

# High Power Bipolar Nickel Metal Hydride Battery for Utility Applications

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## **Abstract**

Under Department of Energy Storage Program contract DE-FC36-02GO12031 being managed by Sandia National Laboratories, Electro Energy, Inc. (EEI) is developing a high rate capable nickel metal hydride battery to meet the broad requirements of distributed energy. As In a departure from the classical cylindrical or prismatic approach to battery packaging approaches, EEI is developing a bipolar design based on flat wafer cells in order to attain even higher power and energy densities and specific power and energy for the nickel-metal hydride chemistry.

A layered assembly is used in fabricating the individual flat wafer cells and each of these are composed of an outer contact face having a single positive electrode, a separator, and a single negative electrode on an outer contact plate. The contact faces in each cell serve not only to contain the cell, as well as to make electrical contact to the positive and negative electrodes. By using this configuration, it is possible to maintain low cell impedance that is essential for attaining high rate capability, i.e. high power. In order to ensure cell integrity, the contact faces on each cell are sealed around the perimeter. These cells are then stacked to create the bipolar stack, and the electrical connections to the battery are made at the end of the series stack. Structural integrity for the stack is created and maintained by housing the stack in an outer container, and the housing also maintains compressive loading on the cells.

This approach to battery design provides several advantages over other approaches. For example, the need for conventional terminals, tabs, current collectors, and individual cell containers is eliminated. This approach provides for a more efficient use of space since the headspace normally required for tabs and terminals in a conventional cell is eliminated. The mean free path for current flow in the electrodes and from cell to cell is minimized since the current flows normal to the plane of the electrodes thereby lowering battery impedance making this configuration well suited for high rate (power) applications. The wafer stack design also has excellent thermal conductivity in the plane of the metal foils, and this significantly aids in the thermal management. Compared to conventional cylindrical and prismatic packaging designs, the use of plastic bonded electrodes in a bipolar configuration offers the potential for considerable reduction in both cost and volume.

There is an increasing need for energy storage devices to be capable of delivering high power. Electro Energy, Inc. has been focused for several years on adapting its bipolar nickel metal hydride technology to some of these tasks. Prior presentations (1) have presented data related to hybrid vehicle and aerospace pulse power applications. This paper will focus on work conducted at higher current levels. Specific power in the range of 2.0-2.2 kW / kg and power density in the range of 5.0-6.5 kW / L were measured at current densities of 400-800 ASF.

### Bipolar nickel metal hydride description

As a departure from classic cylindrical or prismatic battery packaging approaches, EEI is developing a flat, wafer, bipolar design for the nickel-metal hydride chemistry. Figure 1 shows a sketch of the different design concepts.

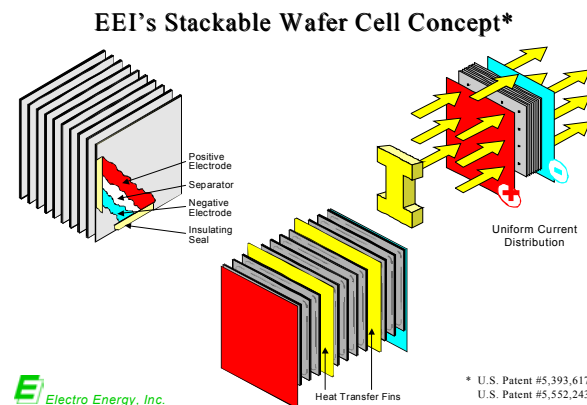


Figure 1. Bipolar Concept

Individual flat wafer cells are constructed with outer contact faces with one positive electrode, a separator and one negative electrode. The contact faces serve to contain the cell and make electrical contact to the positive and negative electrodes. The contact faces are sealed around the perimeter to contain the potassium hydroxide electrolyte. To fabricate a multi-cell battery, identical cells are stacked one on top of each other such that the positive face of one cell contacts the negative face of the adjacent cell making a series connected battery. Figure 2 shows a typical wafer cell in the 6"x12" that is the basis for the data presented. The current is collected at the ends of the cell stack. Structural integrity for the cell stack is obtained by housing the stack in an outer container, which holds the cells in compression.

This battery design has several advantages. The need for conventional terminals, tabs, current collectors, and cell containers is eliminated. Use of available space is maximized, with the headspace for tabs and terminals required in conventional cells eliminated. The path that current has to move in the electrodes and from cell to cell is minimized, since the current flows normal to the plane of the electrodes. Battery impedance is reduced, making this design particularly effective for high rate, power applications. The wafer stack design has excellent thermal conductivity in the planar direction due to the metal

foils in the wafer cell that aid thermal management. Compared to conventional cylindrical and prismatic packaging designs, the use of plastic bonded electrodes offers considerable reduction potential in cost and volume.

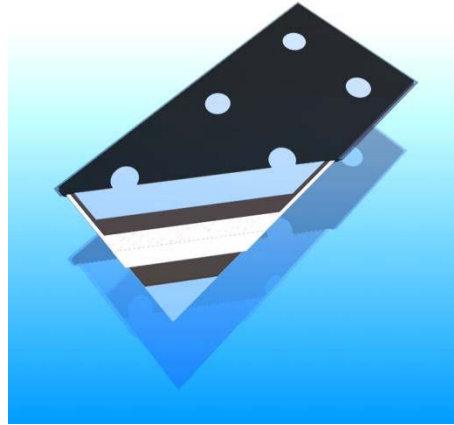


Figure 2. Typical 6" x 12" Wafer Cell Showing Layered Construction

#### **High current pulse description**

Several cells were produced under a DOE pulse power program (SNL series). The cell electrode area was 6" x 12", and the theoretical capacity was 6.48 Ah. All cells were tested in a sealed configuration at 50% SOC. The test for high discharge power capability at various current densities (ranging from 200 to 1000 ASF) was conducted in the following way:

- Discharge of the cell at C/3 rate to 0.8 V
- Charge of cell to 50% SOC (3.24 Ah charge input)
- 3 hour stand
- Discharge of cells at various currents to a discharge cutoff of 0.6 A (for most testing), or 0.3 A (for 450, 500 A tests)

#### **Pulse testing results**

The cells were consistently able to sustain a 10 second discharge at currents up to 300 A (Figures 3 and 4). Discharges up to about 450 A for 1 second to 0.6 V appear possible.

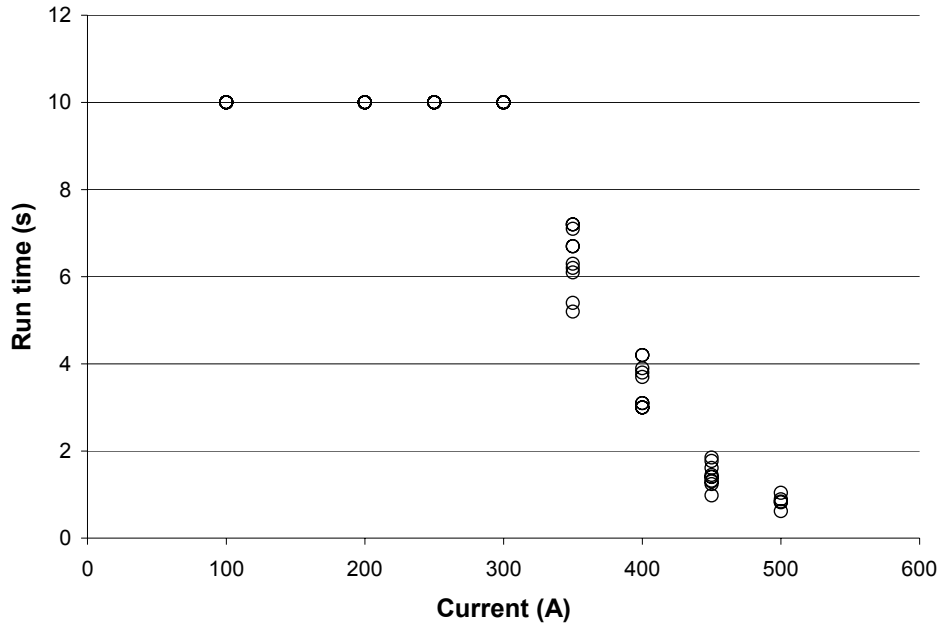


Figure 3. Runtime to 0.6 V lower limit at various discharge currents. Starting SOC was 50%.

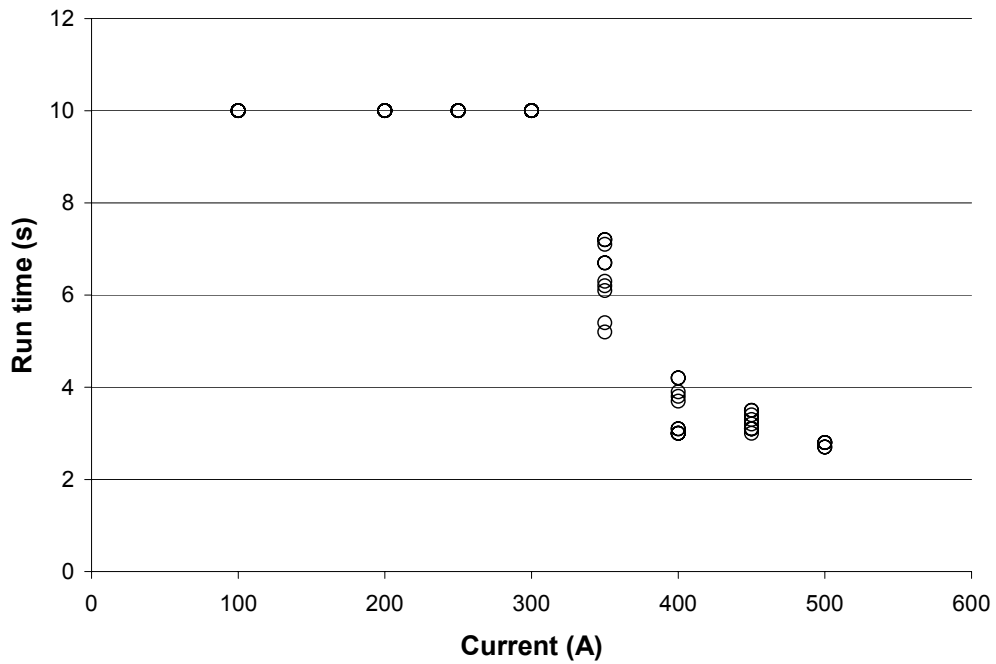


Figure 4. Total runtimes (450 and 500 a runs are to 0.3 V, others are to 0.6 V) at various discharge currents. Starting SOC was 50%.

In terms of specific power, levels up to 2 kW / kg were observed with 10 second data, while the maximum 1 second power density appears to be about 2.2 – 2.4 kW / kg (Figures 5-8). On a volumetric basis, this corresponds to 5.0 – 6.5 kW / L. This power level occurs at discharge currents of 300-400 A. The specific energy figures were calculated on a basis of 125 g per cell weight, and cell dimensions of 6” x 12” x 0.037”.

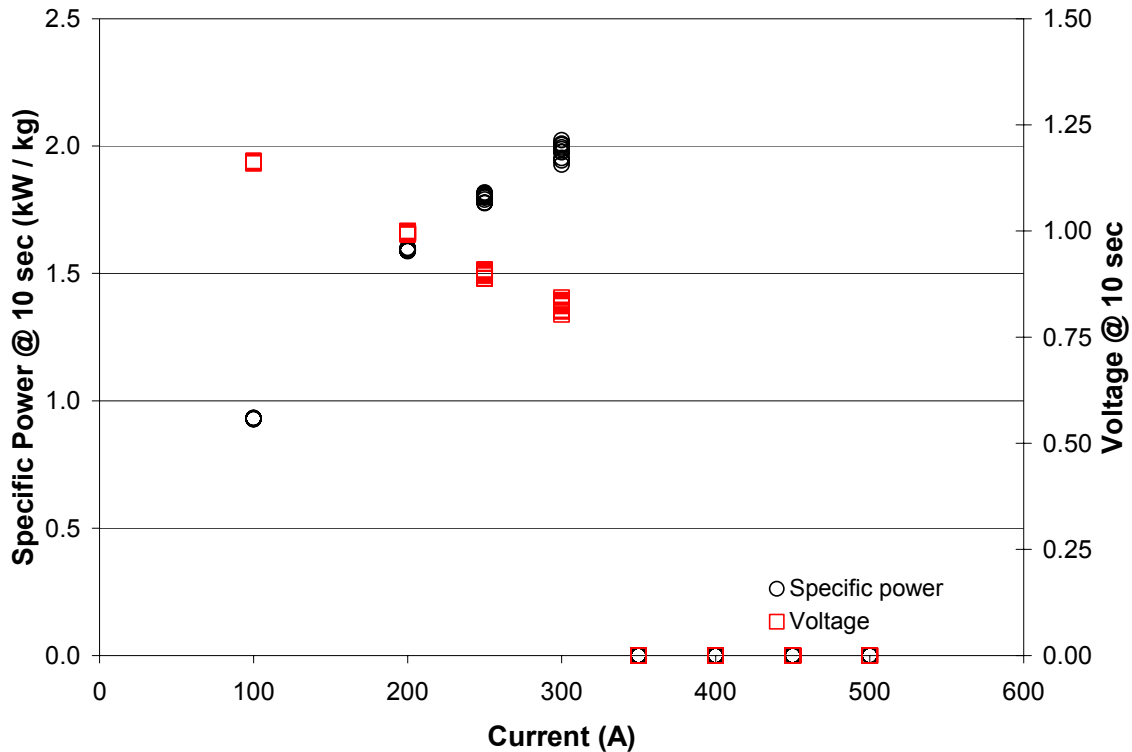


Figure 5. Power capability at the end of a 10 s discharge on a gravimetric basis. Starting SOC was 50%.

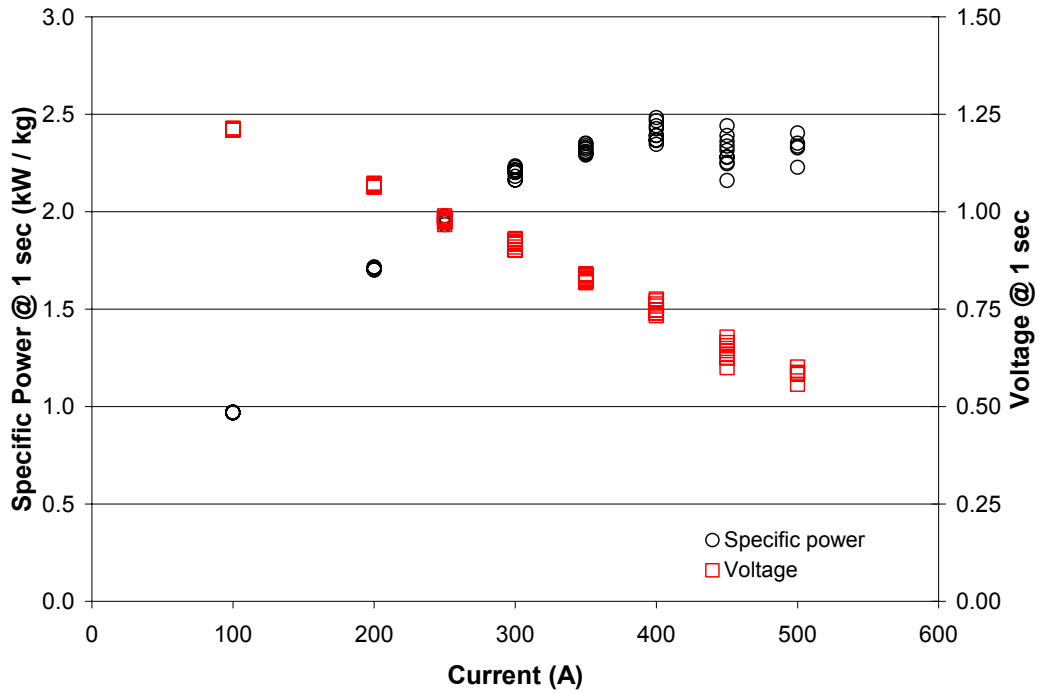


Figure 6. Power capability at the end of a 1s discharge on a gravimetric basis. Starting SOC was 50%.

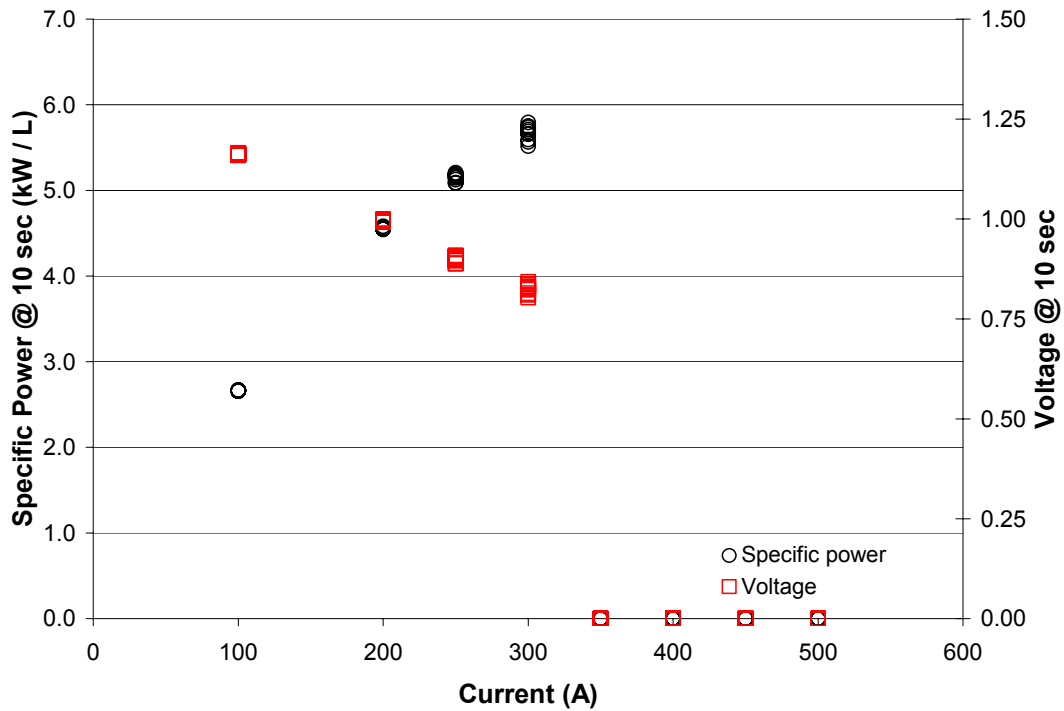


Figure 7. Power capability at the end of a 10s discharge on a volumetric basis. Starting SOC was 50%

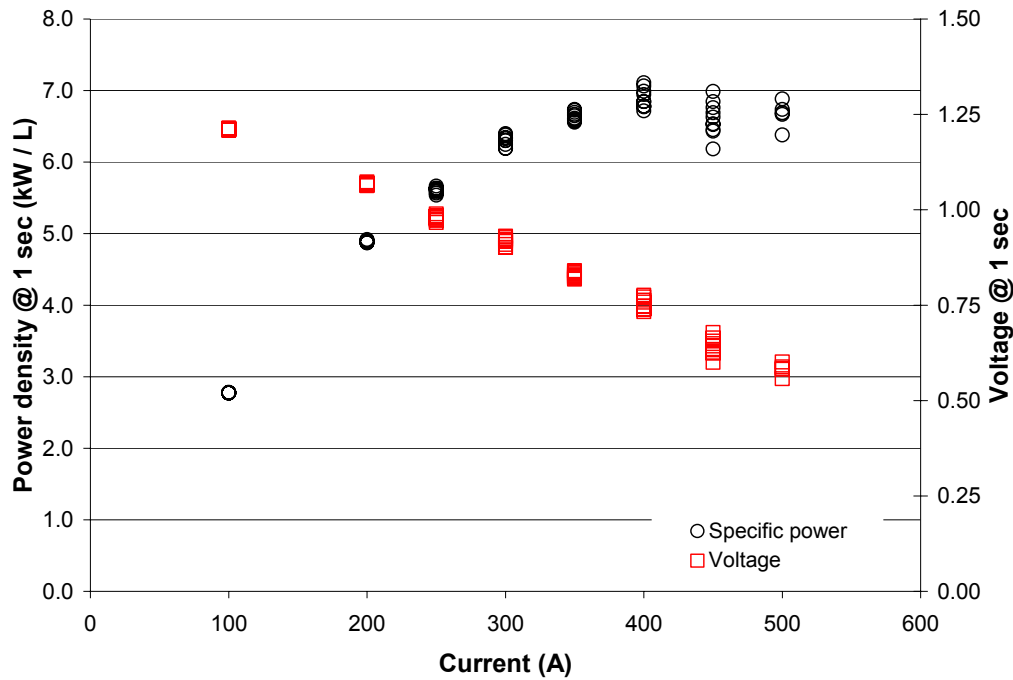


Figure 8. Power capability at the end of a 1s discharge on a volumetric basis. Starting SOC was 50%.

### Reference electrode diagnostics

It is of interest to identify which of the electrodes is polarizing under these discharge conditions. Figure 9 is a plot of a 200 A / 50% SOC discharge conducted in a flooded configuration using zinc metal as a reference. The plot shows that the nickel oxide electrode is primarily responsible for the observed polarization – the metal hydride versus zinc trace is relatively flat during the discharge. This suggests to us that to obtain even greater power, one must either reduce the overall cell ohmic resistance, or reduce the polarization in the nickel electrode (that is, non-ohmic polarization in the negative electrode does not seem to be a problem at this point).

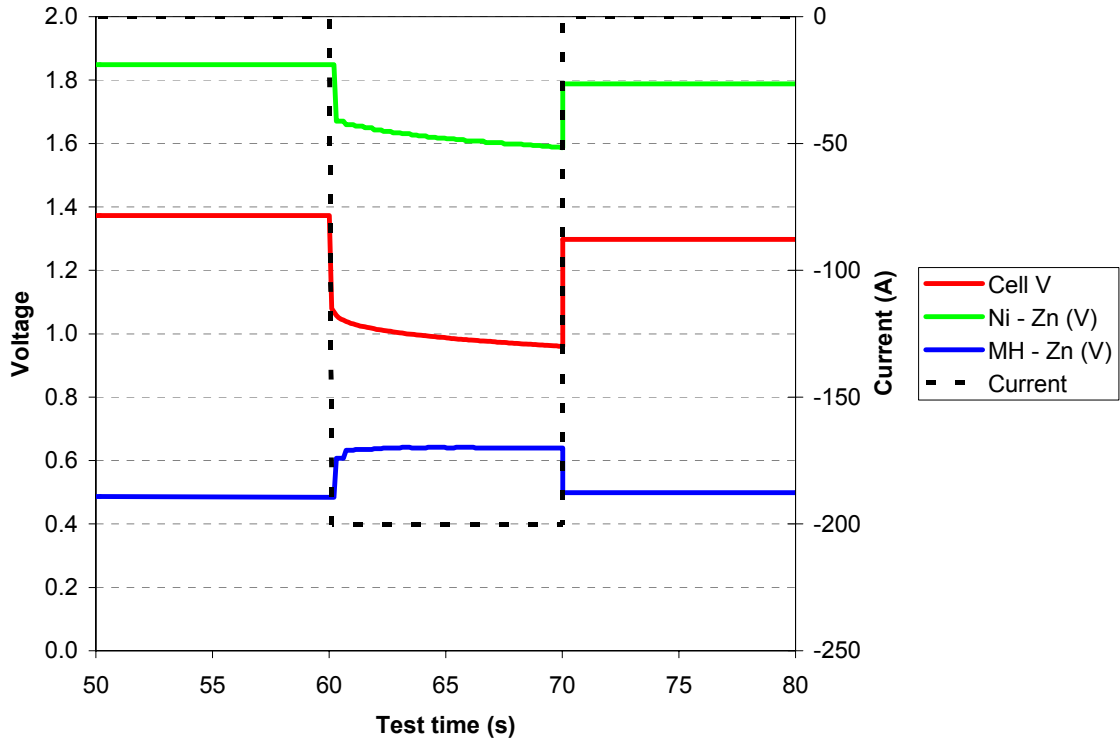


Figure 9. 200 A discharge data (flooded configuration) using a zinc reference.

### Deep discharge behavior at high powers

Additionally, it is conceivable that deep discharge applications may arise at high power levels. Figure 9 shows the discharge of a cell in the flooded configuration starting fully charged. The current used was 200 A (about 31 C based on a theoretical capacity of 6.48 Ah), and a utilization of 86% of theoretical was measured.

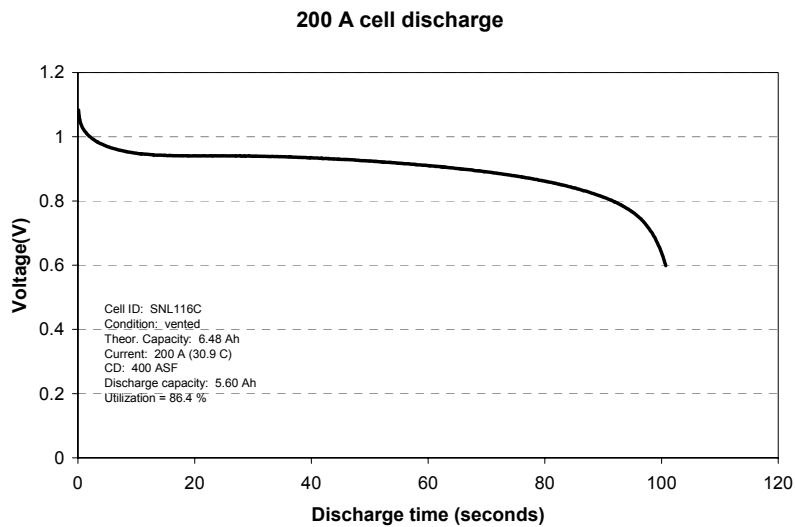


Figure 10. 200 A discharge data (flooded configuration) starting at 100% SOC.

### Prototype Cell and Battery Characteristics

The best cell composition based upon testing was identified and selected for the final deliverable. Cells in the 31cell battery (chosen to match Sandia National Laboratories test equipment availability) had a theoretical capacity of 6.48 Ah capacity (nominal 6 Ah) giving a theoretical capacity of 6.48 Ah for the battery itself. The initial power and power fade after cycling for the cells was also determined, and these evaluations consisted of first bringing the cells to 50% SOC, allowing them to stand at open circuit for three hours, and then discharging at various current densities for 10 seconds. The Battery is shown in Figure 11. Figure 12 shows performance of the batteries compared to that of the individual cells



Figure 11. Nominal 6 Ah 40 Volt Deliverable to SNL

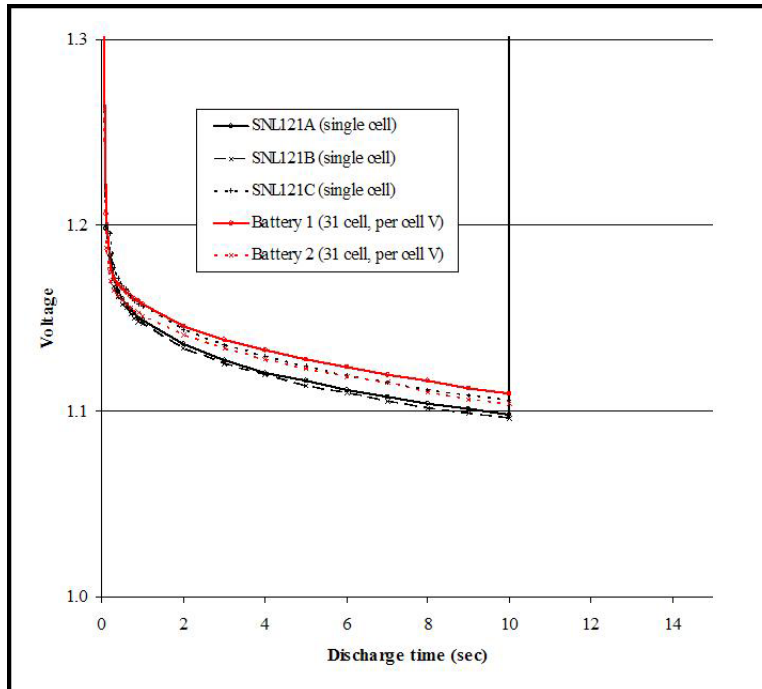


Figure 12. Comparison of 31 Cell Battery to Individual Cells of the Same Configuration

### Summary

This work presents data that shows the EEI bipolar wafer cell construction is capable of high power capability. Data related to both pulsing loads as well as deep discharges were presented. Future work will focus on scaling the single cell results to High Voltage (>100 Volts) batteries.

### References

1. R. Plivelich and M. Eskra, "Pulse Power Nickel Metal Hydride Battery," 2002 Power Systems Conference (Society of Automotive Engineers), Coral Springs, FL (Oct. 2002).

### Acknowledgement

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