A Comparison of US and Chinese EV Battery Testing Protocols and Results

I. Bloom and D. Robertson
Argonne National Laboratory

J. Christophersen and T. Bennett
Idaho National Laboratory

F. Wang and S. Liu
CATARC

9th US-China EV and Battery Technology Workshop
Seattle, WA
August 18-19, 2014

The submitted issue has been created by the University of Chicago as Operator of Argonne National Laboratory ("Argonne") under Contract No. W-31-109-Eng-38 with the US Department of Energy. The US Government retains for itself, and others acting on its behalf, a paid-up, non-exclusive, irrevocable, worldwide license in said article to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the Government.

Progress and Results – Collaborative US/China Protocol Comparison

- Battery testing is a time-consuming and costly process
- There are parallel testing efforts, such as those in the US and China
- These efforts may be better leveraged through international collaboration
- The collaboration may establish standardized, accelerated testing procedures and will allow battery testing organizations to cooperate in the analysis of the resulting data
- In turn, the collaboration may accelerate electric vehicle development and deployment
- There are three steps in the collaborative effort

Step	Status
Collect and discuss battery test protocols from various organizations/countries	Complete
Conduct side-by-side tests using all protocols for a given application, such as an EV	Complete
Compare the results, noting similarities and differences between protocols and test sites	In progress

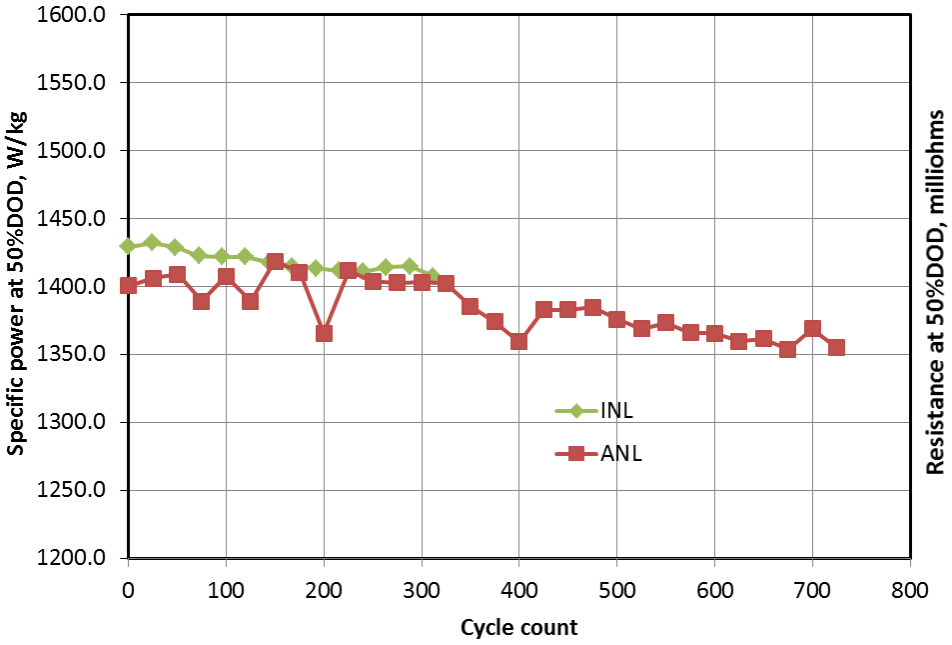
Conduct Side-by-Side Experiments

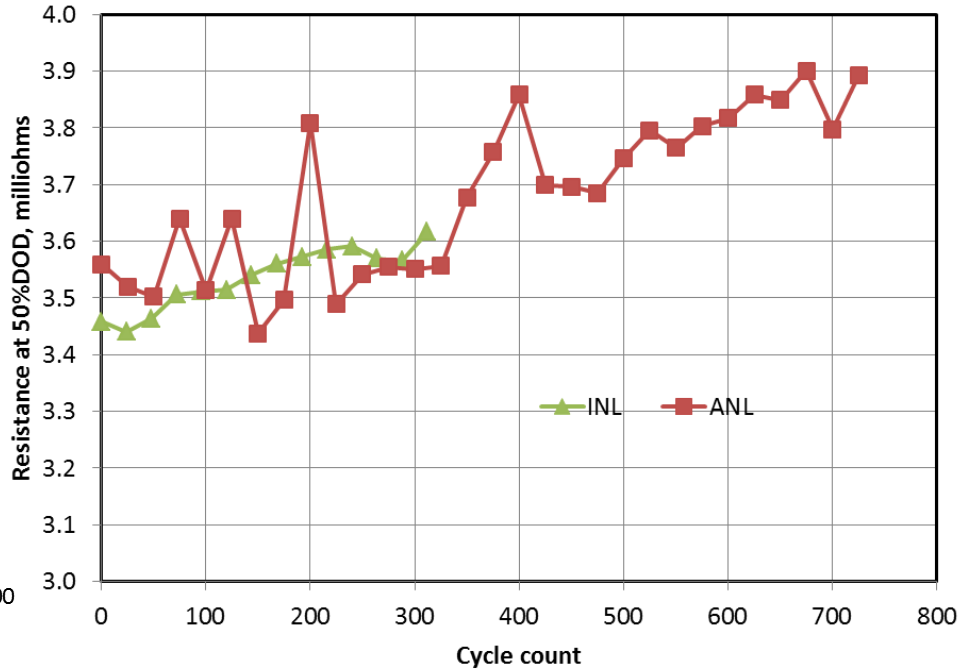
- A test plan based on an EV application was written and agreed to
- Commercially-available batteries based on $LiFePO_4$ and carbon were procured. The batteries were distributed to ANL, INL and CATARC (China)
- Initial similarities and differences
  - The US cycle-life aging protocol consists of a dynamic, constant-power profile (DST) and constant-current charging
  - The Chinese cycle-life aging protocol consists of constant-current discharges and charges
  - USABC Reference Performance Test consists of 2 capacity cycles, peak power pulse test at 10% DOD increments and full DST cycle. The cells are characterized using these performance tests every 50 cycles
  - China Reference Performance Test consists of 1 capacity cycle and 10 second discharge pulse at 50% DOD. The performance of the cells were characterized using these performance tests every 25 cycles
  - Both cycle-life protocols terminate discharge at 80% DOD

Comparing the Protocols Shows…

	USABC	China
DOD (Energy) Window	0-80% DOD	0-80% DOD
Temperature	25 °C	25 °C
Capacity measurement rate	C/3	C/3
End of Test criteria	80% degradation	80% degradation
Cycle Type	Dynamic, Power based	Constant-current
Power Capability Measurement	Peak Power Pulse Estimation at 80% DOD	Pulse Power Density at 50% DOD
Pulse duration	30 seconds	10 seconds
Pulse Current	75A	225A
RPT Frequency	50 cycles (10.5 days)	24 cycles (6 days)
RMS power of cycle	50-51 W	12-13 W
RMS current of cycle	15-16 A	3.5-4 A
Average Voltage of cycle	3.17V fading over time	3.27V without fading
Energy throughput of cycle	27 Wh	19.5 Wh

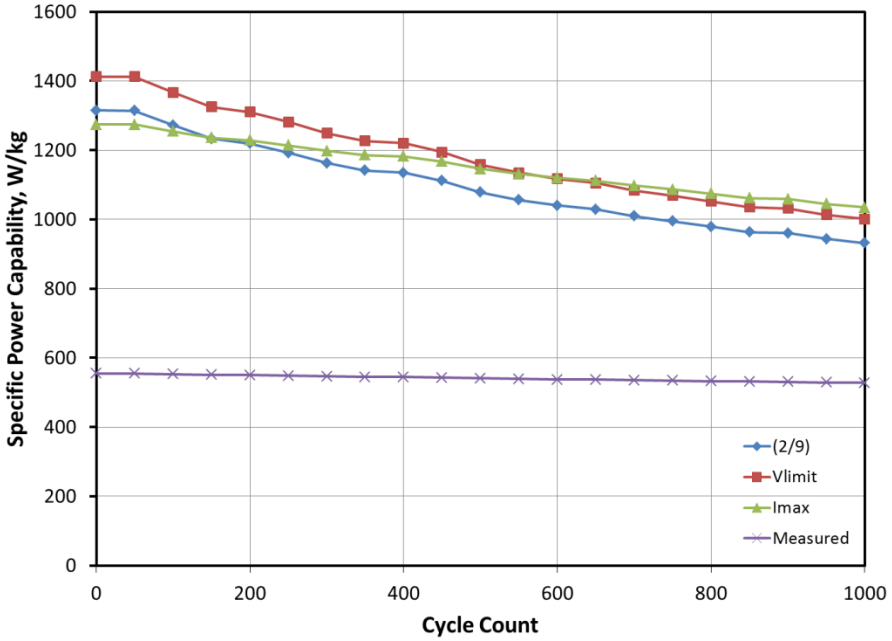
Chinese Protocol Results – Effects of Cycling on Resistance and Power

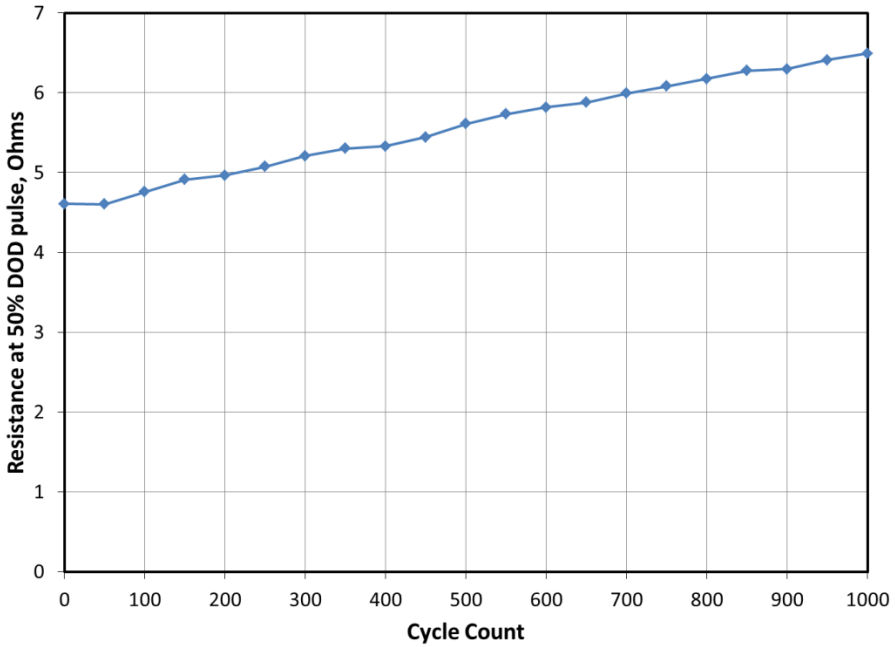




- Power density at 50% DOD decreased ~3.3% over the course of 725 cycles
- Resistance at 50% DOD increased ~9.3%
- Data from INL and ANL are consistent

USABC protocol results - Effects of Cycling on Resistance and Power at 50% DOD

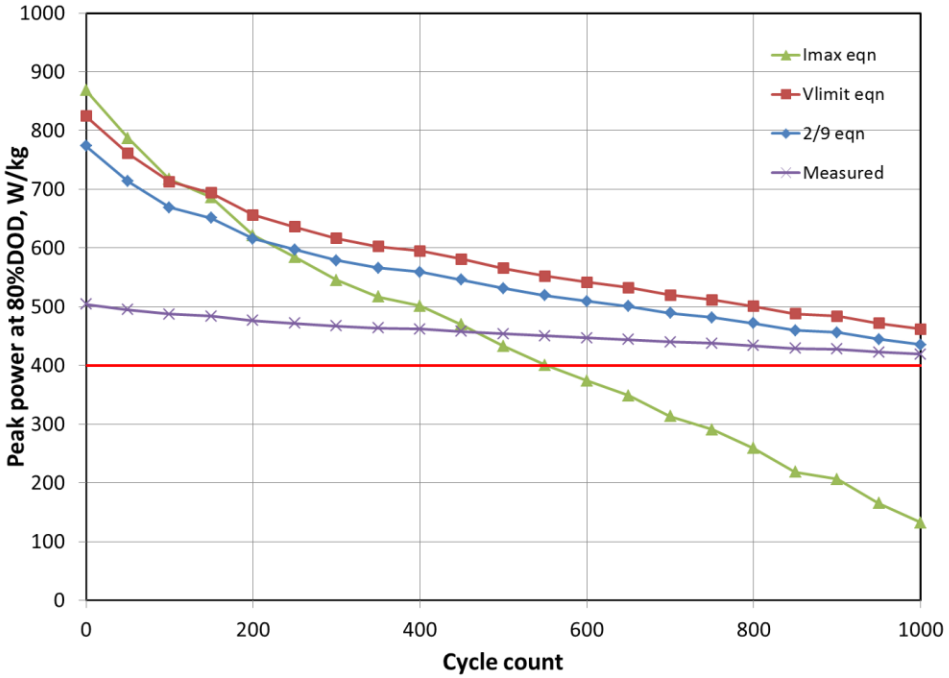


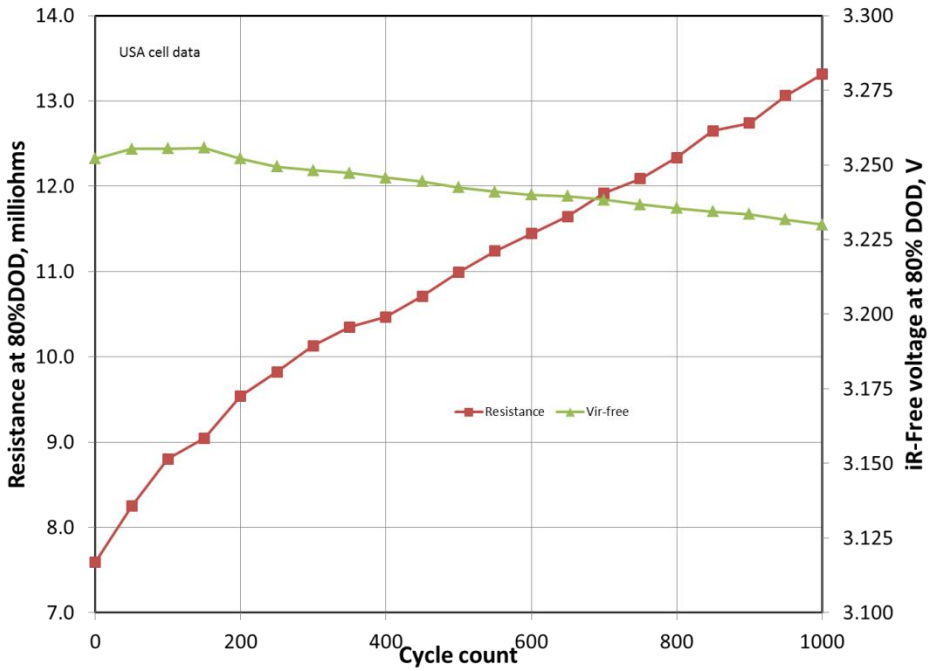


-The effect of USABC DST cycles shows a clear degradation and aging trend in resistance and power capability.

-Comparing the 50% DOD pulse show similar beginning of life capabilities for both test methods.

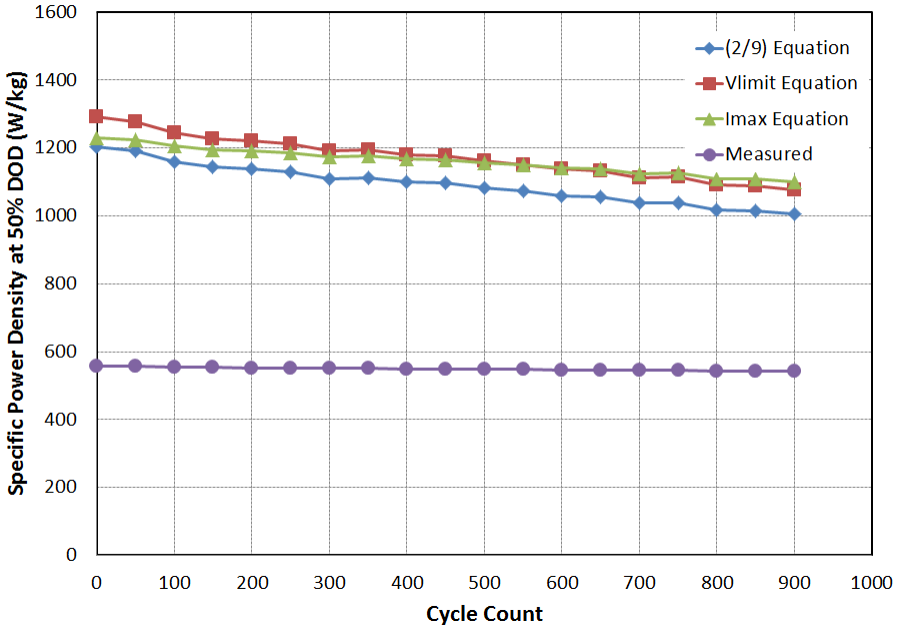
USABC protocol results - Effects of Cycling on Resistance and Power at 80% DOD



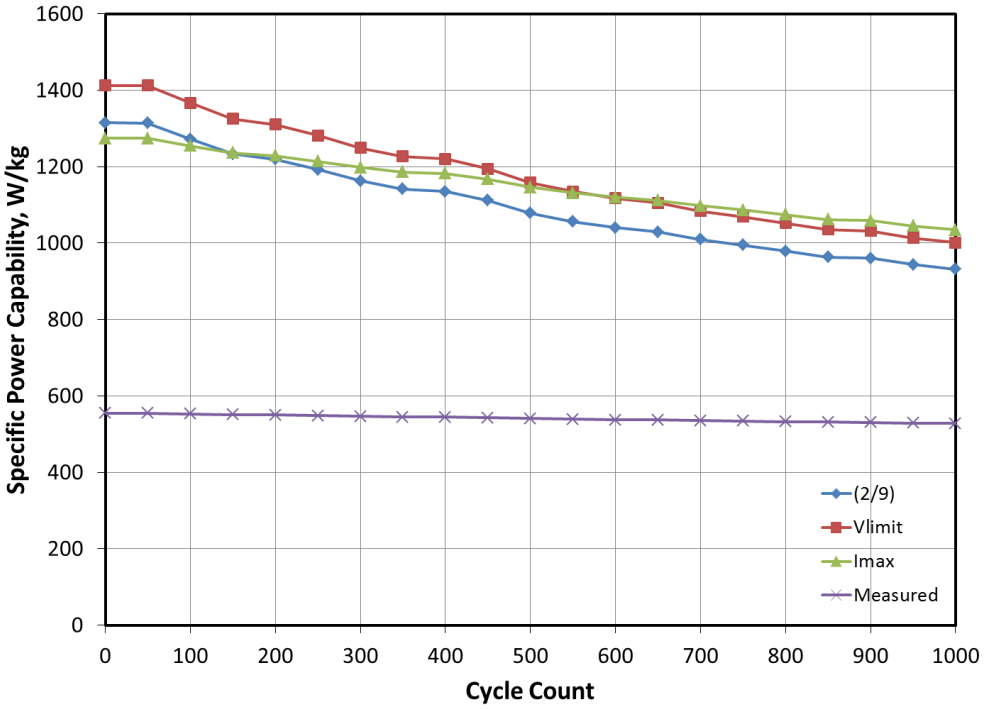


- USABC test method focuses on 80% DOD capability
- 80% DOD is considered worst condition of EV operating range
- Increase in resistance and decrease in power capability are more pronounced at this depth of discharge
- According to USABC protocols, this cell failed at 550 cycles

Comparing USABC Results at 50% DOD from INL and ANL Shows They Are Similar



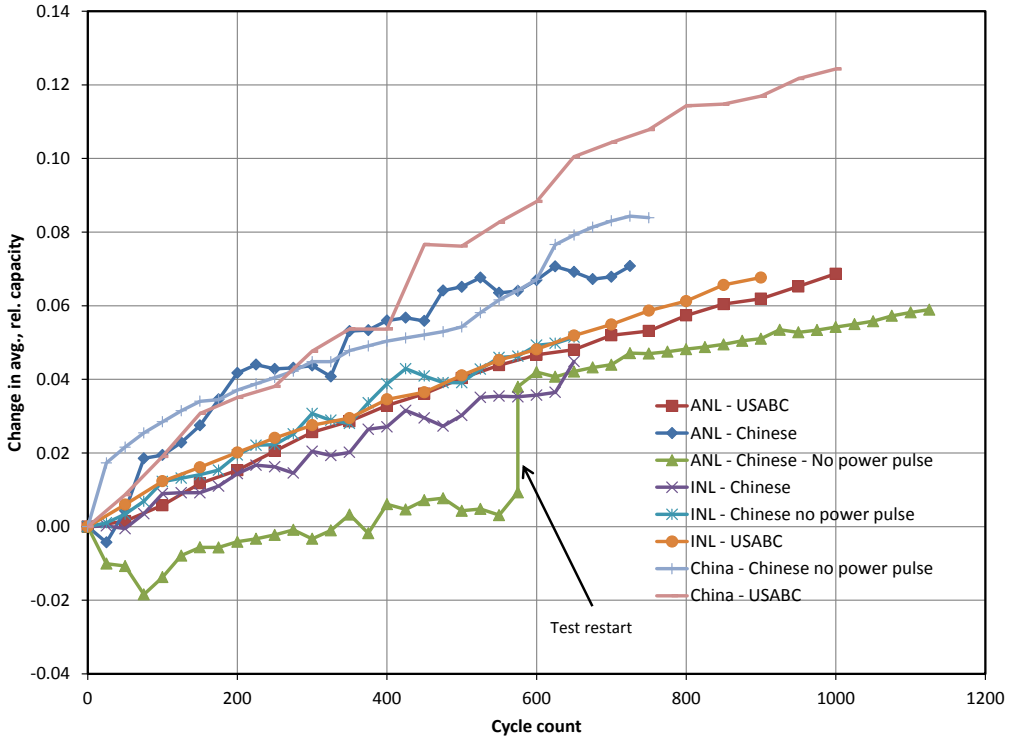
INL



ANL

- Data are similar
- Differences may be due to cell-to-cell variation

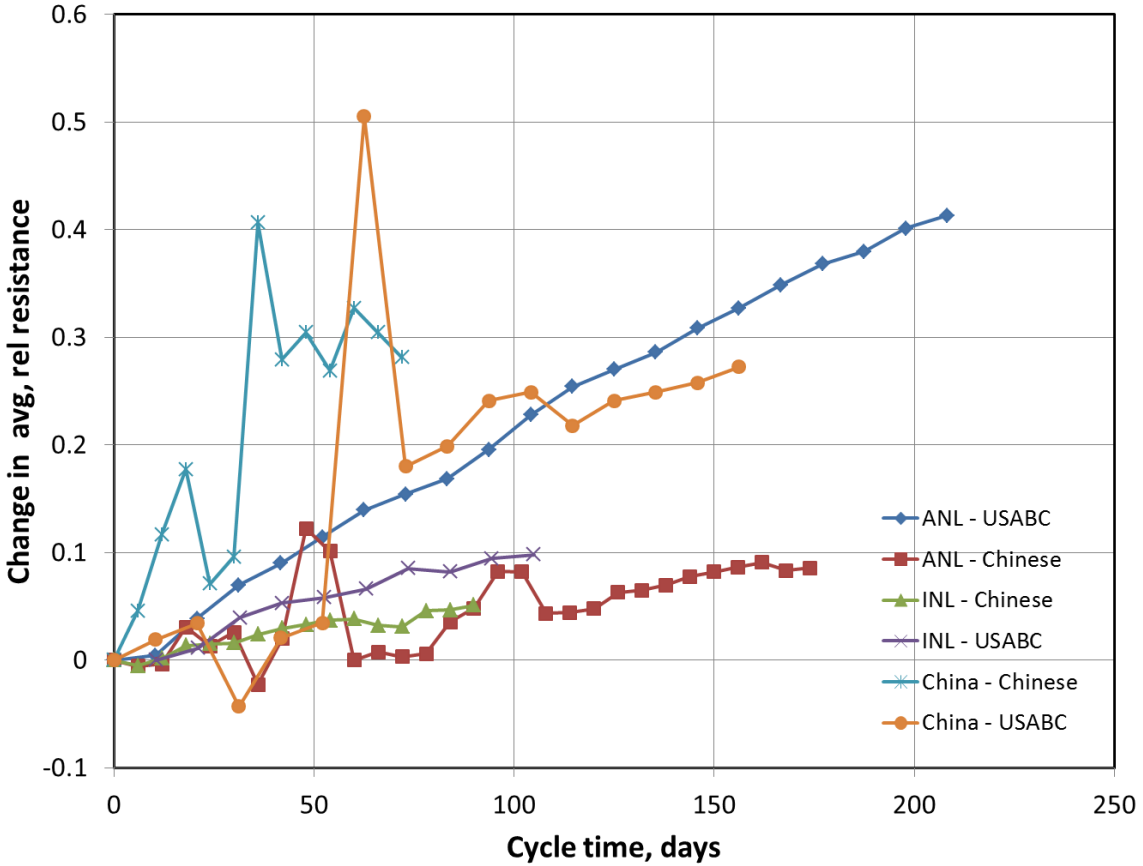
Normalized Capacity Trends



- Capacity degradation observed in all test methods at both sites. There appears to be little dependence on test method
- After restarting the test at ANL after about 8 weeks, a significant capacity loss was seen, but the aging data follow the earlier trend
- The spread in capacity fade could be due to many factors, include cell-to-cell variability and site-specific differences
- Cell-to-cell variability on this order has been seen by others in 18650 cells*

* B-Y Liaw, et al, Orlando Electrochemical Society Meeting, May 2014

Normalized Resistance Trends



- Resistance increase was more significant using the USABC protocol at ANL than those seen at INL or using the Chinese protocol at ANL. It is not known why there were differences between the sites. Cell-to-cell variability is a possible source
- **Temperature had a strong effect on the resistance data!!!**

Comparing the Results Shows…

- There are similarities and differences in the test protocols
- Results indicate that:
  - For capacity, the Chinese test protocol produced slightly more fading than the USABC at both ANL and INL
  - For resistance, the USABC test protocol caused a greater increase in cell resistance at both test sites

Summary and Future Work

- Summary
  - The US/China Protocol Comparison has shown
    - There are similarities and differences in the test protocols
    - For capacity, the Chinese test protocol produced slightly more fading than the USABC at both ANL and INL
    - For resistance, the USABC test protocol caused a greater increase in cell resistance at both test sites

- Future Work
  - Complete the protocol comparison effort by discussing implications of the results with the participants and report them

The work at Argonne National Laboratory was performed under the auspices of the U.S Department of Energy (DOE), Office of Vehicle Technologies, under Contract No. DE-AC02-06CH11357. The program manager was Brian Cunningham.