SUMMARY REPORT

TEST RESULTS OF APOLLO ENERGY SYSTEMS' TPX1 AND GC1 LEAD COBALT SECONDARY BATTERIES BATTERY DESIGNED AND PRODUCED BY: APOLLO ENERGY SYSTEMS, INC.

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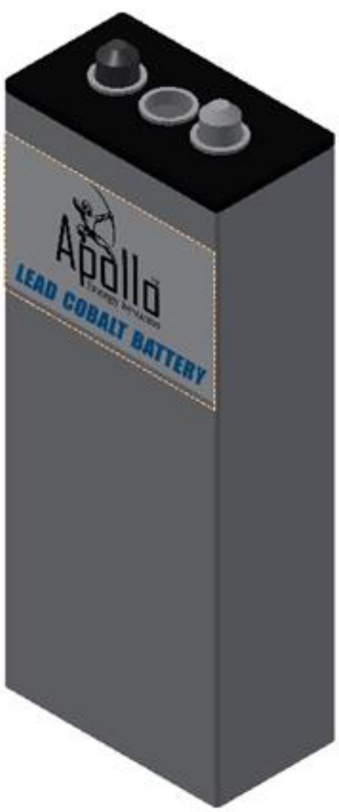
Introduction.
Apollo Energy Systems, Inc. (AES) is an established research & development company, which is catering technology development services in the areas of lead acid batteries and alkaline fuel cells. AES' advanced lead cobalt battery technology belongs to the broad class of SLI (automotive) lead acid batteries. It uses lead dioxide as active material of the positive electrode, metallic lead in the porous form as active material of the negative plate, and an electrolyte based on sulfuric acid. The company operates a pilot facility where the full scale prototypes denoted as TPX-1 (Figure 1) and GC1 (Figure 2) are fabricated.

In March 2017 AES has reported significant news for the industry sector, claiming that they were able to optimize the loadings of paste on the grids, and using a 2 Volt form-factored cell, observed the following preliminary performance results:

i. Capacity: 379.6 Ah vs. the spec value of 292 Ah (30% improvement over the state-of-the art baseline);
ii. Energy: 749.6 Wh vs. the spec value of 584 Wh (28.4% enhancement);
iii. Energy Density: 48.6 Wh/kg vs. the spec of 37.3 Wh/kg (30.3% better than the baseline).

The objective of American Energy Technologies Co. of IL (AETC) was to independently verify the results of promising tests conducted by AES. The starting hypothesis in AETC's case was that the TPX1 battery has a specific energy of approximately 45 Wh/kg, when fully charged. This battery has been through multiple cycles, but the verification test should still yield results of greater than 40 Wh/kg.



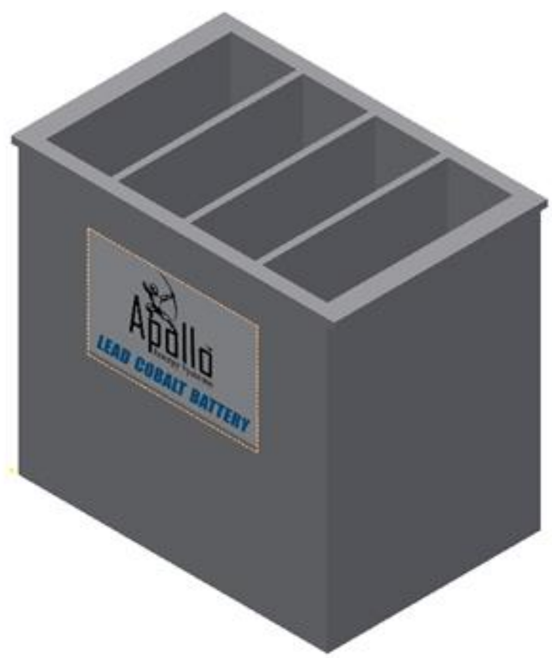


Figure 1. AES' TPX-1 battery. **Figure 2. AES' GC1 battery.**

1. THE ORIGINAL BATTERY TEST SCHEDULE
AES-manufactured battery cells on hand:
Cell #1: TPX-1 Battery 2-volt 6.25"L x 3.50" W x 15.00"H (see Figure 1);
Cell #2: 2V Cell in Tall Golf Cart Jar (GC1, see Figure 2). Cell Dimensions 2.5" L x 7" W x 10.5" H (one of four cells for an 8V x 4-cell golf cart battery, that has overall dimensions that follow: 10" L x 7" W x1 0.5" H.
Testing was to be witnessed by a representative of AETC.

Day 1. Morning

1. Cell #1 will be about 80% discharged with a sp. gr. of approximately 1100. Carry out further discharge for approximately 30-mins, measure final OCV and sp. gr. Put on charge at 20A.

2. Cell #2 is fully charged. Set up for data logging using *DataQ*. Set up TDI Load Bank for discharge at 50A and low voltage limit 1.0V. Include 50A shunt in circuit. Start Discharge. Use millivoltmeter to confirm current across the 50A shunt (1A= 1mV). Measure cell voltage directly across terminals with more than one voltmeter and sp. gr. with more than one hydrometer. Take measurements of voltage, sp. gr. and time at intervals of 10-min.

Day 1. Afternoon.

1. Finish discharge of Cell #2 when cell voltage reaches 1.50V. Continue to measure and record voltage for another 20-mins. Put cell on charge at 10A.

2. At the end of the afternoon, adjust current for Cell #1 Charging to 15A for overnight charge.

Day 2. Morning.

1. Take Cell #1 off charge, check sp. gr. Should be fully charged.

2. Set up Cell #1 for data logging using *DataQ*. Set up TDI Load Bank for discharge at 50A and low voltage limit 1.0V. Include 50A shunt in circuit. Start Discharge. Use millivoltmeter to confirm current across the 50A shunt (1A= 1mv). Measure cell voltage directly across terminals with more than one voltmeter and sp. gr. with more than one hydrometer. Take measurements of voltage, sp. gr. and time at intervals of 10-min.

Day 2. Afternoon.

1. Finish discharge of Cell #1 when cell voltage reaches 1.5V. Continue to measure and record voltage for another 20-mins. Put cell on charge at 15A.

2. Download data on both discharges into excel, plot discharges, make a copy and give it to AETC for processing and analysis.

2. Actual Test Procedure.

The verification of results was conducted by AETC's Derek Schaltz, who has worked on site at AES, using the discharge equipment provided on-site. The independent testing was overseen by Dr. Barry Iseard. Three tests were conducted between 4/20/2017 and 4/21/2017.

4/20/2017 (Day 1).

TPX1 Discharge 1

1. The DataQ cycling program was set up and the positive lead from the power supply was connected to the positive terminal of the TPX-1 battery. Please see the relevant DataQ record as a stand-alone enclosure to this report.
2. A 50 A, 50 mV shunt was added to check the current that is directly going to the terminals of the battery. This shunt was connected between the negative lead from the power supply and the negative terminal of the battery (Figure 3).
3. As soon as all of the leads were secured in place, the DataQ cycling program was started to measure the initial drop in voltage once the power supply was turned on.
4. The open circuit voltage (OCV) was checked just before 9:45 am EST, and the discharge was started at 9:45 am. Directly after, specific gravity was measured and it was confirmed that 49.9 A were going to the terminals using the shunt.
5. The points at 1, 5, and 15 minutes were plotted. Voltage was measured using DataQ and was checked with a voltmeter. After the initial measurements, individual points were plotted in 15 minute intervals. Temperature was also monitored infrequently on this first discharge.
6. Once discharged to 1.5 V (this is considered an industry standard deep cycling discharge cut-off voltage), the power supply was turned off, the time was recorded, and the voltage on the battery was allowed to recover for several minutes.
7. The charging current was then set to 20 A (Figure 4), and changed to 15 A for an overnight charge.

Figure 3. TPX1 with both the DataQ leads (small alligator clamps) and power supply leads (large alligator clamps) connected. The opening in the middle is for outgassing and measuring specific gravity and temperature.

In a parallel development, the dimensions of the TPX1 battery were measured, and they are shown below (Figure 6). The dimensions match those claimed by AES for their TPX-1 battery size format (see Section #1). Please note: the height of terminal lugs has not been factored as part of the overall cell dimensions.

Figure 4. The TPX-1 was set to charge at 20A.

3. Test Data of TPX-1.

The following data table (Table 1) contains the record of as measured and manually recorded performance output variables during the first discharge on 4/20/17. Specific gravity was measured only once at the beginning, and temperature was measured infrequently throughout the first discharge. The voltage data collected was then plotted against the discharge time (please refer to a galvanostatic discharge curve by Figure 7). Since DataQ measured voltage every 5 seconds, the data below and in the following sections is abbreviated to give an idea of how the battery voltage behaved over time, and is therefore by no means exhaustive.

The reason for running this short discharge was to confirm that the battery was fully drained before doing an overnight charge. As one can see in Figure 7, the voltage is already under 2V: based on the data provided in Table 1, the exact voltage at which the discharge began was 1.969 V. The initial voltage quickly dropped to 1.882 V, at which point the measured value on the curve rapidly dropped down to 1.500 V. The entire discharge took 46 minutes.

Figure 5. The power supply (second from the bottom) reads 50.0 A

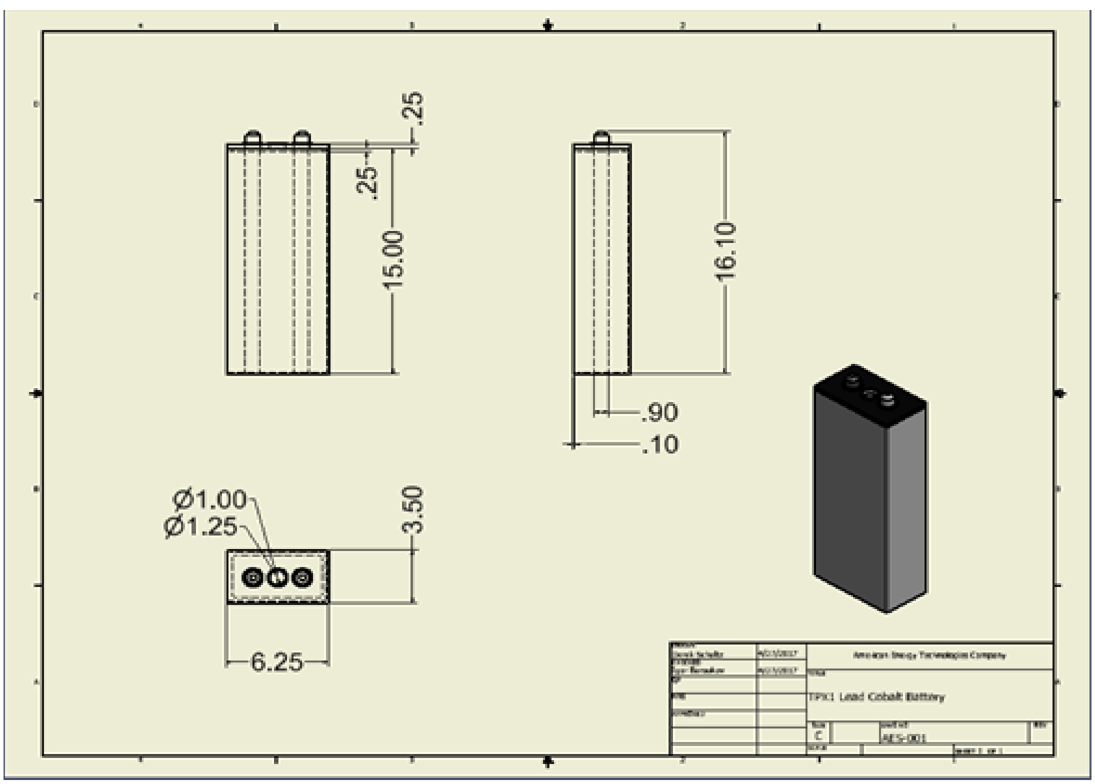


Figure 6. Dimensional drawing of Apollo Energy Systems' TPX-1 battery.
Note: all dimensions are in inches.

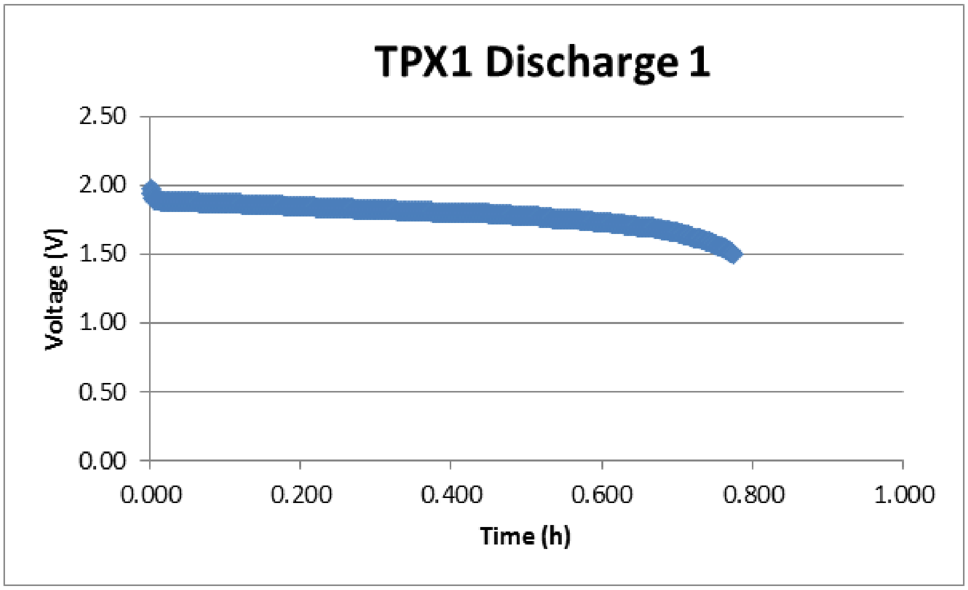


Figure 7. Galvanostatic discharge curve generated from the acquired data points within the DataQ, showing how voltage varied throughout the discharge of the TPX-1 battery.

Table 1. Manual record of the initial discharge with a TPX-1 battery (4/20/17).

Time elapsed (min)	Clock Time (military)	DMM Voltage (V)	DataQ Voltage (V)	Specific Gravity (kg/m^3)	Temperature (°C)	Comments
0	9:45	1.969	1.975	1,100		Voltage measured as open circuit voltage at Time=0; All other voltages were measured with a digital voltmeter.
1	9:46	1.882	1.882			
5	9:50	1.861	1.869			
15	10:00	1.829	1.835			
30	10:15	1.76	1.770		25	
45	10:30	1.546	1.565			
46	10:31		1.500		27	

4. GC1 Battery Discharge.

The procedure for the GC1 (golf cart battery module) discharge was the same as the TPX1, except the mere discharge process took longer (i.e. a total of 203 minutes). Data was recorded at slightly different time intervals, as seen in the data section (please refer to Table 2).

This battery also has a different form factor than the one of TPX-1. Specifically, a battery box is outfitted with slots that can house up to four (4) shorter cells (Figure 2), rather than a singular large cell in case of TPX-1 (Figure 1).

Tests were conducted with one cell (Figure 8) and the amount of energy the four cells would produce was calculated by multiplying a singular cell output by four (Table 3).

The only procedural change that was made at the end of this discharge was as follows: the battery was weighed containing electrolyte (Figure 9, left), then the electrolyte was emptied out and the battery was weighed again (Figure 9, right). These steps were used at a later stage for estimation of specific capacity and specific energy of GC1 battery.

Figure 8. Discharge of a GC1 battery (Day 1). The two alligator clamps are shown here. The shunt is connected to the negative clamp again and then the shunt and positive clamp are connected to the terminals.

Figure 9. Apollo Energy Systems' GC1 battery is being weighed on a scale after being discharged. The electrolyte was not drained from a singular compartment that was being tested (left). The battery was drained of electrolyte only and reweighed (right).

Weight is in Lbs.

5. Data from GC1 battery testing.

The following data log (Table 2) is the hand plotted data that was taken on 4/20/2017.

Table 2. Manual record of the initial discharge with a GC1 battery (4/20/17).

GC1 full discharge 4/20/17						
Time elapsed (min)	**Clock Time (military)**	**DMM Voltage (V)**	**DataQ Voltage (V)**	**Specific Gravity (kg/m^3)**	**Temperature (°C)**	**Comments**
0	12:35	2.185	2.2	1,325	25.5	Voltage measured as open circuit voltage at Time=0; All other voltages were measured with a digital voltmeter.
1	12:36	2.05	2.076			
5	12:40	2.075	2.089			
10	12:45	2.07	2.091			
25	13:00	2.07	2.08	1,305	27	
40	13:15	2.05	2.067			
55	13:30	2.03	2.048	1,280		
70	13:45	2.03	2.035			
85	14:00	2.01	2.019	1,255		
100	14:15	1.998	2.004			
115	14:30	1.982	1.985			
130	14:45	1.956	1.962	1,185	27	
145	15:00	1.939	1.951			
160	15:15	1.914	1.917	1,135		
175	15:30	1.877	1.88			
190	15:45	1.828	1.833	1,090		
203	15:57.3		1.5	<1015	27	

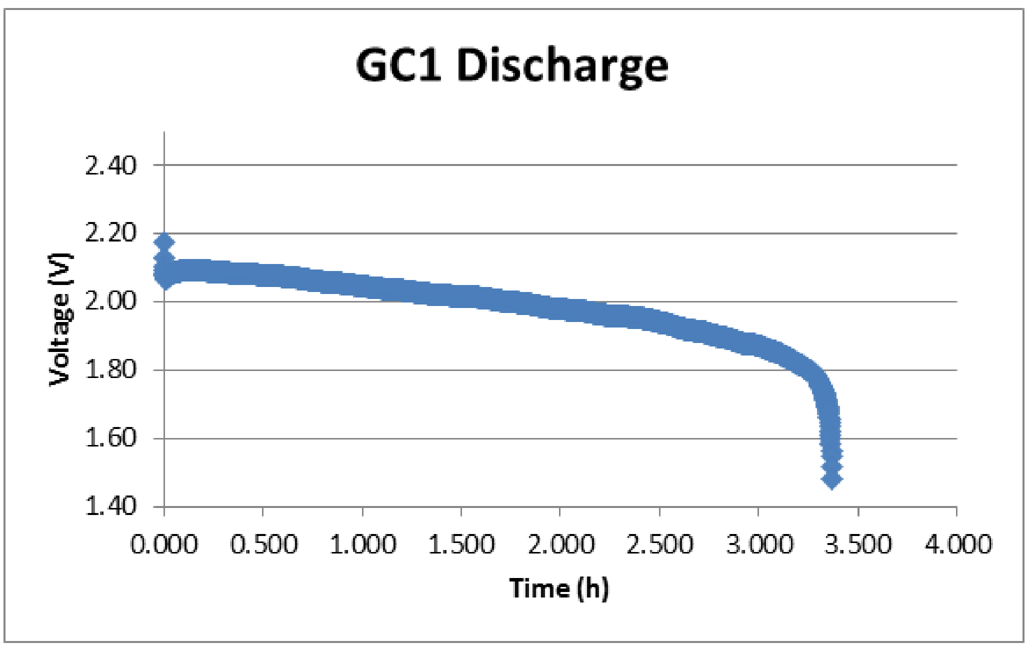


Figure 10. Galvanostatic discharge curve generated from the acquired data points within DataQ showing how voltage varied throughout the discharge time of the GC1 battery.

The data included in Table 2 was collected every 15 minutes during the majority of the discharge, however the first few measurements that are included were taken more frequently. Specific gravity and temperature were measured several times during the discharge. This data was then exported from DataQ and plotted to show voltage vs. time dependence (Figure 10).

Using the curve in Figure 10 and the data log from DataQ (see a standalone enclosure to this report), several calculations were done for the GC1 cell discharge. The results of these calculations are summarized as part of Table 3.

To calculate the weighted watt-hours, the curve in Figure 10 was first roughly integrated in order to determine the average Wh during the discharge. The first integration began at 2.1 V, which was labelled as 2.149- 2.050 V and multiplied by the approximate time interval that it spanned. This value was added to the next interval of 2.0V, which was once again labelled as 2.049-1.950 V and multiplied by the time interval it spanned. This same procedure was repeated until the last interval of 1.500 V. Then the weight of the full cell was converted to kg, giving 18.0 kg, and the Wh value was divided by the weight to give a specific energy value of 18.7 Wh/kg. This value is expected to be low, because the box includes slots for 3 more cells, and only one cell was tested. There is no doubt that the specific energy rating in a different cell format would have produced notably greater values of specific energy in the GC1 cell.

The calculations for the single cell are shown in the first row of Table 3. These numbers were then extrapolated for a full 8V GC1 battery by multiplying the weighted Wh by 4, the results of which are shown in the second row of Table 3.

Table 3. The results of calculations of various properties of a single GC1 battery cell, and of an entire 4-cell GC1 battery unit.

GC cell type	Wh (weighted)	Specific Energy (Wh/kg)	Ah	Full Weight (lbs.)	Full Weight (kg)	Electrolyte weight (lbs.)	Internals weight (lbs.)
Single Cell	335.7	18.7	168.2	39.6	18	1.2	24.6
4 Cell Battery (estimated)	1,342.9	25.3	168.2	117	53.1	4.8	98.4

Since there was no opportunity to weigh the empty cell box without its constructional components inside, the weight of the box was measured indirectly by weighing a piece of the same material used to make the battery box, calculating its weight per square inch, and multiplying that by the dimensions of the box itself. For reference, Figure 11 provides a dimensional drawing of the GC1 battery module.

The approximate weight of the box was determined to be 13.8 lbs. This value was then used to subtract the empty weight from the full weight to get the electrolyte per cell, and to subtract the box weight from the empty weight to get the internal components weight.

The electrolyte weight and internal weight were added, multiplied by 4, and added back to the box weight of 13.8 lbs. This results in 117 lbs of total weight, which was converted to kg and used to calculate the 25.3 Wh/kg. The latter value is an estimate. One should bear in mind that this is a homemade, un-optimized container, so the battery performance can only be improved once AES obtains lighter and thinner wall material for their battery container. As a note, the value of Ah was reached by multiplying the amps discharged by the time interval.

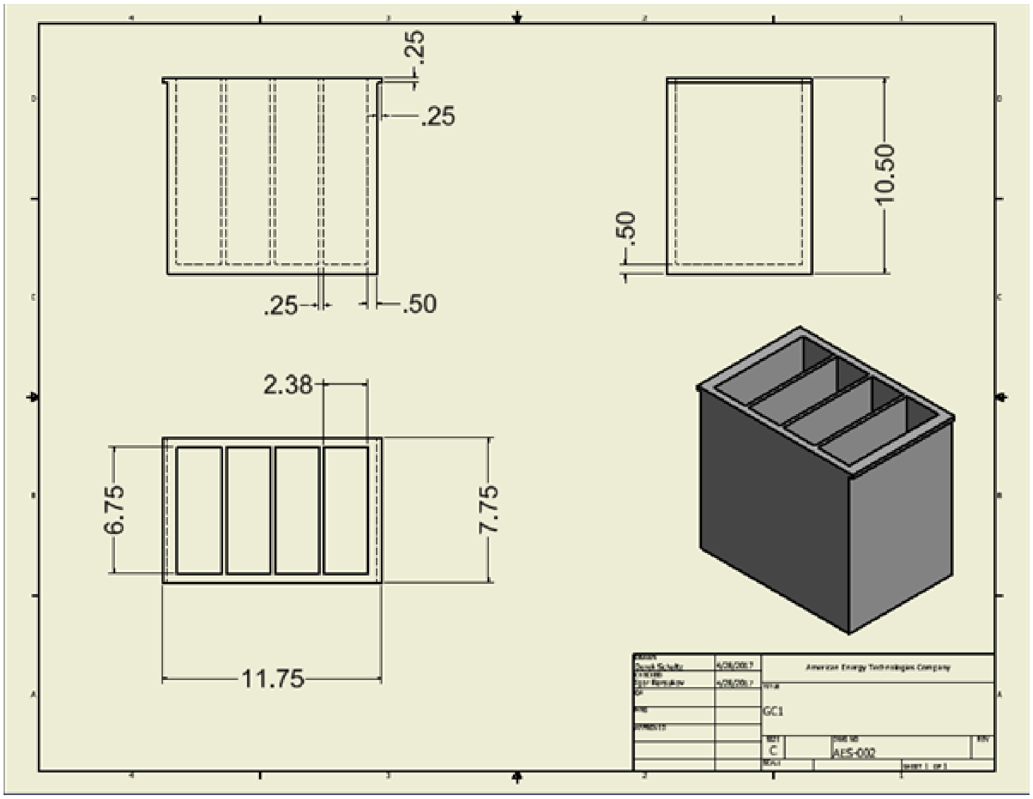


Figure 11. Dimensional drawing of Apollo Energy Systems' GC1 battery box.
Note: All dimensions are reported in inches.

6. TPX1 Discharge – Day 2 (4/21/2017).

The TPX1 was fully discharged following the same discharge procedure but using a different time interval than the previous two discharges. At 8:30 am EST on Day 2, the test began. We followed a different time interval from the previous two discharges. Before starting the discharge, we once again used the scale to measure the weight of the fully charged battery (Figure 12 (a)). After the discharge, we the weight of the fully battery still containing electrolyte (Figure 12 (b)), and finally emptied the electrolyte and weighed once more (Figure 12 (c)).

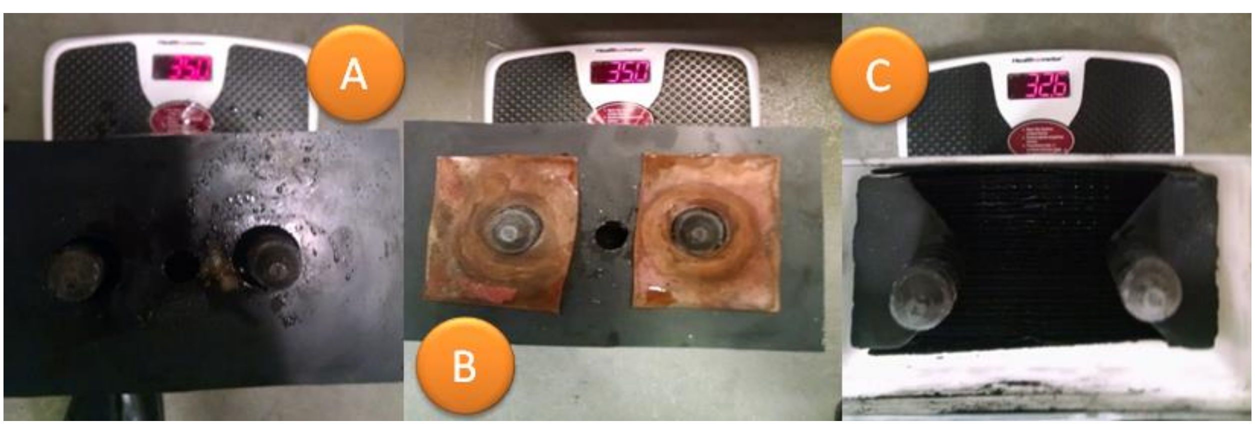


Figure 12. TPX-1 Battery weight schedule: (a) Fully discharged weight; (b) Fully charged weight and (c) weight of the battery with no electrolyte within the battery. Scale: Lbs.

7. Data of discharge with TPX-1 battery.

Data in Table 4 is a result from the same data manipulation procedure as the GC1 discharge.

Table 4. Full discharge of a TPX-1 battery (Day 2).

TPX1 full discharge 4/21/17						
Time elapsed (min)	Clock Time (military)	DMM Voltage (V)	DataQ Voltage (V)	Specific Gravity (kg/m^3)	Temperature (°C)	Comments
0	8:25	2.26				We measured open circuit voltage, but we realized DataQ wasn't open. We had to restart.
0	8:30	2.19				We measured open circuit voltage again and proceeded with the test.
1	8:31	2.07	2.090	1305	33	
5	8:35	2.08	2.098			
20	8:50	2.08	2.098			
35	9:05	2.08	2.095	1300	32	
50	9:20	2.07	2.087			
65	9:35	2.06	2.080			
80	9:50	2.05	2.075	1290	32	
95	10:05	2.05	2.063			
110	10:20	2.04	2.054			
125	10:35	2.03	2.045	1260	31	
140	10:50	2.02	2.036			
155	11:05	2.01	2.026			
170	11:20	2.01	2.019	1230	30	
185	11:35	2.00	2.014			
200	11:50	1.99	2.007			
215	12:05	1.98	1.997	1205	30	
230	12:20	1.98	1.985			
245	12:35	1.97	1.976			
260	12:50	1.956	1.968	1180	29	
275	13:05	1.95	1.958			
290	13:20	1.939	1.953			
305	13:35	1.926	1.936	1150	29	
320	13:50	1.911	1.915			
335	14:05	1.895	1.896			
350	14:20	1.87	1.875	1115	29	
365	14:35	1.842	1.849			
380	14:50	1.804	1.810			
385	14:55	1.781	1.792		29	
390	15:00	1.752	1.755	1075		
395	15:05	1.702	1.707			
401	15:11		1.500			

Please refer to the DataQ log (supplied as a standalone enclosure to this report) for a greater level of detail with this data.

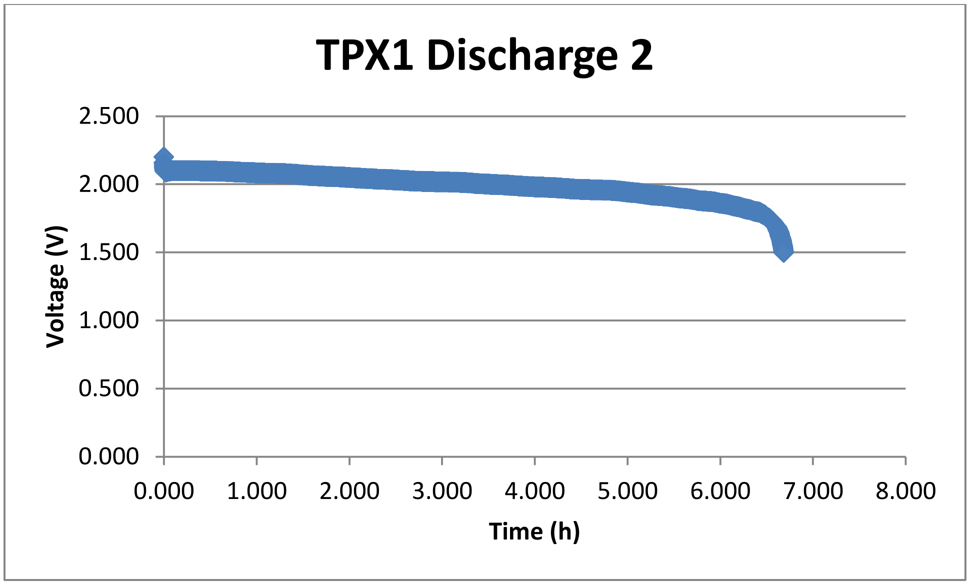


Figure 13. Galvanostatic discharge curve generated from the acquired data points within DataQ showing how voltage varied throughout the discharge of the TPX1 battery.

The data in Table 4 once again includes the hand plotted, abbreviated data, and the galvanostatic discharge curve (Figure 13) is made from the results of DataQ.

8. Performance results with Apollo Energy Systems' TPX1 battery.

The same integration method that was used for calculations of the GC1 battery is also used here to find the Wh value with the TPX-1 battery. Namely, the first data point of 2.1V was multiplied by the appropriate time interval, then the same was done for 2.0V and so on. The full weight of the battery was converted to kg and used to calculate the estimated specific energy in Wh/kg. To calculate specific capacity, the current at which the battery was discharged (i.e. 50.0 A) was multiplied by the number of hours elapsed (based on a DataQ log), to the second. That number was then divided by the full weight in kg to achieve a result of 21.1 Ah/kg (see Table 5).

Table 5. The results of calculations of various properties of Apollo Energy Systems' TPX1 lead cobalt battery.

TPX-1 Energy (Wh)	Specific Energy (Wh/kg)	Specific Capacity (Ah/kg)	Fully charged weight (lbs.)	Fully discharged weight (lbs.)	Weight (kg)	Electrolyte weight (lbs.)
665.6	41.9	21.1	35	35	15.9	2.4

9. Conclusions.

The significance of the specific energy being almost 42 Wh/kg should be viewed against the backdrop that the best batteries on the market are advertised at up to 40 Wh/kg. The going specification, however, is 37.3 Wh/kg.

Therefore, Apollo's TPX-1 battery product is 12.3% better than the market standard for this form factor. Considering that this battery has been cycled multiple times and still outperforms other batteries on the market today we find this to be a remarkable development for the lead acid battery market.

We propose to consider this independent test result on a backdrop of the fact that in the battery industry, which we serve, a 3% performance improvement per year is generally accepted to be the norm for a mature technology. With its 12.3% better performance, AES technology is positioned to be at least 3 years ahead of its competition. This is a very positive result and an achievement for AES. It may open a number of lucrative commercialization opportunities for Apollo Energy Systems in the very near term.

End report.

5/4/2017
For questions about this report, please contact Dr. Igor V. Barsukov of American Energy technologies Co., Arlington Heights, IL, E-mail: IBarsukov@usaenergytech.com;
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Enclosures:
DataQ Log files.