Fast-Charge and Low-Cost Lithium Ion Batteries for Electric Vehicles

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DOE Vehicle Technologies Office
Annual Merit Review (AMR)
June 1 - 4, 2020 – Virtual Meeting

Project ID: BAT247

Program Overview

TIMELINE

- Project start date: Feb 2019
- Project end date: Jul 2021
- Percent complete: 50%

BUDGET

- Total project funding:
  - ✓ DOE share: $2,421,022
  - ✓ Zenlabs share: $2,421,023
- Funding received in FY2019: $862,160
- Funding for FY2020: $984,209

BARRIERS

- Enable fast charge ($\leq$ 15 min) performance from high-energy lithium ion batteries (LIBs)
- Meet cell cost target of 75 $/kWh
- Meet cycle life and calendar life from LIBs integrating silicon dominant anodes

PARTNERS

USABC — UNITED STATES ADVANCED BATTERY CONSORTIUM

INL — Idaho National Laboratory

Sandia National Laboratories

NREL — NATIONAL RENEWABLE ENERGY LABORATORY

Relevance & Objectives

- **Goals:** To develop novel electrolyte formulations, a scalable pre-lithiation solution that enables the use of high capacity silicon oxide anodes, and optimized cell designs that will result in lithium ion batteries (LIBs) capable of meeting the USABC Low-Cost and Fast-Charge (LC/FC) electric vehicle (EV) battery goals for CY 2023

- **Objectives and Tasks:**

✓ Develop electrolyte formulations able to passivate the silicon anode and NCM cathode, reduce gassing from unwanted side-reactions and support high temperature stability and low temperature operation

✓ Support development of a low-cost manufacturable Pre-Lithiation solution able to support silicon-based LIBs

✓ Establish an optimized cell design to ensure meeting the USABC cell metrics, safety and cost targets

✓ Develop and prototype large-capacity (>50Ah) pouch cells meeting the program cell specifications

- **Deliverables:**

Demonstrate & deliver cells that meet the USABC EV cell targets with independent validation from the National Labs (INL, SNL, & NREL)

- **USABC LC/FC EV Cell Targets for 2023:**

End of Life Characteristics at 30°C	Units	Cell Level
Peak Discharge Power Density, 30 s Pulse	W/L	1400
Peak Specific Discharge Power, 30 s Pulse	W/kg	700
Peak Specific Regen Power, 10 s Pulse	W/kg	300
Available Energy Density @ C/3 Discharge Rate	Wh/L	550
Available Specific Energy @ C/3 Discharge Rate	Wh/kg	275
Available Energy @ C/3 Discharge Rate	kWh	50
Calendar Life	Years	10
DST Discharge Throughput, Discharge Energy	MWh	50
Cost	\$/kWh	75
Operating Environment	°C	-30 to +52
Normal Recharge Time	Hours	< 7 Hours, J1772
Fast High Rate Charge	Minutes	80% ΔSOC in 15 min
Minimum Operating Voltage	V	>0.55 Vmax
Unassisted Operating at Low Temperature	%	> 70% Useable Energy @ C/3 Discharge rate at -20 °C
Survival Temperature Range, 24 Hr	°C	-40 to+ 66
Maximum Self-discharge	%/month	< 1

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Milestones and Gates

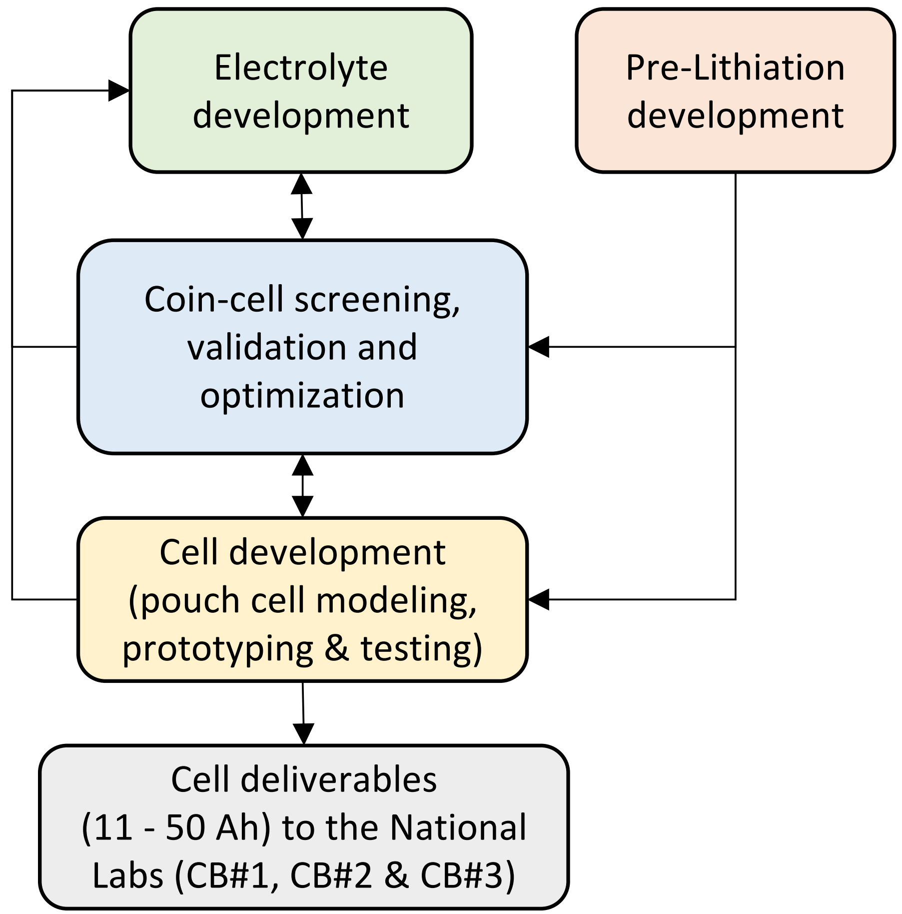
Program Start *(Feb 1st, 2019)* — 2019 — **Current Status** — 2020 — 2021 — **End** *(Jul 31st, 2021)*

Task Number	Major Project Tasks	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Status
		PROJECT TIME												
		YEAR 1				YEAR 2				YEAR 3				
5	**MAJOR PROJECT DELIVERABLE SUMMARY**	■	■	■	■	■	■	■	■	■	■			
4.4	Ship 11 Ah capacity CB#1 pouch cells to the National Labs		◆											Complete
4.9	Ship 11 Ah capacity CB#2 pouch cells to the National Labs						◆							ongoing
4.14	Ship 11 Ah & >40 Ah capacity CB#3 pouch cells to the National Labs										◆			
5.1	Deliver final USABC project report										◆			
9	**REVIEW AND DECISION GATES**	■	■	■	■	■	■	■	■					
1.3	Down-select best Pre-Li solution for Cell Build #2				◆									Complete
1.4	Down-select best Pre-Li solution for Cell Build #3								◆					
2.6	Down-select best electrolyte formulation for Cell Build #2				◆									Complete
2.7	Down-select best electrolyte formulation for Cell Build #3								◆					
3.10	Down-select best cell design for Cell Build #2				◆									Complete
3.11	Down-select best cell design for Cell Build #3								◆					
4.5	Freeze anode, cathode, electrolyte, and cell design for Cell Build #2				◆									ongoing
4.10	Freeze anode, cathode, electrolyte, and cell design for Final Cell Build #3								◆					

- Milestones and gates associated with development of cell build #2 (task 1.3, 2.6, 3.10) have been completed
- Ongoing development is focusing on building and delivering build #2 cells to the National Labs (task 4.5 & 4.9)

Approach

Material, process and cell development strategy:



- Zenlabs is optimizing different electrolyte formulations that incorporate commercially available organic carbonate solvents, additives and salts to meet the Low-Cost Fast-Charge cell targets
- Developing and optimizing high throughput screening for cycle life, gas generation and calendar life
- Supporting and evaluating different Pre-lithiation solutions that will address cost and manufacturability
- Iterative process to down-select the best active and passive components, cell design and cell processing necessary to meet the program targets

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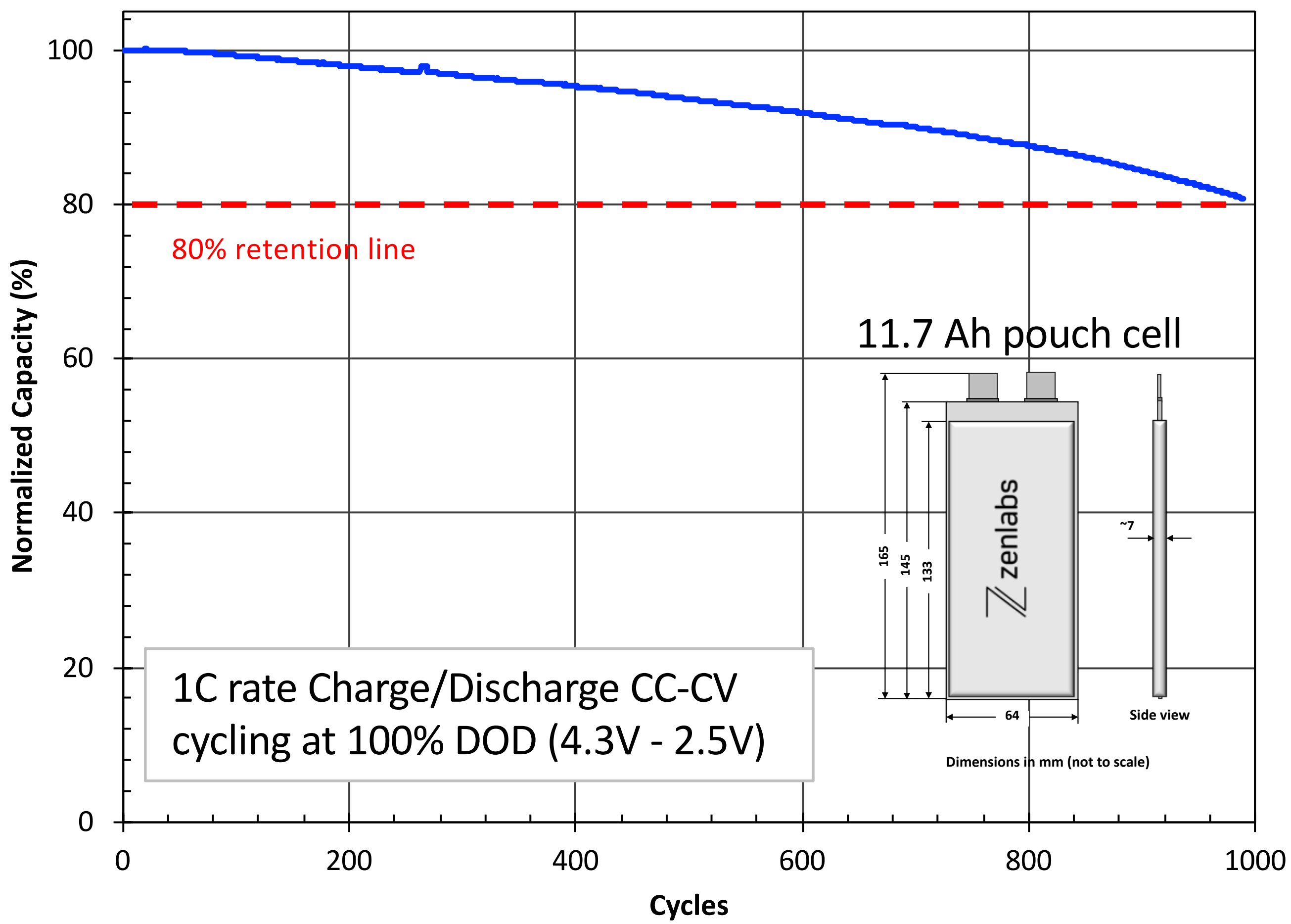
Technical Accomplishments: 1000 Cycles



- **Have achieved 1000 cycles** with 80% capacity retention from pouch cells (11.7 Ah, 310 Wh/Kg rated at C/3 rate) integrating high SiO_x (>50 %) containing anode and Ni-rich NMC cathode
- Cells were cycled at 100% DOD, 1C Charge/Discharge rate, 4.3 V - 2.5 V window

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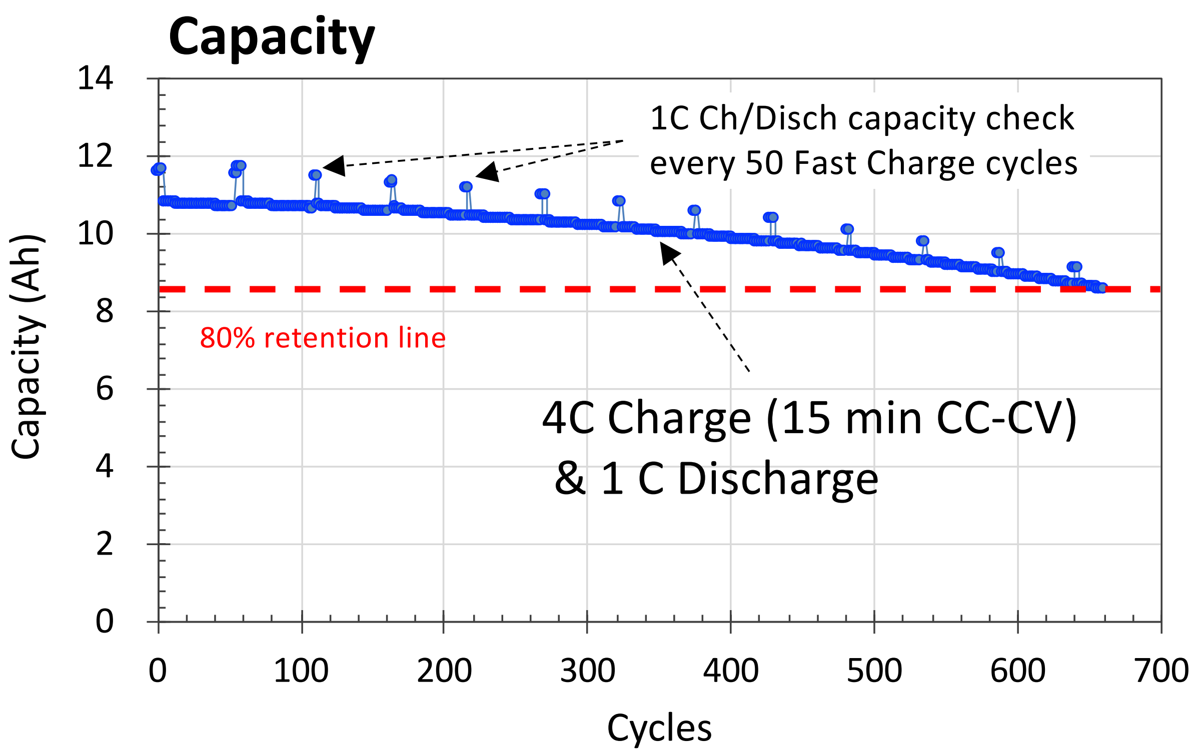
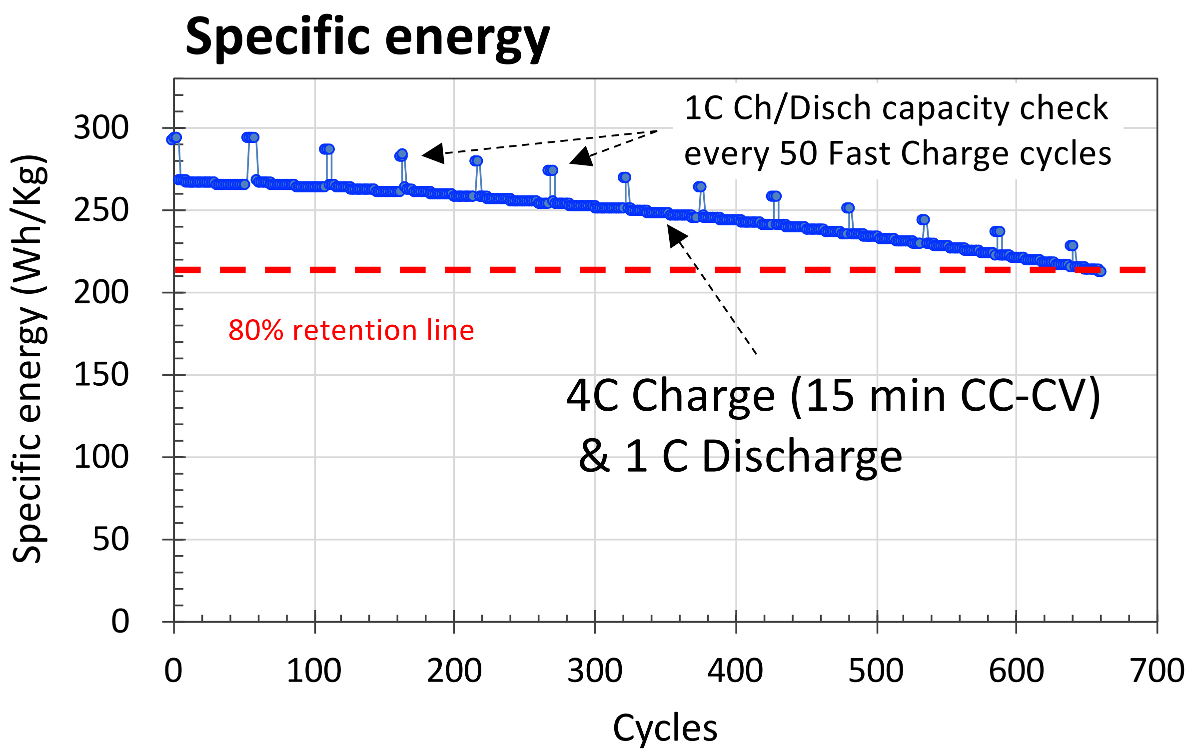
>600 Fast Charge Cycles





- **Have achieved >600 Fast-Charge cycles** (4C rate 15-minute CC-CV charge) with 80% capacity and energy retention from pouch cells (11.7 Ah, 310 Wh/Kg rated at C/3 rate) integrating high SiO_x (>50 %) containing anode and Ni-rich NMC cathode (target is 1000 fast-charge cycles)
- Cells were cycled at 100% DOD at a 4.3 V - 2.5 V window

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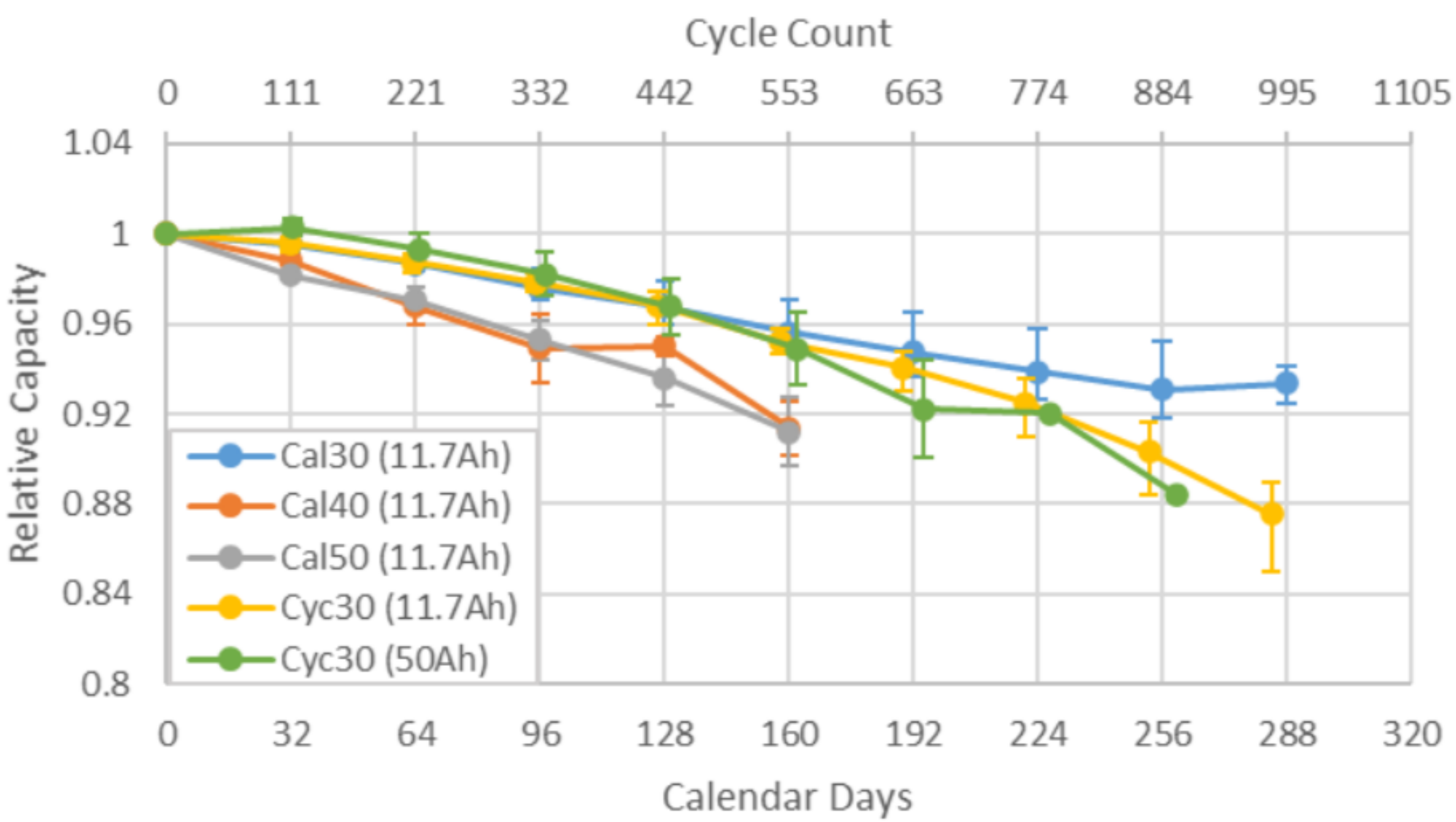
995 DST Cycles to 88% Capacity Retention



- Data was produced by INL, as part of the USABC contract

- **Have achieved 995 DST cycles** with 88% capacity retention from 11.7 Ah, 310 Wh/Kg pouch cells
- Have shown 288 days of calendar life storage at 30˚C with 93% capacity retention
- 11.7 Ah capacity cells were cycled and stored at 4.3V (100% SOC)

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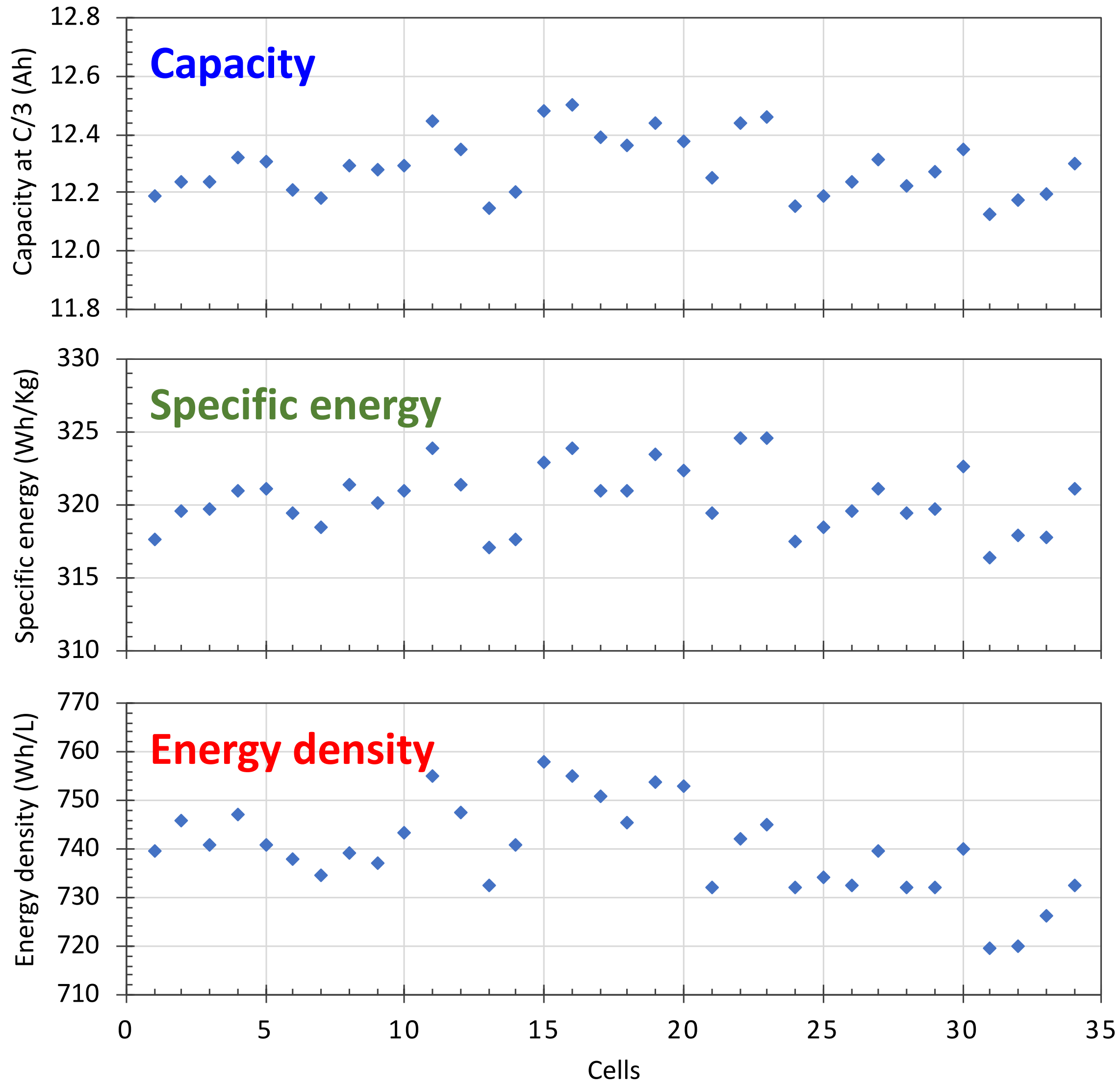
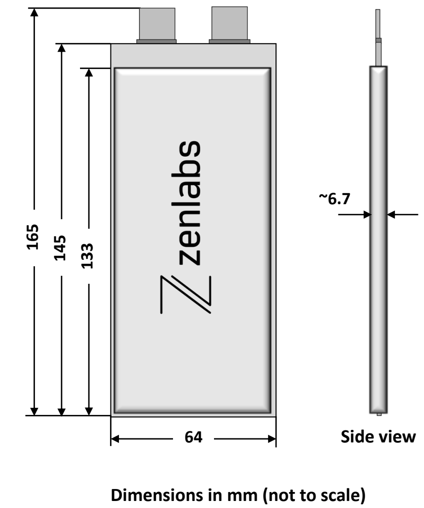
Baseline Cell Build #1 (CB#1) Deliverable



- 34 baseline 12 Ah capacity pouch cell from cell build #1 (CB#1) were delivered to the National Labs (INL, SNL, NREL) for independent testing



- The delivered CB#1 cells showed good reproducibility with an average C/3 rate capacity of 12.3 +/- 0.1 Ah, specific energy of 320.4 +/- 2.2 Wh/Kg and energy density of 739.9 +/- 9.5 Wh/L (without terrace)
- Testing is ongoing both at Zenlabs and the National Labs

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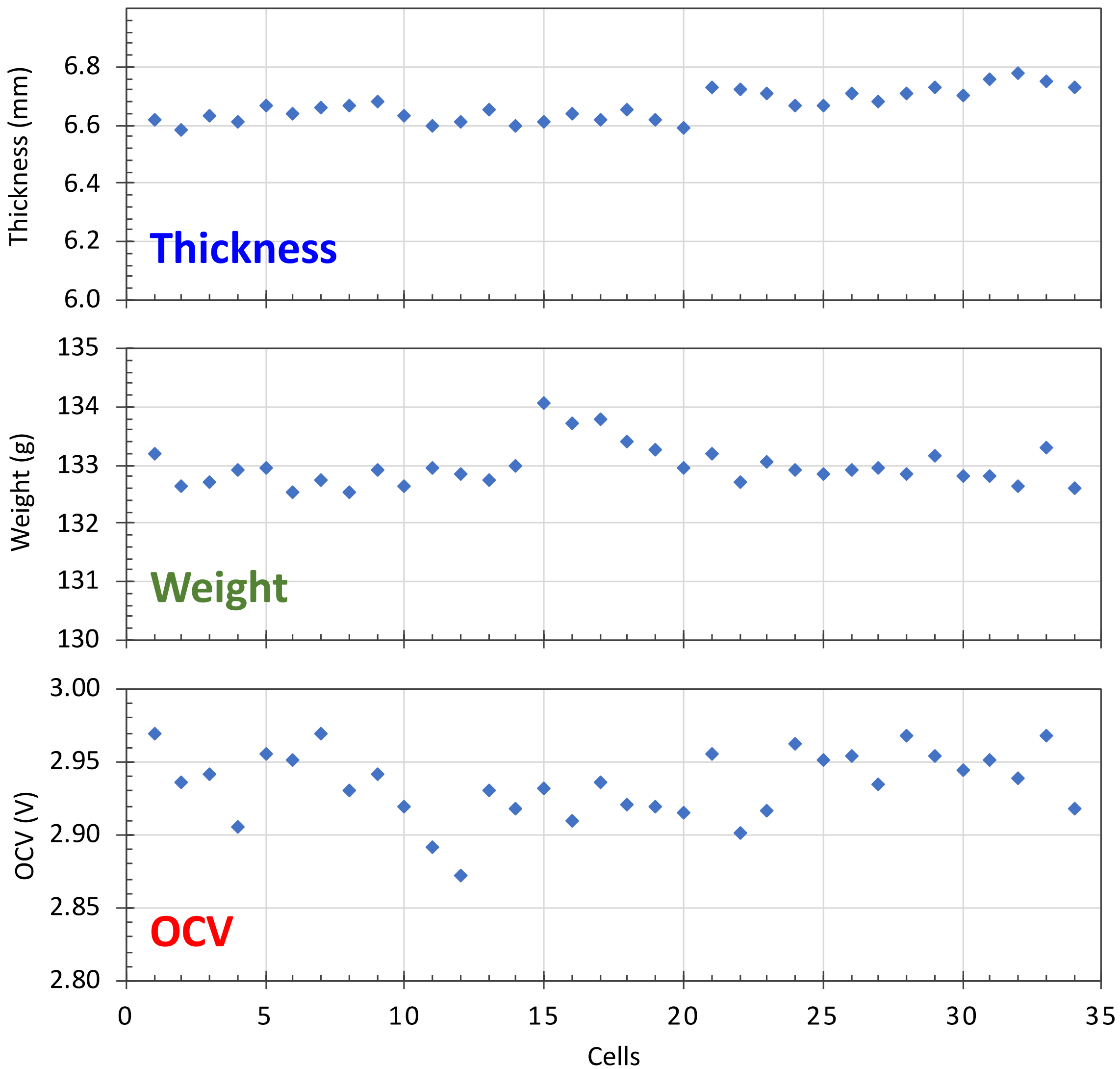
Baseline Cell Build #1 (CB#1) Deliverable



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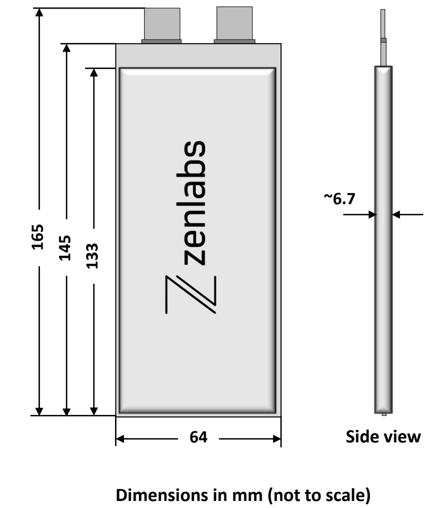

- The delivered CB#1 cells showed good reproducibility with an average cell thickness of 6.7 +/- 0.1 mm, 133.0 +/- 0.4 g and OCV of 2.935 +/- 0.024 V.
- Testing is ongoing both at Zenlabs and the National Labs

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Testing of CB#1 *(National Labs & Zenlabs)*

Baseline LC/FC CB#1 Deliverable 12 Ah cells (145 x 64 X ~6.7 mm)

INL

- 4x - 30°C CL
- 3x - 40°C CL
- 3x - 50°C CL
- 3x - DST (30°C) – 0% Fast charge
- 3x - DST (30°C) – 25% Fast charge*
- 3x - DST (30°C) – 100% Fast charge*
- 2x - DST (30˚C) with pressure monitoring at 0% & 100% Fast charge*
- 2x - Thermal performance, fast charge (FC) & self discharge

23 cells

SNL

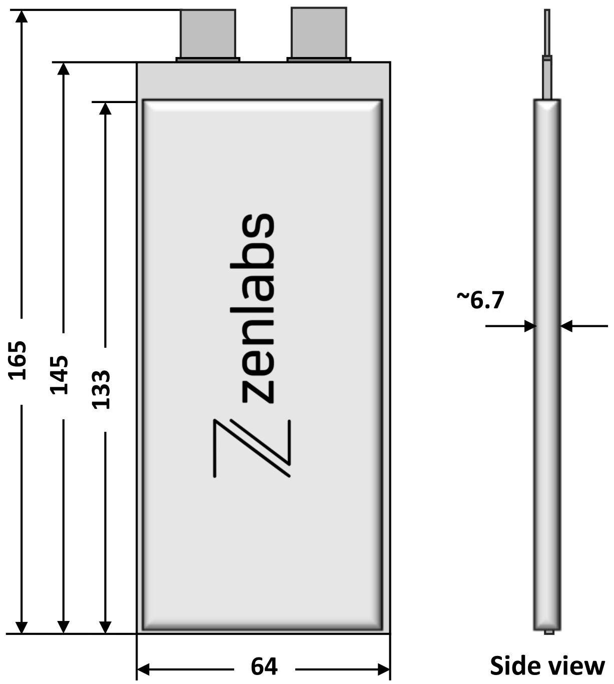
- 2x - Thermal ramp
- 2x - Overcharge
- 2x - Short circuit
- 1x - Nail penetration
- 1x – spare cell

8 cells

NREL

- 3x – Thermal performance

3 cells



Dimensions in mm (not to scale)

TOTAL 34 Cells

- Testing of cells is taking place both at the National Labs and Zenlabs

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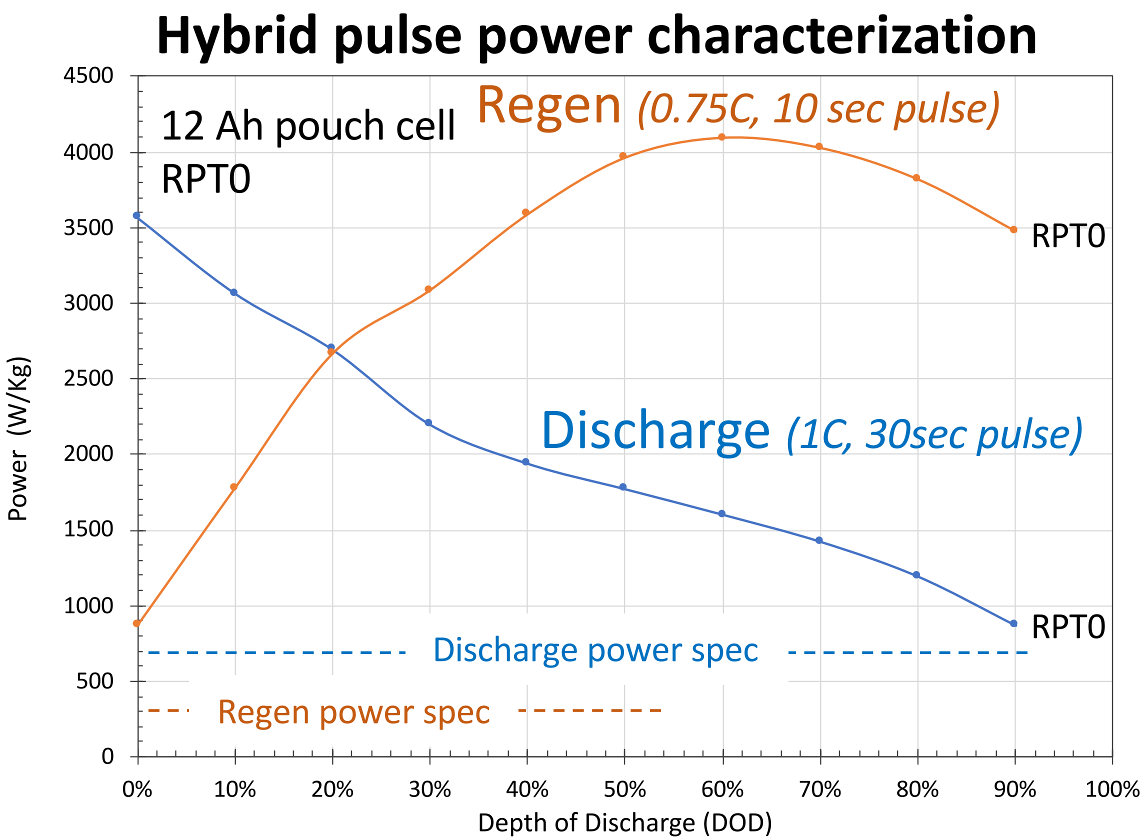
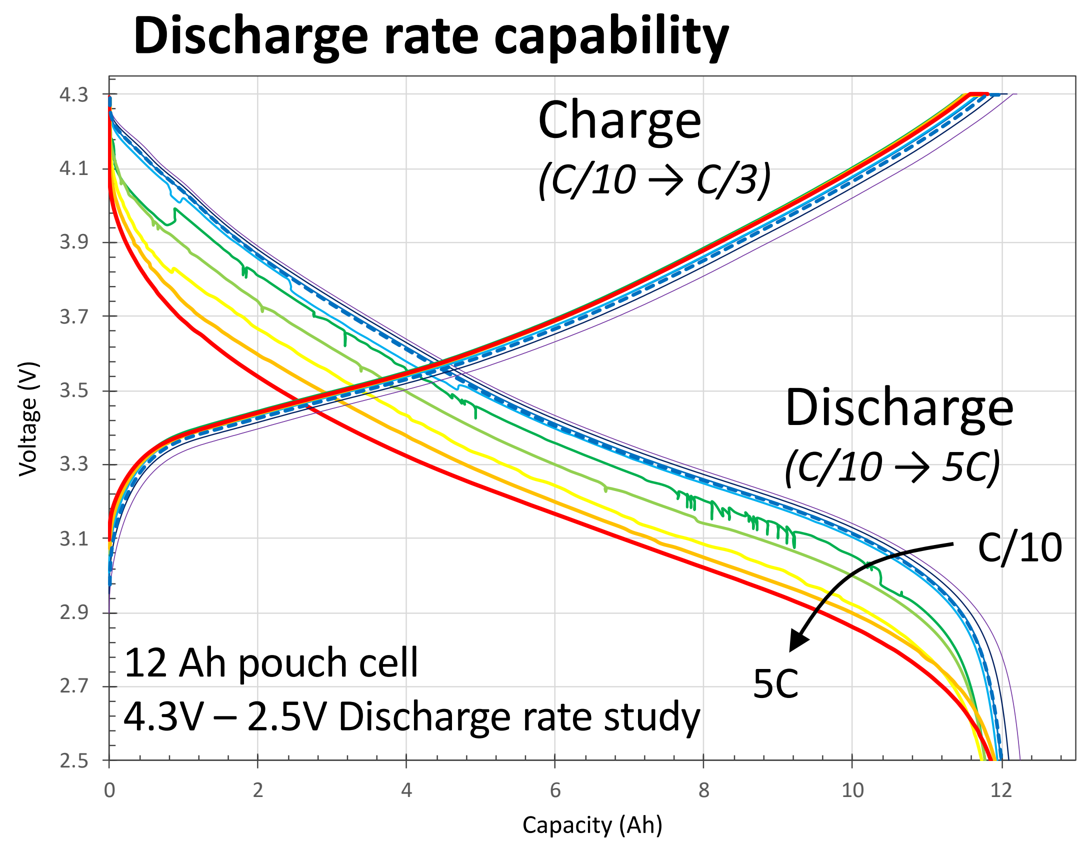
Power Characteristics and Rate Capability





- CB#1 cells are high power capable exceeding USABC power specifications. Cells also show good discharge (also charge) rate capability exceeding > 97% recovery of the C/3 capacity at 5C discharge rates. CL & DST cycling is ongoing

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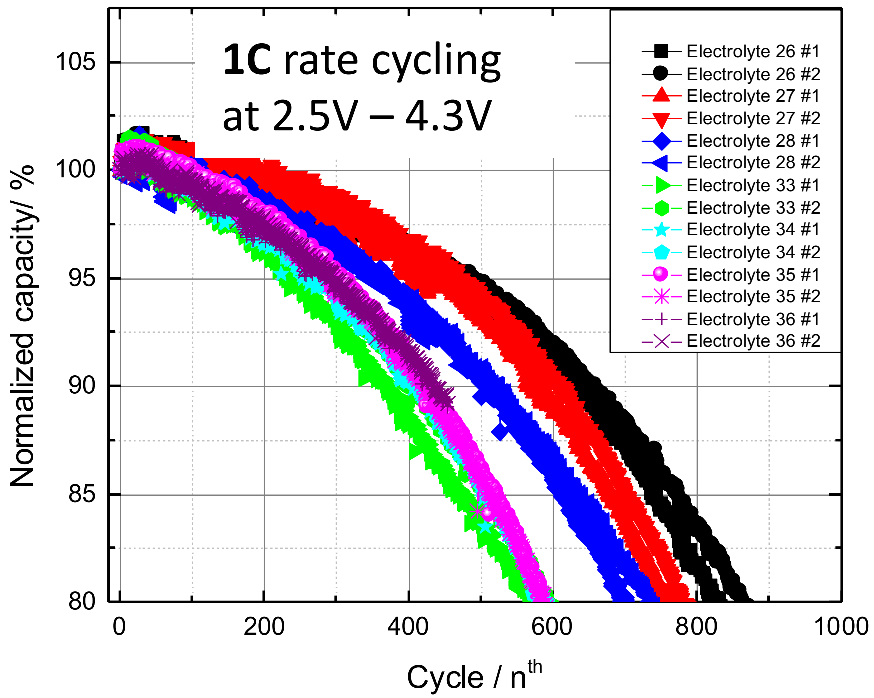
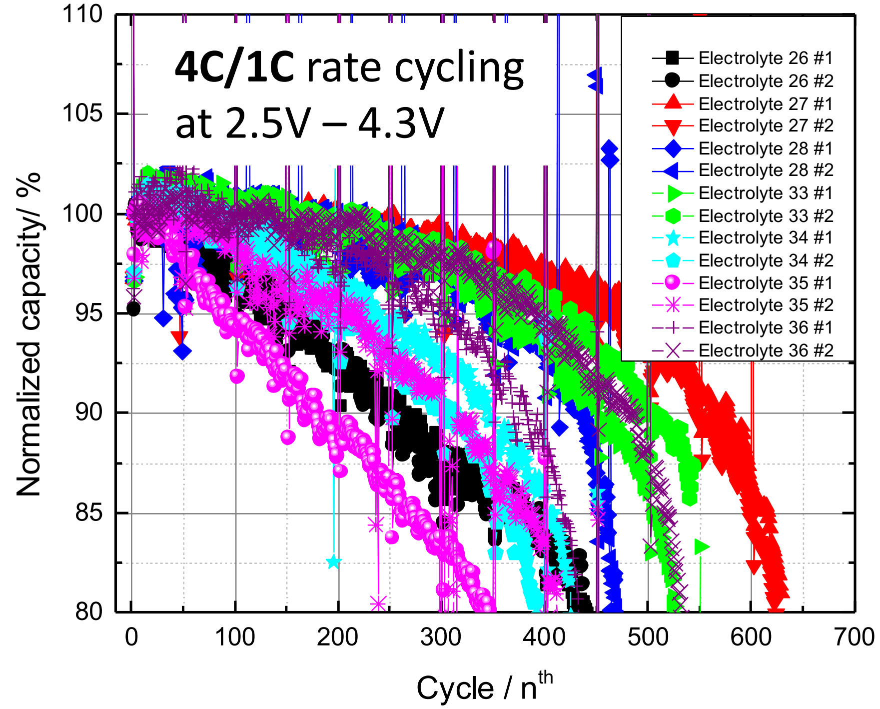
Electrolyte Development





Note: Cycling data collected from coin-cell full-cells using the identical design and active and passive components used in pouch cells

- Zenlabs is screening different electrolyte formulations that incorporate commercially available organic carbonate solvents, additives and salts to meet the Low-Cost and Fast-Charge USABC cell program targets
- Promising high conductivity and low viscosity electrolyte formulations (#27, #28 & #29 [not shown]) have shown reduced gassing, good rate capability, good cycle life (1C and 4C rate) and signs of improved calendar life. Results are being validate in large capacity pouch cells

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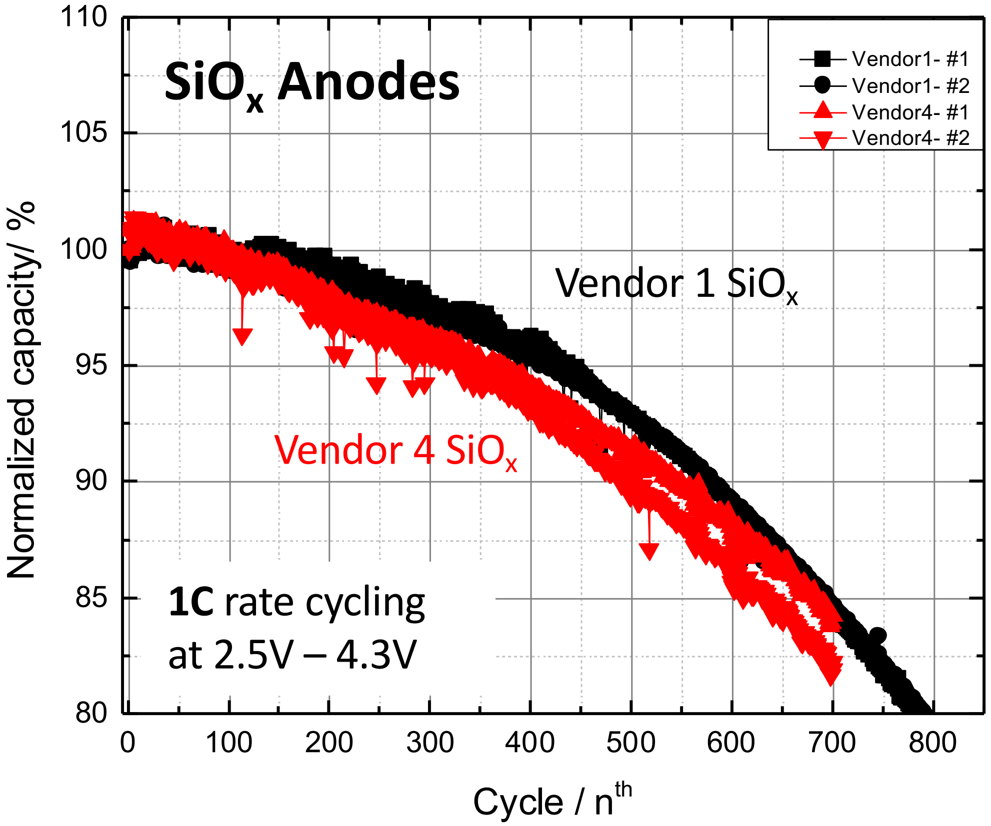
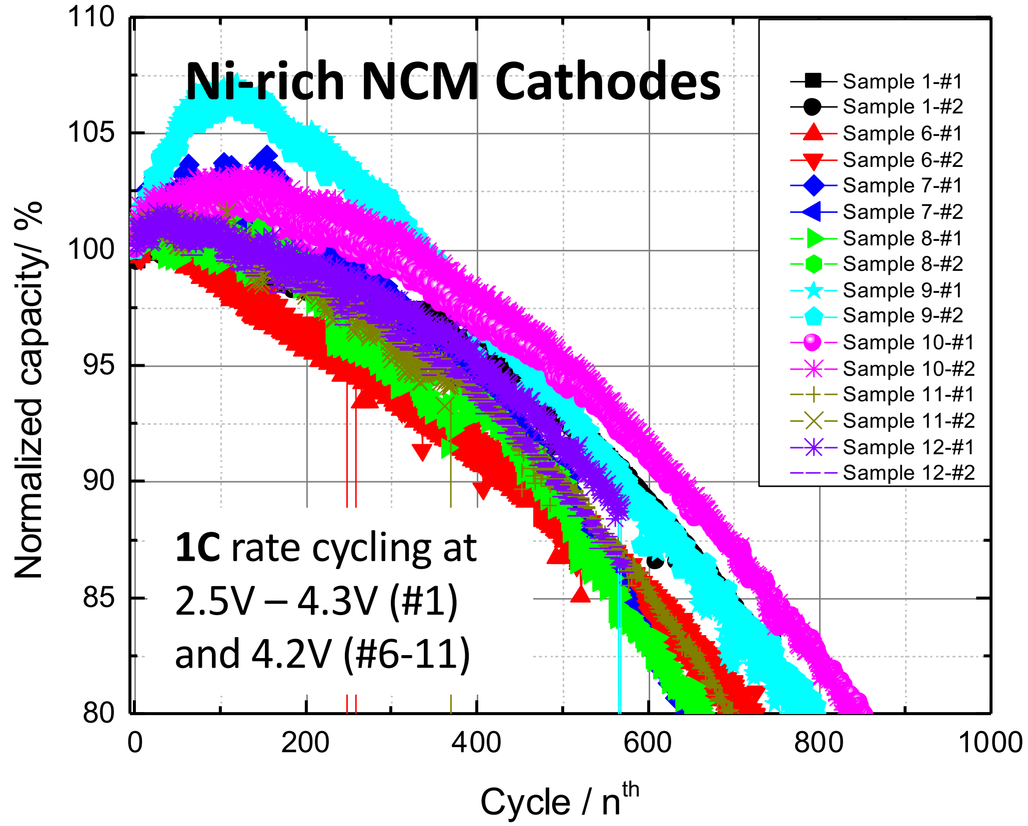
Active Material Development





Note: Cycling data collected from coin-cell full-cells using the identical design and active and passive components used in pouch cells

- Zenlabs has screened various types and sources of SiO_x anode materials and Ni-rich NCM cathode materials to further improve the cell performance and meet the low-cost and fast-charge cell targets. Down-selected anode and cathode materials are being integrated into large capacity pouch cells

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Responses to Reviewers Comments

- This is the first year that the project has been reviewed

Collaborations

- FCA, GM, Ford & DOE – Guidance and support on the technology development, cost model and cell specs & testing
- INL – Cell testing including energy, power, cycle life, calendar life, rate and high and low temperature performance
- SNL – Abuse testing including short circuit, overcharge, thermal ramp and nail penetration
- NREL – Thermal performance characterization including heat generation, cell efficiency and thermal imaging

Remaining Challenges and Barriers

- Meeting the calendar life (CL) targets from high energy silicon-based cells continues to be a significant challenge.
    - CL testing is time consuming requiring long periods of time to collect the data
    - Little is known about the factors that affecting CL in silicon-based cells
- Reducing cell gassing and improving the high temperature cell performance
- Optimizing cell design to meet the high energy, fast charge, and low-cost targets
- Developing a robust, manufacturable and cost-effective Pre-lithiation solution
- Continue to improve the reproducibility and automation of the cell prototyping facility of high capacity (> 50 Ah) large footprint (320 mm x 102 mm) pouch cells

Proposed Future Research

- Understand the mechanisms and identify and optimize the parameters that affect calendar life by testing electrolyte formulations, active materials & cell designs
- Evaluate and down-select the optimal electrolyte formulation to reduce gassing, improve CL and enhance safety while continuing to meet the USABC cell specs
- Down-select best high Ni NCM cathode, high capacity SiO_x-based anode and electrolyte formulation to meet the high energy, fast charge and low-cost targets
- Continue to work with equipment manufacturers to develop and optimize a robust, manufacturable and cost-effective pre-lithiation solution
- Continue to upgrade the cell prototyping facility of high capacity (> 50 Ah) large footprint (320 mm x 102 mm) pouch cells with the proper automated equipment

Summary

- Have demonstrated 1,000 cycles at 1C rate showing an 80% capacity retention at full 100 % DOD and 995 DST cycles to 88% capacity retention from ~310 Wh/Kg – 11.7 Ah silicon-based pouch cells
- Have shown excellent rate and fast charge capability with cells showing >600 continuous fast charge (15 minutes) cycles showing 80% capacity retention at full 100 % DOD from ~310 Wh/Kg – 11.7 Ah silicon-based pouch cells
- Have delivered baseline cell build #1 cells to National Labs and testing is ongoing
- Have identified promising electrolyte formulations integrating standard organic carbonate solvents, salts and commonly used additives that show improvements in gas generation, CL and safety while still meeting the cycle life, power, and temperature cell targets
- Continue to work with different pre-lithiation approaches to enable a robust, manufacturable and cost-effective pre-lithiation solution