New Jersey Energy Storage Analysis (ESA)

Final Report

Responses to the ESA Elements of the Clean Energy Act of 2018

The State University of New Jersey

May 23, 2019

Sodium Nickel Chloride (ZEBRA) batteries

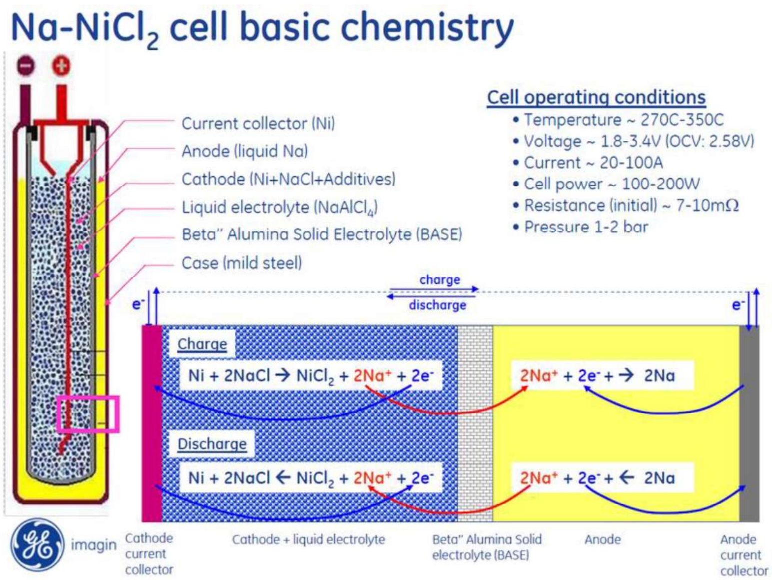

Figure 70: Schematics of a Sodium Nickel Chloride basic cell and its working principles.[204]

Developed in the 1980's, the sodium nickel chloride or ZEBRA battery (Figure 70) is based on a sodium negative electrode and a beta-alumina solid electrolyte, similar to that of the NaS technology. An important difference relative to NaS is that ZEBRA uses a porous solid positive electrode consisting of a mixture of nickel and active nickel chloride impregnated with a molten secondary electrolyte ($NaAlCl_4$) that facilitates transport of sodium ions to/from the beta-alumina electrolyte to/from the reaction site within the electrode. Cells are manufactured in the discharged stated from a mixture of sodium chloride and nickel, which transforms into nickel chloride and sodium upon charge. This improves safety considerations. Reactions are reversed upon discharge. Operating temperatures range over 270–350°C.

Technology:

The ZEBRA battery technology has many benefits. It is based on relatively low cost and abundant materials. The cells, fabricated in the discharged state, are sodium-free and are therefore intrinsically non-toxic, non-explosive and non-flammable, and are safe to handle and ship. Like the NaS technology, the sodium nickel chloride batteries, which are thermally insulated, are independent from ambient conditions.

The ZEBRA battery technology has slightly lower specific energy (100–200 Wh/kg), energy density (150–280 Wh/L), and power density (250–270 W/L) compared to the NaS technology. Due to the ceramic electrolyte, the battery has very little electrochemical self-discharge, however, the elevated operating temperature causes thermal self-discharge; if it is not cycling. Depending on the operation conditions, the thermal loss is compensated by the internal

[204] Green Car Congress (blog). "GE launches Durathon sodium-metal halide battery." (*Green Car Congress*. May 18, 2010. https://www.greencarcongress.com/2010/05/durathon-20100518.html).

electrical loss that is converted to heat so that the overall cell efficiency is 80–95%.[205] AC-based efficiencies can drop below 80%.[206]

The system is very robust, failure tolerant, and thereby maintenance-free. The exothermic heats of reactions are lower than for the NaS technology, and, as such, the temperature of the system is easier to maintain. All materials in the cells have a vapor pressure below 1 bar at its maximum temperature so that no gas should be released. The system also contains lower amounts of corrosive components, making the system safer. Safety is further enhanced by the double-walled and evacuated stainless steel thermal insulation box in which the cells are packaged into approximately 20 kW modules. Finally, there is no freeze / thaw limitation since the thermally induced mechanical stress on the solid-state electrolyte is low, thanks to the cell structure with the positive electrode located at the core (Figure 70), the smaller difference between the ambient temperature and the positive electrode solidification temperature, and lower mismatch in thermal expansion between the secondary and primary electrolyte.

Moreover, if the solid-state separator cracks, then the secondary electrolyte would react with sodium to form sodium chloride salt and aluminum, a safer failure mode than that which occurs in NaS. The cell can also withstand limited overcharge since the secondary electrolyte would react with nickel and provide additional sodium. This additional sodium would enable current to flow even at the end of charge, thereby preventing the voltage to rise further and protecting the solid-state electrolyte from potential failure. [207] When the cells fail they tend to develop low resistance resulting in voltage loss from one cell in the serial connection within the module rather than failure of the complete system.[208] No inter-cell connection or voltage taps is required, and systems can contain long series of batteries.[209] As such, the ZEBRA technology has relatively high cycle life (3000 cycles) and long lifetime (15 years).

Environmental Impact:

ZEBRA batteries are recycled through inexpensive processes. The first step consists of discharging the batteries in order to minimize the sodium content. In the second step, the nickel (II) chloride is reduced to nickel and shredded in equipment similar to that existing in the steel industry. The residual sodium does not cause any problem. In the third step, together with other scrap metals as the main feed, this shredder is fed into an electric arc melting furnace. Finally, the salt, the aluminum chloride, and, the ceramic partition go into the slag. The outgoing products consist of pig iron and slag, which are sold to the market. [210]

---

[205] C.H. Dustmann, Bito A. Safety, J. Garche, C. Dyer, P. Moseley, Z. Ogumi, D. Rand and B. Scrosati, Editors. 2009. (*Encyclopedia of Electrochemical Power Sources*. Vol 4. Amsterdam: Elsevier, p. 324–333, 2009).
[206] M. Musio. 2017. "Terna's grid-scale battery storage projects. Results from experimentation." (Terna Group. PowerPoint presented at Nicosia, November 24, 2017. https://www.wesrch.com/energy/paper-details/pdf-TR1YL6000YPOS-terna-s-grid-scalre-battery-storage-projects#page1).
[207] C.H. Dustmann, Bito A. Safety, J. Garche, C. Dyer, P. Moseley, Z. Ogumi, D. Rand and B. Scrosati, Editors. 2009. (Encyclopedia of Electrochemical Power Sources. Vol 4. Amsterdam: Elsevier, p. 324–333, 2009).
[208] International Electrotechnical Commission (IEC). 2011."Electrical Energy Storage Whitepaper." (*IEC White Papers and Technology Reports*. https://www.iec.ch/whitepaper/energystorage/).
[209] David Linden and Thomas B. Reddy. 1995. *Handbook of Batteries*. Third Edition. (McGraw-Hill, 1995).
[210] C.H. Dustmann, Bito A. Safety, J. Garche, C. Dyer, P. Moseley, Z. Ogumi, D. Rand and B. Scrosati, Editors. 2009. (*Encyclopedia of Electrochemical Power Sources*. Vol 4. Amsterdam: Elsevier, p. 324–333, 2009).

It has also more recently been demonstrated that all of the resulting components of the recycling process, which includes nickel, salt, and boehmite, could be recycled. The nickel was reutilized in the stainless-steel industry, while the salt and ceramic was sold as a replacement for limestone used in road construction.

Case Studies:

The initial development of ZEBRA technology almost exclusively targeted the electric vehicle market and was the result of the effort of several integrated entities. In 1998, AEG Anglo Battery Holdings, which consisted of cooperation between the German entity AEG and the South-African Zebra Power Systems (ZPS) company, had advanced the technology to the production-ready level. In 1999, the Swiss company MES-DEA SA acquired the Zebra technology, including the production and development equipment and Beta Research & Development Ltd. In 2010, after successfully developing numerous ZEBRA cell prototypes in its laboratories, FIAMM Energy Technology S. p. A. (initially FIAMM Energy Storage Solutions) acquired MES-DEA SA, the only manufacturing company of sodium nickel chloride batteries in Europe, and founded the FZSONICK SA to produce cells and modules, to market its ZEBRA technology for stationary and grid applications. In 2017, Hitachi Chemical acquired 51% of its shares.[211] In addition, GE had also launched its Durathon sodium metal-halide battery for the UPS and utility markets and had officially inaugurated its new battery plant in New York in 2012.

By 2013, a few utility-scale projects were announced. By the end of 2015, a few systems in the 1 to 5 MW range built and started operations (Table 20). Terna SA, the owner of the Italian high voltage national transmission grid, commissioned a total of three sodium nickel chloride ES systems within 2014–2015. The two larger systems of 1.2 MW and 4.15 MWh were purchased from FIAMM and were installed in 2014 ([3], Table 20) and in 2015 ([4], Table 20), respectively. The smaller system of 1 MW and 2 MWh was purchased from GE and installed in 2014 ([5], Table 20). The Terna battery systems showed 90% efficiency at the module level (DC-based) while the AC-based efficiency dropped to 77–79%. These installations are part of Terna's grid-scale battery storage pilot projects consisting in the evaluation and comparison of several pilot-scales systems of different technologies, which are tested on the Italian grid for a wide range of applications. The ZEBRA systems have been tested for frequency regulation, voltage support, black start, transmission support, and transmission upgrades due to the wind, as the ultimate goal of the project is to increase the security of electricity systems in the Sicily and Sardinia islands with the installation of storage systems for a total 40 MW capacity.[212]

The 1 MW/2 MWh ZEBRA energy system from GE installed in North Cape Canada in 2014 is being used to integrate wind generation from the 10 MW Wind R&D Park located at Wind Energy Institute of Canada facility ([6], Table 20). As such, the systems' main applications consist of renewables capacity firming and renewable energy time shift. The 1.6 MW/4.5 MWh system from FIAMM was installed in French Guiana in 2015 at the Toucan solar plant to improve the quality and reliance of energy delivery and by absorbing excess solar power and delivering it when needed ([2], Table 20). Finally, a 5 MW/10 MWh system from GE was

[211] FIAMM website. (Accessed May 4, 2019. https://www.fiamm.com/en/north-america/company/history/).
[212] U.S. DOE Global Energy Storage Database. (Accessed May 5, 2019. https://www.energystorageexchange.org/).

commissioned in 2015 in the Annobon Island off Equatorial Guinea. The system powers an island-wide microgrid to provide reliable power and supply enough electricity to handle all of the island energy demand in case of power failure. As such, the systems applications consist of grid-connected commercial reliability and quality, grid-connected residential reliability, and microgrid capability.

The Durathon battery production in New York was halted in 2015. "Durathon battery technology is well-suited for certain applications, but isn't cost effective enough compared to other battery technologies," said Horne, GE's spokesperson. [213] However in 2017, GE Technology Development transferred its technology and know-how to a joint venture with a Chinese entity, Chaowei Lvna, based in Zhejiang. The goal is to continue the research, production, and sale of the Durathon battery, targeting the electric vehicle market.[214]

The ZEBRA batteries provide desirable attributes however it is still an emerging technology. The GE 1 MW/2 MWh system currently in operation in Canada ([2], Table 20) was acquired for $3 million resulting in $3,000 per kW and $1,500 per kWh. More information is needed on actual costs. However, at this stage of development and commercialization, ZEBRA technology may not be competitive enough in terms of proven reliability, performance and cost.

Table 20 Selected sodium nickel chloride energy storage systems showing reference number used for discussion, location, project name, commissioning year, power and capacity rating, duration time, siting, business model and applications. [215]

Ref.	Location	Project Name	Paired Grid Resource	Commiss.	Power	Capacity	Duration	Siting	Business Model	Energy Storage Tech.	Applications
#				Year	MW	MWh	h:mm		Owner		
1	Equatorial Guinea, Annobon Island	Annobon Island Microgrid	5 MW PV	2014	5	10	2:00		Third-Party	GE Energy Storage	Grid-Connected Commercial (Reliability & Quality), Grid-Connected Residential (Reliability), Microgrid Capability
2	French Guiana, Montsinéry-Tonnegrande	EDF EN Guiana, Toucan Project	5 MW PV	2015	1.6	4.5	2:48		Utility	FIAMM Energy Technology	Renewables Energy Time Shift
3	Italy, Codrongianos	Terna Storage Lab 1, Sardinia		2014	1.2	4.1	3:27	Transmission	Utility	FIAMM Energy Technology	Frequency Regulation, Voltage Support, Black Start, Transmission Support, Transmission upgrades due to wind
4	Italy, Ciminna	Terna Storage Lab 2, Sicily		2015	1.2	4.1	3:27	Transmission	Utility	FIAMM Energy Technology	
5	Italy, Codrongianos	Terna Storage Lab 1, Sardinia		2014	1	2	2:00	Transmission	Utility	GE Energy Storage	
6	Canada, North Cape	Wind Energy Institute of Canada Wind R&D Park and Storage System for Innovation in Grid Integration	10 MW Wind	2014	1	2	2:00	Secondary Distribution	Customer	GE Energy Storage	Renewables Capacity Firming and Renewables Energy Time Shift

[213] Stanforth, L. 2019. "GE proclaims success, despite battery plant closure." (*Times Union*. January 12, 2016. https://www.timesunion.com/tuplus-local/article/GE-proclaims-success-despite-battery-plant-6748205.php).
[214] J. Chlinder. 2017. "Patents and know-how power new GE move into China battery market." (IAM. January 16, 2017. https://www.iam-media.com/patents/patents-and-know-how-power-new-ge-move-china-battery-market).
[215] U.S. DOE Global Energy Storage Database. (Accessed February 4, 2019. https://www.energystorageexchange.org/).