



EnerSys®

Power/Full Solutions

Domestic Production of Lithium Ion 18650 cells

Mark Matthews / Vice President EnerSys Advanced Systems

About EnerSys

- EnerSys is the largest industrial battery manufacturer in the world, operating manufacturing and assembly facilities worldwide for customers in over 100 countries.
 - Worldwide and Americas headquarters are located in Reading, Pennsylvania, USA with regional headquarters in Europe and Asia.
- EnerSys is uniquely positioned to provide expertise in designing, building, installing and maintaining a comprehensive stored energy solution for industrial applications throughout the world.
- The company's products and services are focused on three primary markets:
 - Motive Power
 - Reserve Power
 - Aerospace & Defense (EAS)
- EnerSys employs 10,000 people globally with over 30 manufacturing facilities in 18 countries



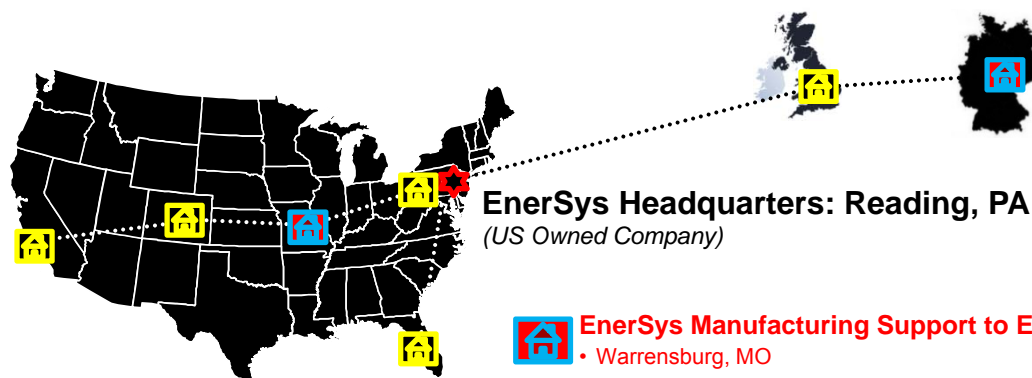
EnerSys Advanced Systems Locations

EnerSys Advanced Systems



EAS Manufacturing Facilities

- Sylmar, CA
- Santa Clarita, CA
- Longmont, CO
- Horsham, PA
- Tampa, FL
- Culham Oxfordshire, UK



EnerSys Headquarters: Reading, PA
(US Owned Company)

EnerSys Manufacturing Support to EAS

- Warrensburg, MO
- Newport, UK
- Zwickau, DE

Four Domestic EAS Battery Engineering Locations Serving Six Markets

Business Line	Brands	Technology	Main Manufacturing Locations
Aerospace	ABSL/Quallion	Lithium-Ion Materials, Cells & Batteries	Longmont CO, Sylmar CA, Culham UK
Medical	Quallion	Lithium-ion Cells & Batteries	Sylmar CA
Munitions	EAS, Enser	Lithium Primary/Liquid Reserve	Horsham PA, Tampa FL
Land & Sea	Hawker/Armasafe	Lead Acid (Thin Plate), NiZn	Warrensburg MO, Zwickau DE, Newport UK
Aviation	Hawker/Quallion	Lead Acid (Thin Plate), Ni-Cd & Lithium-ion	Warrensburg MO, Sylmar CA, Newport UK, Zwickau DE

Current EAS Markets

- **Munitions**
 - Missiles & Smart Weapons
 - Guided Bombs & Projectiles
 - Electronic Fuzing
- **Space**
 - Launch Vehicles
 - Satellites
 - Manned
 - Interplanetary & Landers
- **Aviation**
 - Fixed Wing & Rotary Aircraft including F16/18 & 777
 - UAV's & Target Drones
- **Land**
 - Combat, Tactical & Unmanned Ground Vehicles
 - Microgrids & Forward Operating Bases
- **Sea**
 - Submarines
 - Unmanned Underwater Vehicles
- **Medical**
 - Cochlear Implant Speech Processors
 - Neuromodulation



Outline

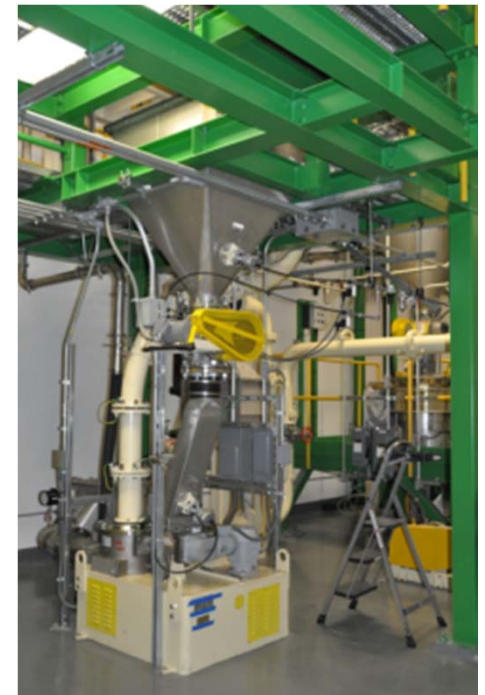
- **Manufacturing Capability and Vertical Integration**
- **18650 Cell Manufacturing Overview**
- **Test Cell and Test Regime**
- **Electrical Cycling Test Results**
 - 100% DOD Cycle Life
 - 40% DOD Cycle Life
 - Varied DOD Cycle Life Summary
- **Cell Development/Improvement Overview**
- **Summary**

MANUFACTURING CAPABILITY AND VERTICAL INTEGRATION

EnerSys Advanced Systems Manufacturing Capability

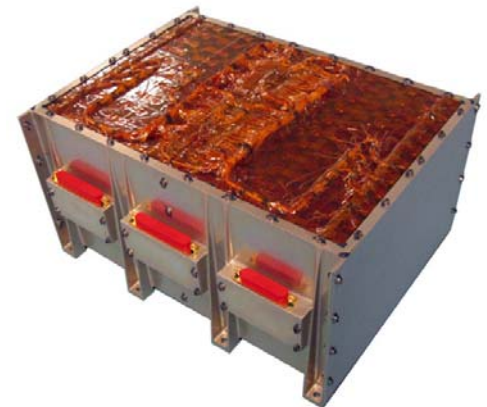
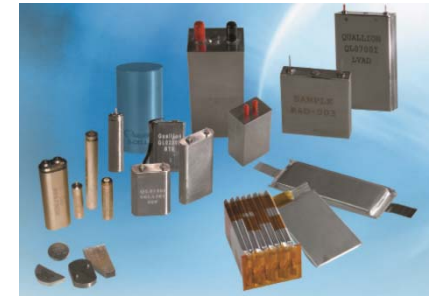
Producer Of Raw Materials

- Cathode and Anode materials manufactured in-house
- 100% control over quality and supply
- **Advantages:** *Locked chemical control to ensure consistent product with no threat of obsolescence or need for expensive re-qualification*
- **Active Negative and Positive Li-Ion Material Production**
 - **Location:** Sylmar and Santa Clarita, CA
 - **Cathode Products:** Lithium Cobalt Oxide & Lithium Nickel Cobalt Aluminum Oxide
 - **Anode Products:** Micro Carbon Micro Beads



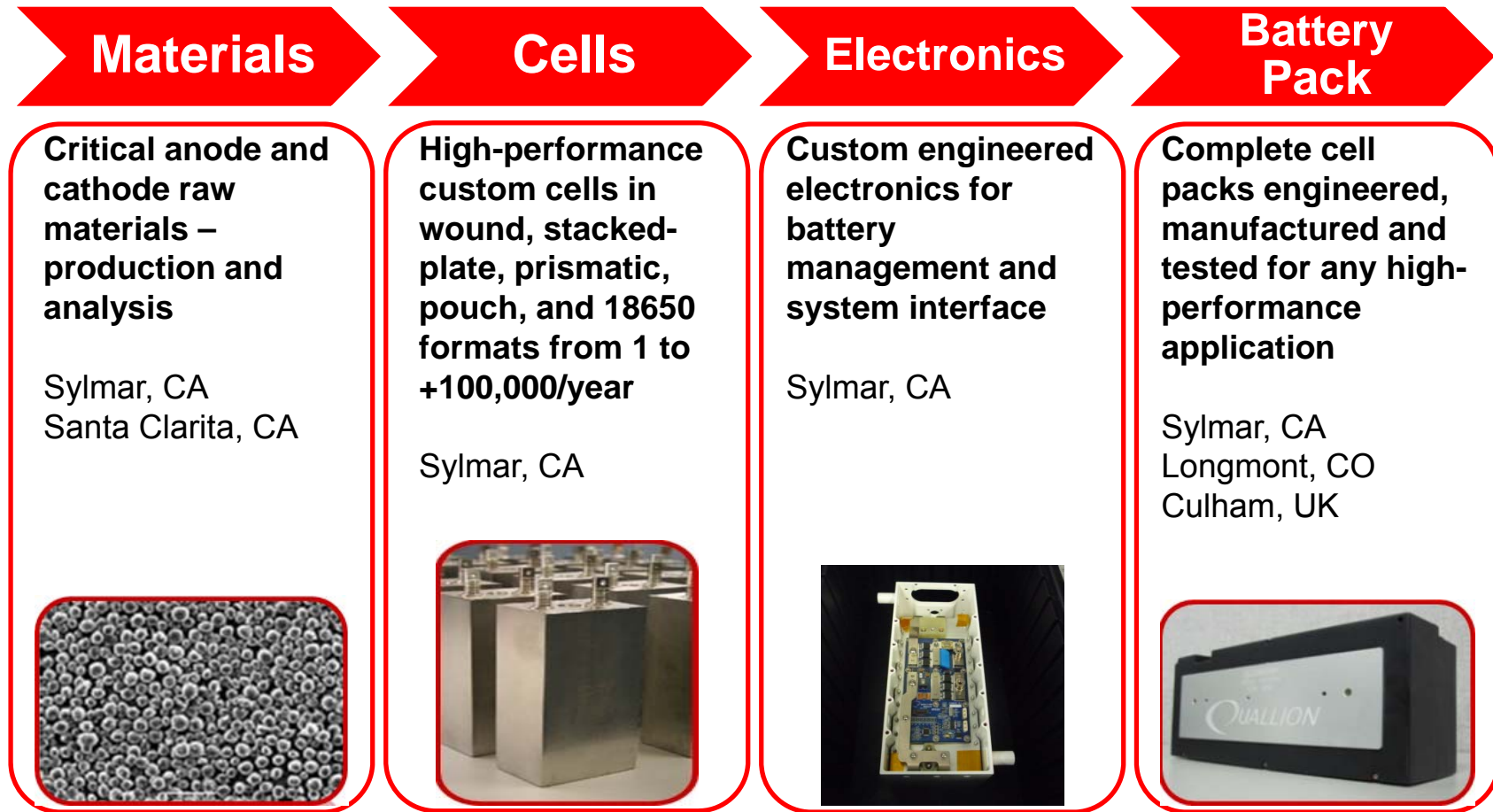
EnerSys Advanced Systems Manufacturing Capability

- **Producer of Various Cell Formats**
 - **Lithium-Ion Cell Production**
 - **Location:** Sylmar, CA
 - **Product:** Small prismatic wound cells, prismatic cells & cylindrical cell designs (1.8mAh to 7200mAh)
 - **Advantages:** *Multiple different types of form factors to meet customer battery requirements*
- **Producer of Complete Battery Assemblies**
 - **Lithium-Ion Module & Battery Production**
 - **Location:** Sylmar, CA; Longmont, CO; Culham, UK
 - **Product:** Module and battery assembly with cylindrical and prismatic cells
 - **Advantage:** *Flexibility in battery designs, semi-automation for module assemblies*



Vertical Integration of Battery Manufacture

- Mitigates Supply Chain Risk



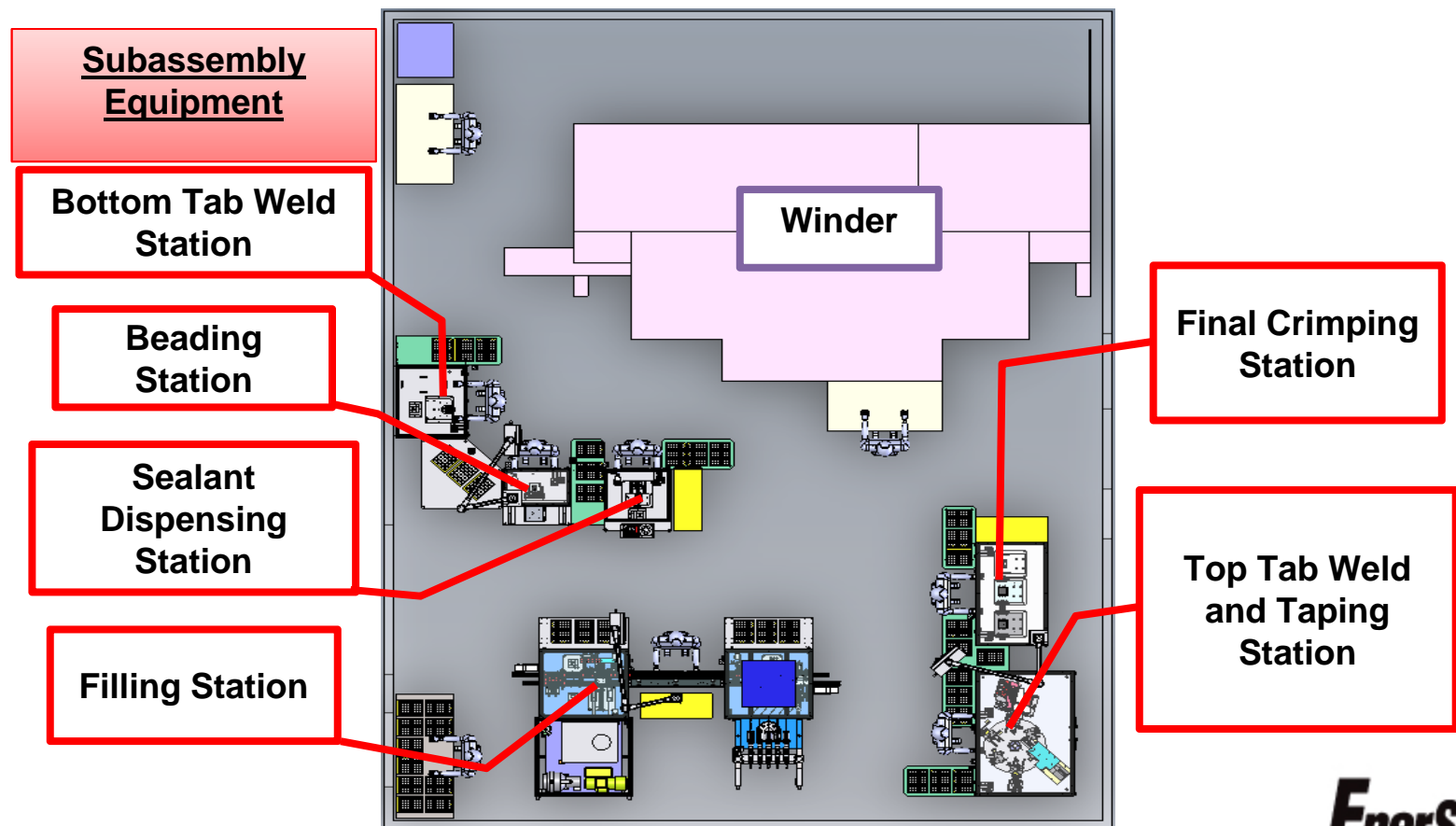
> Unmatched product flexibility and supply-chain stability in one battery partner <



18650 CELL MANUFACTURING EQUIPMENT

18650 Cell Manufacture/Assembly Flow

- 18650 manufacturing and assembly line was designed for optimal process flow from bottom tab welding to the final cell crimping
 - Optimizes overall manufacturing and assembly time



Cell Winder



Subassembly Equipment



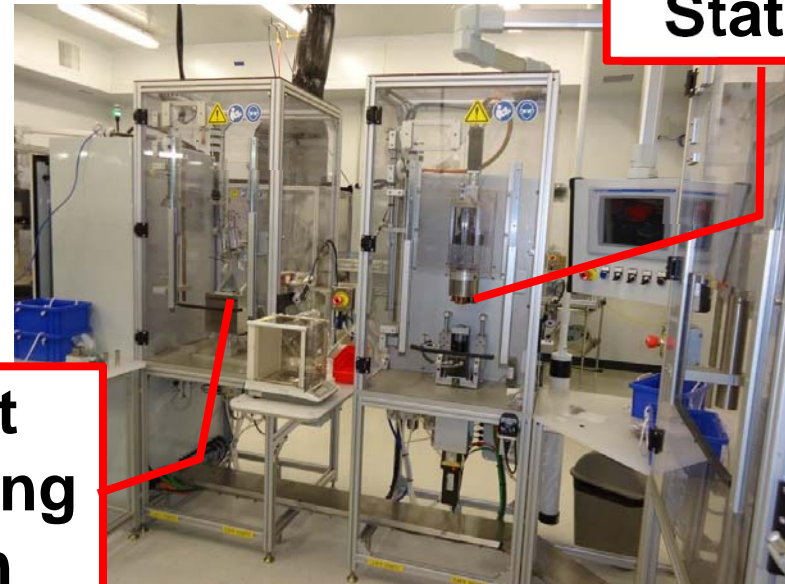
**Bottom
Tab Weld
Station**



**Beading
Station**



**Sealant
Dispensing
Station**



Subassembly Equipment



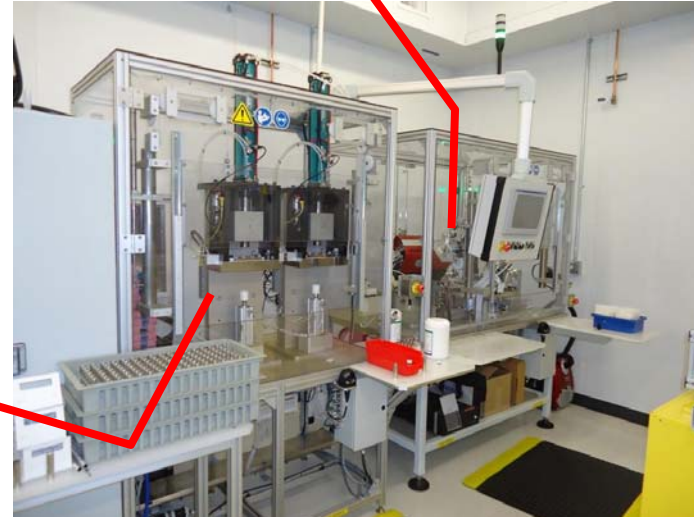
**Filling
Station**



**Top Tab Weld
and Taping
Station**



**Final Crimp
Station**

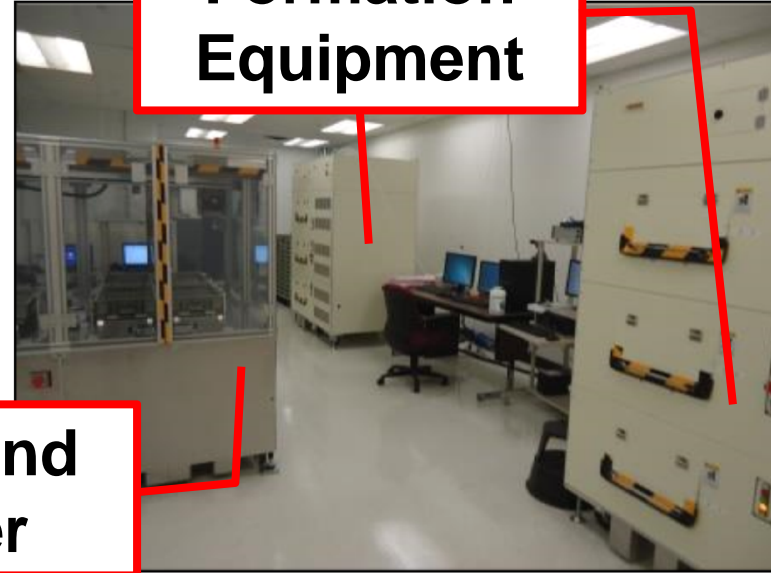


Formation and Sorting Equipment

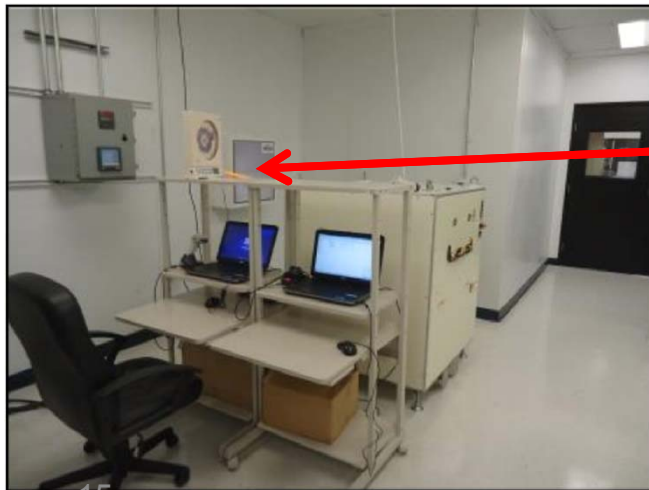
**OCV/ACIR
Tester**



**Formation
Equipment**



**Rank and
Sorter**



**Dry Room to Cell
Formation Area
pass-thru window
for completed cells**



TEST CELL AND TESTING REGIME

Quallion Long Life 18650 Cell



Cell Specifications

Capacity / mAh	1400 \pm 50
Nominal Voltage / V	3.6
Weight / g	42.6 \pm 0.5
Specific Energy / Wh/kg	118

- **Characteristics**
 - Heritage chemistry from long life medical and aerospace cells
 - Full domestic control of active materials and manufacture
 - Safety features including CID, vent, and PTC
 - Excellent storage properties

Test Cell Configuration

- **Cathode:** Medical/aerospace chemistry
- **Anode:** Medical/aerospace chemistry
- **Separator:** Polyolefin
- **Electrolyte:** Carbonate-based
(medical/aerospace chemistry)
- **Mechanical:** Lab scale cell manufacturing equipment; machine wound jellyrolls; cap assembly
- Final cap assembly with PTC

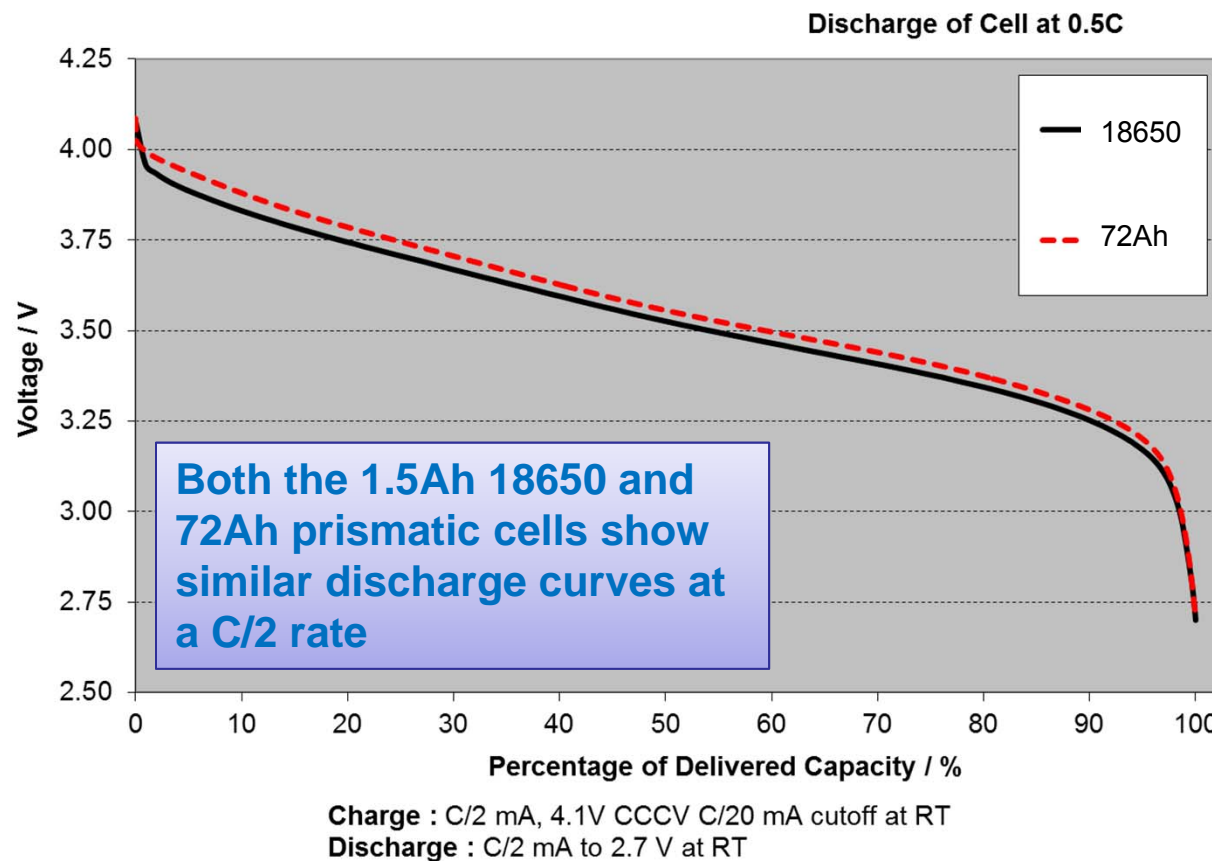
Cell Test Regime

- **100% DoD Charge/Discharge Cycling**
 - **Charge** : C/2 to 4.1V, C/20 CV cutoff at $25^{\circ} \pm 5^{\circ}\text{C}$
 - **Discharge** : C/2 to 2.7V at $25^{\circ} \pm 5^{\circ}\text{C}$
 - **Repeat** : 200 Cycle increments; Capacity check each 200 cycles
- **40% DOD Charge/Discharge Cycling**
 - **Charge** : C/2 to 4.1V, C/20 CV cutoff or 96 minutes at $25^{\circ} \pm 5^{\circ}\text{C}$
 - **Discharge** : C/2 to 2.7V or 48 minutes at $25^{\circ} \pm 5^{\circ}\text{C}$
 - **Repeat** : 400 Cycle increments; Capacity check each 400 cycles
- **For all testing 1C = 1500mA; RT = $25^{\circ} \pm 5^{\circ}\text{C}$**

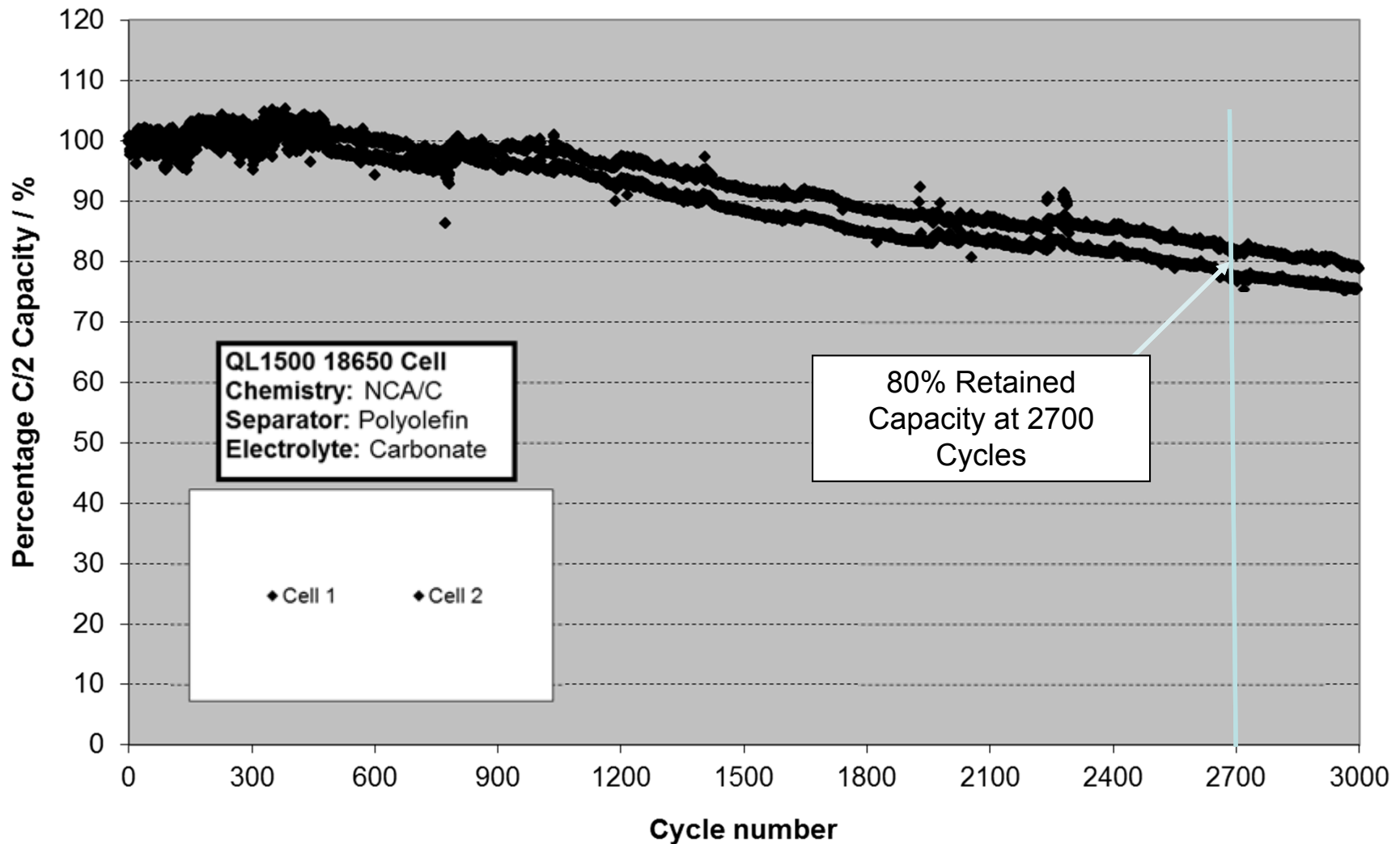
ELECTRICAL CYCLING TEST RESULTS

Chemistry Form Factor Evaluation

- Chemistry cell form factor evaluation
 - Cell performance evaluated at C/2 – 100% DoD cycling in 18650 cylindrical mechanical packaging and 72Ah prismatic mechanical packaging
 - Chemistry performs similarly independent of mechanical form factor

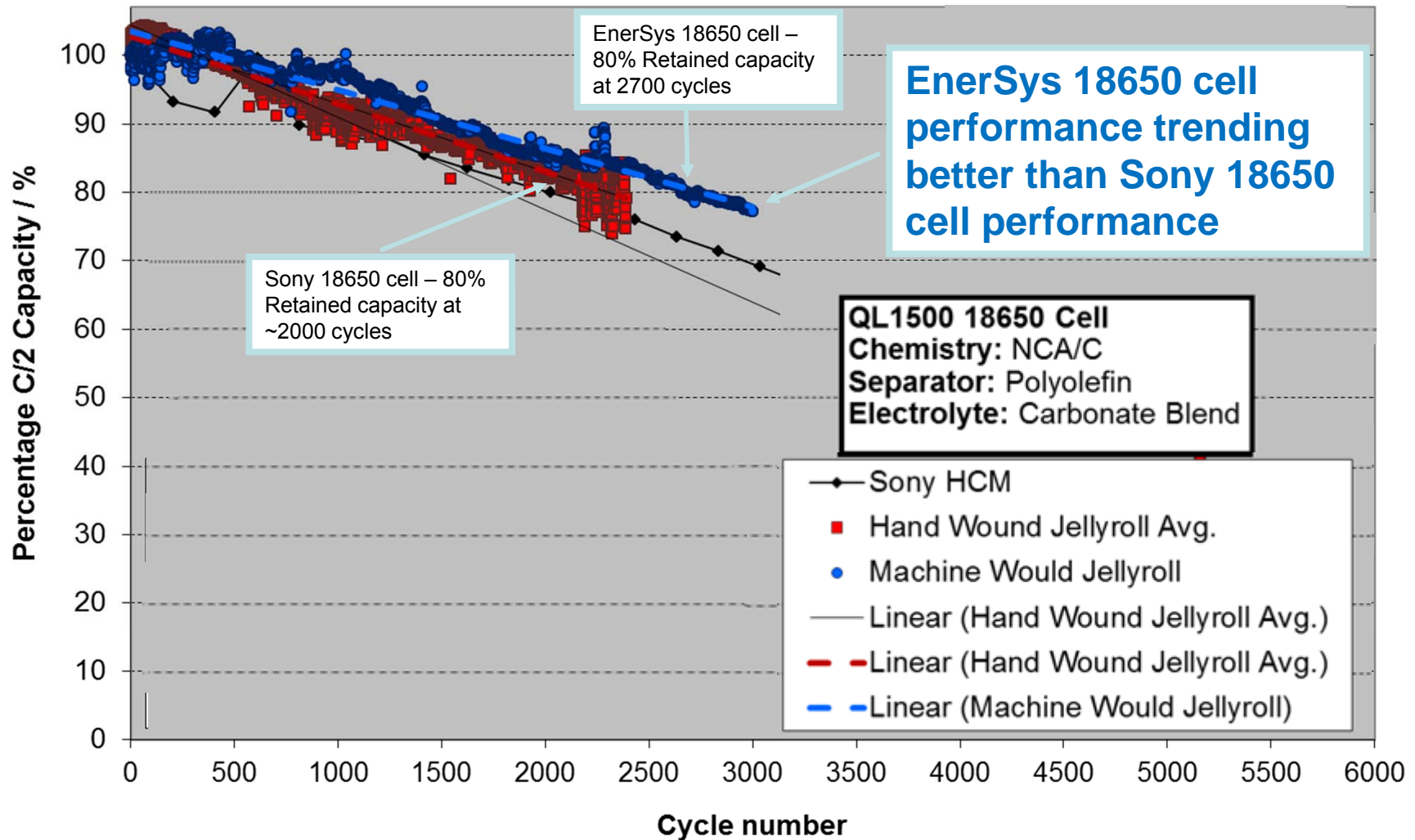


Cycling to 100% DOD



Charge : C/2A, 4.1V CCCV C/20 mA cutoff at RT
Discharge : C/2A to 2.7V at RT

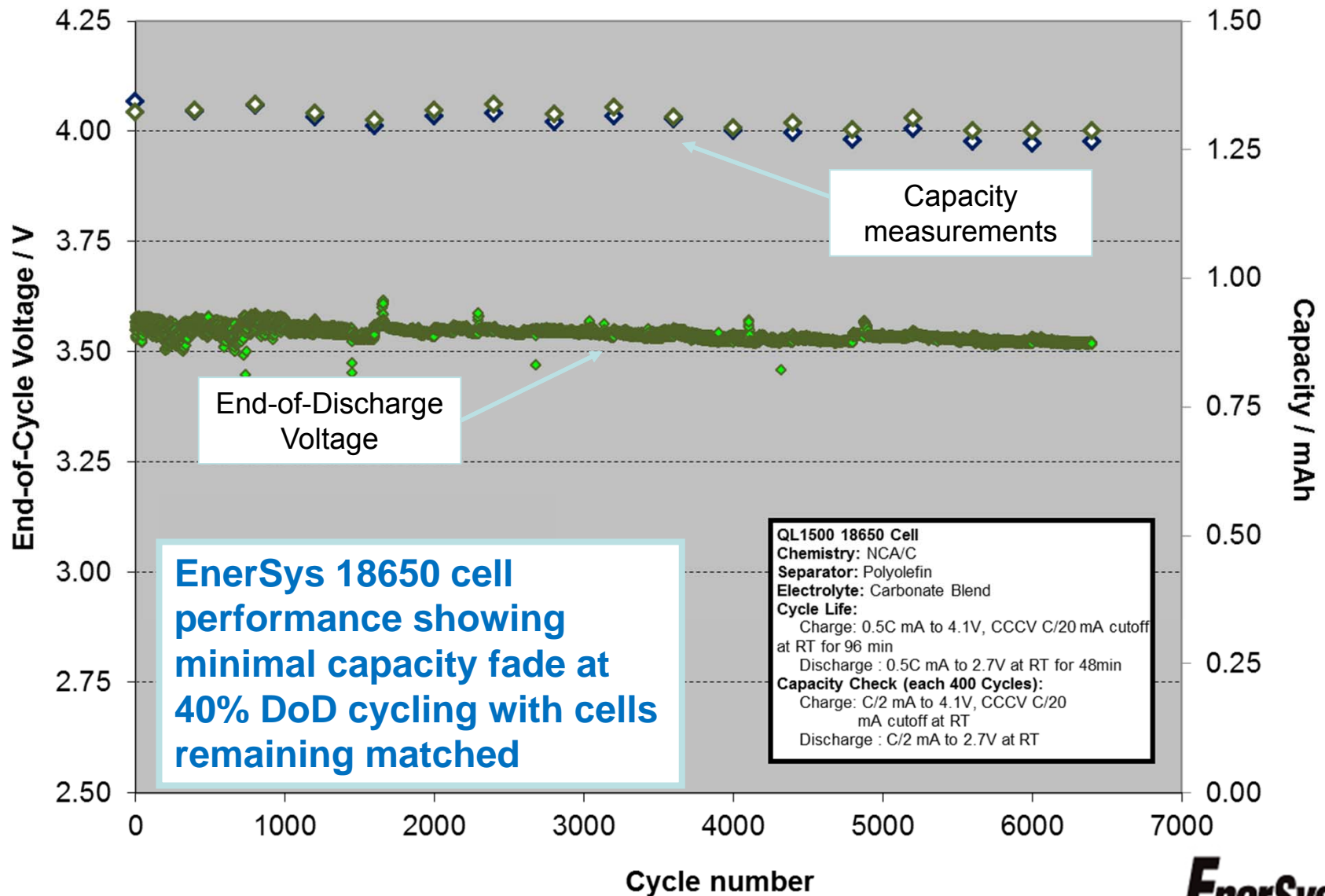
100% DOD Comparison



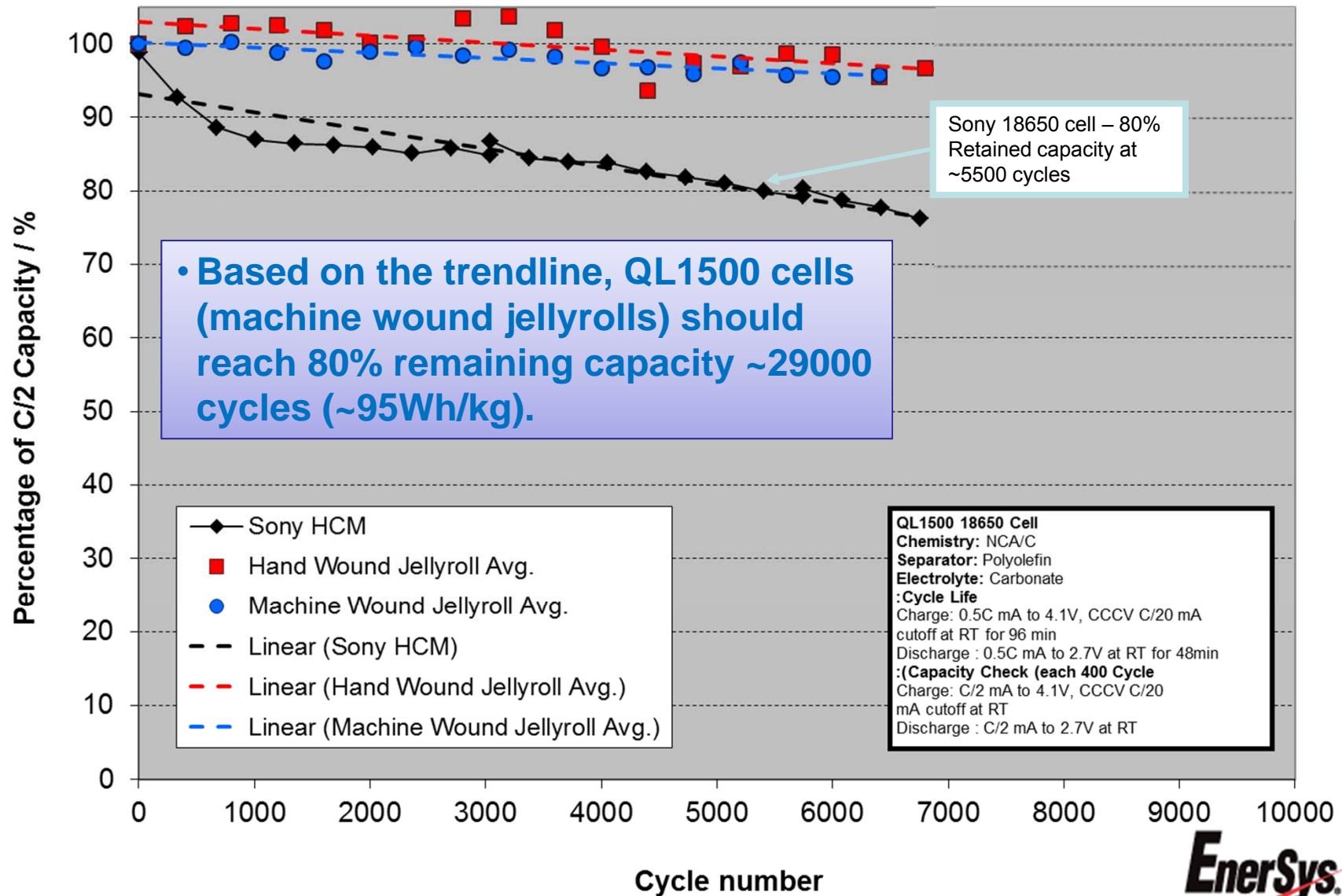
Charge : C/2A, 4.1V CCCV C/20 mA cutoff at RT
Discharge : C/2A to 2.7V at RT



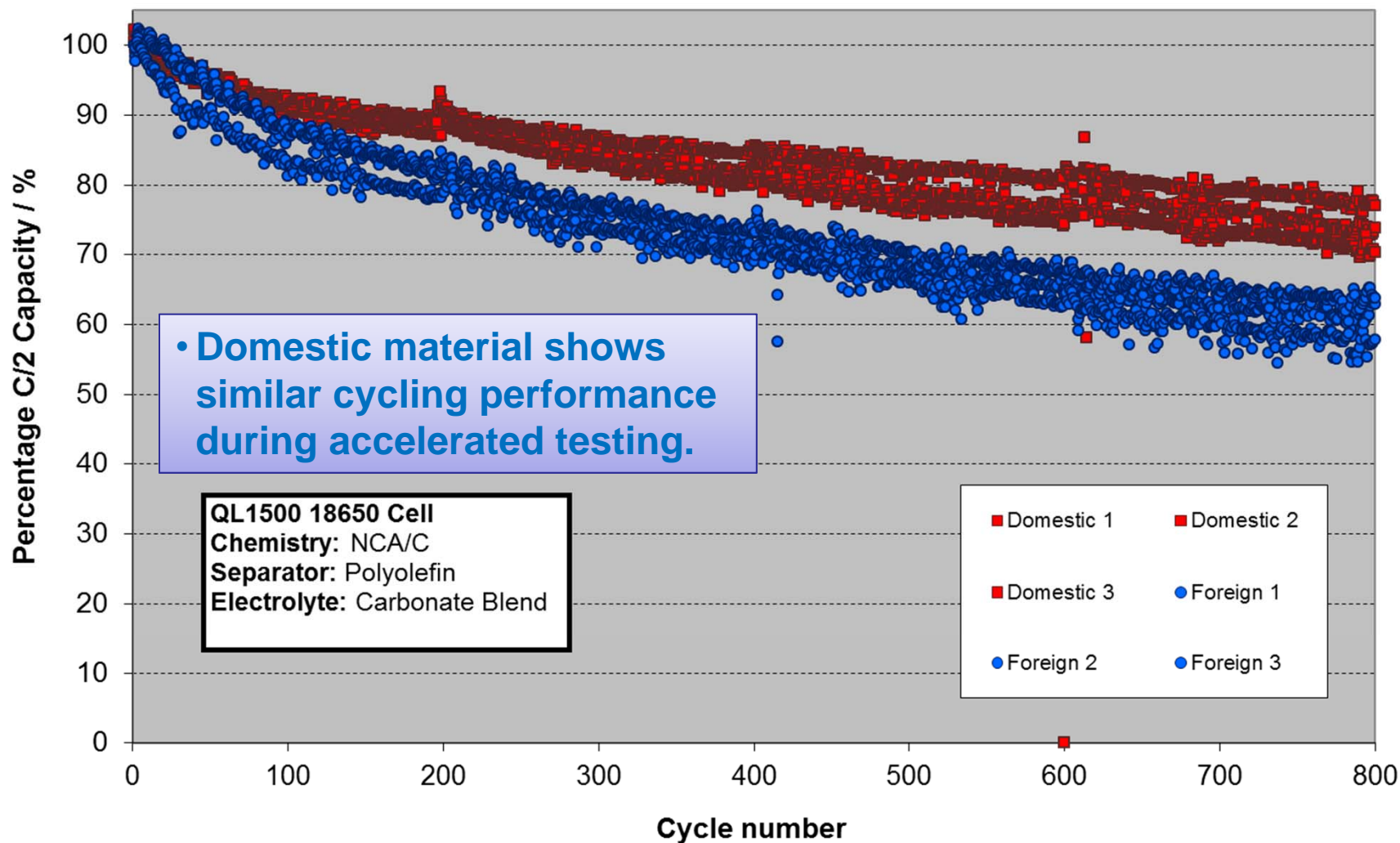
Cycling to 40% DOD



40% DOD Comparison



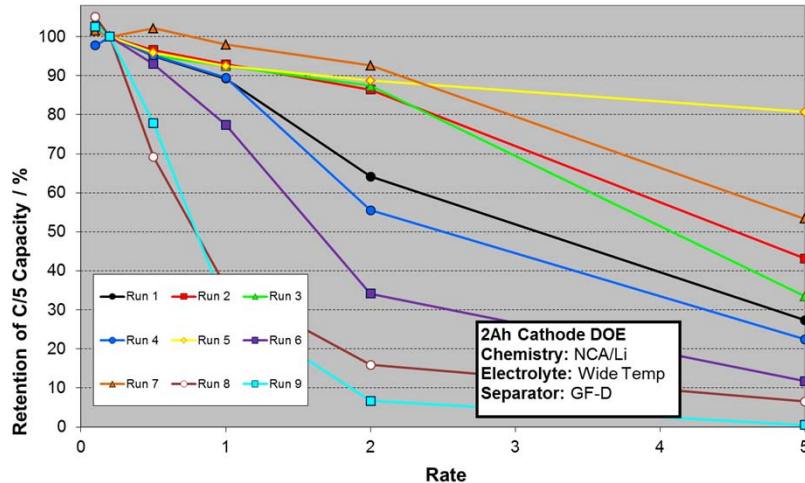
Initial Domestic vs. Foreign Material Testing



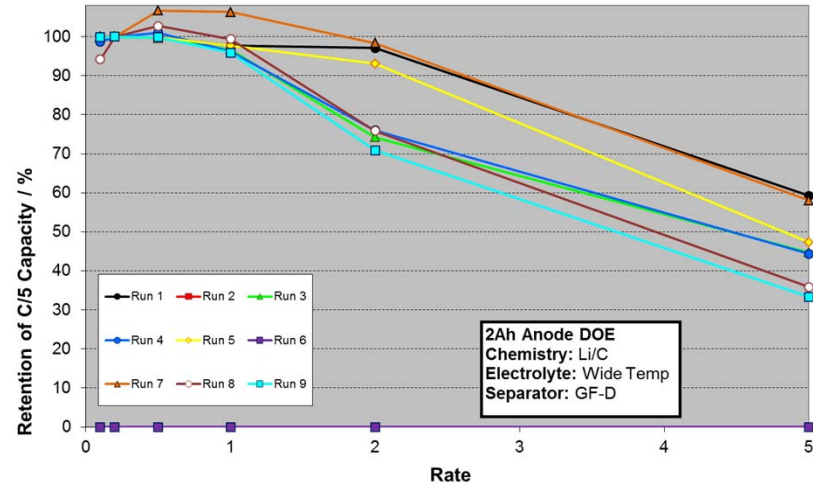
Charge : 1CA, 4.2V CCCV C/20 mA cutoff at RT
Discharge : 1CA to 2.7V at RT

CELL DEVELOPMENT/IMPROVEMENT OVERVIEW

Future 18650 Cell Development



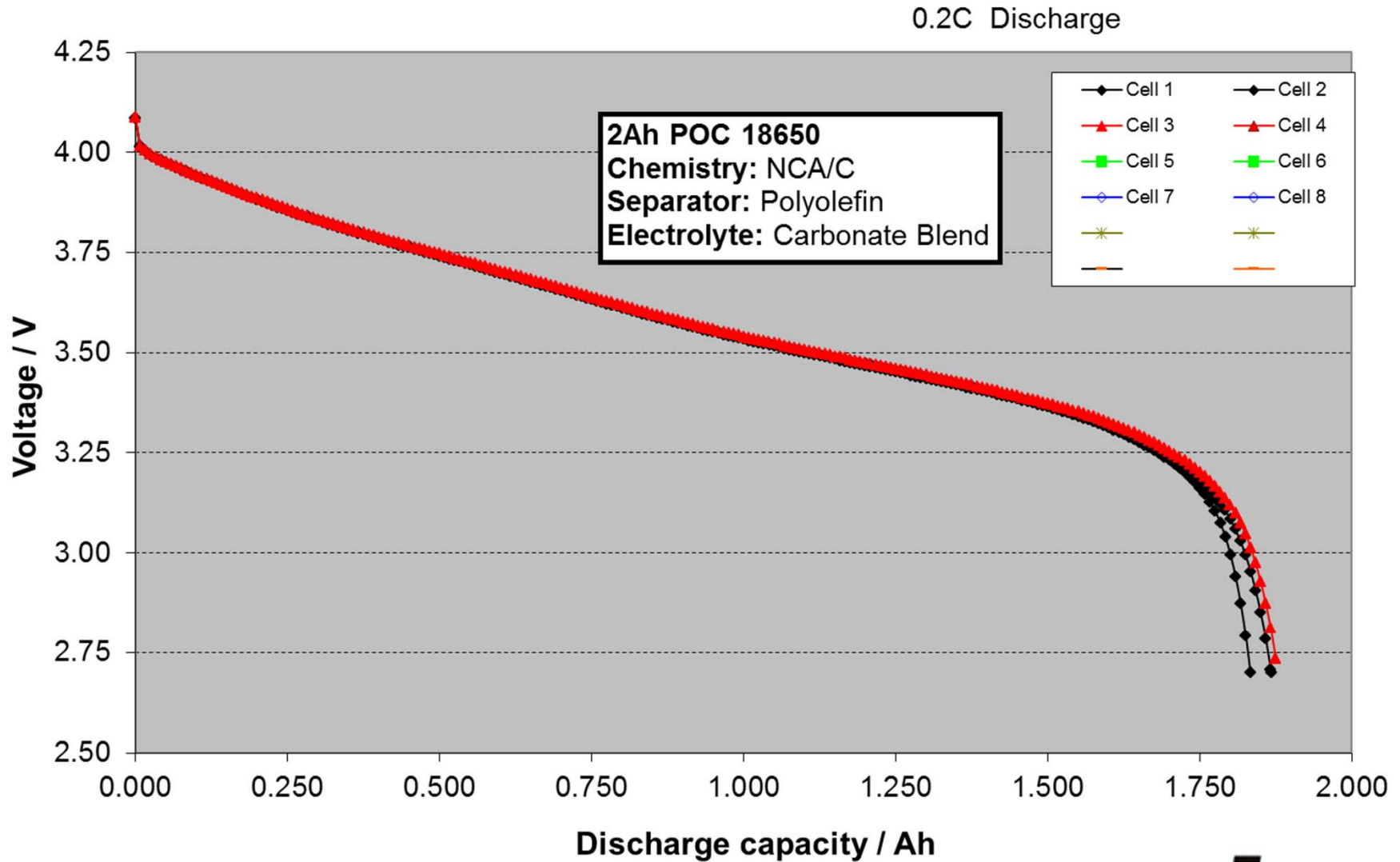
Charge : 0.2C mA, 4.1V CCCV C/20 mA cutoff at RT
Discharge : 0.05, 0.1, 0.2, 0.5, 1, 2, 5C A to 2.7 V at RT



Charge : 0.2C mA, 4.1V CCCV C/20 mA cutoff at RT
Discharge : 0.05, 0.1, 0.2, 0.5, 1, 2, 5C A to 2.7 V at RT

- Electrode development DOE's for new cathode and anode electrode formulations were performed.
- Coin cell testing for various formulations was tested.
- Formulations were analyzed based on rate capability (results shown above), adhesion, cycles to 70% retained capacity, and capacity retention at 100 cycles.

1C Discharge Rate of Developmental 2Ah Cell



Charge : C/2, 4.1V CCCV C/20 mA cutoff at RT
Discharge : C/2 to 2.7 V at RT

Summary

- **Domestic 18650 line has been installed giving complete vertical integration from raw material to pack manufacture.**
- **Prototype Cycle Life**
 - **At 3000 cycles to 100% DOD, cells still deliver >75% of their initial capacity (test ongoing) at $25^{\circ} \pm 5^{\circ}\text{C}$.**
 - **After 6400 cycles to 40% DOD, cells have shown no significant degradation in end-of-discharge voltage, or capacity (test ongoing) at $25^{\circ} \pm 5^{\circ}\text{C}$.**
- **Long life cell qualification is in process. UN 38.3, IEC 62133, and UL 1642 have been completed.**
- **Initial 2Ah cell design is undergoing testing. Based on results, design improvements will be investigated.**