High Electrode Loading Electric Vehicle Cell

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24M Technologies, Inc.
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Project ID# bat332

Timeline

- Project start: 15 June 2016
- Project end: 14 June 2019
- Percent complete: 50%

Budget

- Total project funding
  - DOE share: $3,499,297
  - 24M share: $3,499,297
- Funding received in FY17
  - DOE share: $698,960
  - 24M share: $698,960
- Funding for FY18
  - DOE share: $1,394,220
  - 24M share: $1,394,220

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

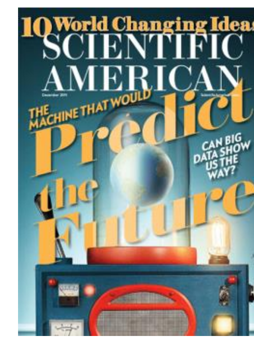
Partners

- 24M Technologies - LEAD

Company Facts

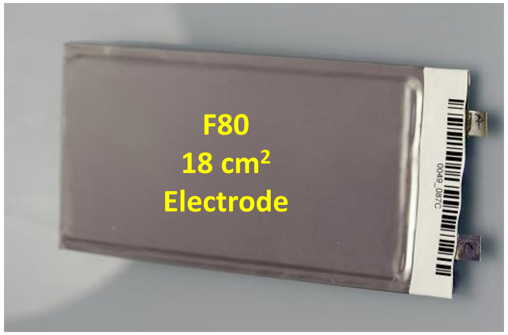
- Summary
  - Experienced management team
  - Top Li-ion talent, 60+ employees
  - 32,000 sq.ft. in Cambridge, MA
  - 4,000 sq.ft. dry room
  - 2000+ test channels
- Timeline
  - 2010-13: R&D proves technology
  - 2014-16: Automated line, sampling
  - *2017-19:* Scale to first factory with partner
- IP Capture:
  - 20 issued patents, 80+ pending
- Funding:
  - Equity: $82.5M (VC, Strategic)
  - DOE Awards: $8M to date
  - USABC Award: $7M program

Recognition



Company Facts

- Year 2013 : Build prototype line in Cambridge
  - 1st Generation production process
  - 17,000 F80 cells made to date in prototype line
    - Small format : single layer & stack
    - 1Ah capacity of single layer
    - 9Ah capacity of stack (9 layers)



- Year 2015 : Build pilot line in Cambridge
  - 2nd Generation production process
  - 14,092 unit cells made to date for testing
    - Production intent size
    - 2.36Ah capacity of one layer
    - 50 layers used to make 118Ah cell

- Year 2016 : A large Industrial Partner build a 7MWh pilot line
  - 3rd Generation production process
  - Core technology provided by 24M
  - Capital provided by Partner
  - Designed to build production intent cells
  - Thousands build to date

- Year 2017 : Start Building 100MWh plant with Industrial partner
  - Facility construction in Progress
  - Equipment fabrication in progress

- 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.

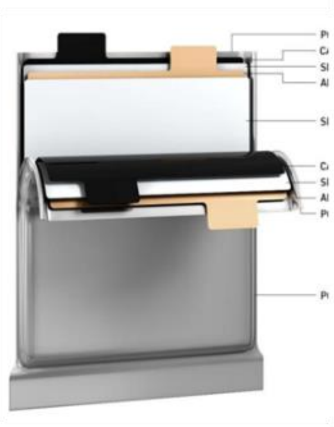
  - Demonstrate that 24M's novel electrode and manufacturing approach can be scaled to mass production suitable for automotive applications.

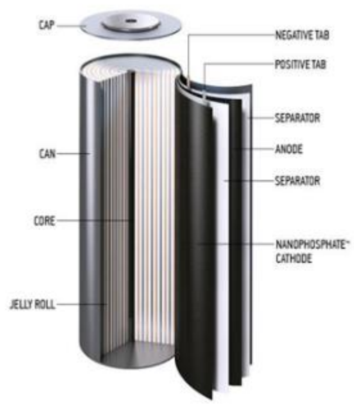
  - Novel electrode architecture that enables abuse tolerant battery systems.

  - Reduction of inactive materials that translates to higher energy density battery systems with a simpler architecture

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

Anode	Cathode
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

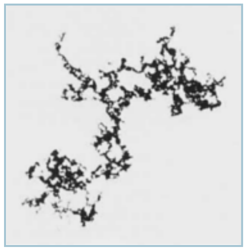
Test &Prep

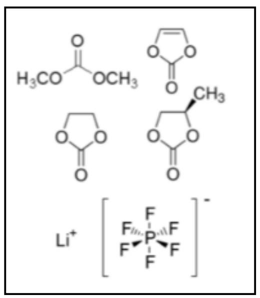
- Pre-Charge
- Formation
- Aging & Sorting/Grading

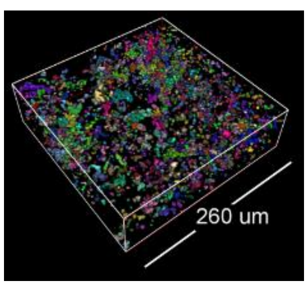
Semisolid Lithium-ion

Flowable high energy density lithium-ion electrodes

Simpler device architecture, disruptive low-cost manufacturing method

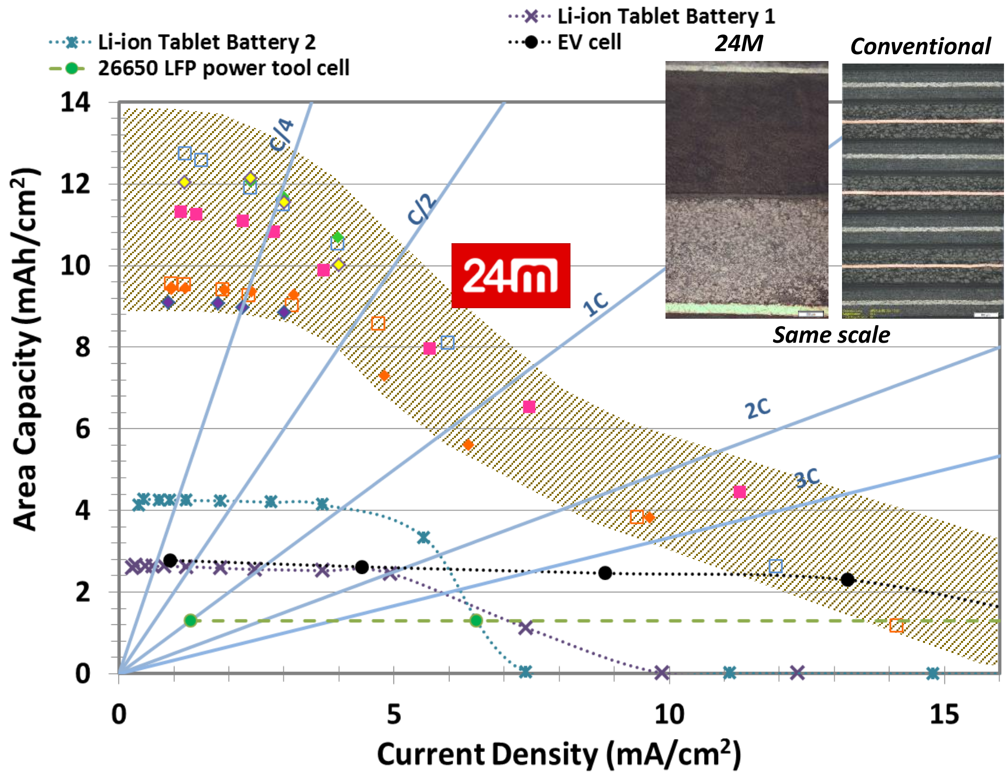






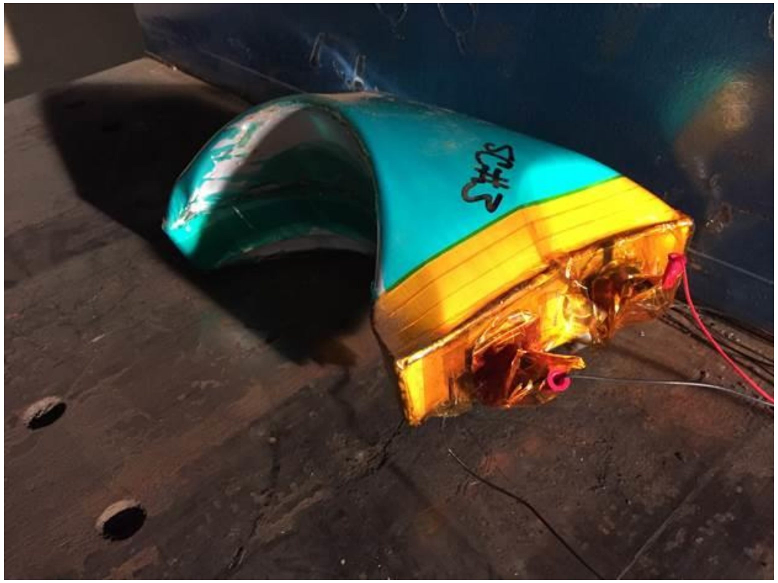
Materials design

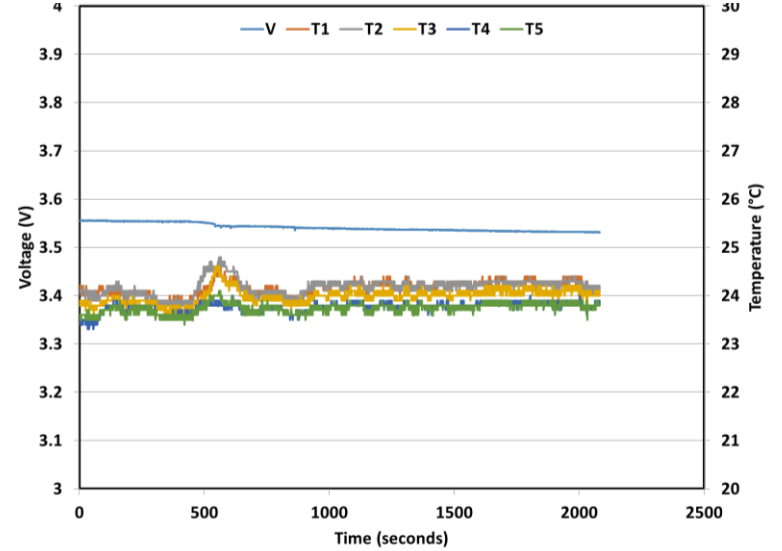
Novel semi-solid electrode form

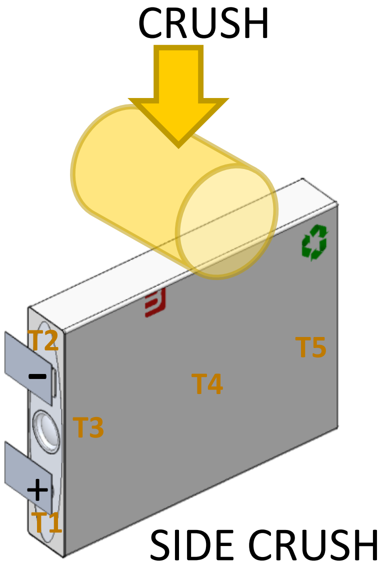


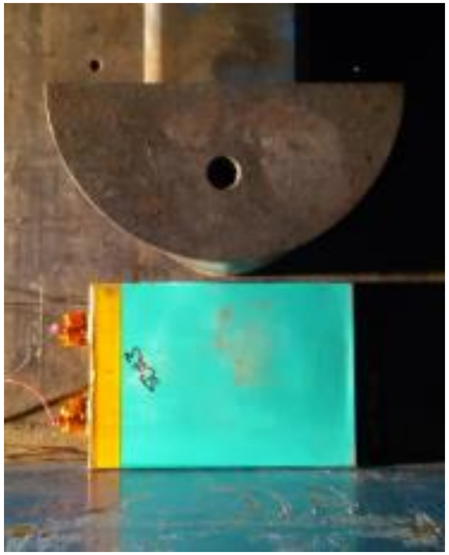
Electrical Abuse Testing – Crush – Unprecedented Level of Safety

	Result
EUCAR rating	EUCAR 1
Venting	No
Max Temp	Ambient

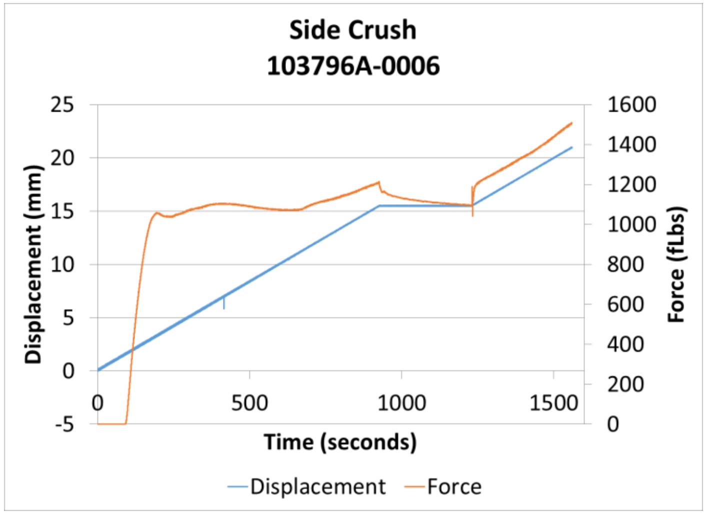


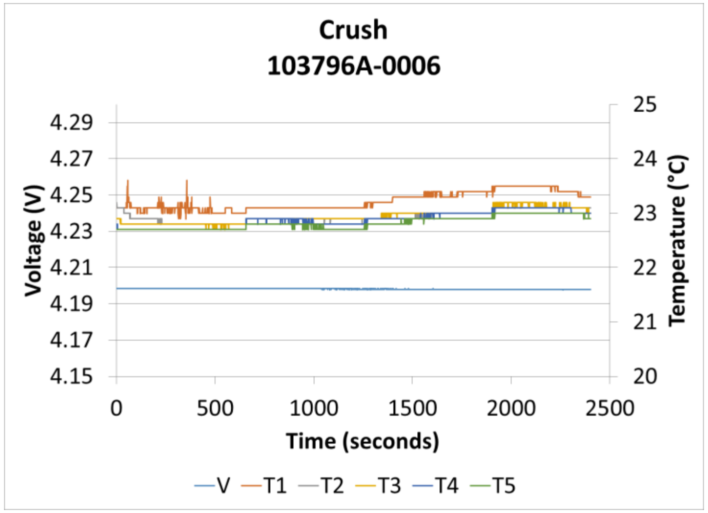




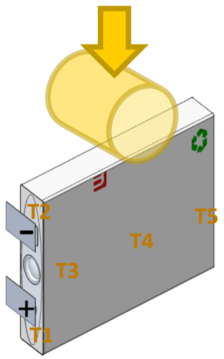


Electrical Abuse Testing – Crush – 39 Ah NMC Abuse



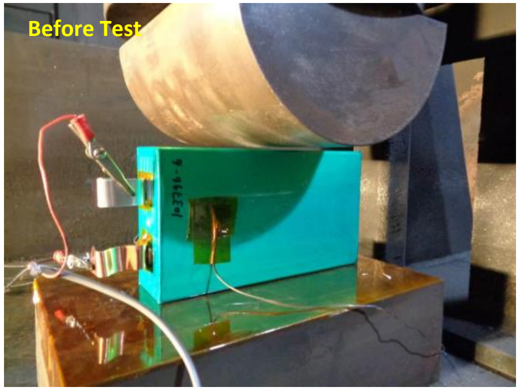


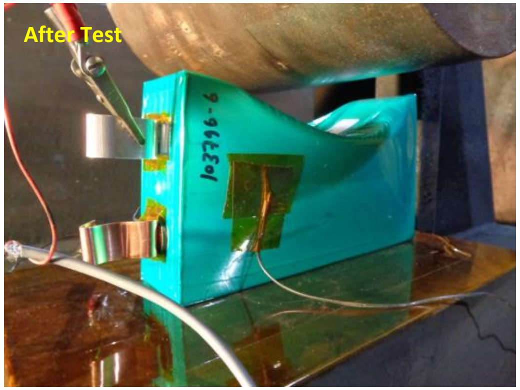
SIDE CRUSH



Cell venting: No
Max. T: 23.6 °C
Max. Deformation: 21.6%
Test Reached Load Max.
Cell Did Not Vent, No Fire

EUCAR 1





Cell did not short and max temperature did not exceed 25°C

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	Completed
Phase 1 Deliverables (GO/NO GO) (D1.1)	6/14/2017	Completed
Gen2 Electrolyte Lock (RT Life + HT stability)	8/4/2017	Completed
60 vol% Loading Cathode	10/30/2017	In progress, Delayed
Gen2 Alloy Anode Blend Formulation	11/29/2017	In progress, Delayed
Next Gen Coating Process Proof-of-Principle	12/27/2017	In progress, Delayed
Gen3 Electrolyte Lock	1/22/2018	In progress, Delayed
Gen2 Safety Design Review	3/16/2018	Completed
Cathode Material Lock	6/14/2018	Completed
Anode Material Lock	6/14/2018	Completed
Active Materials Lock	6/14/2018	In progress, Delayed
Phase 2 Deliverables (GO/NO GO) (D2.1)	6/14/2018	In progress, Delayed
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 >250cm2 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 2 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	
3.2 Double-Sided Coating	
3.3 Safety and Abuse Interventions	
3.4 Electrolyte Development	
4. Cost Modeling	
5. Cell Deliverables	
5.1 Benchmarking Cells	
5.2 Phase 2 Deliverables	

Key	
On Schedule	
Behind Schedule (<1Q); Corrective Action ID’d	
Off-Schedule (>1Q); No Corrective Action ID’d	
Task on hold	

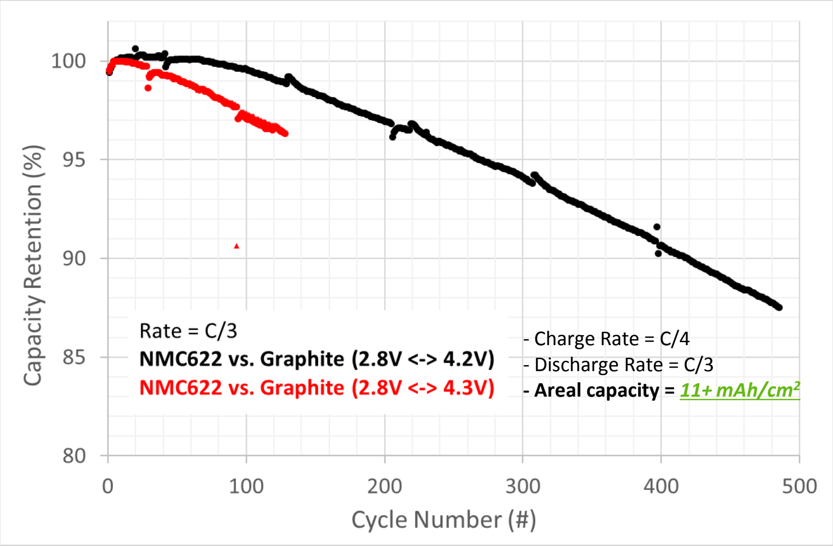
Gap Chart – Q7

End of Life Characteristics at 30°C	Units	Phase 2 Goal	2018-3-14
Peak Discharge Power Density, 30 s Pulse	W/L	1500	3236*
Peak Specific Discharge Power , 30 s Pulse	W/kg	700	1619*
Peak Specific Regen Power , 10 s Pulse	W/kg	300	(90**)*
Available Energy Density @ C/3 Discharge Rate	Wh/L	640	413
Available Specific Energy @ C/3 Discharge Rate	Wh/kg	290	195
Useable Energy @ C/3 Discharge Rate	Wh	36.5	0.23
Calendar Life	Years	15	0 (BOL)
DST Cycle Life	Cycles	1000	0 (BOL)
Normal Recharge Time	Hours	<7	2
High Rate Charge, 15 minutes	% SOC	50%	
Maximum Operating Voltage	V	N/A	4.3
Minimum Operating Voltage	V	N/A	2.5
Peak Current, 30 s	A	300	
Maximum Self-discharge	%/month	<1%	
Survival Temperature Range, 24 Hr	°C	-40 to +66	
Unassisted Operating at Low Temperature @ C/3, -20C	%UE	50%	
Operating Environment	°C	-30 to +52	
Selling Price @ 100K units	$/kWh	100	[Protected]

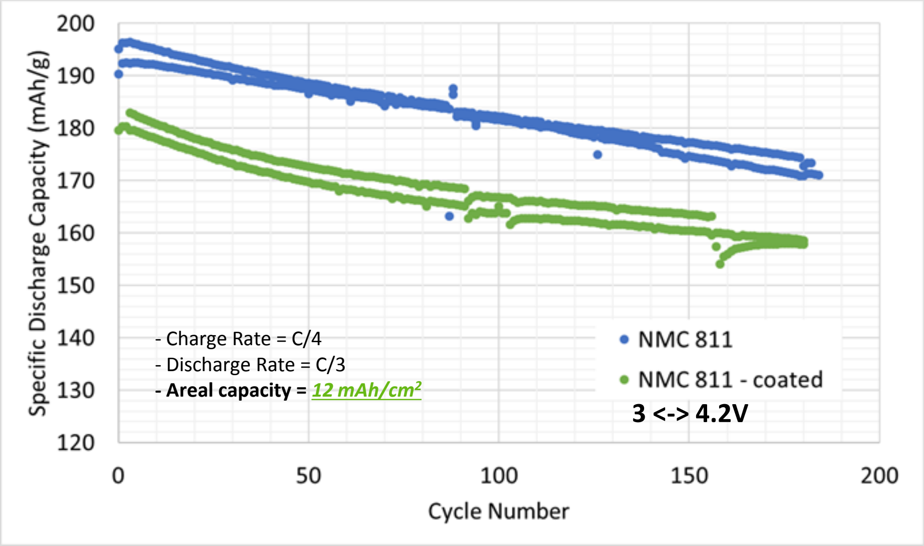
- Goals are EOL, Data is BOL
- *Process equipment needed for high power cells still in development, actual cells HPPC tested use slightly thinner cathode and much thicker anode than target design due to current process limitations. We do not expect a significant change in pulse power with intended cell design.
- **V_{op} is relatively close to V_{max} for this cell due to low cell impedance, so regen pulse finishes in CV step and is artificially low. Next regen pulse at 10% energy removed is 329Wh/kg

- High Nickel NMC cell development beyond NMC111

NMC 622 / Graphite



NMC 811 / Graphite



- NMC-based chemistries with higher Ni content are being developed to increase cell energy density beyond NMC111
  - Targeting to achieve 500-600Wh/L cells for EV applications in large cell format.
  - Showing similar cycle behaviors of conventional lithium ion while having much higher area capacity

Proposed Future Work

- Continue phase 2 development
- Deliver Phase 2 deliverable cells for testing at Argonne National Lab by September 15, 2018 (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"

- 24M is demonstrating the versatility of semi-solid electrode platform using NMC622/Graphite and NMC811/Graphite in phase 2 of this USABC program
- Significant process improvements with a new more robust casting equipment enabled high solid loading electrodes
- 24M semi-solid electrode enable an effective pre-lithiation
- Confirmed 24M Binderless semi-solid slurries are intrinsically more robust to silicon large volume expansion