   

Advanced ZeroVolt Lithium-Ion Technology

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Overview

- This presentation will provide an update to the performance testing of the EnerSys/Quallion large prismatic ZeroVolt chemistry cells under test at NAVSEA Crane.
- Testing is being performed at the individual cell level and at a battery module level.
- Testing being performed is Real-Time GEO, Real-Time HEO, 40% DoD LEO, and 30% DoD LEO cycling.
- Cells underwent qualification level vibration testing prior to electrical testing

Test Cells

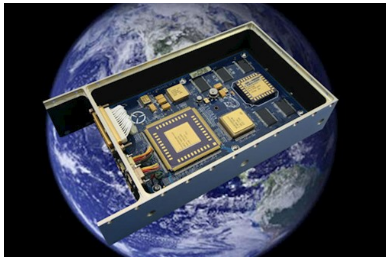
- **Testing is being performed on the EnerSys/Quallion 72Ah baseline cell (capacity as defined by Quallion, 3.0V to 4.1V)**
- **Cells were manufactured using Quallion domestically produced electrode materials from the Quallion Santa Clarita manufacturing facility**
- **Anodes consist of Meso-Carbon Microbead graphite material**
- **Cathodes consist of Nickel Cobalt Aluminum (NCA) material**
- **Cell incorporate ZeroVolt technology enabling the cell to be fully discharged to a 0V potential**

Why ZeroVolt Technology

ZeroVolt technology allows one to discharge the cell/battery to a 0V potential and hold the cell/battery there for an extended period-of-time without causing degradation to the electrical performance

Being capable of discharging to a 0V state without performance degradation provides in-orbit resiliency and increased mission flexibility.

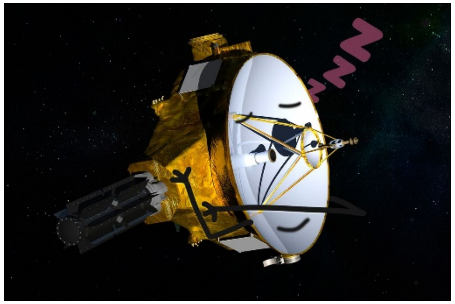
Satellite Computer Issue
Cyber Attack



Dead-Bus Failure

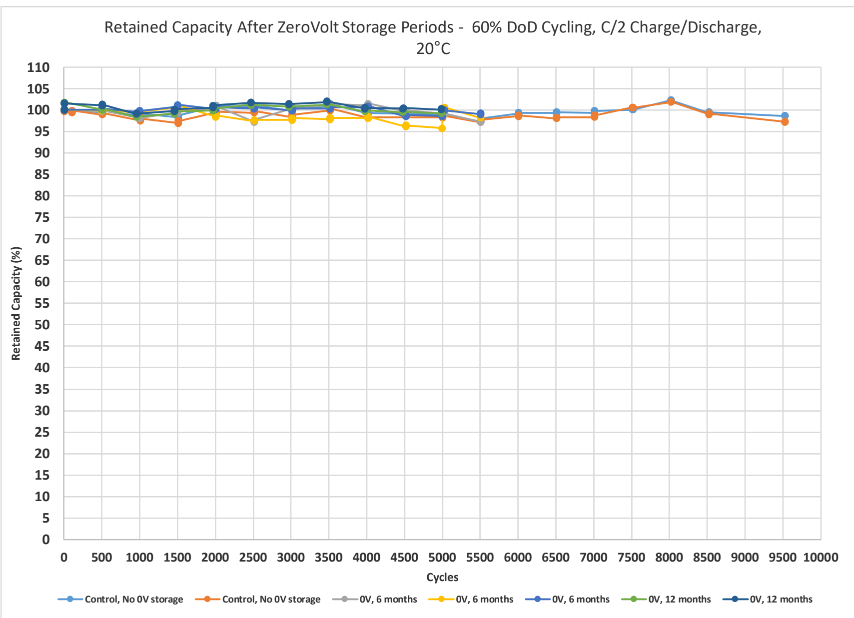
In-Orbit Servicing

Satellite Hibernation

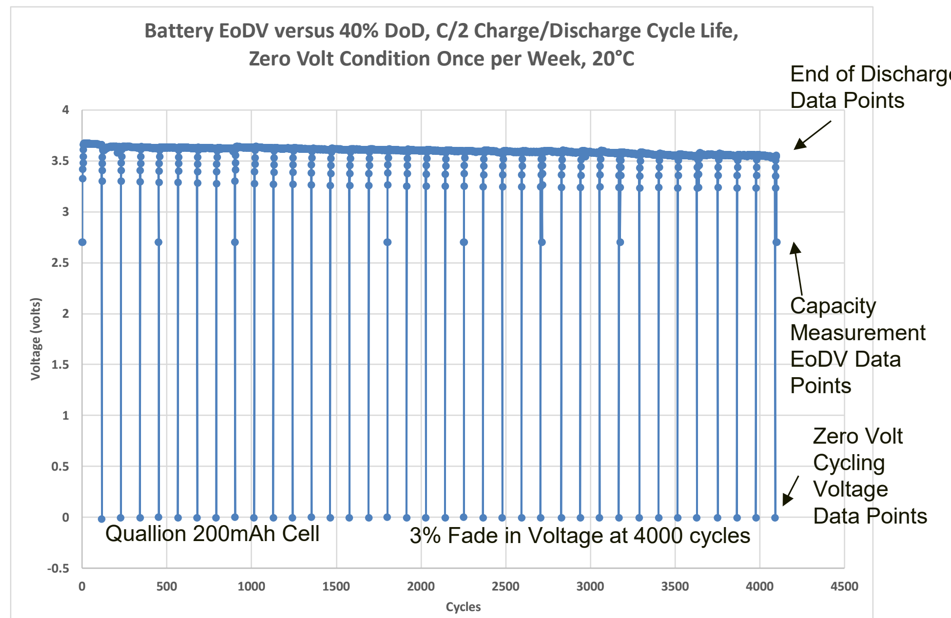


ZeroVolt Technology Performance

Extended 0V storage



Repeated 0V cycling

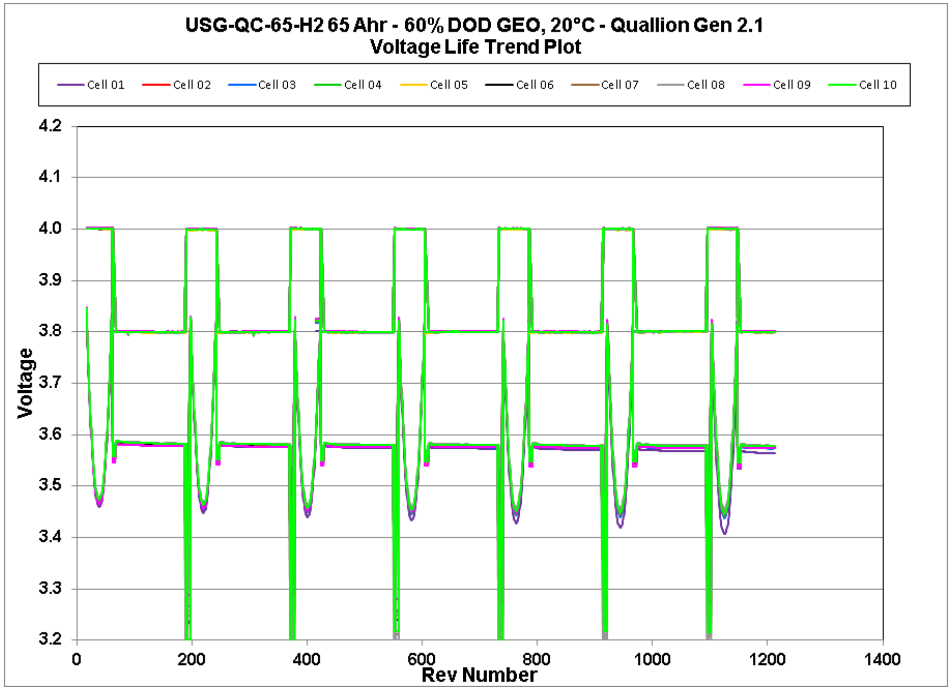


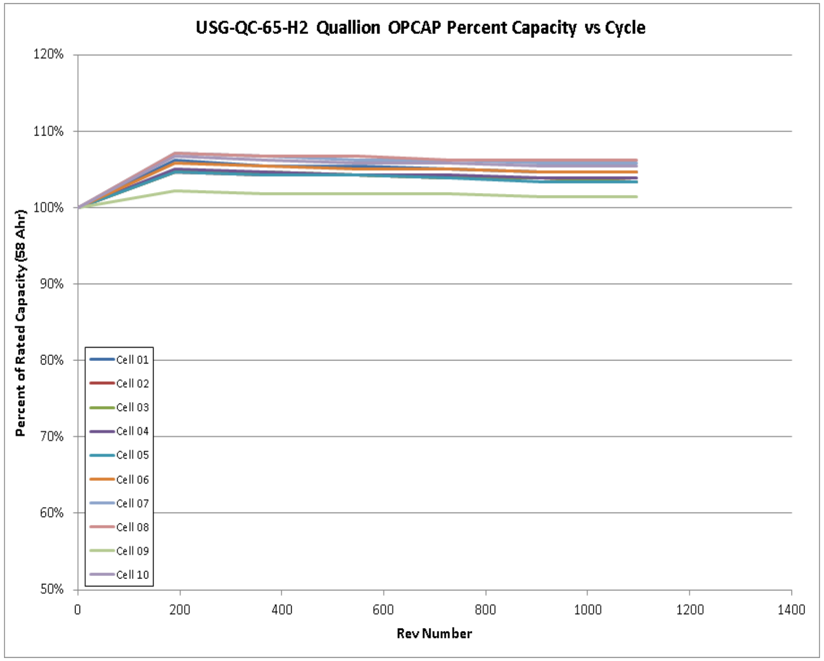
Real-Time GEO Testing

- **Testing is performed on a 10-cells at 20°C**
- **Individual cell voltage and temperature monitoring is performed**
- **Testing was reaching the 8th eclipse cycle as of April 2020**
- **Real-Time GEO testing is using the following cycling profile.**
  - 2 - 45-day eclipse periods per year with maximum DoD of 60%
  - 2 - 37.5-days solstice periods per year with module voltage set to a value associated with 60% SOC
    - During solstice periods, weekly 2.4-hour discharges (30%) to simulate periodic station-keeping needs
  - Operational Capacity (OPCAP) measurements are performed on day 131 of each solstice period over a voltage range of 3.0V EoDV to 4.0V EoCV.
    - Cell resistance is measured during each OPCAP using a 10-second current change from C/2 to C/10.

Real-Time GEO Testing

- Individual cell voltage monitoring shows matched cell performance during the cycling periods.
- Slight decay in EoDV ~30mV at eclipse period 7
- Showing stable capacity performance finishing year 4 cycling



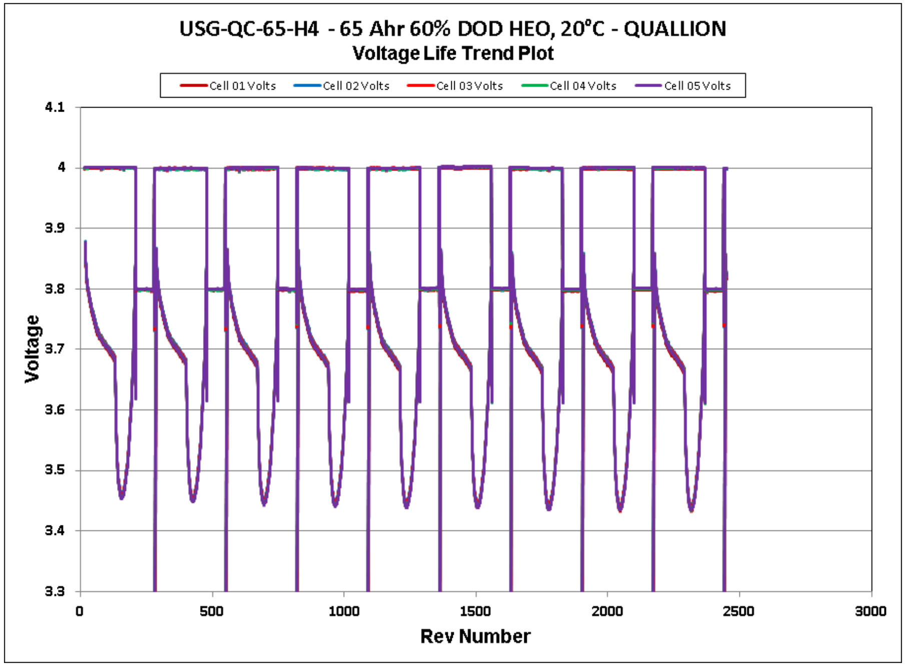


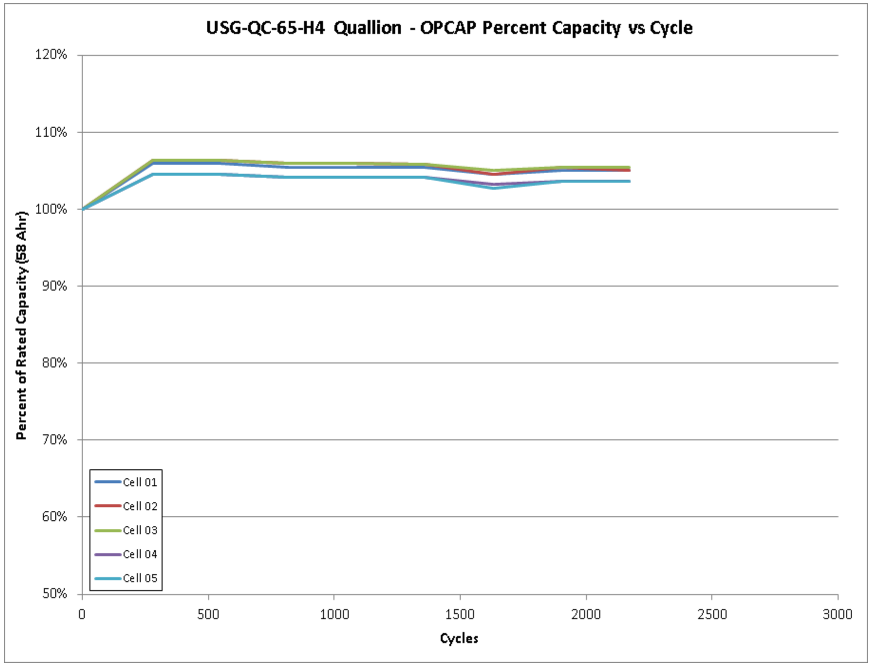
Real-Time HEO Testing

- **Testing is performed on a 5-cells at 20°C**
- **Individual cell voltage and temperature monitoring is performed**
- **Testing was reaching the 10th eclipse cycle as of April 2020**
- **Real-Time HEO testing is using the following cycling profile.**
  - 3 - 96-day eclipse periods per year with maximum DoD of 60%
  - 2 - 39-days solstice periods per year with module voltage set to a value associated with 60% SOC
  - Operational Capacity (OPCAP) measurements are performed on day 37 of the solstice period over a voltage range of 3.0V EoDV to 4.0V EoCV.
    - Cell resistance is measured during each OPCAP using a 10-second current change from 0.545C to C/10.

Real-Time HEO Testing

- Individual cell voltage monitoring shows matched cell performance during the cycling periods.
- Slight decay in EoDV ~20mV at eclipse period 9
- Showing stable capacity performance finishing year 3 cycling



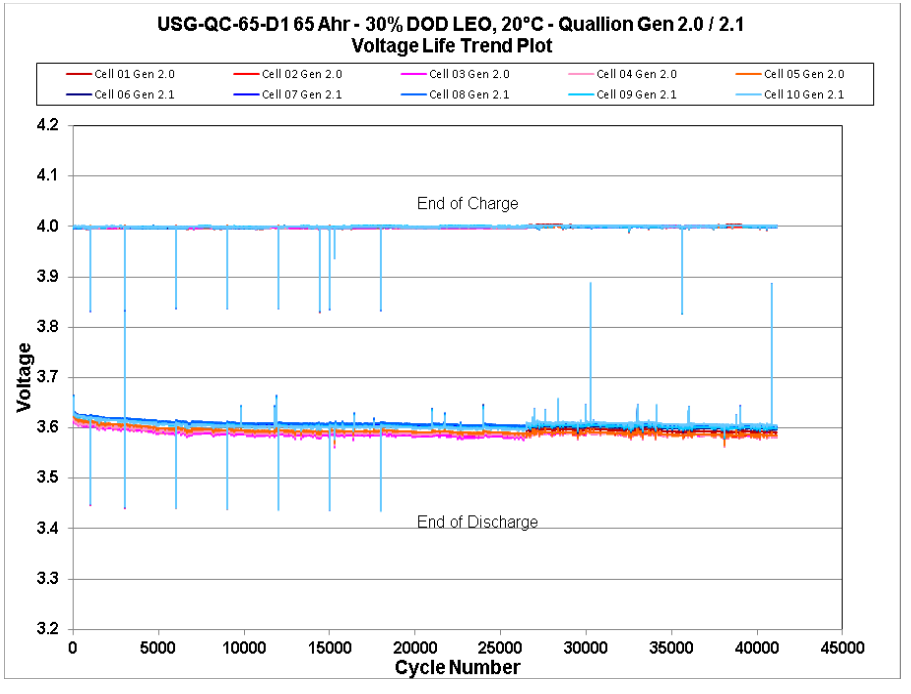


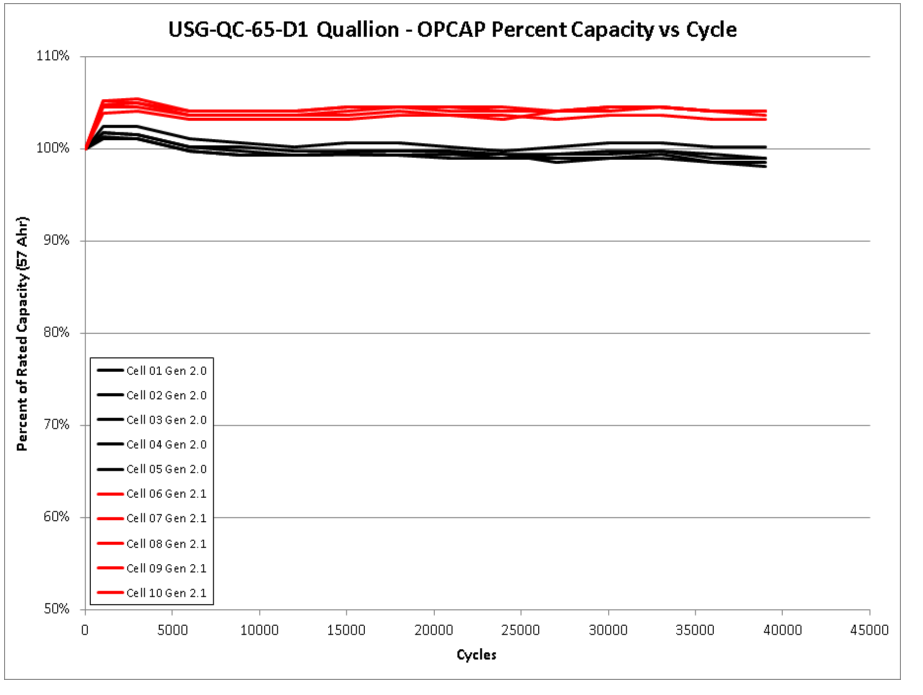
Real-Time 30% DoD LEO Testing

- **Testing is performed on 5-Gen 2.0 cells and 5-Gen 2.1 cells at 20°C**
  - This test set included 5-cells with the latest anode material (Gen 2.1)and 5-cells using the previous anode material (Gen 2.0). Gen 2.1 material was created due to unavailability of Meso-Carbon Graphitized Fiber (MCGF) material
- **Individual cell voltage and temperature monitoring is performed**
- **30% LEO testing is using the following cycling profile.**
  - 96-minute orbit with 35-minute eclipse period
    - 0.514C discharge, 0.332 recharge
  - Operational Capacity (OPCAP) measurements are performed at cycle 1, 500, 1,000, 2,000, and every 3,000 cycles thereafter
    - Measured between 3.0V EoDV and 4.0V EoCV
    - Cell resistance is measured during each OPCAP using a 10-second current change from C/2 to C/10.

30% LEO Testing

- Individual cell voltage monitoring shows matched cell performance during the cycling periods.
- Flat EoDV performance at ~41,000 cycles
- Showing stable capacity performance at ~ 7.5 years cycling



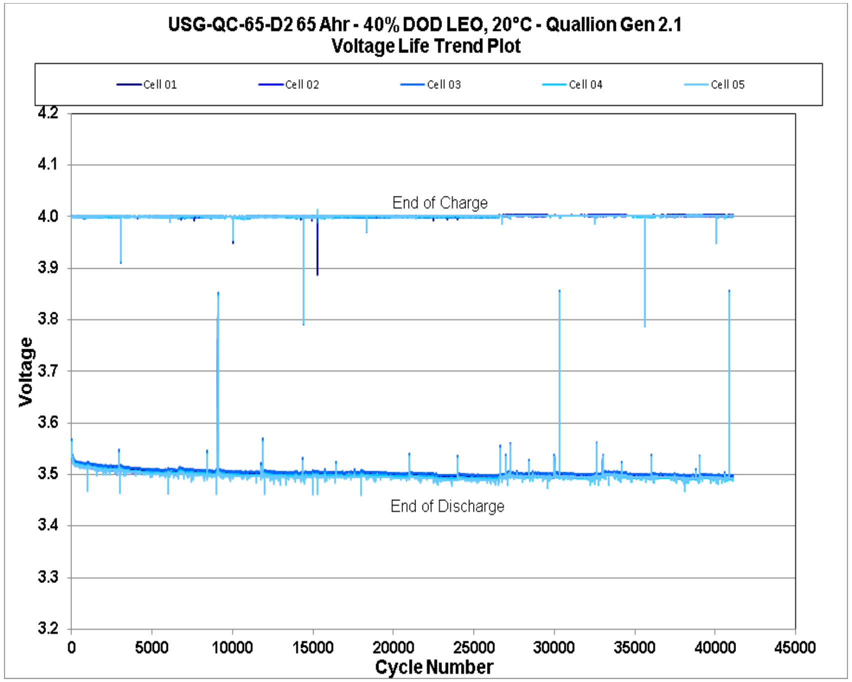


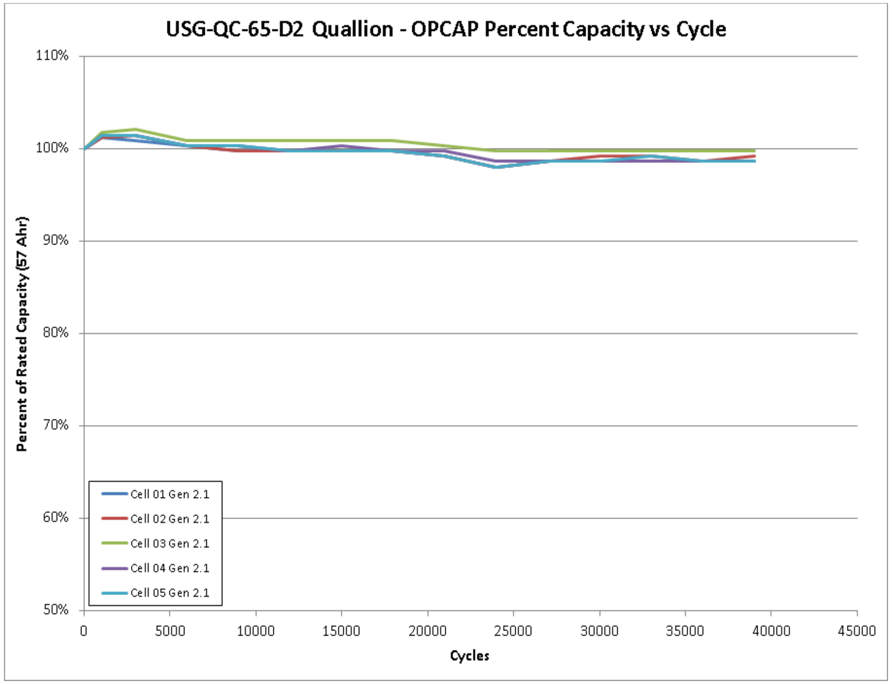
Real-Time 40% DoD LEO Testing

- **Testing is performed on 5-Gen 2.1 cells at 20°C**
- **Individual cell voltage and temperature monitoring is performed**
- **40% LEO testing is using the following cycling profile.**
  - 96-minute orbit with 35-minute eclipse period
    - 0.686C discharge, 0.443 recharge
  - Operational Capacity (OPCAP) measurements are performed at cycle 1, 500, 1,000, 2,000, and every 3,000 cycles thereafter.
    - Measured between 3.0V EoDV and 4.0V EoCV
    - Cell resistance is measured during each OPCAP using a 10-second current change from C/2 to C/10.

40% LEO Testing

- Individual cell voltage monitoring shows matched cell performance during the cycling periods.
- Flat EoDV performance at ~39,000 cycles
- Showing stable capacity performance at ~ 7.1 years cycling





Summary

- **EnerSys/Quallion ZeroVolt chemistry allows for discharges to a 0V potential without performance degradation**
- **EnerSys/Quallion ZeroVolt chemistry provides for long life operation with minimum capacity fade due to cycling.**
  - Real-Time GEO testing data demonstrates minimum capacity fade over 4-years of cycling with testing on-going.
  - Real-Time HEO testing data also demonstrates minimum capacity fade over 3.7 years of cycling with testing on-going
  - 30% LEO testing data demonstrates minimum capacity fade at 41,000 cycles or ~ 7.5 years.
  - 40% LEO testing data demonstrates minimum capacity fade at 39,000 cycles or ! 7.1 years.

Thank You!!!

For questions or comments, contact:
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