ACKNOWLEDGMENTS

- Funded by the Energy Storage Systems Program of the U.S. Department Of Energy (DOE/ESS) through Sandia National Laboratories (SNL).
The Cyclon valve regulated lead-acid (VRLA) battery (25 Ah Cell) invented by the Gates Corp. and manufactured by EnerSys is a cylindrically wound battery made from a high purity lead/tin grid alloy, which improves power, cycle-life, float-life, and increases the operational temperature range.

Sandia’s Power Sources Component Development Dept. tested this battery using a modified Battery Council International (BCI) and supercapacitor test procedure.

Sandia was interested in this battery because:
- the manufacturer’s high cycle-life of 5,000 cycles at 10% DOD at 25°C,
- high temperature performance, and
- as a possible low cost replacement for supercapacitors.
Modified BCI Test Procedure

  - Immerse in 46°C water bath
  - 0.2C (4.9A) discharge/charge rate
  - Fixed discharge/charge time at slightly over 30 minutes
  - Finish-charge every 100 cycles, 12 h at 2.47 vpc (14.85V)
  - Capacity test at 0.2C rate after each finish-charge
  - End-of-life at 80% initial capacity
Cyclon VRLA Battery Under Test
BCI Cycle-Life Test
Cycle Profile

Cyclon Cycle-Life Test
Cycle #5

Volts

Current

Time (hh:mm:ss)

Cell Volts

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End-of-Discharge Cell Voltage

Cyclon Lead-Acid Battery Cycle-Life Test
End-of-Discharge Cell Volts

Volts

Temperature C

Cycle Number

Water Bath Temp

EODCV (Cycle 100)

22.99 Ah

23.30 Ah

23.26 Ah

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Cycle-Life Test Results

Cyclon Lead-Acid Battery BCI Cycle-Life Test
Test Temperature = 46°C

- Battery Capacity (100% DOD)
- End-of-Discharge Cell Volts (10% DOD)
- Load Fault

Manufacturer End-of-Life Specifications
- 819 10% DOD cycles at 46°C = 5,000 cycles at 25°C
- 46 100% DOD cycles at 46°C = 300 cycles at 25°C
Projected Cyclon Deficit-Charge Cycle-Life

Cyclon VRLA Battery
BCI Cycle-Life Vs. Temperature

Projection Based on 1/2 cycle-life for every 8°C above 25°C

10% DOD
Projected

10% DOD
Manufacturer's Specifications

10% DOD
Measured
The measured deficit-charge cycle-life has exceeded the manufacturer’s specifications by about a factor of seven

- Manufacturer’s temperature adjusted cycle-life at 46C is 816 cycles
- Measured 6,100 deficit-charge cycles and 58 deep-cycles at 46C
- Capacity loss was less than 14% (24.51 Ah initial to a low of 21.06 Ah), but it also recovered to 23 Ah after 6,100 cycles.
- A 5% increase in load current at cycle 5,000 caused a full discharge after 100 deficit-charge cycles. Battery recovered without damage.
High Power Supercapacitor Cycle-Life Test

- **Modified Sandia supercapacitor cycle-life test procedure**
  - Immerse in 22°C water bath
  - 5.6C (140A) discharge for 65 sec. (2.5 Ah)
  - 5 minute rest
  - 5C (125A) charge for 94 sec. to 2.57 vpc (15.4V)
  - 5 minute rest
  - Finish-charge every 100 cycles, 12 h at 2.5 vpc (15.0V) at 22C
  - Capacity test at 0.2C rate after each finish-charge
Cyclon High Power Cycle Profile

Cyclon High Power Test
Cycle #38

Time (hh:mm:ss)
Volts
Current
Cell Volts

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End-of-Discharge Cell Voltage

Cyclon Lead-Acid Battery High Power Cycle-Life Test
End-of-Discharge Cell Volts

- **Cycle Number**: 1800 to 2300
- **Volts**: 1.00 to 2.00
- **Temperature C**: 20 to 70
- **Cell Volts**
- **Cell Temp**
- **Water Bath Temp**
- **22.8 Ah**
- **22.8 Ah**
- **22.6 Ah**
- **22.4 Ah**
- **EODCV Cycle 100**
Cyclon High Power Cycle Results

Cyclon High Power Cycle Test
Exterior Cell Temperature = 38°C

Battery Capacity (100% DOD)

End-of-Discharge Cell Volts (10% DOD)

Recovered Cell Voltage

Ah

Volts

Cycle Number

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The Cyclon battery maintained relatively stable capacity after 2,100 cycles.

Exterior cell temperature stabilized at about 16°C (38°C) above the 22°C water bath temperature.

At about 800 cycles the capacity increased to 24.96 Ah from a low of 22.74 Ah. This increase in capacity is most likely due to the recovery in End-of-discharge Cell Voltage of two low voltage (low capacity) cells.
Summary

- The Cyclon battery exceeded the manufacturer’s specifications for cycle-life by a factor of seven using deficit-charge cycling (from 816 to over 6,100 cycles).
- Using the manufacturer’s temperature vs. cycle-life relationship of, \( \frac{1}{2} \) cycle-life for every 8°C above 25°C, the projected deficit-charge cycle-life at 25°C should be over 37,000 cycles.
- High power cycling at the 5.0C charge and 5.6C discharge rate indicated that the battery could handle high power applications if the required cooling and/or cycle profile was used.
- At about $0.64 per Watt-hour the Cyclon VRLA battery could be very competitive in some high power applications where supercapacitors or oversized VRLA batteries would normally be used.