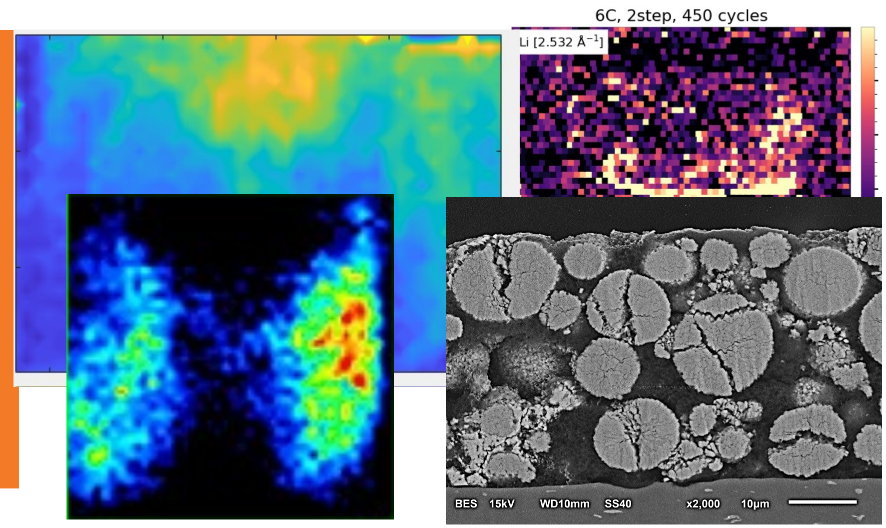
XCEL
eXtreme Fast Charge Cell Evaluation of Lithium-ion Batteries

BAT 386

EXTREME FAST CHARGE CELL EVALUATION OF LITHIUM-ION BATTERIES (XCEL): OVERVIEW



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AMR 2021

OVERVIEW

Timeline

- Start: October 1, 2017
- End: September 30, 2021
- Percent Complete: 75%

Barriers

- Cell degradation during fast charge
- Low energy density and high cost of fast charge cells

Budget

- Funding for FY20 – $5.6M

Partners

- Argonne National Laboratory
- Idaho National Laboratory
- Lawrence Berkeley National Lab
- National Renewable Energy Laboratory
- SLAC National Accelerator Lab
- Oak Ridge National Lab

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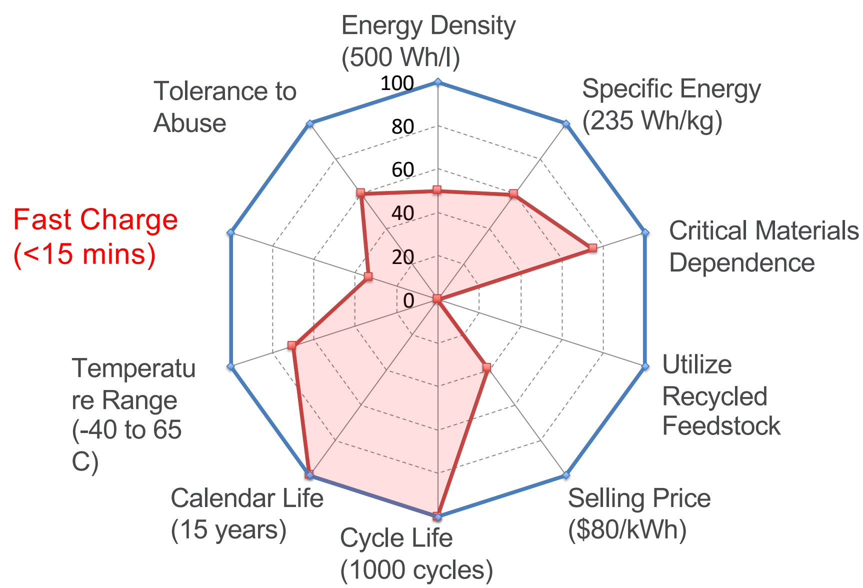
RELEVANCE: FAST CHARGE REMAINS AN ISSUE FOR WIDESPREAD ADOPTION OF EVS



Fast charging a major issue. While fast charge cells exist, they are cost prohibitive or have poor life

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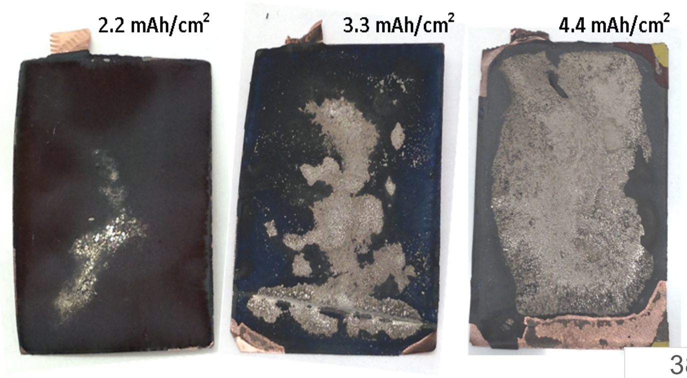
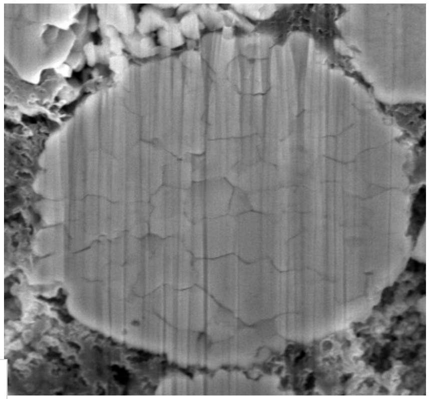
RELEVANCE: WHAT LIMITS FAST CHARGE?

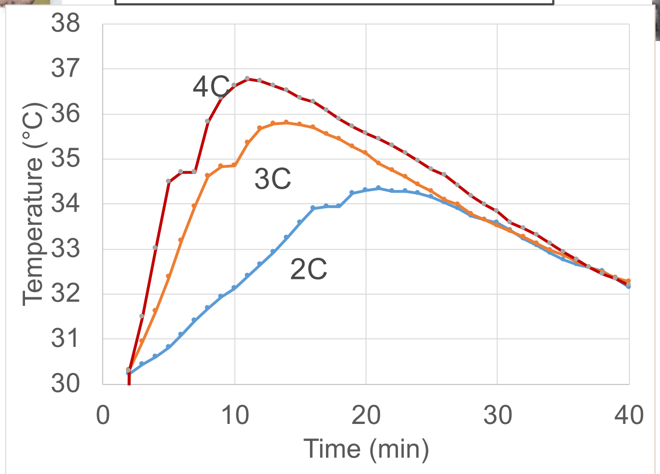
Li plating



Particle breakup

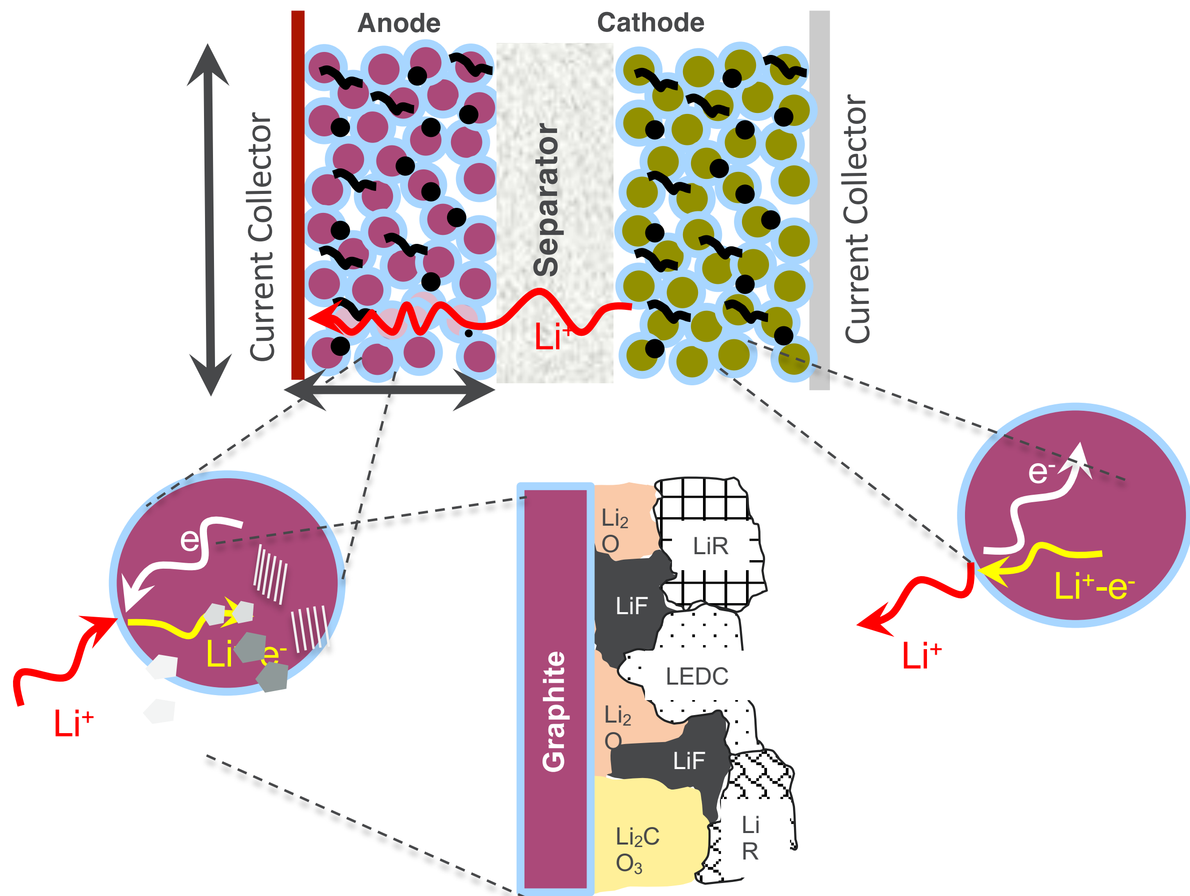


Temperature rise



We need to understand how all three issues impact fast charge

RELEVANCE: CHALLENGES AT MULTIPLE SCALES



COLLABORATION ACROSS LABS AND UNIVERSITIES

Argonne NATIONAL LABORATORY: Cell and electrode design and building, performance characterization, post-test, cell and atomistic modeling, cost modeling

BERKELEY LAB: Li detection, electrode architecture, diagnostics

INL Idaho National Laboratory: Performance characterization, failure analysis, electrolyte modeling and characterization, Li detection, charging protocols

NREL NATIONAL RENEWABLE ENERGY LABORATORY: Thermal characterization, life modeling, micro and macro scale modeling, electrolyte modeling and characterization

SLAC NATIONAL ACCELERATOR LABORATORY: Li detection, novel separators, diagnostics

OAK RIDGE National Laboratory: Detailed Li plating kinetic models, SEI modeling

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ESRF The European Synchrotron

UCL

PURDUE UNIVERSITY

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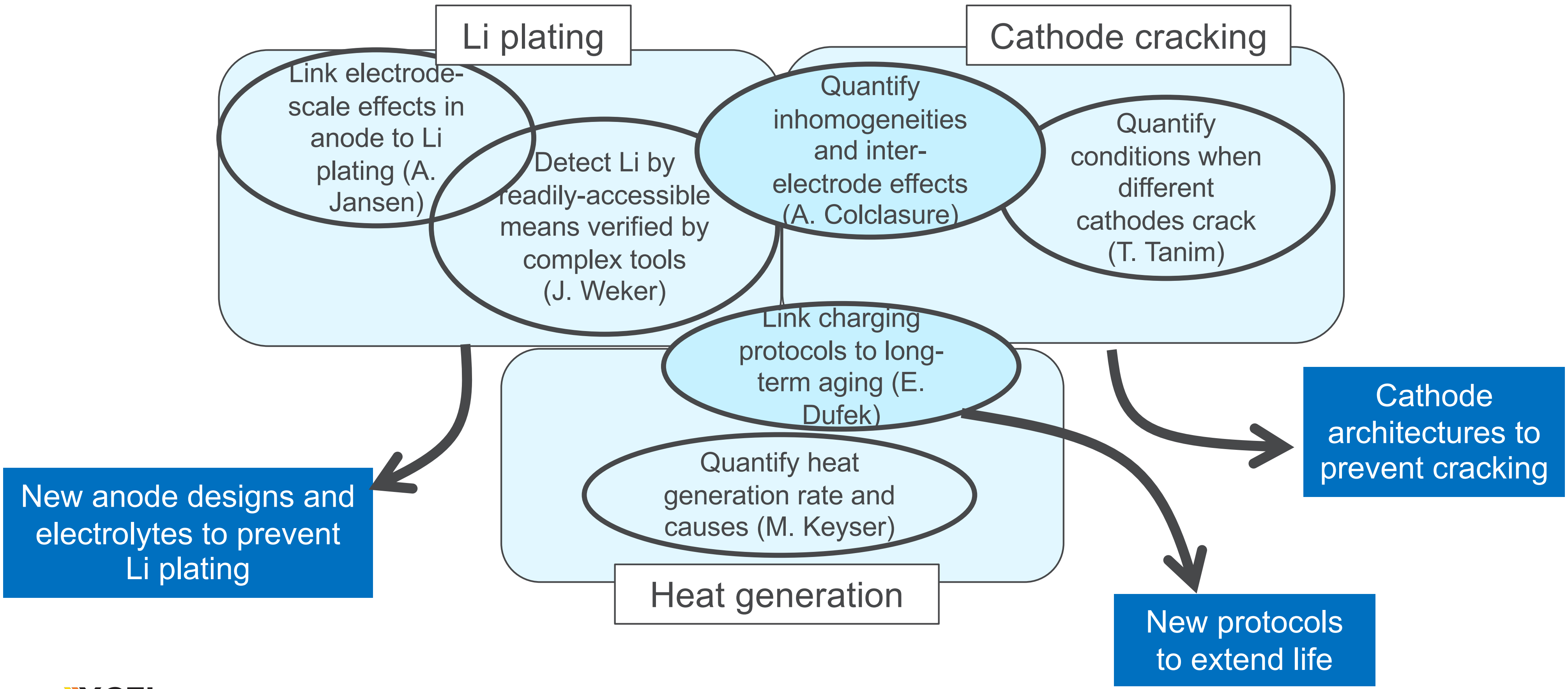
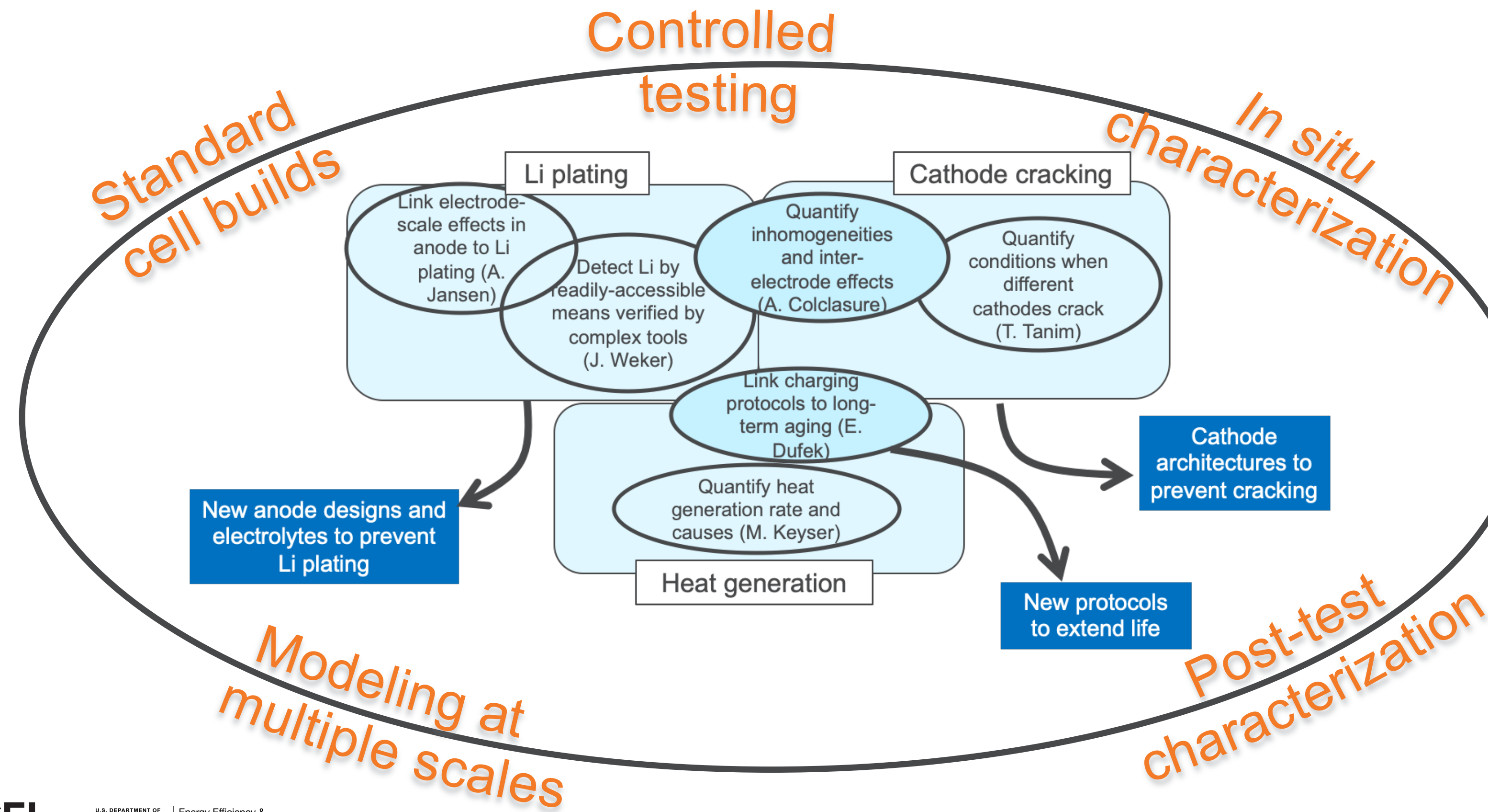
APPROACH: UNDERSTAND THE PROBLEM TO ENABLE SOLUTIONS



APPROACH COMBINES MULTIPLE EXPERTISE



SUMMARY OF ACCOMPLISHMENTS

2017

- Plating free: 10 min charge at 1.7 mAh/cm^2
- 532 cathode exhibits 22% capacity fade (6C charge; 600 cycles)#

* Hero cell with latest anode design, new electrolyte, and new separator

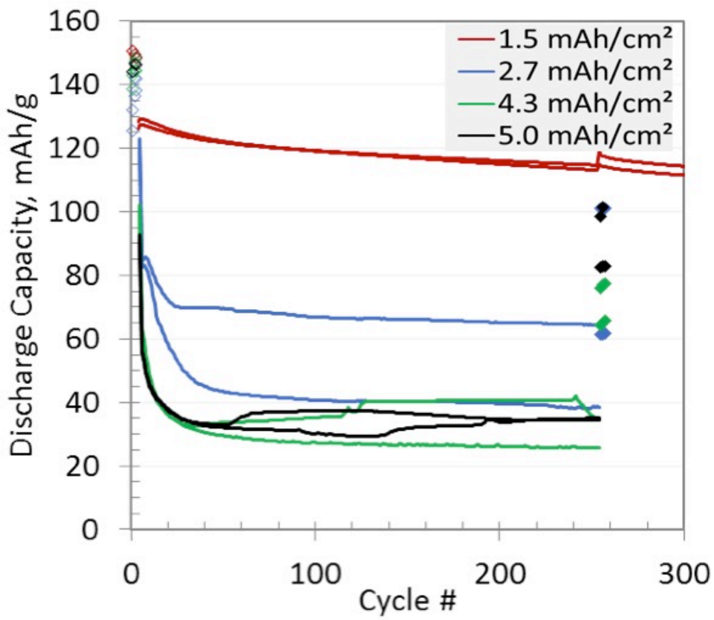
532 and 811 cathode cycled to 4.1V

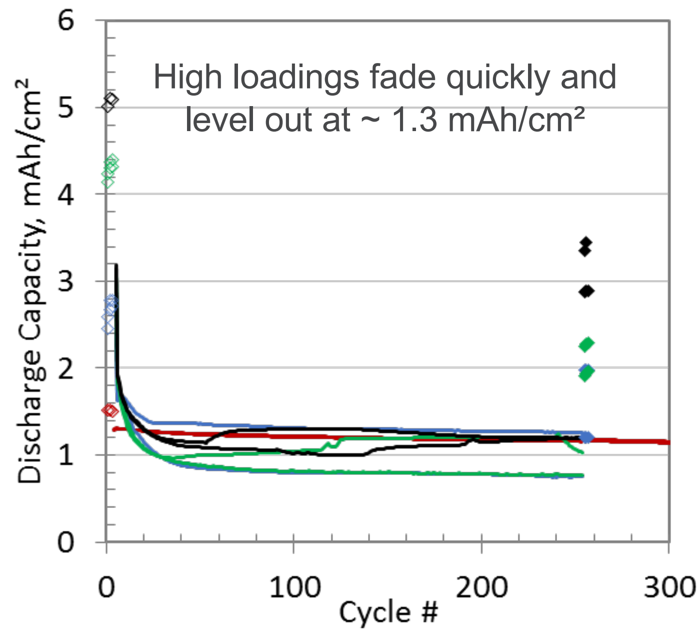
2021

- 10 min charge at 3 mAh/cm^2*
- 811 cathode exhibits 7% capacity fade (6C charge; 600 cycles)#
- Developed electrolytes w/ enhanced transport
- Developed multiple Li detection methods
- Quantified heat generation during fast charge and impact on life
- Developed model-informed charge protocols
- Developed methods to detect SOC and Li plating heterogeneity across scales

WHAT DRIVES LI PLATING?

6C charge; C/2 discharge full cells



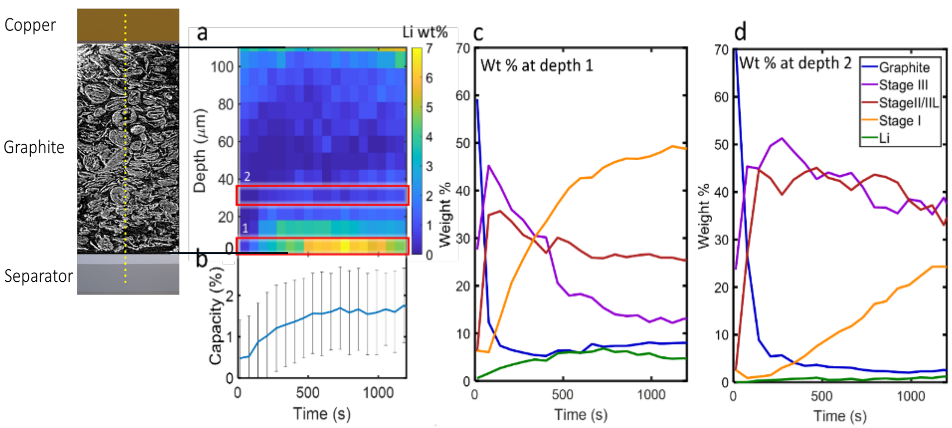


Round 1: 2 mAh/cm^2 – baseline
Round 2: 3 mAh/cm^2

Future: 4 mAh/cm^2

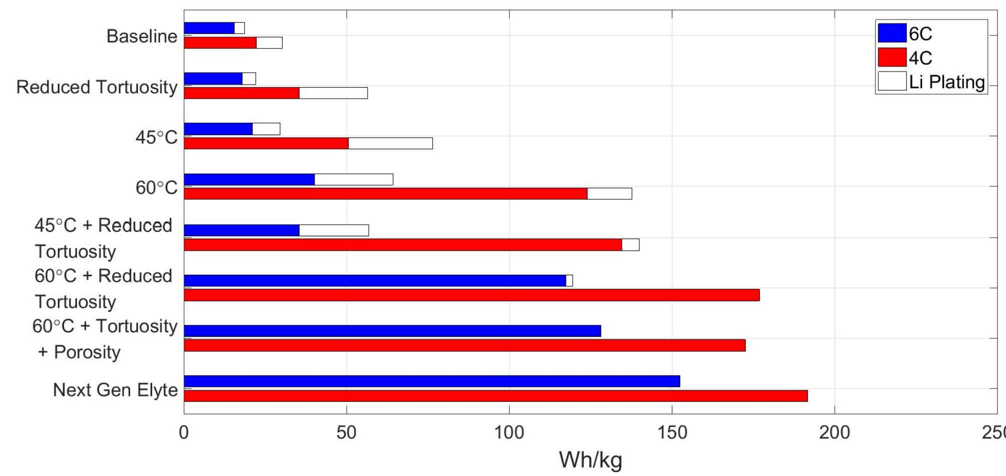
XCEL developed a deep understanding of the underlying issues

ALL THE ACTION HAPPENS CLOSE TO THE SEPARATOR.



Li plates near separator during charge

4 mAh/cm^2 (230 Wh/kg cell; 110 micron electrodes)



- Next Gen Electrolyte = 2X ionic conductivity, 4X diffusivity, and transference number increased by 0.15

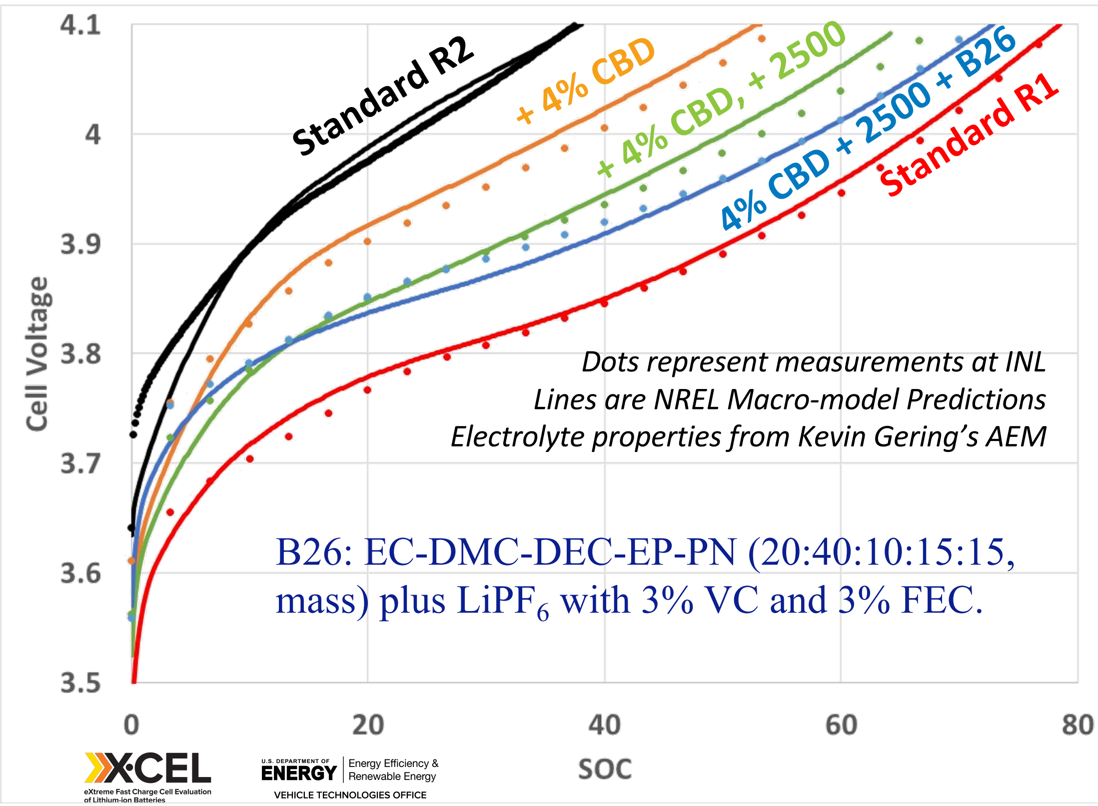
Need a combination of solutions to enable fast charge

See BAT456

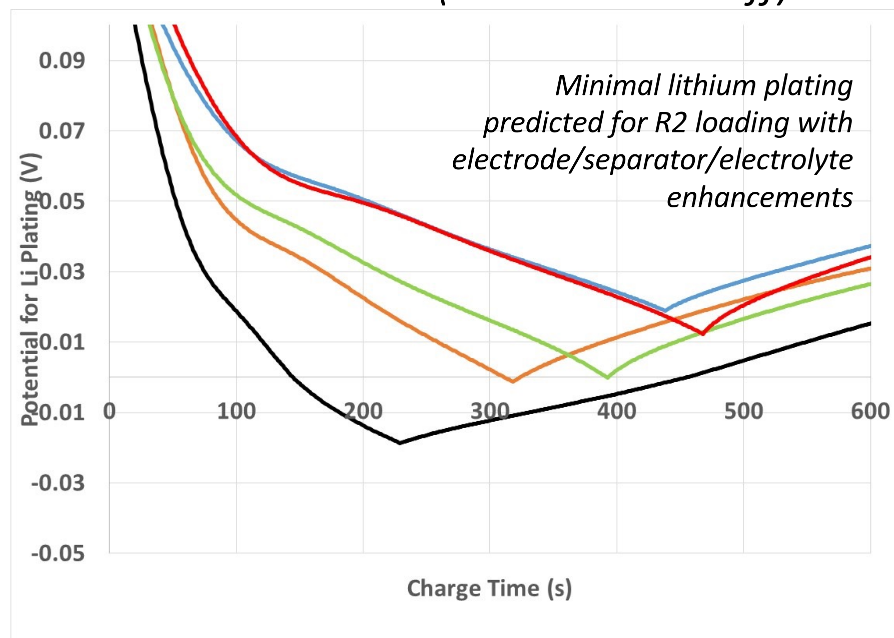
"HERO" CELL SHOWS IMPACT OF SYSTEMATIC CHANGES

Reduced CBD loading + Celgard separator 2500 + enhanced electrolyte

6C CC Charging of Single Layer Pouch Cells



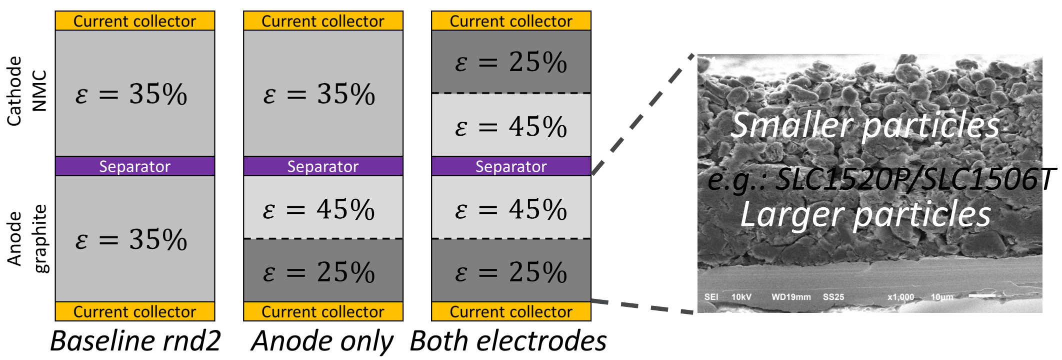
6C CCCV to 4.1 V (10 minutes cutoff)



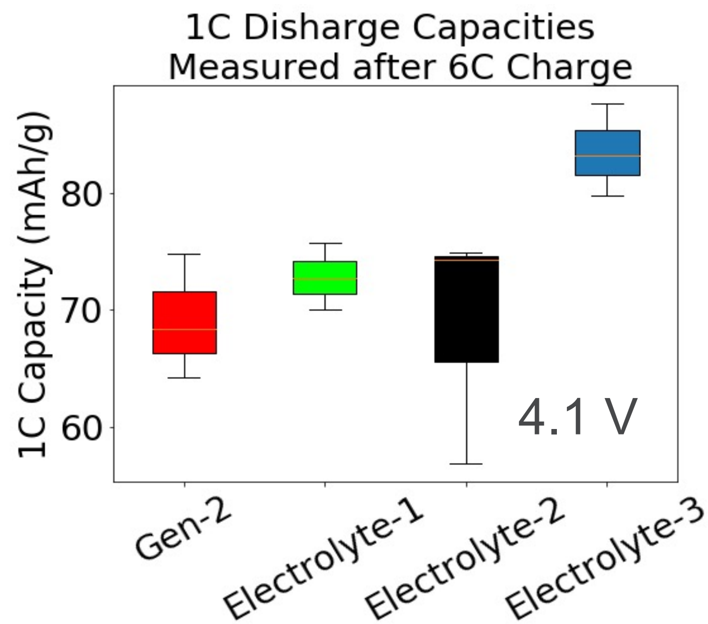
3 mAh/cm^2 behaves like 2 mAh/cm^2 cell. Model predictions match exp. data

IMPROVEMENTS TO ANODE DESIGN AND ELECTROLYTE CONTINUE

See BAT456



Particle size/graded porosity

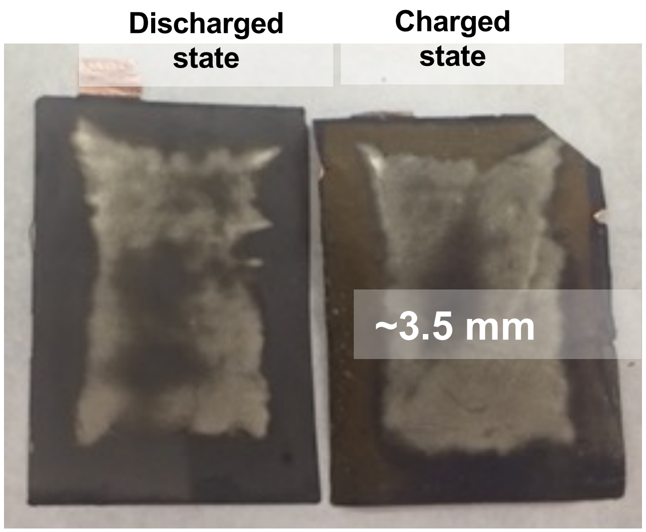


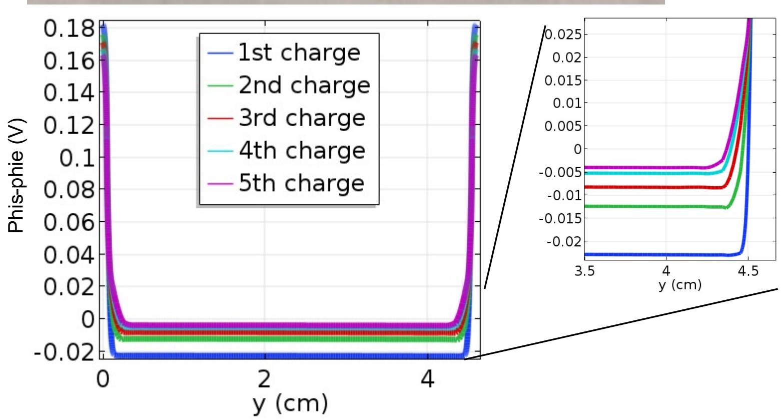
Implementation of these changes in the pipeline

Electrolyte 3 = Solvent C:EC:EMC, 1.2M $LiPF_6$ + 1% FEC + 1% VC

See BAT461

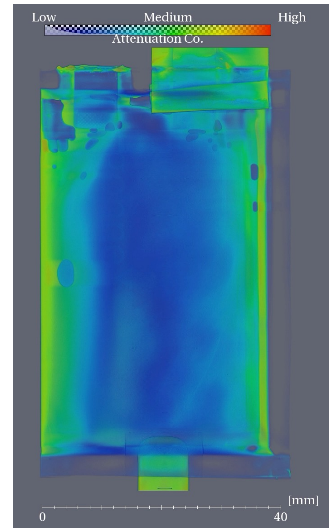
WE ARE EXAMINING OTHER HETEROGENEITIES





Saturation Distribution

1.0 (red > orange > yellow > green > blue > indigo > violet) 0.9



Neutron imaging confirms model observations that electrolyte wetting needs consideration

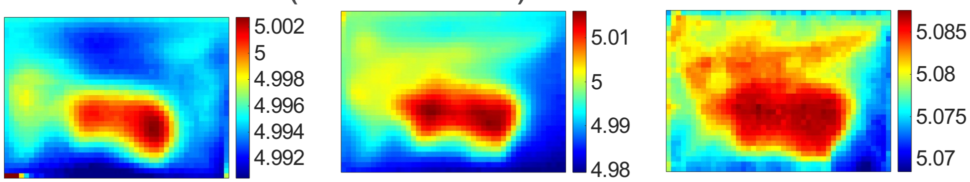
Edge effects partially explain the data (~2 mm)

MAPPING HETEROGENEITIES REMAINS AN AREA OF IMPORTANCE

See BAT461

Discharge Cycle 10 | Discharge Cycle 452 | Charge Cycle 453

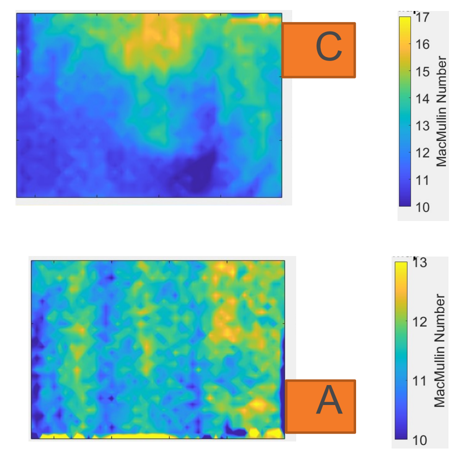
Cathode: c/a lattice ratio - increasing heterogeneity.
Cathode SOC (red = less Li)



c/a = 4.9951±0.0033 | c/a = 4.9962±0.0084 | c/a = 5.0797±0.0042

Anode: x in Li_xC_6 - low heterogeneity

Mapping of ionic resistance



Quest continues to understand all the sources of inhomogeneity and to correlate it to Li plating

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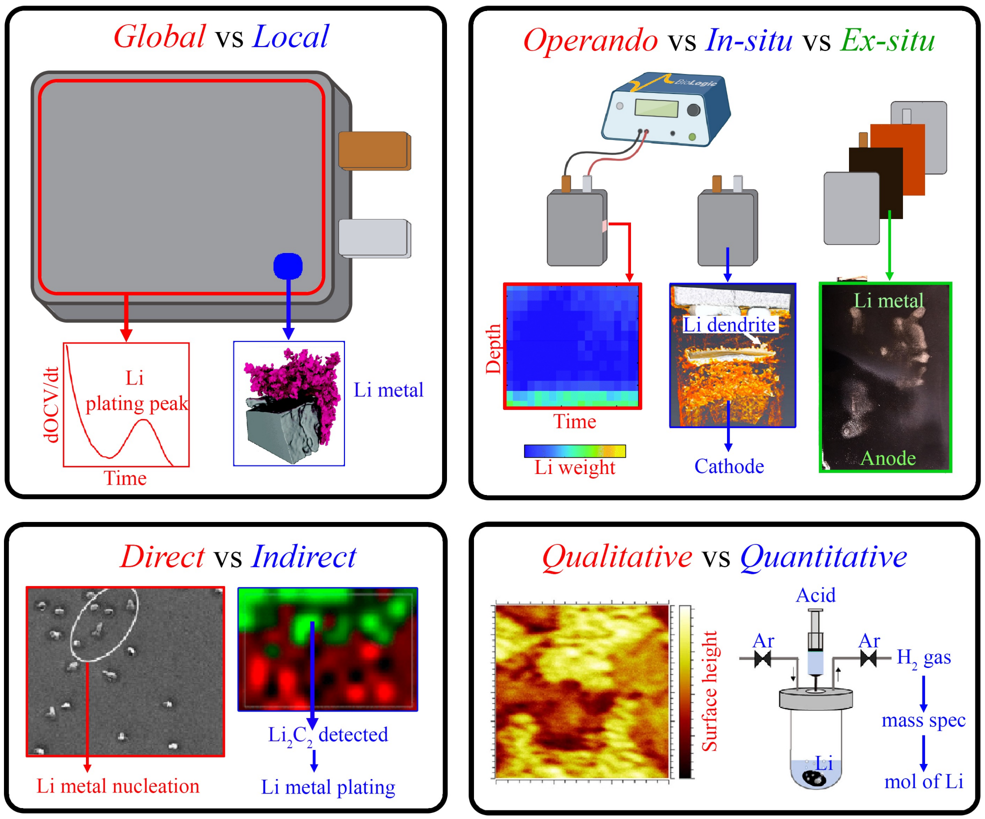
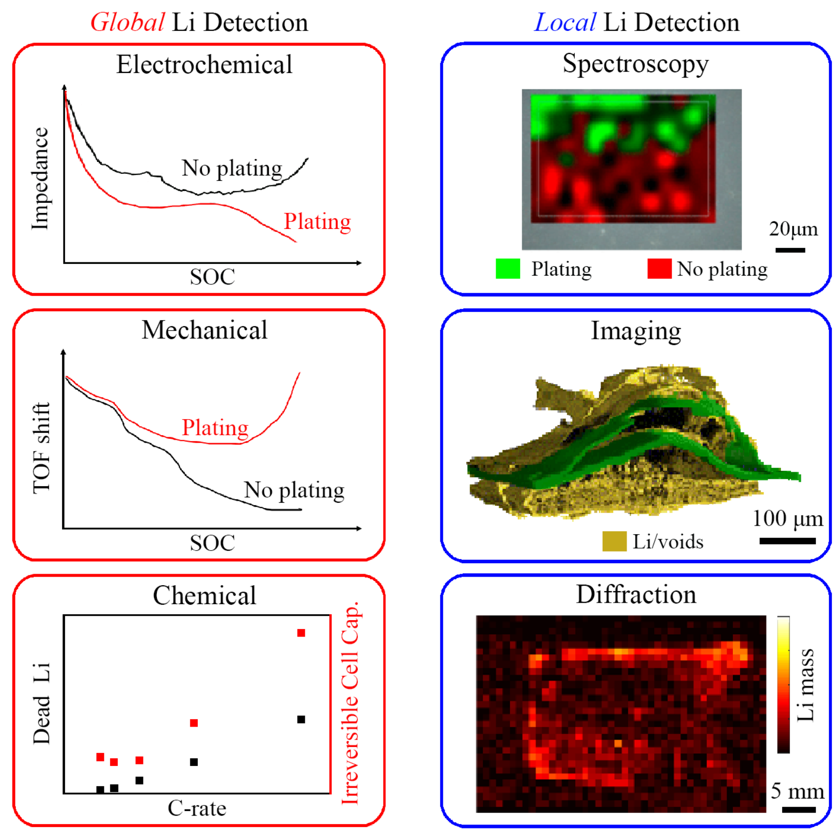
CLASSIFICATION OF LI DETECTION TECHNIQUES

See BAT457



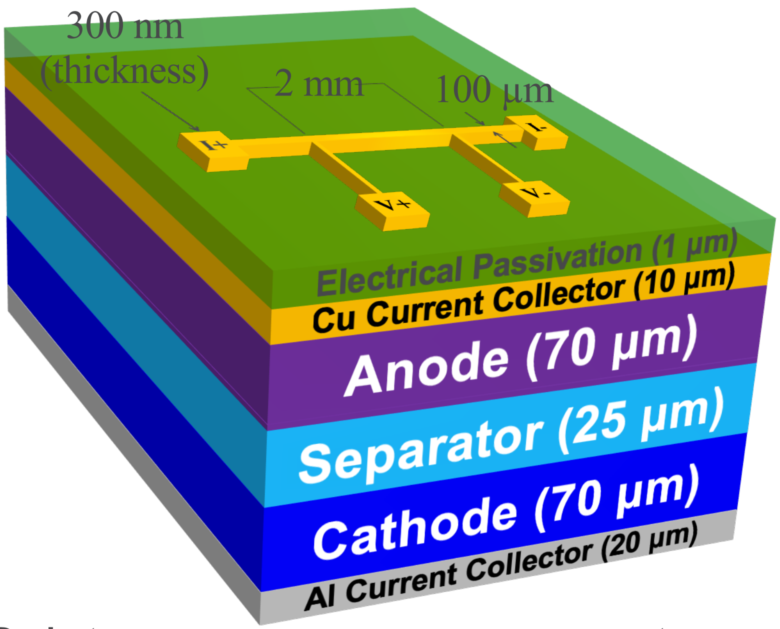


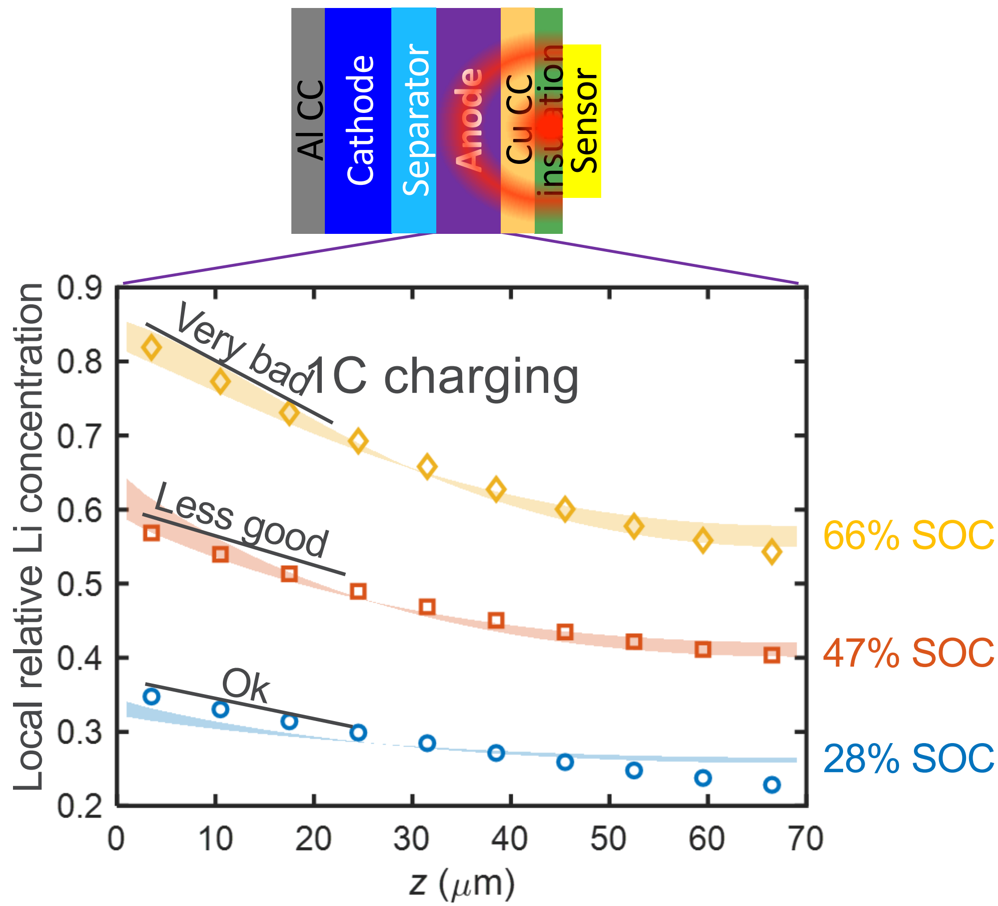
Paul, Partha P., et al. "A Review of Existing and Emerging Methods for Lithium Detection and Characterization in Li-Ion and Li-Metal Batteries." *Advanced Energy Materials* 11.17 (2021): 2100372.

See BAT457

MAP LI CONCENTRATION GRADIENT IN ANODE

Stronger gradient precursor to Li plating





Points = sensor measurements

Shading = agnostic predictions from electrochemical simulations

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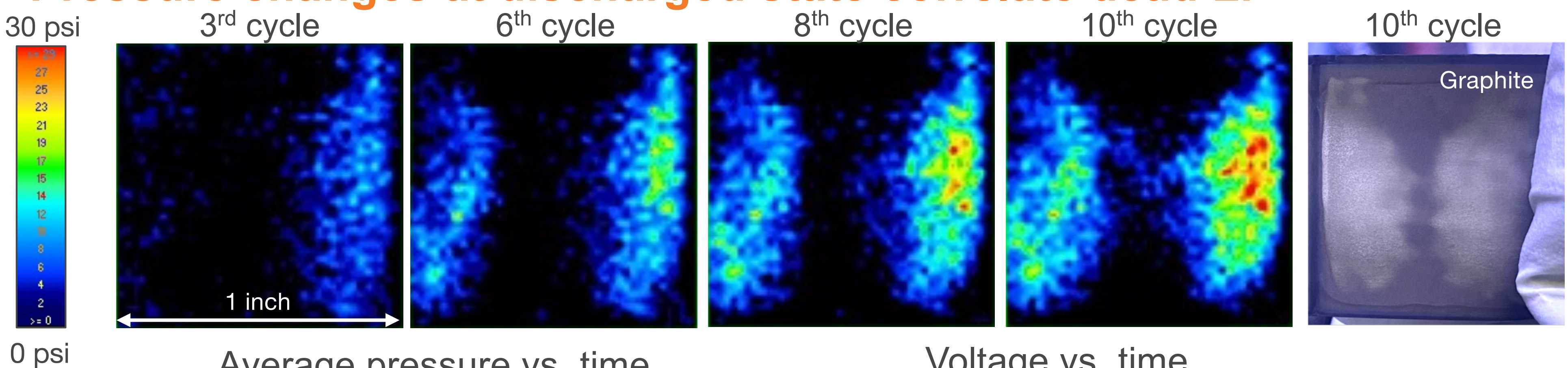
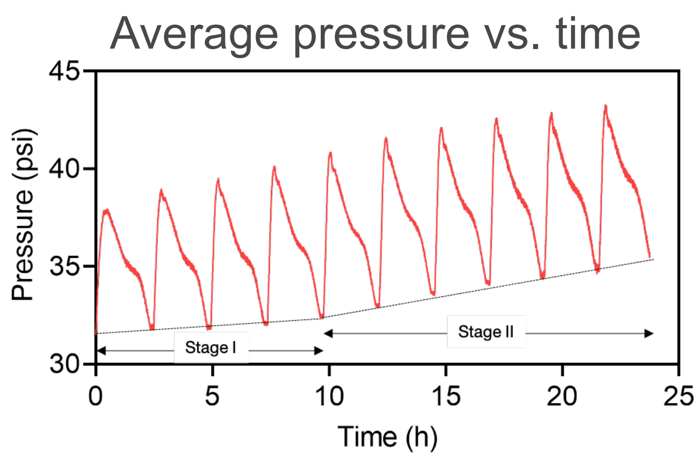
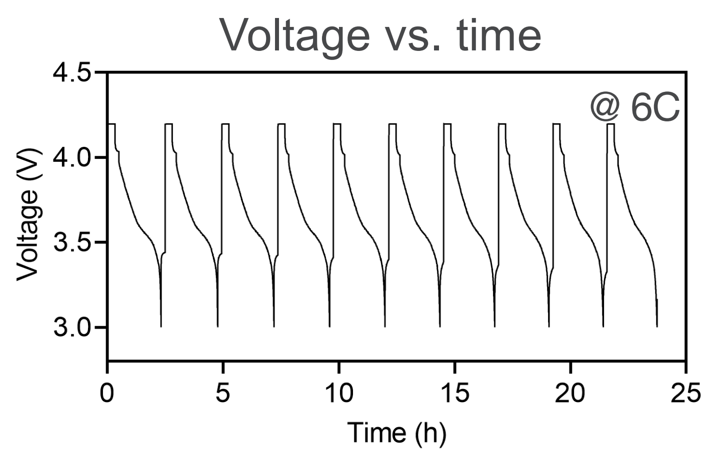
PRESSURE EVOLUTION WITH CYCLING

See BAT457

Pressure changes at discharged state correlate dead Li

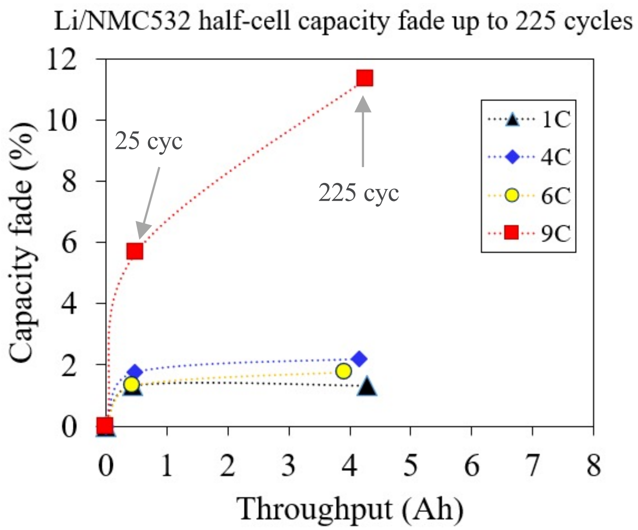


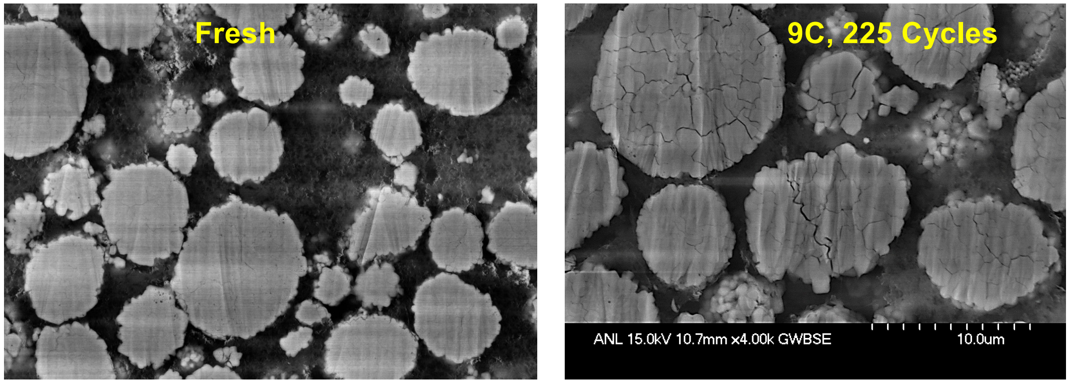




See BAT463

CATHODE CRACKING IDENTIFIED AS AN ISSUE





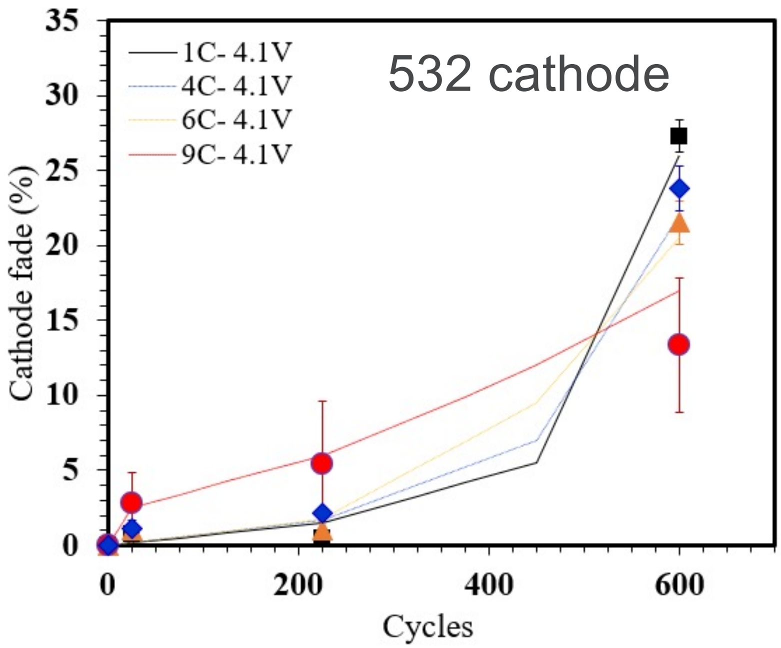
- Li plating dominates <6 C
- Cathode cracking > 6C

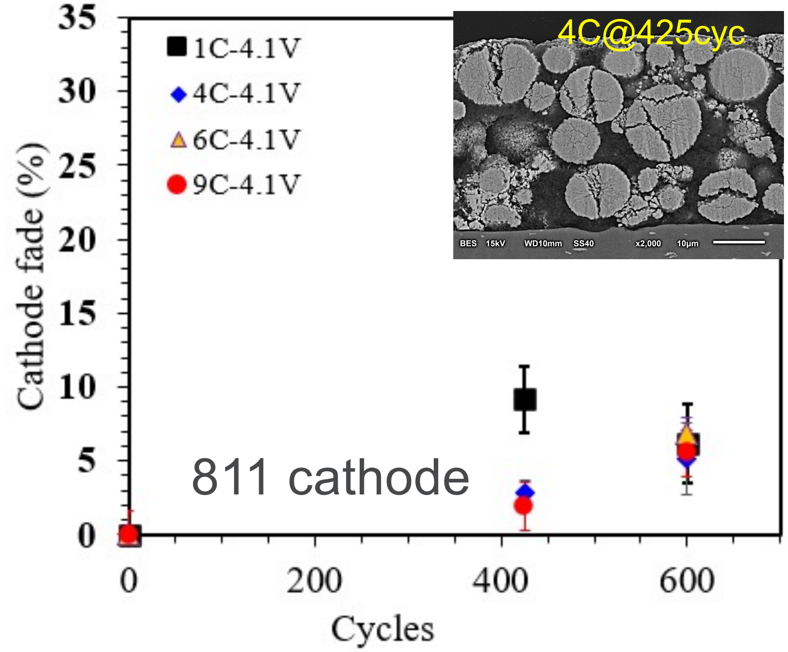
- SEM images show propensity for cracks after cycling

Program started with 532 cathode. Over the last year, transitioned to 811

See BAT463

EARLY RESULTS ON NMC 811 PROMISING

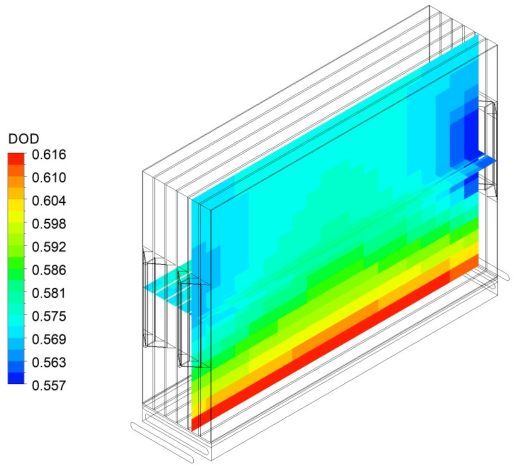




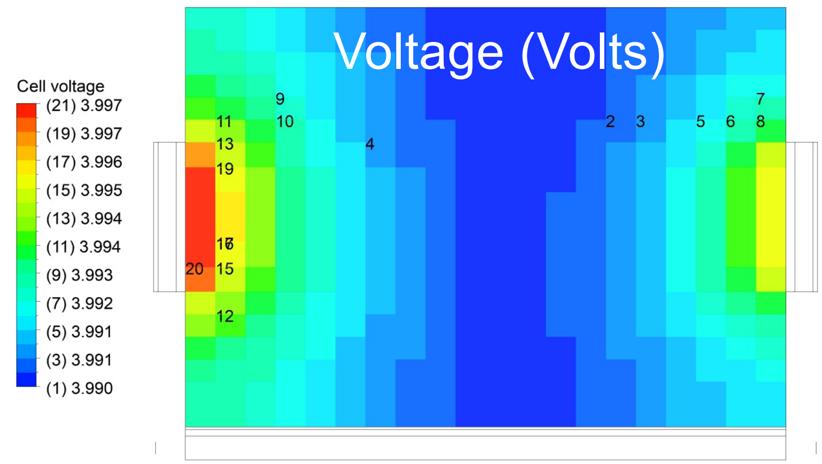
While cracking remains an issue, does not appear to exacerbate on cycling.
Now examining single crystal cathodes.

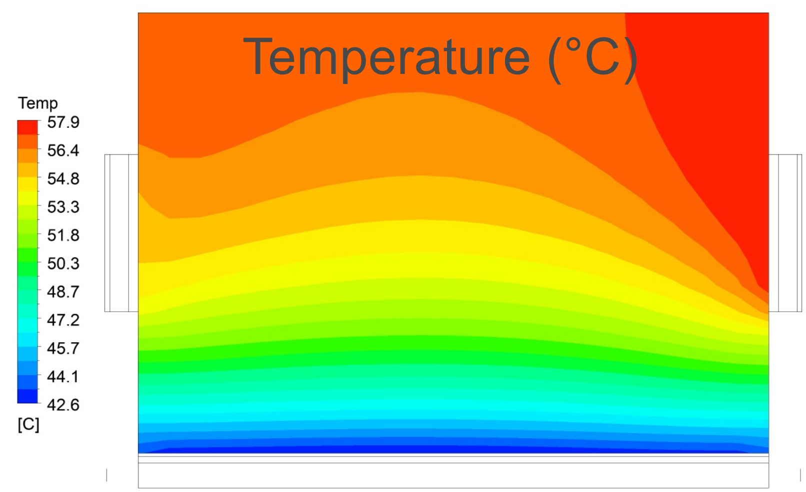
HETEROGENEITY AT LARGE SCALES

See BAT459



25 Ah pouch cell simulation





- Primary reasons for heterogeneity:
  - Higher current density near the tabs.
  - Higher temperatures away from the cold plates leading to higher conductance of electrode.

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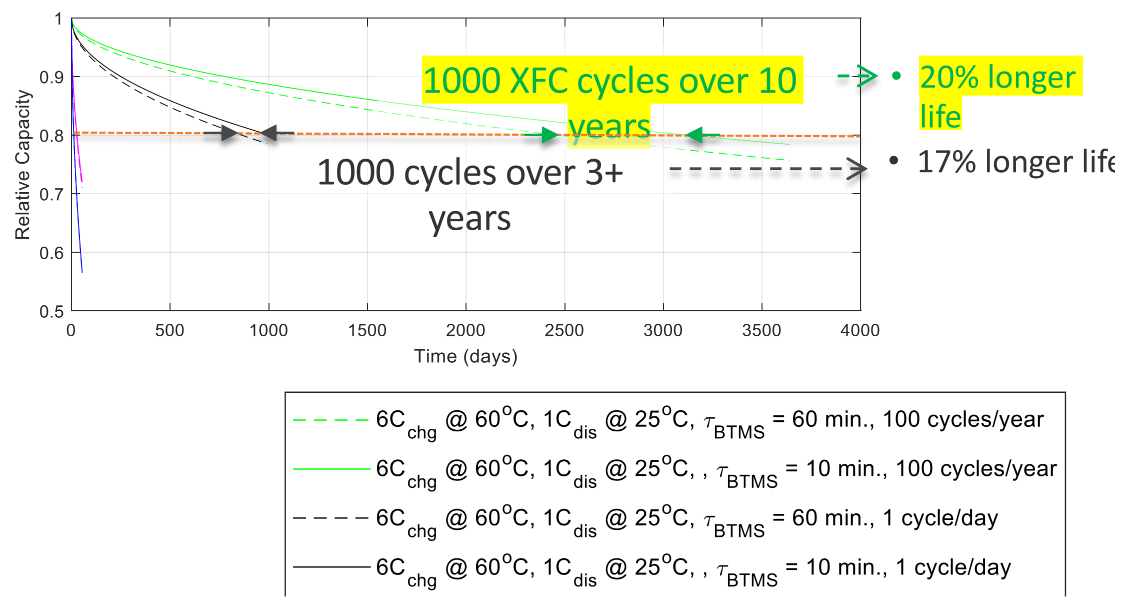
See BAT459

THERMAL RAMP AS A KNOB

Investigating 6C CCCV charging at 50°C and various cooling rates back to 30°C during discharge

- NMC811/1506T cells with Gen 2 electrolyte and B26 electrolyte under test at 3 thermal ramp rates during C/2 discharge (20, 40 and 60 minutes)
- Tests now underway
- Modeling shows the importance of rapid cooling
  - Accounts for cathode cracking and SEI/CEI growth. Does not include Li plating



Rapid cooldown important for extending calendar life

RESPONSE TO PREVIOUS YEAR REVIEWER'S COMMENTS

- This project was not reviewed last year

REMAINING CHALLENGES AND BARRIERS

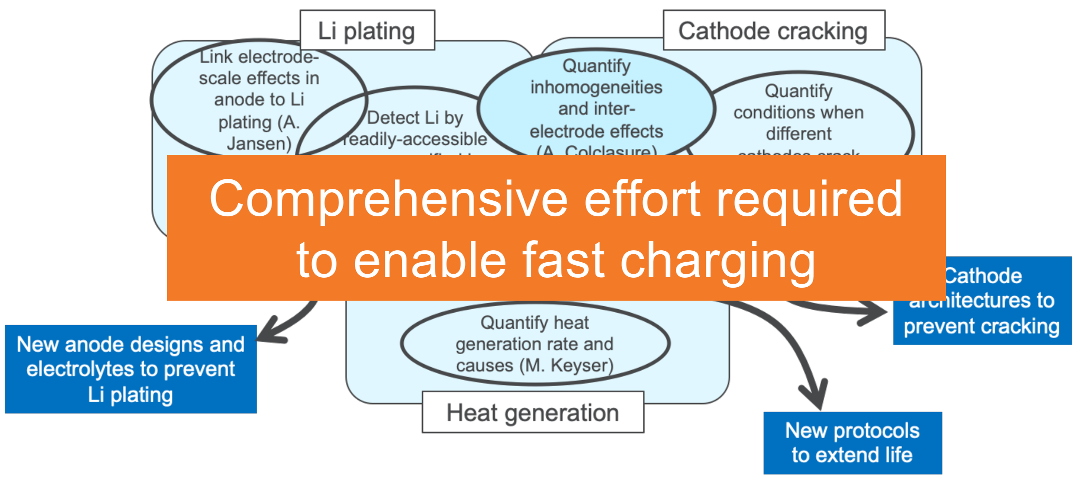
1. Can we ensure good cycle life on 3 Ah/cm^2 Gr-811 cells charging at 6C?
2. What knobs can be push to get 4 mAh/cm^2 cells charging at 6C?
3. Do single crystal NMC-811 cathodes allow cycling at 4.2 V without cracking?
4. Can we quantify impact of higher temperature charge on cycle life?
5. How much inhomogeneity can we tolerate without impacting cycle life?

PROPOSED FUTURE WORK*

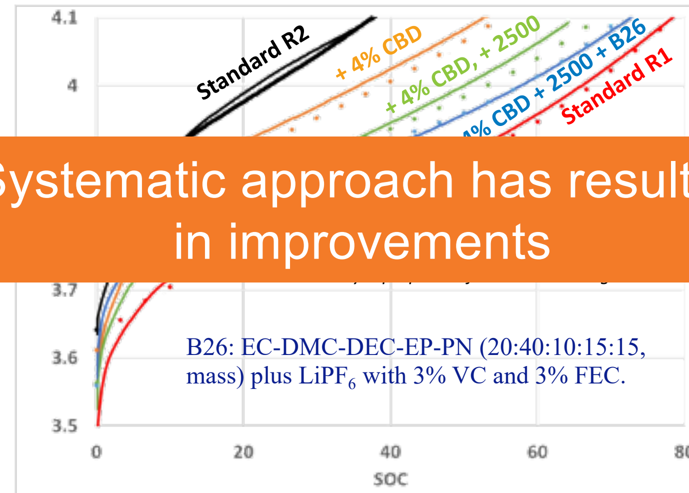
1. Can we ensure good cycle life on 3 Ah/cm^2 Gr-811 cells charging at 6C?
2. What knobs can be push to get 4 mAh/cm^2 cells charging at 6C?
3. Do single crystal NMC-811 cathodes allow cycling at 4.2 V without cracking?
4. Can we quantify impact of higher temperature charge on cycle life?
5. How much inhomogeneity can we tolerate without impacting cycle life?

*Caveats related to funding apply

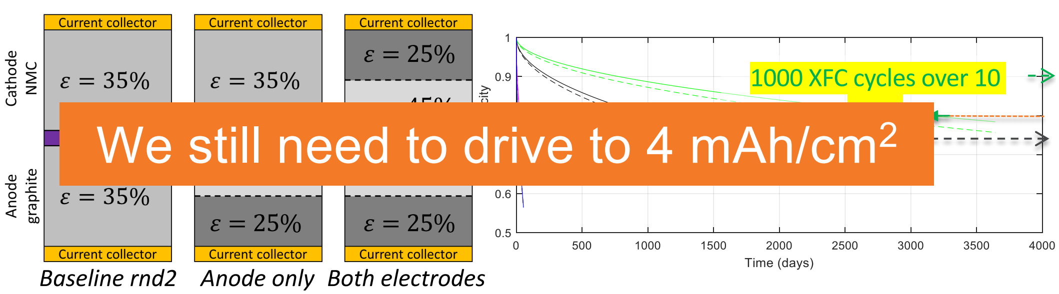
SUMMARY



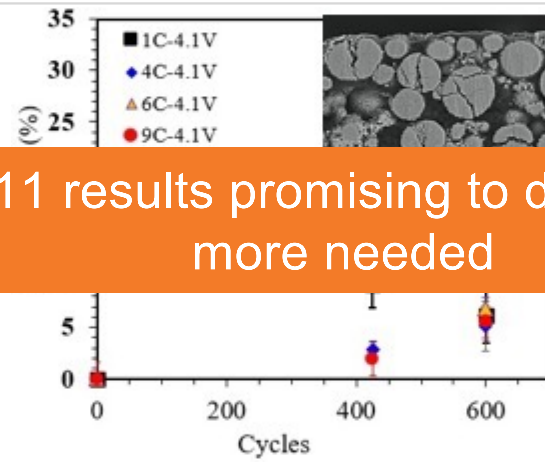
Comprehensive effort required to enable fast charging



Systematic approach has resulted in improvements



We still need to drive to 4 mAh/cm^2



811 results promising to date; but more needed