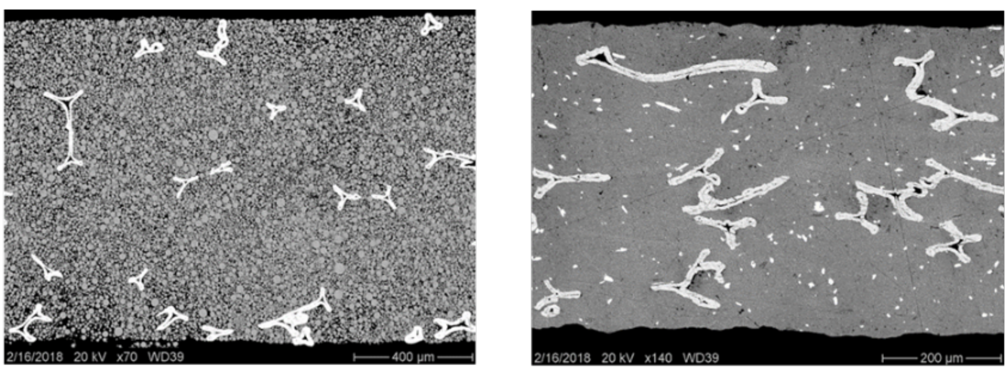
NICKEL-ZINC: ENVIRONMENTALLY FRIENDLY AND COST-EFFECTIVE UPS SOLUTIONS

Kirk Plautz
VP of Business Development
Æsir Technologies
Joplin, Missouri

Associate's Name: Dr. Adam Weisenstein
Associates Title: Chief Technology Officer
Company Name: Æsir Technologies
City & State: Bozeman, MT

Introduction

Nickel-Zinc (Ni-Zn) is an aqueous chemistry, with a nickel hydroxide positive electrode and a zinc negative electrode, as shown in Figure 1, that are recyclable and RoHS compliant. This chemistry provides an optimal combination of high power and energy in a rechargeable large format battery with low safety risks due to the non-flammable electrolyte. Ni-Zn batteries have a specific energy and energy density of 60-90 Wh/kg and 90-170 Wh/L, respectively [1]. As shown in Figure 2, Ni-Zn batteries have demonstrated > 600 deep discharge cycles. The technology can also sit on float charge for extended periods. Ni-Zn offers a reduced footprint and lower lifecycle cost for data center applications, as discussed below, when compared to the traditionally used Lead-Acid batteries. Complex battery management systems and controls are not required with Ni-Zn, as thermal runaway is not an issue with this chemistry, resulting in cost savings and low safety concerns. The Ni-Zn chemistry can also operate at high temperatures, which results in reductions of HVAC requirements and costs, thereby increasing the energy efficiency of data centers.



Positive electrode: $2NiOOH + 2H_2O + 2e^- \rightarrow 2Ni(OH)_2 + 2OH^-$

Negative electrode: $Zn + 2OH^- \rightarrow Zn(OH)_2 + 2e^-$

Figure 1: Ni-Zn electrodes and reactions [1]

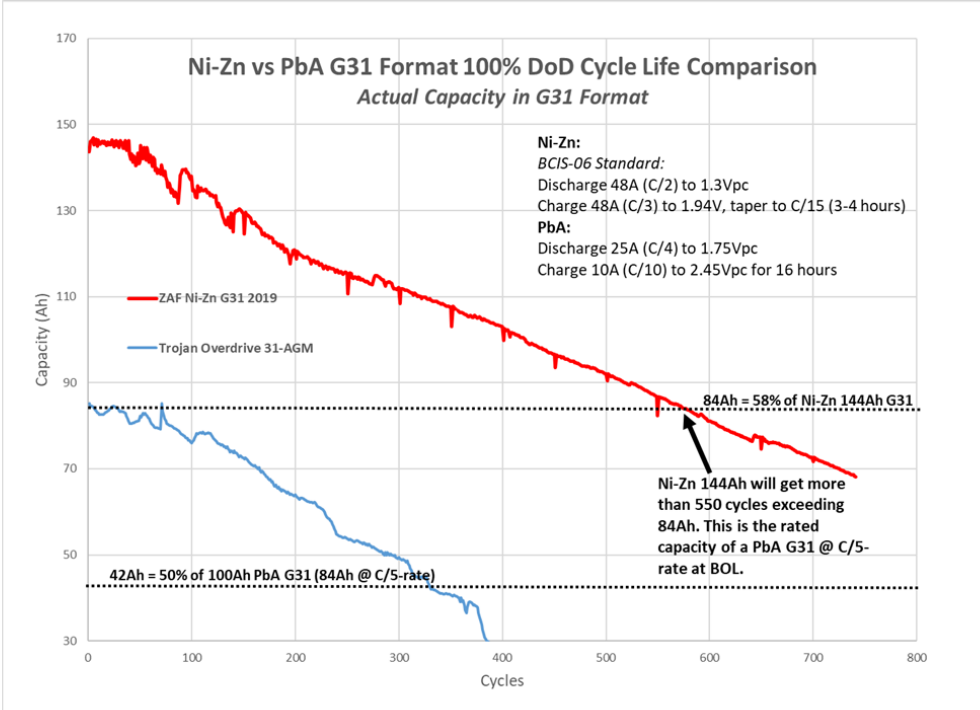


Figure 2: Ni-Zn BCIS-06 standard cycle life vs Lead-Acid (Curtesy of ZAF Energy Systems)

Historically, the redistribution of zinc, or shape change, in the zinc negative electrode has hindered Ni-Zn from obtaining specific energies close to the theoretical value and prevented this chemistry from achieving long cycle life [1,2,3]. Shape change can lead to the creation of zinc clusters away from the electrode, which can become electrochemically inaccessible, resulting in reduced power and utilization. Under recharging conditions, zinc may also preferentially plate onto the electrode high points/protrusions rather than in a uniform manner. Repeated charge cycles will eventually lead to the formation of zinc dendrite structures that can penetrate the separator causing a short in the cell. This dendritic shorting is dictated by current density distribution, surface shape, and electrolyte amount and molarity. Although excess electrolyte can promote shape change, the loss of electrolyte, or dry out, is another common failure mode encountered in long term cycling of Ni-Zn cells [1,2]. Dry out in sealed cells can occur via the decomposition of water into oxygen and hydrogen at the positive and the negative electrodes during overcharge, respectively. The electrolysis of water typically takes place at the end of charge with the rate of reaction dependent on charge voltage. Dry out has prevented the use of long-term float charging of the Ni-Zn chemistry; however, this failure mode can be prevented through voltage regulation and the use of zinc electrode additives that increase the voltage at which electrolysis occurs. Recombination devices can also be used to recombine the generated oxygen and hydrogen into water that is returned into the cell [1].

Nickel-Zinc Data Center Related and Projected Performance

Preliminary testing with Ni-Zn for data center applications is currently being conducted in a large-scale data center in Atlanta. The cells have been on long duration constant float charge at 20°C from the beginning of January 2020. This system is rated at 675 kW for 10 minutes, with a float voltage of 553 V and a minimum voltage of 380 V. The battery system required 300 4.64cm x 23.7cm x 17.1cm (LxHxW) sized cells (G31 format) per cabinet, with three cabinets in parallel. An image of one cabinet is shown in Figure 3. Each cabinet has 30 units, each with 10 cells. The entire system has a total of 90 units. These 122 Ah cells have been tested for long term float and pulse performance. An example is shown in Figure 4. Such a cell has been discharged at 588 A for 1 minute every 1 to 2 months over the span of 1.5+ years to ensure high-rate discharge performance of the cells after constant float charging. The Ni-Zn cells have shown no significant performance degradation over the duration of this testing, as shown in Figure 4.

Figure 3: Data center cabinet containing Ni-Zn batteries (Courtesy of ZAF Energy Systems)

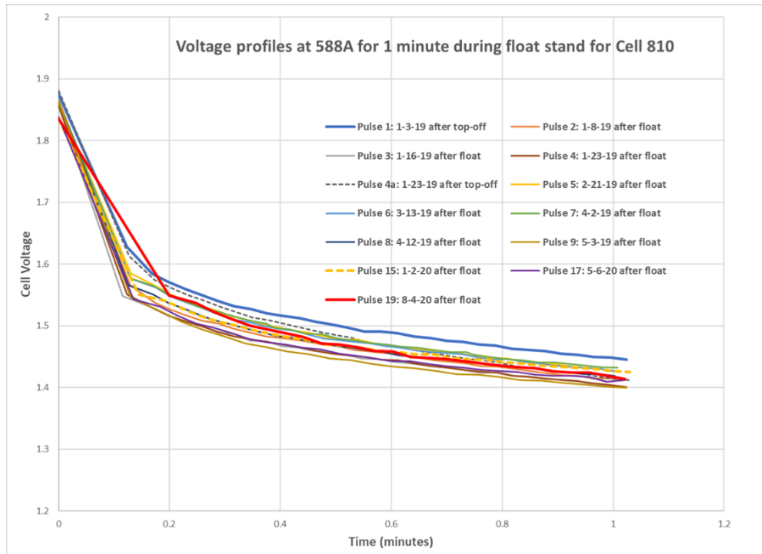


Figure 4: NiZn Cell Float Data (Courtesy of ZAF Energy Systems)

Ni-Zn battery optimized for the demanding data center power requirements and for ease of installation into existing racks and cabinets is shown in Figure 5. The battery consists of 8 Ni-Zn cells This system could produce 8,400 W per battery for a 5-minute duration. The projected performance per cell, as shown in Figure 6, is based upon electrochemical modeling which was developed from power testing of 4.64cm x 23.7cm x 17.1cm (LxHxW) sized Ni-Zn cells with a power and capacity hybrid design.

Model Name	Dimensions in (mm)			Weight lb (kg)	Handles
	Length	Width	Height		
Z-0005	23.00 (584.2)	4.74 (120.4)	12.74 (323.5)	101.2 (46)	Cloth Strap

Volts Per Cell	Watts per cell		
	1 min	2 min	5 min
1.318	1,050	1,216	1,296

Volts Per Battery (8 cells)	Watts per battery		
	1 min	2 min	5 min
10.54	8,400	9,728	10,368

Figure 5: Specifications for Ni-Zn battery designed for data center applications

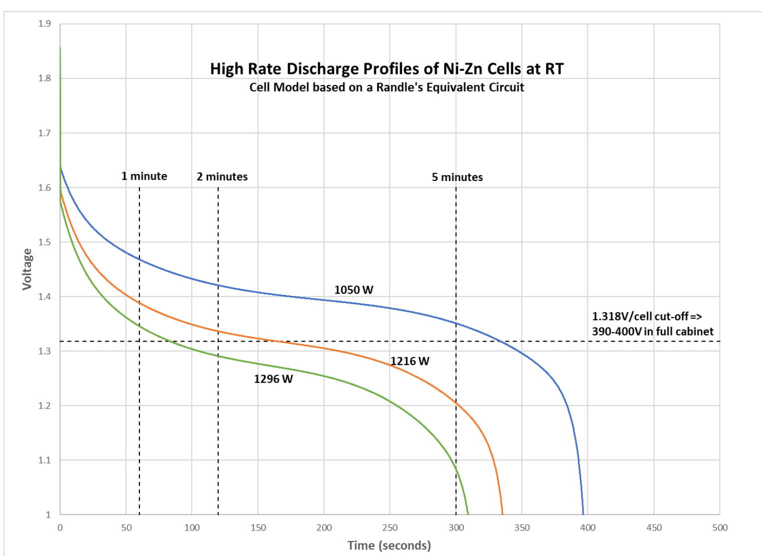


Figure 6: Projected high-rate discharge profiles for Ni-Zn battery designed for data center applications

Nickel-Zinc Data Center Projected Performance and Cost

With data centers being one of the fastest growing markets for energy storage, Ni-Zn battery systems are being designed for large scale data centers to help meet future demands. Based on data from the 675 kW data center testing, Ni-Zn projects to be competitive in both performance and cost with megawatt scale centers operating with Lead-Acid and Lithium-Ion. Table 1 below shows the initial and operating cost for a 100 MW data center over a 20-year period. On the pure cost analysis, Ni-Zn can provide a 25% or more cost savings over Lead-Acid and Lithium-Ion. The savings in part come from a measurable reduction in HVAC expenses, since Ni-Zn can operate at 85°F versus 75°F. These results are supported by our data center case study, where the owner/operator was able to shut down their second chiller resulting in a $25,000 savings per year.

Table 1: Projected initial and operating cost for a 100 MW data center over a 20-year period

	Advanced PbA	Lithium - NCM	LFP	Nickel Zinc
Megawatts	**100**	**100**	**100**	**100**
Batteries / Data Center	16,000	1,000	1,100	13,680
Price Per Battery	$450	$18,000	$18,000	$725
Battery Cost	$7,200,000	$18,000,000	$19,800,000	$9,918,000
Shipping Costs	$480,000	$175,000	$192,500	$175,104
Load Bank Test	$2,000,000	$2,000,000	$2,000,000	$2,000,000
Battery Cabinets / Racks	$3,000,000			$3,000,000
Total CapEx	**$12,200,000**	**$20,000,000**	**$21,800,000**	**$14,918,000**
Operational Expense				
Maintenance Bi-Annually	$96,000	$50,000	$50,000	$82,080
Maintenance Periods	40	40	40	40
HVAC Savings	**0%**	**0%**	**0%**	**15%**
Total Cost of Maintenance	**$3,840,000**	**$2,000,000**	**$2,000,000**	**$3,283,200**
Battery Replacement				
Replacements over 20 Yrs	2	1	1	1
Replacement Batteries	32,000	1,000	1,100	13,680
Cost/Battery Replacement	$450	$18,000	$18,000	$725
Battery Replacement Cost	**$14,400,000**	**$18,000,000**	**$19,800,000**	**$9,918,000**
Replacement Shipping Cost	$960,000	$175,000	$192,500	$175,104
Load Test Per Swap	**$40,000**	**$20,000**	**$20,000**	**$20,000**
Replacement Labor	**$1,280,000**	**$1,000,000**	**$1,100,000**	**$547,200**
Total OpEx	**$20,520,000**	**$21,195,000**	**$23,112,500**	**$13,943,504**
Recyling Rebate / Cost	**($1,080,000)**	**$0**	**$3,960,000**	**($1,400,832)**
Total Cost of Ownership	**$31,640,000**	**$41,195,000**	**$48,872,500**	**$27,460,672**
Total Cost/kw	*$316*	*$412*	*$489*	*$275*
Runtime - Beginning of life	10 Minutes	10 Minutes	10 Minutes	10 Minutes
Runtime - End of life	5 Minutes	5 Minutes	5 Minutes	5 Minutes
Warranty	7 year limited	10 year	10 year	10 year
Max Temperature	75° F	75° F	75° F	85° F

In addition to HVAC savings, the Ni-Zn batteries were a drop-in replacement for the 16V battery that was in place prior to the upgrade, utilizing the pre-existing cabinets, cabling, and controls in the data center. Repurposing the existing infrastructure lowered project cost and highlighted our sustainability message of reducing the project's carbon footprint by reducing construction waste, materials consumption, and installation time.

Nickel-Zinc Recycling

Research and development of Ni-Zn battery recycling has been conducted over the last 18 months. The goal of this project is to produce battery grade nickel, cobalt, and zinc precursors from recycled batteries using very little energy input. This "cold recycling" process for Ni-Zn batteries is a low temperature, hydrometallurgical-based method designed to reduce energy consumption and maximize extraction efficiency via a direct leachate to synthesis process. Due to the global abundance of zinc and the demand for nickel and cobalt in the battery industry, initial efforts have focused on the recycling of Ni-Zn positive electrodes, shown in Figure 7.

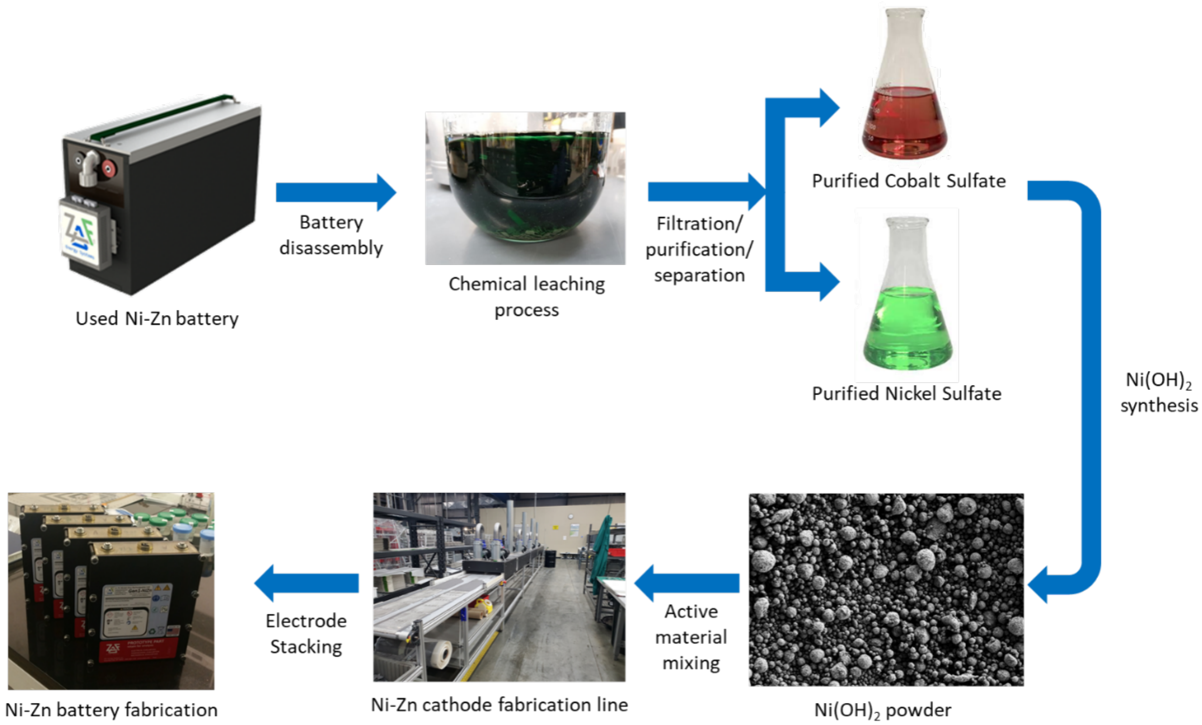


Figure 7: Flow diagram of the recycling and synthesis process of doped nickel hydroxide (Courtesy of ZAF Energy Systems and Battery Grade Materials)

The nickel and cobalt produced by recycling spent nickel electrodes will create domestic supply chains, which will become increasingly important as the U.S. battery market continues to grow to meet the energy storage needs of an expanding renewable grid and electrified transportation network. A high-quality and reliable supply of nickel sulfate/hydroxide and cobalt will be necessary for the fabrication of the positive electrodes in several battery chemistries including Ni-Zn, Nickel-Metal Hydride (NiMH), and Nickel-Cadmium (Ni-Cd), and Lithium-Ion. Nickel sulfate solutions can also serve as the starting material for cathode materials such as lithium nickel manganese cobalt and lithium nickel cobalt aluminum in Lithium-Ion batteries. In addition to serving as a nickel source, used nickel electrodes can serve as a domestic supply of cobalt, which can make up almost 10% of the cathode slurry material in Ni-Zn electrodes and more than 20% in Lithium-Ion electrodes. Cobalt is one of 35 elements identified by the U.S. Department of Interior as a critical material in 2018; therefore, establishing a domestic, conflict-free supply will benefit the U.S. battery industry by increasing the economic competitiveness of the United States. Initial testing of recycled nickel electrodes show very similar utilization retention at 100% DOD and C/3 cycling in pouch cells, as shown in Figure 8. Cells with electrodes fabricated with nickel hydroxide synthesized from a single round of the aforementioned recycling process, performed slightly better over 180 cycles; however, cells containing nickel hydroxide that had gone through two rounds of the recycling process exhibited a decrease in performance. This lower performance has been attributed to the accumulation of impurities, such as iron. Research is currently being conducted on purification steps to reduce the impurity levels during recycling.

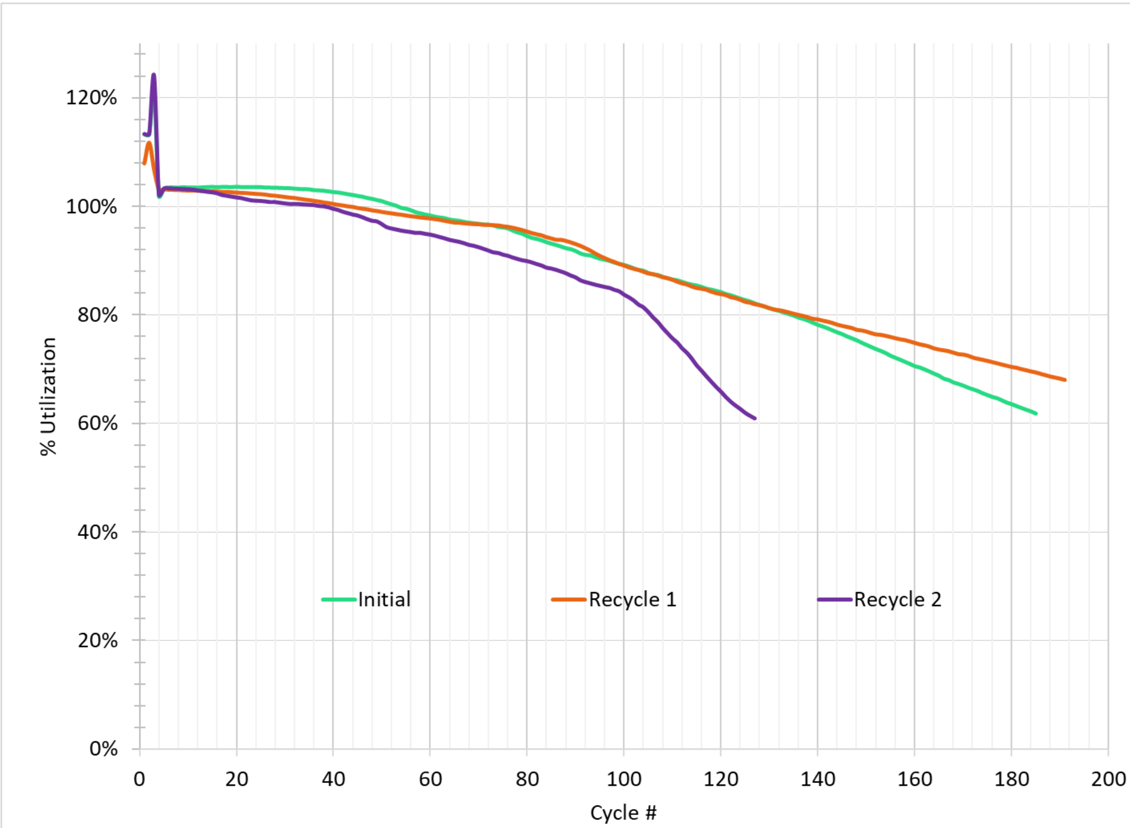


Figure 8: Cycling performance with Ni-Zn pouch cells built with recycled nickel hydroxide (Courtesy of Battery Grade Materials)

Summary

The Ni-Zn battery offers an efficient, low cost, safe, and environmentally friendly design for data center applications. The following are the key reasons that Ni-Zn should be considered as a viable alternative for existing battery systems and for new data center installations.

<u>Efficient Designs</u>: Ni-Zn can operate at 85°F versus 75°F, resulting in potential reductions of HVAC requirements and costs, thereby increasing the energy efficiency of data centers. Ni-Zn can also utilize existing racks, cabinets, cabling, inverters, and controls; therefore minimizing waste, cost, materials consumption, and installation time.

<u>Safety and Environmental Concerns</u>: Ni-Zn cells do not contain flammable components or material and have low risk of thermal runaway. UL 1989 certification has been completed on the block. Ni-Zn offers sustainability advantages of long life, improved performance, and recyclability. In comparison to Lithium-Ion, the Ni-Zn carbon footprint is lower due to its ability to operate at higher temperatures and repurposing of existing infrastructure that was designed for Lead-Acid battery systems in data center applications.

Works Cited

[1] Weisenstein, A.; Listerud, E.; Charkey, A. Nickel-Zinc. In Linden's Handbook of Batteries, 5th ed.; McGraw-Hill, 2019; pp 668-683
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[3] Parker, J. E.; Pala, I. R.; Chervin, C. N.; Long, J. W.; Rolison, D. R. Minimizing Shape Change at Zn Sponge Anodes in Rechargable Ni-Zn Cells: Impact of Electrolyte Formulation. J. Electrochem. Soc. 2016, 163(3), A351-A355.