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
Four Domestic EAS Battery Engineering Locations Serving Six Markets

### 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

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

- ABSSL
- ARMASAFE
- Cyclon
- EAS
- HAWKER
- Quallion
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
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**

**Materials**
- Critical anode and cathode raw materials – production and analysis
  - Sylmar, CA
  - Santa Clarita, CA

**Cells**
- High-performance custom cells in wound, stacked-plate, prismatic, pouch, and 18650 formats from 1 to +100,000/year
  - Sylmar, CA

**Electronics**
- Custom engineered electronics for battery management and system interface
  - Sylmar, CA

**Battery Pack**
- Complete cell packs engineered, manufactured and tested for any high-performance application
  - Sylmar, CA
  - Longmont, CO
  - Culham, UK

> 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

- Filling Station
- Top Tab Weld and Taping Station
- Final Crimp Station
Formation and Sorting Equipment

- OCV/ACIR Tester
- Dry Room to Cell Formation Area pass-thru window for completed cells
- Rank and Sorter
- Formation Equipment
TEST CELL AND TESTING REGIME
Quallion Long Life 18650 Cell

Cell Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Capacity / mAh</td>
<td>1400 ± 50</td>
</tr>
<tr>
<td>Nominal Voltage / V</td>
<td>3.6</td>
</tr>
<tr>
<td>Weight / g</td>
<td>42.6 ± 0.5</td>
</tr>
<tr>
<td>Specific Energy / Wh/kg</td>
<td>118</td>
</tr>
</tbody>
</table>

• 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° ± 5°C
  - **Discharge**: C/2 to 2.7V at 25° ± 5°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° ± 5°C
  - **Discharge**: C/2 to 2.7V or 48 minutes at 25° ± 5°C
  - **Repeat**: 400 Cycle increments; Capacity check each 400 cycles

- For all testing 1C = 1500mA; RT = 25° ± 5°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

Both the 1.5Ah 18650 and 72Ah prismatic cells show similar discharge curves at a C/2 rate

Charge: C/2 mA, 4.1V CCCV C/20 mA cutoff at RT
Discharge: C/2 mA to 2.7 V at RT
Cycling to 100% DOD

QL1500 18650 Cell
Chemistry: NCA/C
Separator: Polyolefin
Electrolyte: Carbonate

80% Retained Capacity at 2700 Cycles

Charge: C/2A, 4.1V CCCV C/20 mA cutoff at RT
Discharge: C/2A to 2.7V at RT
Based on the trendline, QL1500 cells (machine built jellyrolls) 80% remaining capacity reached at approximately 2700 cycles (~95Wh/kg).

EnerSys 18650 cell – 80% Retained capacity at 2700 cycles

EnerSys 18650 cell performance trending better than Sony 18650 cell performance

QL1500 18650 Cell
Chemistry: NCA/C
Separator: Polyolefin
Electrolyte: Carbonate Blend

Sony 18650 cell – 80% Retained capacity at ~2000 cycles

Charge: C/2A, 4.1V CCCV C/20 mA cutoff at RT
Discharge: C/2A to 2.7V at RT
Cycling to 40% DOD

EnerSys 18650 cell performance showing minimal capacity fade at 40% DoD cycling with cells remaining matched.

- **End-of-Discharge Voltage**
- **Capacity measurements**

**QL1500 18650 Cell**
- **Chemistry:** NCA/C
- **Separator:** Polyelefin
- **Electrolyte:** Carbonate Blend

**Cycle Life:**
- **Charge:** 0.5C mA to 4.1V, CCCV C/20 mA cutoff at RT for 96 min
- **Discharge:** 0.5C mA to 2.7V at RT for 48 min

**Capacity Check (each 400 Cycles):**
- **Charge:** C/2 mA to 4.1V, CCCV C/20 mA cutoff at RT
- **Discharge:** C/2 mA to 2.7V at RT
• Based on the trendline, QL1500 cells (machine wound jellyrolls) should reach 80% remaining capacity ~29000 cycles (~95Wh/kg).
Initial Domestic vs. Foreign Material Testing

- Domestic material shows similar cycling performance during accelerated testing.

QL1500 18650 Cell
Chemistry: NCA/C
Separator: Polylefin
Electrolyte: Carbonate Blend

% C/2 Capacity vs Cycle number

Charge: 1CA, 4.2V CCCV C/20 mA cutoff at RT
Discharge: 1CA to 2.7V at RT
CELL DEVELOPMENT/IMPROVEMENT
OVERVIEW
• 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

2Ah POC 18650
Chemistry: NCA/C
Separator: Polyolefin
Electrolyte: Carbonate Blend

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° ± 5°C.
  – After 6400 cycles to 40% DOD, cells have shown no significant degradation in end-of-discharge voltage, or capacity (test ongoing) at 25° ± 5°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.