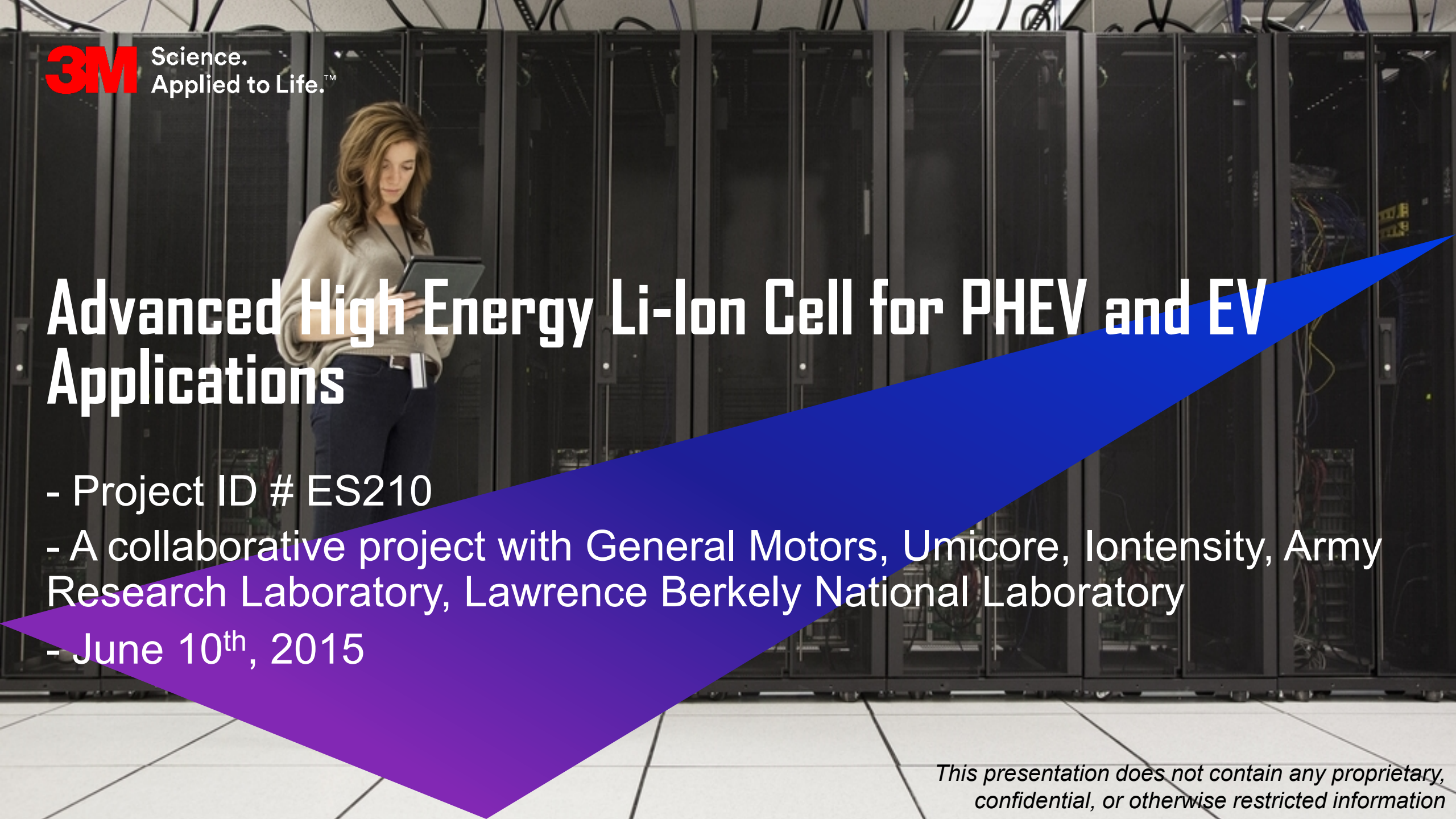


3M Science. Applied to Life.™

Advanced High Energy Li-Ion Cell for PHEV and EV Applications

- Project ID # ES210
- A collaborative project with General Motors, Umicore, Iontensity, Army Research Laboratory, Lawrence Berkely National Laboratory
- June 10th, 2015

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Timeline

- Start Date:10/01/2013
- End Date:09/30/2015
- Percent Complete:15%

Budget

- Total Project Funding
  - DOE* Share: $3,000,043
  - Contractor Share: $774,314
- Funding Received
  - FY13: $0
  - FY14: $979,746
  - FY15: $550,876 (through March)

Barriers

- Cycle Life, Specific Energy, Cost

Partners

- Collaboration:
  - GM: Dr. Meng Jiang
  - Umicore: Wendy Zhou
  - Leyden: Dr. Marie Kerlau
  - ARL: Dr. Richard Jow
  - LBNL: Dr. Gao Liu
- Interaction
  - Dalhousie University
  - ANL: Deliverable Testing
- Project Lead:3M

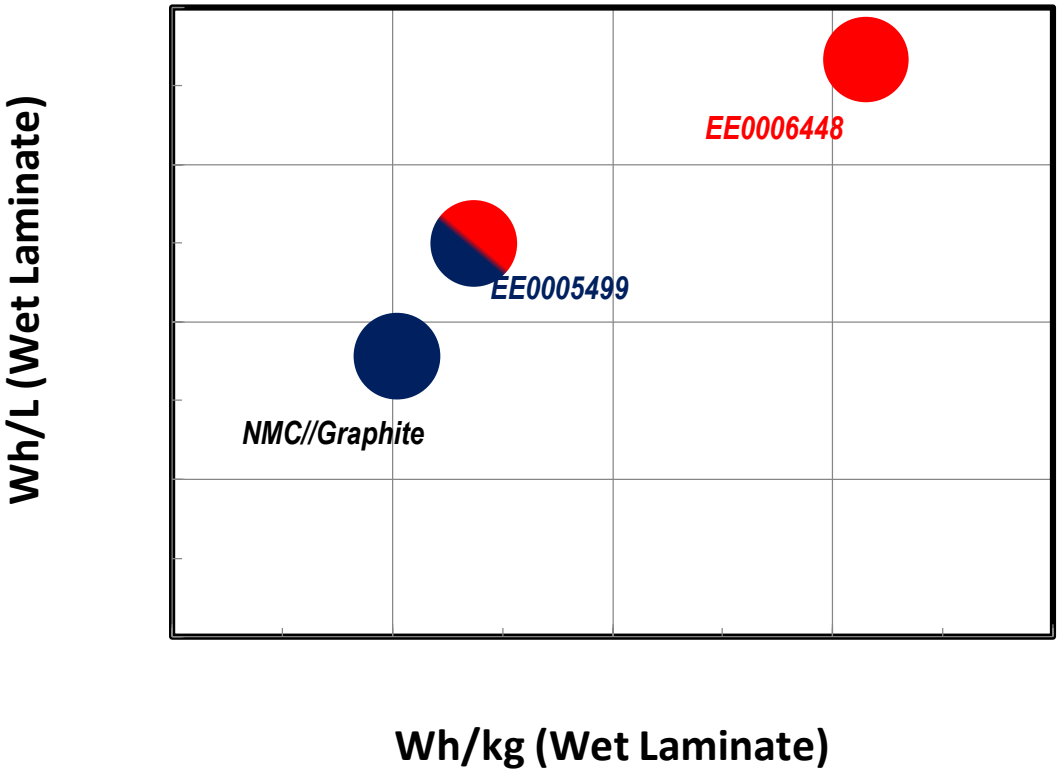
3M and the team appreciates the support and funding provided by DOE

Objective

A collaborative team approach to leverage crucial Li-ion battery technologies and expertise to help enable

Key deliverables

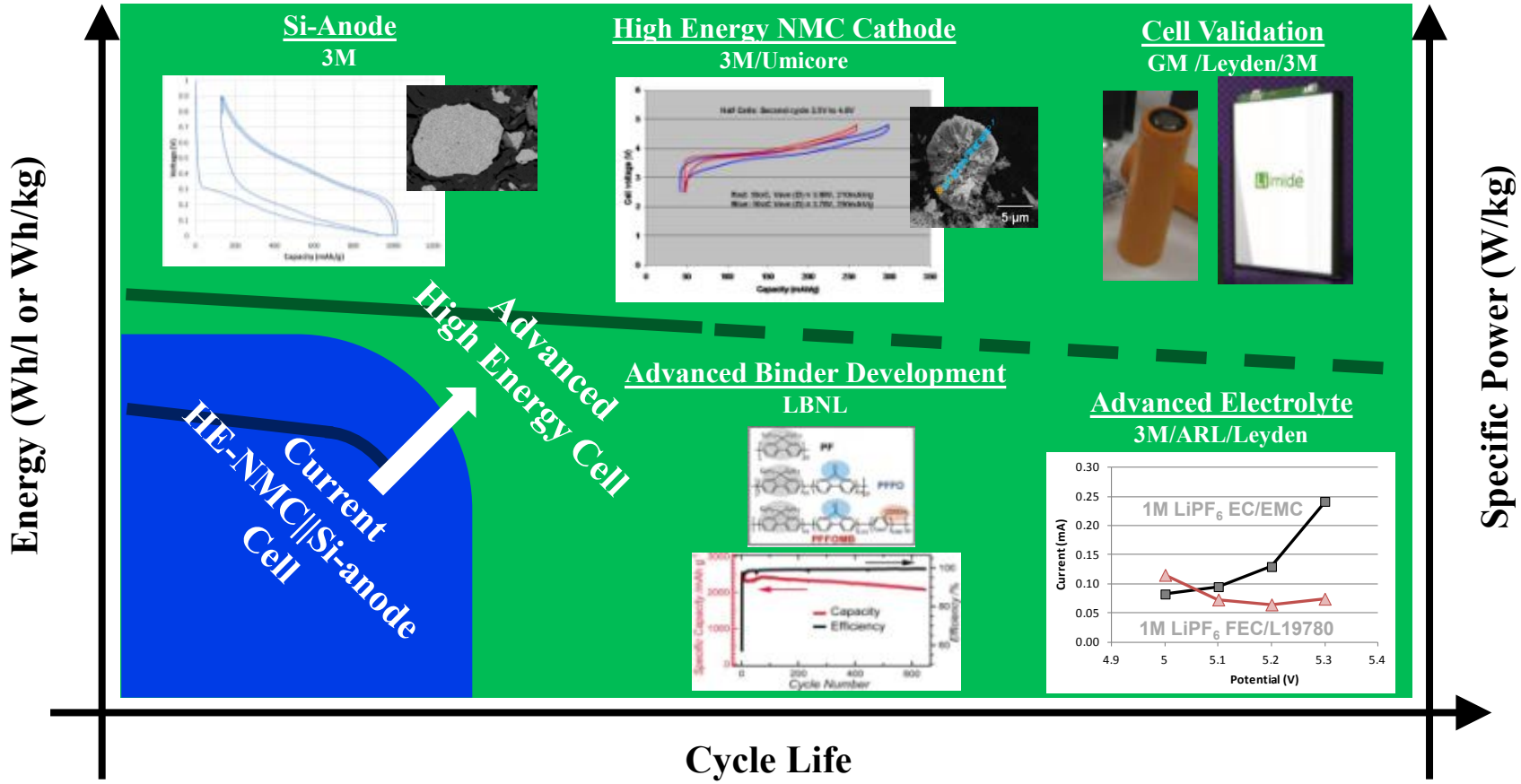
- Advanced High Energy Li-Ion Cell
- Superior Performance Envelope
  - Long Cycle Life,
  - High Power Capability,
  - Wide Operating Temperature
- Lower Cost ($/Wh)



Milestones

Month / Year	Milestone	Status
09/30/2014	Baseline material validation in 18650/pouch cells	✓
09/30/2014	Advanced materials synthesis optimization	✓
03/31/2015	Advanced material development	✓
03/31/2015	Capability demonstration: Full cell data on advanced materials	✓
03/31/2015	Advance materials synthesis and production	✓
09/30/2015	Advanced materials testing	*WIP*
09/30/2015	Final cell deliverable	*WIP*

Approach / Strategy



Synergistic team approach to address vital components.

Approach / Strategy

1. Develop advanced material to meet energy targets

Si Alloy Anode

Scalable process to develop high capacity Si alloy with stable microstructure

Binder - Si Anode

Innovative conductive binder for superior Si anode composite

Advanced Electrolyte / Additives

SEI and high voltage stability to enhance performance

High Energy NMC Cathode

Develop composition with high Wh/kg to increase cell energy

2. Characterize performance in 18650 / pouch cells

Electrode Formulation Study

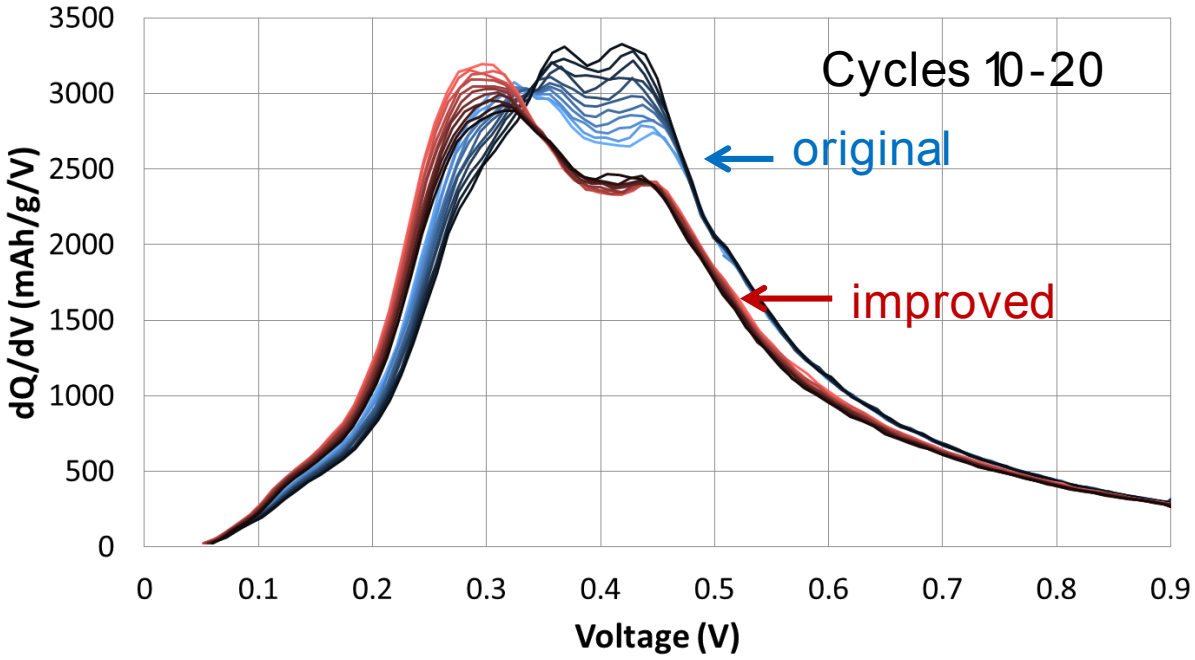
Tune Formation Protocol

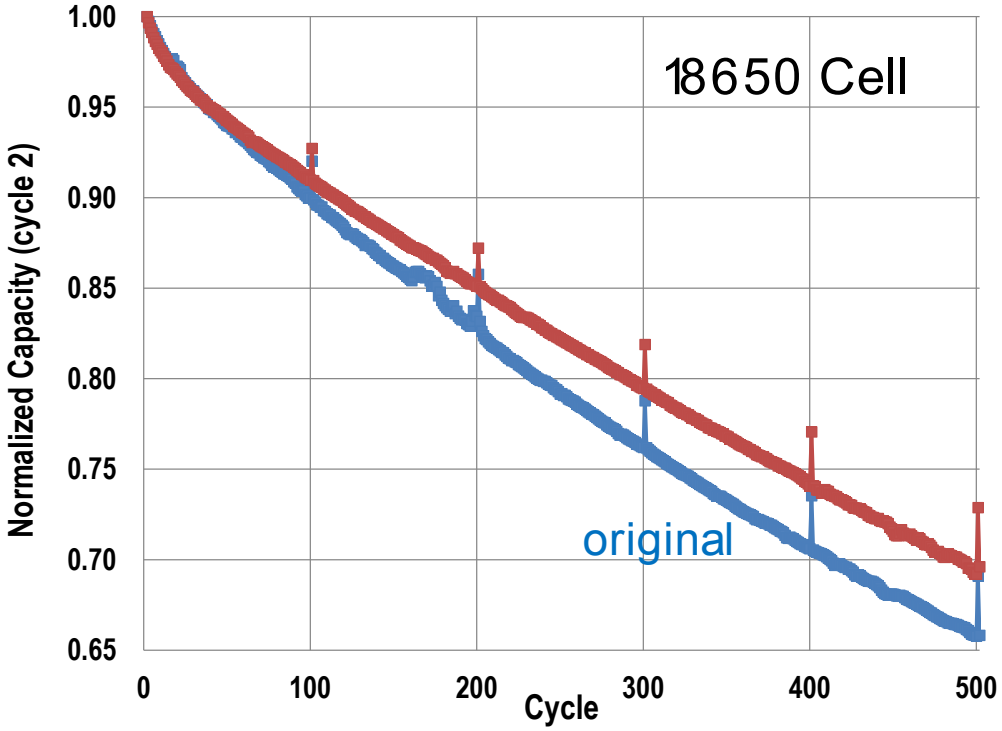
Evaluate Dispersion, Roll to Roll Coating and Drying

Gap Analysis and Diagnostics

Energy and Life Validation

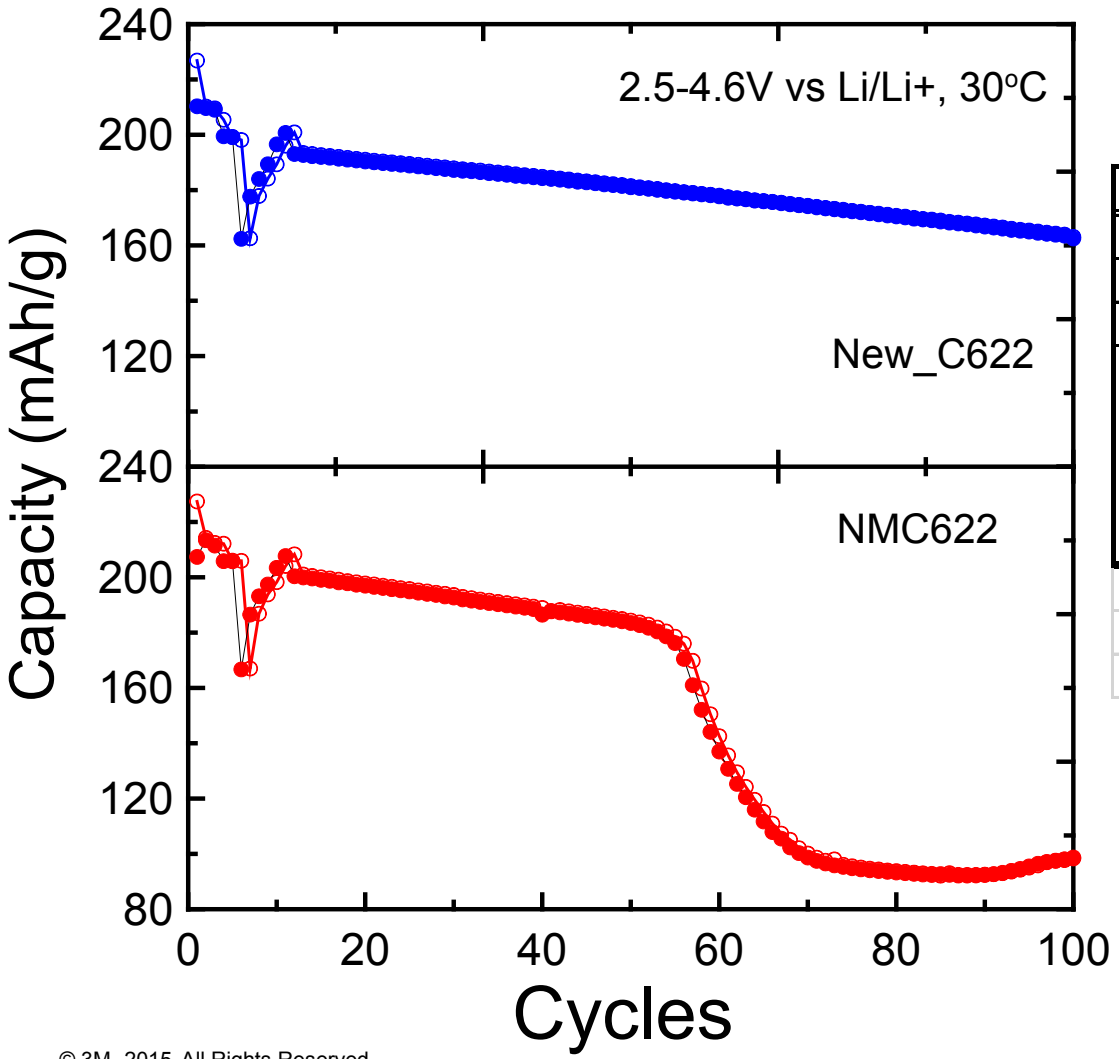
Accomplishment
-Si alloy anode with improved microstructure





Improvement in Si alloy through alloy design and synthesis

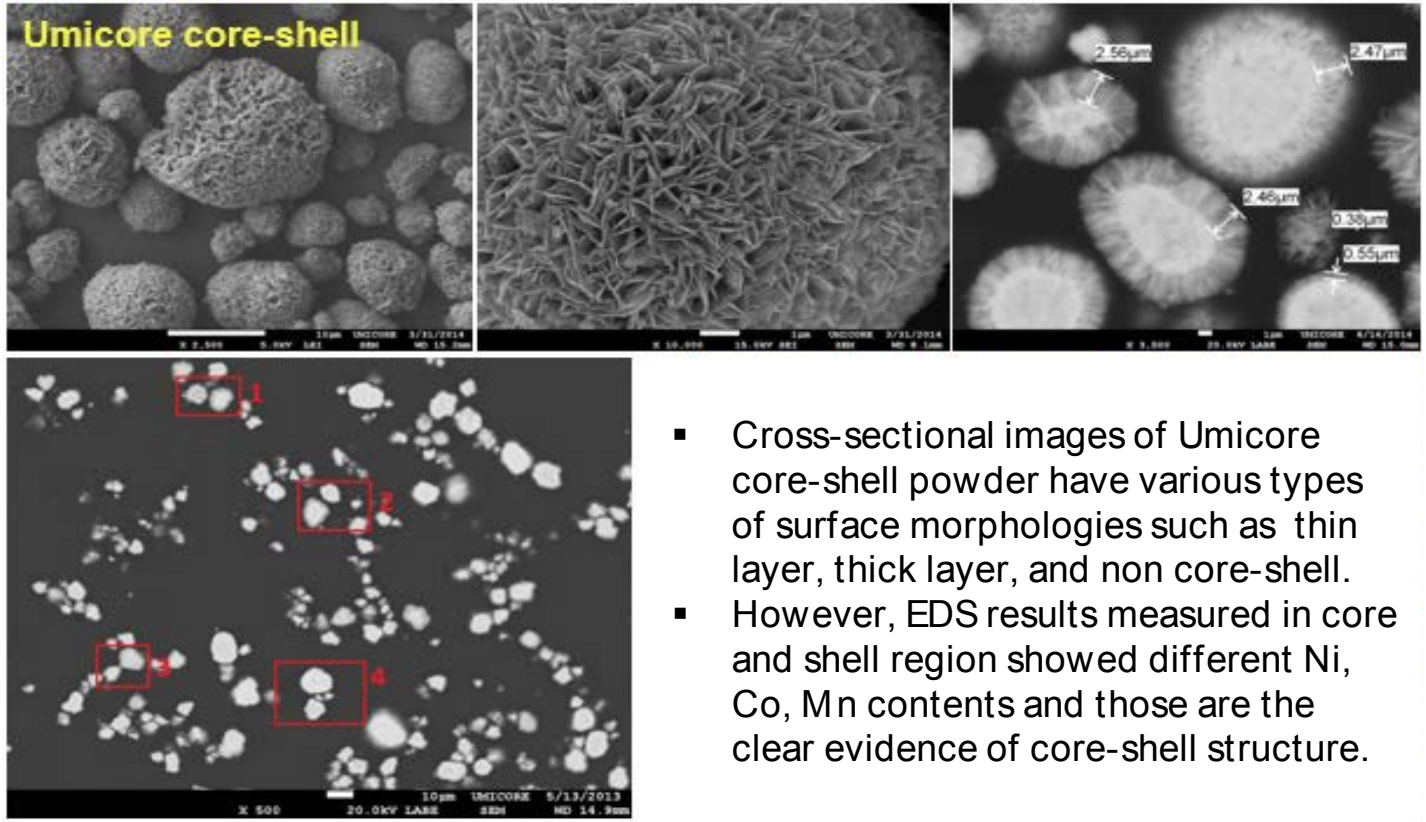
Accomplishment:
- Developed advanced cathode (high voltage NMC)



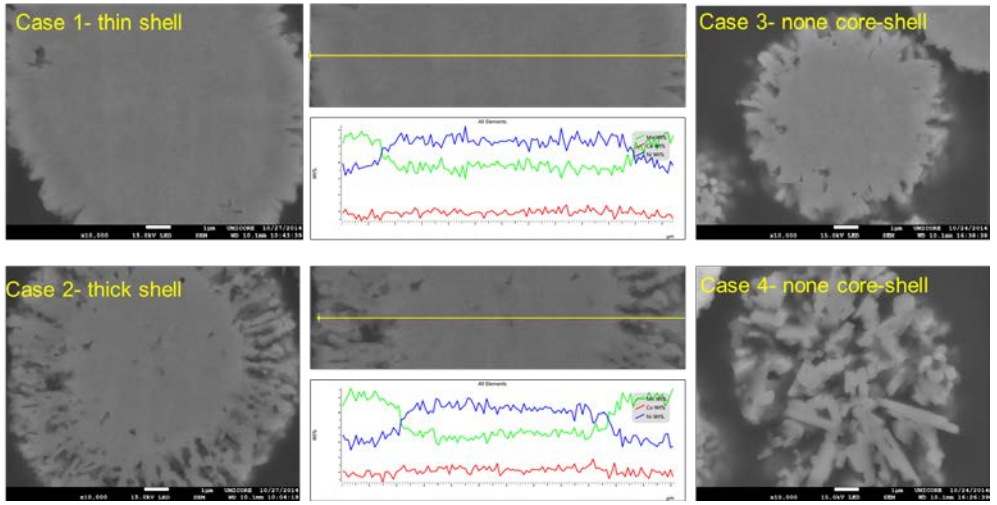
		NMC622		C622		New_C622	
C1	(mAh/g)	234		225		226	
D1	(mAh/g)	211		202		207	
Irr	%	9.8%		10.2%		8.4%	
Gravimetric Capacity (mAh/g)	C/15	211	100%	202	100%	207	100%
	C/10	205	97%	195	97%	200	97%
	C/5	202	96%	191	95%	197	95%
	1C	192	91%	179	89%	185	89%
	2C	187	89%	173	86%	179	86%

2.5-4.6V at 30oC
1C=200mAh/g

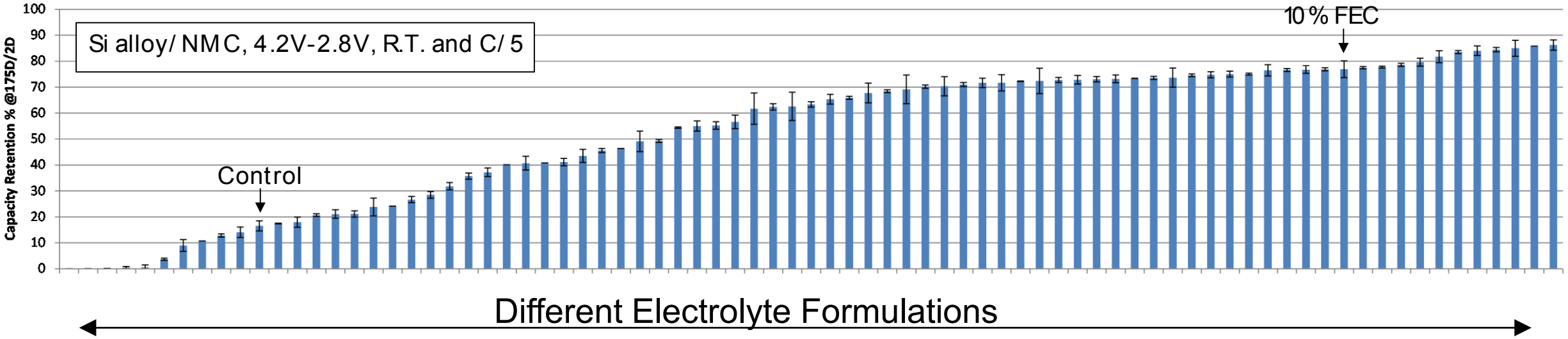
Accomplishment: Umicore
- Cathode scale up with core shell structure



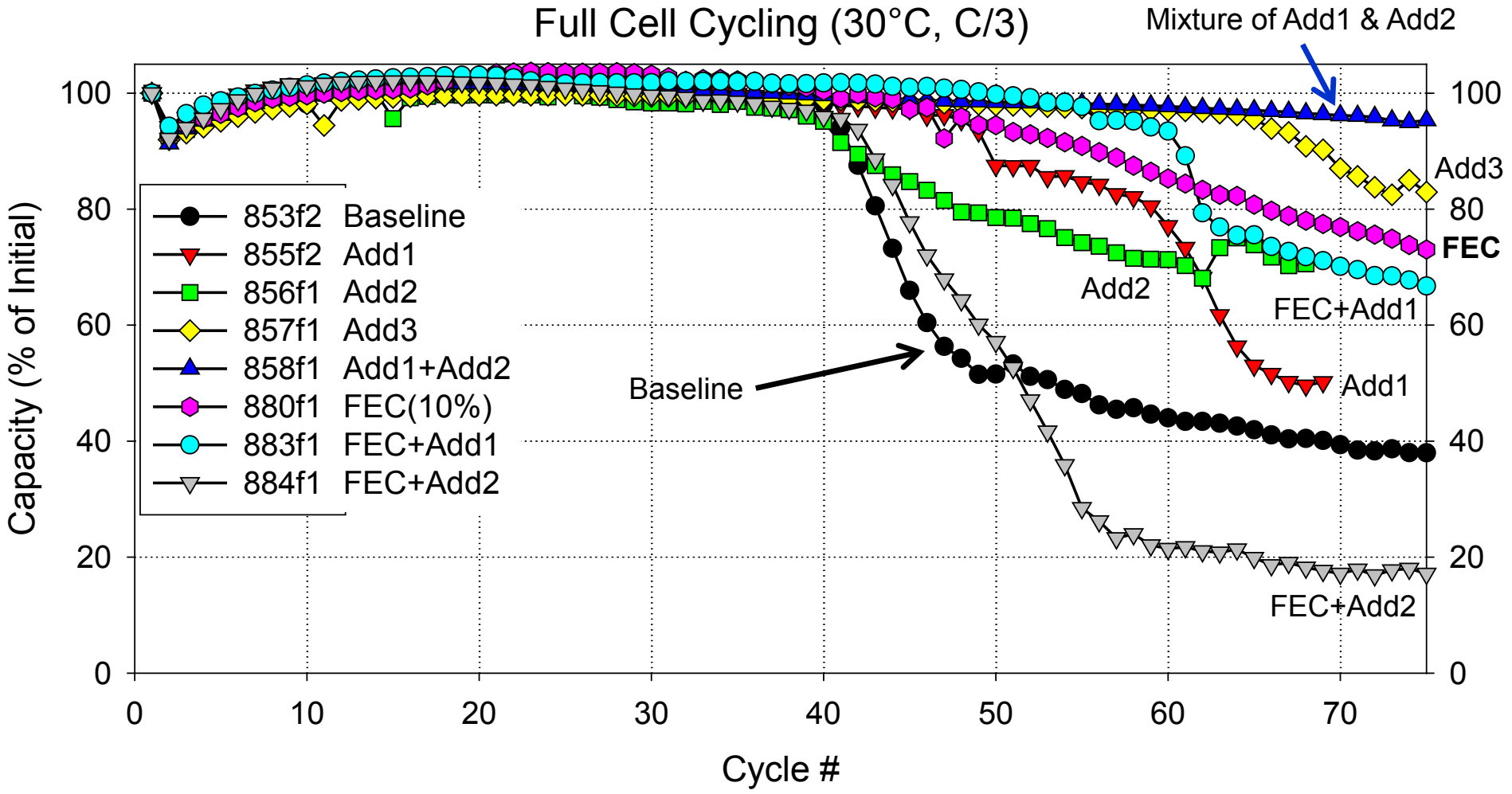
- Cross-sectional images of Umicore core-shell powder have various types of surface morphologies such as thin layer, thick layer, and non core-shell.
- However, EDS results measured in core and shell region showed different Ni, Co, Mn contents and those are the clear evidence of core-shell structure.



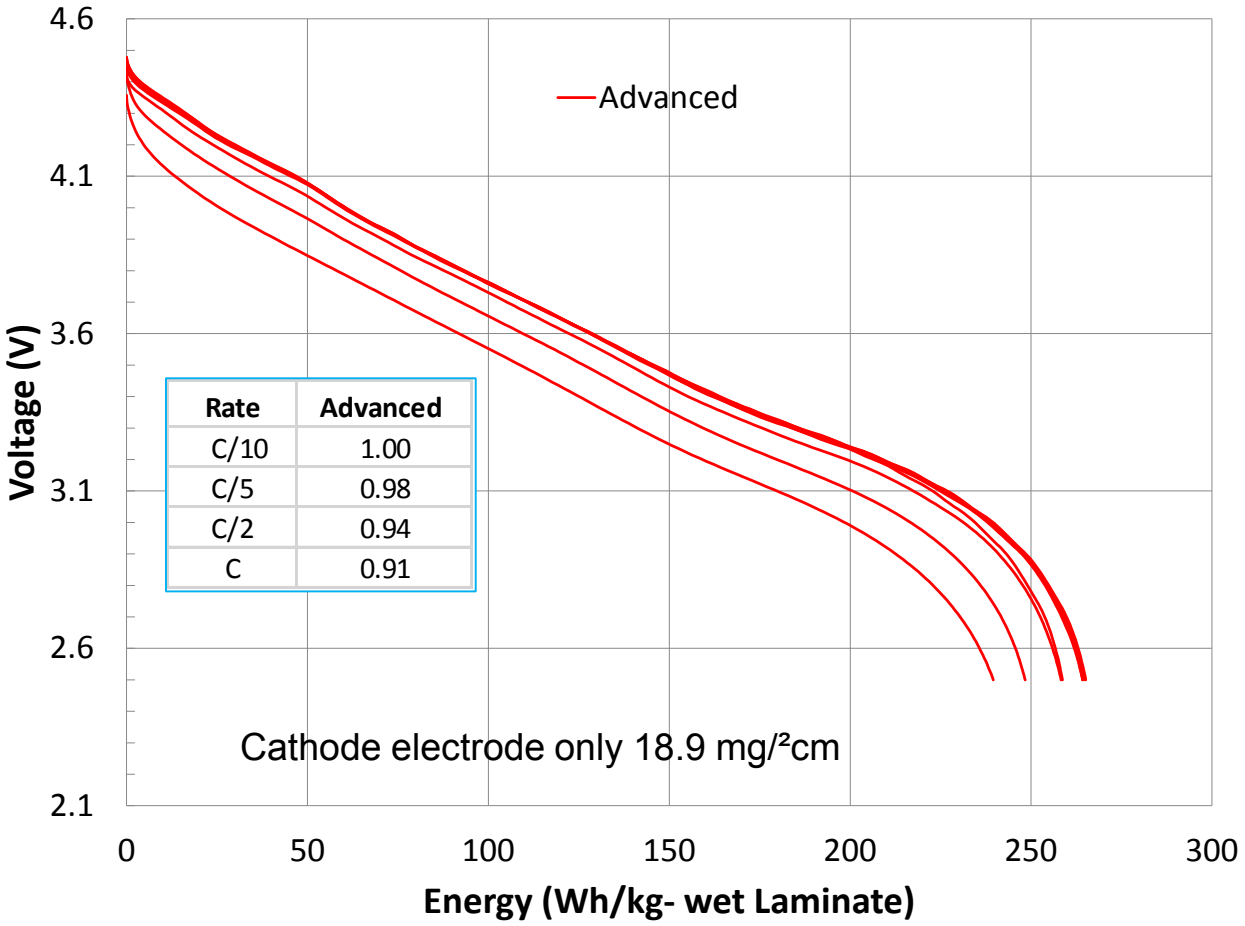
Accomplishment: 3M
- Identified electrolyte to improve cycle life of Si alloy



Accomplishment: Army Research Laboratory - Identified additives to improve cycle life

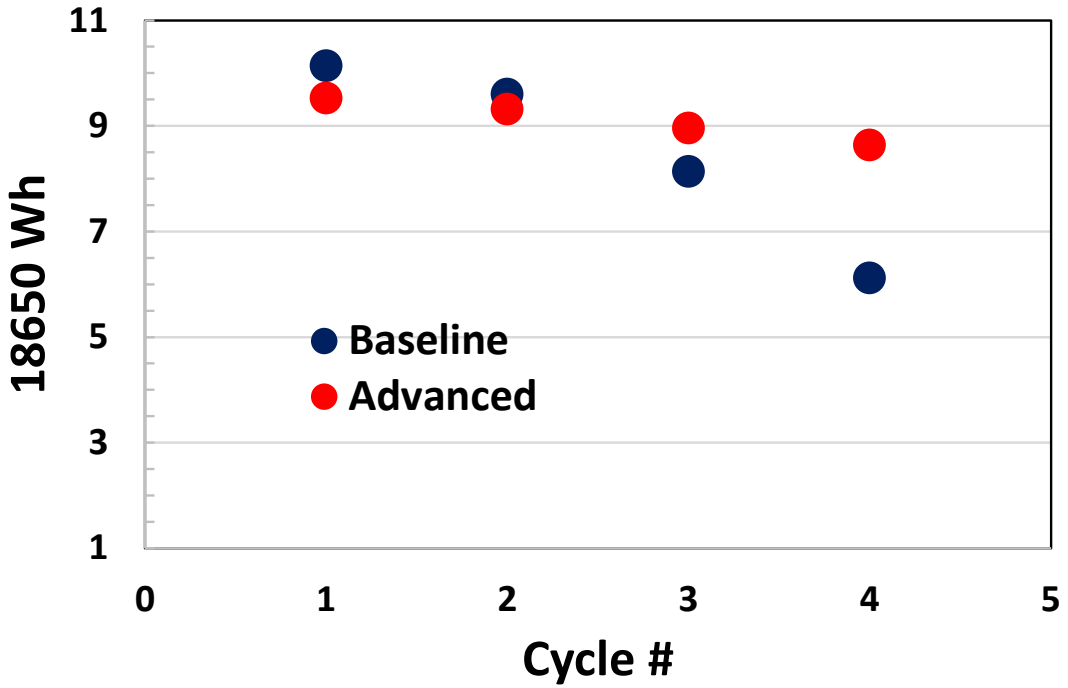


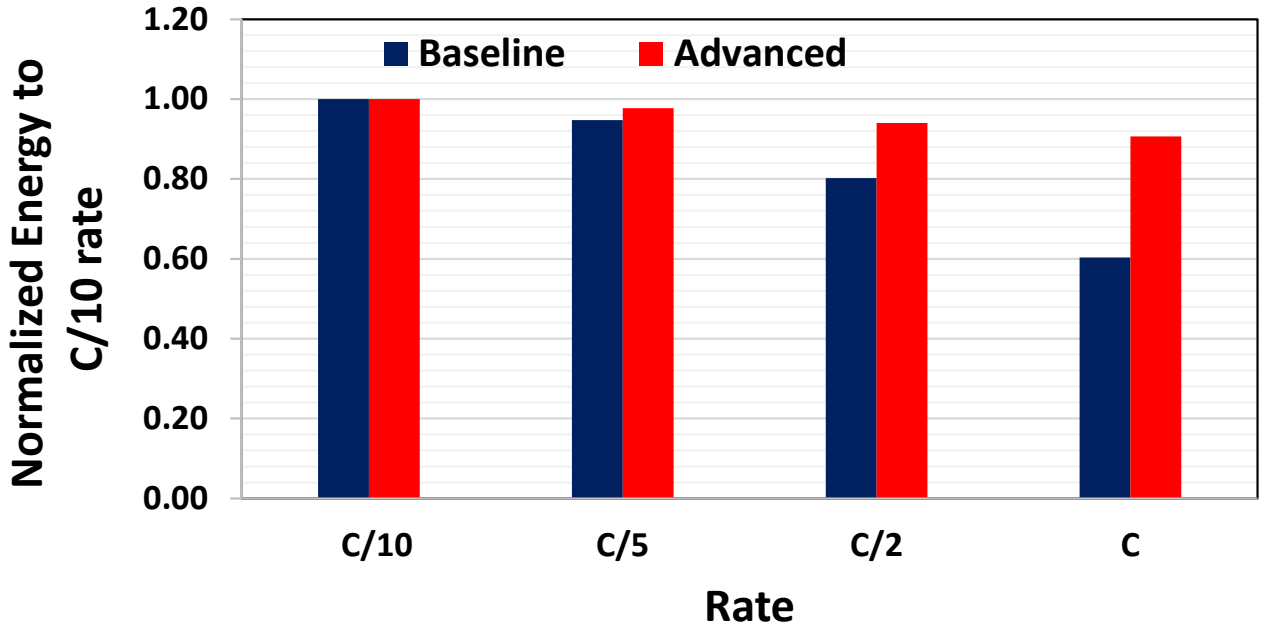
Accomplishment: 3M
- Preliminary 18650 cells with advanced chemistry



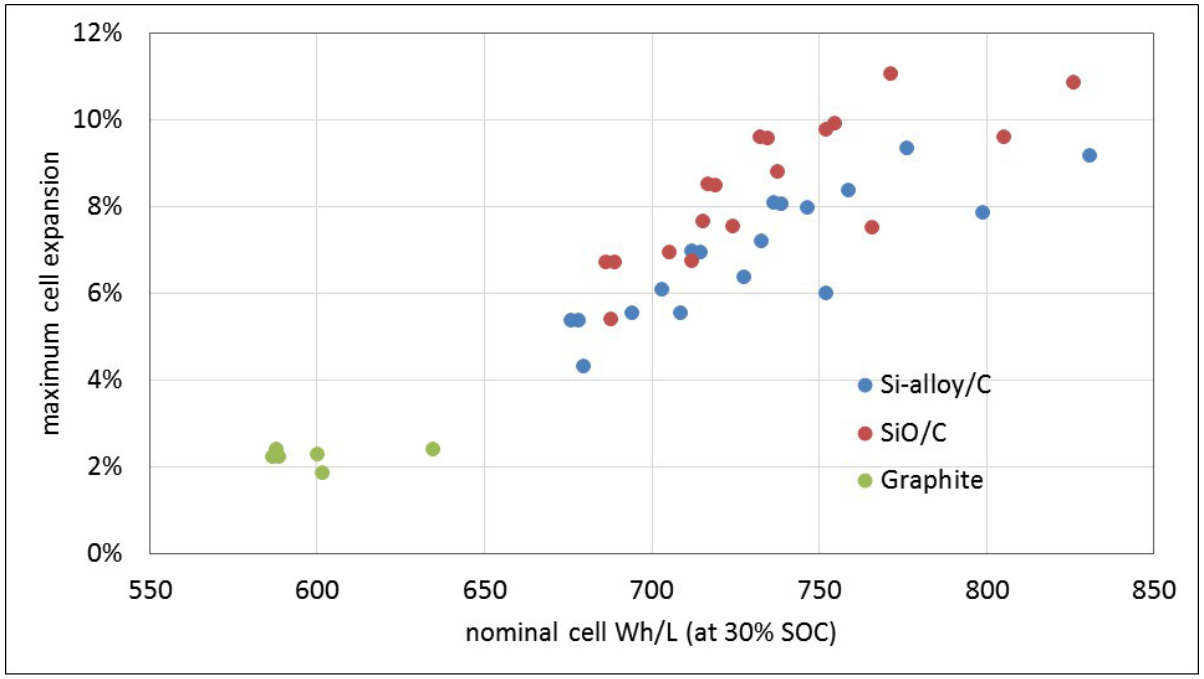
True weight mg/cm2	Density gm/cm3	Porosity	Winding test	.8R Tension	.8R Compression
0.000	0.00	100.00			
27.127	3.35	24.65	Pass	Pass	Pass
30.871	3.51	21.07	Pass	Pass	Borderline pass
33.202	3.46	22.19	Pass	Pass	Fail
33.545	3.29	26.01	Pass	Pass	Fail
33.881	3.14	29.42	Pass	Pass	Fail
0.000	0.00	100.00			

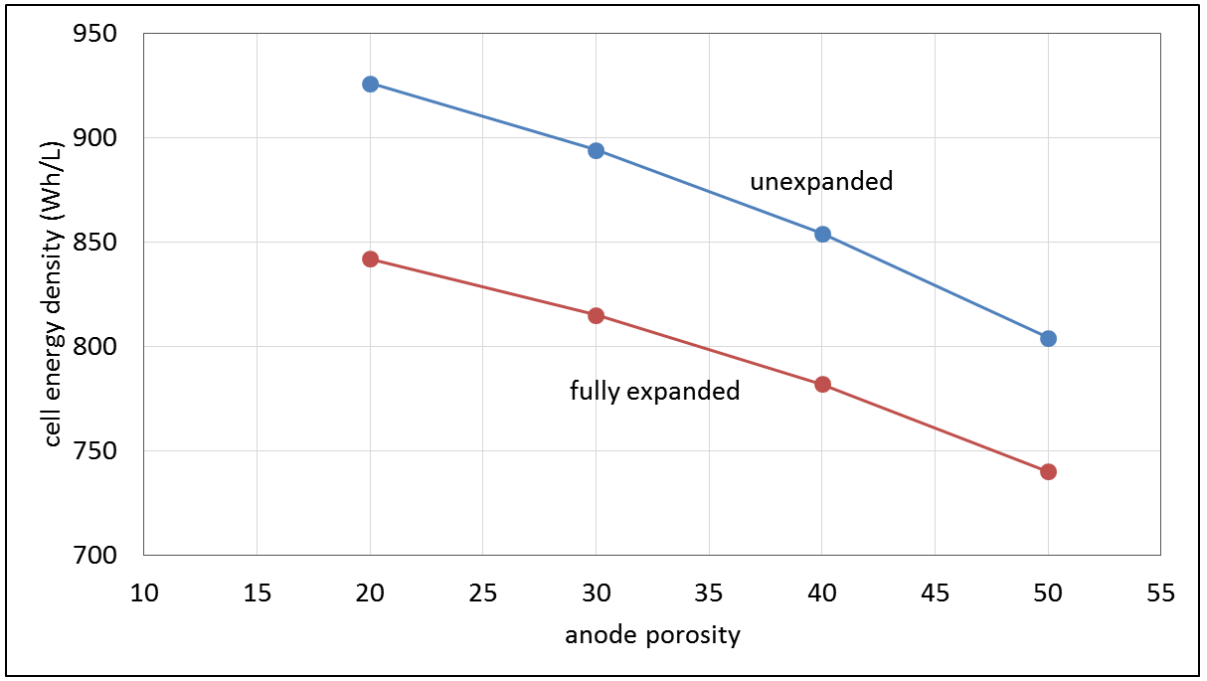
Accomplishment: 3M
- Advanced cell chemistry with better rate capability





Accomplishment: General Motors - Cell energy sizing results





Collaboration and Coordination

- **3M**
  - Sample electrodes (ARL, Leyden, GM), Si alloy anode powder (Leyden, GM, LBNL), high energy NMC cathode powder (Iontensity, GM) and Cells (GM).
- **ARL**
  - Develop and sample electrolyte and additives (3M, Iontensity).
- **GM**
  - Evaluate, analyze and diagnose cells (3M, Iontensity).
- **LBNL**
  - Optimize and evaluate binder chemistry for Si alloy anode (3M).
  - Binder scale up (3M) for testing in 18650 and pouch cells.
- **Leyden Energy**
  - Optimize Composite Electrodes and Pouch Cells. Sample cells (GM, 3M).
- **Umicore**
  - Optimize process and scale up cathode material. Sample materials (3M).

Proposed Future Work

- **Si alloy anode**
  - Scale up for final cell deliverables
- **HE NMC cathode material**
  - Scale up cathode material for final cell deliverables
  - Optimize materials synthesis conditions for scale up
- **Electrolyte and additives**
  - Test different electrolyte formulations with advanced chemistry
  - Identify Materials to Improve Active Material Performance
- **18650 / pouch cell**
  - Optimize electrode formulation and processing, cell design
  - Benchmark cell performance against baseline. Optimize cell performance for long life
  - Deliver final cells to Argonne National Laboratory

Summary

- **Collaborative team R&D in progress**
  - Advanced anode and cathode selected for final deliverable
  - Binder development at LBNL on 3M Si alloy anode
  - Cell modeling with advanced materials at GM
  - Identified electrolyte formulations and additives
  - Preliminary 18650 cell data with advanced cell chemistry
- **Successful scaled up active materials**
  - Baseline materials: High energy NMC and Si alloy anode
  - Advanced materials: Next gen Si alloy anode and 3 kg batch of cathode material
- **Initiated full cell testing with advanced materials**
- **Initiated pouch cell optimization at Iontensity**
  - Electrode formation optimization
  - Electrolyte study