Battery Modeling and Prognostics for Improved Safety and Longevity

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The ARTS-Lab at USC

We use

foundational science

Day School

to develop essential tools

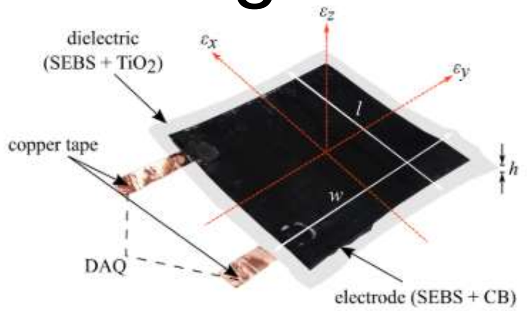
Dan Thompson

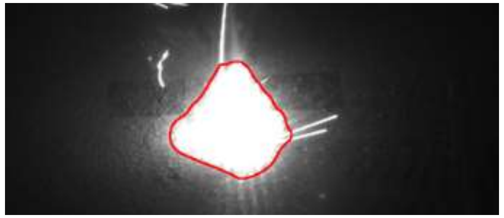
to solve real-world problems

public domain

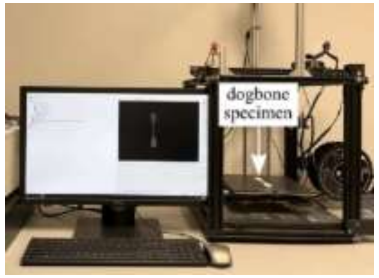
We are Engineers (mostly)

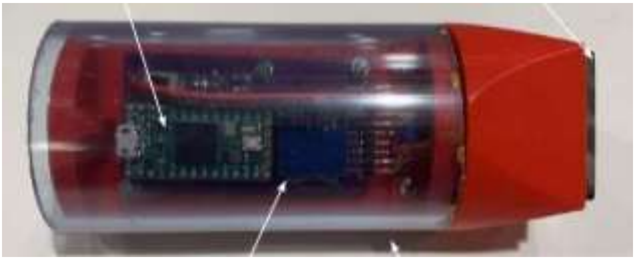
Sensing



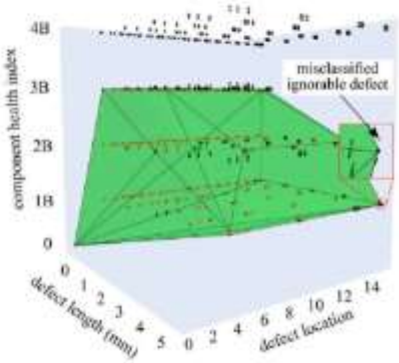


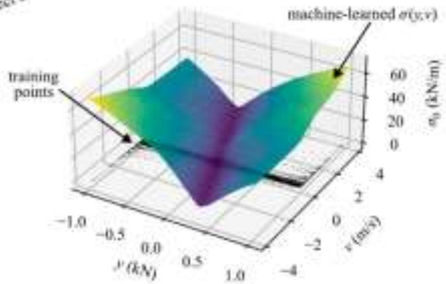
Data Assimilation





AI/ML

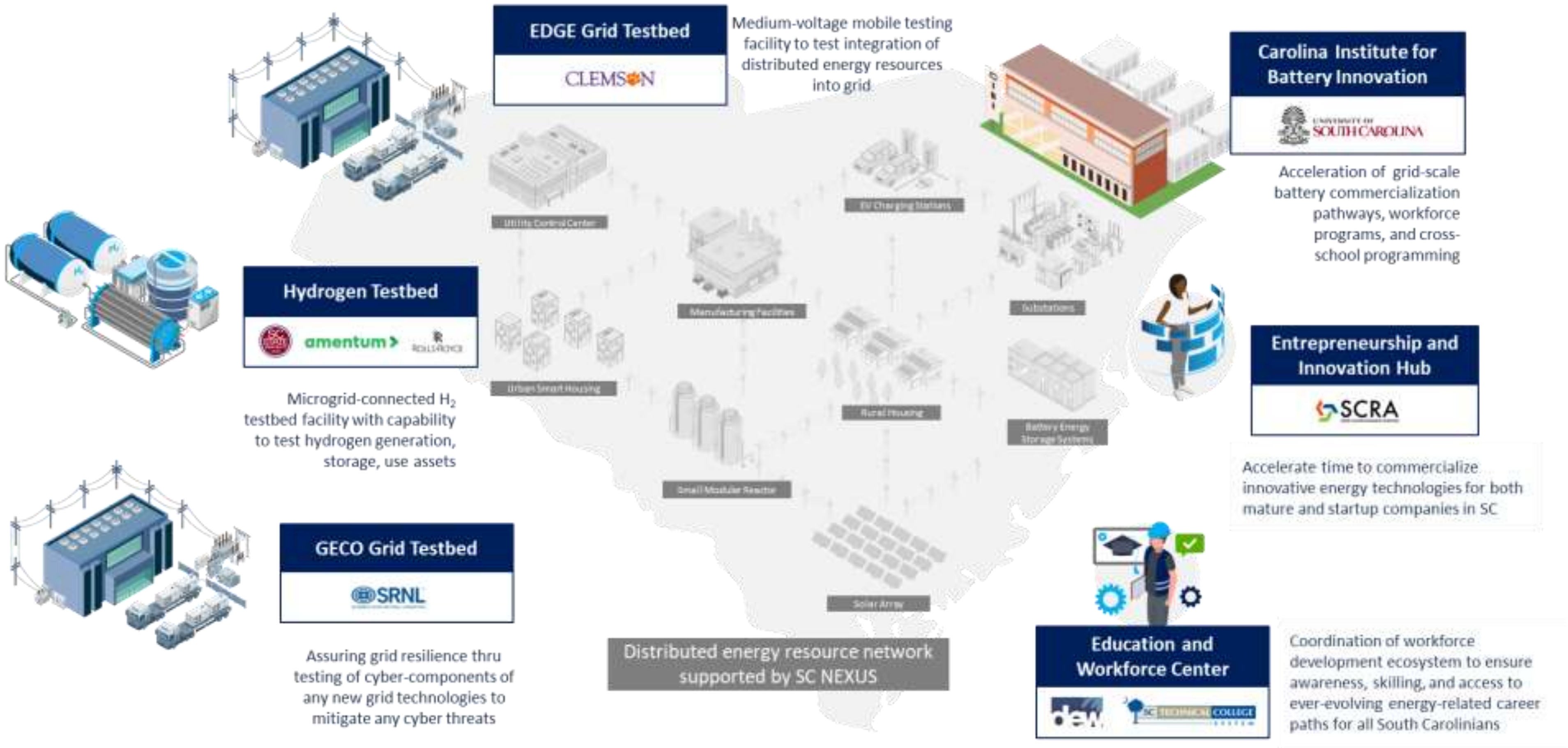




Embedded Systems

Battery Research at USC

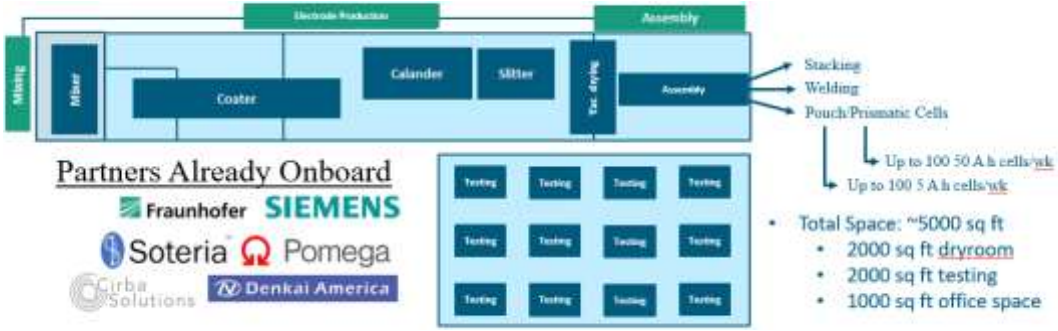
Projects that will enable SC NEXUS to become global leader in bolstering grid resilience through distributed energy resources



The **SC Nexus** for Advanced Resilient Energy (**SC NEXUS**) received $45 **million** in implementation grant funding through the US Department of Commerce

Carolina Institute for Battery Innovation (CIBI)

- Pilot manufacturing of prismatic, pouch, and cylindrical cells
- World-class battery safety and abuse testing lab
- Large battery cycling/performance lab
- Wet labs for fundamental and applied battery R&D
- Education, workshops, and hands-on training at all levels
- 15 Faculty, ~50 Graduate Students + UGs



Fulbright Scholar-in-Residence Program

Fulbright Scholar-in-Residence Program

Lucy Joy Wachira of Kenya teaching during her S-I-R exchange at Temple University in 2022-2023

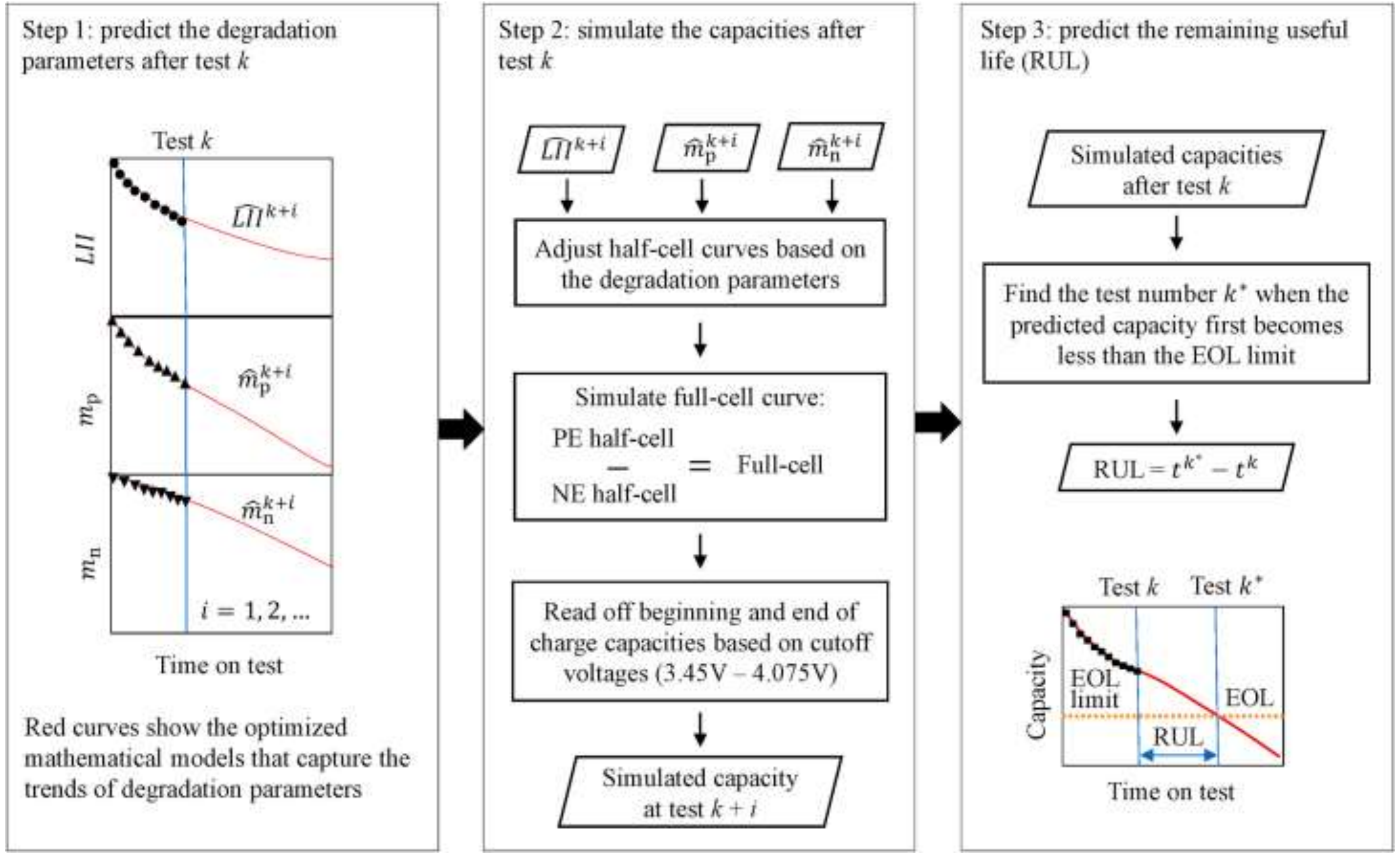
The Fulbright Scholar-in-Residence (S-I-R) Program is a unique Fulbright Scholar Program initiative that is specifically driven by the goals of U.S. institutions of higher education to enhance internationalization efforts on their campuses. Through the S-I-R Program, institutions host a scholar from outside of the United States for a semester or full academic year to teach courses, assist in curriculum development, guest lecture, develop study abroad/exchange partnerships and engage with the campus and the local community. S-I-Rs work across departments and curricula in a variety of ways to widely enhance or expand an existing international program, develop new world area studies programs, add an international dimension to existing coursework or provide an opportunity for U.S. students to learn about a particular world region or country.

https://fulbrightscholars.org/sir

Battery Degradation Forecasting

Physics-based Prognostics

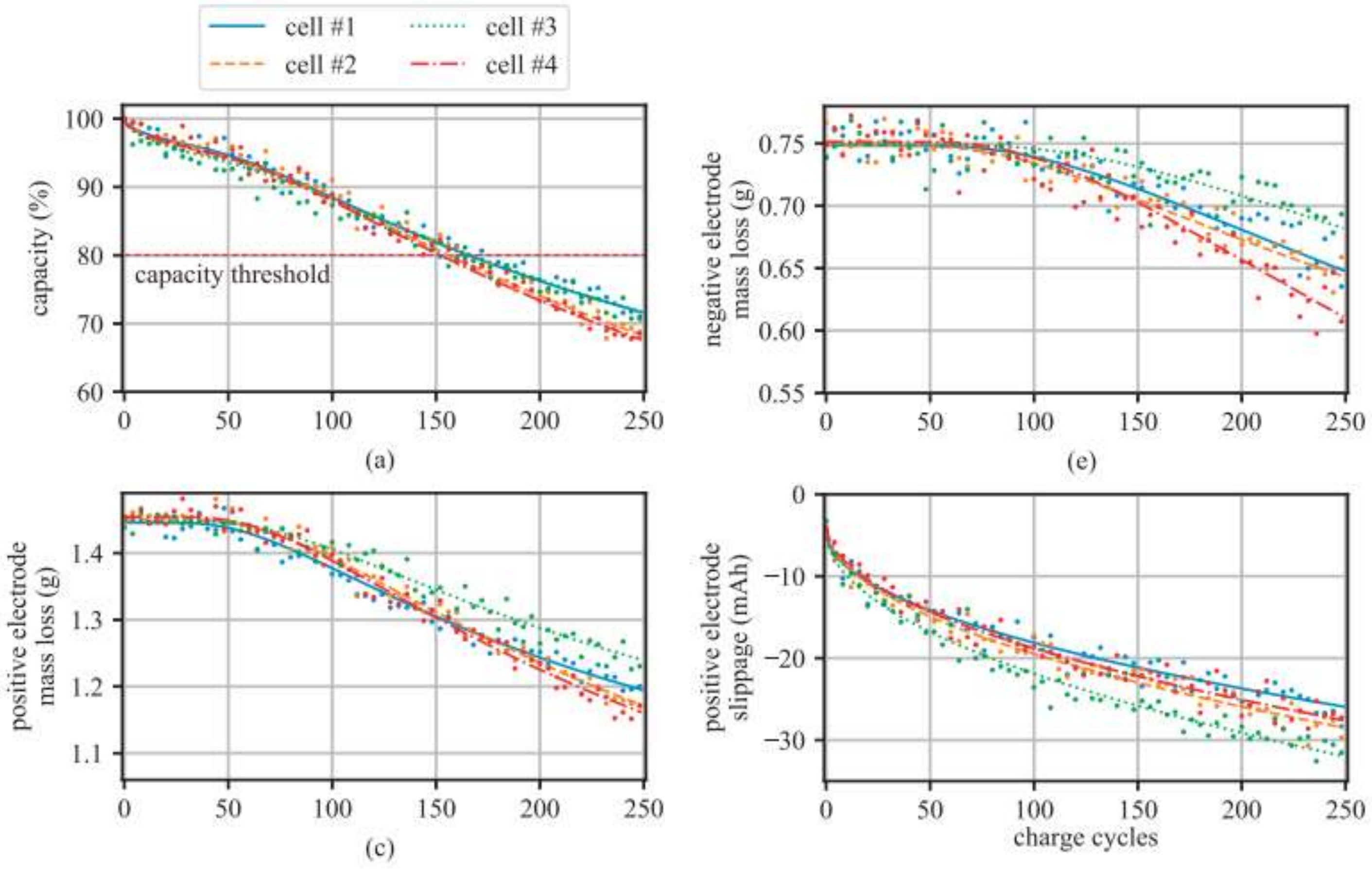
- Traditional methods forecast cell RUL based on capacity fade
- This work explored forecasting individual model parameters and inferring RUL from a model



Yu Hui Lui, Meng Li, Austin Downey, Sheng Shen, Venkat Pavan Nemani, Hui Ye, Collette VanElzen, Gaurav Jain, Shan Hu, Simon Laflamme, and Chao Hu. Physics-based prognostics of implantable-grade lithium-ion battery for remaining useful life prediction. Journal of Power Sources, vol. 485, 2020, p. 229327, doi.org/10.1016/j.jpowsour.2020.229327.

Degradation cases for 8 cell models

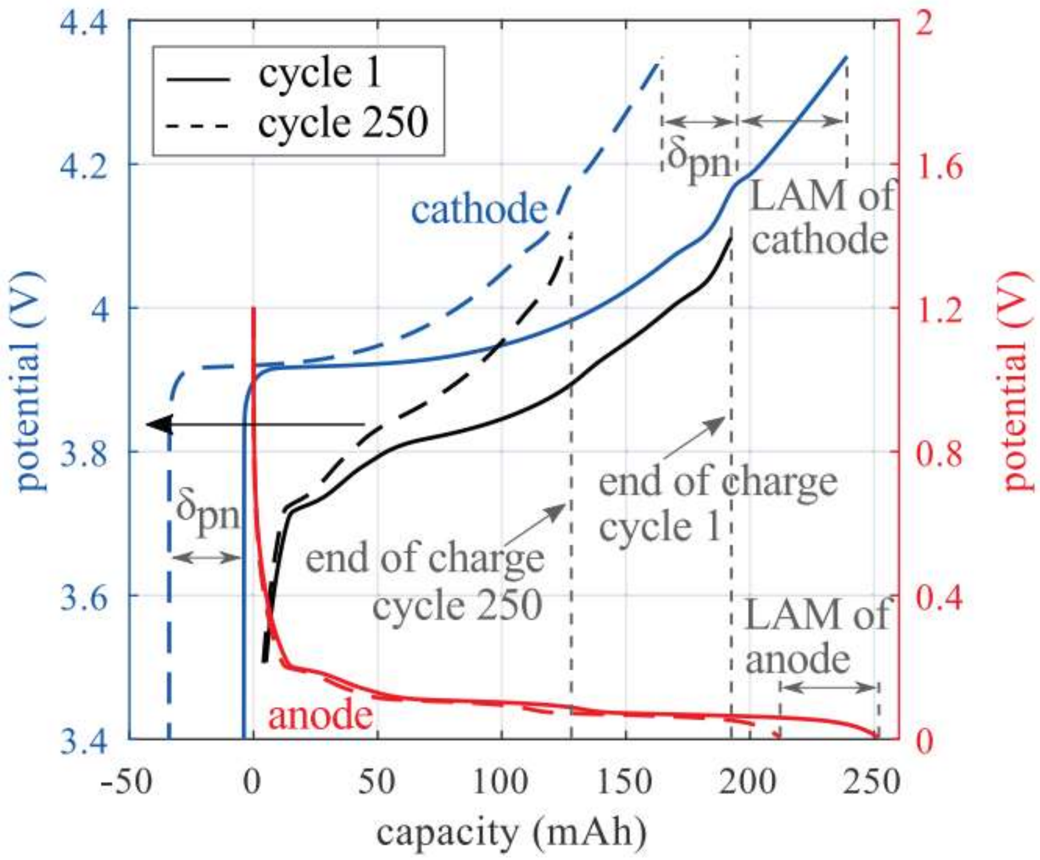
- Tested 8 cells.
- Modeled:
  - Positive electrode mass loss (g)
  - Negative electrode mass loss (g)
  - Positive electrode slippage (mAh)
- These parameters are forecasted (not capacity)



Austin Downey, Yu-Hui Lui, Chao Hu, Simon Laflamme, and Shan Hu. Physics-Based Prognostics of Lithium-Ion Battery Using Non-linear Least Squares with Dynamic Bounds. *Reliability Engineering & System Safety*, vol. 182, 2019, p. 1-12 doi:10.1016/j.ress.2018.09.018.

Half-cell Curve Analysis

- These parameters were obtained from the half-cell curve analysis.
- Half-cell curve analysis with the key components annotated.
- Experimental data matched to hall cell by comparing capacity



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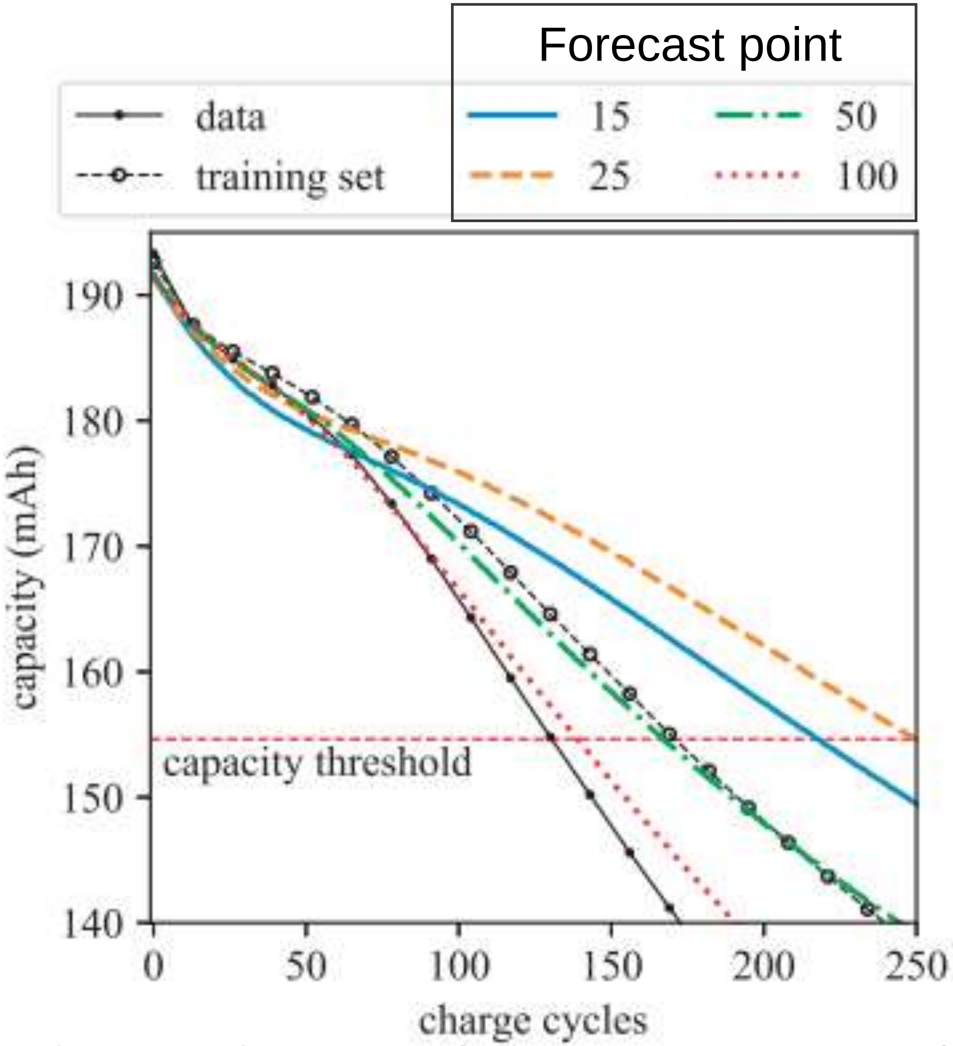
Mechanistic Capacity Predictions

- Forecast the three parameters.
- Use forecasted model parameters and experimental data from cells to get forecasted capacity.
- Forecast improves as more data comes online



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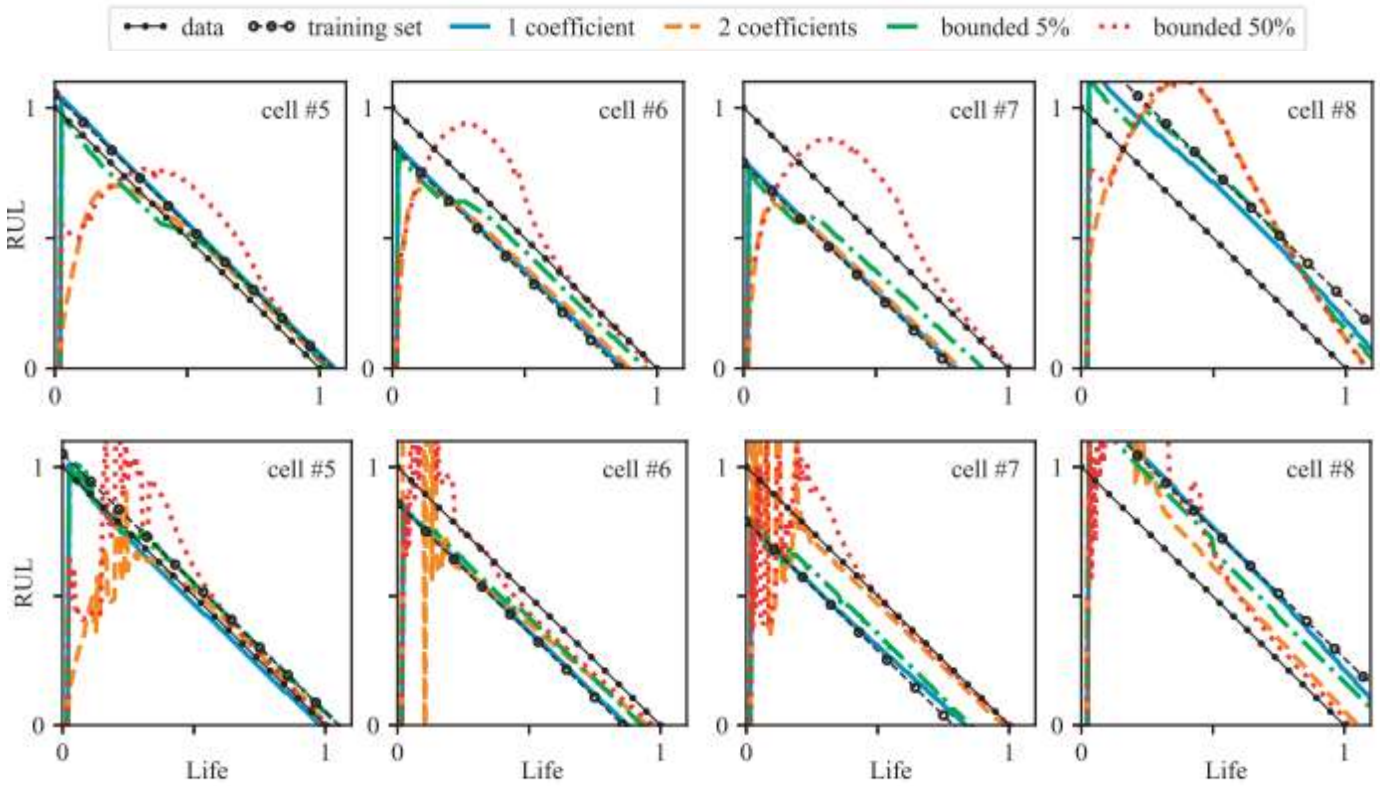
Remaining Useful life Results

- **Strength:** Physics-based forecasting learns the state of the cell faster than capacity-based forecasting.
- **Weakness:** Requires the building of half-cell experimental setups



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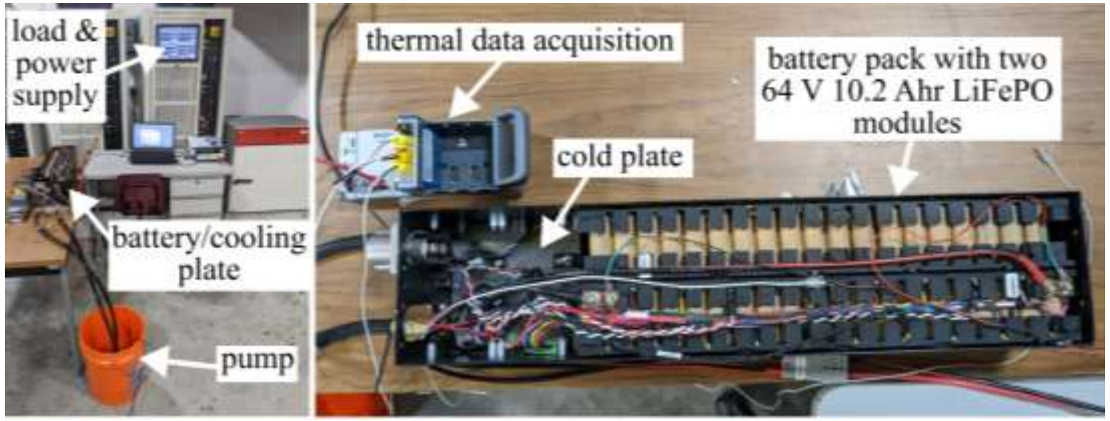
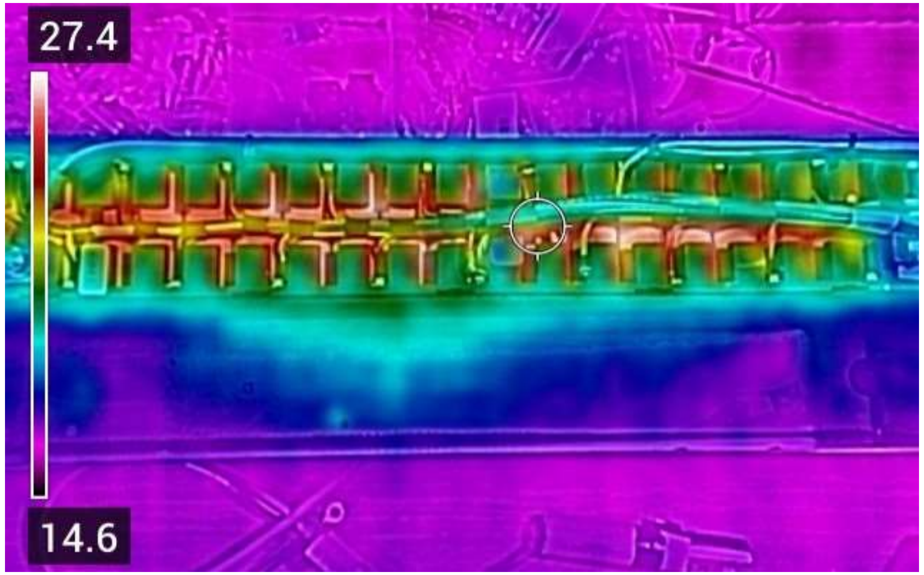
USC Battery Pack Lab
(General Overview)

High-Voltage Battery Pack Testing Capabilities

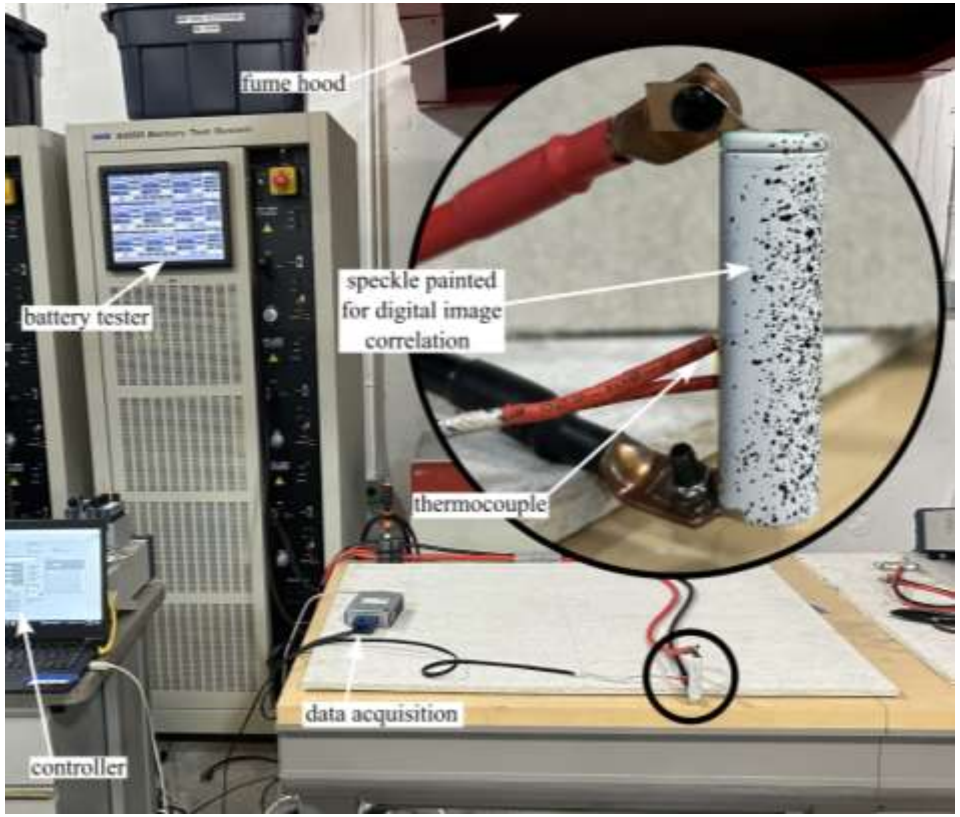
Full-scale Battery Pack Testing

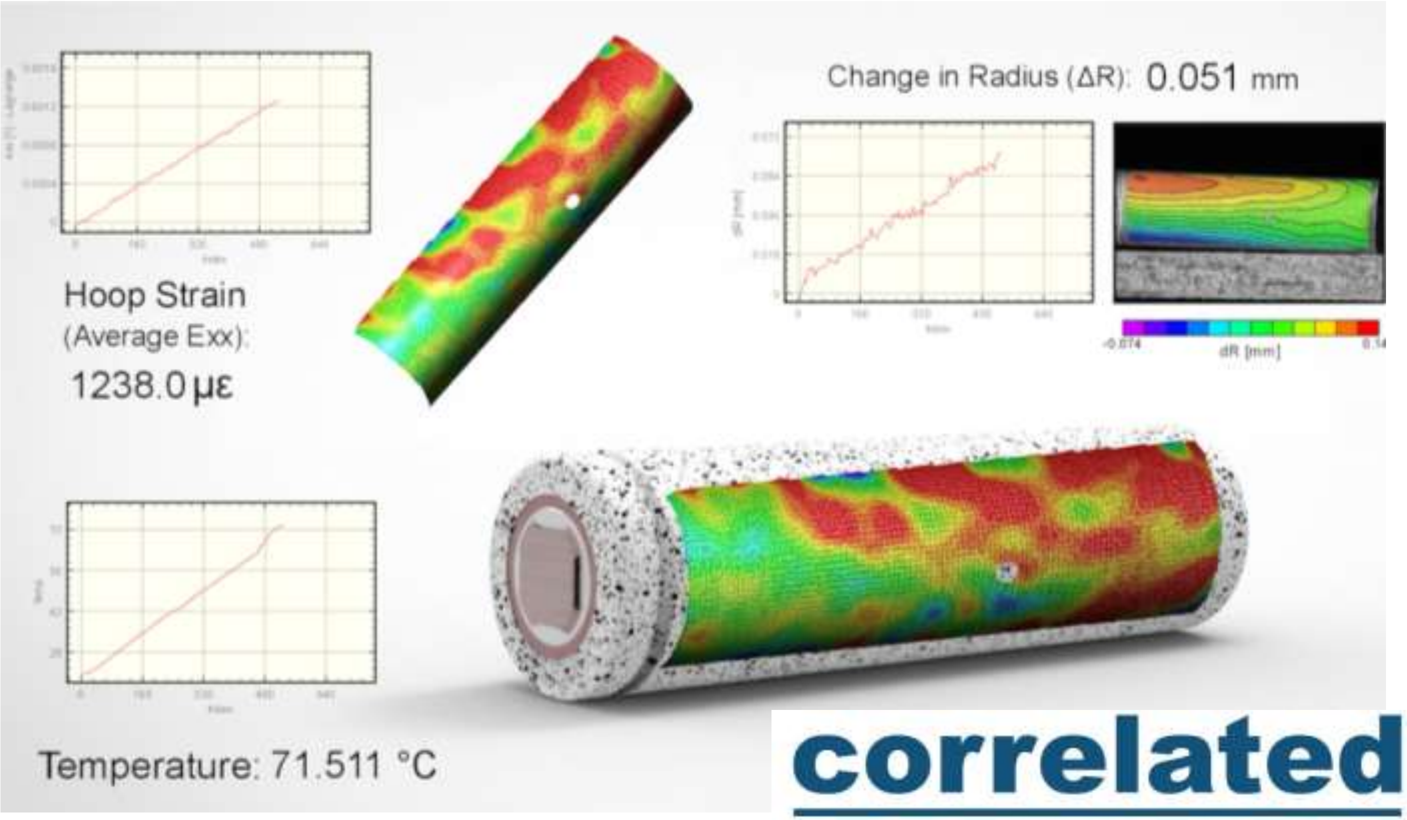
- Full-Scale pack testing
- Setting up for automotive pack testing
- Liquid-cooled Li-Iron Phosphate Battery Pack
- Pack is two 64 V 10.2 Ahr modules





Strain-based Cell Failure Investigations

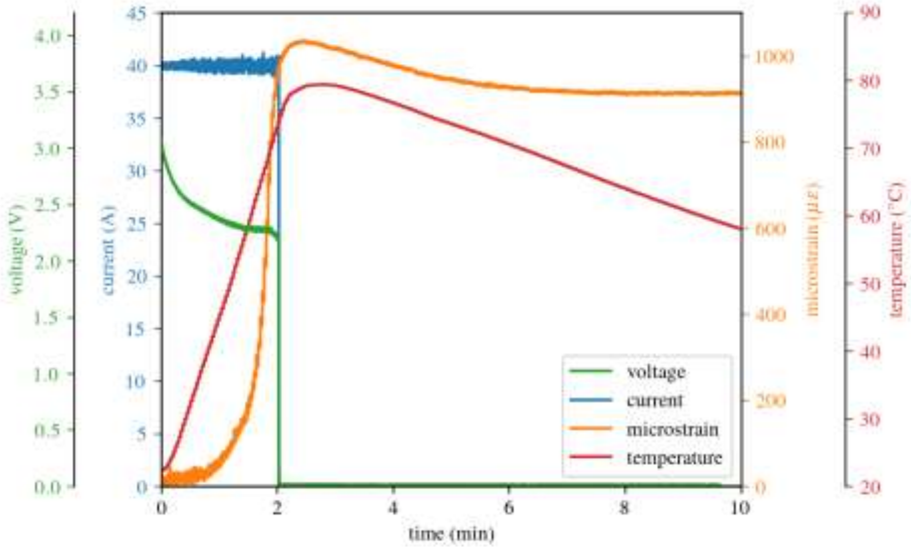


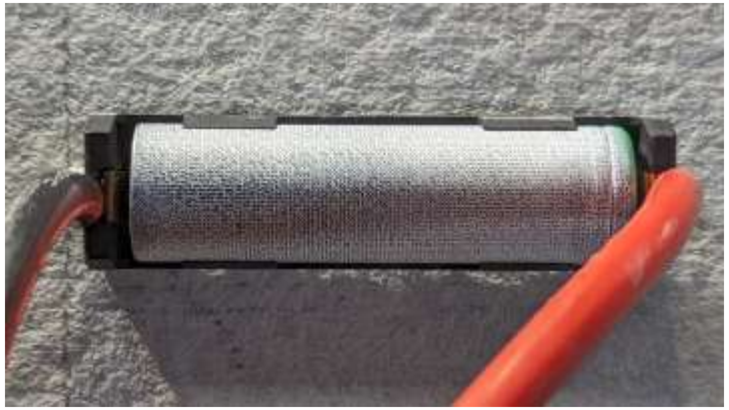


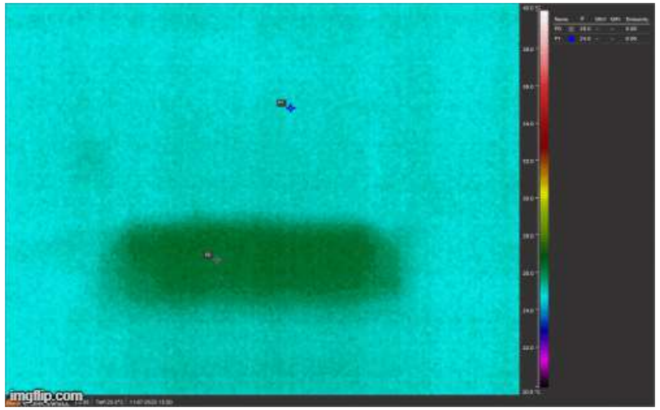
correlated SOLUTIONS

Current Interrupt Device Testing

- Tested cells till CID failure
- Cells did not enter thermal runaway
- Interested in the controllability of cells during rapid discharge

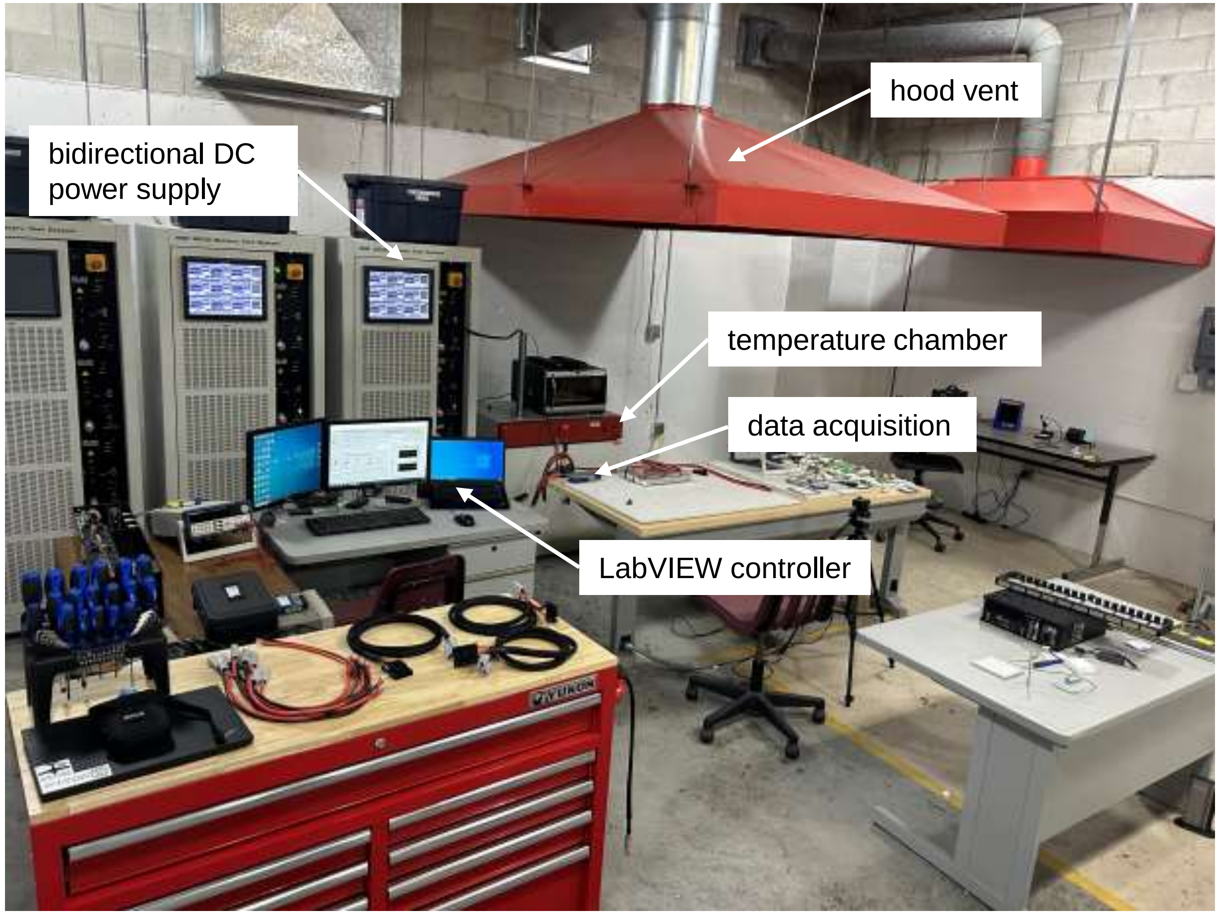




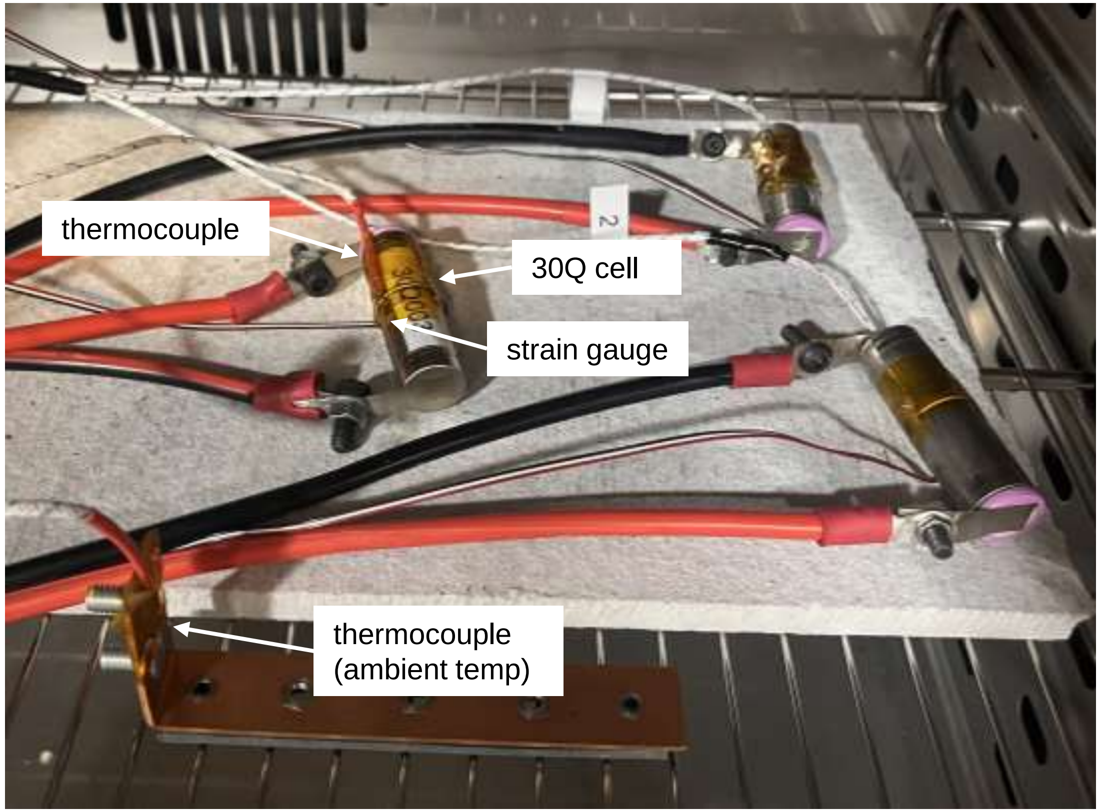


Strain Monitoring
(Early Experimental Work)

Cycling and Strain Monitoring of a Samsung 30Q Cell



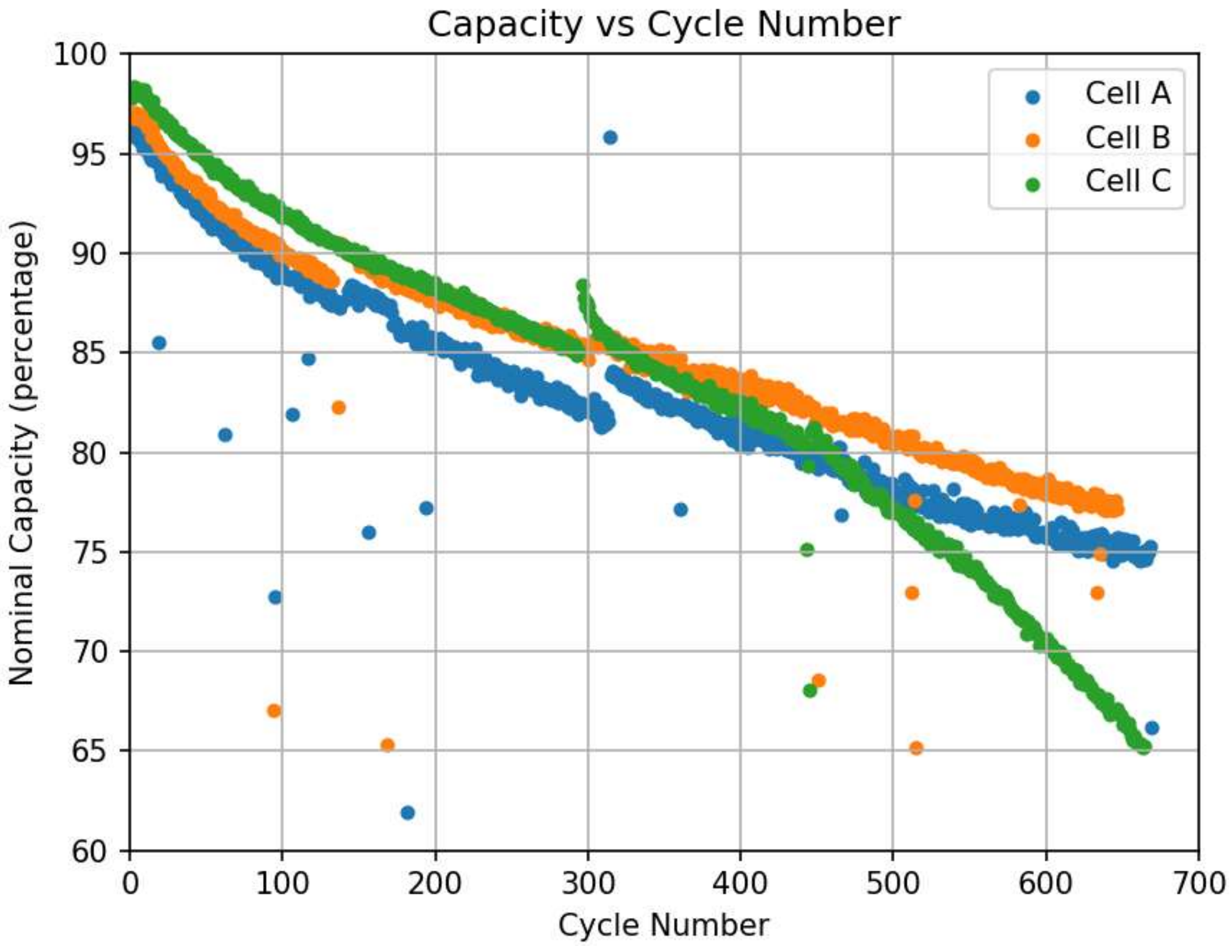
Cell strain analysis setup



Cell cycling setup within temperature chamber

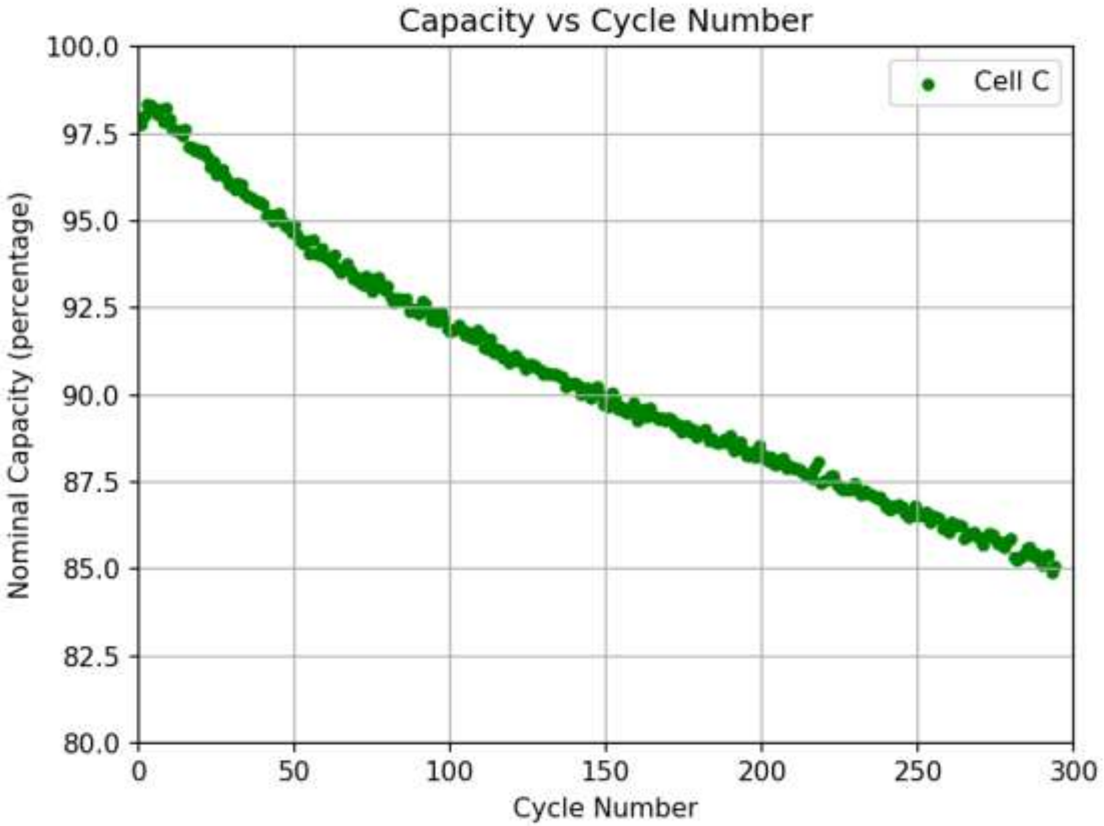
Capacity Degradation Results

- 650 cycles on 3 individual cells.
- Noise in data produced from imperfect LabVIEW programming.
- Jumps in capacity caused by over/under charge events. Result of power outages or Windows updates.



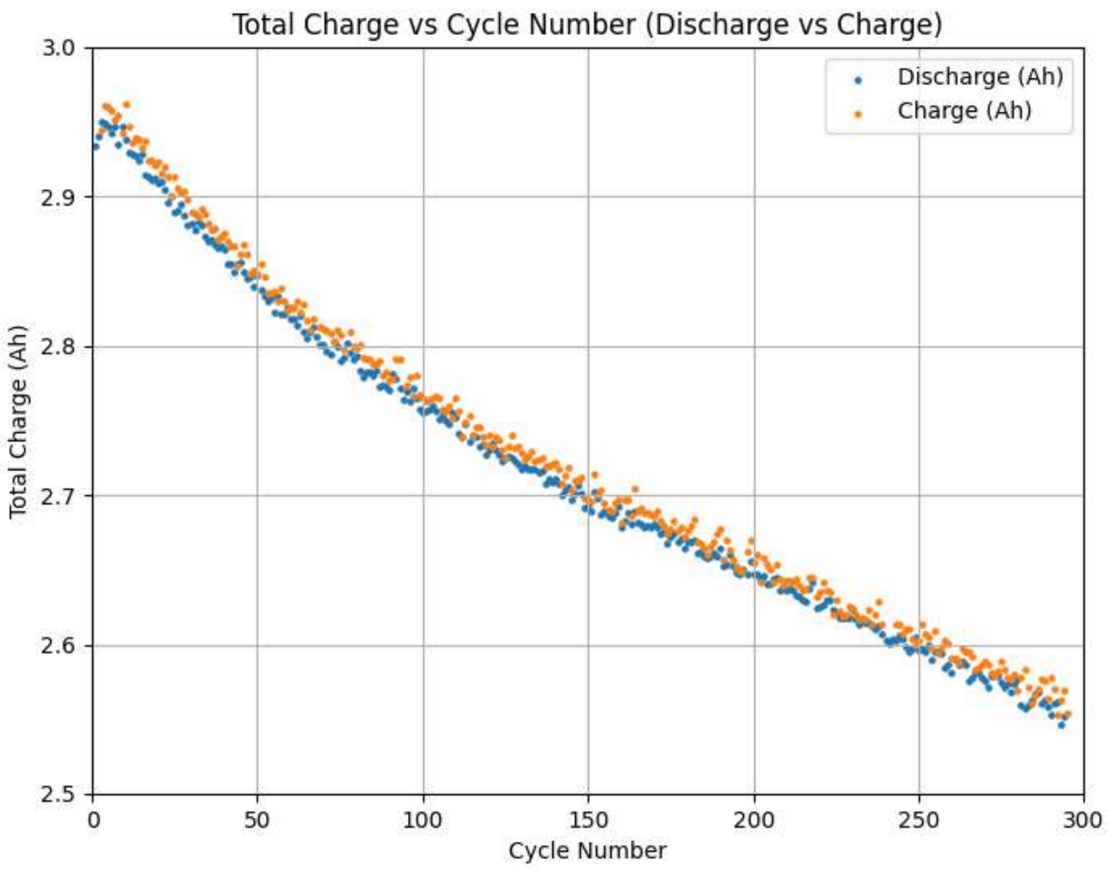
Sub-Sectioning Data for Analysis

- Analysis will focus on cell C which contains no errors within the selected range.
- Limiting data range to approximately 300 cycles.



Charge/Discharge Cycle Monitoring

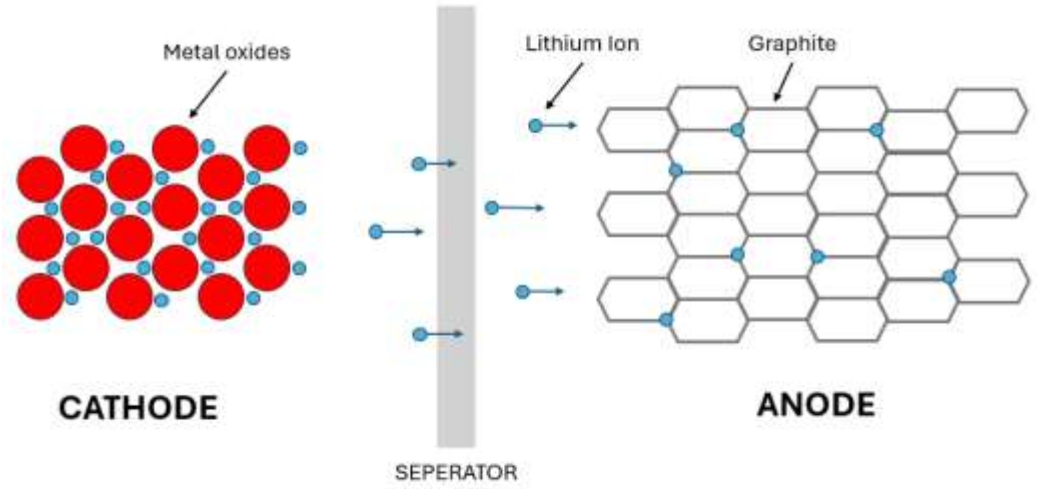
- Coulomb counting was used to calculate the total charge in and out of the cell during charge and discharge cycles.
- While there is a separation between charge and discharge, it is not too significant.

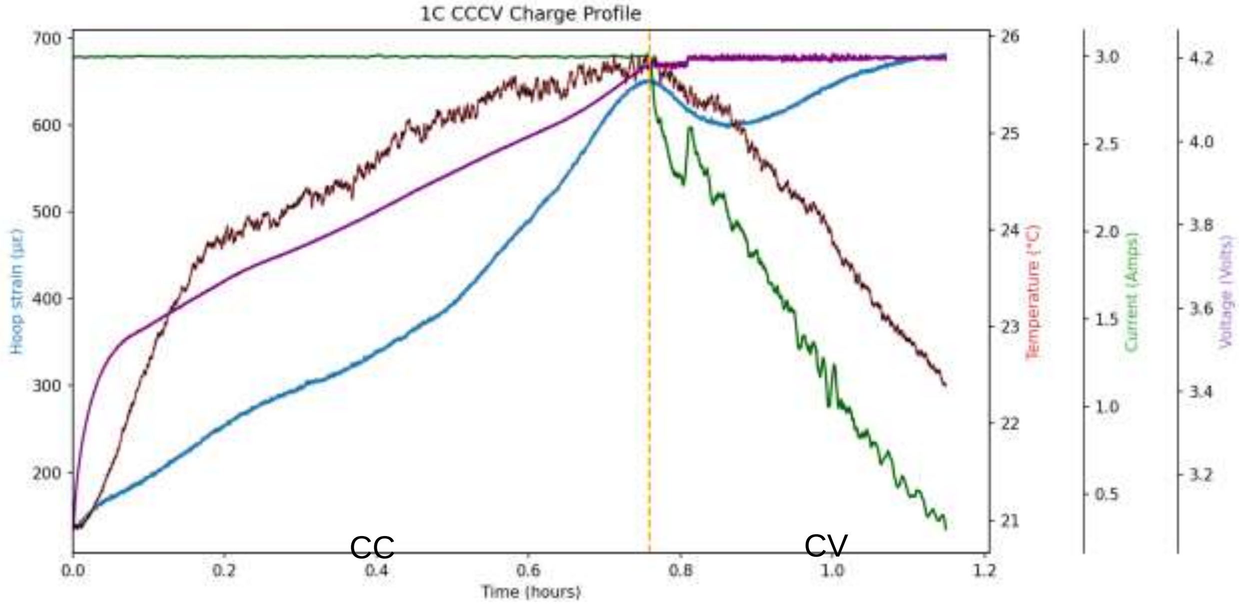


Charge Analysis

Experimental monitoring of battery strain shows unique features:

- Dip during CV charging
- Not strictly thermally driven expansion
- Two distinct strain initial strain rates.
- The working assumption is that strain is driven by the expansion of the anode.

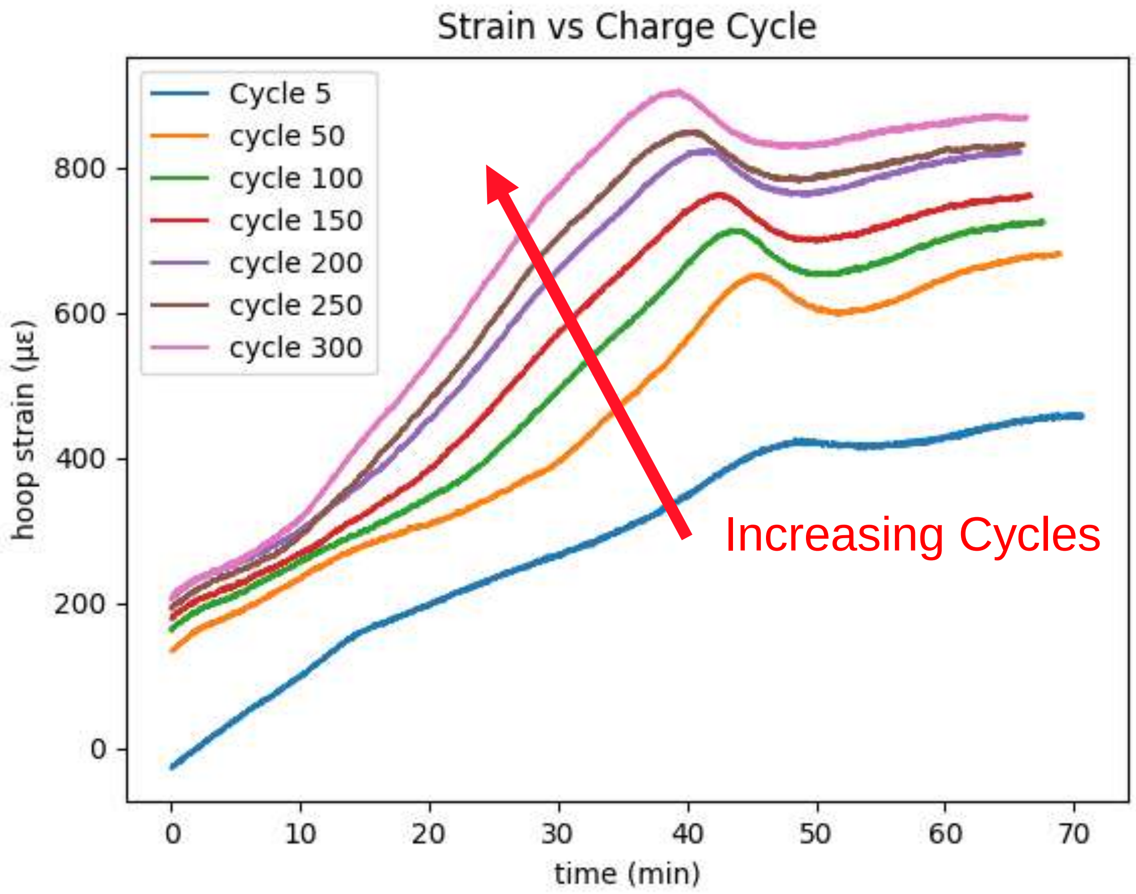




Cell C Charge Profile @50 Cycles

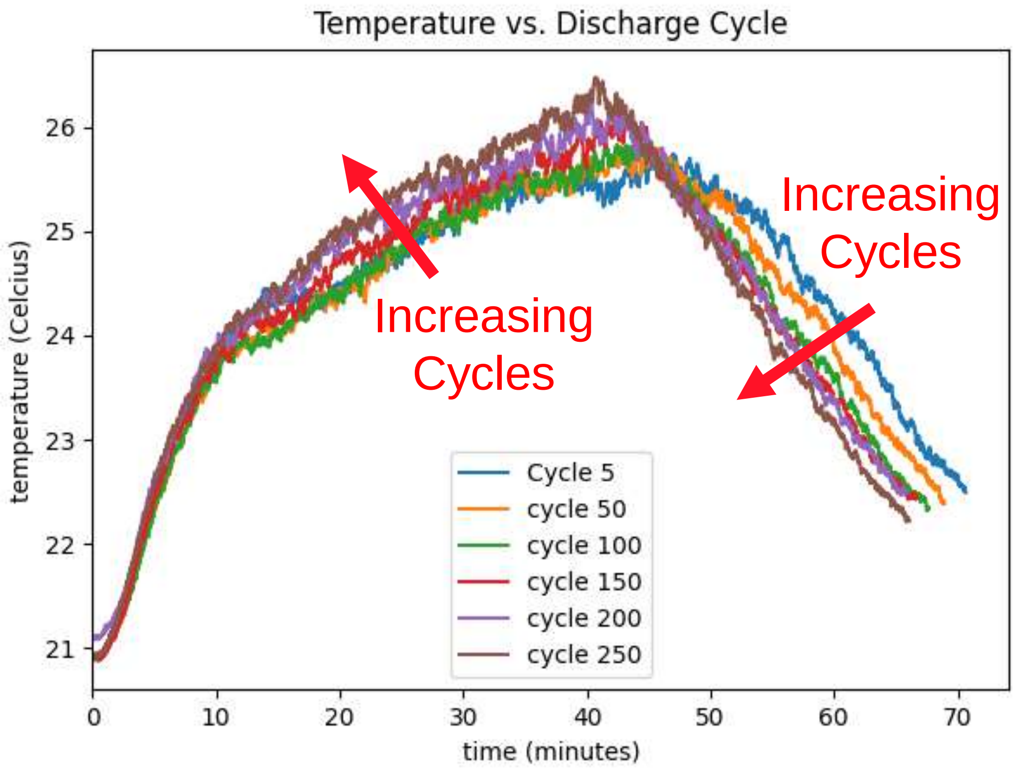
Charge Strain Curves

- Observations:
  - Two distinct strain rates initially present before peak
  - Development of peak region
  - Strain recovery after peak
  - Strain profile expands in a predictable fashion.



Charge Temperature Data

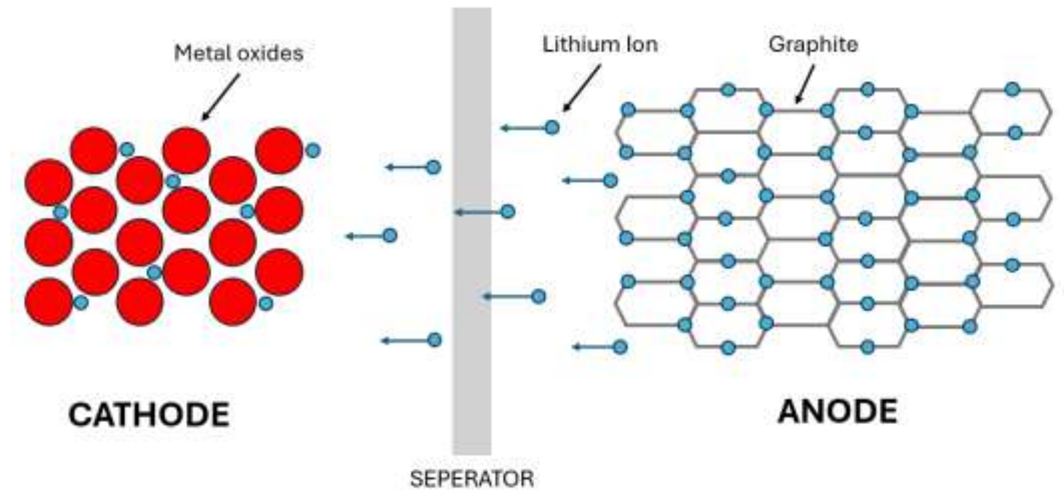
- Within 250 cycles temperature only varies within ~1 degree C
- Initial thermal increases if very similar
- Need to inspect in terms of capacity

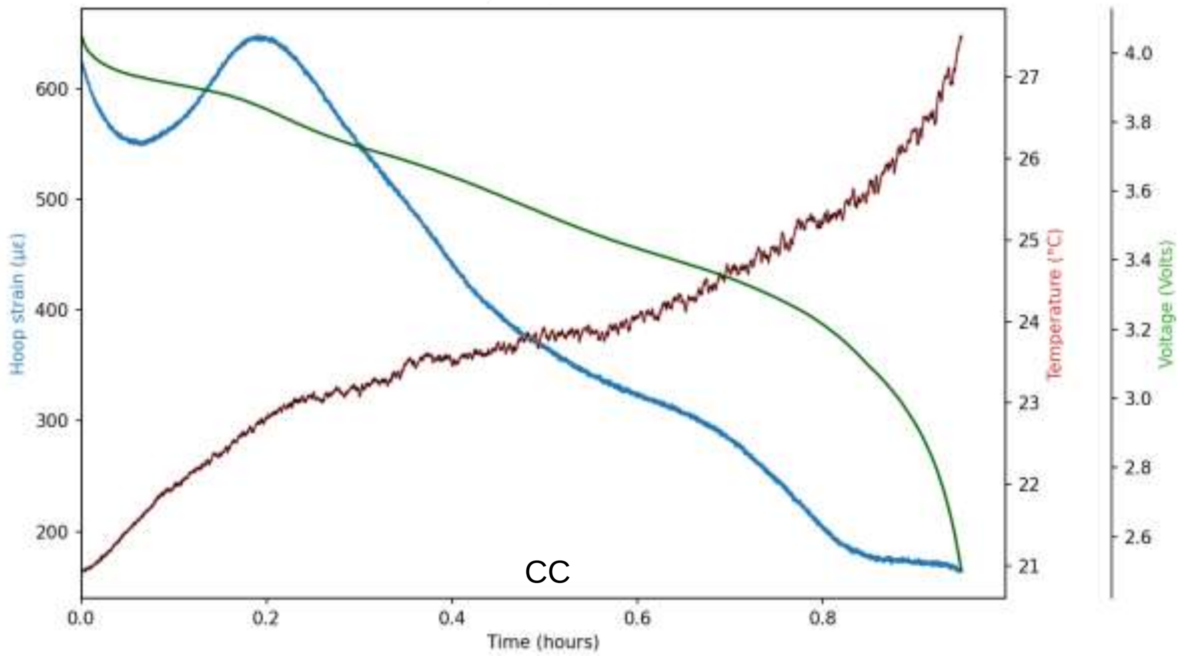


Discharge Analysis

Experimental monitoring of battery strain shows unique features:

- A hump in the strain at 0.2 hours
- Does not appear to be thermal driven

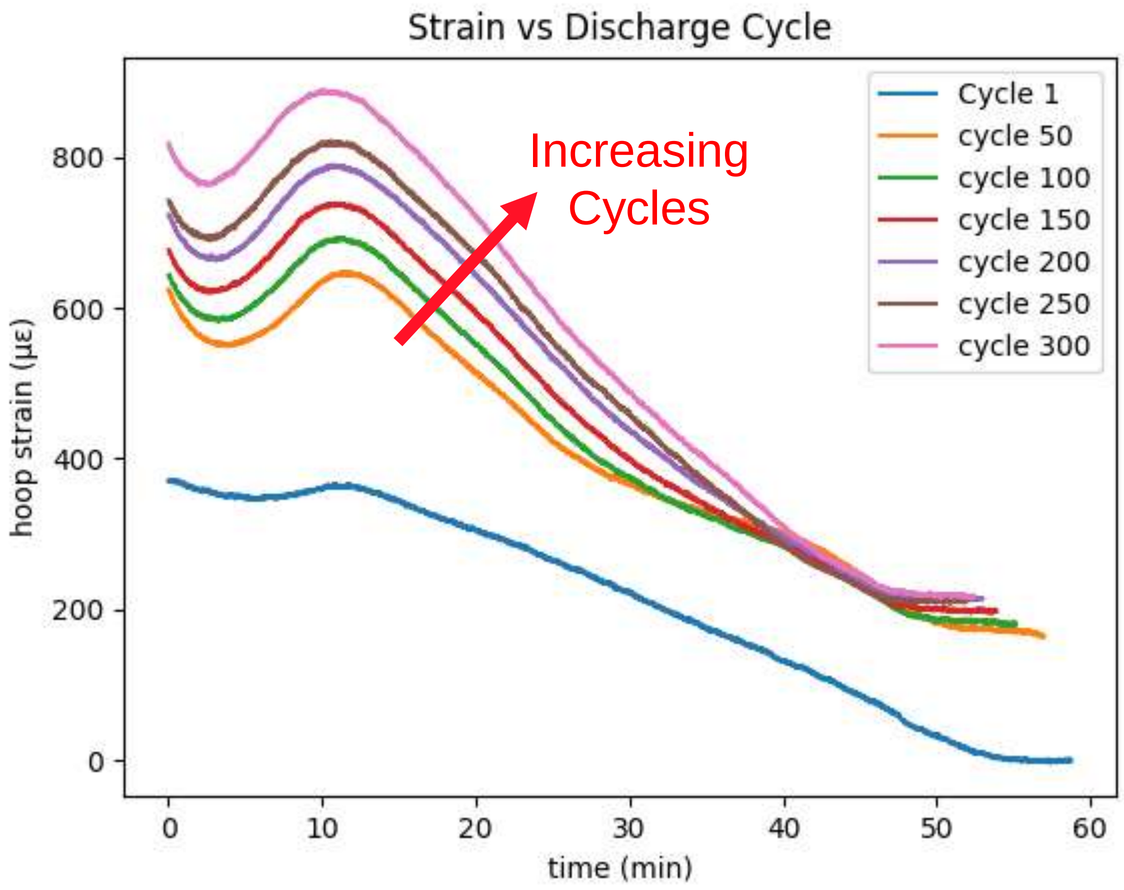




Cell C Discharge Profile @50 Cycles

Discharge Strain Curves

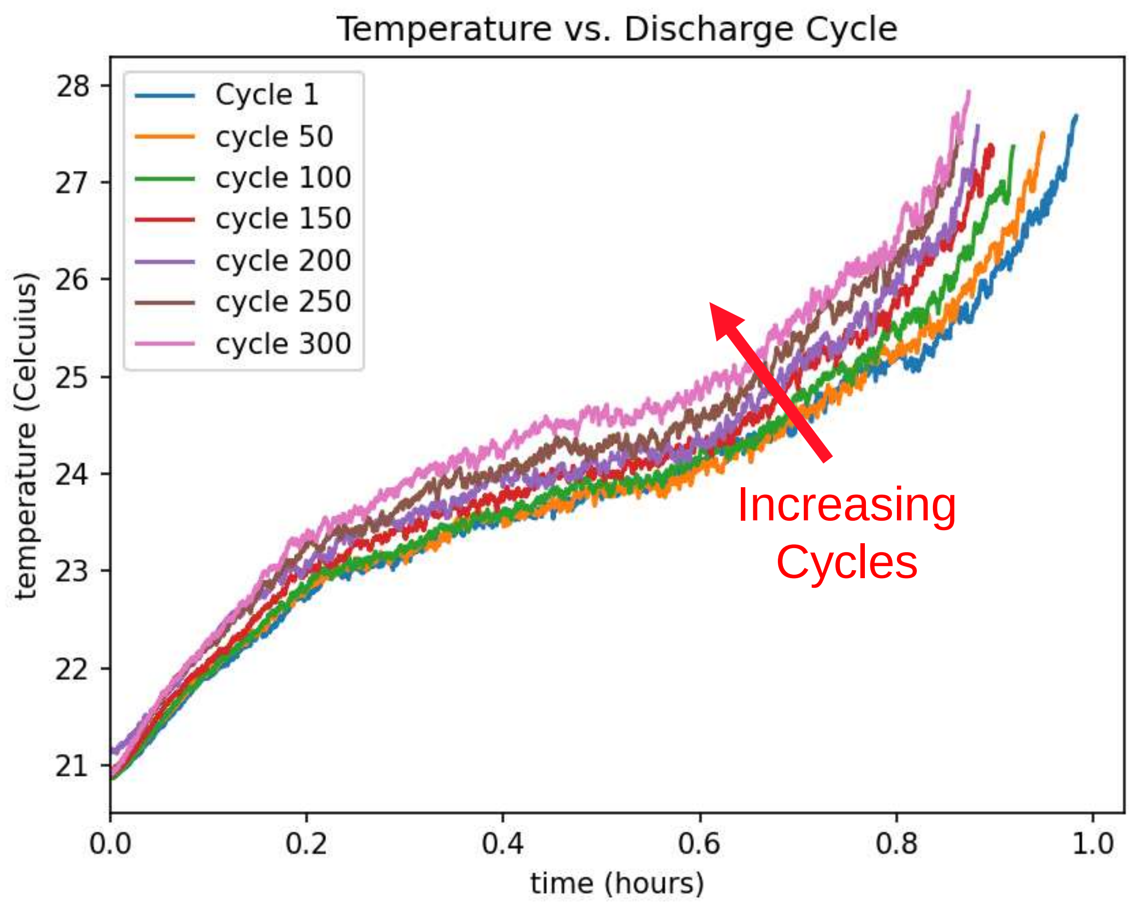
- Development of “hump” region
- Increasing peak and initial strain values
- Rapid jump to increased settling strain level between 1 and 50 cycles
- Converging strain values at 40 minutes



First 300 cycles from cell C

Discharge Temperature Data

- Temperature increases at a given time with cycle.
- Temperature at the end of the cycle is roughly equal throughout cycle life.
- Temp in the first ~10 minutes is very close for all cycles, while the discharge hump varies in this region.



Thank You for Your Time

Open-Source Data Set

GitHub

https://github.com/ARTS-Laboratory/dataset-cycling-with-strain-monitoring-for-samsung-30Q-cell

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