Effects of Low Temperatures on the Performance of COTS Li-Ion Cells

Space Power Workshop 2026
Energy Storage II – Cell Level Developments

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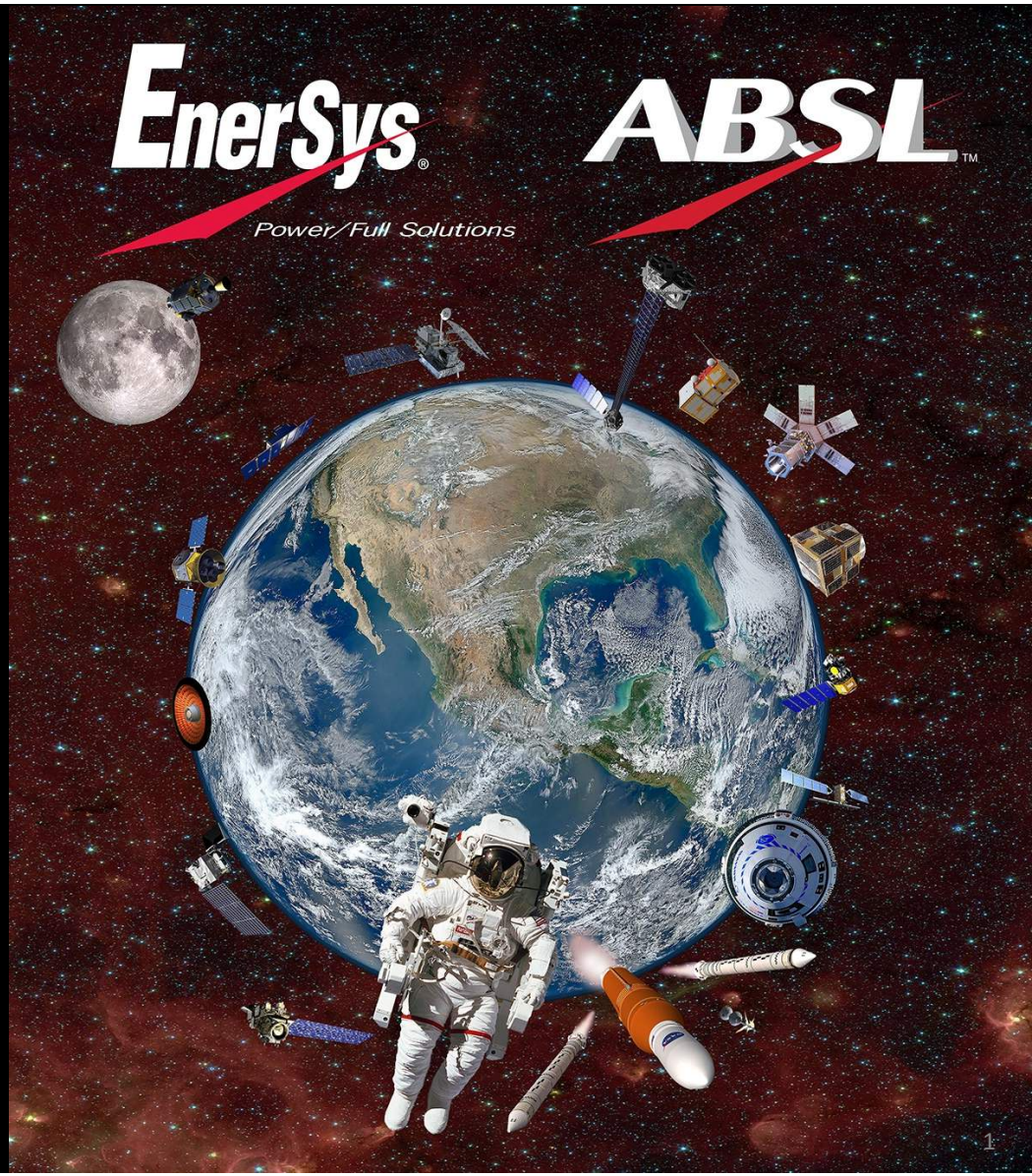
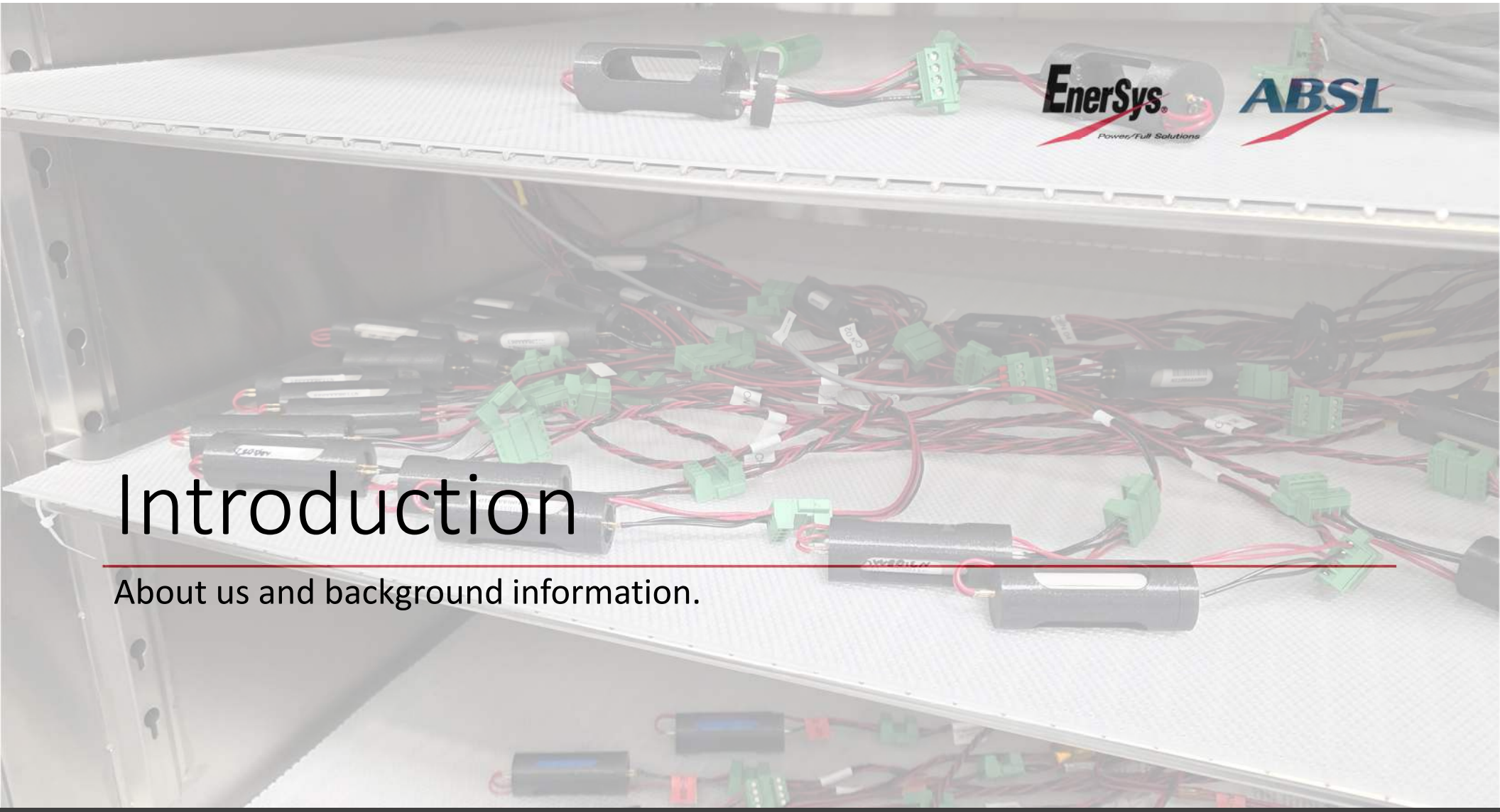


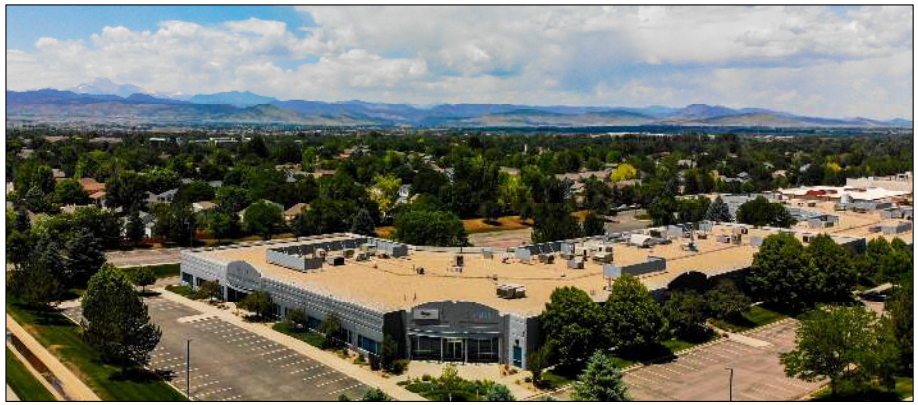
Contents



Introduction

About us and background information.

About ABSL



- Located in Longmont, CO about 45 minutes away from Denver and Boulder.
- Established US location in 2008 and joined EnerSys in 2011.
- Over 40,000 sq ft. of manufacturing, test, and office space.
- In-house environmental testing, destructive testing, and CT scanning.
- Offer standard and custom engineering and manufacturing solutions.

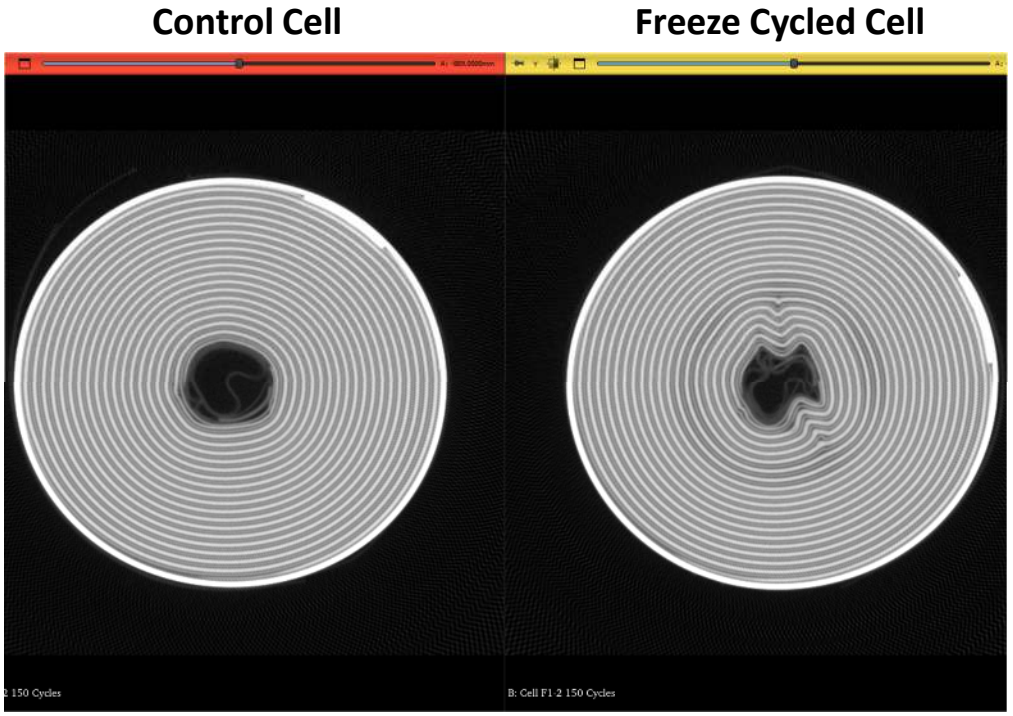
Surviving the Lunar Night

- Batteries are critical to lunar missions, but surviving lunar night is challenging.
- Lunar night can reach temperatures below -180°C for a 14-day duration.
- Thermal management systems increase power consumption and mass.

Lunar Sunset from NASA cameras on Firefly's Blue Ghost Lander

Previous ABSL Research

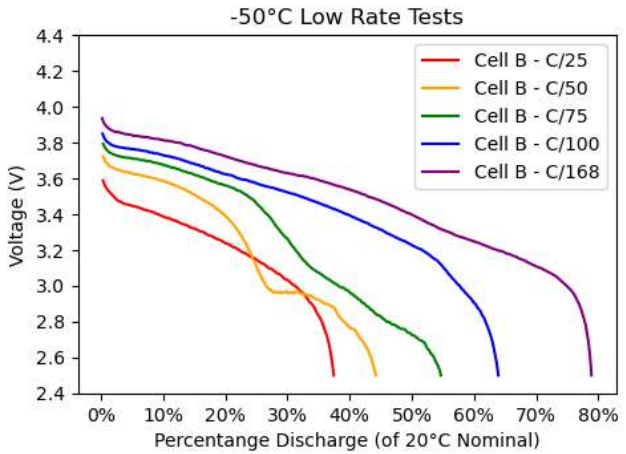
- Storage at -60°C for 28 days had negligible impact on retained capacity.[1]
- Freeze cycling the cells had negligible immediate capacity loss, but long-term capacity loss was accelerated.[2]
- Freeze cycling the cells accelerates delamination and core collapse.[2]

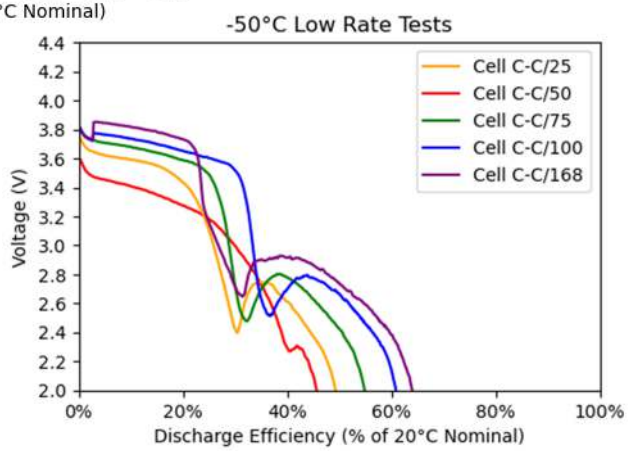


[1] Pritchard, Ryan et al, "*Investigation of COTS Li Ion Cell Performance at Low Temperature*", Space Power Workshop 2024
[2] Rauchwarg, Justin et al, "*Effects of Low Temperature Freeze Cycles on COTS Li-ion Cells",* Space Power Workshop 2025

Previous ABSL Research

- Temperature is a larger contributor to discharge efficiency when discharging cells between -20°C and -50°C.[3]
- When comparing 18650 and 21700 power cells, the 21700 has a lower maximum discharge efficiency that may be due to electrode thickness differences.[3]

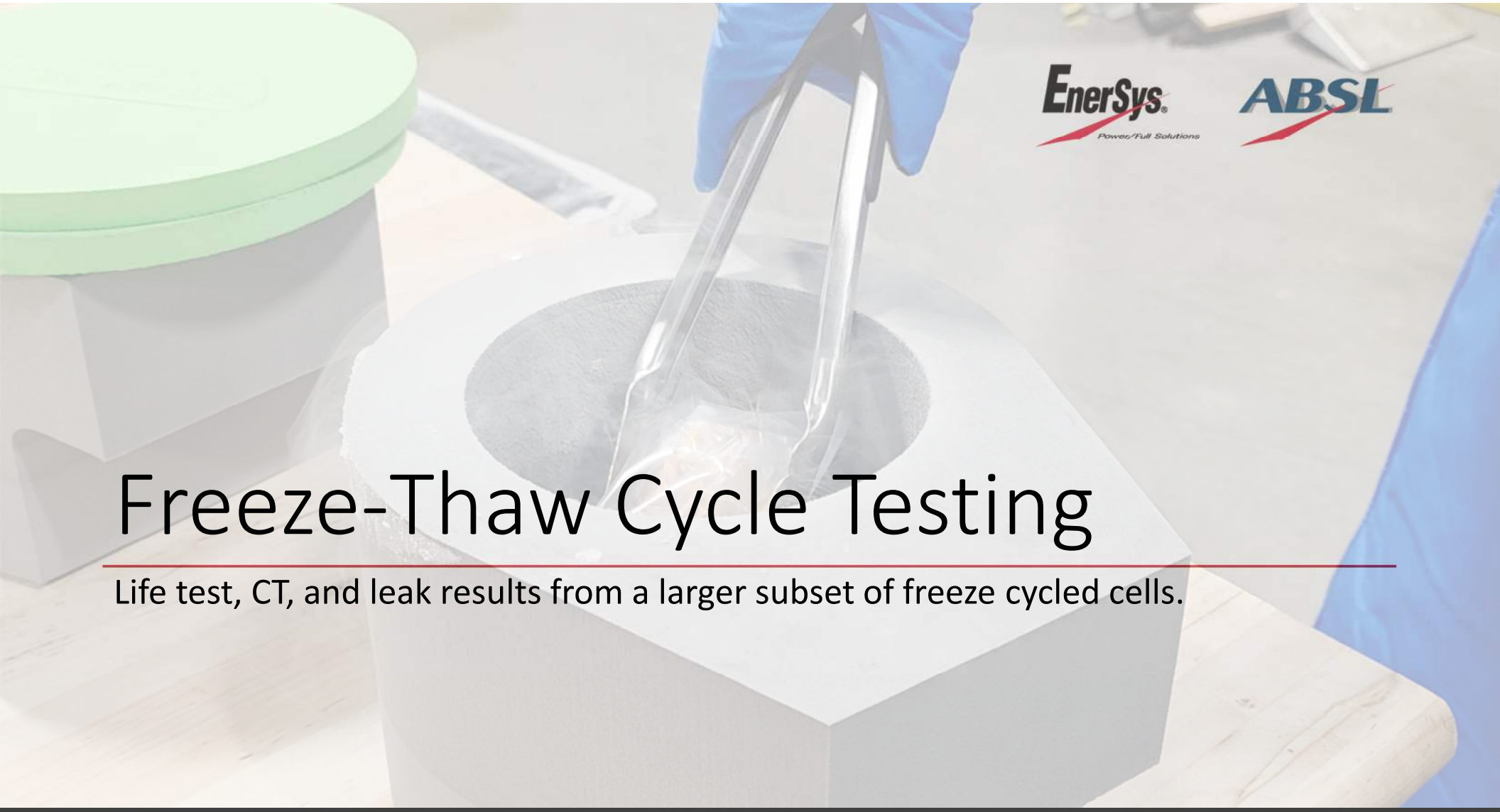




[3] Branken, Jesse et al, "Low Temperature Performance of Space Qualified COTS Li-ion Cells ", NASA Battery Workshop 2025

Motivation

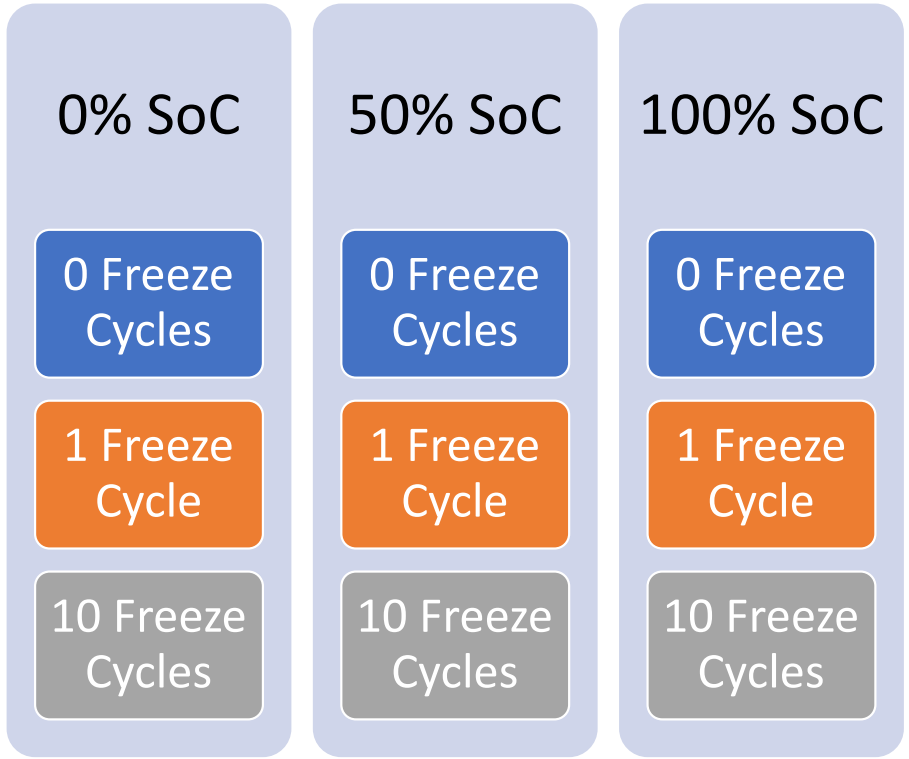
- Compare previous results across different cell types.
- See how recovered capacity is impacted by the SoC (state of charge) during freeze-thaw cycles.
- Respond to discussion points from the previous year's presentation.



Freeze-Thaw Cycle Testing

Life test, CT, and leak results from a larger subset of freeze cycled cells.

Test Overview



- Two independent variables – SoC during freeze cycles and number of freeze cycles.
- Cells were subjected to a baseline capacity measurement, freeze-thaw cycling, then life cycling.
- CT scans were taken after freeze cycling, and after approximately 300 life cycles.

Electrical Cycling Details

Capacity Measurement

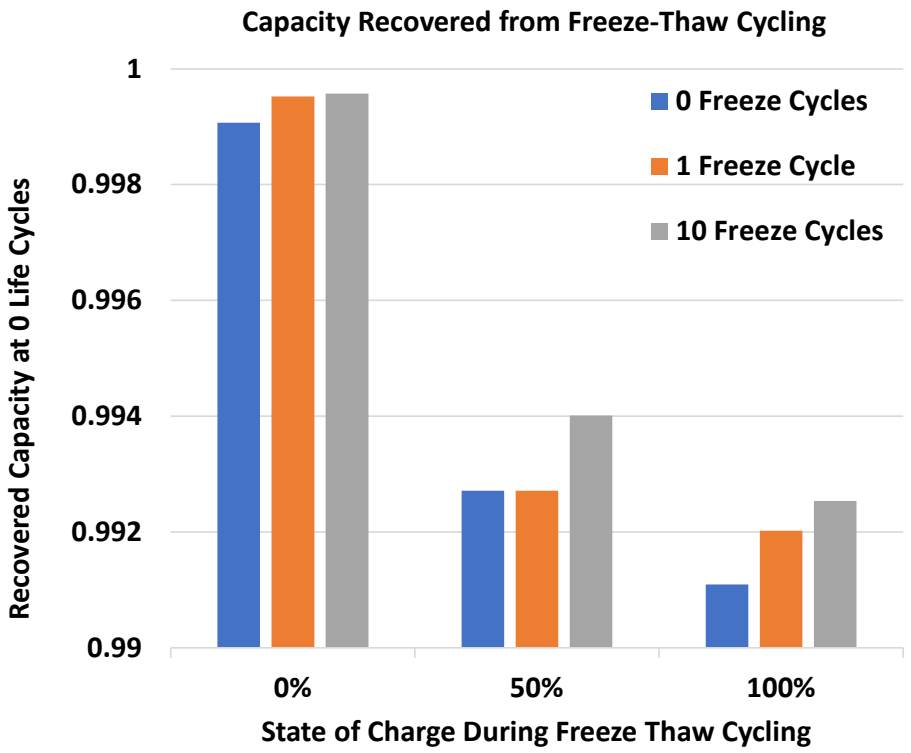
- C/10 Charge to 4.2 V with taper to C/100
- C/10 Discharge to 2.5 V
- 20°C

Life Cycle

- 1C Charge to 4.2 V with 90-minute taper
- 1C Discharge to 2.5 V
- 20°C

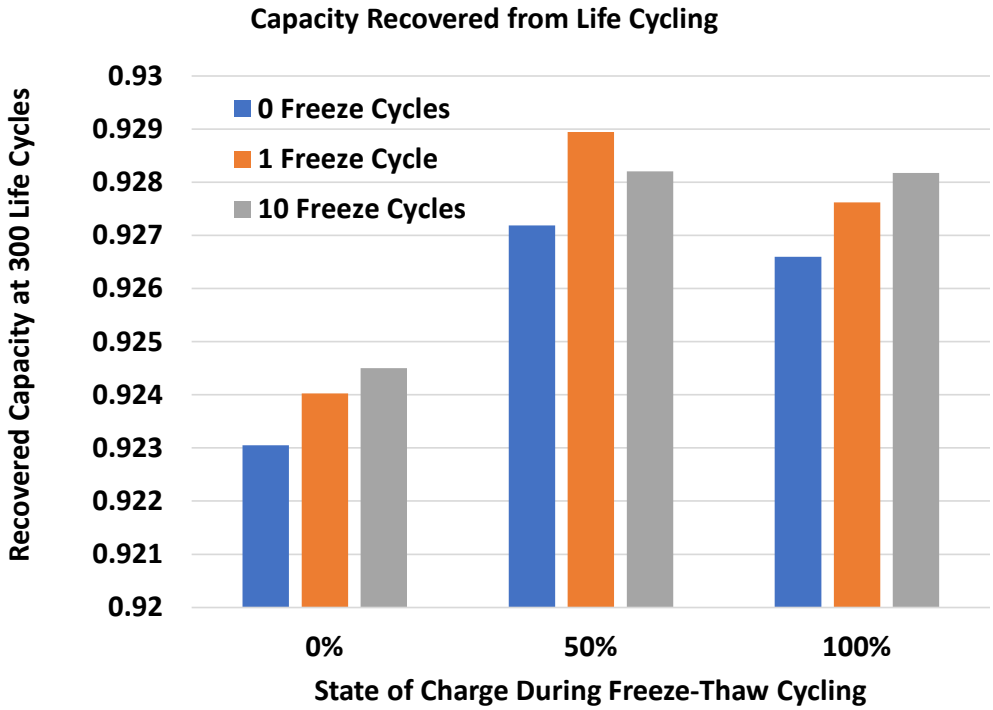
Freezing Results

- As SoC increases, recovered capacity decreases.
- As number of freeze cycles increases, recovered capacity increases.
- Both independent variables and the interaction between them were statistically significant ($p < .01$).



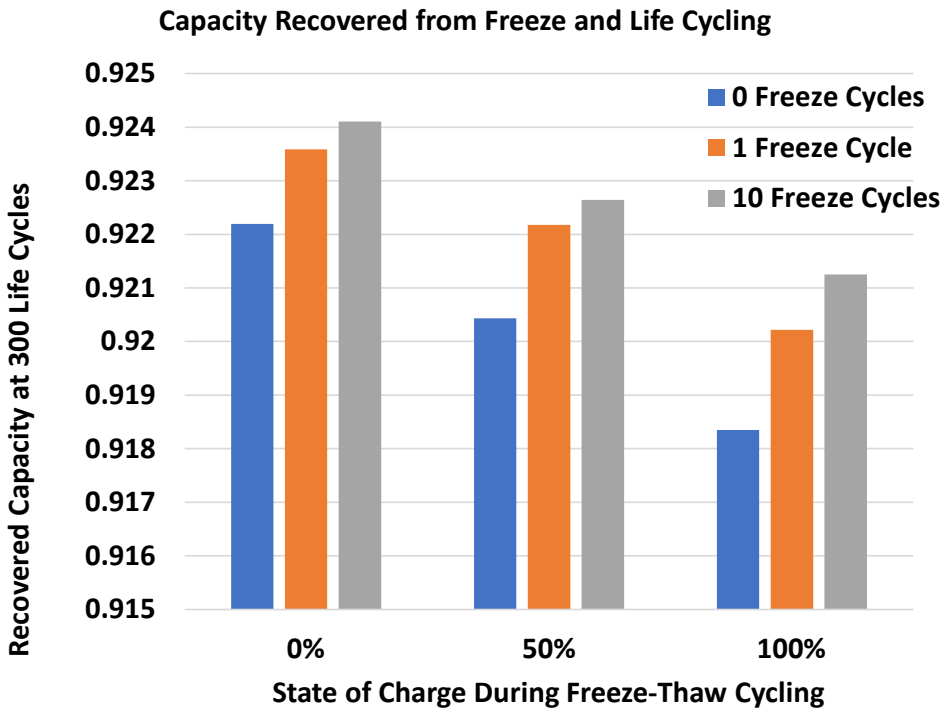
Life Cycling Results

- Higher SoC groups recover more capacity than 0% SoC group.
- As number of freeze cycles increases, recovered capacity increases.
- Both independent variables are statistically significant ($p < .01$); the interaction between them is not .



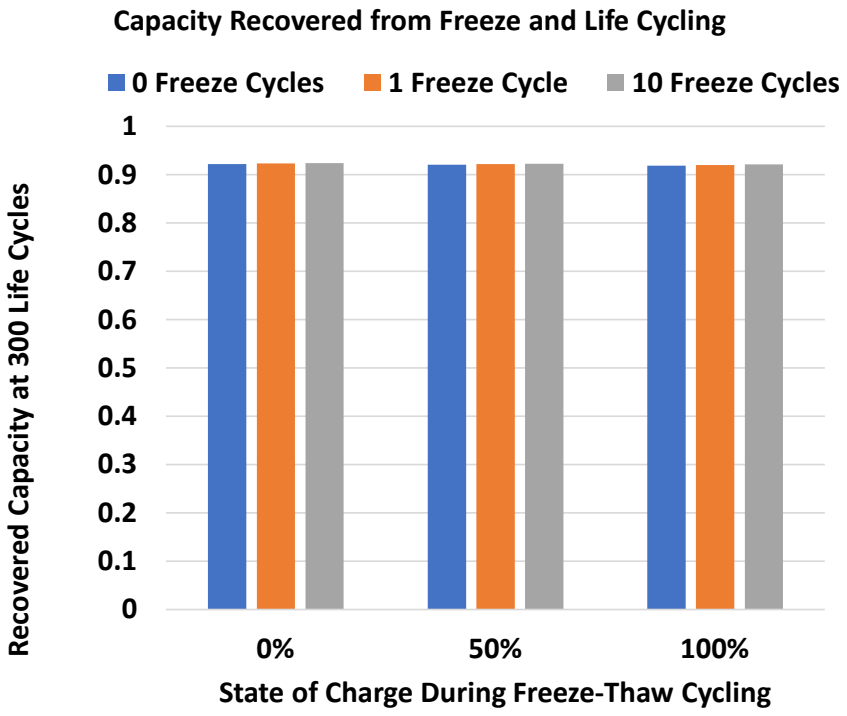
Combined Results

- Impacts of SoC on recovered capacity become less prominent.
- Impacts of number of freeze cycles on recovered capacity become more prominent.
- Both independent variables are statistically significant ($p < .01$); the interaction between them is not.



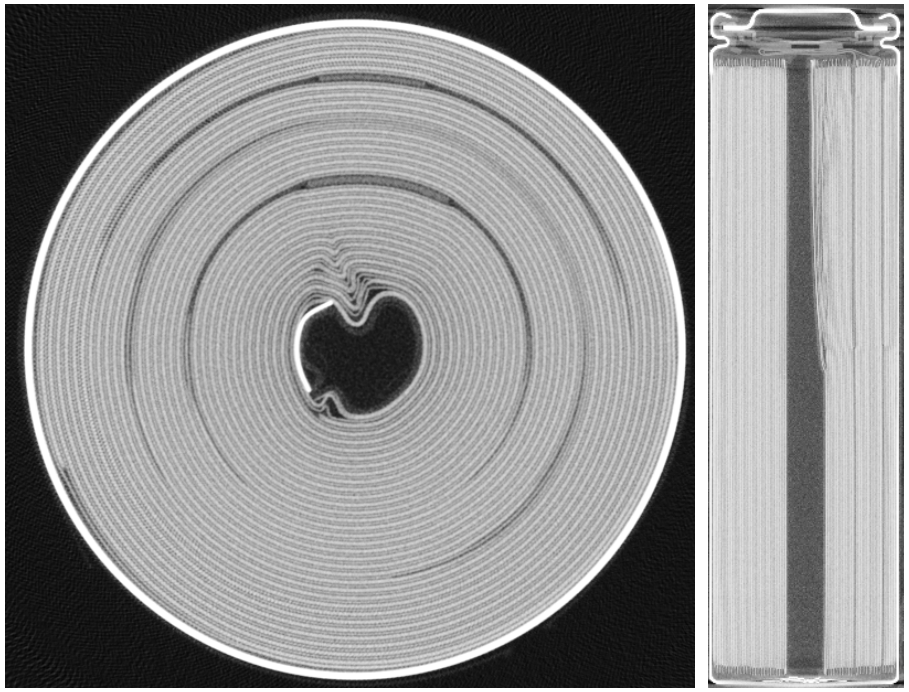
Zooming Out

- Difference in recovered capacity is less than 0.6% across all test groups.
- Cells at 100% SoC with 0 freeze cycles lost an average of 8.2% (241 mAh) of their capacity.
- Cells with 10 freeze cycles at 100% SoC lost an average of 0.3% less (232 mAh) of their capacity.

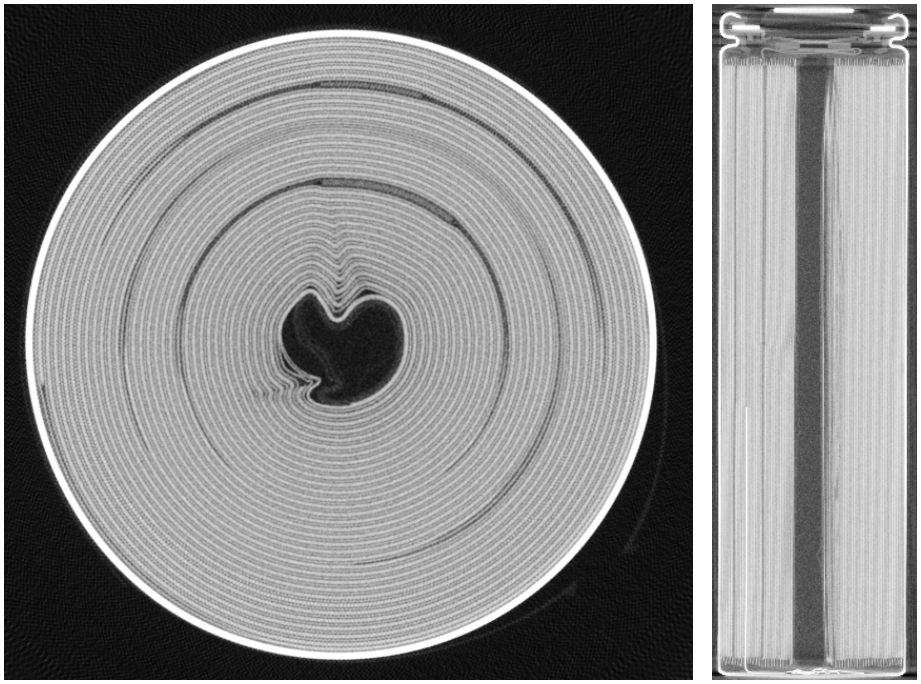


Comparison by Freeze Cycles

100% SoC, 0 Freeze Cycles
After 300 Life Cycles

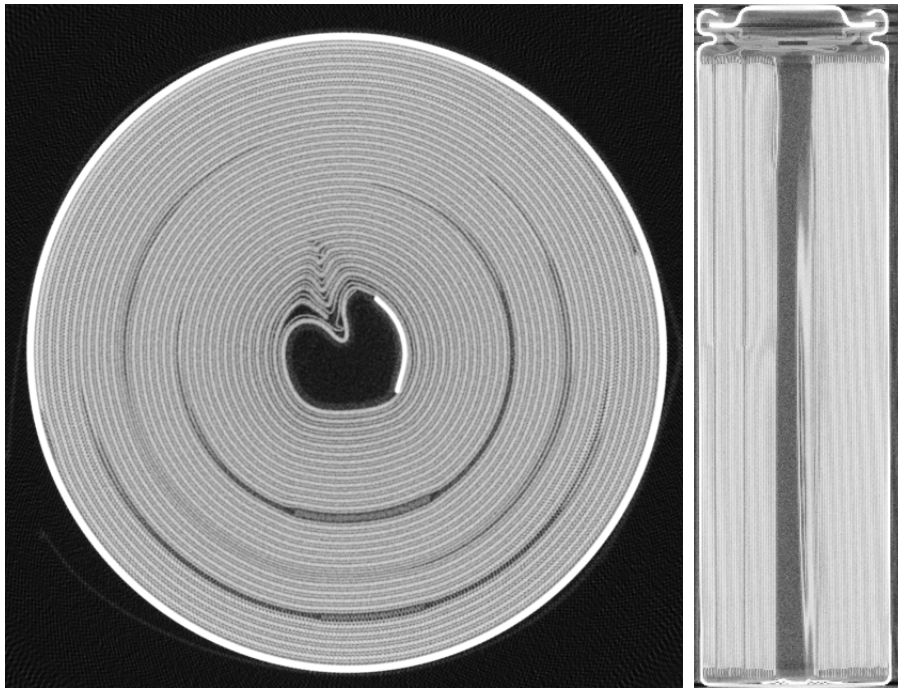


100% SoC, 10 Freeze Cycles
After 300 Life Cycles

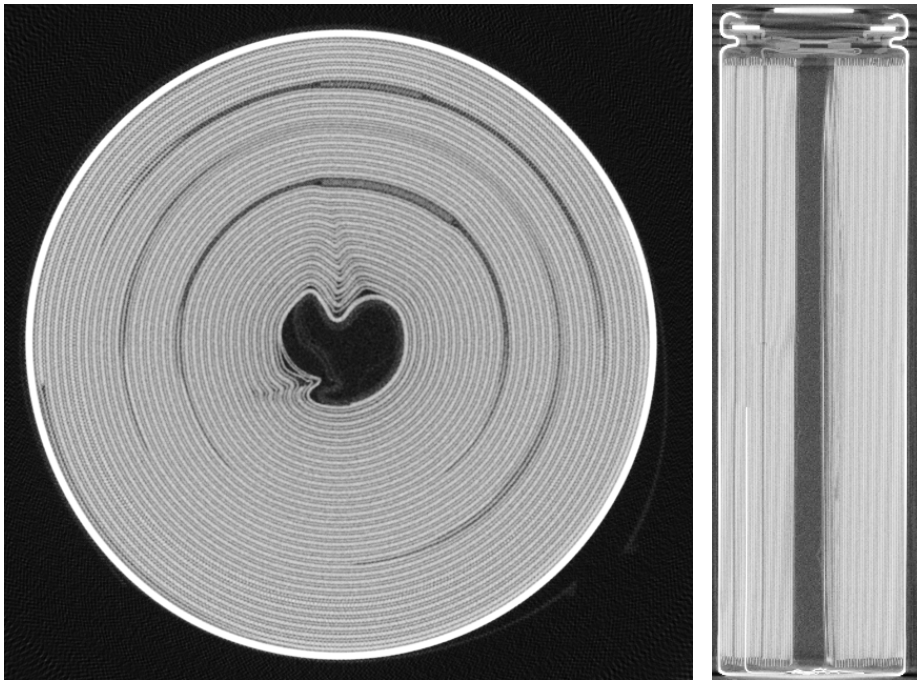


Comparison by State of Charge

0% SoC, 10 Freeze Cycles
After 300 Life Cycles



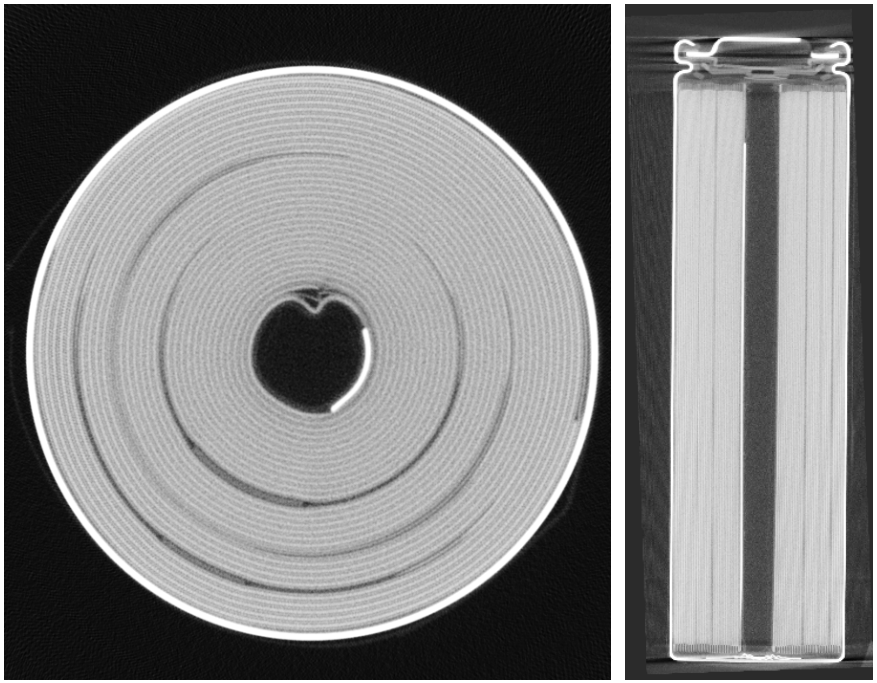
100% SoC, 10 Freeze Cycles
After 300 Life Cycles



Before and After Life Cycling

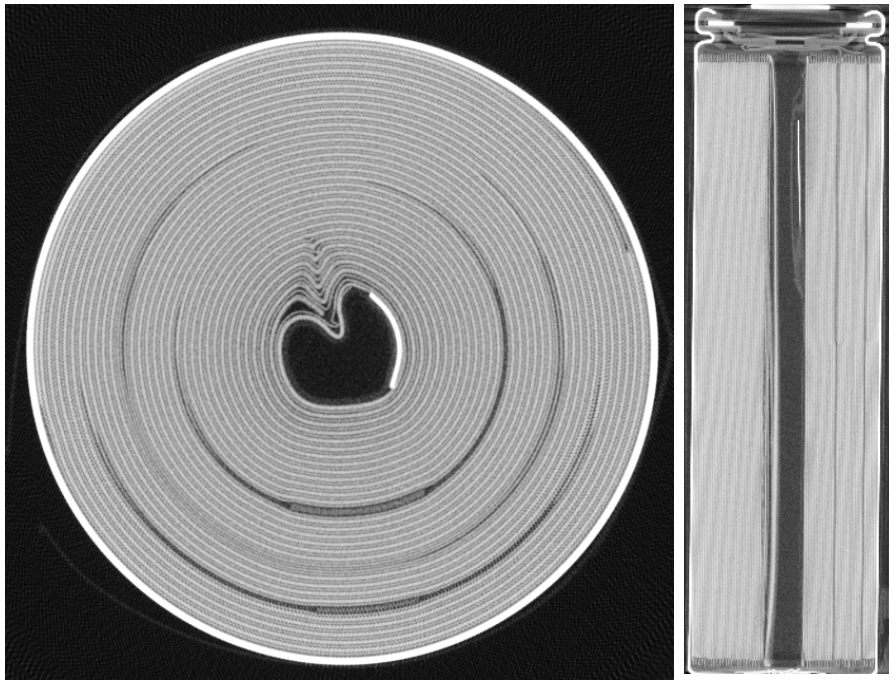
0% SoC, 10 Freeze Cycles

Before Life Cycles



0% SoC, 10 Freeze Cycles

After 300 Life Cycles



Additional Test: Helium Leak

Prep — Anode cut off from each cell and active material removed.

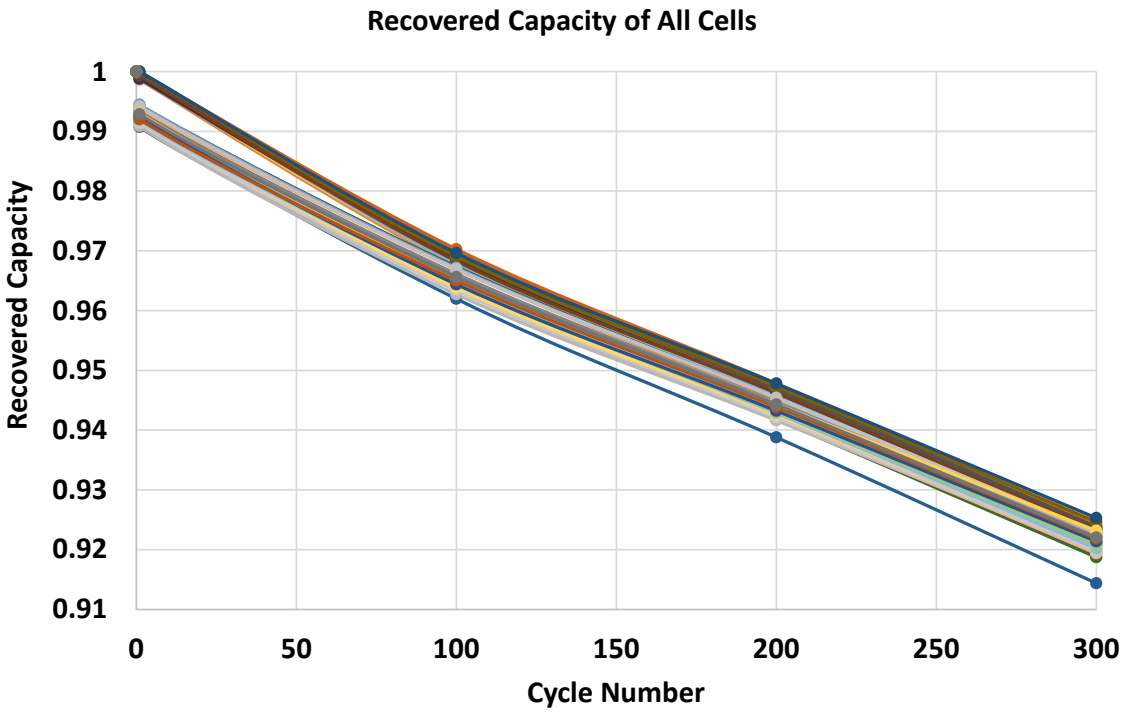
Freeze — Cathode header assembly and cell-can undergo 1 or 10 freeze-thaw cycles.

Test — Connected to Helium Leak Tester and checked leak rate.

- All cells passed testing and showed no sign of leaking.
- One cell was tested while still frozen and did fail leak testing.

Discussion

- All cells show strong calendar aging effects independent of number of freeze cycles.
- Life cycling revealed that number of freeze cycles has little effect on overall capacity loss trend.

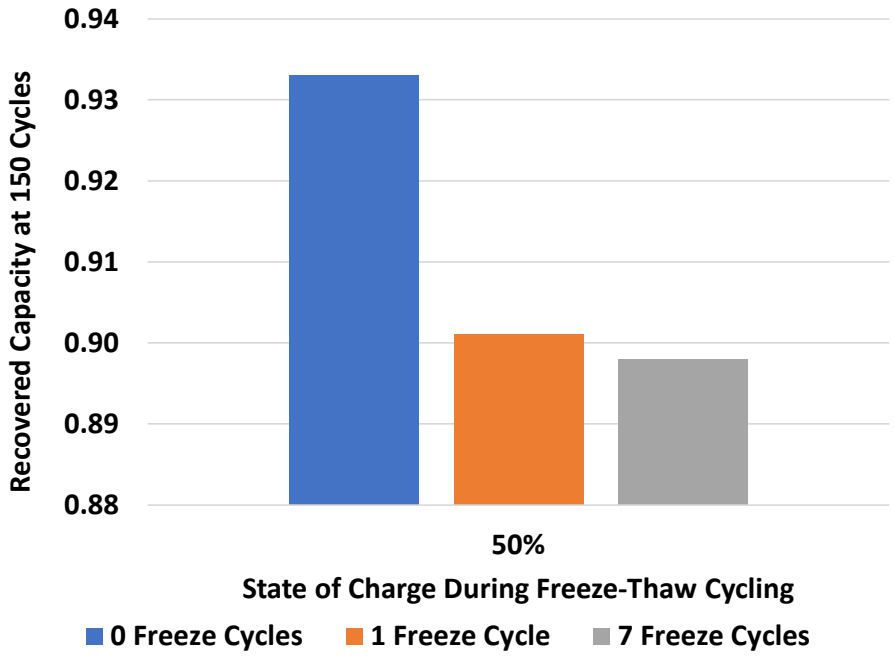


Freeze Cycling Conclusions

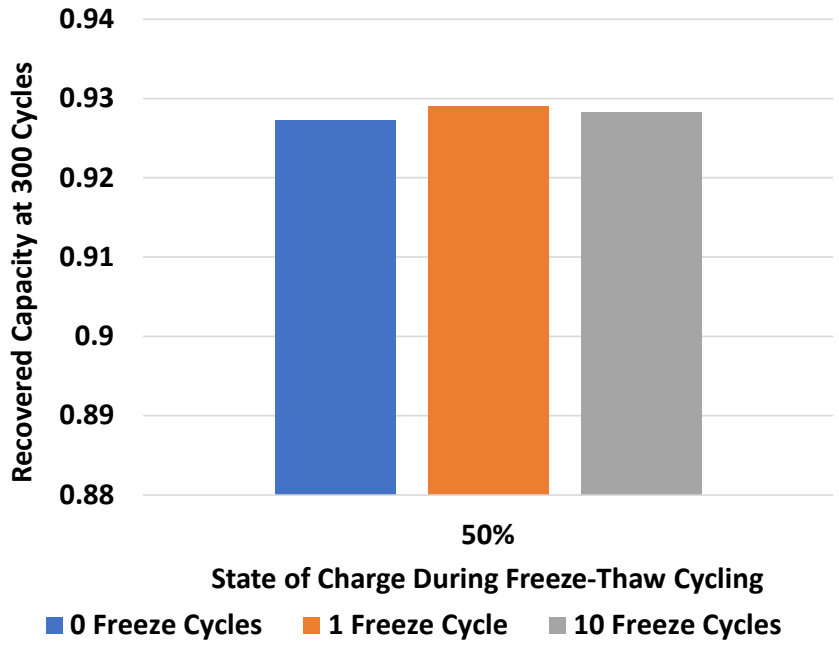
- Freezing this cell type at different SoCs does not seem to impact recovered capacity, but storing cells at a higher SoC does have a negative effect on recovered capacity.
- Looking at the electrical data, this cell type seems resilient to freeze-thaw cycles or may benefit from them. The positive effect on recovered capacity may come from effectively reducing the storage period for these cells.
- This cell type did not have notable visual differences in CT scans based on number of freeze cycles.

2025 Results vs 2026 Results

2025 Results – 3.5 Ah Energy Cell



2026 Results – 3.0 Ah Power Cell



Discussion and Next Steps

- Different cell types may respond differently to freeze-thaw cycles.
  - Perform tests on more cell types.
  - Standardize cycling so results can be more easily compare between groups.
- Correct for storage effects even over small time periods.
- Perform full 14-day freeze-thaw cycle tests.

Acknowledgements

Ryan Pritchard – Previous research and presentations furthering this topic.

Alex Saldaña – CT scanning and review.

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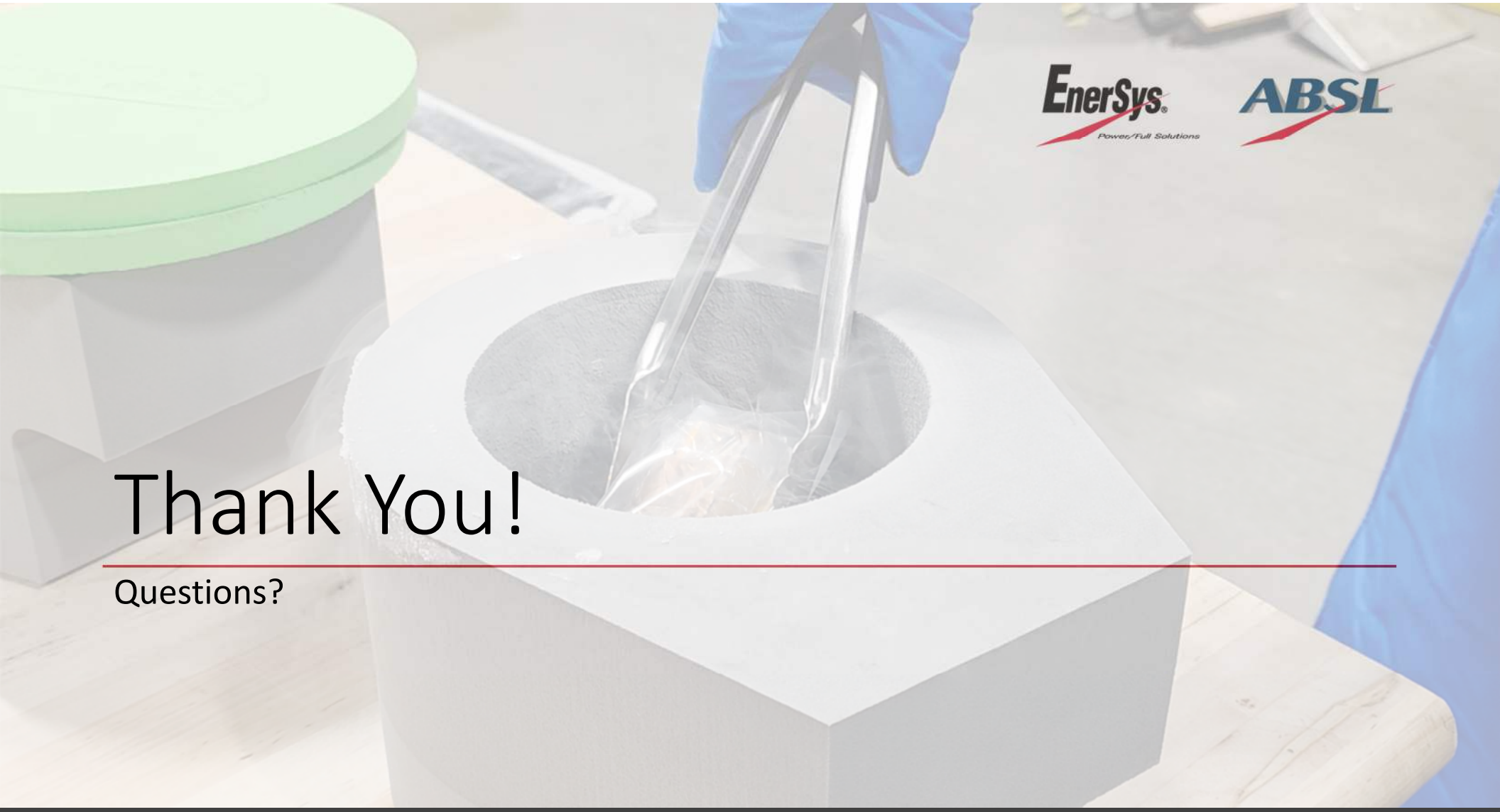
Gerard Herbert – Presentation writing.

Jessee Kirkland – Presentation writing.



Thank You!

Questions?