Robust, high-performance Li-ion cell technology with exceptional over-discharge and 0V tolerance for dead-bus-recoverable spacecraft batteries

David Ofer, Daniel Kaplan, Mark Menard, Celine Yang, Sharon Dalton-Castor, Chris McCoy, and Suresh Sriramulu

Contact:
Ofer.David@camxpower.com
Sriramulu.Suresh@camxpower.com

Space Power Workshop
Torrance, CA
April 4th, 2019

CAMX Power
35 Hartwell Avenue
Lexington, MA
02421-3102

www.CAMXPOWER.com

About CAMX Power

- TIAX was formed in 2002 with Advanced Battery Materials as its largest division.
- Recently, the Advanced Battery Materials Division was established as a separate company, CAMX Power, an affiliate of TIAX.
- Technology development areas at CAMX Power:
  - Technologies for enhancing battery safety
  - High-Nickel cathode material platforms (CAM-7® and GEMX™)
    - CAM-7® licensed to Johnson Matthey (eLNO) and BASF
    - GEMX™ under development
  - Advanced cathode and anode materials
  - Prototyping advanced Li-ion cells for diverse DoD applications based on CAM-7 cathode
  - Low rate initial production of battery packs

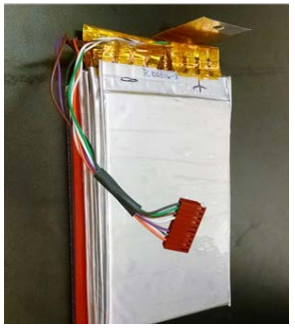
CAMX Power has facilities and expertise ranging from materials development and optimization, to cell and pack prototyping.

Materials Development → **Materials Scale-Up** → **Electrode & Cell Development** → **Cell Prototyping &Testing** → **Prototyping of Packs**

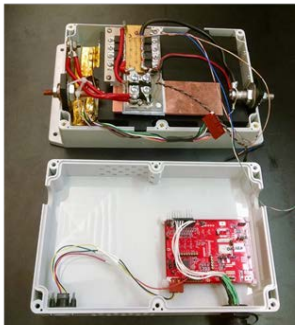










This presentation describes CAMX Power's robust 0V-tolerant cell technology based on its CAM-7 cathode material LTO anode material.

- This presentation will summarize:
  - Performance of CAM-7/LTO pouch cell technology (called CELX-RC™)
    - Emphasis of testing to date has been on vehicle battery applications, but results demonstrate attractive attributes for space applications.
  - Overcharge, overdischarge, and 0V tolerance of CAM-7/LTO pouch cells and packs
    - Demonstrate technology's tolerance for loss of battery management functionality and discharge to 0 V.

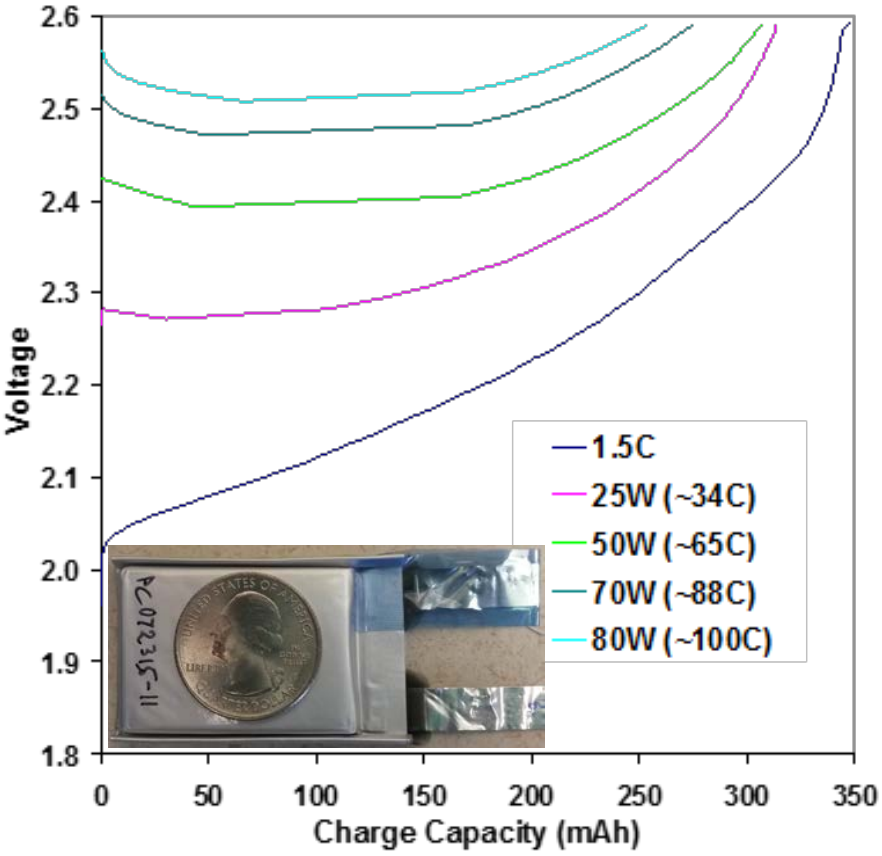
Performance of CAM-7/LTO pouch cell technology

CAM-7® and LTO are rugged Li-ion active materials with high power capability

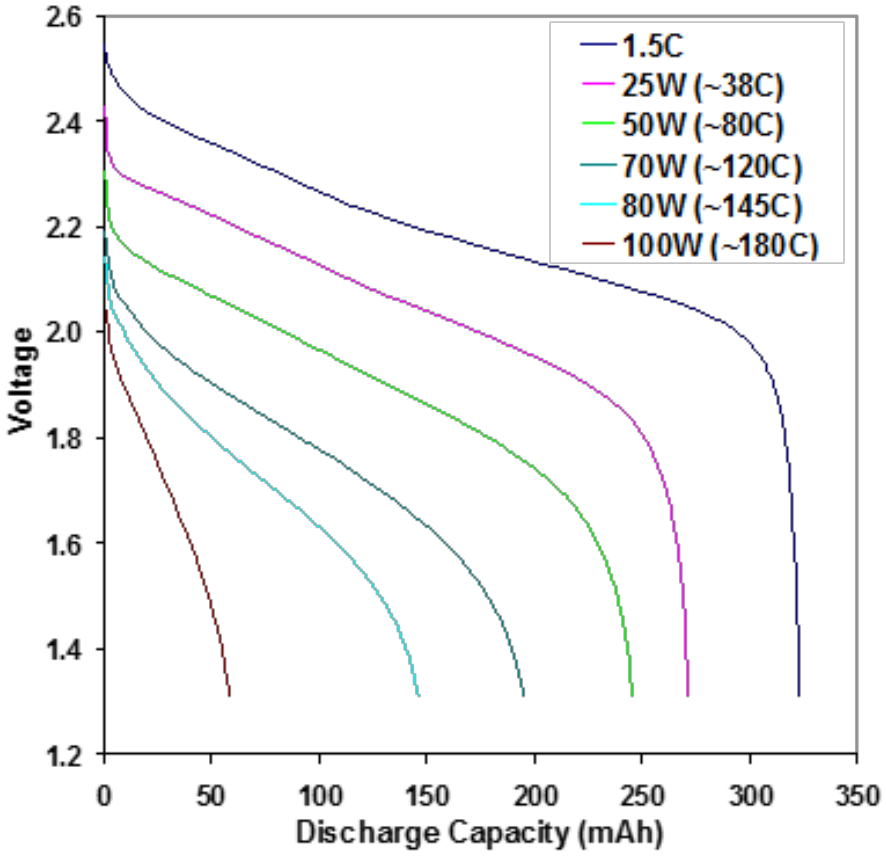
- CAM-7® is a $LiNiO_2$-class cathode material
  - Developed by CAMX Power and predecessor TIAX over 15+ years.
  - Uniquely high combined energy content and power capability.
  - Licensed to BASF and Johnson Matthey for high-volume commercialization.
- LTO is the $Li_4Ti_5O_{12}$ or lithium titanate anode material
  - Very robust: long life and safety.
  - Nano-structured (10 m^2/g SSA) for high power.
  - High potential (1.55V vs. Li) enables wide flexibility in electrolyte optimization.
    - But gives lower energy density than conventional carbon anode.

CAM-7 and LTO have intrinsic high power capability for high-performance cells

charge to 2.59 V*



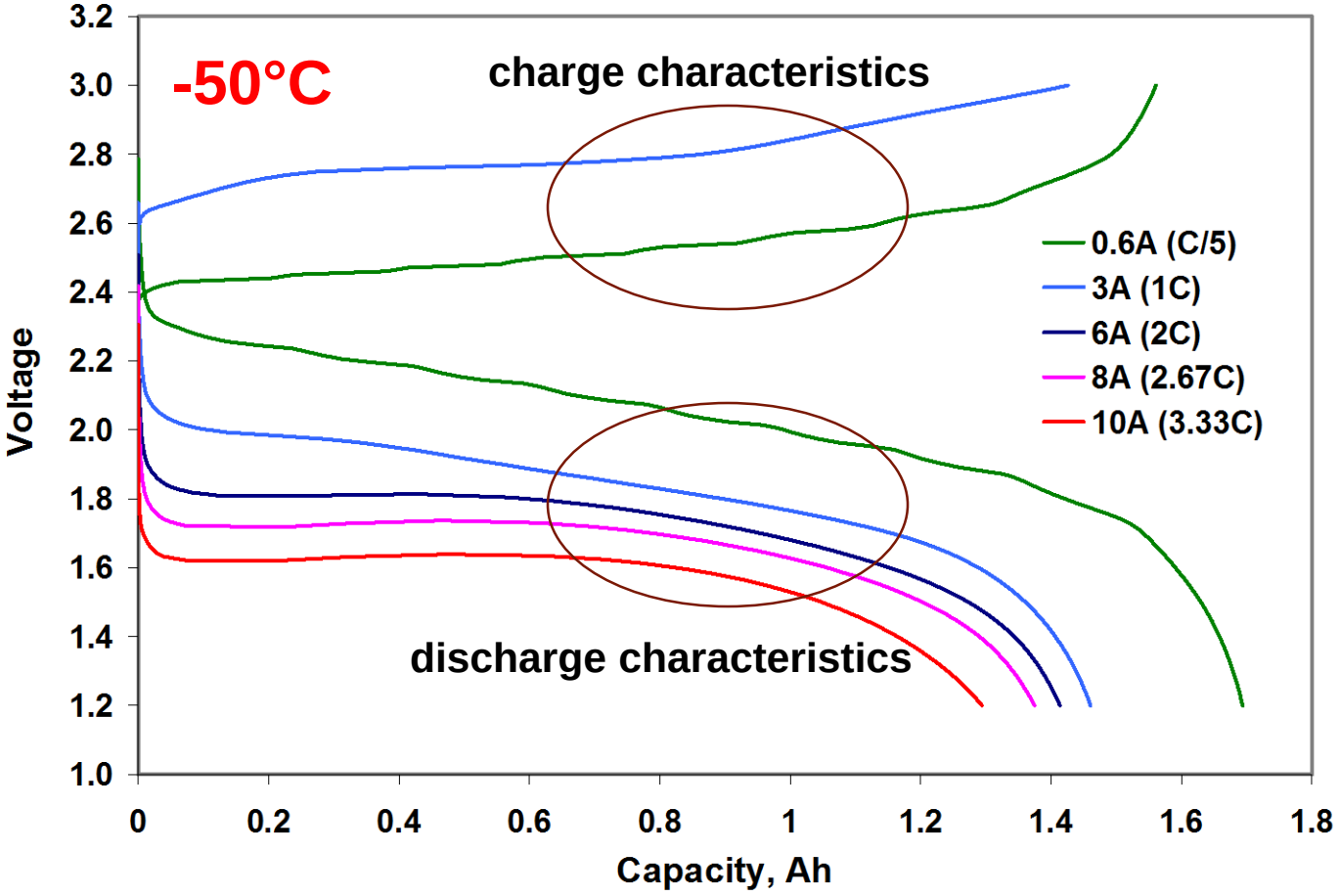
discharge to 1.31 V*



320 mAh, 700 mWh, 7 cc CAM-7®/LTO pouch cell made with low loading electrodes (0.5 mAh/cm^2) to minimize electrolyte-based rate limitations.

***corresponds to 28.5 V – 14.4 V operation of 11-series-cell 6T vehicle battery**

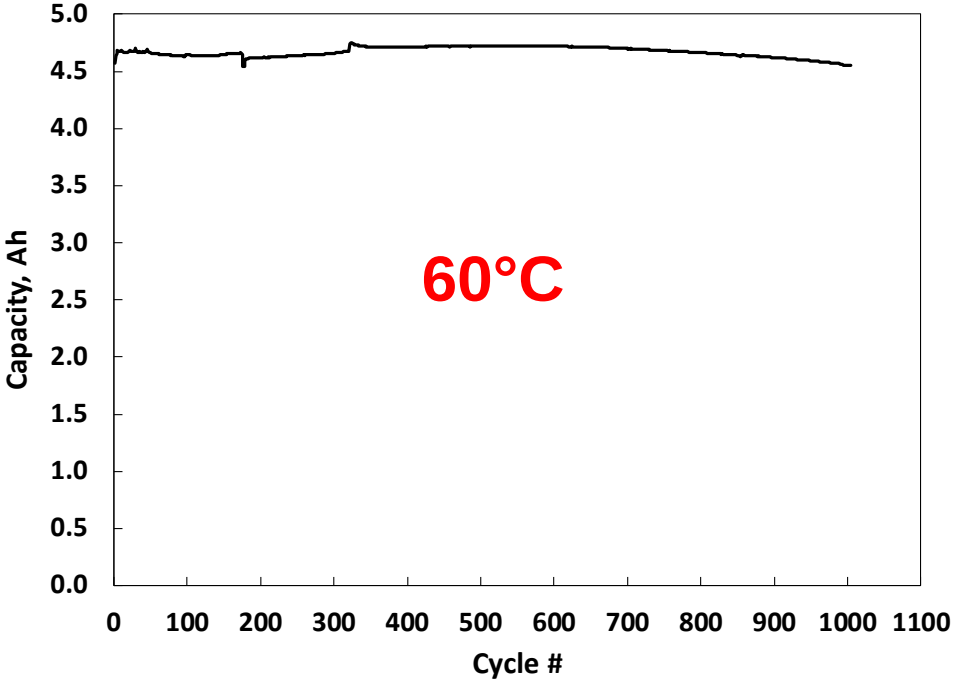
CAM-7 and LTO can be matched with electrolyte tailored for exceptional low-temperature capability



3 Ah, 90 Wh/kg CAM-7®/LTO pouch cell charged and discharged at -50 °C (-58 °F).

CAM-7/LTO pouch cells have excellent elevated-temperature stability and high-rate charge acceptance

40A charge & discharge: 2.43V – 1.2V*



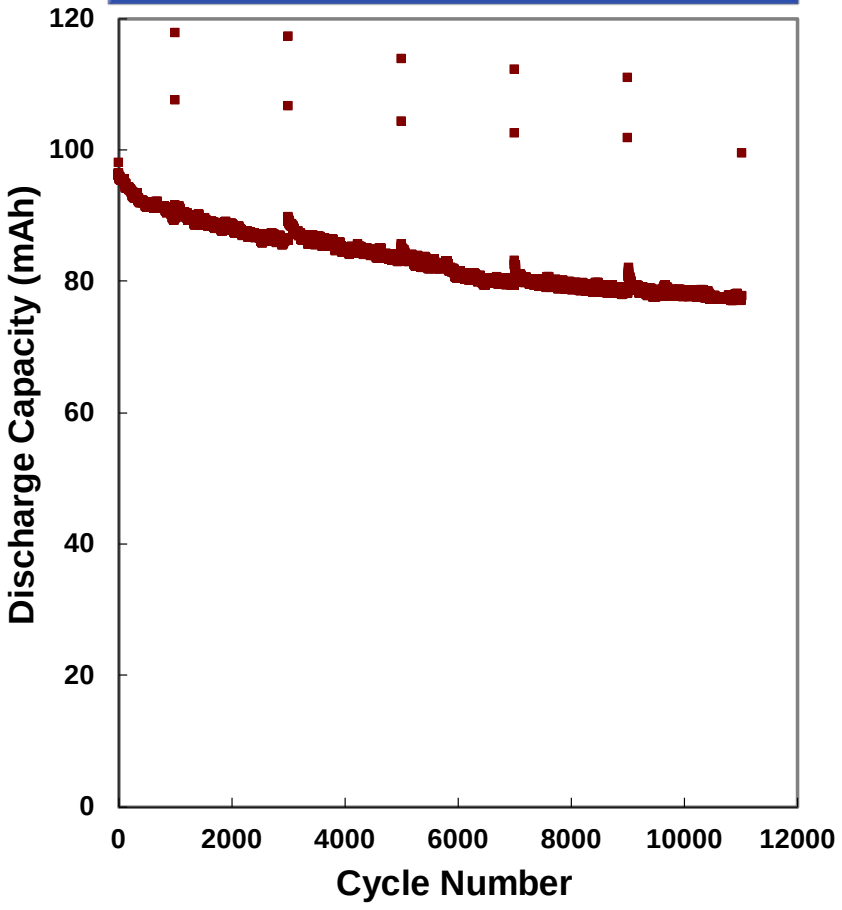
No gassing/swelling evident

5Ah, 80 Wh/kg CAM-7®/LTO pouch cell 8C/8C cycled at 60 °C average cell temp.

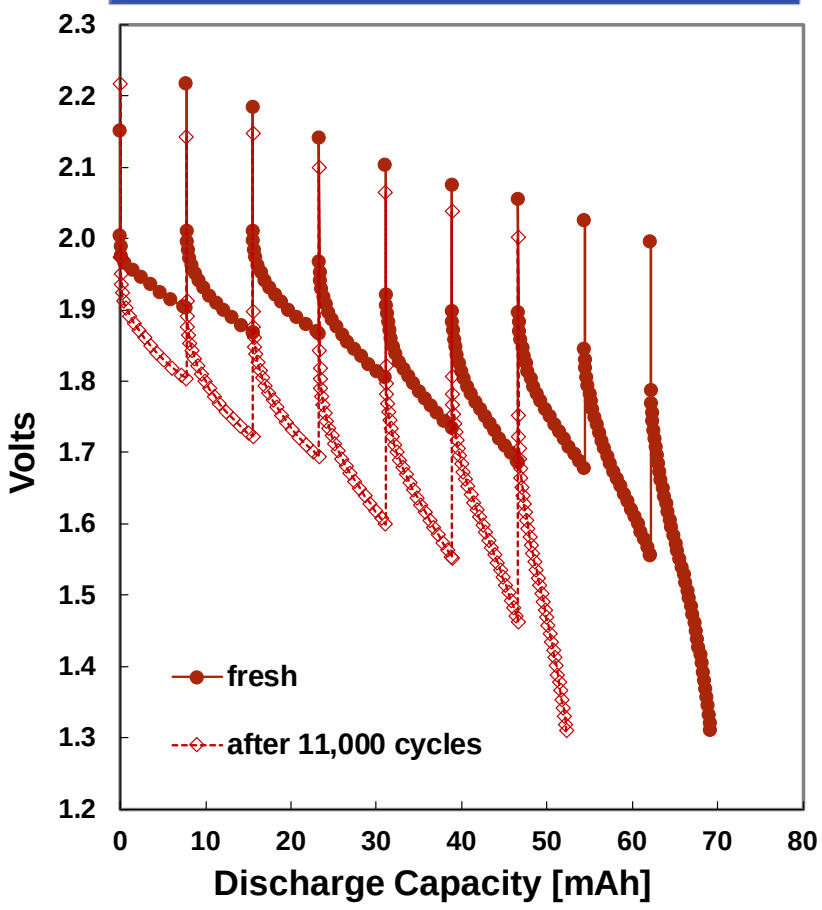
*voltage limits for 6-series-cell start-stop vehicle battery

CAM-7/LTO cells have excellent retention of capacity power delivery capability

10C/10C cycling at RT, C/5 and 1C discharges every 2000 cycles



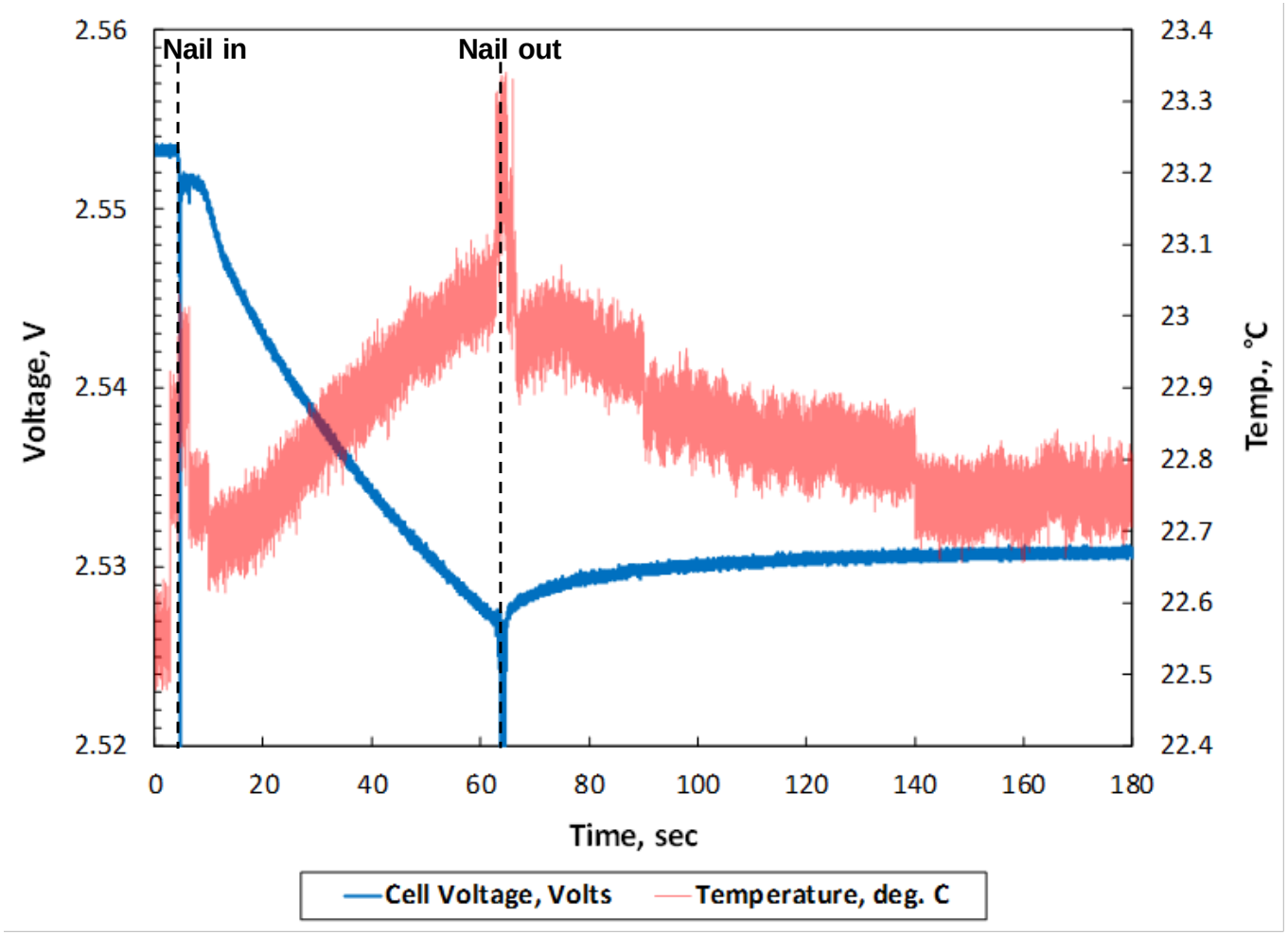
0.93A*, 30 second pulse discharges with 30 minute rests at -18 °C (0 °F)



120 mAh CAM-7®/LTO pouch cell cycled between 2.59 V and 1.31 V.

*scaled to 600 A in 28 V 6T vehicle battery

CAM-7/LTO cells have outstanding abuse tolerance



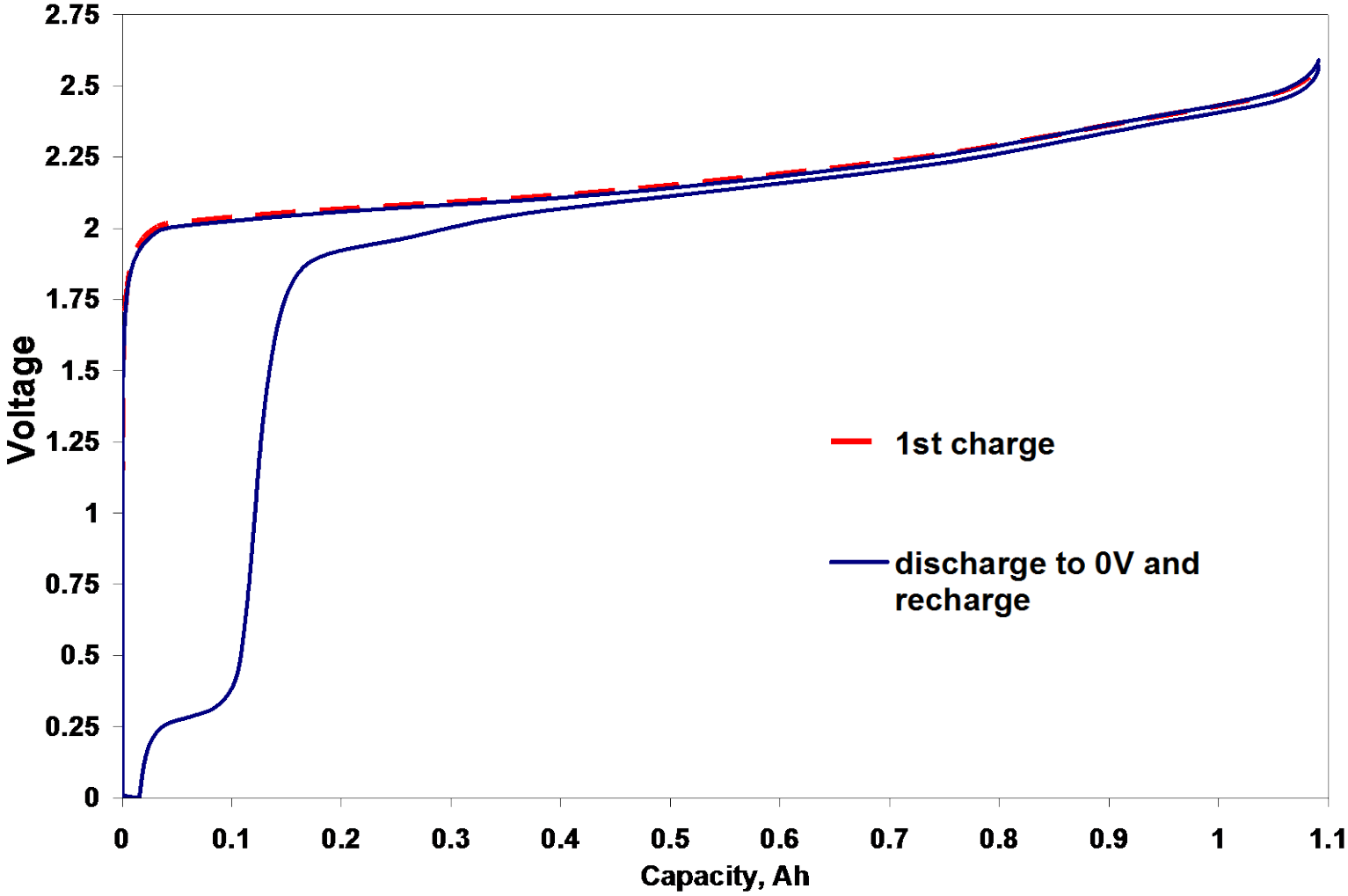
2.7 Ah CAM-7®/LTO pouch cell charged to 2.65V undergoing blunt 2 mm diameter nail penetration at 1 cm/sec

Overcharge, Overdischarge, and 0V Capability

CAM-7/LTO cells can tolerate overcharge, overdischarge, and 0 V condition

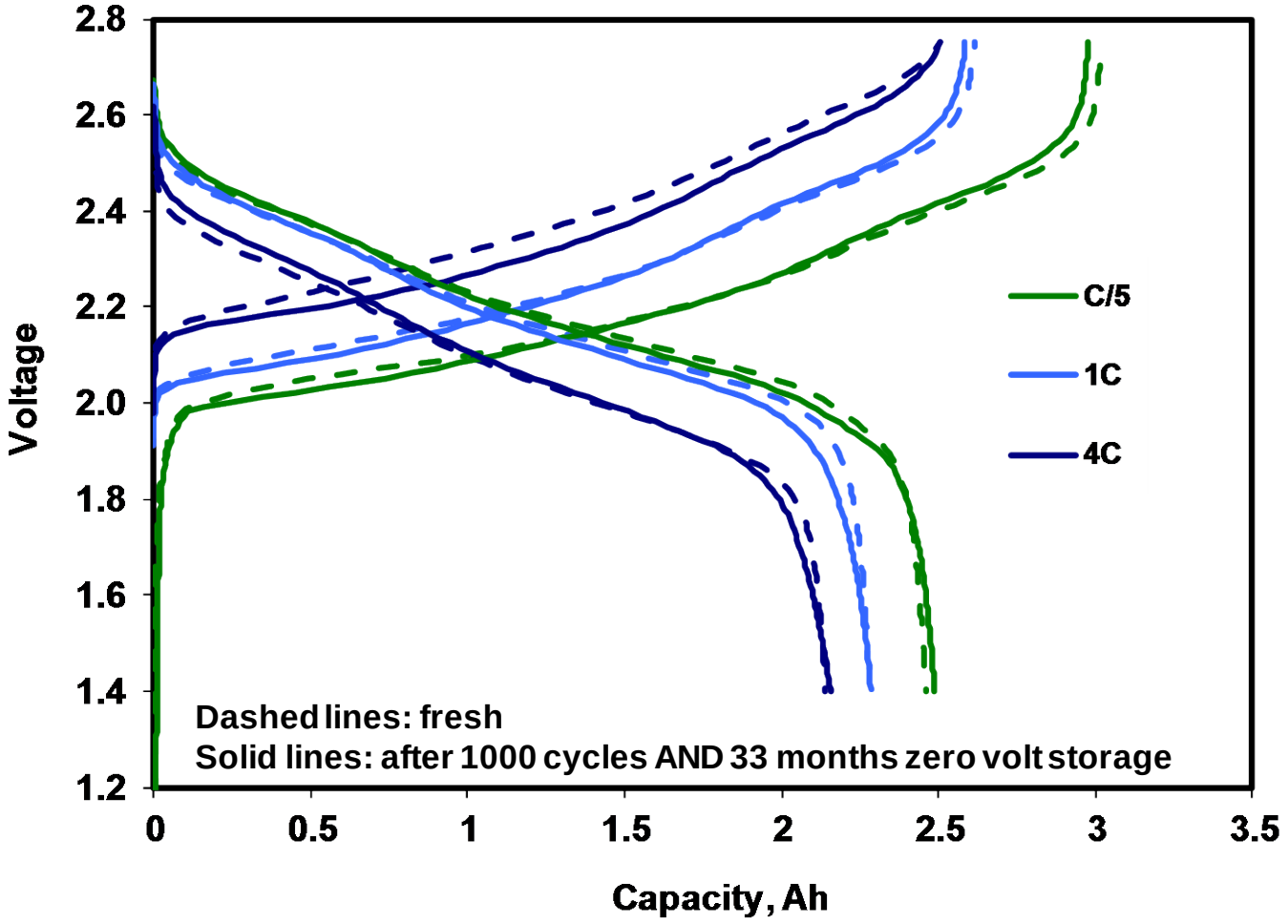
- Cells' overcharge and overdischarge tolerance means that batteries can tolerate loss of management and/or cell balancing, and can recover from dead bus events that take entire battery to 0 V.
  - Cell overcharge can occur in absence of battery management system or cell balancing functions.
  - Cell overdischarge and reversal can occur when a series-cell string is driven to 0 V as a unit, as when a multi-cell battery is discharged to 0 V.

Charging after discharge to 0V reproduces 1st charge; cell is unchanged.



1.1 Ah pouch cell

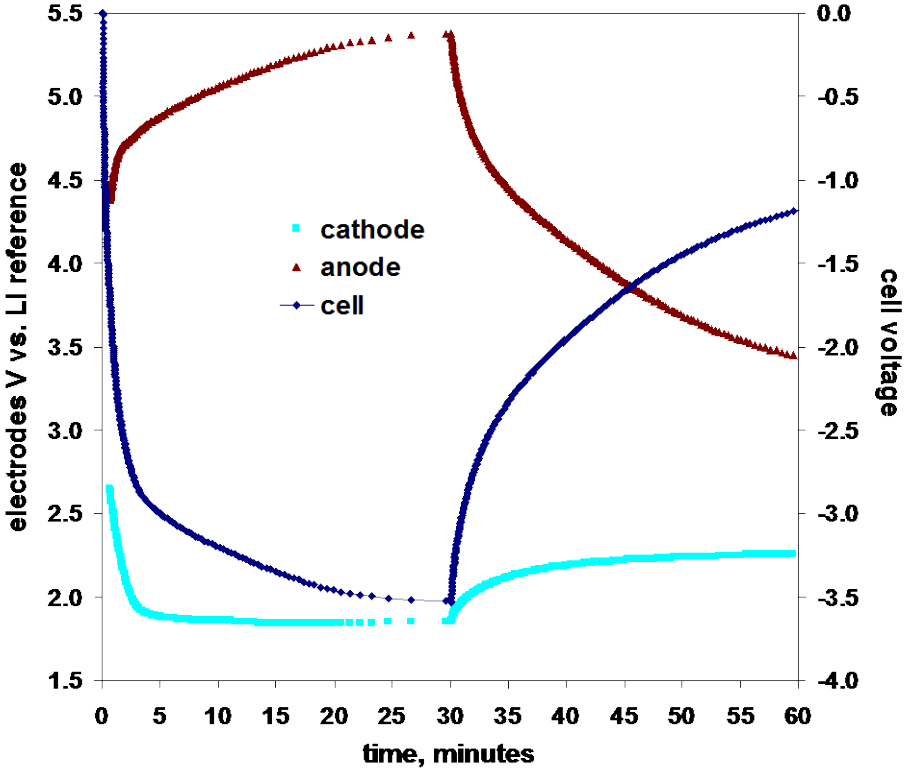
RT capacity and performance are unchanged by almost 3 years storage at RT (and preceding cycling).



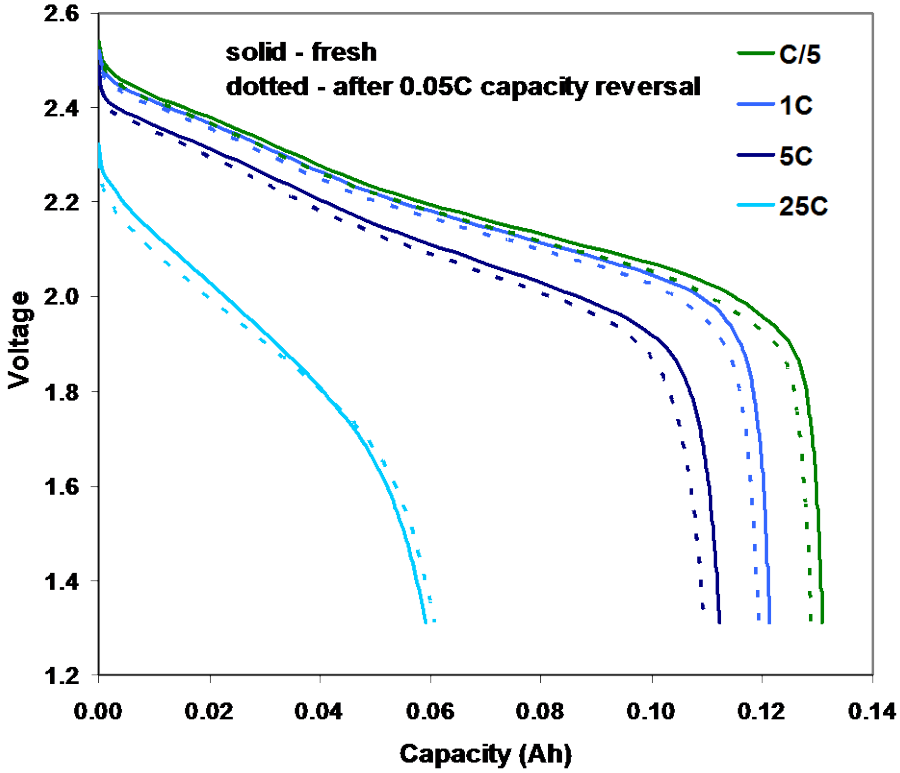
Unsupported 2.5 Ah pouch cell 1C/1C cycled 1,000X at RT and stored 33 mo. at 0V.

Cell technology tolerates reversal to -3.5V and over-discharge by 5% of capacity below 0V without impact on performance.

Reversing the 0V-discharged cell by 5% of cell capacity at 0.1C rate



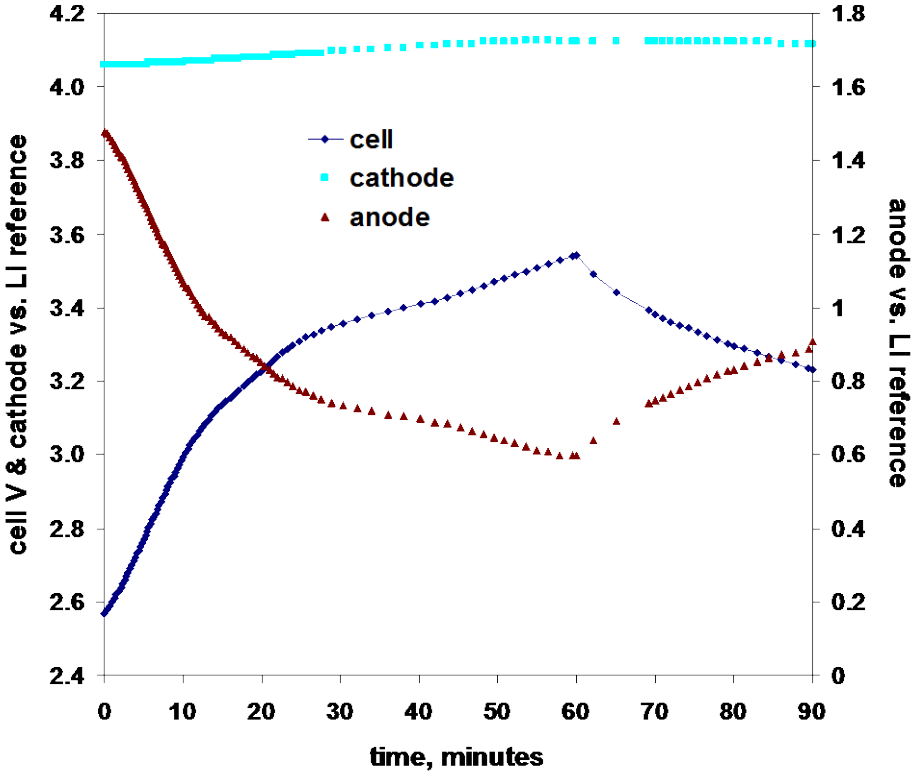
RT discharge from charge to 2.59V



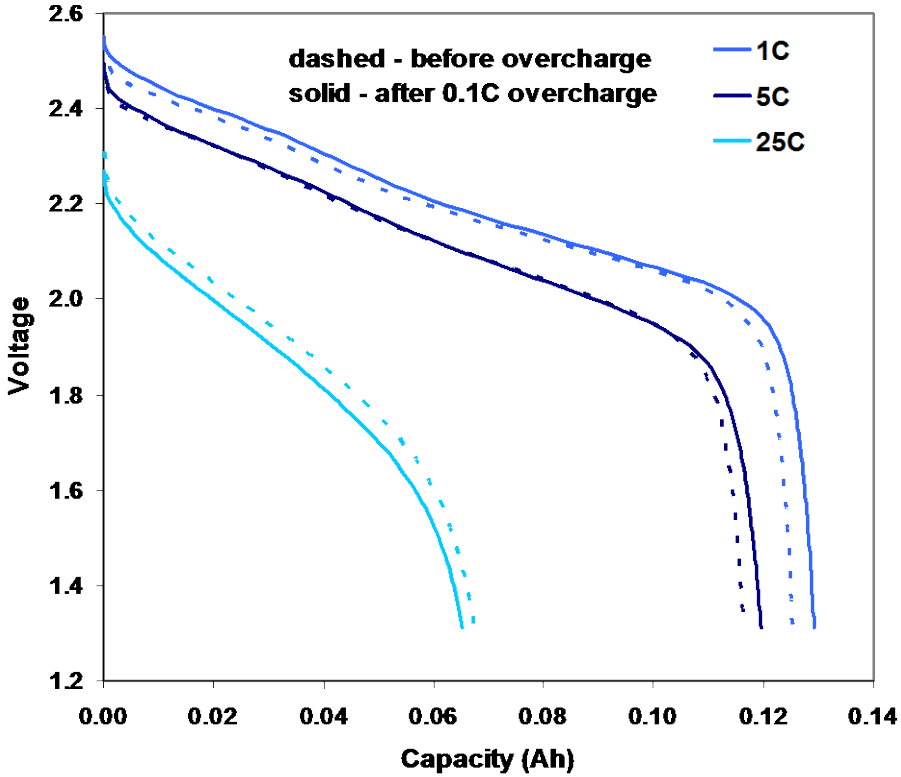
Unfixtured 130 mAh cell with Li metal reference electrode

Cell technology tolerates overcharge to +3.5V and by 10% of capacity above 2.59V* without impact on performance.

Overcharging the 2.59V-charged cell by 10% of cell capacity at 0.1C rate



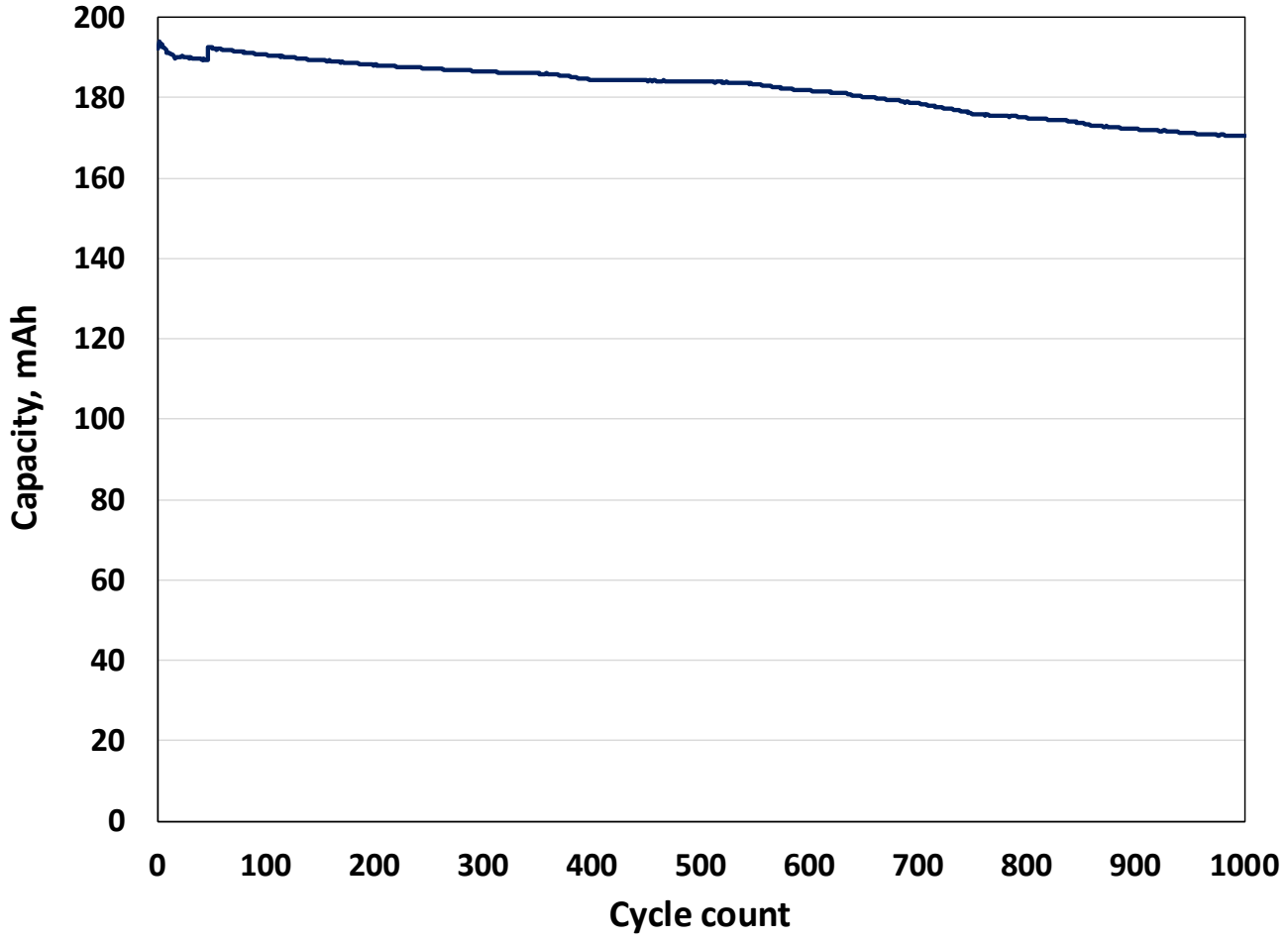
RT discharge from charge to 2.59V



Unfixtured 130 mAh pouch cell with Li metal reference electrode

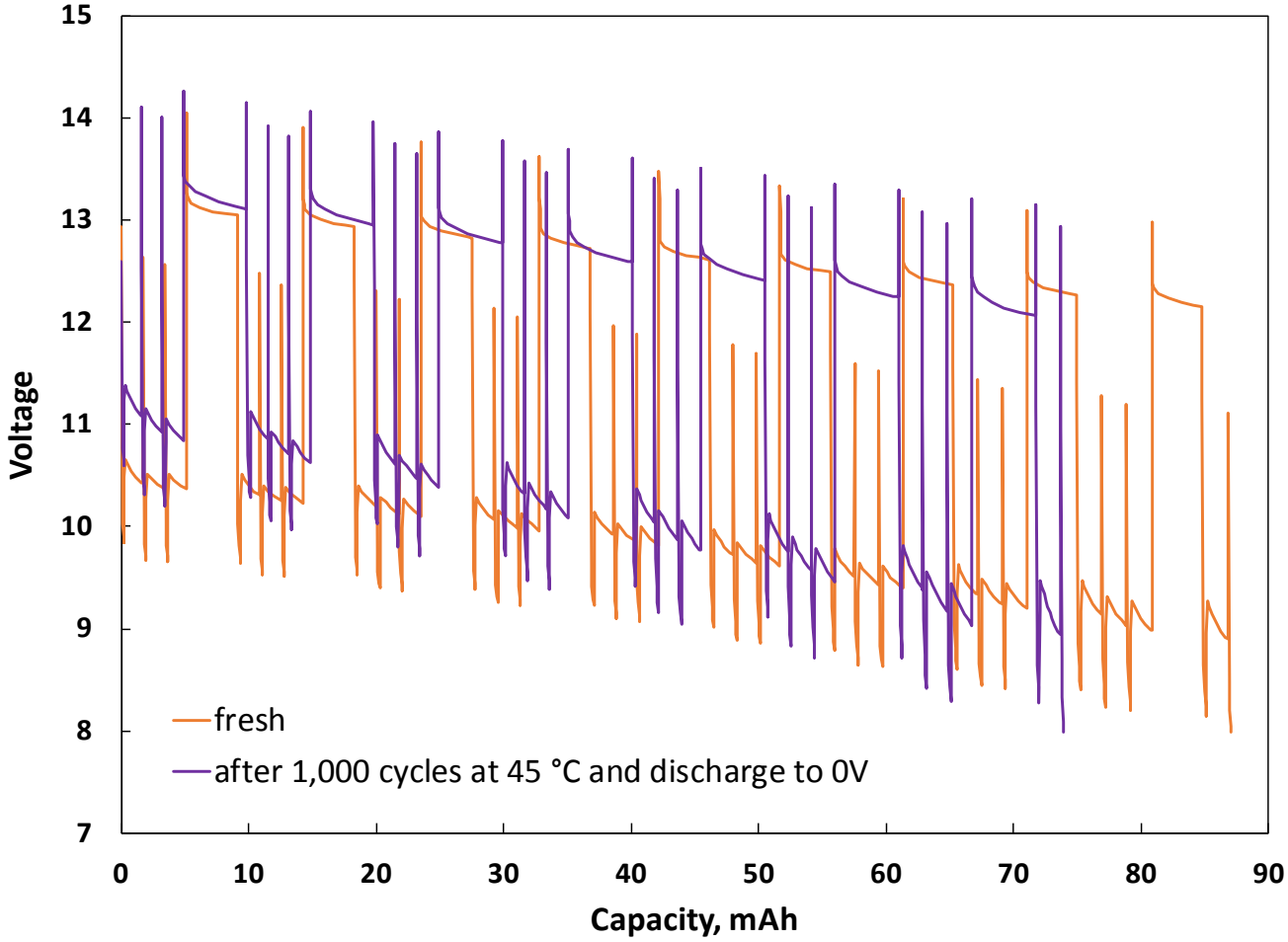
***per cell charge voltage for 11-series-cell string charging to 28.5V bus**

Cell technology's robustness enables cycling of series cell strings without management or balancing.



Unclamped 6-series-cell 200 mAh CAM-7/LTO pouch cell stack (cells with 1C range of 213-216 mAh) 10C/10C (2.38 A) cycled 1,000 times between 14.6 V and 10.5 V at 45 °C: 89% capacity retention.

Demanding high-power pulse testing at low temperature demonstrates retention of high power delivery capability after 0V battery condition.



Cod-crank testing at -18 °C to scaled requirements of USABC start-stop vehicle battery test manual. 3X (20.3W/0.5sec, 13.6W/4sec, 10sec rest) followed by 150 mA dchg for 2 min.: repeat to 8 V cutoff.

CELX-RC can be adapted to many specialized uses including space power

- CAMX Power's CELX-RC cell technology has many attractive attributes for a wide range of applications:
  - Long term storage at zero volts without compromising performance.
  - Tolerance to over-charge and over-discharge.
  - Tolerance to extreme abuse events.
  - Charge and discharge at very low temperatures.
  - Ability to be charged rapidly (< 10 minutes).
  - Ability to be fielded in battery packs with no management electronics.
- We invite opportunities from the DoD community to implement this cell technology for specialty batteries.

Acknowledgements

- US Army (TARDEC) SBIR Phase II contract # W56HZV-12-C-0065
  - TPOC: Laurence Toomey
- US Navy (NAVFAC) SBIR Phase II contract # N39430-14-C-1506
  - TPOC: Ken Ho
- US Defense Logistics Agency SBIR Phase I contract # HQ0147-15-C-8003
  - TPOC: Traci Myers
- US Department of Energy (EERE) SBIR Phase I contract # DE-FOA-0001227
  - TPOC: Brian Cunningham