2021 DOE Vehicle Technologies Office Annual Merit Review

All Solid State Batteries Enabled by Multifunctional Electrolyte Materials

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Project ID: BAT486

Overview

Timeline

- Project start date: October 2019
- Project end date: September 2022
- Percentage complete: 60%

Barriers

- Need a solid state electrolyte (SSE) enabling solid-state battery for EV
- Need scalable processes for solid state cell fabrication
- Need an EV battery capable of > 1000 cycles and > 350 Wh/kg

Budget

- Total project funding $1,250,000
  - DOE share: $1,000,000
  - Contractor share: $250,000
- FY 2020 funding: $430,000
- FY 2021 funding: $420,000

Partners

- University of California San Diego
- Project lead: Solid Power Inc.

RELEVANCE

Impact

- Development of a solid state electrolyte enabling high energy solid state batteries
- Fabrication of solid state battery cells in roll-to-roll processes
- Demonstration of large format solid state Li cells for the EV market

Objective

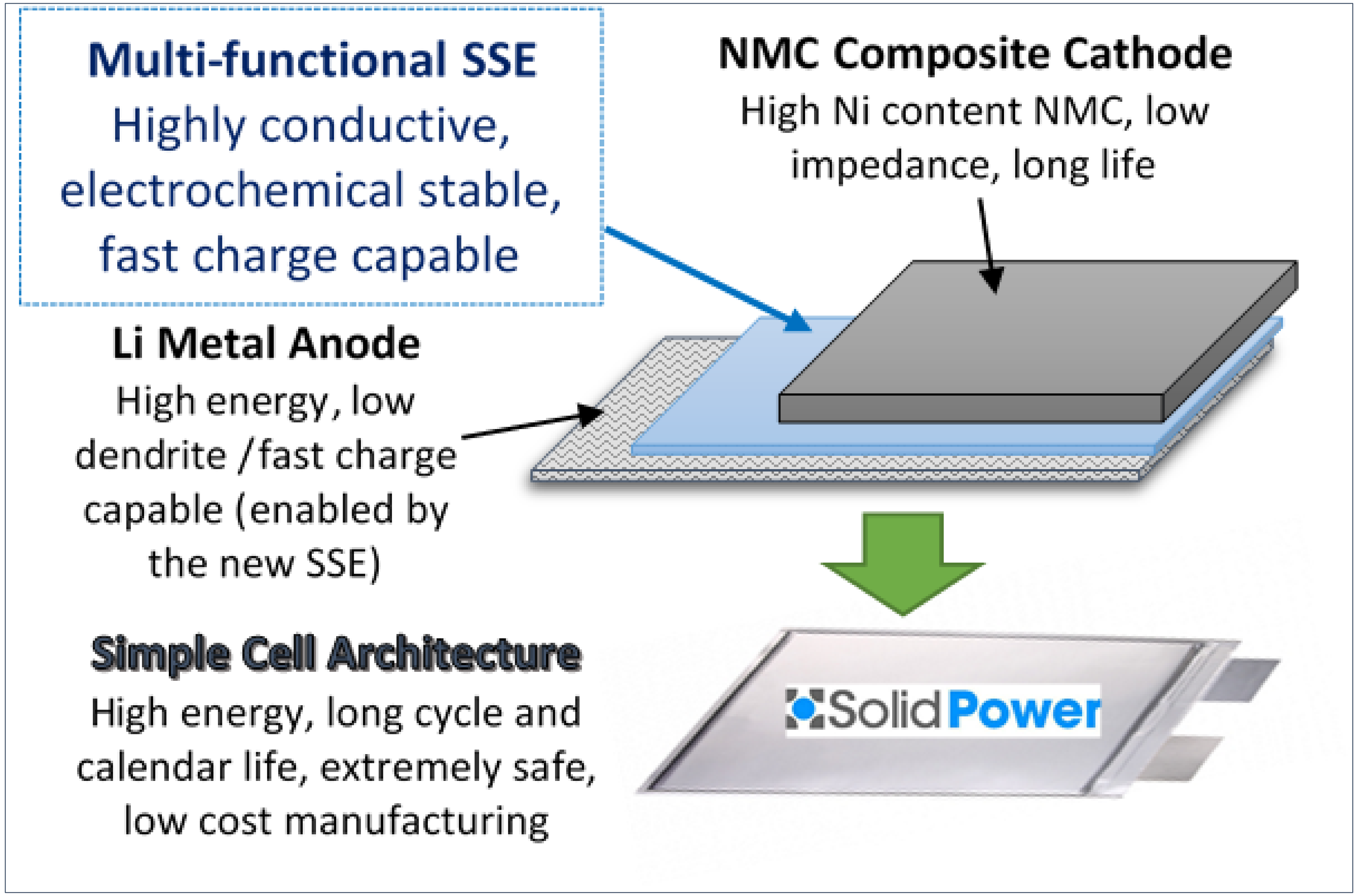
Develop solid state Li metal cells enabled by multifunctional solid state electrolytes for use in EVs

- —Cell capacity ≥ 2 Ah
- —Useable specific energy ≥ 350 Wh/kg
- —Cycle Life ≥ 1,000 cycles
- —Cost ≤ $100/kWh

MILESTONES

Month/Year	Description of Milestone or Go/No-Go Decision	Status
December 2019	Precursor and equipment secured	Complete
March 2020	Cathode down-selected	Complete
June 2020	Cathode loading ≥ 3.5 mAh/cm^2 demonstrated	Complete
September 2020	Go/No-Go: SSE ionic conductivity ≥ 3 mS/cm and full cell cycle life ≥ 200	Complete
December 2020	Solid state cell charge rate ≥ 0.5 C demonstrated	Complete
March 2021	Pouch cell ≥ 200 mAh fabricated	Complete
June 2021	SSE critical current density (CCD) ≥ 18 mA/cm^2 demonstrated	On Target
September 2021	Go/No-Go: SSE ionic conductivity ≥ 5 mS/cm and full cell cycle life ≥ 500	On Target

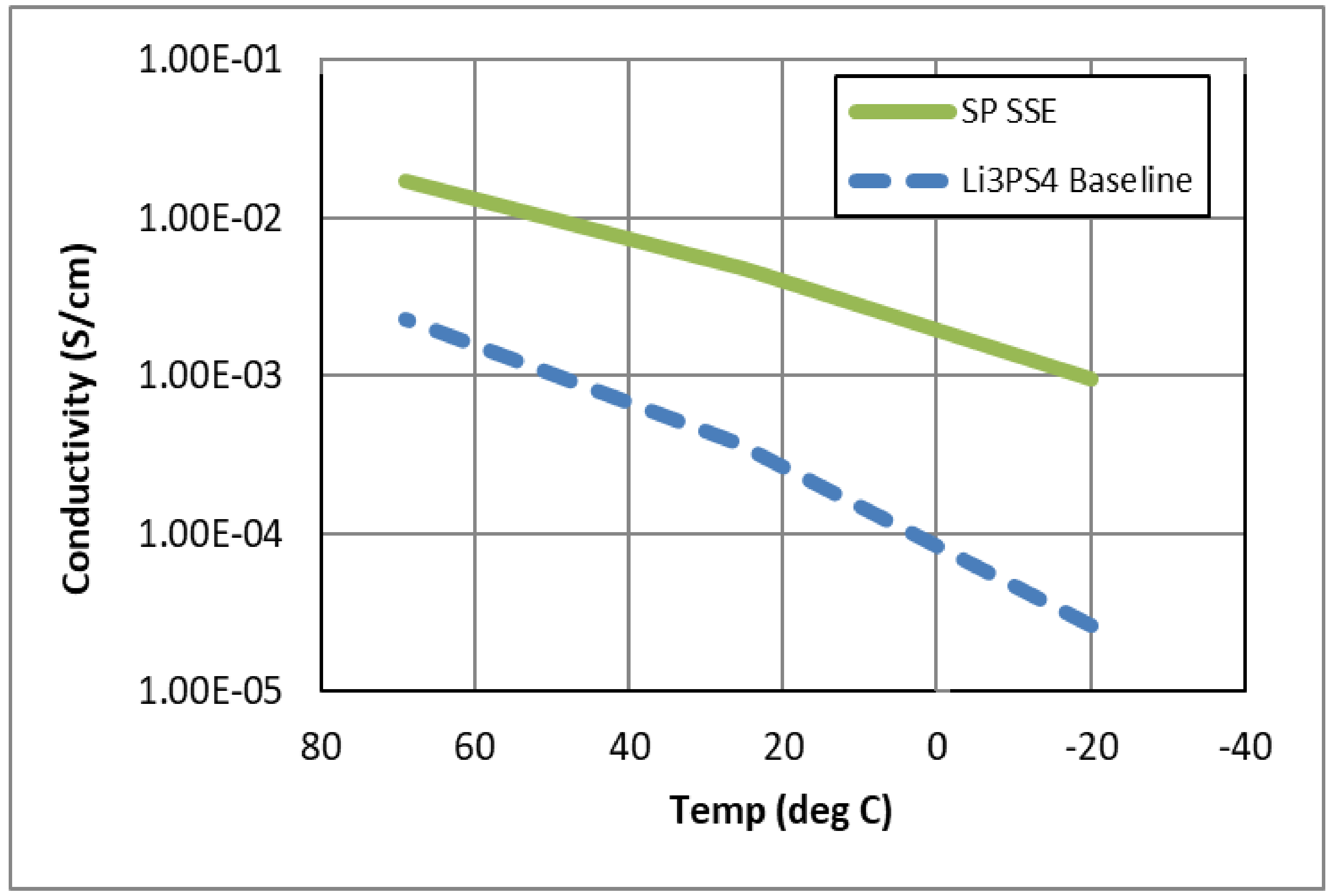
APPROACH



- Develop a **Multifunctional SSE**
  - high Li conductivity (up to 10 mS/cm)
  - high electrochemical stability (0 – 4.5V)
  - fast charge capability (2C)
  - large scale manufacturing process compatibility
- Apply Li metal anode and Ni-rich NMC cathode in the solid state cell for high energy density
- Adopt roll-to-roll process for solid state cell fabrication for low cost cell production
- Deliver solid state Li cell of ≥ 2 Ah for performance demonstration

- **Sulfide based SSE has been developed with high conductivity and stability**
  - It met the Year 1 targets and is on track of meeting Year 2 targets
  - Li ion conductivity of ***4.5 × 10^{-3} S /cm*** at 25 °C, 10 times higher than baseline LPS
  - Critical current density (CCD) ***> 6.0 mA/cm^2***, 5 times higher than baseline LPS

Li ion conductivity vs. temperature



Current status of conductivity and CCD

Parameter	Year 1 Target	Current Status	Year 2 Target
Conductivity (mS/cm)	≥ 3	4.5	≥ 5
CCD (mA/cm^2)	≥ 6	12	≥ 18

- **SSE separator film has been fabricated in a R2R mode**
  - The film was coated with a slurry-cast method
  - NMC cathode was also coated R2R
  - SSE was laminated to cathode to form a bi-layer film

SSE separator coated by a slot-die coater

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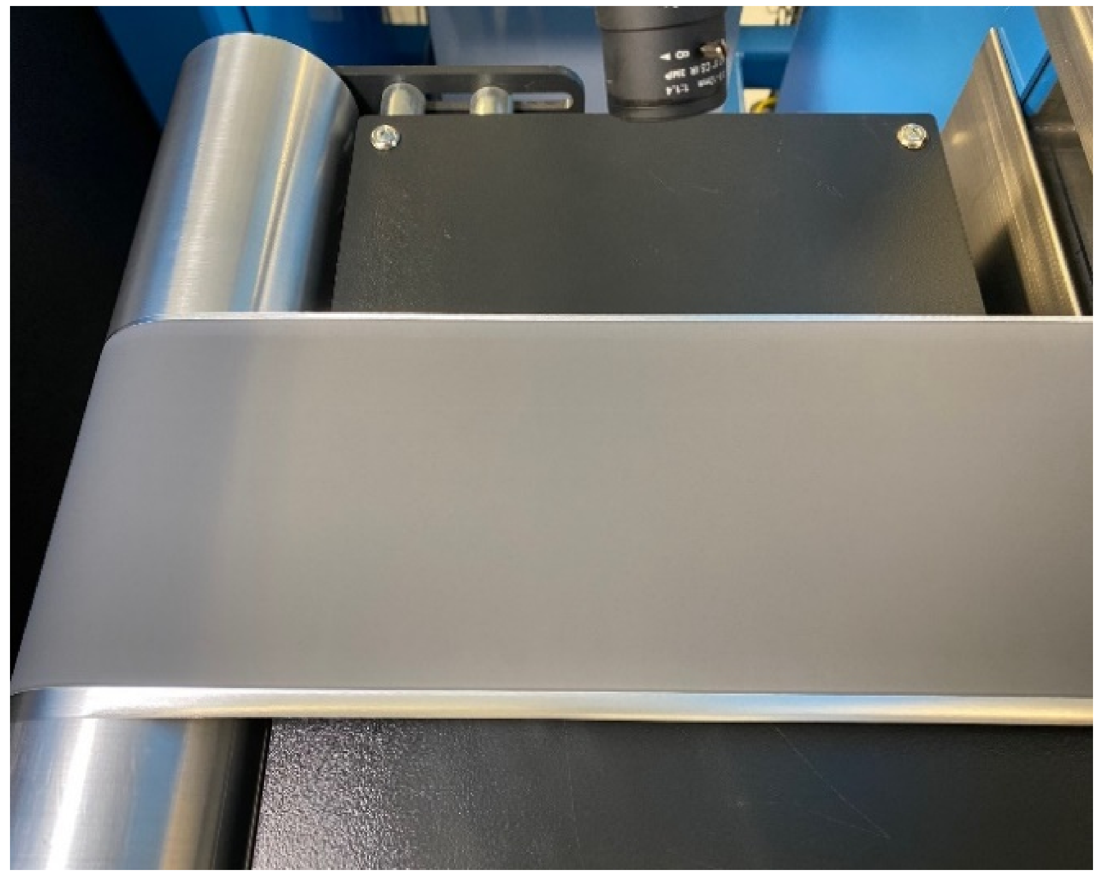

NMC cathode coated by a slot-die coater

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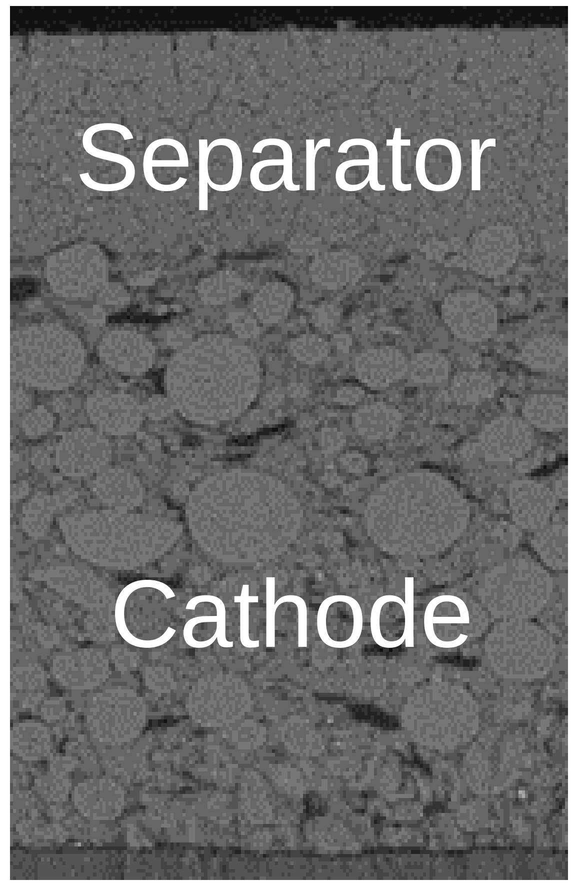


Bi-layer film formed by a lamination process

- **NMC/Li solid state pouch cell containing the multifunctional SSE has been demonstrated**
  - Baseline pouch cell ≥ 5 mAh was demonstrated in Year 1
  - Large format pouch cell ≥ 200 mAh has been successfully assembled and is under evaluation in Year 2
  - Final prototype pouch cell ≥ 2 Ah demonstration is on schedule in Year 3

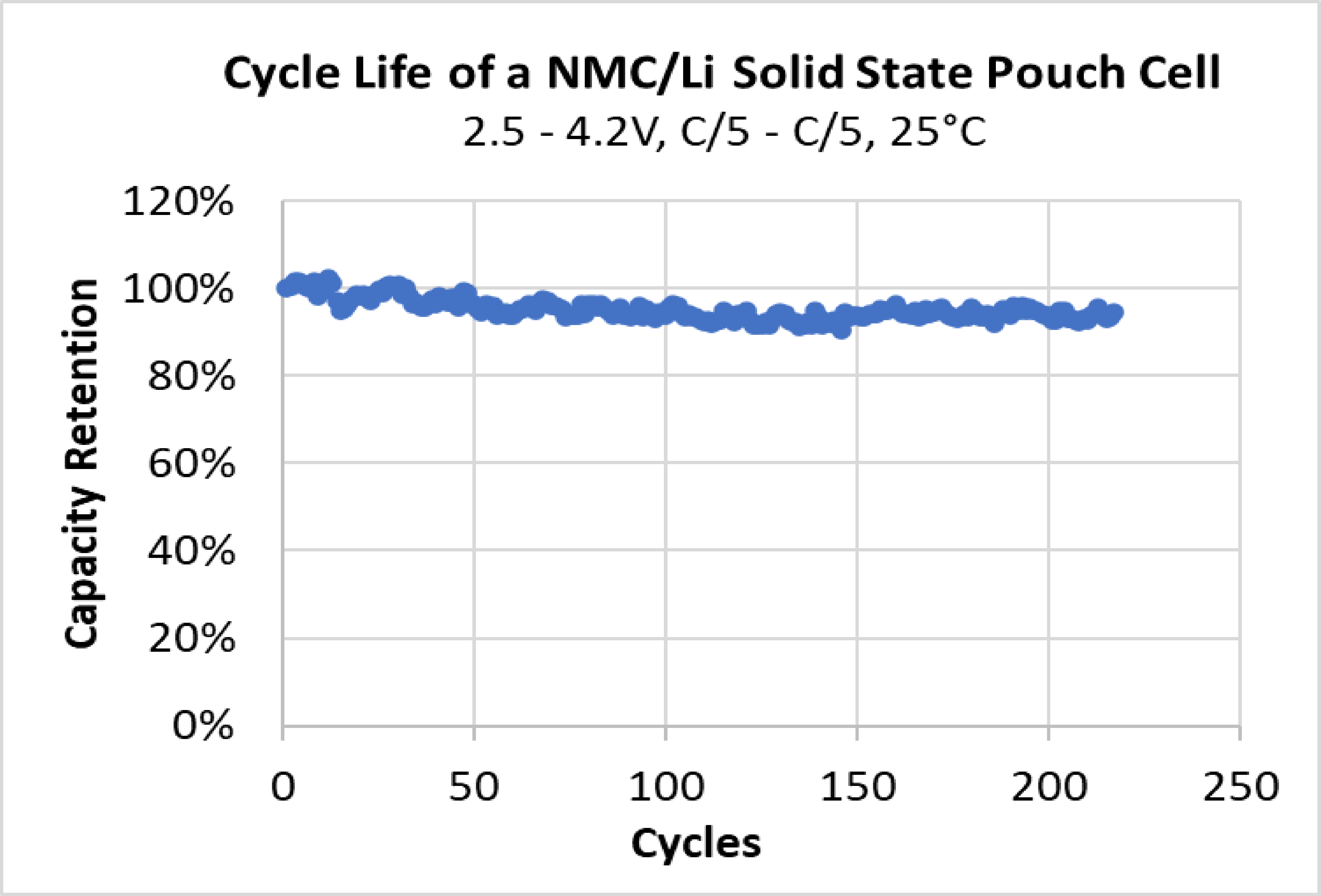
Baseline Pouch Cell

Interim Pouch Cell

Prototype 2 Ah Pouch Cell

Pouch cell cycle life ≥ 200 has been demonstrated

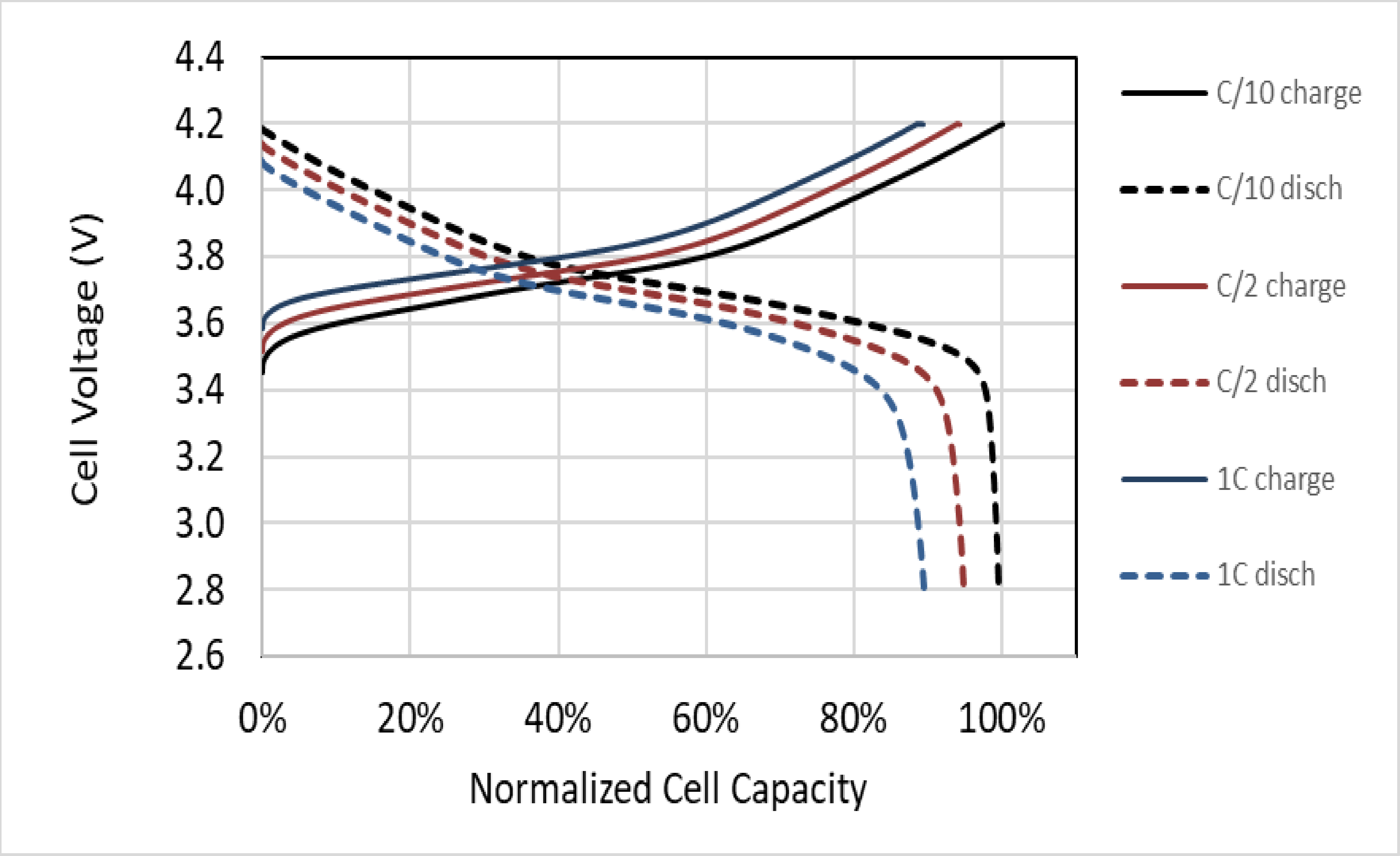
- Cell test
  - Lab pouch cell at 6 mAh
    - NMC622 cathode (at 3 mAh/cm^2)
    - 70 µm SSE separator
    - 35 µm Li anode
  - 2.8 – 4.2V, C/5 – C/5, and 25°C
- Cell performance
  - 93% capacity retention after 220 cycles
    - Met Q4 milestone of 200 cycles



* Capacity fluctuation is due to the ambient temperature change

Pouch cell rate capability has been demonstrated

- Cell test
  - Lab pouch cell at 6 mAh
    - NMC622 cathode (at 3 mAh/cm^2)
    - 70 µm SSE separator
    - 35 µm Li anode
  - 2.8 – 4.2V, +0.1C/-0.1C to +1C/-1C, 70°C
- Cell performance
  - 95% capacity retention at C/2, when compared to C/10
    - Met Q5 milestone of C/2 charge
  - Testing at lower temperatures in progress



Solid Power has established the pilot-scale capability at both material and cell levels

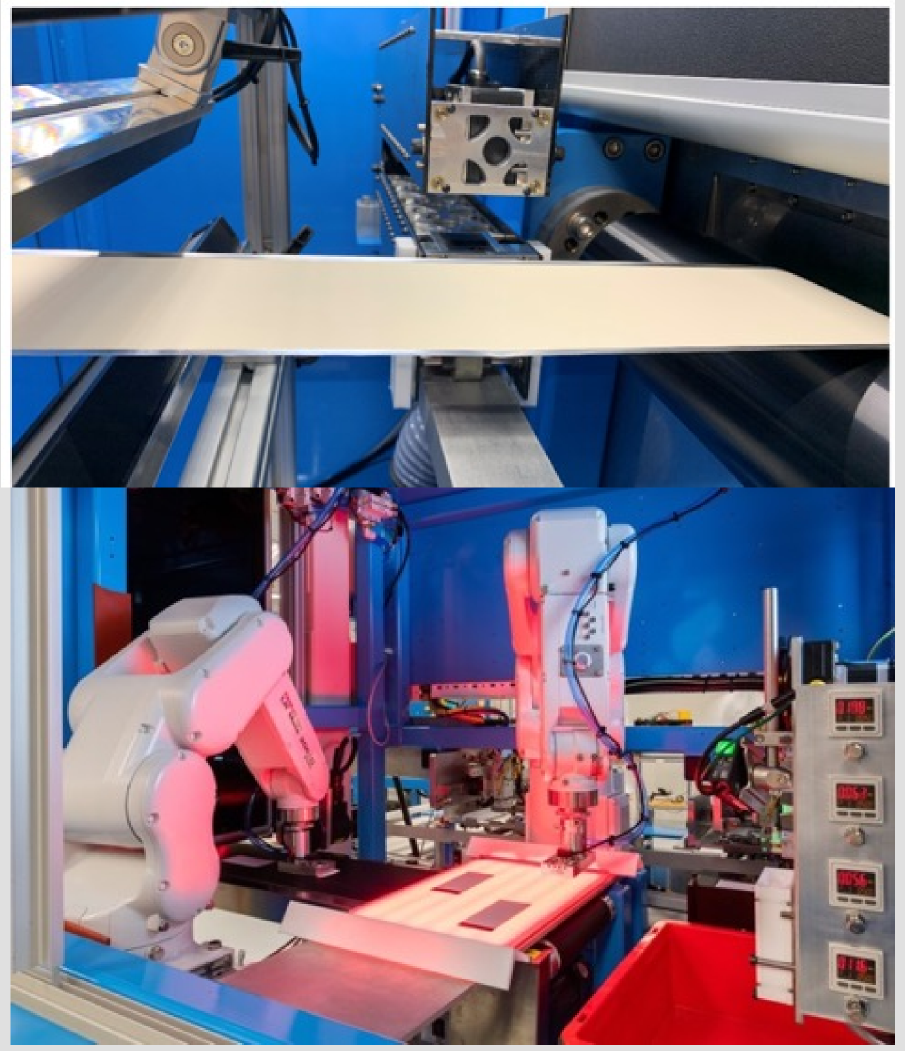
SSE Precursor

The SSE precursor developed in-house and via partners for low cost and optimized for mass production of electrolyte and cells

Electrolyte

Best all-around solid electrolyte materials produced using low-cost scalable processes

Production



Pilot scale production using the same equipment as conventional Li-ion to quickly enable low-cost GWh-scale production

Prototype Cell

Multi-Ah pouch cells deliver >50% energy advantage over Li-ion while also being inherently safer

Responses to Previous Year's Reviewers' Comments

This is the first year that the project has been reviewed

Collaboration and Coordination

- Solid Power Inc. (Prime; PI: Dr. Pu Zhang)
  – Material synthesis, process development, cell assembly, and cell test

- University of California San Diego (Subcontractor; PI: Dr. Shirley Meng)
  – Material characterization and cell failure analysis

Remaining Challenges and Barriers

- Achieving high rate capability and low temperature performance
  - Further improvement of the electrolyte conductivity and stability
  - Optimization of electrode and separator formulations for lower resistance
  - Further development of cell stack fabrication processes for optimized interfaces

- Understanding solid state cell performing mechanisms
  - Both chemical and mechanical changes during the cell operation
  - Cell failure modes
  - Engagement of industrial and academic partners

Proposed Future Research

- Demonstrate a solid state cell with 500 cycles in a 300 Wh/kg design by Q8
  - Electrolyte with improved stability → longer cycle life
  - Thinner separator ≤ 60 μm → higher specific energy and energy density
  - Lower resistance cell → cell operation at room and lower temperatures

- Deliver a prototype pouch cell ≥ 2 Ah with 1000 cycles, 350 Wh/kg by Q12
  - Optimized electrolyte → cycle life ≥ 1000
  - Separator ≤ 40 μm → specific energy ≥ 350 Wh/kg
  - NMC with >80% Ni content (validation pending) → potentially ≥ 400 Wh/kg

Summary

- The team met all the Year 1 targets and is on track of meeting Year 2 targets
- A multifunctional electrolyte was developed with a Li ion conductivity of 4.5 mS/cm at 25°C
- The SSE separator and electrodes were fabricated in a R2R mode
- A solid state Li metal pouch cell has been demonstrated and the cell retains 93% of initial capacity after 200 cycles
- Pilot scale production capabilities have been established for both the electrolyte synthesis and large format cell assembly within Solid Power

Thank You!