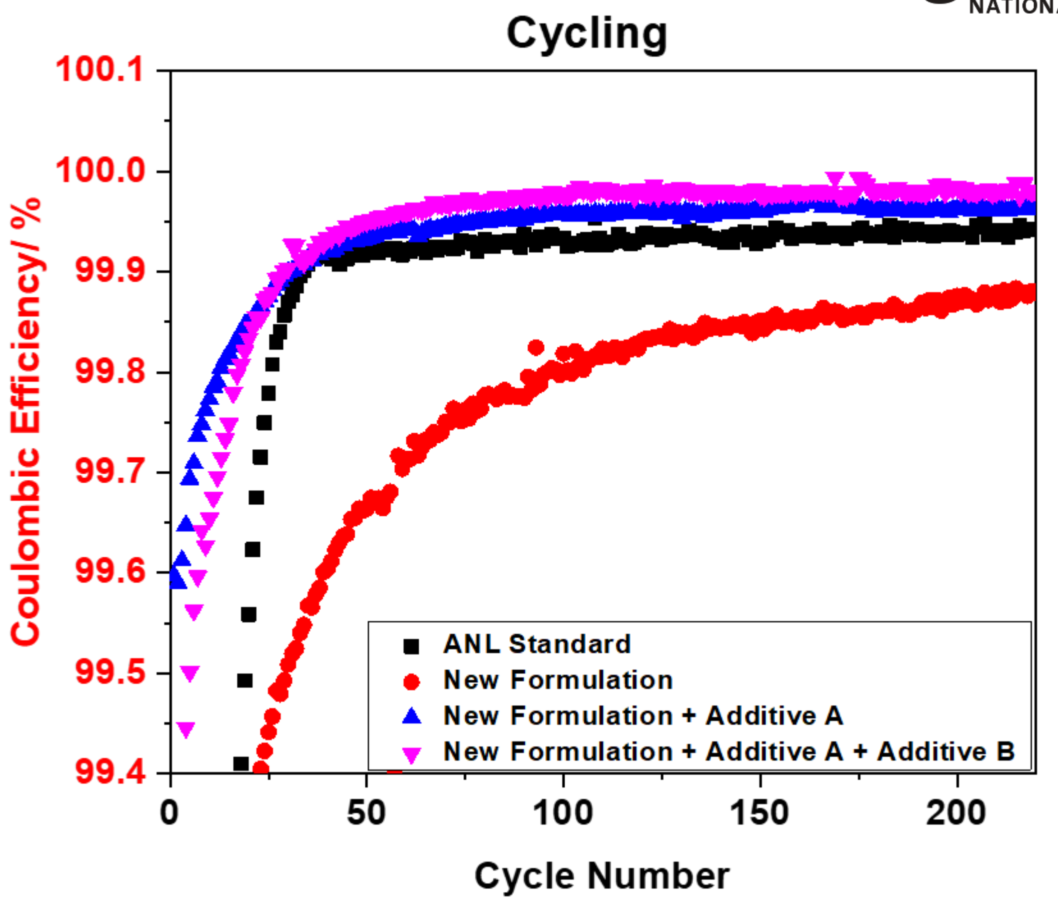
FCG cathode and graphite anode supplied by Microvast. X-ray fluorescence after 100 cycles provides quantitative analysis of transition metal in electrolyte/separator and in anode electrode. Findings from the analysis are:

- Mn is the most soluble element among Ni, Co and Mn
- Increasing charge rate will accelerate TM dissolution
- Electrolyte additive LiDFOB can effectively suppress TM dissolution

Collaborating with Argonne APS

Developing An XFC Electrolyte



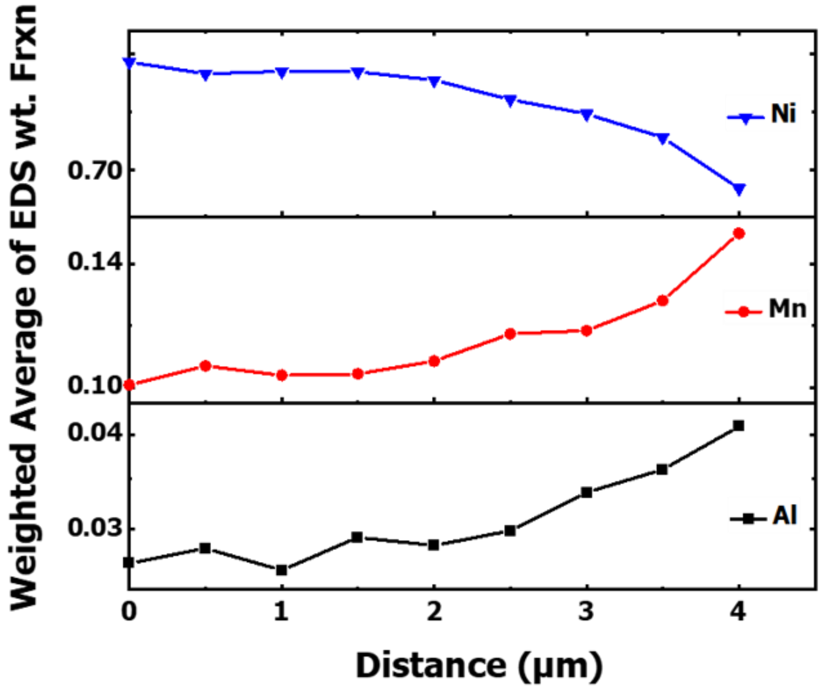


Test Conditions:
Coin cell / Anode: Graphite / Cathode: FCG
Cycled 2.7-4.2 V, 1C @ 50^0C

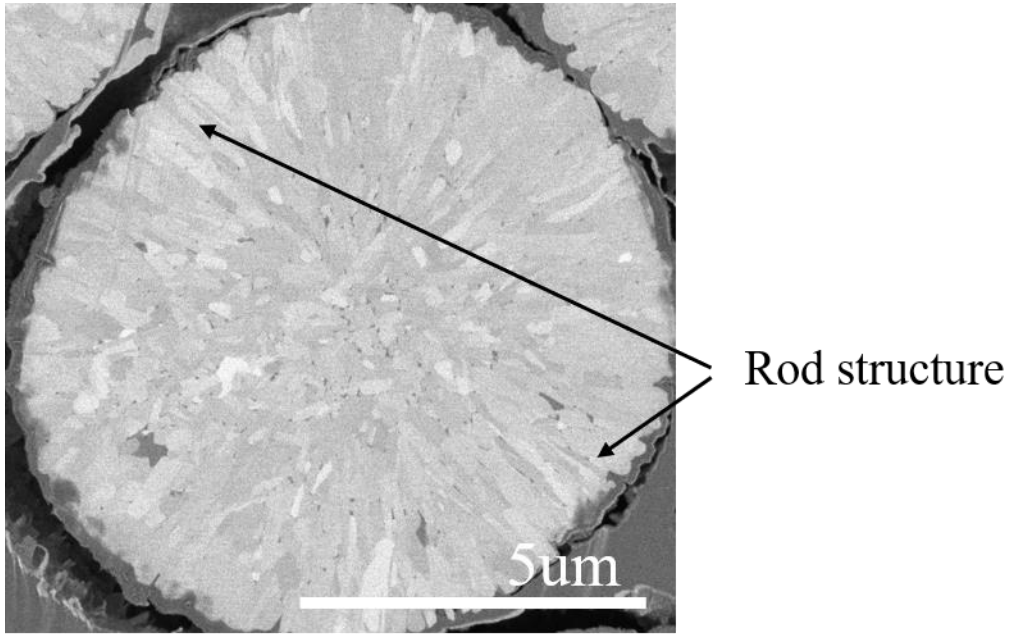
- New electrolyte for XFC cells developed
- Improved cycle efficiency at high temperature, important since XFC peak T increase observed in testing

Developed Cathode Scaled-Up

Analysis of cross section particle shows gradient in nickel, manganese and aluminum exists in material. Gradient used to make material safer and more stable during operation.

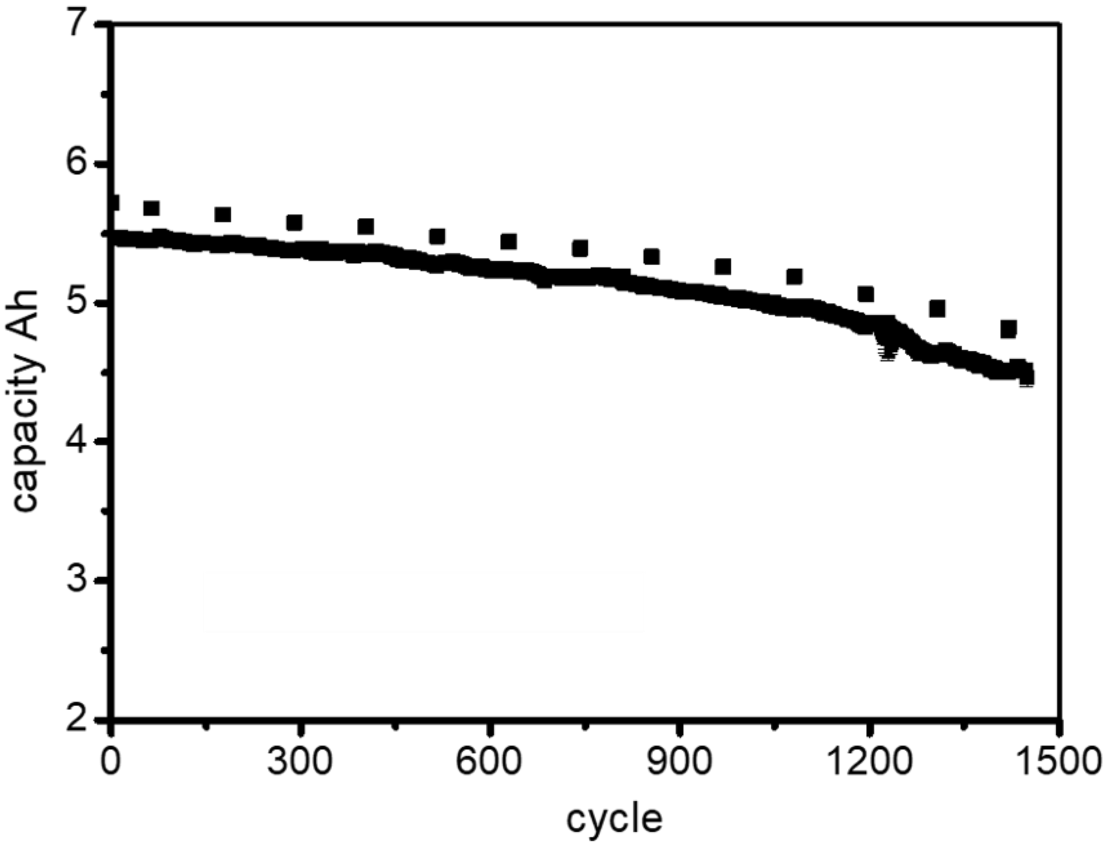


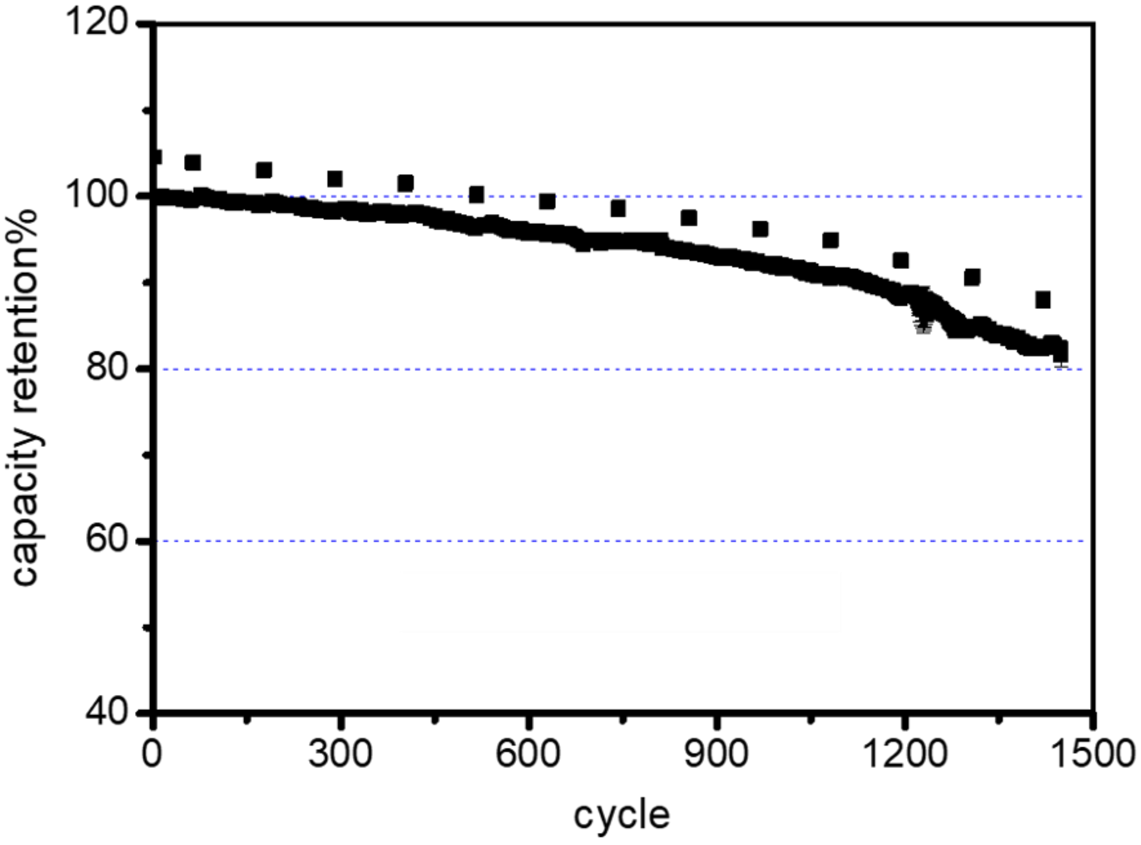
Rod structure in concentration gradient materials aligns the lithium diffusion direction of 2D crystal with particle surface. The rod is thought to improve rate performance.



High nickel full concentration gradient material (cobalt constant concentration) has been scaled to 100 kg level for use in XFC cell studies

Gen3 Cathode Pouch Cell Test

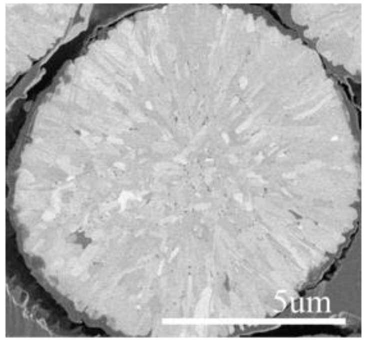


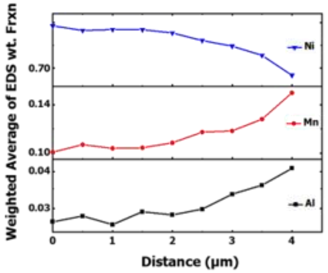


Scaled up cathode shows good cycle stability.

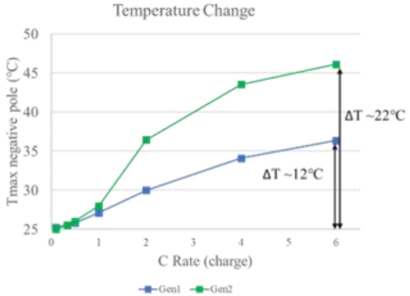
Test conditions: 2.7-4.25V, 25^0C, 1CCCV/1CD with periodic 0.33C reference cycles.

Preparing for Next Cell Build





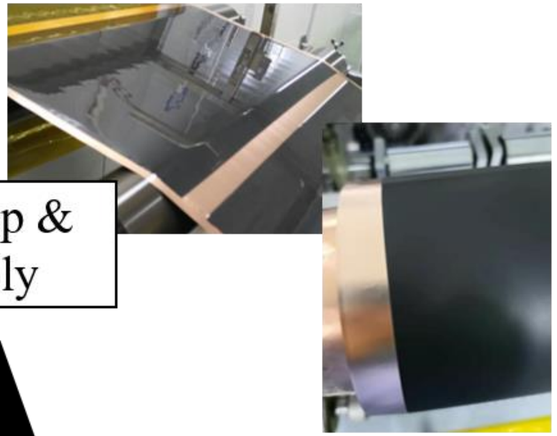
FCG-Variable Slope Cathode

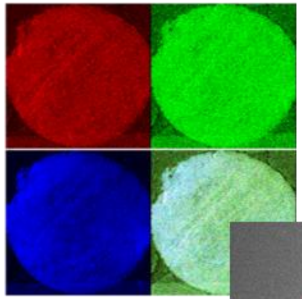


XFC Test Data

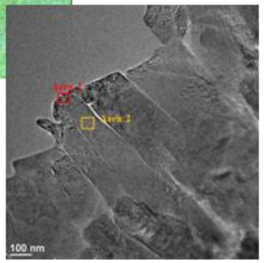
Combining advanced materials and new insights to design projects Gen3 cell

Electrode prep & cell assembly



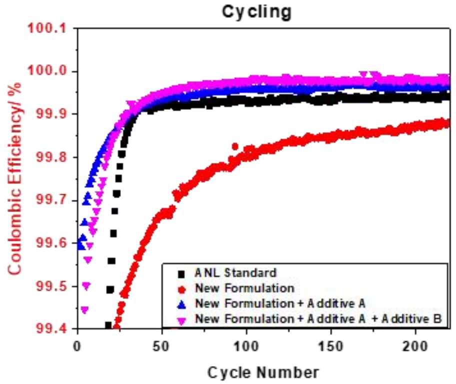


Anode

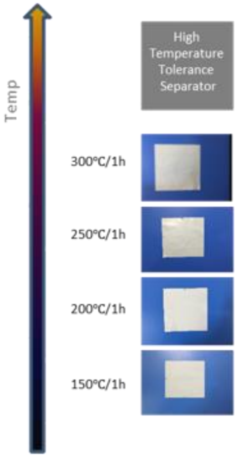


Post Cycle Analysis

High Efficiency Electrolyte



High Stability Separator



Construct XFC Cells

Pouch Cell

Hard Can

Response to Prior Year Review Comments

General Comments:

- The project’s team is a good collaboration between National Labs and Industry. They team is working well together and does a good job meeting milestones.
- The projects material development seems geared toward higher energy density material improvements, and it is not clear how those improvements relate to fast charging.
- The projects future work could be better explained.

Response:

Thank you for the constructive feedback. We’ve tried to better explain our projects approach to clarify why material development and fast charge cell performance is related.

Partnerships / Collaborations

Sub-contractor (National Laboratory)
New cathode and electrolyte additive development; advanced characterization of materials and post-mortem electrodes

Sub-contractor (Industrial)
Hard can (jelly roll) cell build; advanced fast charge protocols; input on commercial battery EV specs

Remaining Challenges and Barriers

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- This program primarily focuses on kinetic solutions to fast charge; but innovations to overcome diffusion limitations of ions during charge/discharge remains a challenging barrier;
- Setting reasonable safety limits for fast charging protocols;
- Identifying lithium plating conditions in XFC cells so the correct material or engineering counter measures can be instituted.

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

Proposed Future Research

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- Cell Build and Testing
  - XFC automotive AH cell build integrating all materials developed as part of program; and to then test performance.
- Final Deliverable
  - Prepare a final pouch cell batch and deliver cells to US National Lab for performance testing.

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

Summary

- 220 Wh/kg pouch cells can complete 500 XFC cycles with ~90% retention;
- Surface stabilized Mn / Al particle exterior for improved safety and cycle stability;
- Microvast's aramid separator will be applied to Gen3 XFC cells to improve safety;
- Lower resistance interface lowers local overpotential, to reduce lithium nucleation and plating onto anode surface;
- Rate retention is decreasing as cell energy density grows;
- Temperature rise is significant during XFC charging;
- Higher rates cause more Mn dissolution from cathode to occur;
- Electrolyte can help improve XFC performance. Some of the improvement may come from lower Mn dissolution;
- High nickel full concentration gradient cathode was scaled to 100 kg batch sizes for XFC prototype testing.

Technical Back-Up Slides

XFC Cell Active Materials

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Generation	Cathode	Anode	Graded Energy Density (pouch cell) Wh/kg
Baseline	NCM – 532	Synthetic Graphite	200 Wh/kg
Gen1A	FCG (Ni:Mn:Co 60:30:10)	Synthetic Graphite	210 Wh/kg
Gen1B	FCG (Ni:Mn:Co 60:20:20)	Synthetic Graphite	218 Wh/kg
Gen2	FCG (Ni > 80%)	Synthetic Graphite	235 Wh/kg
Gen3	FCG (Ni > 80%)	Synthetic Graphite	TBD

Anode: Synthetic Graphite and Synthetic Graphite/MCMB blends are being investigated and considered for later generations

Cathode: Adjustment to cell voltage range and concentration gradient Ni content are being considered for later generations