SAFT-USABC 12V Start-Stop Phase II
2017 DOE Annual Merit Review

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Project ID: ES291

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Overview

Timeline

- Start date: 23 June 2015
- End date: 31 Dec 2017
- Percentage complete*: 73%

Barriers

- Cold cranking at -30°C
- High-temperature stability
- Control gassing

Budget

- Total program funding: $6.1M
  - DOE share: $3.05M
  - Contractor share: $3.05M
- Funding for FY16: $2.3M

Partners/Collaboration

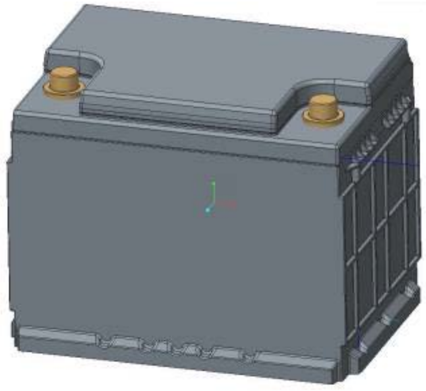
- SAFT Cockeysville, SAFT Bordeaux, INL, Soulbrain, ForgeNano
- Project lead: SAFT Jacksonville

* As of April 2017

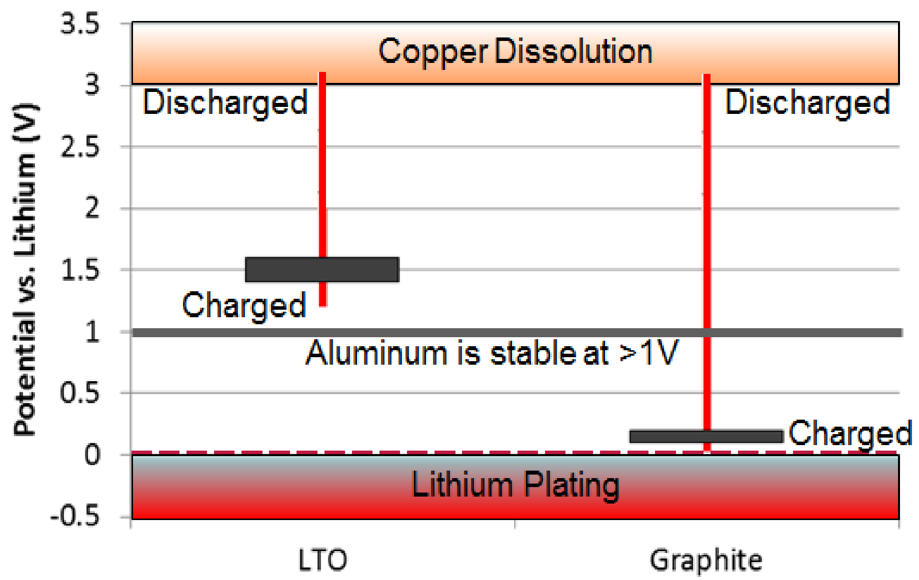
Objectives

Develop advanced, high-performance battery module for 12V Start-Stop (12VSS) vehicle application:

- Develop cell electrochemistry based on SAFT's proprietary lithium titanate (LTO) lithium-ion battery technology and work undertaken in the Phase I development project with USABC
- Design and develop cell and module to meet USABC energy and cost targets
- Develop battery management and electronic controls
- Deliver cells and 12V test modules to USABC



Approach – Chemistry Based on LTO



Pros:

- No solid electrolyte interface (SEI) formation (ideally)
- Very fast charge capability (>7C)
- Storage and shipment at 0V

Cons:

- High-temperature durability issues
- Excessive gas generation
- High impedance growth
- Low energy density

Strategy to Meet USABC Electrochemistry Target

Optimize electrode and electrolyte formulation to stabilize electrode/ electrolyte interface without compromising cold crank at -30°C

LTO anode

Li^+ ⇄

LMO cathode

1.Cold crank

High ionic conductivity
+
Chemical stability

2. Gassing

- Moisture in components

→ **Proper drying protocols**

- Electrolyte reduction (~1.5V)
- Crosstalk: migration of transition metals and/or oxidized species from positive electrodes
- Absence of stable SEI

→ **Electrolyte additives, barrier layer coating, optimized electrode design**

3. Impedance growth

- Formation of surface layer (SEI or cathode electrolyte interface) due to electrolyte oxidation

→ **Electrolyte additives, surface coatings**

- Loss of intra particle and inter particle contact due to volume expansion

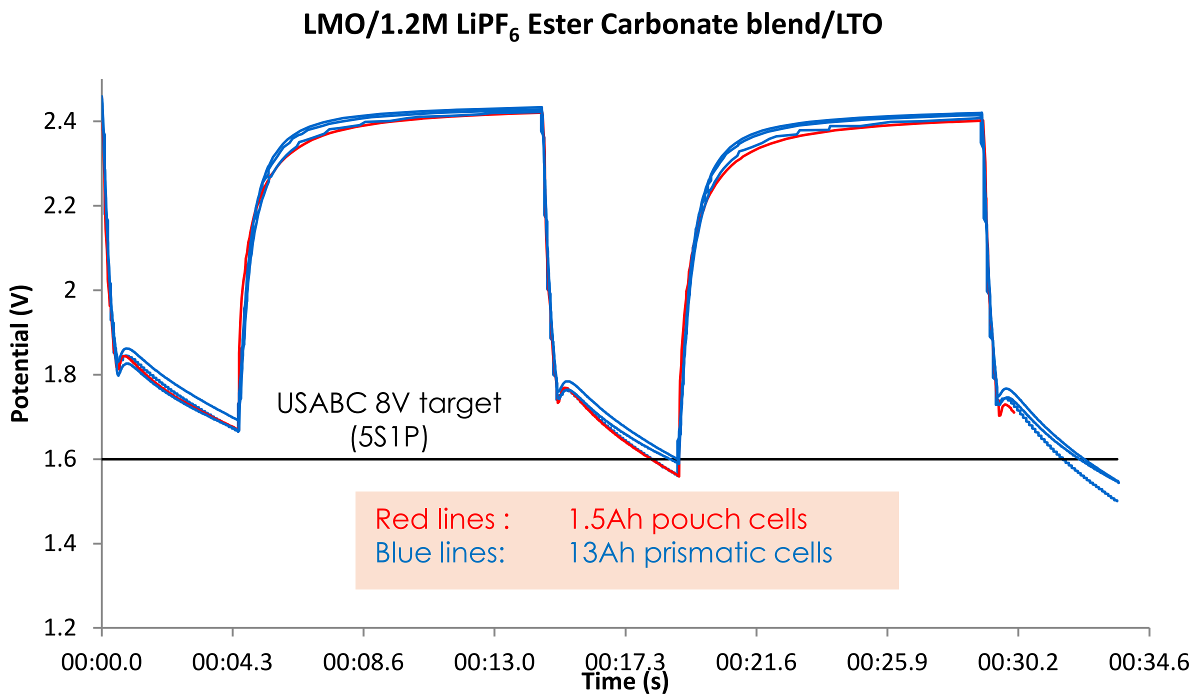
→ **Optimize electrode formulations and active material structure**

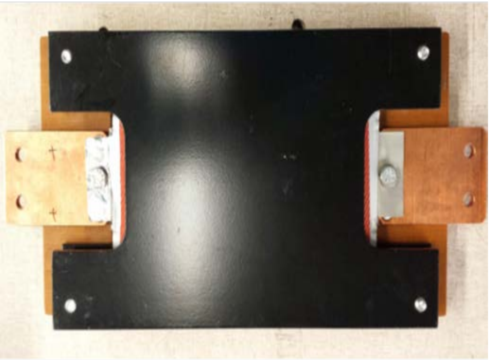
Technical Accomplishments

- **Electrochemistry development**
  - Delivered 1st set of cells to USABC (June 2016) and tested for cold crank and life performance (calendar & cycle life) for under hood condition (SAFT and Idaho National Laboratory (INL))
  - Electrode development
    - Optimized LTO formulation to improve cold crank performance resulting in lower gassing rate compared to first deliverable cells – finalized formulation for 2nd deliverable cells
  - Electrolyte development
    - Evaluated electrolyte solvent, salt mixture to find high conductivity, high boiling/flash point
    - Investigated impedance growth mitigation via film-forming additives
- **Mechanical/Module development**
  - Completed thermal analysis to simulate cell temperature under high temperature storage
  - Completed cell swelling testing
  - Completed 46Ah cell design
- **Electronic development**
  - Evaluated and down-selected suppliers for cost-effective battery monitoring system that provides voltage measurement, temperature measurement, cell balancing and data communication

Progress: 1st Cell Deliverables to USABC – Cold Crank

1.5Ah pouch cell and **13Ah** prismatic cell with lithium-ion manganese oxide (LMO)/LTO chemistry were delivered to INL



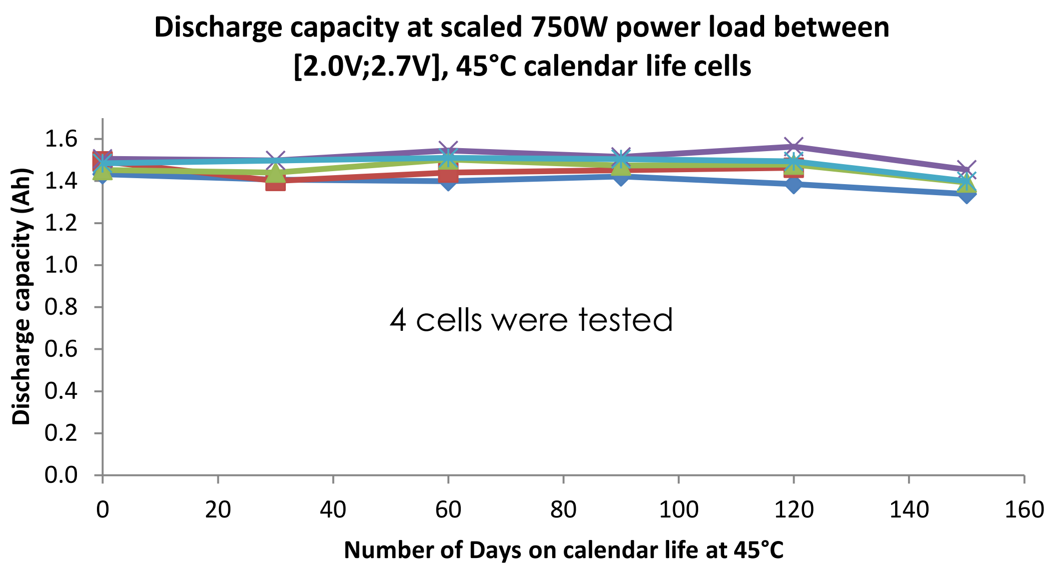


1.5Ah pouch cell

13Ah prismatic cell

- **Cold cranking (0.5s of 6kW pulse and 4s of 4kW pulse) after removing 360Wh (scaled) at -30°C, cells did not pass three complete cold crank pulse series**
- **No significant difference between formats**

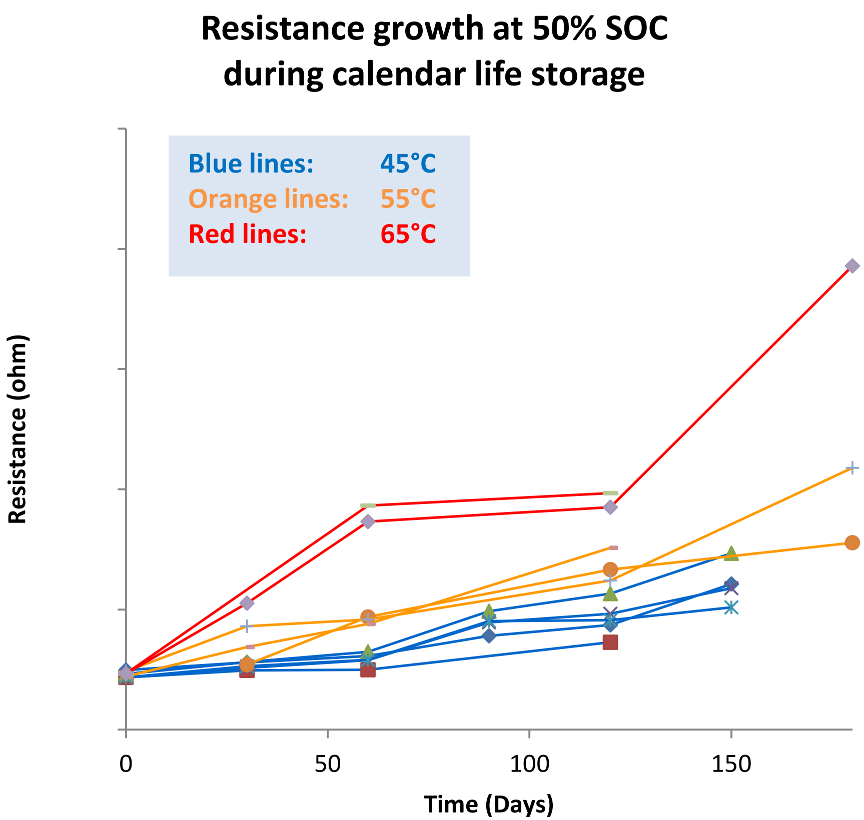
Progress: 1st Cell Deliverables – Energy and Power Retention

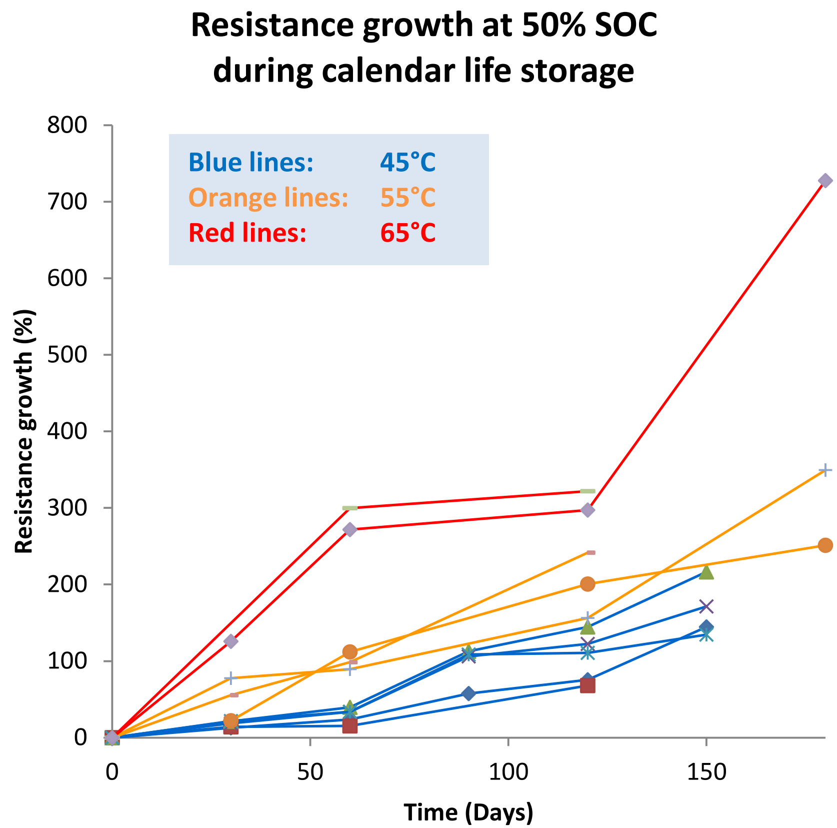


GAP Analysis chart								
45°C								
End of Life Characteristics	**Units**	**Under Hood target**	**RPT0 calendar life cells**	**RPT1 calendar life cells**	**RPT2 calendar life cells**	**RPT3 calendar life cells**	**RPT4 calendar life cells**	**RPT5 calendar life cells**
Discharge Pulse, 1s	KW	6	11.5	11.5	11.5	11.5	11.5	11.5
Available energy (750W accessory load power)*	Wh	360	503	497	509	513	504	503

- 1st cell deliverables stored at 45°C have almost no capacity loss
- 1st cell deliverables meet available energy and power requirements after RPT5

Progress: 1st Cell Deliverables Calendar Life – Impedance Growth

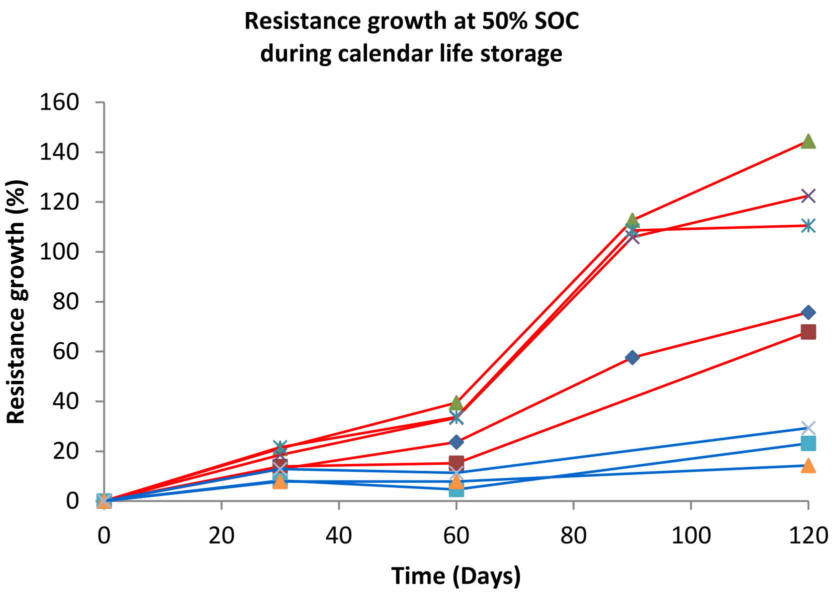


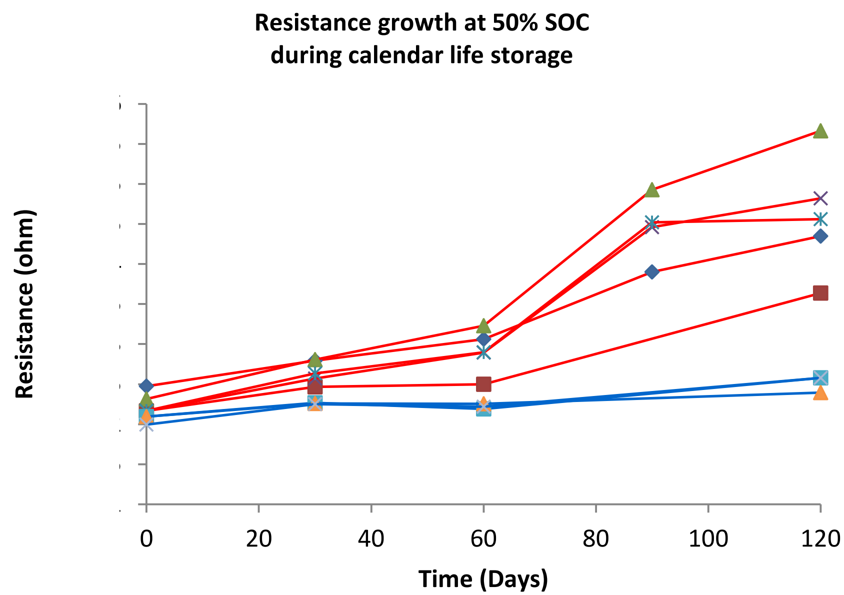


Cells at 45°C have an average resistance increase of X2.7 between RPT0 and RPT5

Progress: 1st Cell Deliverables Cycle Life – Impedance Growth

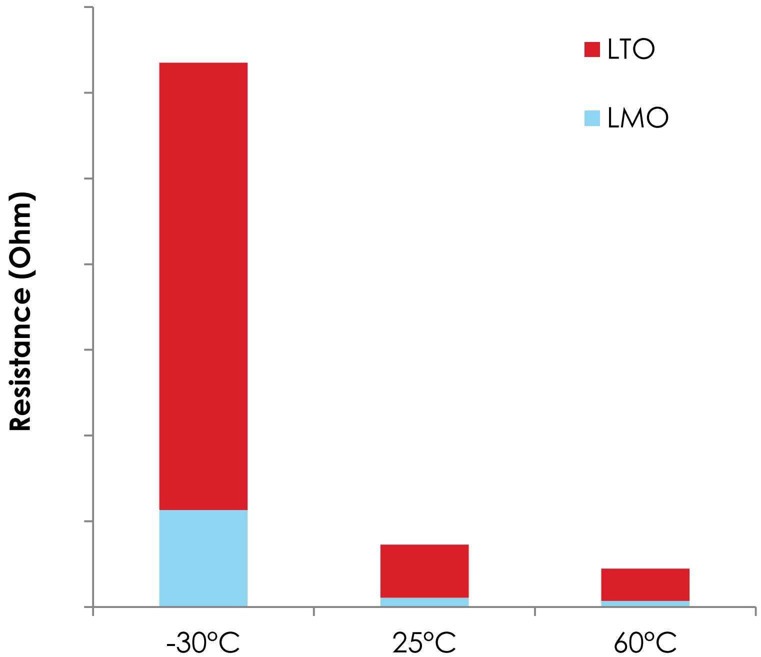
Blue lines: 45°C cycle life
Red lines: 45°C calendar life

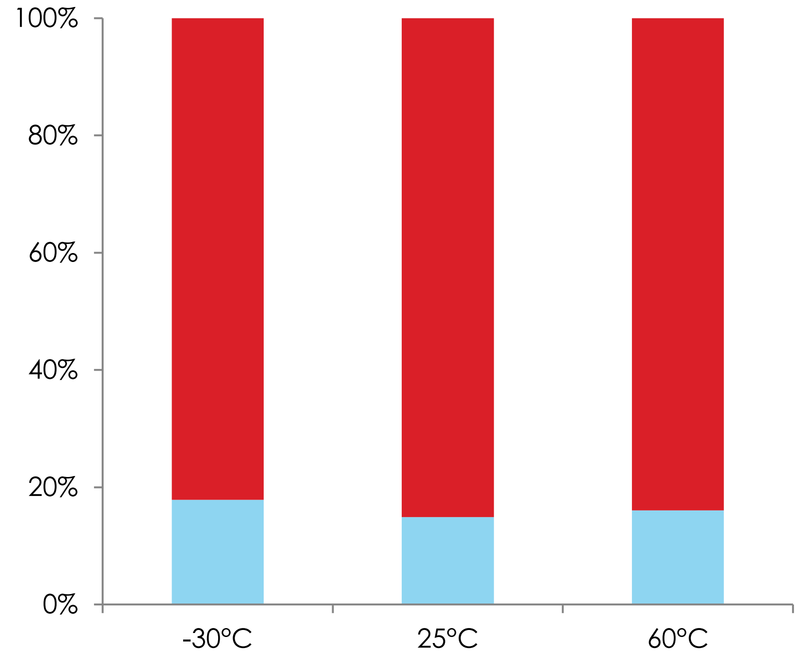




45°C cycle life cells' resistance growth is lower than the resistance growth of cells on calendar life testing at 45°C

Progress: Electrode Development

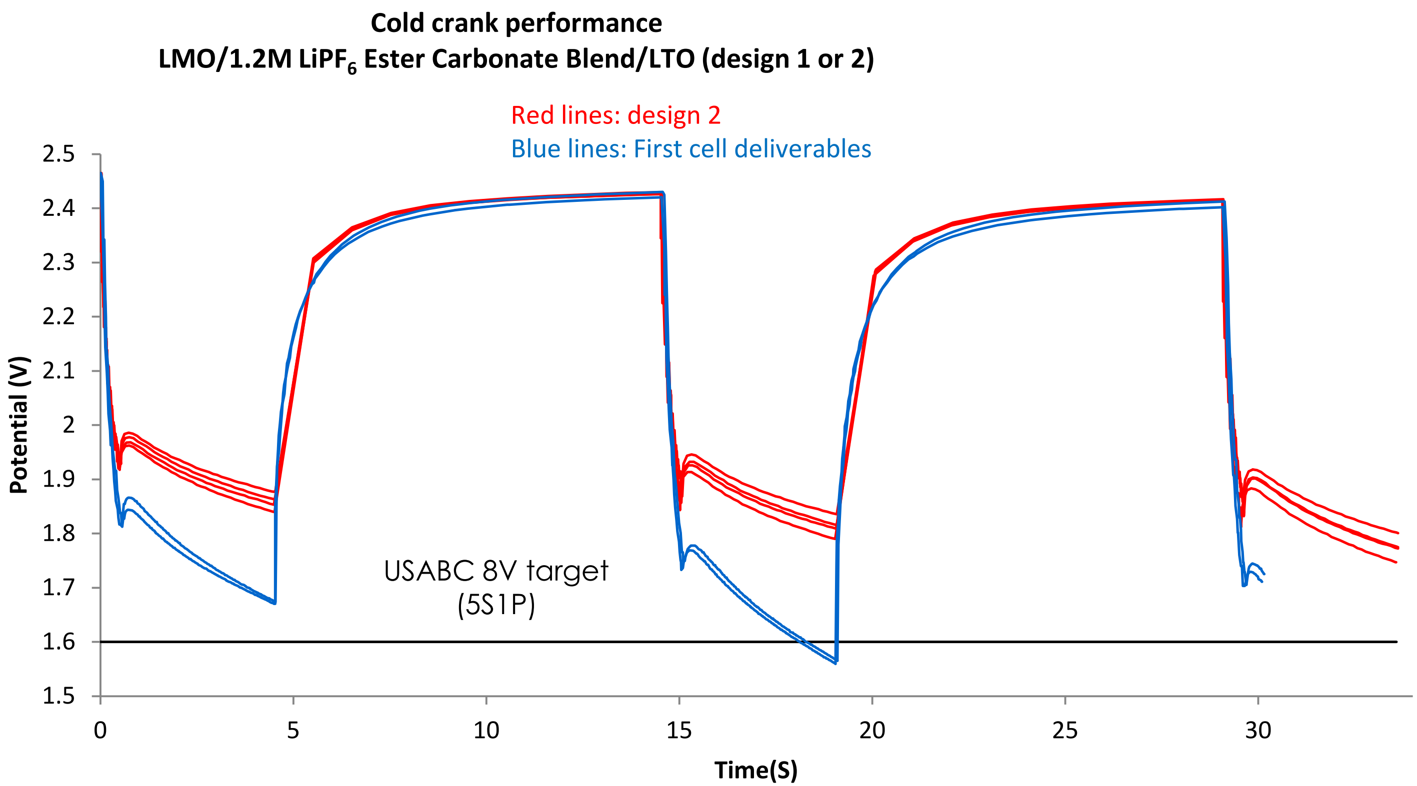




LTO contributed ~80% total impedance at wide temperature range from HPPC

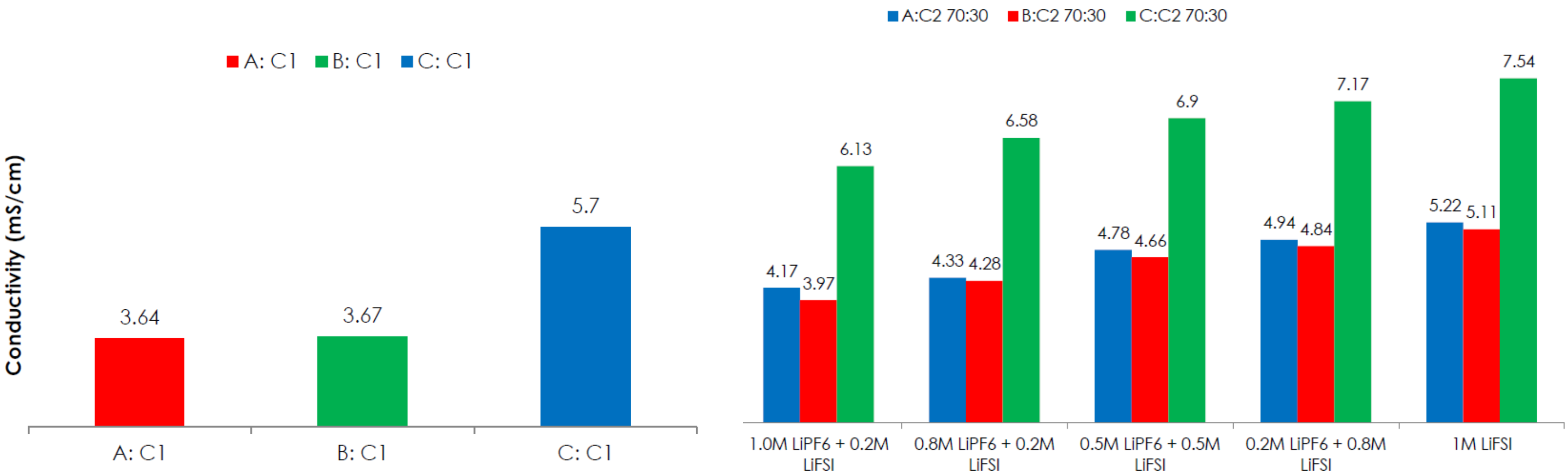
- **Path forward: optimize formulation of LTO to improve cell performance at -30°C and stability at >45°C**

Progress: Electrode Development - Cold Crank Performance with New LTO Design



New LTO design 2/LMO chemistry passes all 3 cold crank pulses without compromising gassing

Progress: Electrolyte Development – Solvent and Salt Blend

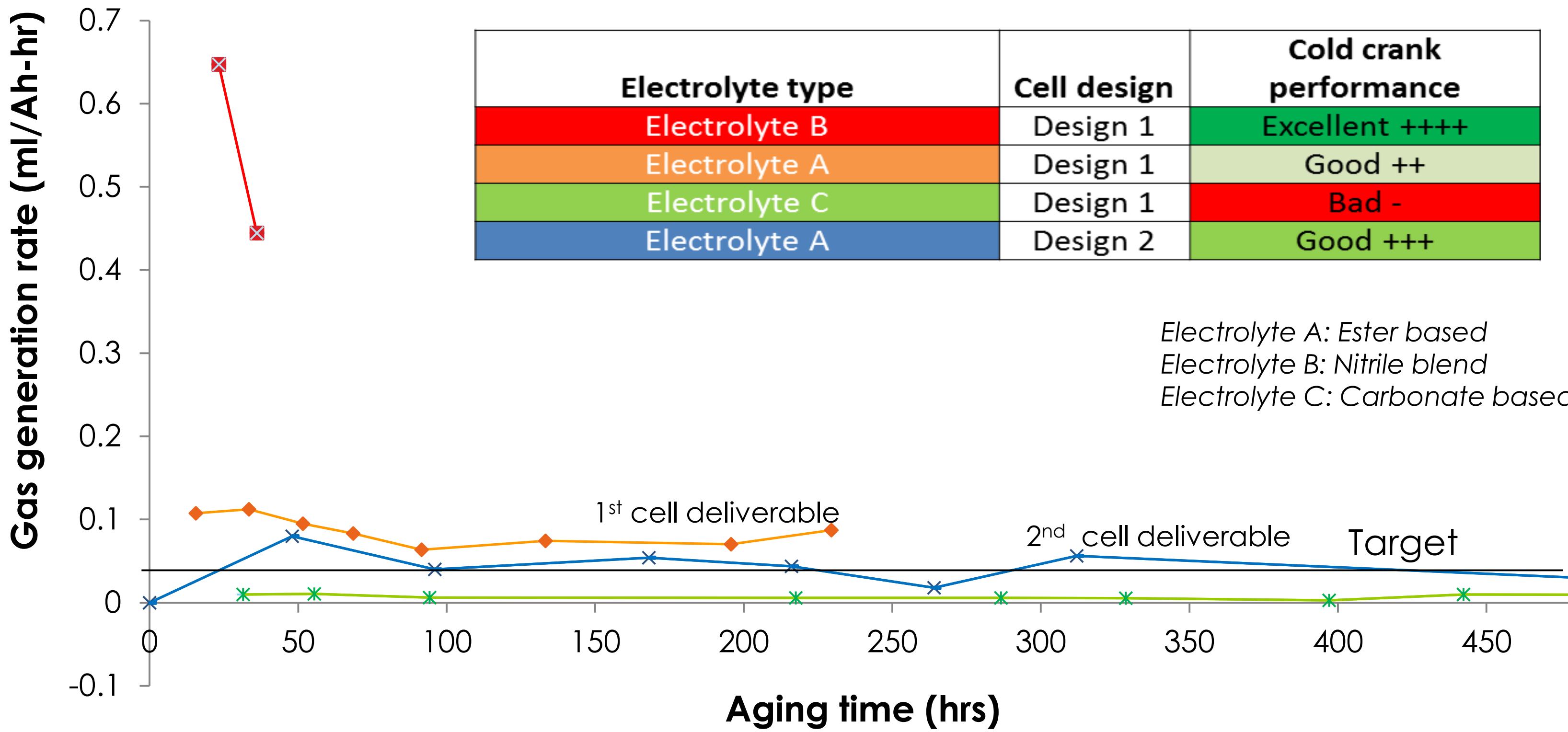


Ionic conductivity measurement at -30°C were tested to find suitable electrolyte systems give higher conductivity and high stability

- **Nitrile based solvent was excluded due to chemical instability**
- **Ester C and carbonate blend showed highest conductivity**
- **Addition of LiFSi salt improves ionic conductivity**

Progress: Electrolyte Development – Gassing

Comparing gassing rate for different cell design and electrolyte
Cells were aged at 60°C and stored at 100% SOC



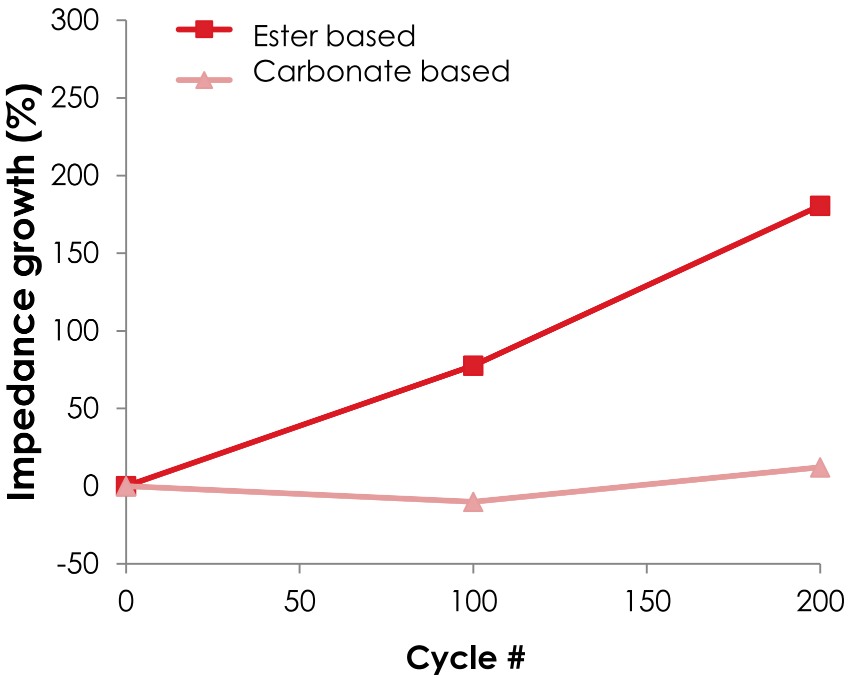
Electrolyte type	Cell design	Cold crank performance
Electrolyte B	Design 1	Excellent ++++
Electrolyte A	Design 1	Good ++
Electrolyte C	Design 1	Bad -
Electrolyte A	Design 2	Good +++

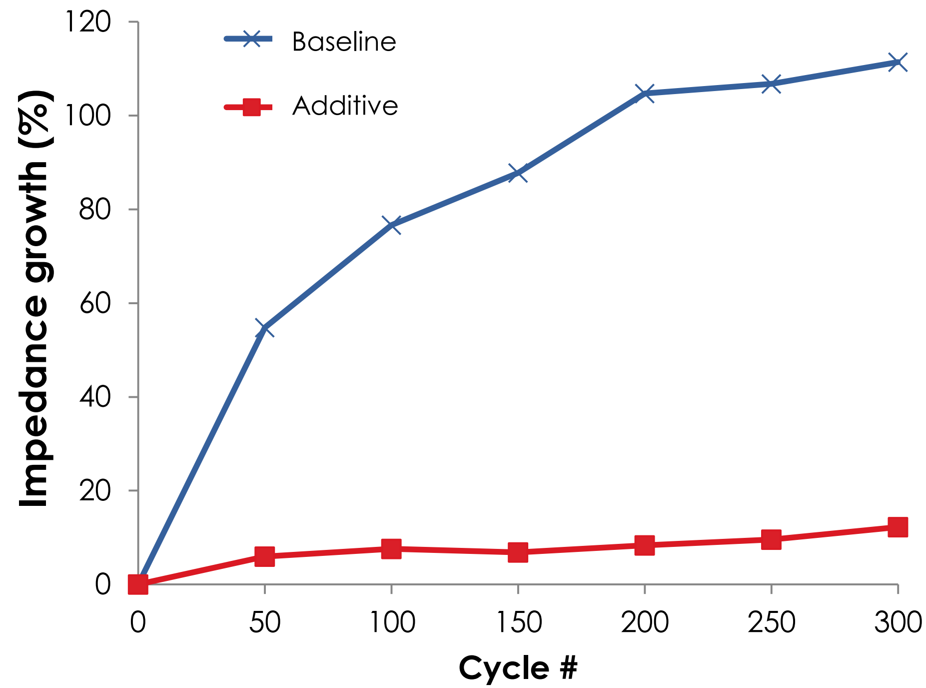
Electrolyte A: Ester based
Electrolyte B: Nitrile blend
Electrolyte C: Carbonate based

- **Electrolyte selection and electrode formulations have shown to be critical to reduce gassing**
- **Optimizing the LTO electrode helped to decrease gassing while changes on the LMO did not contribute to gassing mitigation**

Progress: Electrolyte Development – Additive

Aging protocol:
(100% DOD at 1C, 55°C)

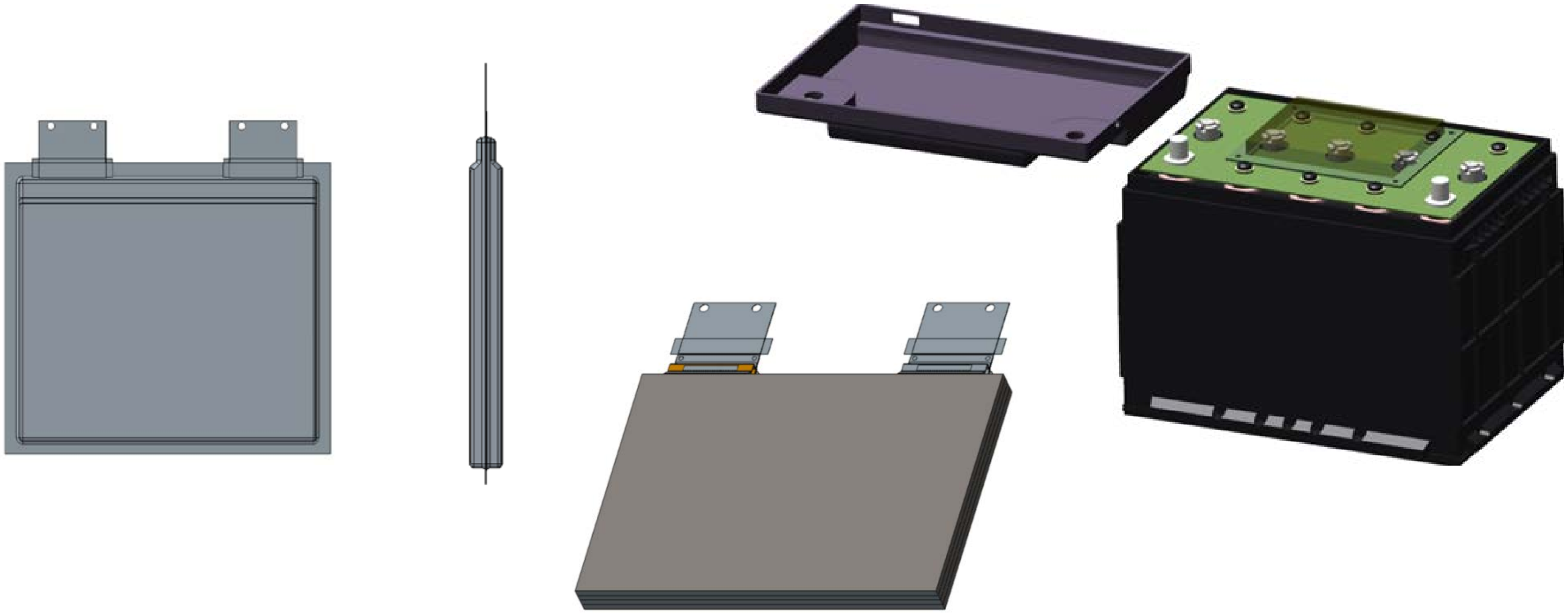




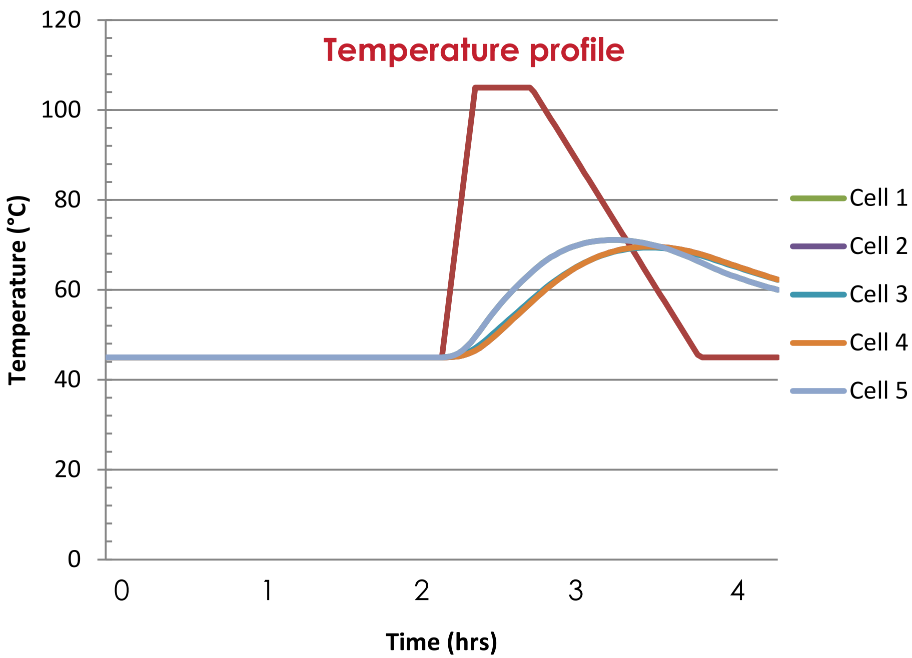
- Choice of electrolyte has a significant effects on impedance growth
- Impedance growth is prevented via film-forming additives

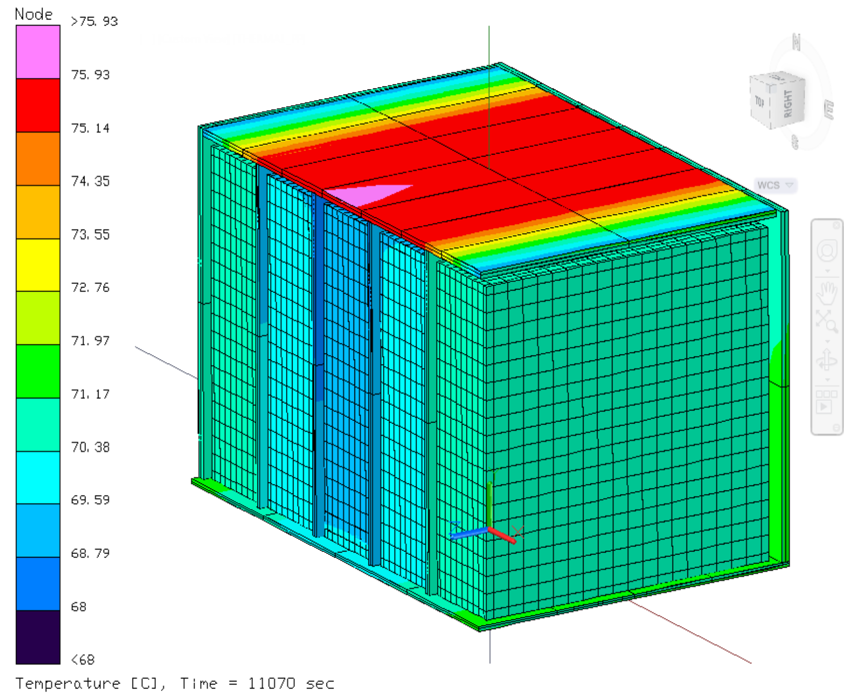
Progress: Module Development – Mechanical Design

- Completed design for 46Ah pouch cell
- Swelling testing is being carried out to determine the mechanical impact of operation on the stack thickness over time
  - Initial preliminary tests were carried out on 1.6Ah pouch cells which demonstrated no significant impact over 1 week
- Identified tooling required to manufacture 46Ah pouch cells



Progress: Module Development – Thermal Analysis





Thermal analysis during survivability test (105°C for 15min) simulated that cell temperature doesn't increase above ~72°C

Projected Cost for 46Ah Pouch Cells Module

Cost Breakdown				
Component Group	**Usage per Module**	**Cost Each ($)**	**Cost/ Module ($)**	**Current Best projection with pouch cells module ($) (@250k units/year)**
Housing	1	5.00	5.00	5.05
Electronics Cover	1	2.00	2.00	0.24
Terminals	2	0.06	8.00	0.12
Electronics	1	10.00	10.00	10.00
Main Bus Strap	2	1.50	3.00	0.10
Cell to Cell Bus Strap	4	1.50	6.00	2.00
Addnl. Mechanical Parts	-	-	-	5.00
Temp sensor	1	1.00	1.00	1.00
Cell Stack Components	5	25.50	127.50	124.20
Pouch cell tabs	10	-	-	2.00
Pouch cell film	$0.6m^2$	-	-	4.00
Cost Target			167.00	153.71

Future Work

- Further improvement in electrode formulation (e.g. porosity, binder, carbon percolation network) to decrease gassing while maintaining superior cold crank performance

- Surface coatings (ALD, dry-coatings) to mitigate gassing and impedance growth

- Electrolyte optimization (solvent, salt, and additive) to further improve life of LTO based cells at high temperature

- Module and system development to build prototype 12V SS

Our objective is to develop, manufacture and deliver 46Ah cells and modules, including an integrated electronic system, contained in a novel architecture, and to identify a path to full commercialization

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

Summary

- 1st deliverable cells were built and delivered to USABC for cold crank and life testing
  - The cells pass energy/power requirement at RPT6 at 45°C
- 2nd deliverable cells LMO/LTO cells with optimized electrode formulations passed cold crank at -30°C after removing 360Wh scaled energy
- Electrolyte selection and electrode formulations are critical to reduce gassing
- Impedance growth can be mitigated via film-forming additives
- Mechanical and Module Electronics System developments are on-going to support USABC deliverable
- Current best projection of cost for pouch cell modules is of $160 with 250K modules/year

Acknowledgements

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Saft POC

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