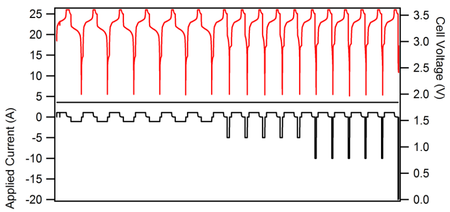
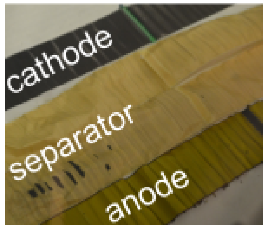
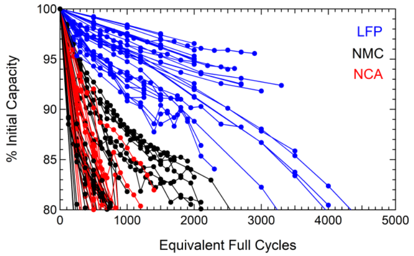
SAND2022-13700C

Sandia National Laboratories

Update on systematic cycle aging of NMC and NCA 18650 Li-ion batteries







PRESENTED BY

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242nd ECS Meeting

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Challenge: battery selection and operation is fraught with uncertainty

Head of rural electric cooperative, after operating a $1.4 million BESS for a year:

"Here is what we learned about BESS….Deep cycling causes rapid loss of life, shallow cycling extends life and total kWh throughput"

Insurance company representative:

"I am researching Li-ion battery reliability…would you be able to point me towards any data on Li-ion battery failure modes and rates in energy storage systems?"

Energy-storage startup (non-battery):

"I believe my technology can perform better than Li-ion batteries at XX condition. Do you know how batteries perform in that window?"

Motivation for 18650 Li-ion long-term cycling study

Problem:

Limited Li-ion battery performance and safety data is publicly available

- Manufacturers provide a range of recommended operating conditions, but limited insight into variable performance in that range

Without adequate information, there is potential for unintended abuse and rapid aging conditions

Objective:

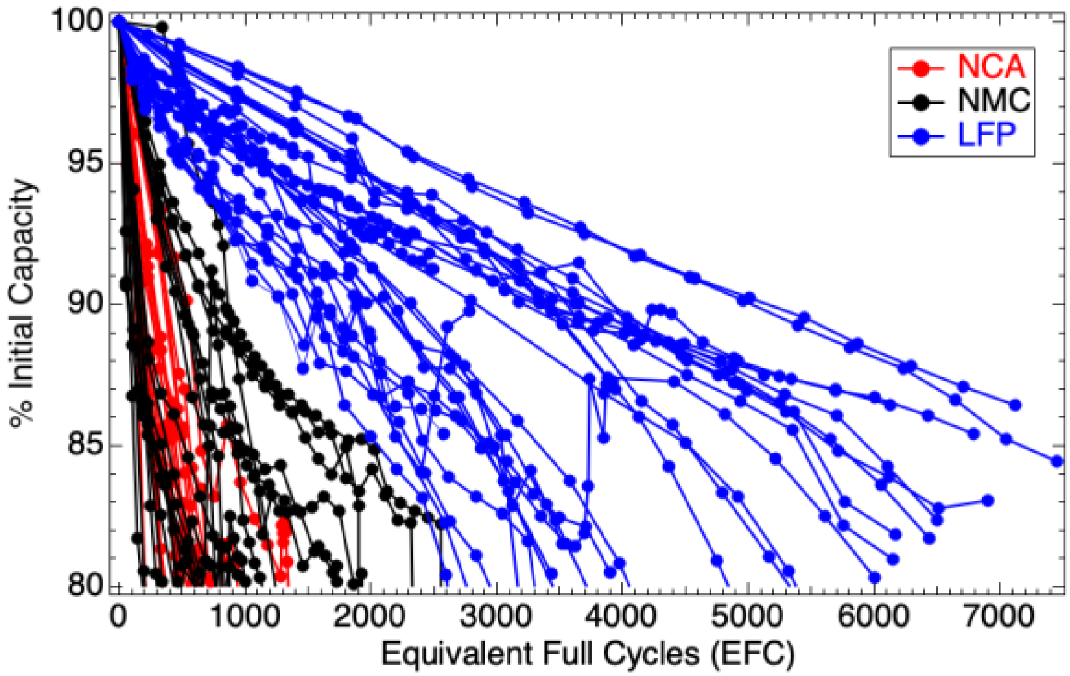
Quantify performance of popular Li-ion chemistries in ‘apples to apples’ approach and identify ‘tipping points’ in performance

Approach to long-term cycling study

Design of experiment with at least two cells at each condition, aged to 80% capacity

Variables:

- Chemistry: LFP, NCA, NMC
- Charge Rate: 0.5C
- Discharge Rate: 0.5C, 1C, 2C, 3C
- State-of-Charge Range: 40-60%, 20-80%, 0-100%
- Temperature: 15°C, 25°C, 35°C



Preger et al. *J. Electrochem. Soc.* **2020**, *167*, 120532.
(plot updated with more recent data)

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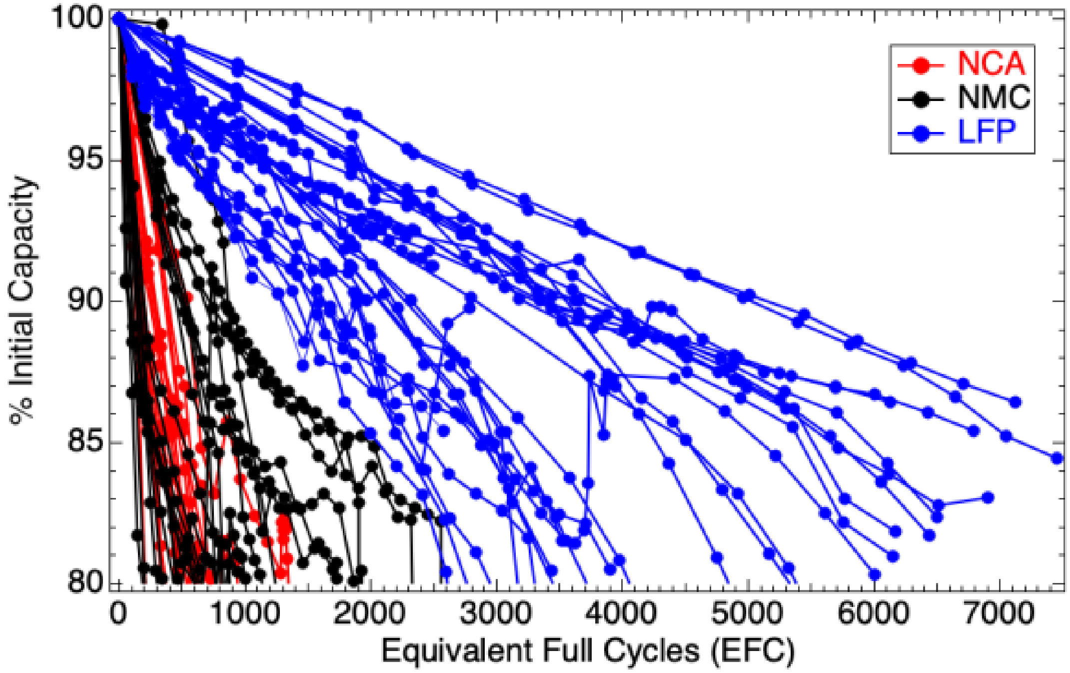

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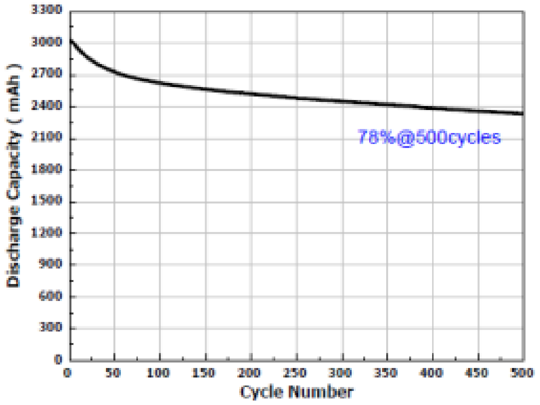
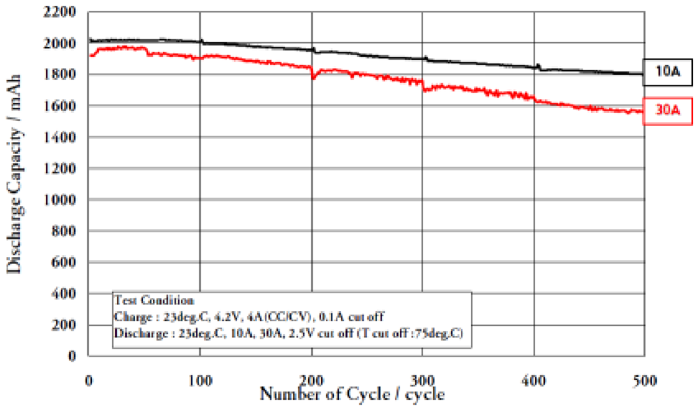
Next phase: what does degradation look like beyond 80% capacity?

Moving beyond 80% capacity endpoints

- 80% capacity is a common reference point in manufacturer spec sheets

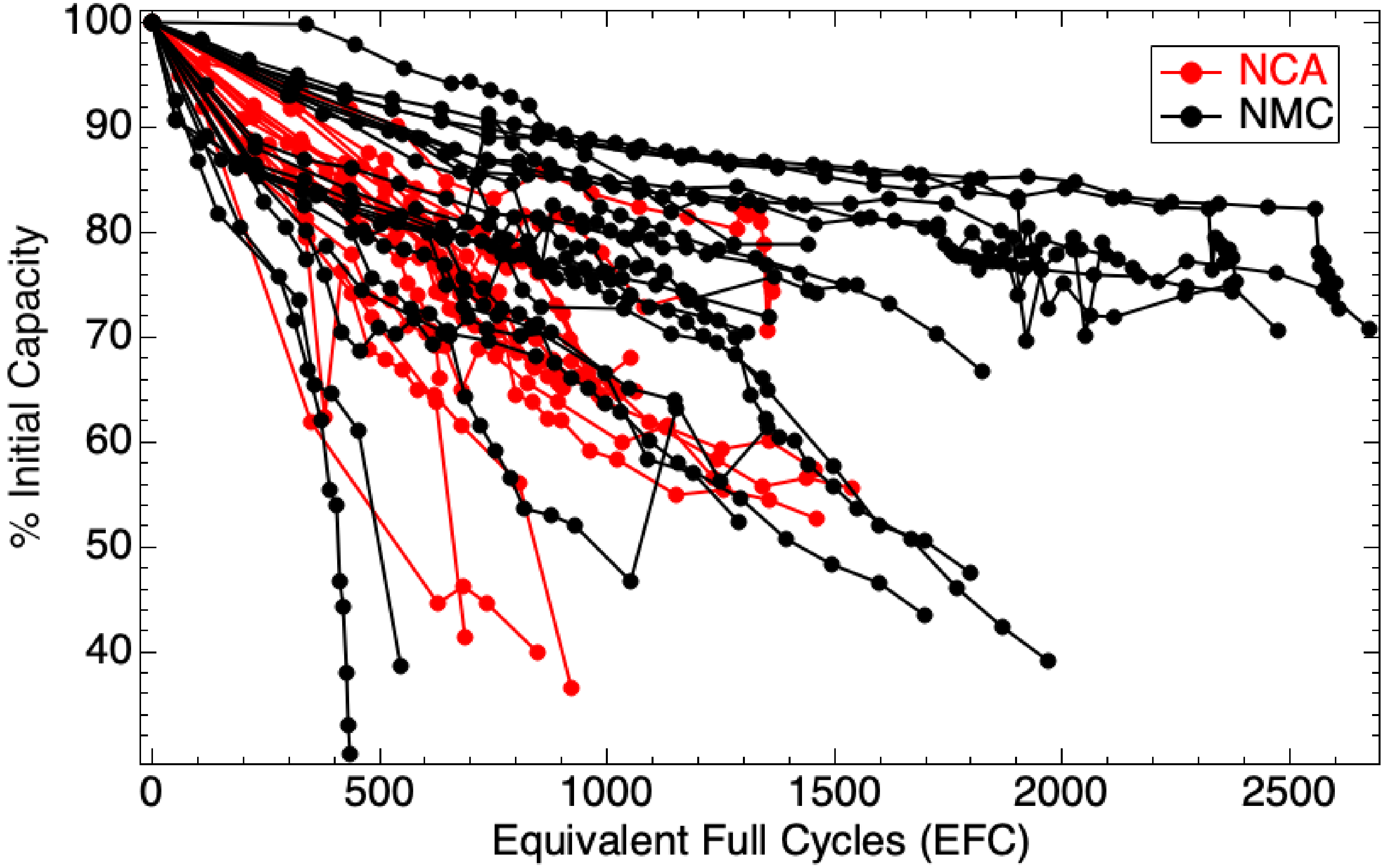




- 80% capacity is a holdover from early EV days
  - USABC 1996: "*EV batteries should be removed from automotive use when **current battery capacity is 80% of initial battery capacity** and current battery power capability is 80% of initial battery power capability*"
  - At this time, EVs were primarily powered by Ni-based batteries

- Understanding remaining useful life is critical for first life valuation and non-negotiable for second life applications

Cells cycled as low as 40% remaining capacity



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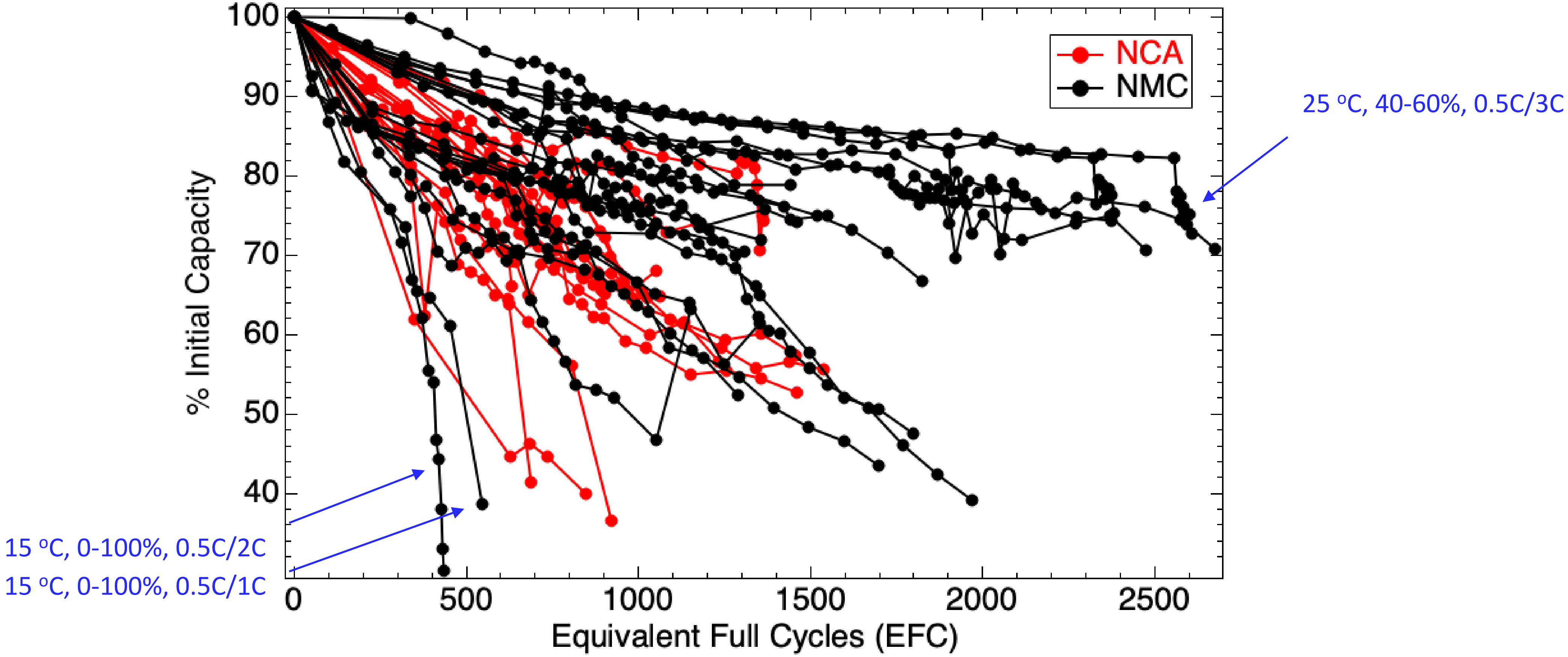
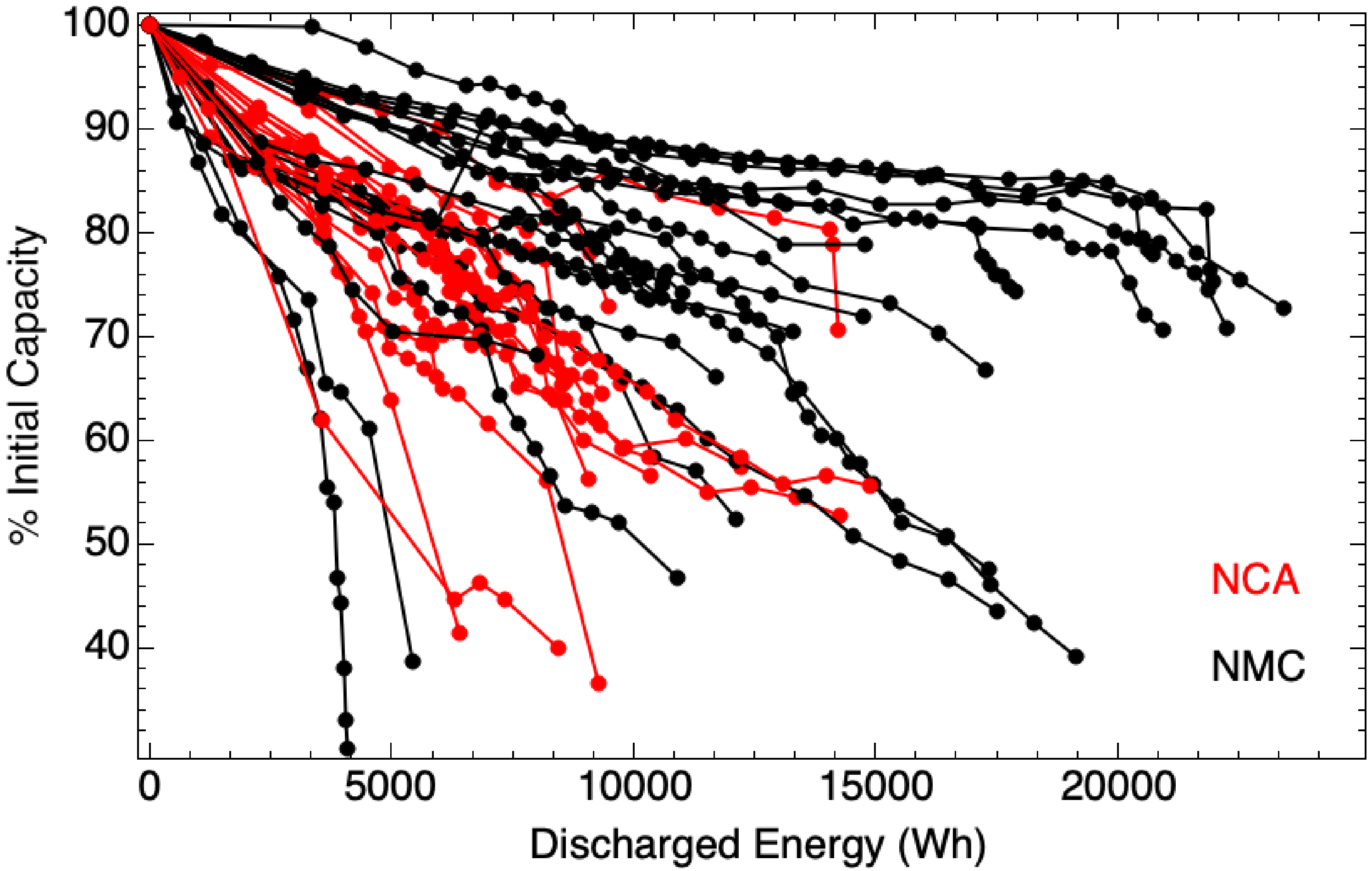
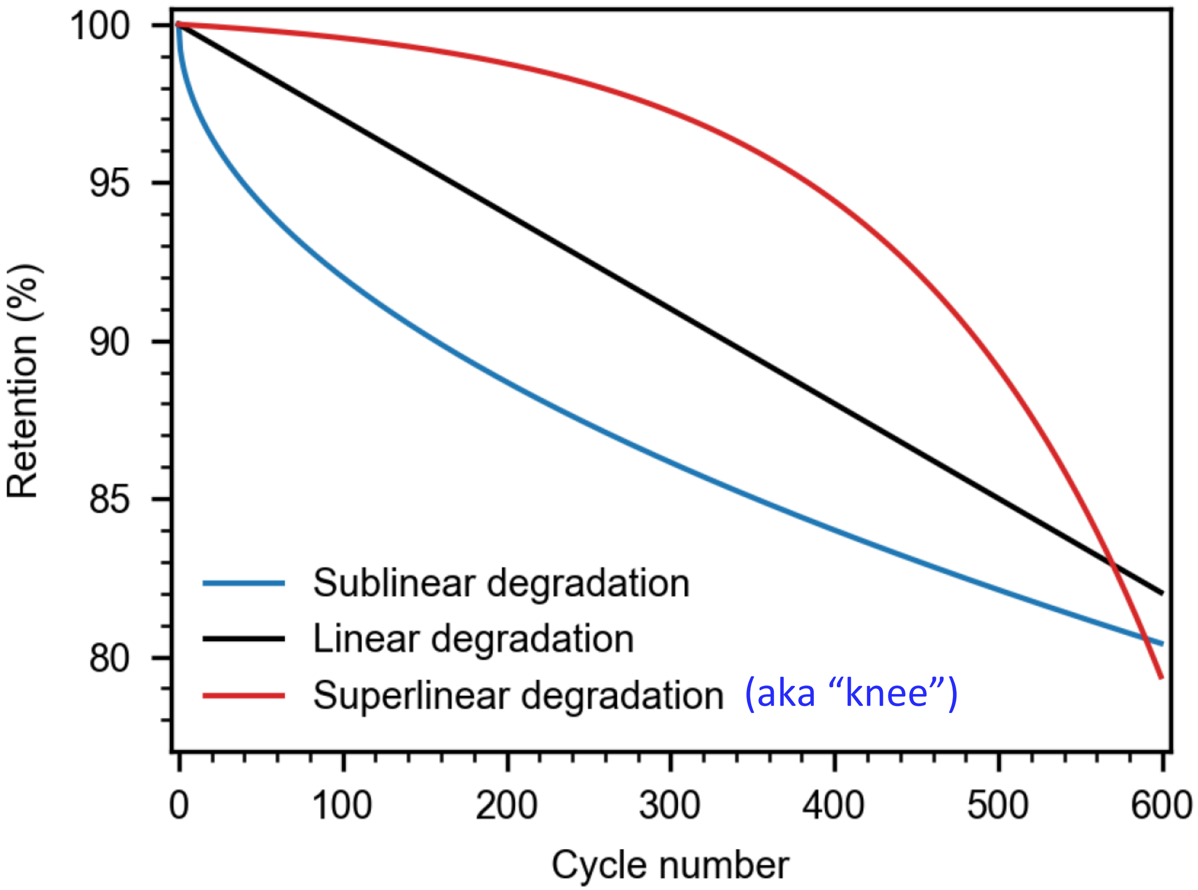


Even with manufacturer's specifications, cycling conditions have a significant impact on results

Single cells had discharge energy throughput up to 25 kWh



What is the shape of the aging trajectory?



Attia et al. *J. Electrochem. Soc*. **2022**, *169*, 060517.

Aging trajectory impacts the remaining useful life of the battery

Assessment of previous experimental studies of “knees”

Knees are complex and occur under many conditions

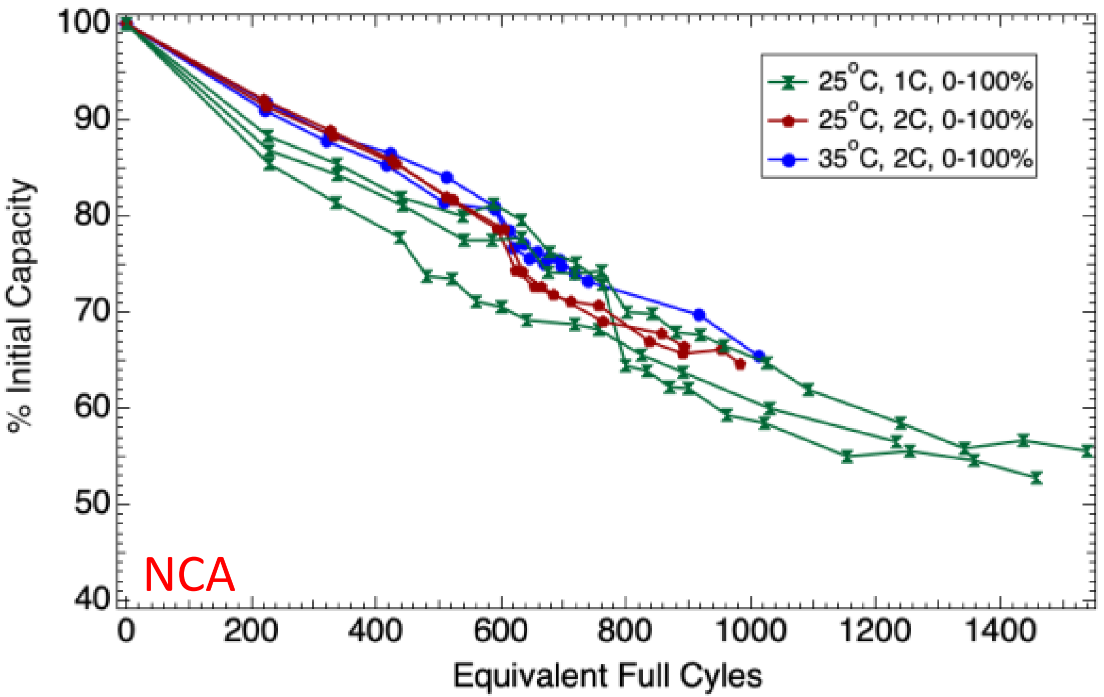
- Higher charging rate and wider DOD consistently accelerate knees
- Temperature/pressure have a ‘sweet spot’ outside of which knee is accelerated
- Discharge rate/rest time – it varies

- Knees can occur during cycling within manufacturer specifications
- Knees observed as high as 90% remaining capacity and as low as 40%

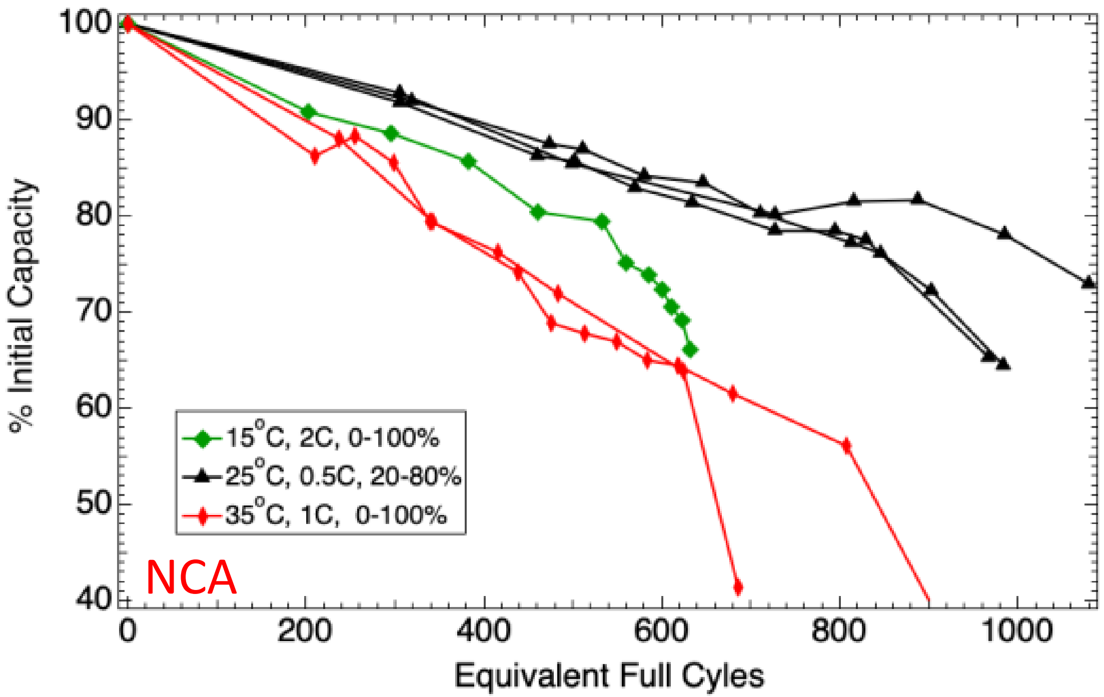
Attia et al. *J. Electrochem. Soc*. **2022**, *169*, 060517.

Knee points arose under a range of conditions in present study

No Knee



Knee



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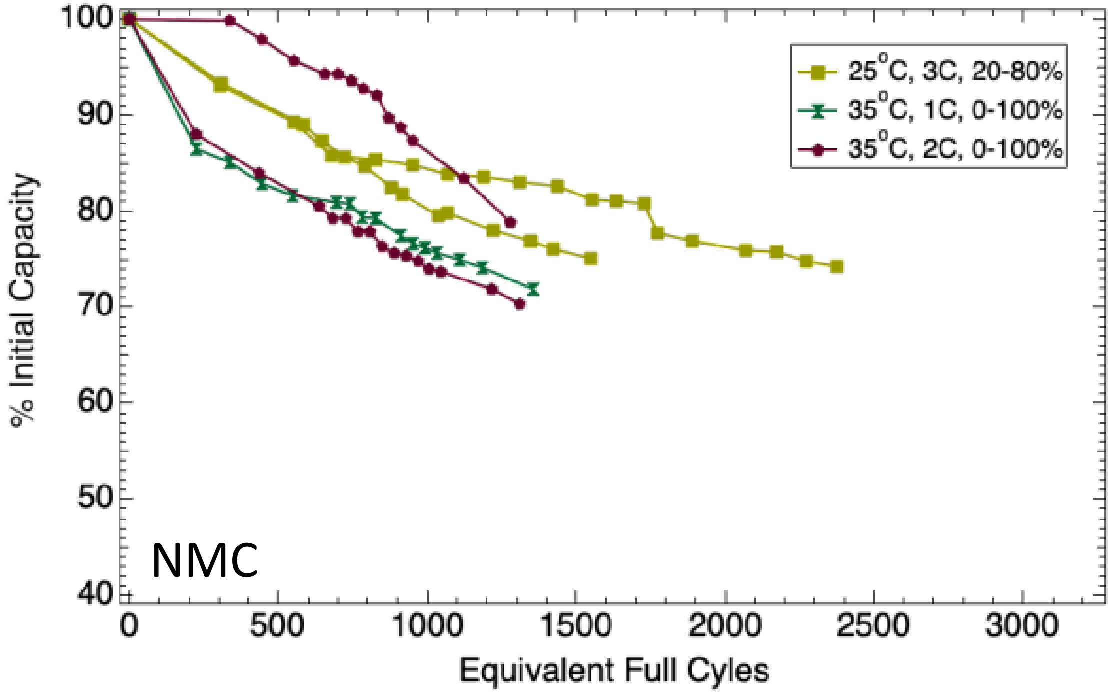
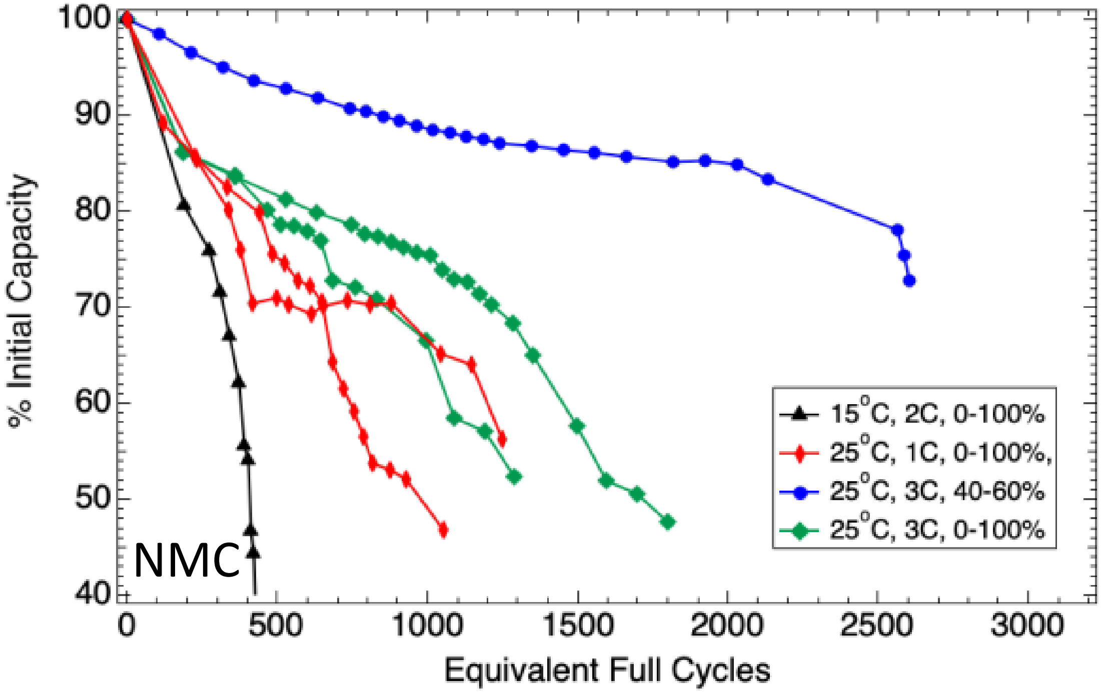
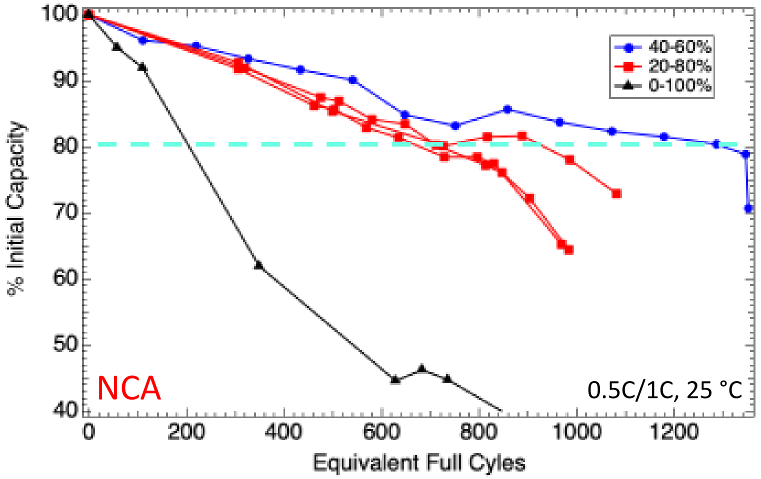


Knee



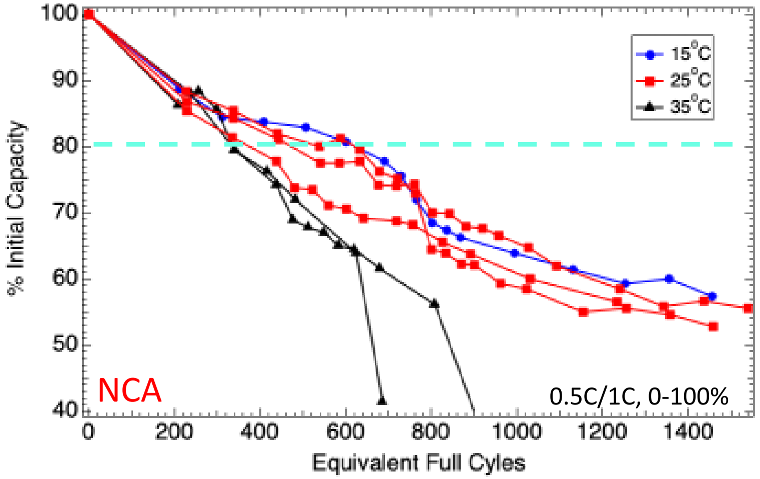
Influence of cycling conditions on NCA cell degradation

SOC



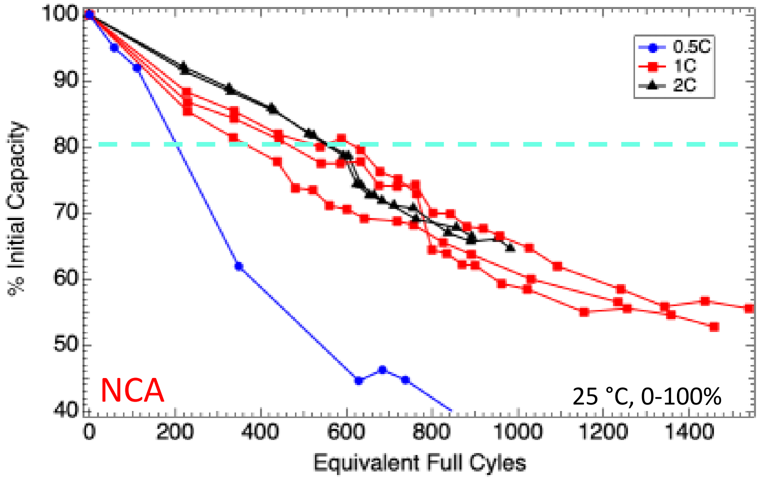
Higher SOC window accelerates degradation

Temperature



Starting to see temperature dependence after 80% (higher temp. worse)

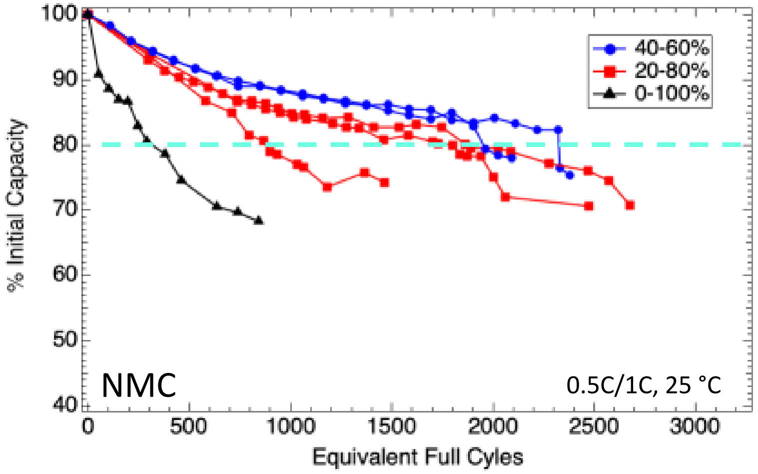
Discharge rate



Lower discharge rate shows slightly higher capacity fade

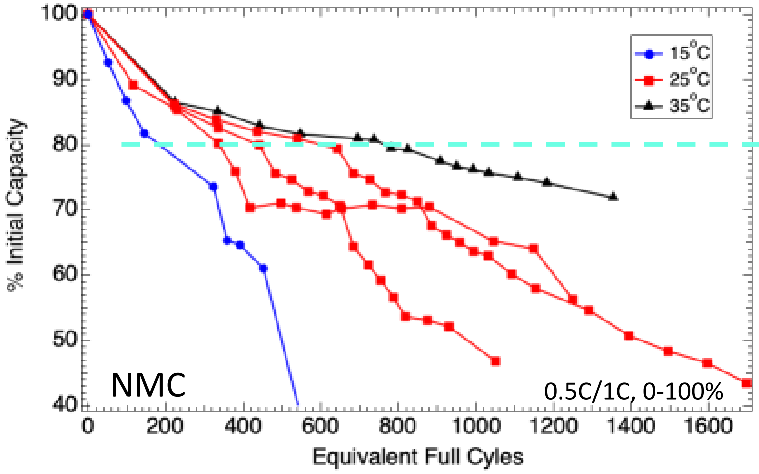
Influence of cycling conditions on NMC cell degradation

SOC



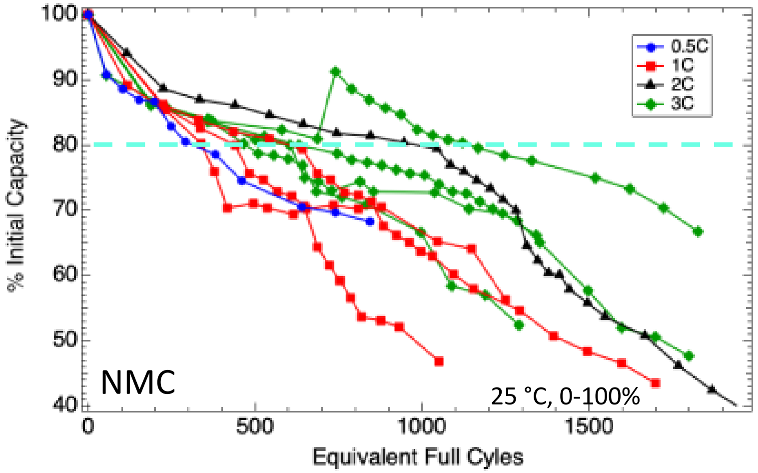
Higher SOC range continues to lead to faster capacity fade

Temperature



Pronounced temperature dependence below 80% (higher degradation at lower temp.)

Discharge rate



Lower discharge rates show slightly higher capacity fade

Summary

- Cells can have long cycle life beyond 80% capacity (as low as 40%)
- Relationship between cycling conditions and ‘knee’ not always straightforward
- Impact of cycling conditions depends on the cell
  - NMC and NCA both do better with lower SOC window
  - NMC has accelerated degradation at lower temperature, but NCA shows limited temperature dependence

Acknowledgments

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