Sandia National Laboratories

Long Term Cycling of 18650 Li-ion Cells Beyond 80% Capacity

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Introduction

- Li-ion battery performance is not well understood beyond the traditional 80% capacity retention end-of-life (EOL) cutoff
- This standard was established for batteries used in vehicles and may not apply for grid applications
- In 2017 we started the largest public study of post 80% cycling of Li-ion batteries

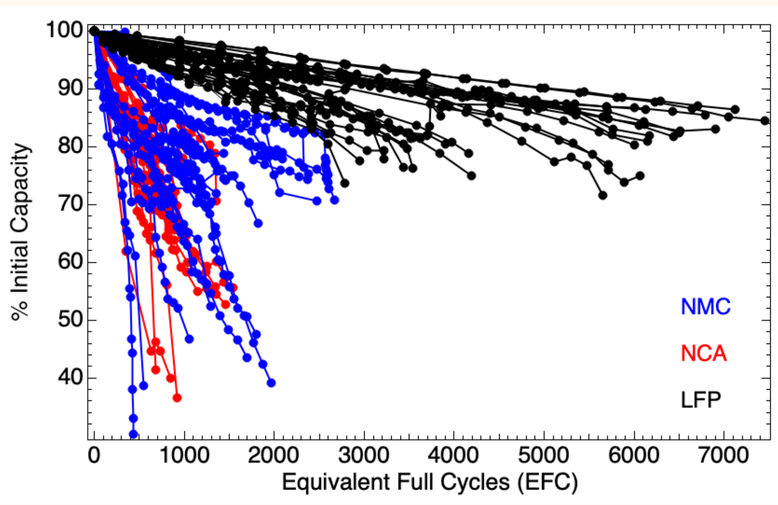
Methods

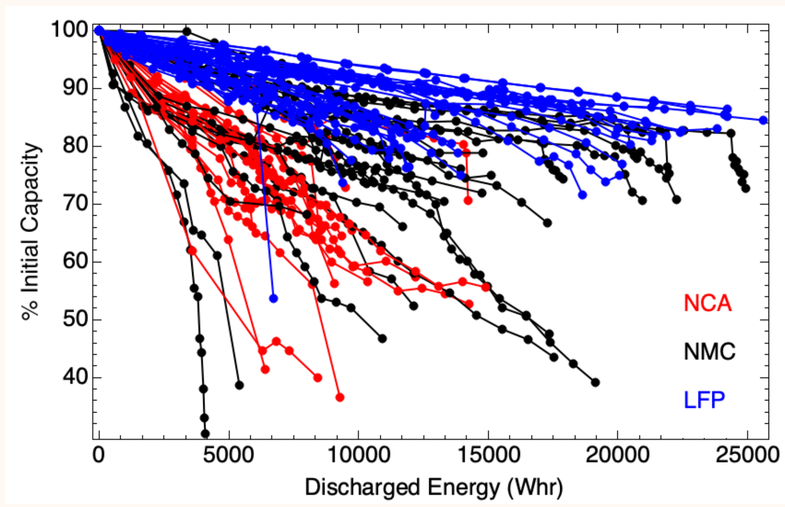
- Cycled 18650 format cells to 80% initial capacity[1] and now, to EOL of 40%
- Materials characterization on selected cells at 80% capacity and EOL

Conditions of Cycling (DOD, Temperature, Discharge Rate*)			
40-60%, 25°C, 0.5C	0-100%, 15°C, 1C	0-100%, 15°C, 2C	40-60%, 25°C, 3C
20-80%, 25°C, 0.5C	0-100%, 25°C, 1C	0-100%, 25°C, 2C	20-80%, 25°C, 3C
0-100%, 25°C, 0.5C	0-100%, 35°C, 1C	0-100%, 35°C, 2C	0-100%, 25°C, 3C

*0.5C charge rate for all

Study Status Fall 2022





- There is significant useful life in post 80% cells depending on chemistry and cycling conditions
- Generally LFP has the longest cycle life then NMC and NCA
- Discharge energy may be a more informative metric to evaluate battery life for grid applications

Chemistry	# of Cells Below 80%	# of Cells at EOL	Mean EFC+ Post80% to date	Mean Energy Discharged Post80% to date	Mean Capacity of Post80% Cells
NMC	19	3	685 +/- 306	6.8 +/- 3 kWhr	63%
NCA	13	3	486 +/- 286	4.9 +/- 2.8 kWhr	60%
LFP	15*	0	392 +/- 291	1.4 +/- 0.9 kWhr	74%

+EFC is equivalent full cycles defined as the capacity to charge and discharge the cell fully against its rated capacity * 17 LFP cells cycling are still above 80% Capacity

Impact of Cycling Conditions

Initial impact of cycling conditions:

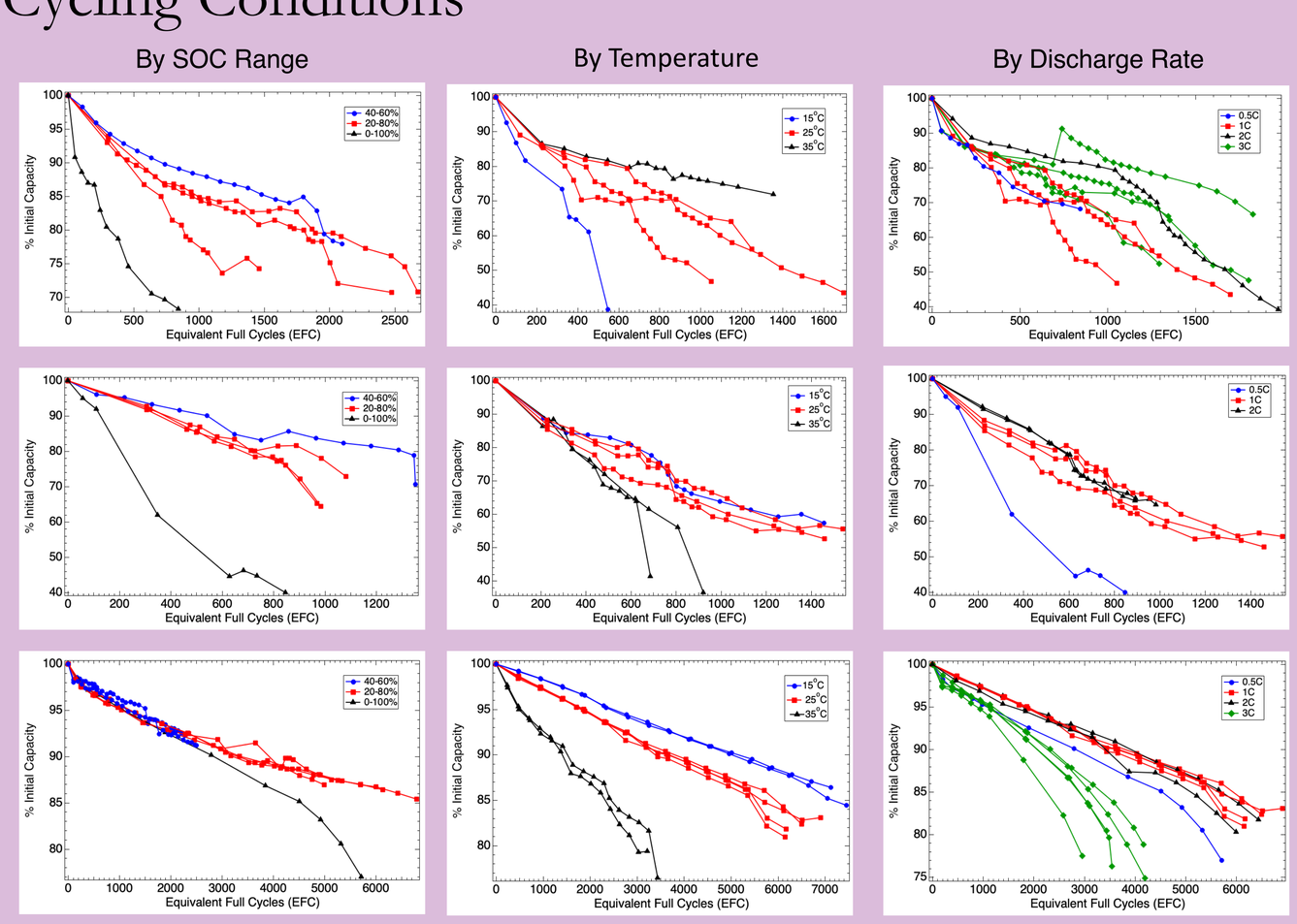
- Increased SOC range increases rate of fade
- Temperature dependence varies by chemistry
- Discharge rate shows a mixed response in LFP cells and no significant response in NMC and NCA cells

Evolution of trends post 80%:

- Differences in fade rate increase in cycling beyond 80% capacity
- NCA cells show increased capacity fade as temperature increases
- NCA and NMC cells start to show increased capacity fade at lower discharge rates beyond 80%

Knee points do not always occur:

- Most cells show linear degradation even beyond 80% capacity
- Knee point occurrence varies by condition and chemistry



Conclusions

- Depending on conditions of cycling there is significant available safe and useful life post 80% for grid use and/or second life
- In post 80% cycling, trends in capacity fade become more distinct, and variables that did not initially influence capacity fade rate can start to impact capacity fade
- Knee points occurrence depends on chemistry and cycling condition

Next Steps

- Cycle cells to EOL of 40% and conduct materials characterization of selected cells
- Study abuse response of cells at EOL
- Publications expected in the next year:
  - Materials degradation during cycling down to 80%
  - Update on post 80% cycling capacity fade

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Reference:
[1]Preger et al. "Degradation of Commercial Lithium-Ion Cells as a Function of Chemistry and Cycling Conditions" *J. Electrochem. Soc.*, **2020**, *167*, 120532.

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