# Solvent-free and Non-sintered 500 Wh/kg All Solid-State Battery

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*Navitas Advanced Solutions Group*

**Project ID: BAT451**

June 3, 2020

2020 DOE Vehicle Technologies Office Annual Merit Review

# Overview

## Timeline

- Project start: Oct. 2017
- Project end: June 2021
- Percent complete: ~70%

## Budget

- Total project funding: **$1.34M**
  - DOE Share: $1,025k
  - Contractor Share: $312k
- Funding for FY2019: **$310k**

## Partners

- University of Maryland
- Oak Ridge National Lab
- **Project lead: Navitas**

## Barriers

- Low ionic conductivity and air stability of solid-state electrolyte (SSE) limit SSB application
- Lack of large scale and low-cost solid-state battery (SSB) processing
- Low SSB performance due to unstable interphases of cathode/SSE and SSE/Li

# Relevance

## **Impact:**

Demonstrate a fabrication method for all solid-state Li-ion battery to support Battery 500 program with similar performance to liquid-based systems but has:

- Higher cell energy density due to high-quality thick cathode enabled by dry process;
- Much lower cost through solvent-free electrode and non-sintered, stabilized sulfide SSE process;
- Improved safety due to usage of optimized solid-state electrolyte and strategies for stabilized interphases.

## **Objectives:**

- The program aims to demonstrate a solvent-free and roll-to-roll fabrication process to enable large format solid state batteries incorporating stabilized sulfide solid-state electrolytes (SSE), high capacity cathodes and protected lithium metal anodes, that can deliver 500 Wh/kg specific energy and achieve life of 1000 charge/discharge cycles.

# Milestones

## Phase II (July 2019 – June 2021):

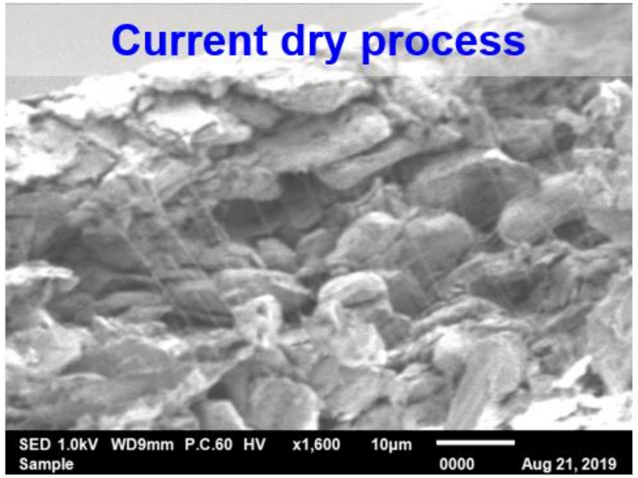
| Month/Year | Milestone or Go/No-Go Decision Point | Status |
|---|---|---|
| October 2019 | **1-1.** Solid-state electrolyte: air stability >4h, ionic conductivity >0.5 mS/cm | **Complete** |
| July 2020 | **1-2.** Solid-state electrolyte: further improve air stability and ionic conductivity **(Go/No-Go)** | On schedule |
| September 2020 | **2-1.** Cathode process down-selection | On schedule |
| December 2020 | **2-2.** 500g cathode powder production | On schedule |
| December 2020 | **3.** Thin Li anode, Li protection method verification | On schedule |
| April 2020 | **4-1.** Cathode loading > 3 $mAh/cm^2$ | **Complete** |
| December 2020 | **4-2.** Large area and ultrathin SSE film | On schedule |
| July 2020 | **5-1.** Preliminary cells assembled **(Go/No-Go)** | On schedule |
| March 2021 | **5-2.** 2.5 Ah pouch cell demonstrated | FY21 |
| June 2021 | **5-3.** 12 Final test cells delivery | FY21 |
| March 2021 | **6-1.** 500 Wh/kg cell demonstrated | FY21 |
| June 2021 | **6-2.** Cycle life ≥ 1000 | FY21 |

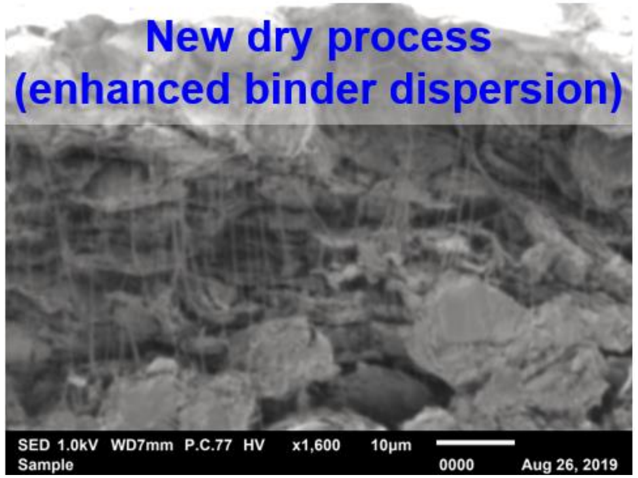
# Approach

- **<u>Address Material Limitations:</u>**
  - Increase SSE ionic conductivity by modifying structures and additives
  - Increase SSE air stability by additives
  - Increase cell energy by high loading cathode and thin SSE
  - Surface protection on both cathode and Li anode for longer cell cycle life

- **<u>Address Process Challenges:</u>**
  - Optimize dry process for thick electrodes and thin SSE to increase cell specific energy
  - Optimize dry process for large scale battery fabrication and low cost (2.5Ah Pouch Cells)
  - Non-sintered SSE to simplify battery fabrication and lower the cost

# Accomplishments

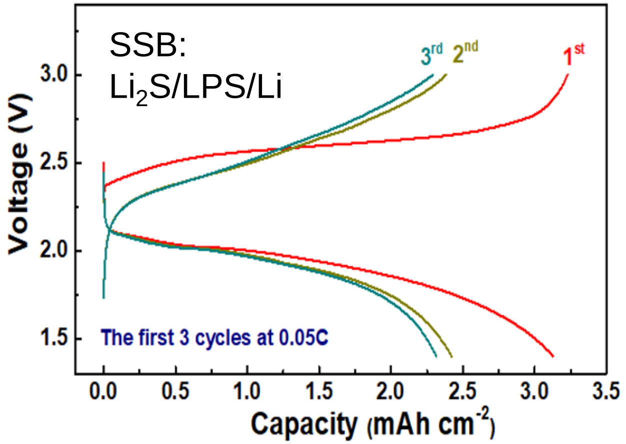



- **Advanced dry electrode process** with high-throughput and enhanced binder dispersion (left bottom) comparing to current dry process (left top) to lower binder content for higher ionic conductivity and high tensile strength.
- **Coming new DOE project** (>$5M) on electrode process that initially supported by and will benefit Battery 500 program.
- **Patent application, Mar. 2020:** New dry electrode processing technology for higher battery performance and lower cost.

## Other Technical Accomplishments:

- **SSE:** ionic conductivity >0.5 mS/cm, stable in dry room >4h
- **Li anode protection** via wet chemistry or PVD that prevent Li dendrite growth
- **Cathode** (NMC811 and $Li_2S$) high loading for SSB



## Responses to Previous Year Reviewer's Comments

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

## Collaborations and Coordination

**University of Maryland (Sub)** (C. Wang, S. Liu, J. Chen)

- Optimization of solid-state electrolyte (conductivity, stability)
- Demonstrate solid-state battery chemistry
- Li anode protection by wet chemistry (Li-F rich SEI)

**Oak Ridge National Laboratory (Sub)** (D. Wood, J. Li)

- Thin Li anode preparation
- Li anode protection by PVD

**Navitas Advanced Solutions Group (Prime)** (M. Wixom, B. Li, P. Zhang, R. Sosik, J. Hopkins, M. Soueid, J. Seong)

# Remaining Challenges and Barriers

- 500 Wh/kg target requires ideal condition of all components, such as high capacity cathode, thin SSE and stable interphase, which is very challenging.
- Long cycle life is difficult to achieve for SSB with thick cathode.
- Scalable fabrication of ultrathin sulfide SSE film technically is very difficult. A stable SSE, a proper binder content and dispersion are required to retain a balance of high ionic conductivity and film mechanical strength.

# Proposed Future Research

- **<u>FY20:</u>**
  - Increase SSE conductivity and air stability
  - Optimize cathode and SSE formulation for balance of long cycle life and film strength
  - Initial test of preliminary pouch cells
- **<u>FY21:</u>**
  - Scalable dry process of cathodes/SSE/Li stack towards 500Wh/kg pouch SSB
  - Improve interphase stability of cathode/SSE, Li/SSE for long cycle life
  - Assemble, test and optimize 2.5Ah pouch SSB

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

# Summary

- **Accomplishments:**
  - Optimized solid-state electrolyte with higher ionic conductivity and air stability that suitable for industry process.
  - Optimized dry electrode process with enhanced binder dispersion and lower cost.
  - Fabrication of SSB with high-loading cathode and stabilized interphases.
- **Technical highlights:**
  - We have developed a high-throughput dry electrode process with enhanced binder dispersion and lower cost. (US Patent application, 2020)
- **Impact toward VTO Objectives:**
  - This project will demonstrate a high energy density solid-state battery with feasibility to scale up to support Battery 500 program.
  - The advanced dry electrode process can significantly reduce the cost of both solid-state batteries and liquid-electrolyte batteries.