CELL ANALYSIS, MODELING, AND PROTOTYPING (CAMP) FACILITY RESEARCH ACTIVITIES

Project ID: ES030

ANDREW N. JANSEN

2016 U.S. DOE HYDROGEN and FUEL CELLS PROGRAM and VEHICLE TECHNOLOGIES OFFICE ANNUAL MERIT REVIEW AND PEER EVALUATION MEETING

OVERVIEW

Timeline

- Start: October 1, 2014
- Finish: September 30, 2017

Budget

- $2,200 K for FY16
  - 100% DOE-ABR
  - $200 K to NREL

Barriers

- Need a high energy density battery for Electric Vehicle (EV) use that is safe, cost-effective, has long cycle life, and meets or exceeds DOE/USABC goals.
  - Independent validation analysis of newly developed battery materials are needed in cell formats with at least 0.2 Ah before larger scale industrial commitment

Partners

- NREL
- BMW Group
- PPG Industries, Inc.
- Coordinated effort with DOE-EERE-VTO Next Generation Anodes and HE-HV Projects (ANL, LBNL, SNL, ORNL, NREL)
- Argonne Facilities: MERF, EADL, CNM & PTF
- See Collaboration list at end

RELEVANCE/OBJECTIVES

- Transition new high energy battery chemistries invented in research laboratories to industrial production through independent validation and analysis in prototype cell formats (xx3450 pouch & 18650 cells).

- Researchers are often not able to provide the quantities of novel materials needed to make a full size PEV cell to demonstrate the merits of their discoveries. The CAMP Facility is ideally sized to explore new materials with quantities as small as 50 grams for active materials, and even less for electrode/electrolyte additives.

APPROACH

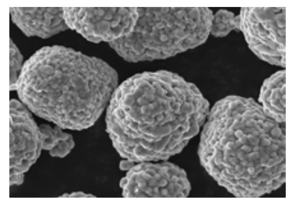
- Researchers submit materials with promising energy density
- Small hand-coated electrodes are made
- Coin cells are made and tested

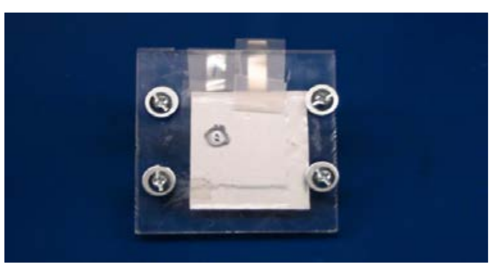
} Glove box Benchtop

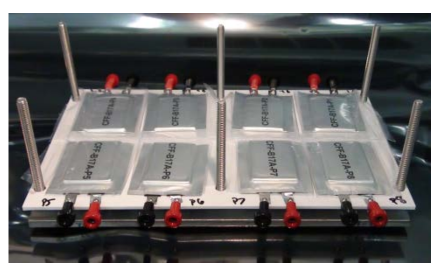
- Larger material samples are obtained (MERF, partnerships, etc.)
- Longer lengths of electrode are made from scaled materials
- Pouch cell or 18650s are made and tested

} Dry Room Pilot scale

- Extensive diagnostics & electrochemical modeling on promising technologies







FY16 PROGRESS MEASURES & MILESTONES

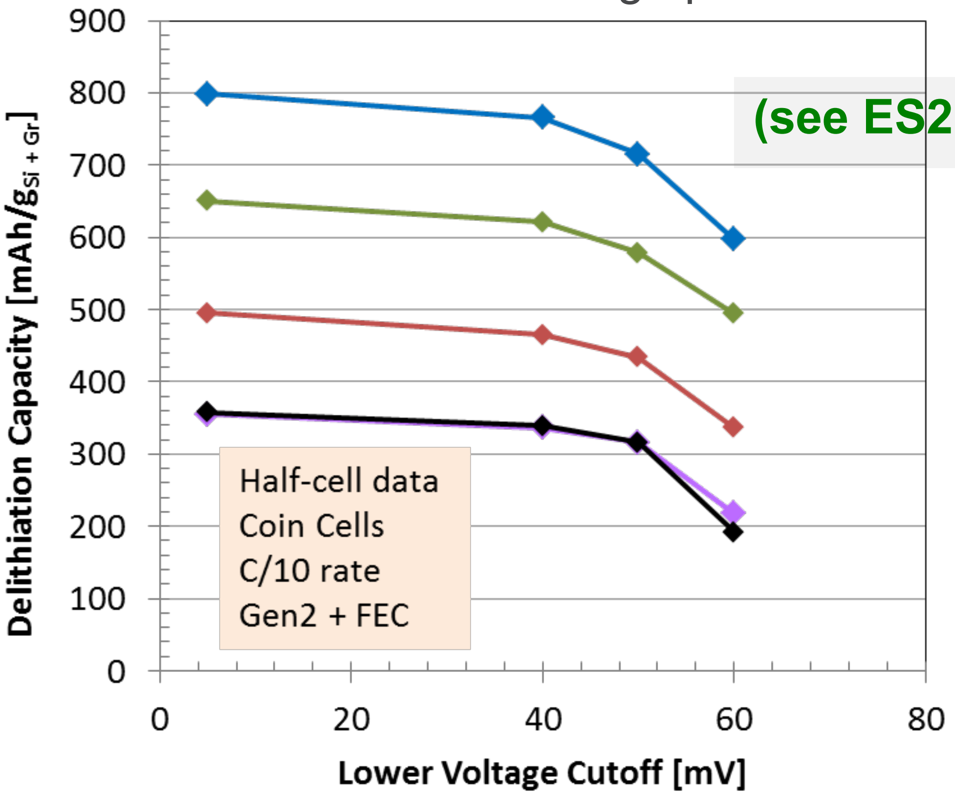
Milestone	Planned End Date	Milestone Type	Status
Deliver to "Next Generation Anodes" project at least 10 meters of single-sided negative electrode based on 15% silicon-graphite with > 2 mAh/cm² loading for baseline	12/23/2015	Progress Measure	**Complete**
Deliver to SNL at least 10 meters of three double-sided negative electrodes with 3 mAh/cm² based on 0, 5, and 15 % silicon with graphite for thermal abuse studies in "Next Generation Anodes" project	3/31/2016	Milestone	**Complete**
Deliver at least 5 single-sided electrodes to "High Energy/High Voltage" project based on latest cathode developments and provide pouch cells as needed	6/30/2016	Progress Measure	**Complete**
Submit final report on advanced battery materials validated in FY16 and summary of Electrode Library activity	9/30/2016	Progress Measure	On-going
Assess performance of full cells with LiFSI and LiTDI-based electrolytes using multiple electrochemical and physicochemical characterization techniques	9/30/2016	Milestone	On-going
Fabricate pouch cells with at least 400 mAh based on latest improvements to silicon-composite negative electrode developed in CAMP and NMC positive electrode	9/30/2016	Milestone	On-going
Advance development of electrochemical models focusing on silicon-composite negative electrodes & NMC positive electrode	9/30/2016	Progress Measure	On-going

TECHNICAL ACCOMPLISHMENTS

- Fabricated silicon-graphite electrodes and pouch cells with 0, 5, 10, and 15% silicon
- Investigated LiFSI salt with FEC and VC electrolyte additives for silicon-graphite electrodes
- Fabricated silicon-graphite electrodes and matched NCM523 for SNL thermal abuse tests
- Measured electrode swelling as a function of silicon content & SOC for silicon-based cells
- Supplied numerous baseline electrodes and prototype electrodes & cells for High-Energy High-Voltage Project **(see ES252, ES253, ES254)**
- Supplied numerous baseline electrodes and technical support for Next Generation Anodes Project **(see ES261, ES262)**
- Fabricated calendered and uncalendered electrodes for NREL's ALD coating scale up
- Held numerous discussions with materials suppliers regarding their materials **(see ES028)**
- Tested Al_2O_3 coating on NCM523 cathode particles **(see ES254)**
- Conducted study with BMW Group on impact of electrode loading on cell performance
- Worked with PPG Industries in CRADA on novel aqueous cathode binder **(see ES263)**
- Explored new versions of conductive binder from LBNL with Argonne's MERF **(see ES168)**
- Fabricated interim pouch cell build for DOE-EERE Award-Amine (high energy couple)
- Fabricated pouch cell builds for DOE-EERE Award-Zhang (high voltage electrolyte)
- Supplied numerous electrodes via Electrode Library and expanded its offerings
- Continued study of silicon-graphite cells with Argonne's Post-Test-Facility
- Expanded electrochemical model for interfacial impedance and bulk transport

SILICON CONTENT HAS SIGNIFICANT IMPACT ON PERFORMANCE

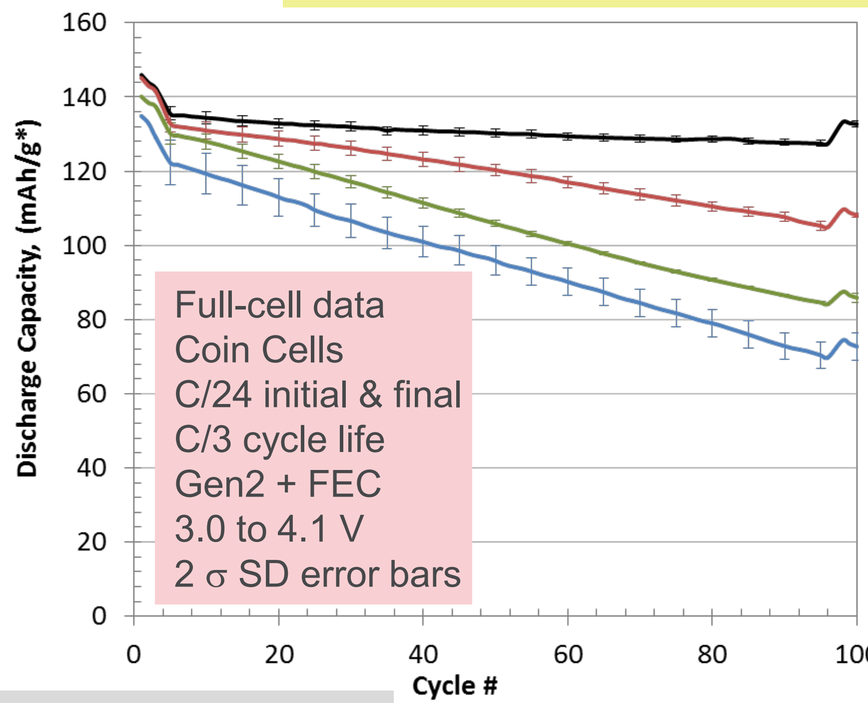
Use coin cell data to design pouch cells



(see ES261, ES262)

- 0% Silicon, PVDF
- 0% Silicon, LiPAA
- 5% Silicon (50-70 nm)
- 10% Silicon (50-70 nm)
- 15% Silicon (50-70 nm)

- Presence of even 5% silicon leads to significant drop in capacity retention
- Cycling performance worsens with increasing silicon content
- 10% and 15% have similar capacity fade rates



* weight of NCM 523

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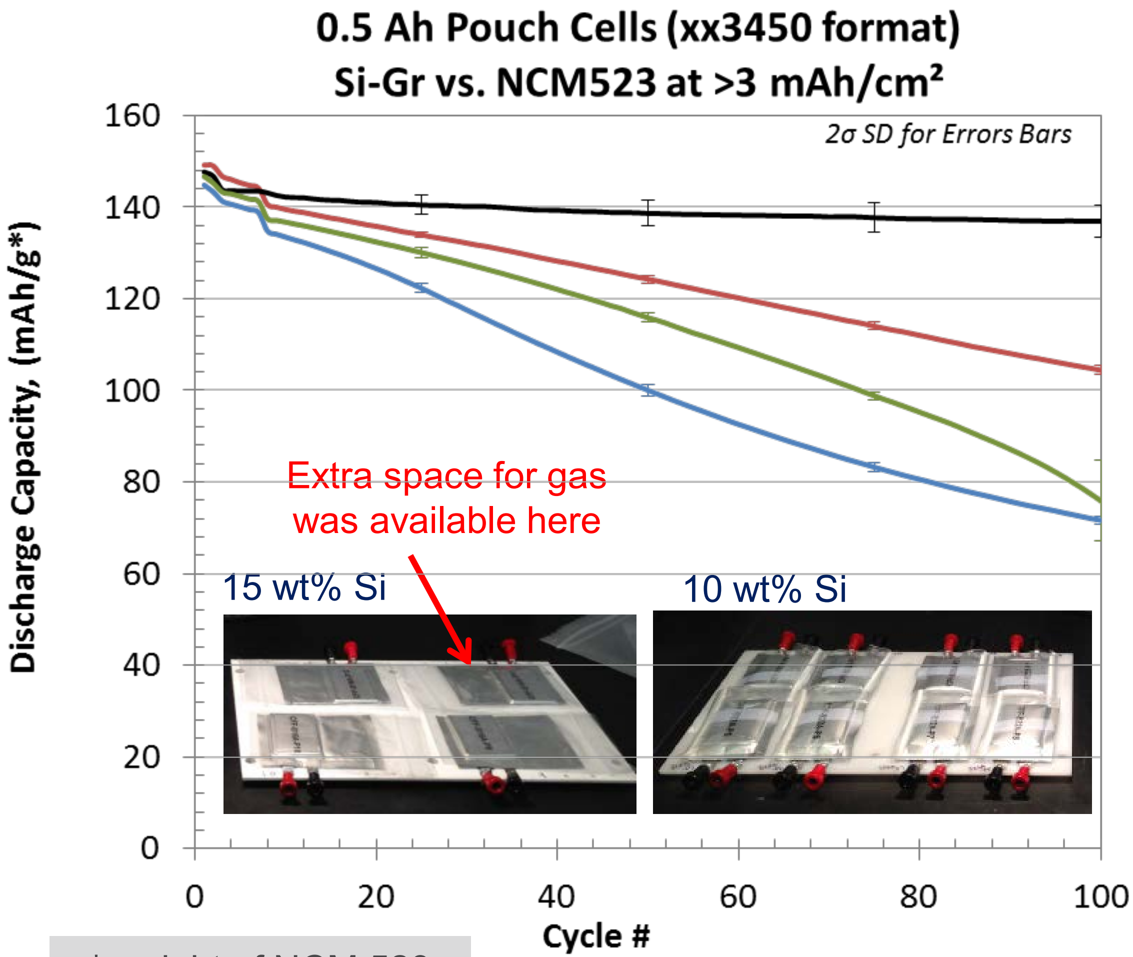
CYCLING PROBLEMS ALSO SEEN IN MULTI-LAYER 0.5 Ah POUCH CELLS – BUT WITH GASSING TOO



10% silicon cells had severe performance drop at ~cycle 100 → gassing observed during cycling and smaller available volume caused cell to “balloon” and lose initial stack pressure

* weight of NCM 523

- C/3 Charge And C/2 Discharge
- 1.2M $LiPF_6$ in EC:EMC 3:7 by wt. + 10wt.% FEC
- 3.0 to 4.1V, 30°C

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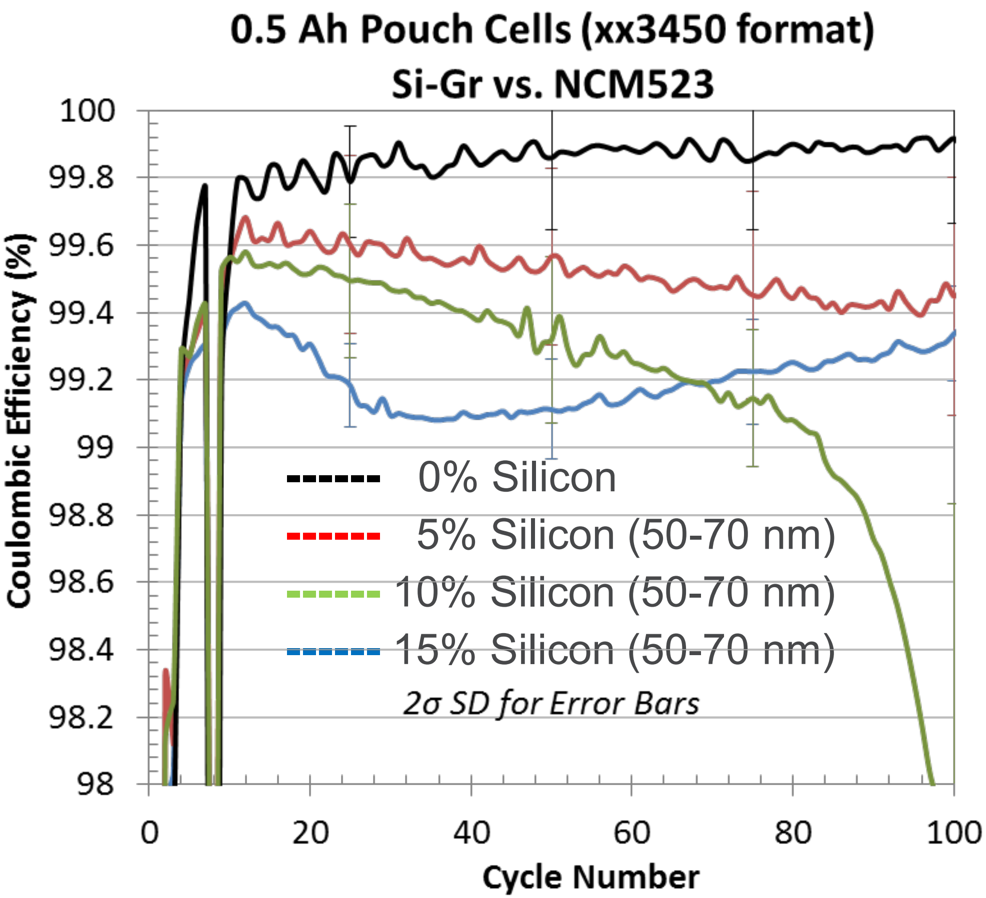
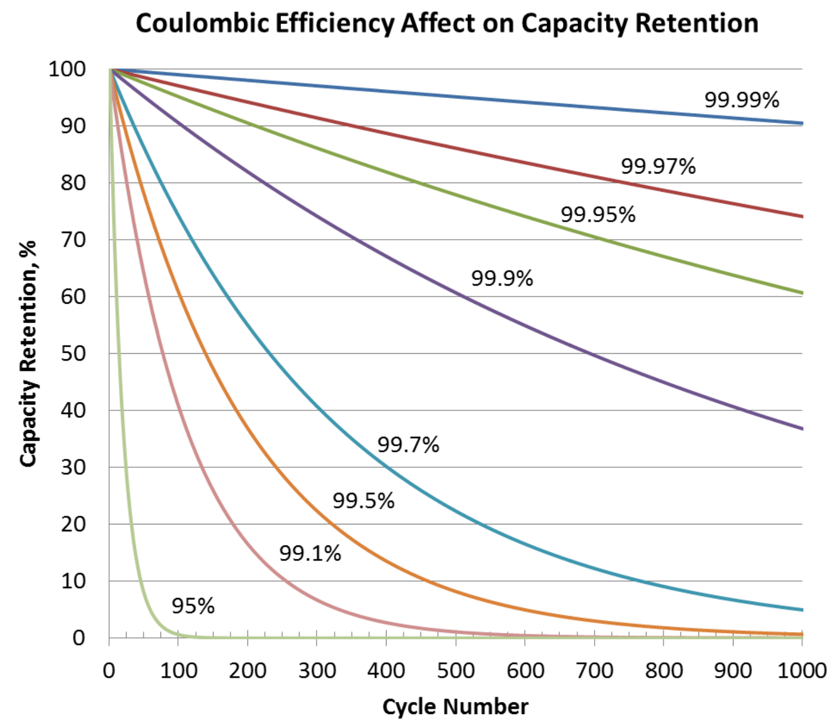
DESPITE OPTIMIZATION OF SILICON-GRAPHITE ELECTRODE, CYCLE LIFE SEVERELY LIMITED

Due to Poor Coulombic Efficiency





A coulombic efficiency >99.98% is needed to reach 1000 cycles with 80% of capacity remaining.

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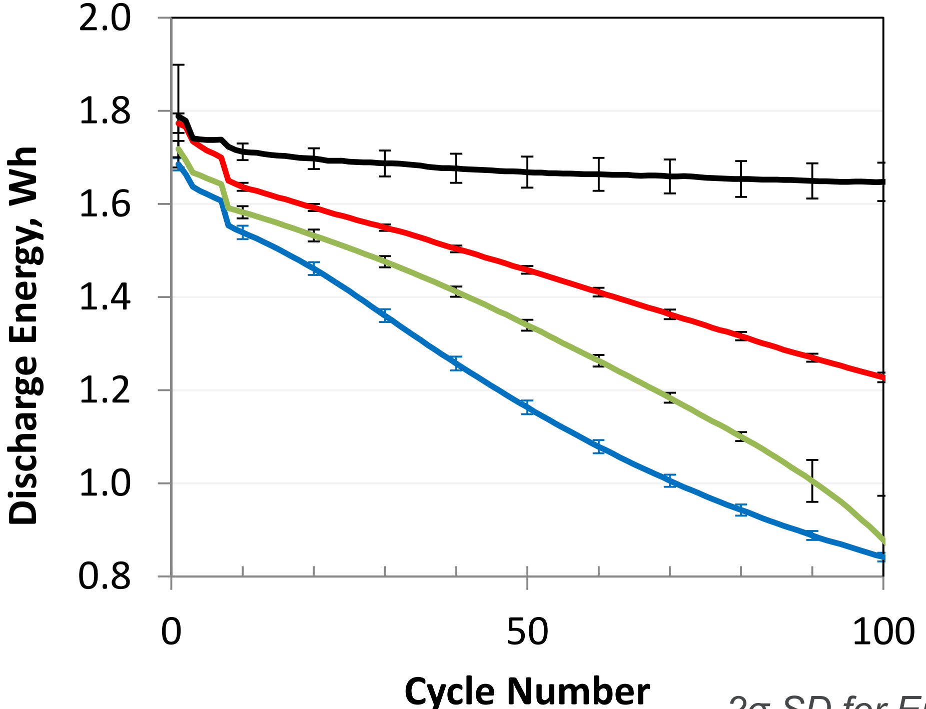
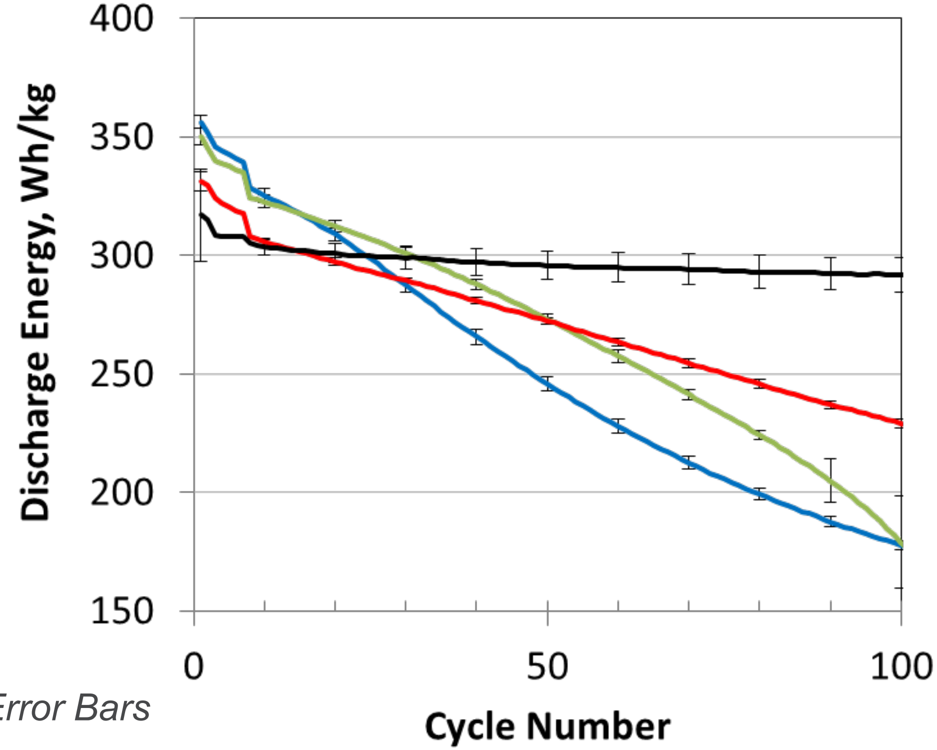
SILICON'S POSITIVE IMPACT ON SPECIFIC ENERGY OF POUCH CELLS (0%,5%,10%,15% NANO-SILICON)

0.5 Ah Pouch Cells (xx3450 format) Si-Gr vs. NCM523





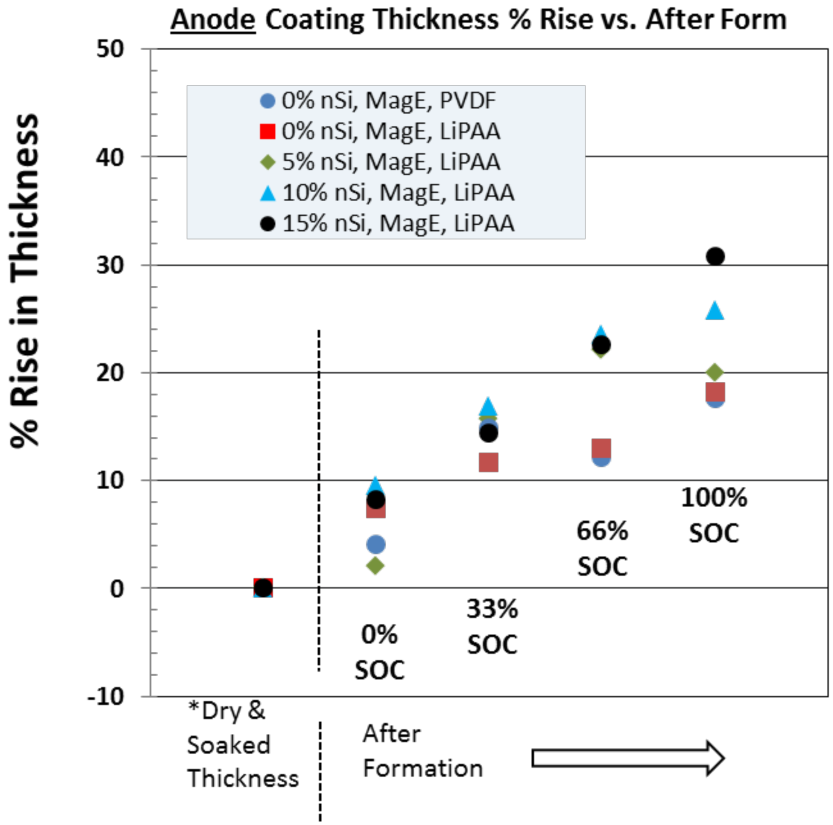
2σ SD for Error Bars

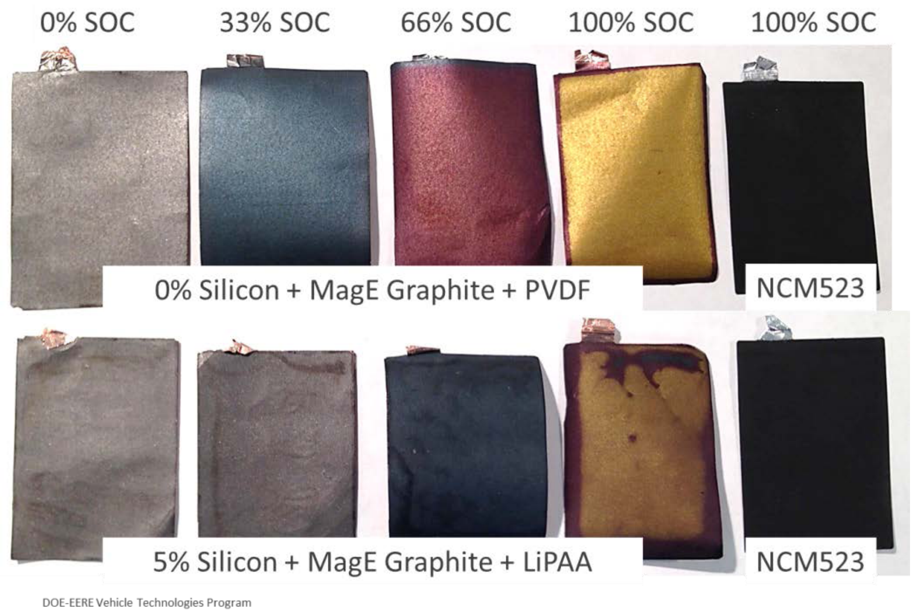
Wh

- 0% Silicon
- 5% Silicon (50-70 nm)
- 10% Silicon (50-70 nm)
- 15% Silicon (50-70 nm)

Wh/kg (No hardware, foil, separator, or electrolyte)

SWELLING MUST BE ACCOUNTED FOR IN ELECTRODE DESIGN





Cathode and separator showed negligible change

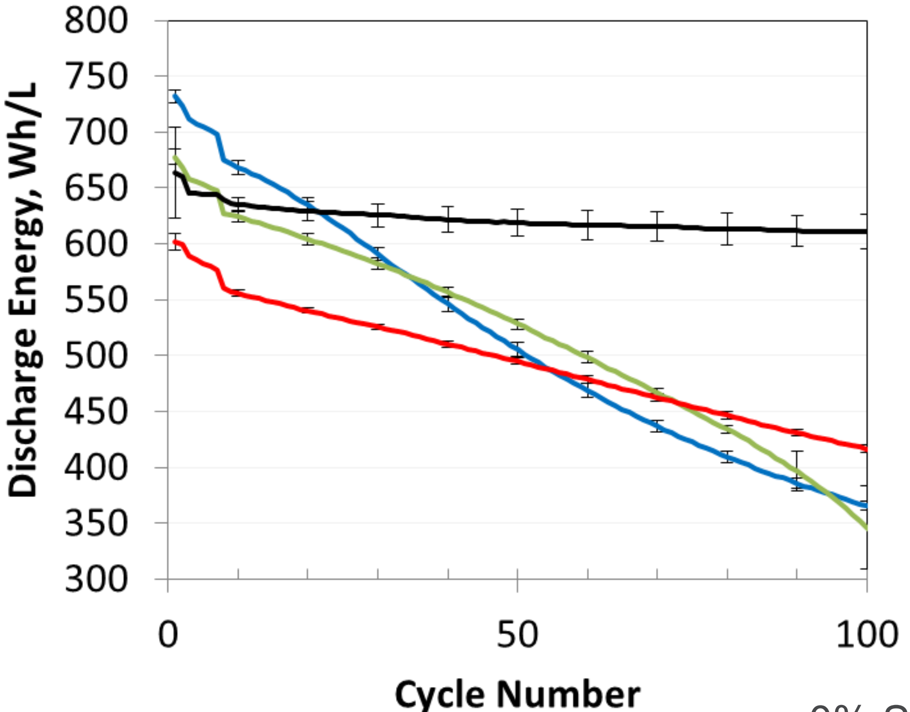
***Electrode soaked in electrolyte (4 days) showed no change in thickness vs. dry fresh electrode**

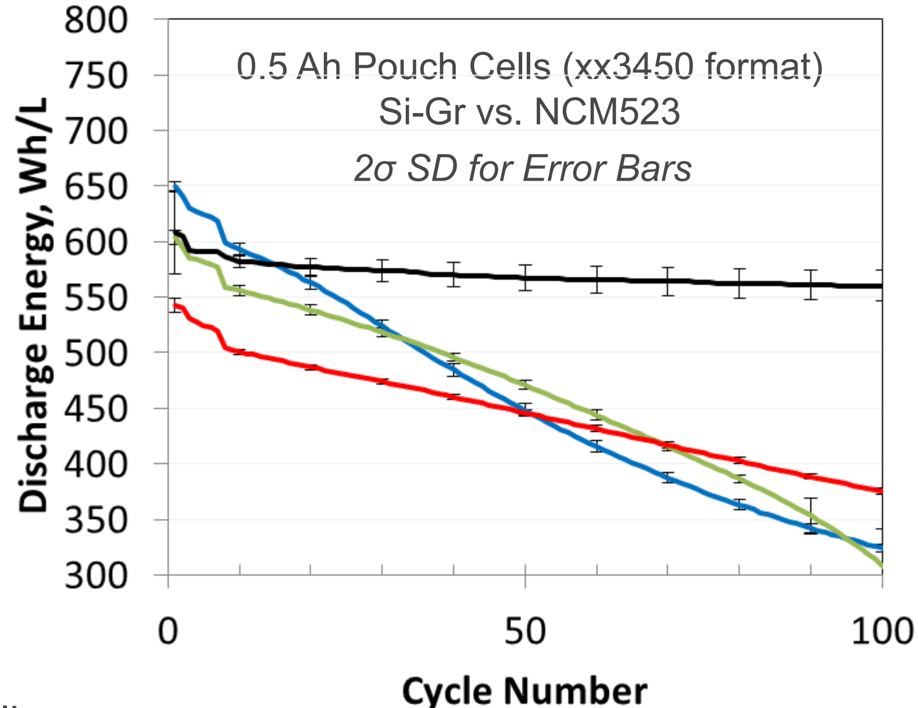
2 mAh/cm² loading
Single layer pouch cells

Jansen, *et al*., ECS 2015, IMLB 2016

SWELLING LOWERS ENERGY DENSITY OF SILICON CELLS MORE SO THAN FOR GRAPHITE CELLS

Volumetric energy density improved for >10% silicon, if maintained





------ 0% Silicon
------ 5% Silicon (50-70 nm)
------ 10% Silicon (50-70 nm)
------ 15% Silicon (50-70 nm)

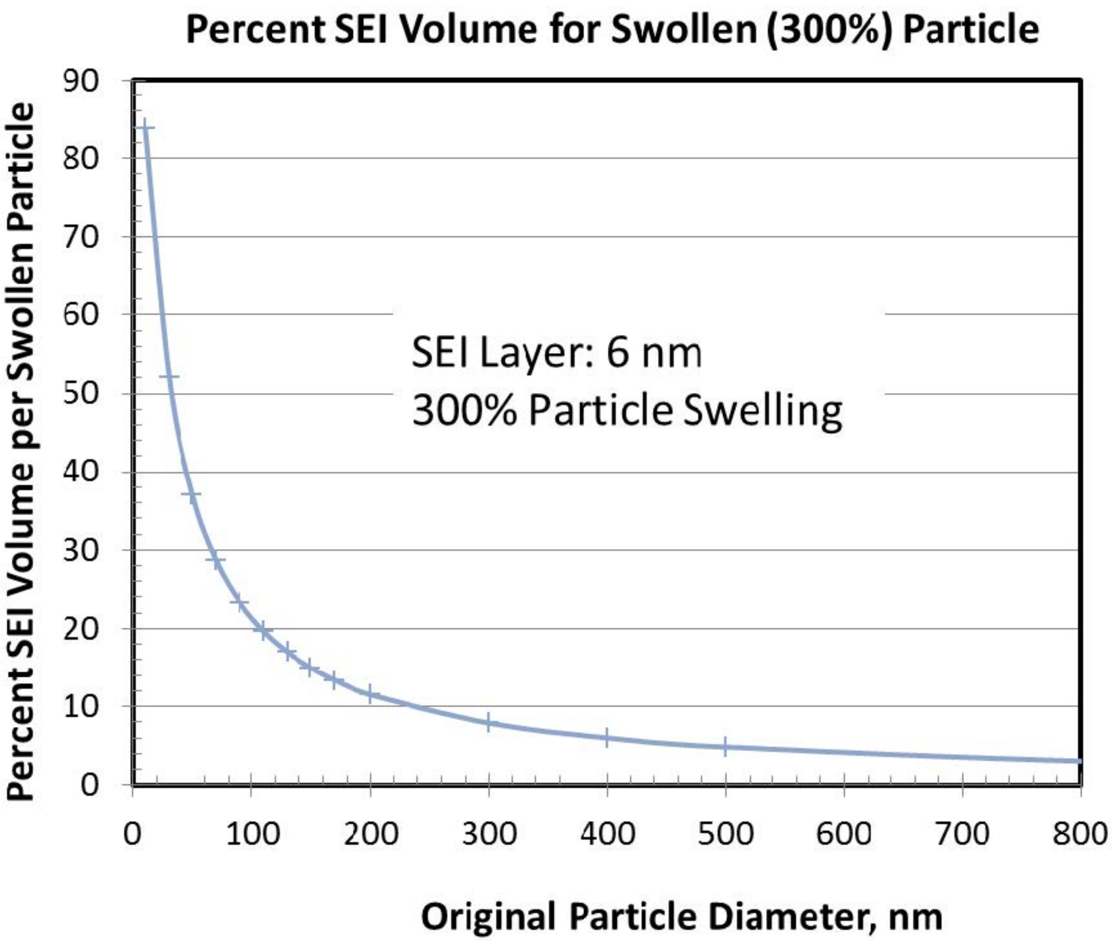
Wh/L
(Before Formation)
(No hardware, foil, or separator)

Wh/L
(100% SOC)
(No hardware, foil, or separator)

Porosity not optimized

IMPACT OF VOLUME EXPANSION AND SEI FILM ON SILICON PARTICLE – USE LARGER SILICON PARTICLES

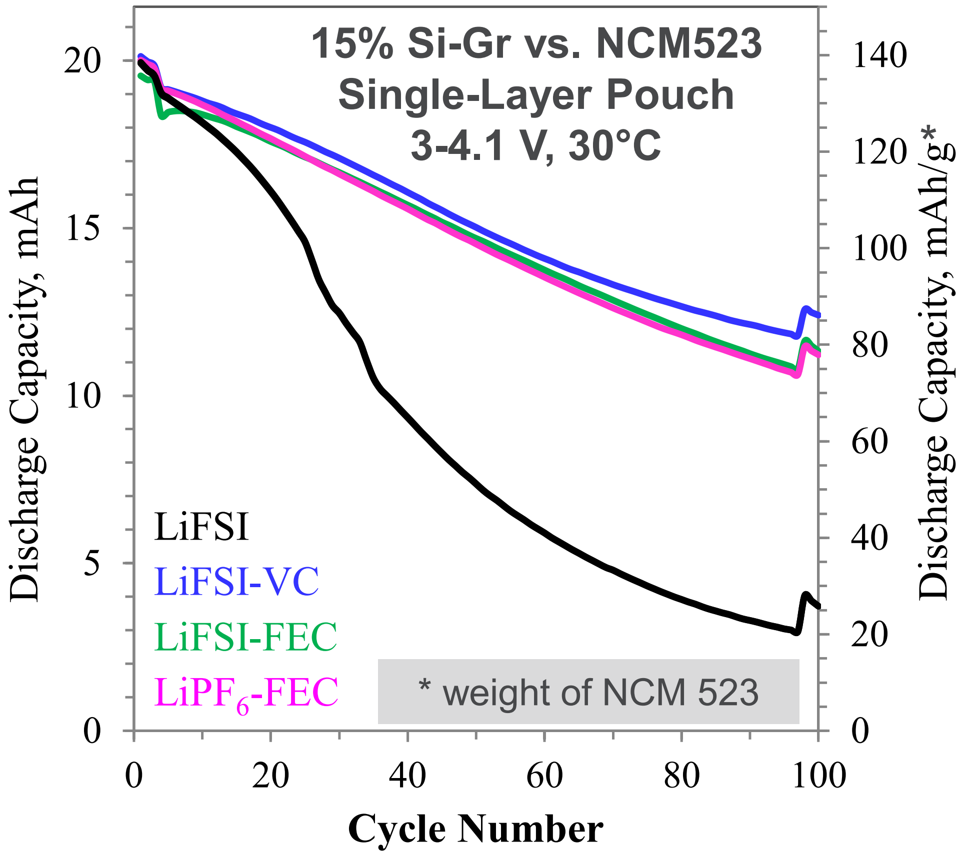
SEI thickness recently measured by Gabe Veith (ORNL)



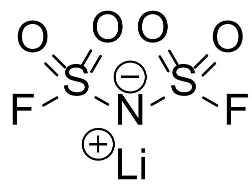
Graphite	Silicon
372 mAh/g	~3800 mAh/g
818 mAh/mL	~8800 mAh/mL
Volume Expansion	
~10 %	~300 %

- Move toward 70-130 nm Si from NanoAmor
- Calculate impact on electrode energy density
- Calculate amount of SiO_2
- Need density estimate of SEI film

SILICON PERFORMANCE NOT IMPROVED BY CHANGE IN SALT



Trask, et al., JES **163** (2016)
Shkrob, et al., J. Phys. Chem. C ***119*** *(2015)*



- Shows a thermal stability up to 200°C in thermogravimetric tests
- More stable toward hydrolysis
- Higher ionic conductivity over a wide temperature range (-50 to 50 ˚C)
- Does not passivate Al above 4.2V vs. Li

The LiFSI cell capacity retention is similar to that for a LiPF6 “Gen2” electrolyte cell.

VC and FEC addition significantly improves cell capacity retention possibly due to crosslinked polymer formation in SEI

FABRICATED SILICON ELECTRODES FOR NEXT GENERATION ANODES PROJECT

Electrodes also in CAMP Electrode Library

Cathode: A-C013A
90 wt% Toda NCM 523
5 wt% Timcal C45
5 wt% Solvay 5130 PVDF

Al Foil Thickness: 20 µm
Total Electrode Thickness: 62 µm
Coating Thickness: 42 µm
Porosity: 33.6%
Coating Loading: 11.32 mg/cm^2
Coating Density: 2.70 g/cm^3

- ~2 mAh/cm^2 electrode couples
- Matched to ~1.10 to 1.30 n:p ratio

(see ES261, ES262)

0% nSi

Anode: A-A007
91.83 wt% Hitachi MagE graphite
2 wt% Timcal C45 carbon
6 wt% Kureha 9300 PVDF Binder
0.17 wt% Oxalic Acid

Cu Foil Thickness: 10 µm
Total Electrode Thickness: 51 µm
Coating Thickness: 41 µm
Porosity: 29.9%
Coating Loading: 6.23 mg/cm^2
Coating Density: 1.52 g/cm^3

5% nSi

Anode: A-A009
83 wt% Hitachi MagE
5 wt% Nano&Amor Silicon (50-70nm)
2 wt% Timcal C45
10 wt% LiPAA (LiOH titrate)

Cu Foil: 10 microns
Total Electrode: 59 microns
Coating Thickness: 49 microns
Porosity: 46.1%
Coating Loading: 5.36 mg/cm^2
Coating Density: 1.10 g/cm^3

10% nSi

Anode: A-A008
78 wt% Hitachi MagE
10 wt% Nano&Amor Silicon (50-70nm)
2 wt% Timcal C45
10 wt% LiPAA (LiOH titrate)

Cu Foil: 10 microns
Total Electrode: 43 microns
Coating Thickness: 33 microns
Porosity: 46.0%
Coating Loading: 3.63 mg/cm^2
Coating Density: 1.10 g/cm^3

15% nSi

Anode: A-A006A
73 wt% Hitachi MagE
15 wt% Nano&Amor Silicon (50-70nm)
2 wt% Timcal C45
10 wt% LiPAA (LiOH titrate)

Cu Foil: 10 microns
Total Electrode: 40 microns
Coating Thickness: 30 microns
Porosity: 46.4%
Coating Loading: 3.28 mg/cm^2
Coating Density: 1.10 g/cm^3

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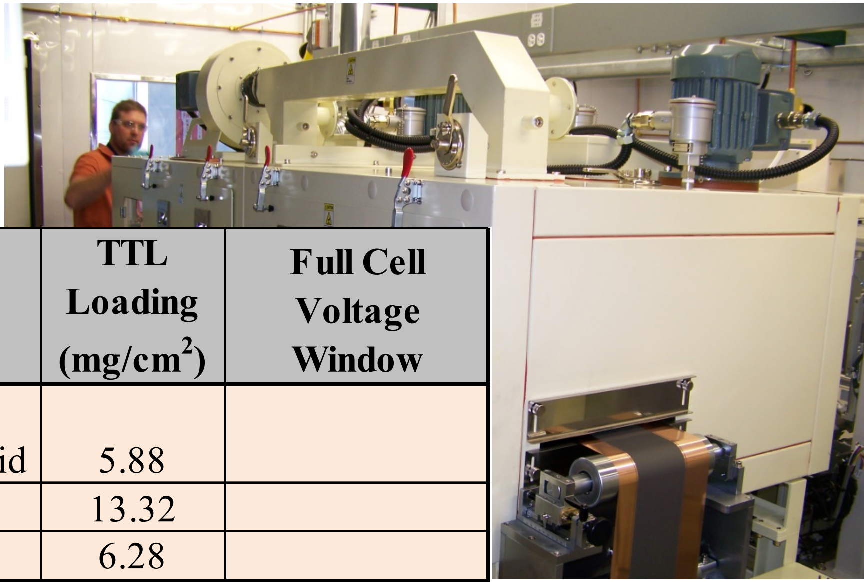
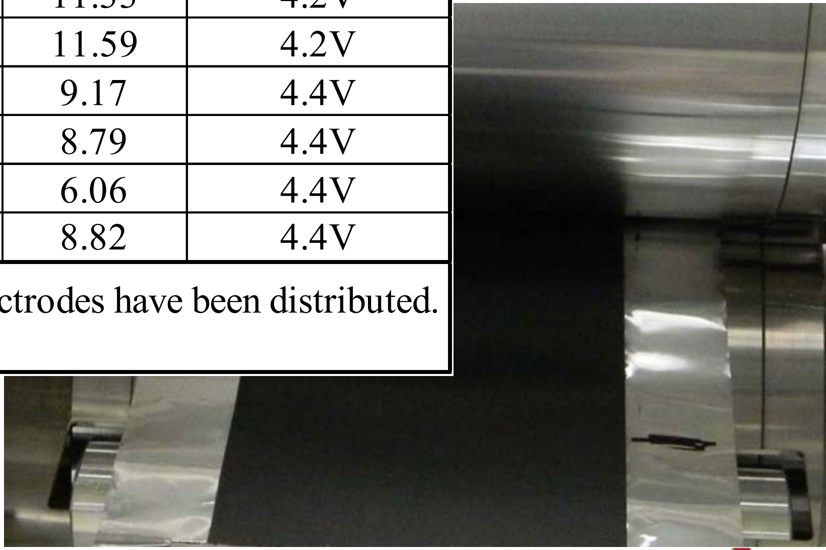
BASELINE ELECTRODES PRODUCED FOR HE-HV



Electrode Library ID	Electrode Type	Material	TTL Loading (mg/cm^2)	Full Cell Voltage Window
A-A002A	Anode	A12 Graphite+C45+9300+ Oxalic Acid	5.88	
A-A004A	Anode	NEI LTO + C-45 + 9300	13.32	
A-A005A	Anode	SLC1520P + C45 +5130	6.28	
A-C011	Cathode	ECOPRO 622 + C45 + 5130	10.03	4.2V
A-C013A	Cathode	Toda 523+ C45 + 5130	11.33	4.2V
S-C002	Cathode	Toda NCA+SFG-6+SuperP+5130	11.59	4.2V
A-C015	Cathode	Toda 523+C45+5130	9.17	4.4V
A-C016	Cathode	Toda NCA+C45+5130	8.79	4.4V
A-C017	Cathode	Toda HE5050+C45+5130	6.06	4.4V
A-C018	Cathode	ECOPRO 622 + C45 + 5130	8.82	4.4V
A total of **262** Electrode Sheets (**6.34 sq. meter**) of the Baseline Electrodes have been distributed. (to date)				



(see ES252, ES253, ES254)

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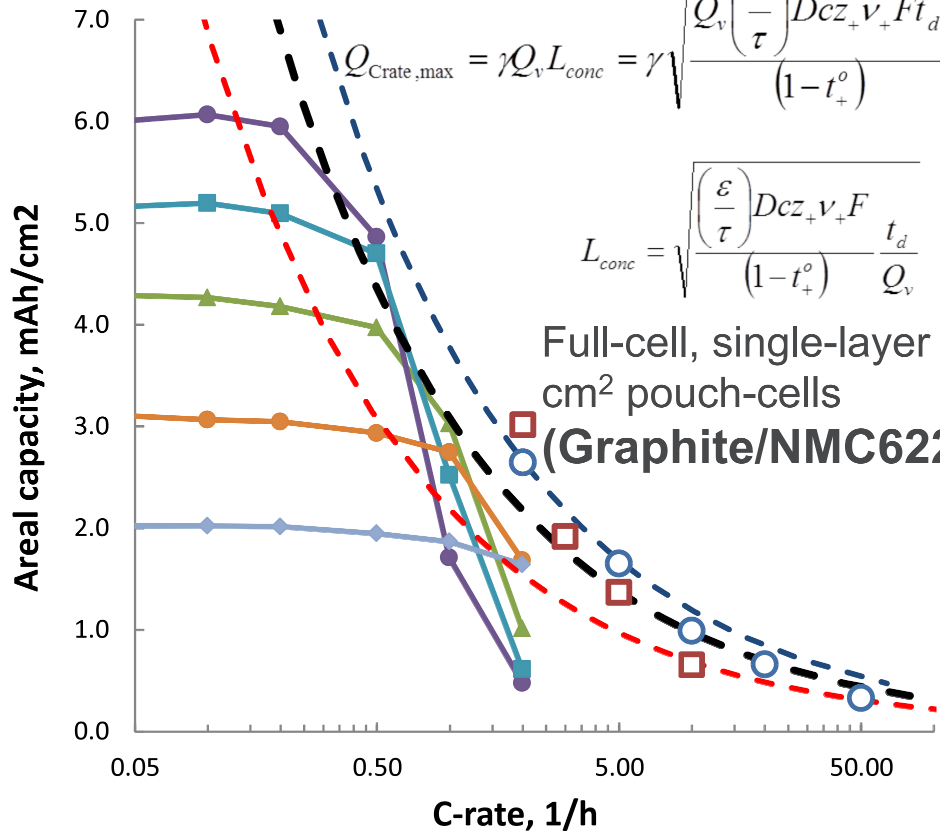
MEASURED RATE CAPABILITY AS A FUNCTION OF ELECTRODE LOADING – Need Gradient (3D) Electrodes for Faster Rates

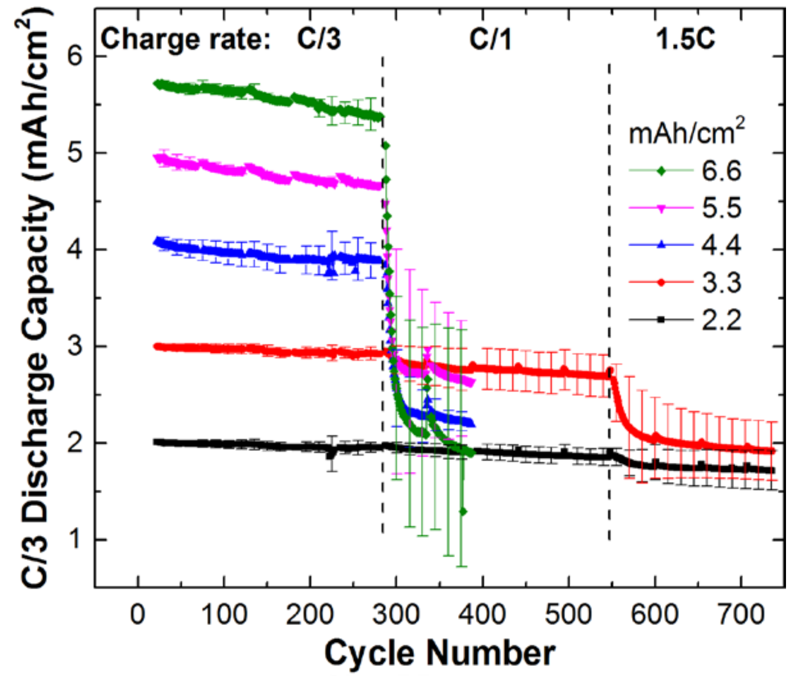
$$Q_{Crate,max} = \gamma Q_v L_{conc} = \gamma \sqrt{\frac{Q_v \left(\frac{\varepsilon}{\tau}\right) D c z_+ \nu_+ F t_d}{\left(1-t_+^o\right)}}$$

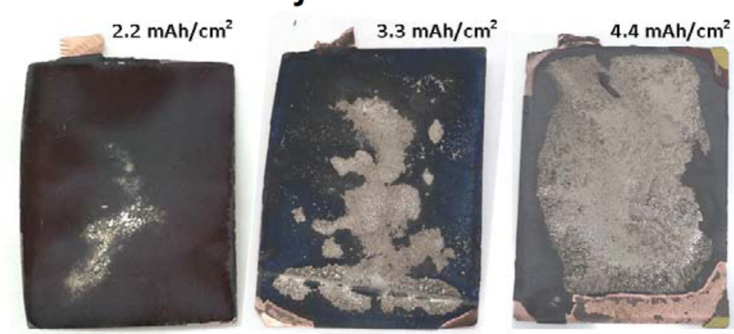
$$L_{conc} = \sqrt{\frac{\left(\frac{\varepsilon}{\tau}\right) D c z_+ \nu_+ F}{\left(1-t_+^o\right)} \frac{t_d}{Q_v}}$$



Lines of γ = **0.3**, **0.6 & 0.9**

Open symbols transformed from: Battaglia *et al.*, LFP/Gr & NMC333/Gr

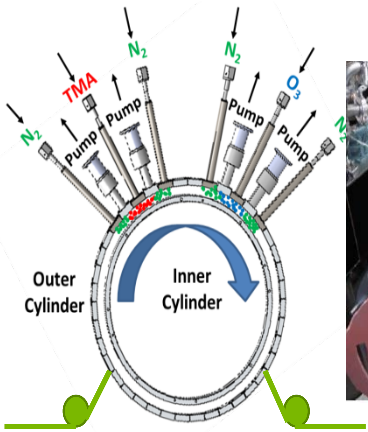


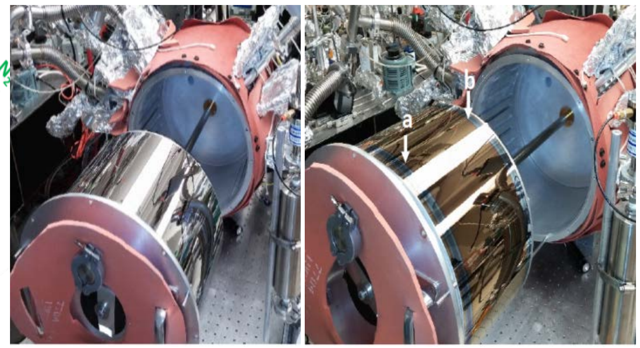


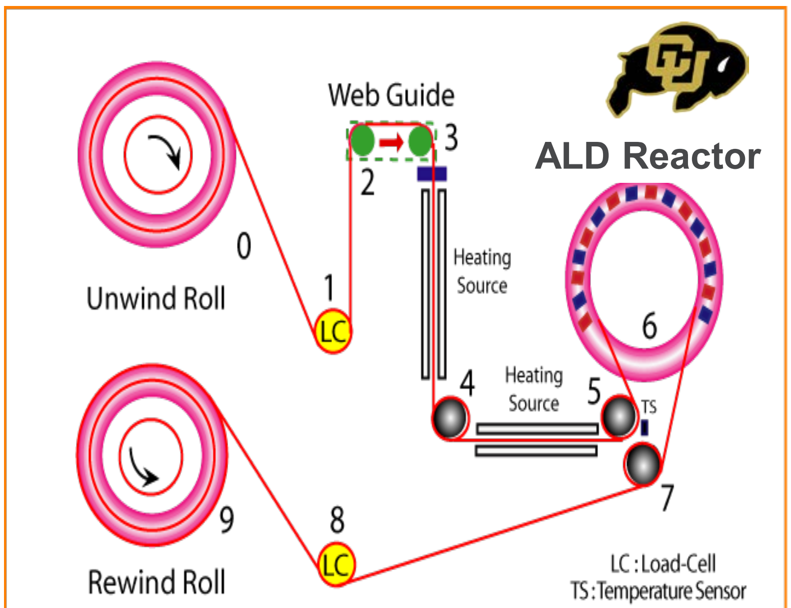
Cycle # 812 Cycle # 812 Cycle # 548

*Gallagher, *et al.*, *JES* 2016

CAMP FACILITY SUPPORT OF ROLL-TO-ROLL ALD DEVELOPMENT AT NREL





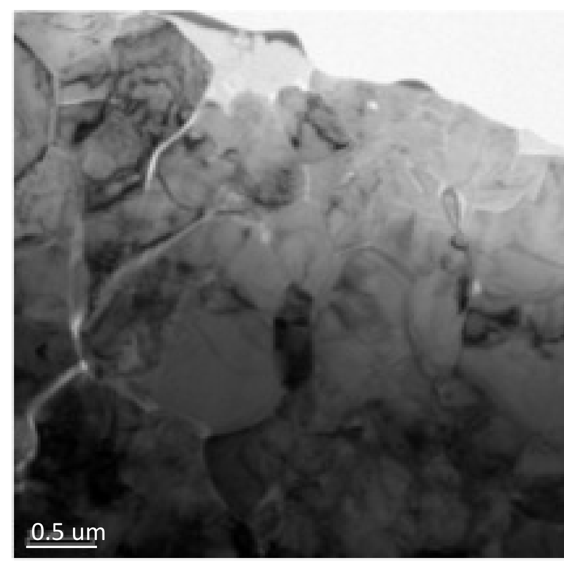


(see ES253)

CAMP Facility provided calendered and un-calendered NCM523 electrodes to NREL for ALD coating tests with in-line reactor.

Initial coating process development focused on alumina on baseline NMC materials.

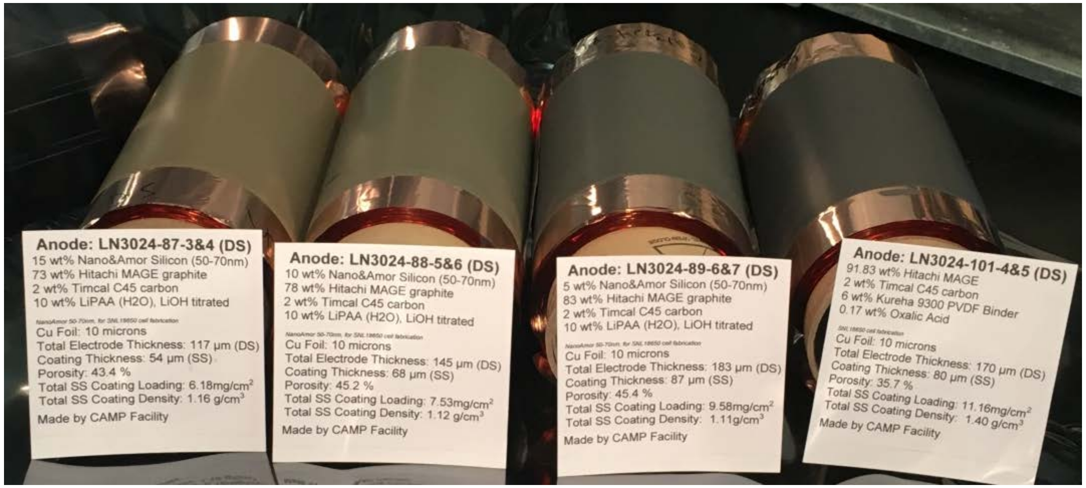
TEM results appear to indicate that precursor penetration into laminate may be limited.



PRODUCED DOUBLE-SIDED Si-GR COMPOSITE ELECTRODES AND BALANCED NCM523 ELECTRODE FOR THERMAL ABUSE STUDY AT SNL

- Over 10 meters of 0, 5, 10, and 15 wt% Si with MagE graphite electrodes were delivered to Sandia National Laboratory
- Over 25 meters of n:p matched NCM523 electrodes were delivered to SNL
- SNL will produce 18650 cells and test thermal abuse response as a function of silicon content.

- Difficulty in making 0 wt% Si using LiPAA as the binder
  - LiPAA contracted too much during drying - used PVDF as binder for this electrode
  - Will make thinner 0 wt% Si electrode using LiPAA in future to test effect of binder (with matched NCM523)



CAMP FACILITY'S ELECTRODE LIBRARY SERVES THE BATTERY COMMUNITY

- The Electrode Library serves as a supply of standard electrodes that are designed to be interchangeable with one another (capacity matched).
- Electrodes can be made with as little as 50g of experimental material, and can be made to match an existing counter electrode.

	Electrodes Delivered							
	FY 13		FY14		FY15		FY16 (Oct-April)	
Argonne	79	23.5%	116	13.3%	206	12.2%	108	11.7%
Other Labs	102	30.4%	213	24.4%	373	22.0%	524	56.8%
Universities	56	16.7%	119	13.6%	83	4.9%	85	9.2%
Industry	98	29.2%	423	48.5%	1028	60.8%	205	22.2%
Total	**335**		**871**		**1690**		**922**	

Currently Available:

- 11 anodes
- 19 cathodes

- Neg:Pos balanced
- 2 mAh/cm^2

- 220 mm x 110 mm of coating per sheet

CAMP FACILITY: ELECTRODE & CELL FABRICATION COLLABORATORS

Universities

- BYU – Brigham Young University, Provo, Utah
- Cornell University
- Georgia Institute of Technology
- University of California, San Diego
- Illinois – University of Illinois at Urbana-Champaign
- University of Maryland
- UK – University of Kentucky
- The University of Wisconsin–Madison
- CU
- The Ohio State University
- RIT – Rochester Institute of Technology
- Northwestern University
- North Carolina State University
- The University of Akron – Ohio's Polytechnic University
- University of Arkansas
- Iowa State University
- UIC – University of Illinois at Chicago
- University of Washington
- University of Rochester

Industry

- TODA America
- Superior Graphite
- Wildcat Discovery Technologies
- Silatronix
- BASF – The Chemical Company
- NEI Corporation
- MILTEC
- XG Sciences – The Material Difference
- CoorsTek Specialty Chemicals
- Arkema – Innovative Chemistry
- Solvay
- BTR – power your life
- DreamWeaver
- SiNode Systems
- JSR Micro – Materials Innovation
- Paraclete Energy
- Celgard
- PSI – Physical Sciences Inc.
- pH Matter LLC
- parc – A Xerox Company
- nohms Technologies
- Zeon
- Blue Current
- TDA Research
- CSquared Innovations
- Aerospace – Assuring Space Mission Success
- Inventek Corporation

National Laboratories

- JCESR – Joint Center for Energy Storage Research
- ARL
- Oak Ridge National Laboratory
- Berkeley Lab
- INL – Idaho National Laboratory
- JPL – Jet Propulsion Laboratory
- Sandia National Laboratories
- Pacific Northwest National Laboratory
- NREL – National Renewable Energy Laboratory
- WMG – Innovative Solutions
- Catapult – High Value Manufacturing
- Brookhaven National Laboratory
- CSIRO
- ARPA-E
- CEES

WORK IN PROGRESS/FUTURE WORK

- Fabricate new generation of silicon-graphite electrodes using larger silicon particles
  - 70-130 nm silicon from NanoAmor
  - 500 nm from American Elements
  - Move towards 30% silicon
- Master new Buhler mixer that will enable CMC-SBR (and other) aqueous binders
- Continue effort on effects of electrode loading
  - Use reference electrodes to determine rate limiting electrode (anode or cathode)
  - Determine influence of segmented charge rates for low, medium, and high SOC
  - Study effect of electrode and separator porosity on lithium plating
- Collaborate with Next Generation Anodes Project on binder systems and electrolyte additives for silicon-based cells
- Continue support of High-Energy High-Voltage Project with new electrode and cell builds
- Work with Post-Test Facility on determining failure mechanisms in silicon cells
  - Analyze multi-layer pouch cells for gas and electrolyte composition
  - Analyze surface of cycled silicon electrodes
- Continue development of Gr-Si electrode electrochemical model
- Continue work with MERF on demonstrating performance of new materials, including new conductive binders for silicon (with LBNL)

REVIEWER COMMENTS FROM 2015 ANNUAL MERIT REVIEW

- *"The reviewer thought that Andrew Jansen's poster (es030) on the Cell Analysis, Modeling, and Prototyping (CAMP) lab at Argonne National Laboratory (ANL) showed that the team has been extremely productive and are providing a valuable service to the community. More importantly, the reviewer thought that the team appears to be involved in planning the work. This is a crucial involvement to both ensure relevance of the work and good data interpretation. "*
- We hope to continue providing this level of support for the battery community.

- *"The reviewer remains very concerned that after more than a decade of extensive work, silicon (Si) anodes are only being used in very small amounts in consumer applications (LG and Samsung) where cycle life demands are far less rigorous. The reviewer pointed out that despite all the work showing good cycle life of Si anodes, getting stable performance in a full cell still seems to be very challenging."*
- We agree that silicon based electrodes need more development before they can be a viable replacement of graphite electrodes. The DOE-EERE-VTO addressed this concern by initiating the multi-lab Next Generation Anodes (Silicon) project. The CAMP Facility is working closely with them.

SUMMARY

- Multi-stack pouch cells of 0.5 Ah were fabricated with 0, 5, 10, and 15% silicon (50-70 nm) to establish silicon effect on energy density and cycle life
  - Cycle life inversely correlates with silicon content due to poor coulombic efficiency
  - Volume expansion of silicon-electrodes lowers energy density and must be accounted for in electrode and battery design
  - Volume of SiO_2 and SEI film on silicon particle is significant for small (<200 nm) particles
  - **More electrode design and SEI Formation/Binder Interface work needed!**
- Electrode loading of <4 mAh/cm² best for C/3 rate applications (EV driving)
- Fabricated electrodes and pouch cell builds for DOE-EERE Awards
- The performance of LiFSI-FEC and $LiPF_6$-FEC cells are very similar.
  - The electrolyte salts play a much smaller role in performance degradation than the electrolyte solvent.
- Provided High-Energy High-Voltage Project and Next Generation Anode Project with baseline and experimental electrodes and cells
- Fabricated NCM523 & silicon-based matched electrodes for SNL thermal abuse
- Supplied numerous electrodes via Electrode Library and expanded its offerings

CONTRIBUTORS AND ACKNOWLEDGMENTS

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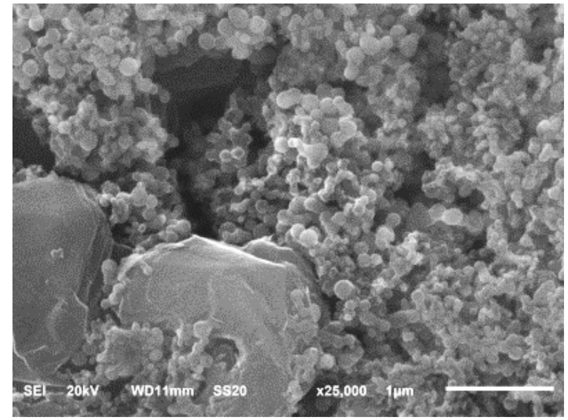
TECHNICAL BACK-UP SLIDES

MAKING A PHYSICALLY ROBUST & FLEXIBLE SILICON-GRAPHITE ELECTRODE WITH >3 mAh/cm²

- **The Challenge**
  - Develop a physically robust, uniform, flexible, and high performance silicon-graphite electrode as a drop-in replacement of a graphite-only electrode for lithium-ion batteries.
- **The Approach**
  - Use Argonne's Cell Analysis, Modeling, and Prototyping (CAMP) Facility's pilot scale equipment to engineer and evaluate slurry and electrode development bearing silicon and graphite.
  - **Identify**:
    1. Viable and industrially available silicon powders
    2. Compatible graphite
    3. Compatible binders enabling improved cycle life
    4. Effective mixing methods
- **The Result**
  - A step forward in achieving a practical, physically robust, uniform, flexible, and high performance silicon-graphite electrode with > 3 mAh/cm^2 that can be used for pouch cell evaluation and included in the Electrode Library.



*SEM micrograph Si powder (NanoAmor) and graphite (Mag-E) laminate (CAMP Electrode A-A006)

*SEM micrographs from Argonne's Post Test Facility (PTF)

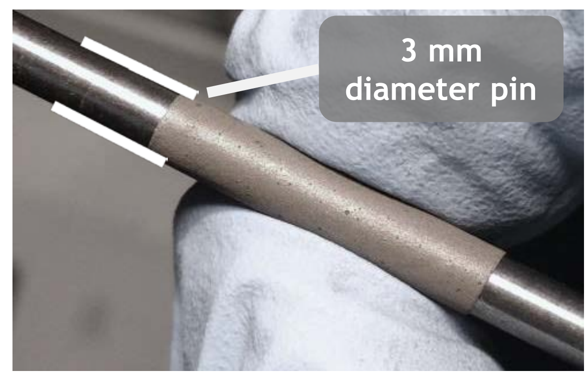


Photo image of the silicon-graphite electrode (3.7 mAh/cm^2) passing a 3 mm diameter pin test without visible cracking or adhesion issues.

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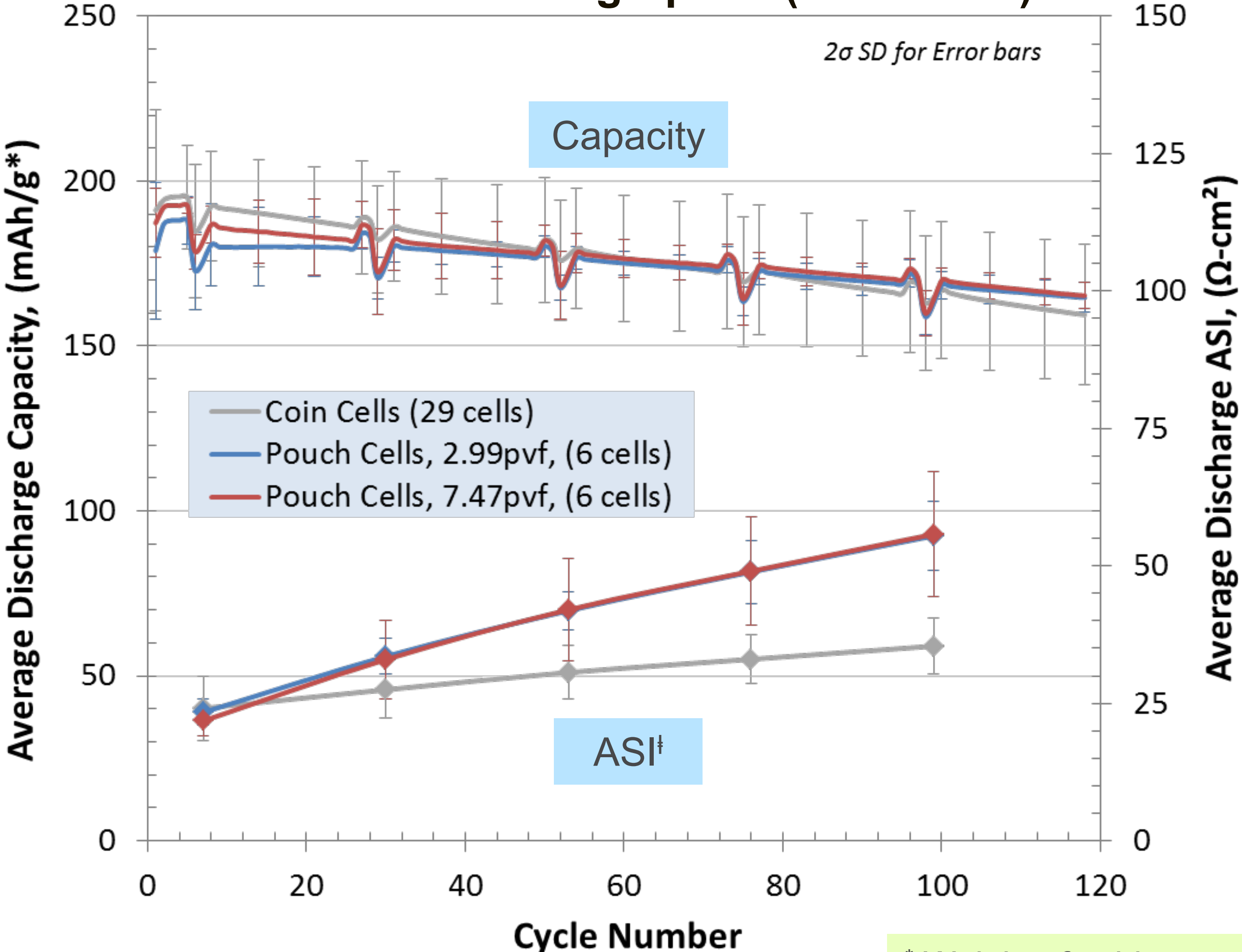
COIN CELL TO POUCH CELL COMPARISON FOR HE-HV BASELINE MATERIALS

NCM 523 vs. A12 graphite (3.0 to 4.4V)



Coin (HEHV.ZZY)	Pouch (CAMP)
Cathode Area [cm^2]	
1.54	*14.1*
Oxide Weight [mg]	
~12.9	*116.4*
Test 1C-Rate [mA]	
~2.2	*20*

- Comparable cycling performance from coin cell to pouch cell
- ASI rise rate is higher for the pouch cell:
  - Stack pressure?
  - Cell dimensions?
  - Need to compare to multi-layer cell to see if the non-typical trend is still present

* Weight of oxide
ǂ 50% DOD (3.72-3.76V)

(see ES252, ES253, ES254)

SPECIALTY ELECTRODES PRODUCED FOR HE-HV

Experimental Electrode ID	Material	Loading (mg/cm^2)
LN3012-171-1,2,3,4,5 (small samples of each)	nSi (50-70nm)+C45+LiPAA	
LN3012-180-3, extra small section uncalendered	Toda 523+C45+5130	4.08
LN3012-184-3	NCM 622 + C45 + 5130	10.21
LN3012-188-1 (1 rolled and 1 unrolled)	NEI LTO + C-45 + 9300	24.83
LN3012-188-1 (unrolled)	NEI LTO + C-45 + 9300	24.83
LN3012-79-3	Toda 523(2nm ALD Al2O3) + C45+5130	11.37
LN3012-80-2	Toda 523(2wt% Al2O3 WC) + C45+5130	11.28
LN3012-91-5	Toda 523(1nm ALD Al2O3) + C45+5130	11.25
LN3024-52-3	NEI LTO + C-45 + 9300	19.75
LN3024-52-5	NEI LTO + C-45 + 9300	24.83
LN3032-42-5	NEI LTO + C-45 + 9300	19.65
LN3032-60-3b	MERF LL, ES-20150514 + C45 + PVDF	8.96
LN3032-60b	MERF LL, ES-20150514 + C45 + PVDF	8.96
LN3032-61-4	Toda 523(2C ALD Al2O3) + C45+5130	9.22
LN3032-61-7	Toda 523(2C ALD Al2O3) + C45+5130	11.09
LN3032-62-2	Toda 523(4C ALD Al2O3) + C45+5130	9.22
LN3032-62-5	Toda 523(4C ALD Al2O3) + C45+5130	11.38
LN3024-60-3 (90/5/5 composition)	Toda 523+ C45 + 5130	4.08
LN3024-60-3 (90/5/5 composition)	Toda 523+ C45 + 5130	4.08
LN3024-56-4 (80/10/10 composition)	Toda 523+ C45 + 5130	4.46
LN3024-57-3 (70/15/15 coposition)	Toda 523+ C45 + 5130	4.08
S-A001	A12 Graphite+ SP+9300+ Oxalic Acid	6.06

Additionally, a total of 5885 grams of cathode powders have been distributed to researchers in this project. (ANL, ORNL, NREL)

A total of **84** Electrode Sheets (**2.03** sq. meter) of Specialty Electrodes have been distributed. (to date)

(see ES252, ES253, ES254)

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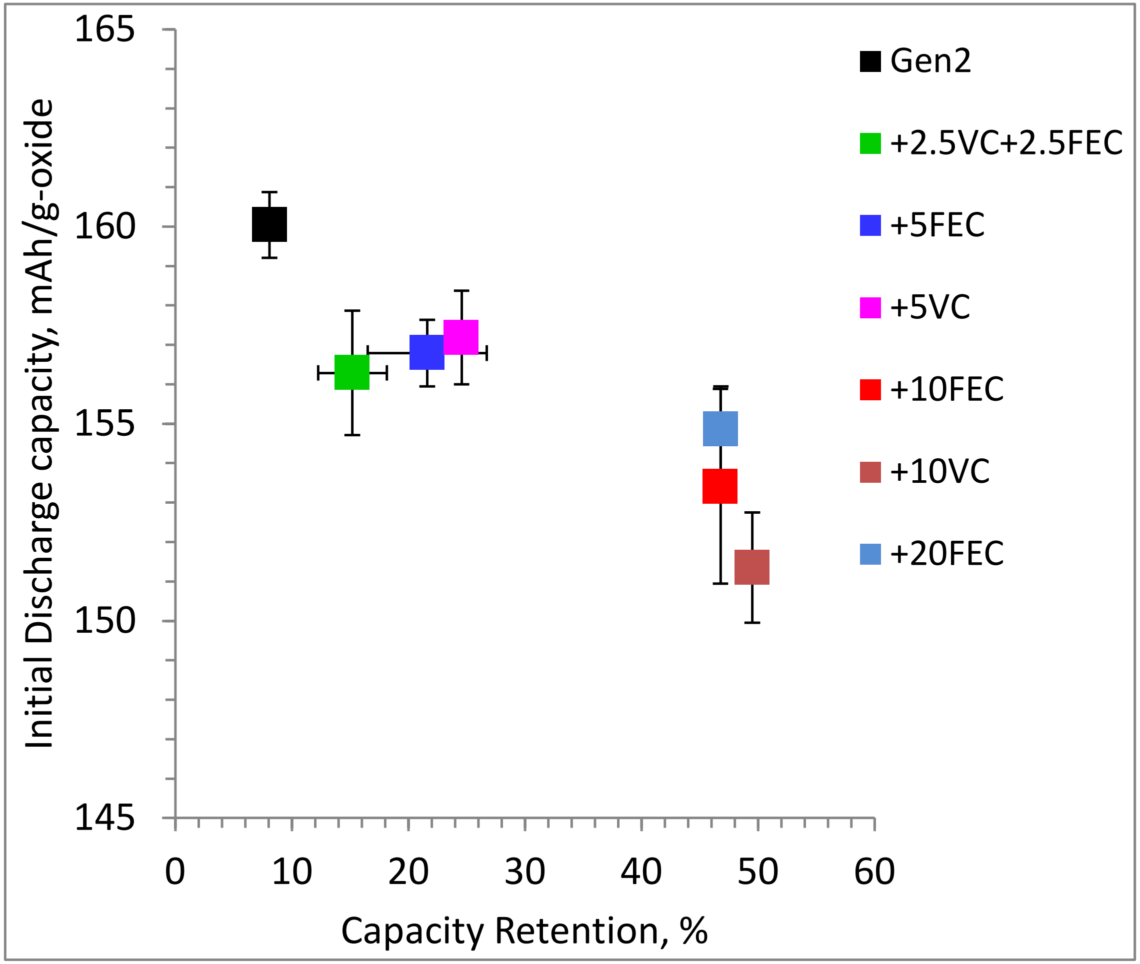
10% FEC CHOSEN AS ELECTROLYTE ADDITIVE FOR SILICON CELLS



Coin Cell Data
15% Si-Gr/NCM523
2.5-4.1 V, 2x C/20,
100x C/3, 2x C/20,
30°C

"Gen2" is 1.2 M $LiPF_6$ in EC:EMC (3:7 wt)

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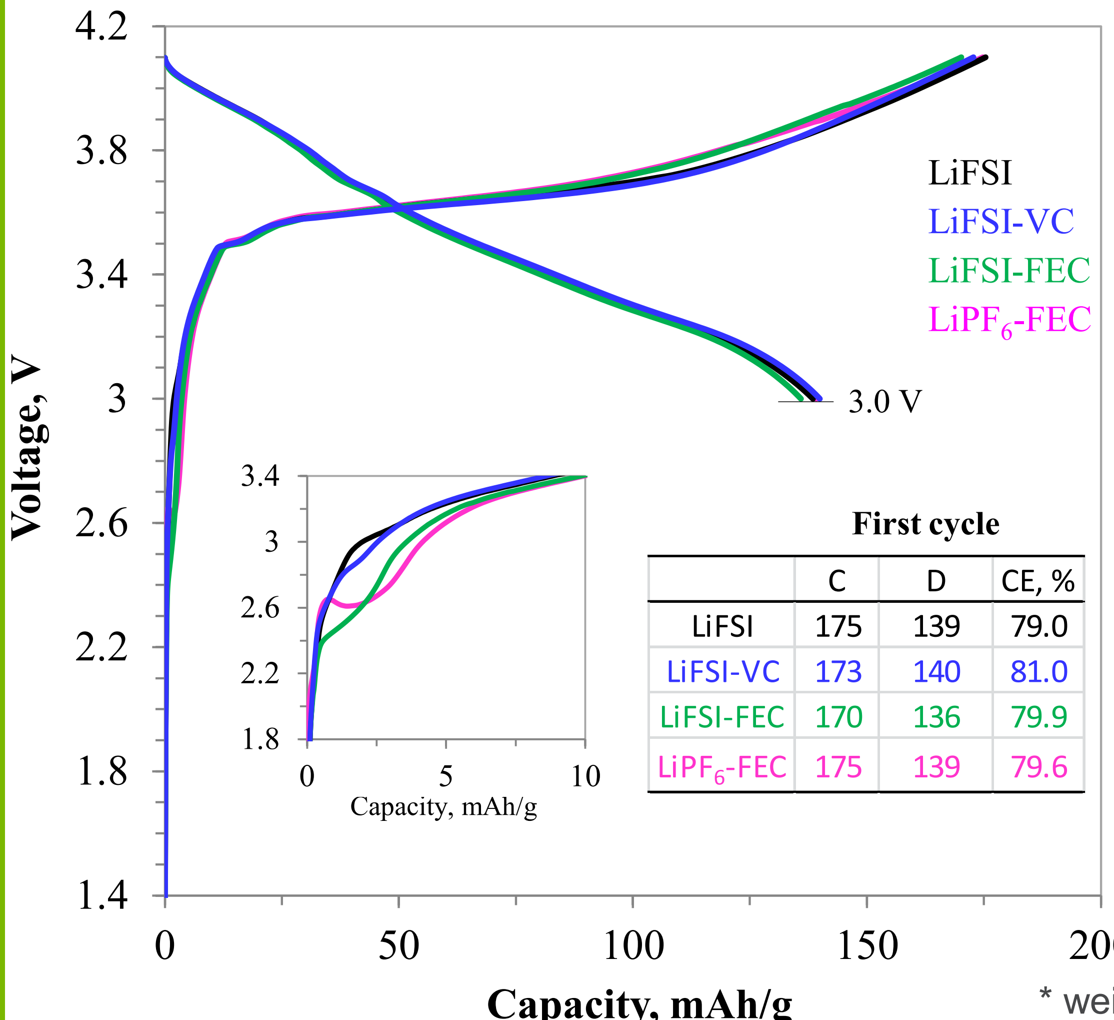
CAMP FACILITY DIAGNOSTICS - COMPARING LiFSI AND $LiPF_6$

1ST CYCLE, ~C/20, 3-4.1 V, 30°C



First cycle

	C	D	CE, %
LiFSI	175	139	79.0
LiFSI-VC	173	140	81.0
LiFSI-FEC	170	136	79.9
$LiPF_6$-FEC	175	139	79.6

* weight of NCM 523

First cycle voltage profiles were similar except for portions associated with SEI formation on the negative electrode.

Capacity and coulombic efficiencies were also similar.

Electrolyte composition has a strong effect on SEI formation