# High Electrode Loading EV Cell

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Project ID#
ES332

# Overview

## Timeline

- Project start: 15 June 2016
- Project end: 14 June 2019
- Percent complete: 33%

## Budget

- Total project funding
  - DOE share: $3,499,297
  - 24M share: $3,499,297
- Funding received in FY16
  - DOE share: $303,095
  - 24M share: $303,095
- Funding for FY17
  - DOE share: $1,115,930
  - 24M share: $1,115,930

## Barriers

- Cost – current costs are three times too high on a kWh basis
- Performance – High energy density battery systems are needed to meet both volume and weight targets
- Abuse tolerance, reliability, ruggedness – many Li-ion batteries are not intrinsically tolerant to abusive conditions

## Partners

- 24M Technologies - LEAD

# About 24M

- Re-inventing the Li-ion Battery
  - Cost reduction down to 50% of today's cost
  - Higher energy density, safer systems
- Dramatically simpler manufacturing
  - Half the CapEx of conventional Li-ion
  - Scale in small increments (1/10$^{th}$ conventional)
- Unlocks $100B+ market
  - First market: stationary storage
  - Next market:  electric transportation
  - Customer, partner MoUs signed > 1 GWh
- Accelerating commercialization
  - Series Close: 1Q2017
  - Customer Sampling: 2016-2017
  - Factory Complete: end-2017
  - High Volume Production: mid-2018

http://borgsolar.com/solutions/

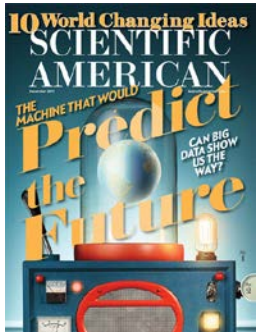
http://bjackcity.com/douglas/index.php?p=powersubstation

http://photoelectricdreams.blogspot.com/2014_01_01_archive.html

# Company Facts

- Summary
  - Experienced management team
  - Top Li-ion talent, 60+ employees
  - 32,000 sq.ft. in Cambridge, MA
  - 4,000 sq.ft. dry room
  - 2000+ test channels
- Timeline
  - 2010-13: R&D proves technology
  - 2014-16: Automated line, sampling
  - *2017-18: Scale to first factory with partner*
- IP Capture:
  - 20 issued patents, 80+ pending
- Funding:
  - Equity: $74.5M (VC, Strategic)
  - DOE Awards: $8M to date
  - USABC Award: $7M program


**Recognition**

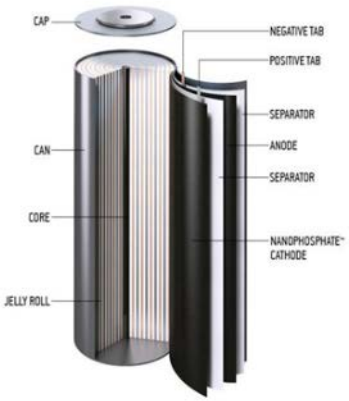

# Relevance

- Program Objective: Develop and demonstrate EV-capable cells based on 24M's semi-solid electrode technology
  - Increase the energy density of semi-solid electrodes through chemistry and cell design improvements
  - Demonstrate that 24M's novel electrode and manufacturing approach can be scaled to mass production suitable for automotive applications.
  - Novel electrode architecture that enables abuse tolerant battery systems.
  - Reduction of inactive materials that translates to higher energy density battery systems with a simpler architecture

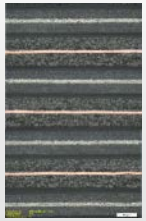

13,000+ prototype cells built

# Li-ion Shortcomings: Too Much Mass, Volume, Cost

## Cell Design Challenges




25 separate layers, 14 inactive material layers in 1mm cross section



Inactive material fraction too high.
Inactive material cost % too high.

## Manufacturing Challenge: Complex, wet/dry/wet operations

| | | |
|---|---|---|
| Electrode Creation | Mix Anode | Mix Cathode |
| | Coater & Inspection | Coater & Inspection |
| | Slitter & Cleaning | Slitter & Cleaning |
| | Press/Calendar | Press/Calendar |
| | Die Punch | Die Punch |
| | Clean & Buffer | Clean & Buffer |
| | Vacuum Drying | Vacuum Dry |

Complex and expensive operations with multiple yield sensitivities

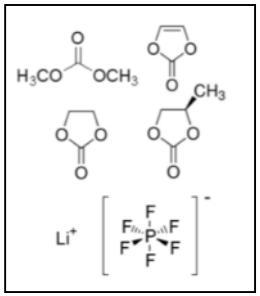
| | |
|---|---|
| Cell Assembly | Stacking |
| | Welding |
| | Jelly Roll Insertion & Electrolyte Fill |

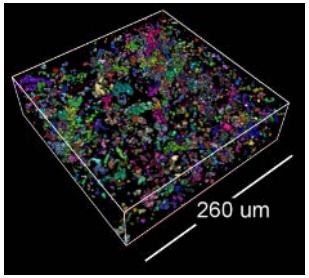
| | |
|---|---|
| Test &Prep | Pre-Charge |
| | Formation |
| | Aging & Sorting/Grading |

# Semisolid Lithium-ion

Flowable high energy density lithium-ion electrodes

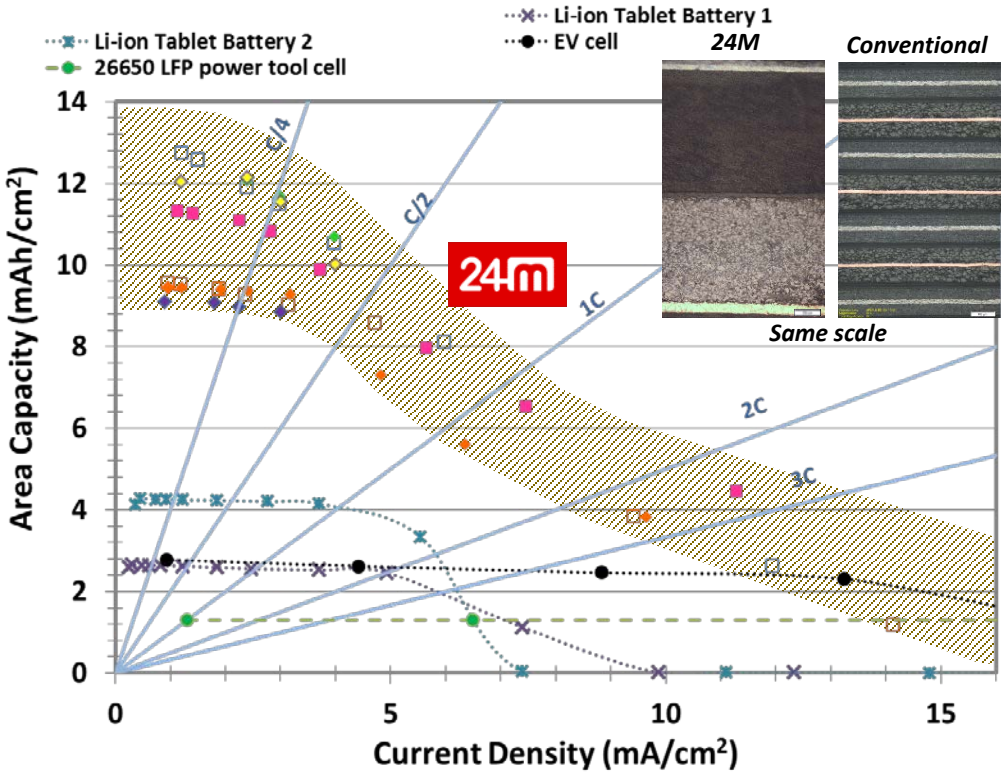
Simpler device architecture, disruptive low-cost manufacturing method



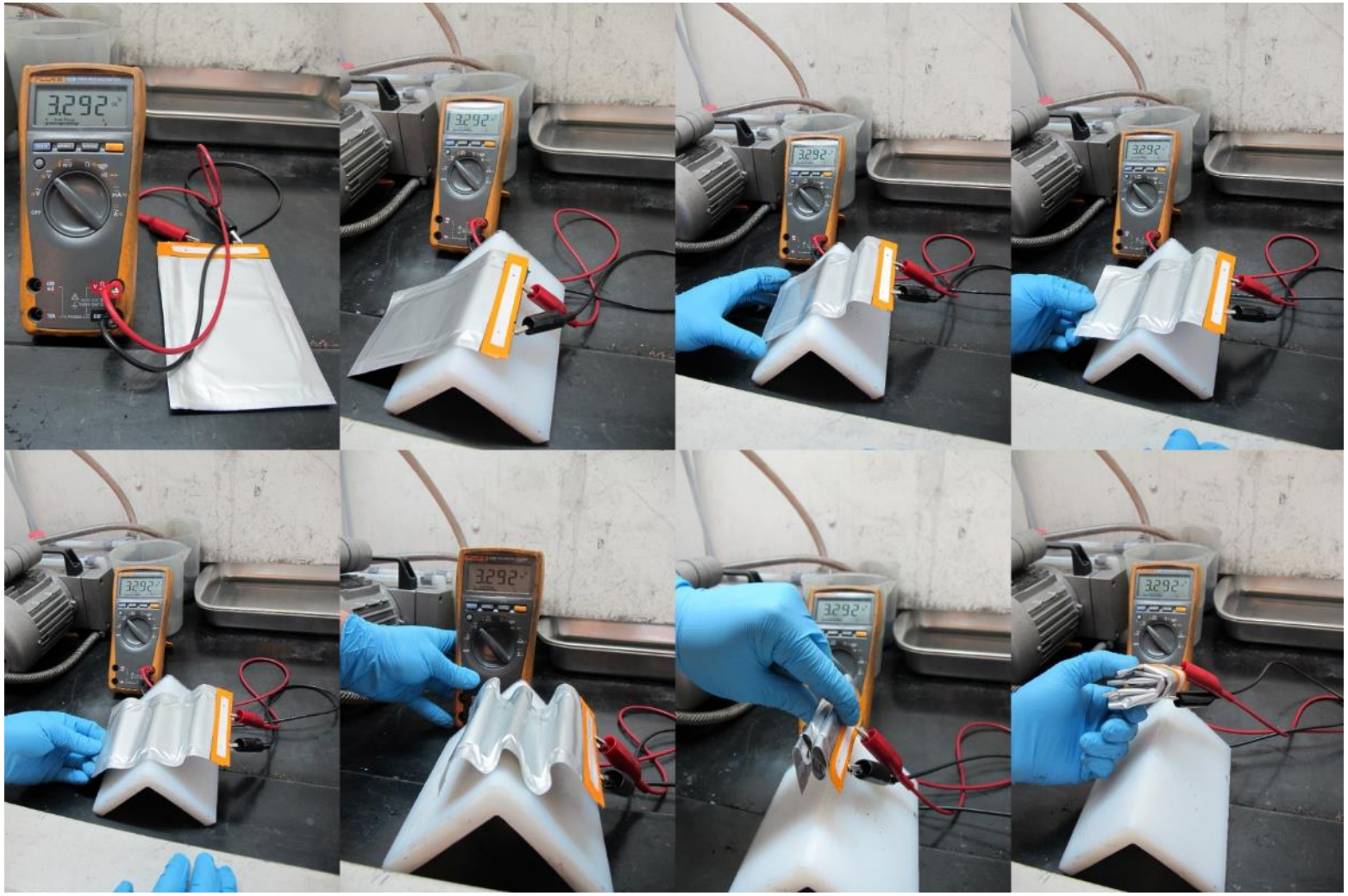




Materials design

Novel semi-solid electrode form

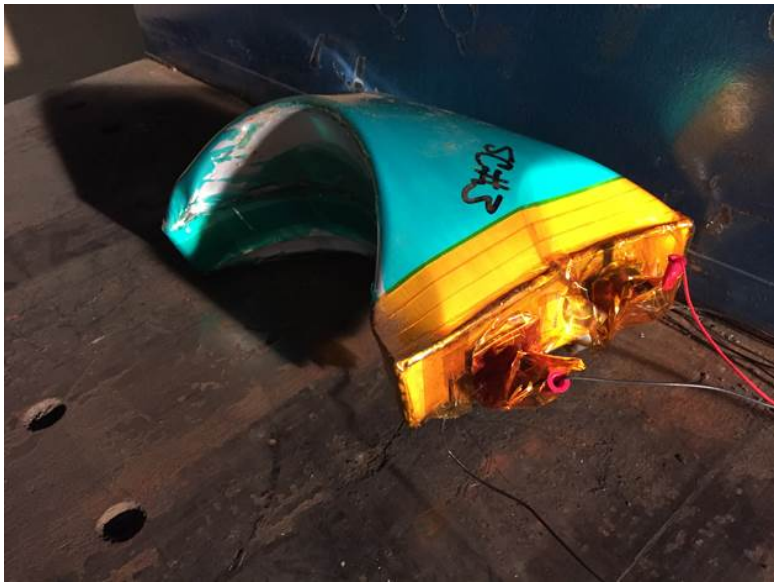


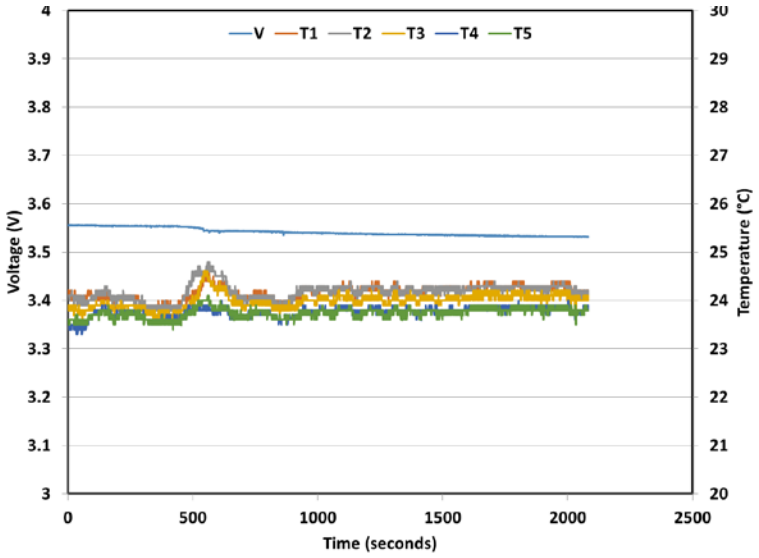
# 24M Cell Design Has Unique Abuse Tolerance



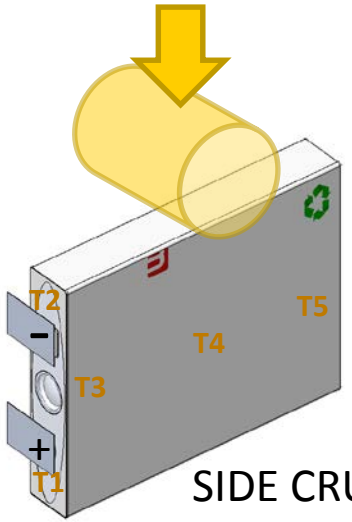
# Electrical Abuse Testing – Crush – Unprecedented Level of Safety

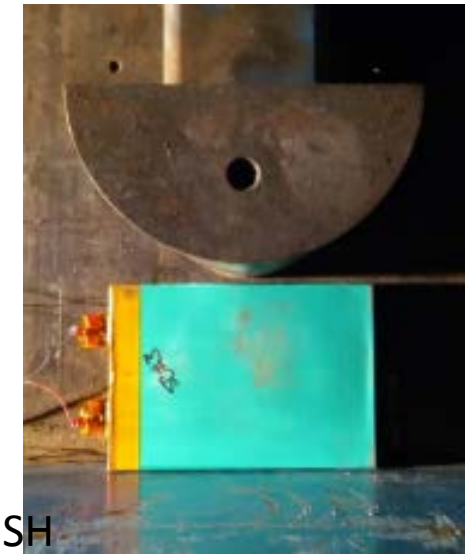
| | Result |
|---|---|
| EUCAR rating | EUCAR 1 |
| Venting | No |
| Max Temp | Ambient |






CRUSH



SIDE CRUSH

# Milestones/Deliverables

| Description of Milestone or Deliverable | Target Date | Status |
|---|---|---|
| Kick-Off | 6/15/2016 | Completed |
| Baseline Cell Gap Analysis Completed | 12/14/2016 | Completed |
| Gen1 Safety Design Review | 1/25/2017 | Completed |
| Cost Model Alignment | 3/16/2017 | Completed |
| Gen2 Cathode Active Material Down-selection | 6/14/2017 | Completed |
| Anode Active Material Down-selection (2-3 materials) | 6/14/2017 | In Progress, Delayed |
| Phase 1 Deliverables (GO/NO GO) (D1.1) | 6/14/2017 | In Progress |
| Gen2 Electrolyte Lock (RT Life + HT stability) | 8/4/2017 | In Progress |
| 60 vol% Loading Cathode | 10/30/2017 | In Progress |
| Gen2 Alloy Anode Blend Formulation | 11/29/2017 | In Progress |
| Next Gen Coating Process Proof-of-Principle | 12/27/2017 | Future Work |
| Gen3 Electrolyte Lock | 1/22/2018 | Future Work |
| Gen2 Safety Design Review | 3/16/2018 | Future Work |
| Cathode Material Lock | 6/14/2018 | Future Work |
| Anode Material Lock | 6/14/2018 | Future Work |
| Active Materials Lock | 6/14/2018 | Future Work |
| Phase 2 Deliverables (GO/NO GO) (D2.1) | 6/14/2018 | Future Work |
| Next Gen Coating Process Down-Select | 9/14/2018 | Future Work |
| Gen3 Cell Safety Design Review | 12/14/2018 | Future Work |
| Final Electrolyte Lock | 12/14/2018 | Future Work |
| Deliver >250cm$^2$ footprint Cells (D3.1) | 12/14/2018 | Future Work |
| Phase 3 Deliverables (GO/NO GO) (D3.2) | 4/14/2019 | Future Work |
| Cost Optimized Cell Designs | 5/14/2019 | Future Work |
| Program Conclusion | 6/14/2019 | Future Work |

# Phase 1 Status Dashboard

| Task / Sub-Task | Status |
|---|---|
| 1. High Energy Active Materials Selection | |
| 1.1 Cathode Materials | |
| 1.2 Anode Materials | |
| 2. Increase Solids Loading | |
| 3. Cell Architecture Development | |
| 3.1 High-Energy-Active Electrode Forming | |
| 3.3 Safety and Abuse Interventions | |
| 3.4 Electrolyte Development | |
| 4. Cost Modeling | |
| 5. Cell Deliverables | |
| 5.1 Benchmarking Cells | |
| 5.2 Phase 1 Deliverables | |

| Key | |
|---|---|
| On Schedule | |
| Behind Schedule (<1Q); Corrective Action ID'd | |
| Off-Schedule (>1Q); No Corrective Action ID'd | |

Anode development behind due to personnel resources and materials availability

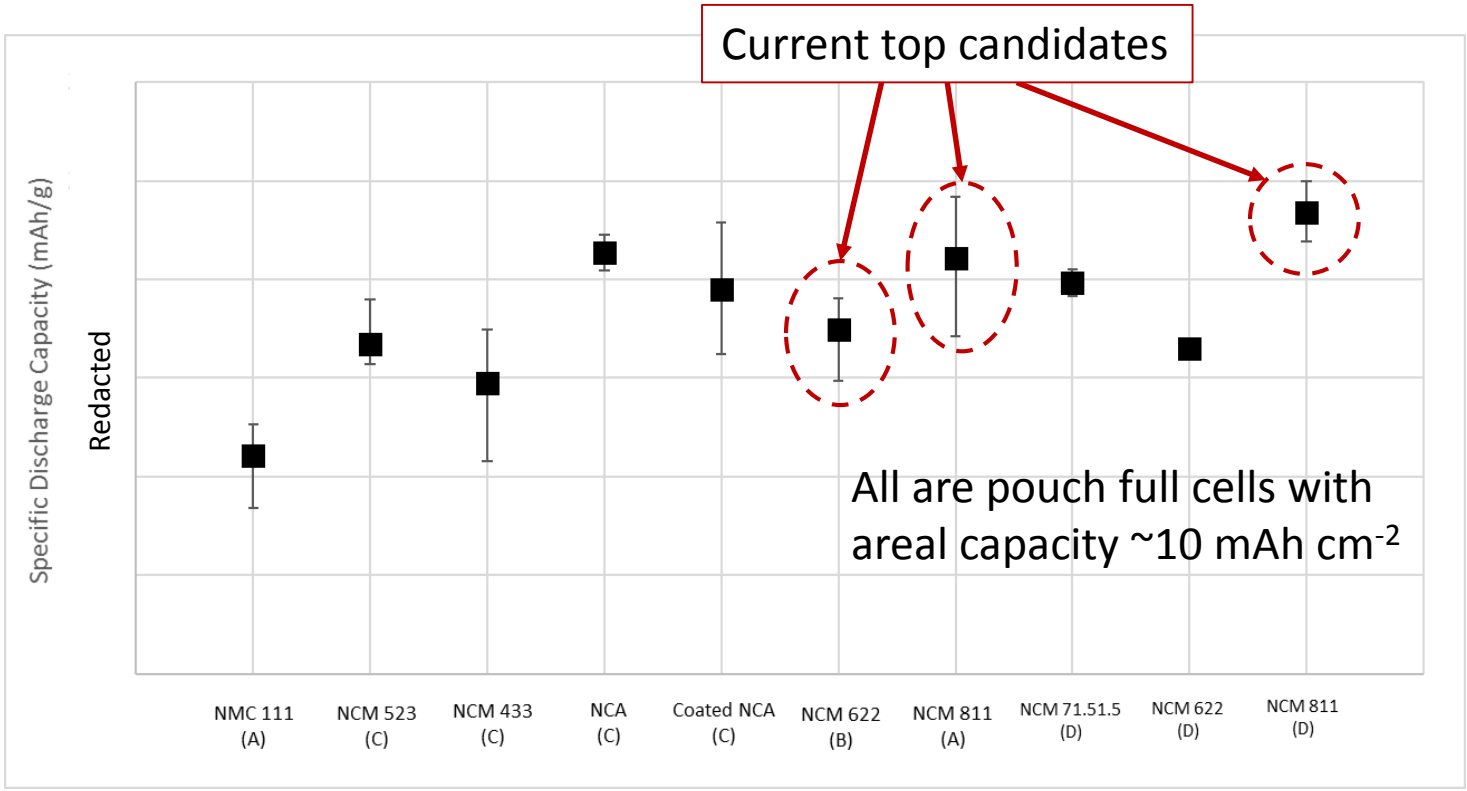
# Gap Chart – Q3

| Characteristics at 30°C | Units | Phase 1 Goal | Q3 (2017-03-28) |
|---|---|---|---|
| Peak Discharge Power Density, 30 s Pulse | W/L | 1500 | 1597 |
| Peak Specific Discharge Power , 30 s Pulse | W/kg | 700 | 885 |
| Peak Specific Regen Power , 10 s Pulse | W/kg | 300 | 300 |
| Useable Energy Density @ C/3 Discharge Rate | Wh/L | 400 | 413 |
| Useable Specific Energy @ C/3 Discharge Rate | Wh/kg | 200 | 229 |
| Useable Energy @ C/3 Discharge Rate (Test vehicle size) | Wh | 21.5 | 2.82 |
| Calendar Life | Years | 15 | 0 (BOL) |
| DST Cycle Life | Cycles | 1000 | 0 (BOL) |
| Normal Recharge Time | Hours | 4 | 4 |
| High Rate Charge, 15 minutes | % SOC | 35% | 44.6% |
| Maximum Operating Voltage | V | 4.2 | 4.2 |
| Minimum Operating Voltage | V | 2.5 | 2.5 |
| Peak Current, 30 s | A | 400 | |
| Maximum Self-discharge | %/month | <1% | |
| Survival Temperature Range, 24 Hr | °C | -20 to +55 | -20 to +55 |
| Unassisted Operating at Low Temperature @ C/3, -20C | %UE | 50 | 15.2% |
| Unassisted Operating at Low Temperature @ C/3, 0C | %UE | 50 | 61.0% |
| Operating Environment | °C | -20 to +55 | 0 to +55 |
| Selling Cost @ 100K units | $/kWh | 250 | [Protected] |
| Areal Capacity | $mAh/cm^2$ | | 10.6 |
| Solids Loading Level (Anode/Cathode) | Vol % | | [Protected] |

Goals are EOL, Gen1.6 is BOL

# Task 1 – High-Energy Cathode Candidate Testing

- Several promising high energy density cathode active materials have been identified which can achieve our target energy and power requirements
  - Manufacturer's specified capacity well correlated to obtained gravimetric capacity in 24m cell format



# Proposed Future Work

- Continue Phase 1 development
- Deliver Phase 1 deliverable cells for testing at Argonne National Lab by June 15, 2017 (30x cell)
- Execute on high energy density initiatives to achieve Phase 2 and Phase 3 targets

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

# Summary

- 24M is demonstrating the versatility of the semi-solid electrode platform using NCM111/Graphite in Phase 1 of this USABC program
- Semi-solid cells with high areal capacity electrodes are demonstrating surprisingly high power-to-energy performance
- Cell chemistry and architecture improvements are underway to further increase energy density toward the EV 2020 targets