Development of Advanced High-Power Batteries of Hybrid Electric Vehicle Applications

Joseph Carcone

POWERGENIX
10109 Carroll Canyon Rd
San Diego, CA 92131

ABSTRACT

The theoretical advantages of sealed rechargeable Nickel-Zinc batteries have been known for some time. They can be up to 35% lighter than conventional Nickel-Cadmium or Nickel-Metal Hydride batteries and up to 30% smaller. They are also more powerful, non-toxic and easily recyclable.

However, problems associated with the instability of Zinc have hampered their development. Previous batteries of this type have had problems with dendrite formation (a Zinc outgrowth within the battery than can lead to short circuits) and the changing of electrode shapes over multiple charges and discharges.

PowerGenix has solved the technical problems associated with Nickel-Zinc batteries, allowing their practical use in a number of applications. Using both a patented electrolyte and a patented electrode composition, PowerGenix has eliminated issues of dendrite formation and shape change of the Zinc electrode. The result is a size effective battery with low internal resistance and higher voltage than Nickel-Cadmium batteries, enabling significant space and cost savings. Obvious applications include power tools, high power military equipment, consumer 1.5 alkaline battery alternatives and emerging light electric and hybrid vehicles.

1 HEV AND MOBILITY

PowerGenix's Nickel-Zinc technologies offer many compelling benefits for use in hybrid electric vehicles and other mobility applications. Nickel-zinc offers the high-power, high-cycle life and required energy density to meet the high torque and discharge demands of many of these vehicles at cost effective performance levels. Nickel-Zinc also performs very well at both high and low temperatures, a key performance requirement for HEVs. And importantly, Nickel-Zinc is extremely safe, environmentally clean, and recyclable without any special handling needs.

Performance and cost aspects of Nickel-Zinc technology that compare very favorable to battery technologies used in HEVs today, or being considered for future use in HEVs include:

- Nickel-Zinc technology offers more energy density than the Nickel-Metal Hydrate batteries being used in HEVs today, providing for up to a 40% smaller and lighter battery, very attractive dynamics for HEV applications.
- Nickel-Zinc battery solutions for an HEV are less expensive than Nickel-Metal Hydrate because you need 35+% less cells, and the materials used in a Nickel-Zinc battery are less expensive than those used in a Nickel-Metal Hydrate battery. A Ni-Zn battery uses half of the Nickel required in a Ni-MH battery.
- Expensive safety power control systems and manufacturing processes required by Lithium-Ion batteries are not necessary for a Nickel-Zinc battery, making a Nickel-Zinc about ½ the cost per watt hour of a Lithium-Ion battery.
- The materials used in Nickel-Zinc batteries are not combustible, so they can not explode, making them inherently much safer than a Lithium-Ion battery.
- Both Nickel and Zinc are widely available and economically recoverable at levels needed to meet the expected large increase in demand to sustain a worldwide HEV market. It is unclear how a large increase in demand for Lithium would impact the availability and price of Lithium. Worldwide Lithium reserves are concentrated in South America and China, while the U.S. and rest of the world have limited reserves of economically recoverable Lithium.

PowerGenix intends to exploit the Nickel-Zinc price/performance, form and safety advantages for HEV and other light weight mobility applications. PowerGenix is currently developing a sealed rechargeable Nickel-Zinc D cell for use initially in smaller mobility applications such as scooters and power-assisted bikes. PowerGenix will then further develop this Ni-Zn D cell technology with select strategic partners for use in HEVs as an alternative to Nickel-Metal Hydrate and Lithium-Ion.

1.1 Cell Life Comparisons

There are several technologies which are in development that have potential to meet the demands of HEVs and the increase energy and power densities required for PHEV. The final battery solution will support a non-combustible engine assisted electric vehicle.

The current status of sealed rechargeable Nickel-Zinc technology today and in the near future clearly addresses power requirements dictated to the load requirements for vehicles in the HEV and low end PHEV segments.

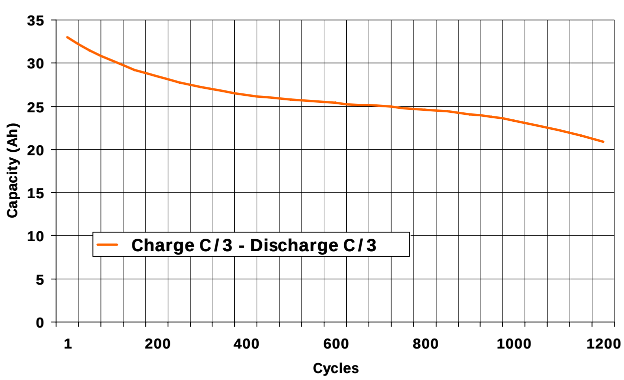
It is imperative that the battery system has a duty cycle and cycle life which address the overall power and life requirement of the vehicle.

Today, leading manufacturers are balancing the duty cycle with cycle life to support overall life requirements of 7 to 15 years which are necessary to meet customer expectations.

Due to early stages of development of a truly advanced hardened Nickel-Zinc technology, comparisons have been made between current NiZn designs and comparable Nickel-Metal Hydride and Lithium Ion technology. This indicates that NiZn can meet and exceed competitive technologies when tested in similar regimens.

The data supplier below indicates that Nickel Zinc has the potential to address HEV and PHEV duty and cycle life which are currently used in the market.

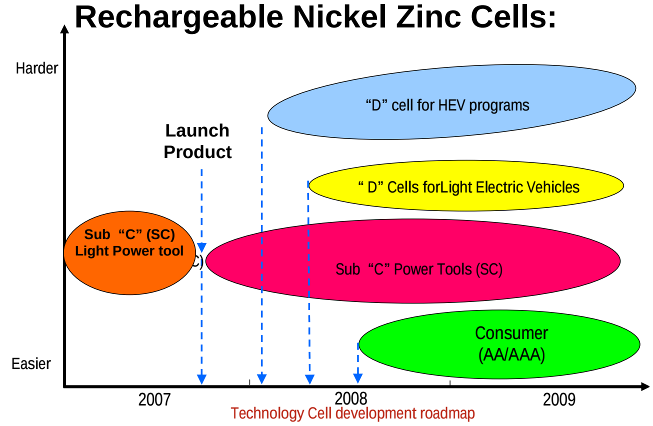
Cycling Curve – 30Ah NiZn Batteries
Charge at 80% of nominal capacity – Discharge 100%
Temperature: 25°C (77°F)



2 POWERGENIX: TECHNOLOGY OPTIMIZATION

- Performance
  - Energy Density
    - Positive/negative electrode formulation new materials
    - Low weight, high porosity substrates for Anode/Cathode
    - Separator: new weight and pore sizes
  - Cycle life
    - Cell design: Increase cell reserve charge Positive capacity
    - Reduction of oxidation of metals
    - Separator enhancements; thickness and oxidation levels
- Costs
  - Design for manufacture optimization
  - Metals and constituents costs management
  - Cost per Watt/Hr / Life cycle costs
- Ramp up requirements
  - Cell chemistry and design configuration
  - Testing validation program
  - Calendar life
  - Duty cycle/ Temperature environment
  - Shock and Vibration: Crash tests criteria

Technology/Product roadmap: Sealed Rechargeable Nickel Zinc Cells:



3 PATENT INFORMATION

- Electrolyte and Electrode Composition
- Charging Algorithms
- Cell Design
- Manufacturing Technology

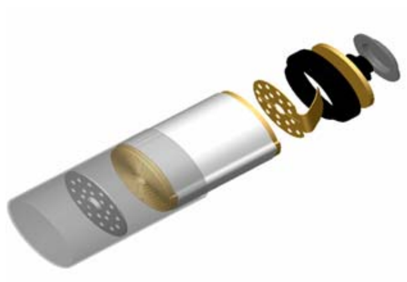
Initial cell design used in Power tools and other demanding high rate applications;

Sealed, Rechargeable Nickel Zinc cell with construction configuration: 1.6 Volts at 2.0 Amp Hours

- Cell configuration: Outer can – inner electrode spiral role: Cathode and Anode Electrical connection parts to top cover assemble and outer can
- Internal resistance optimized for high rate performance:
  - The high negative potential of Zinc allows for a high conductivity copper alloy current collector.
  - Pressure fitted, full contact negative current collector
  - Average cell impedance (AC): ~ 4 mΩ
  - Lower impedance equals increased power and torque.
  - Charge acceptance is optimized at high rates.

Clean Technology 2008, www.ct-si.org, ISBN 978-1-4200-8502-0

- Packaging constraints or limitations applicable to application and special conditions, such as vertical only orientation, minimum footprint, etc.
  - Current design is cylindrical cell and has no limitation to orientation
  - Footprint would be dependent on design objective



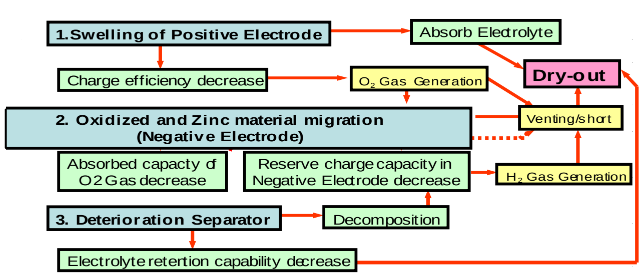
4 ENVIRONMENTAL BENEFITS

- No environmental or safety issues relating to manufacturing, recycling, use or disposal of the proposed technology.
- This technology has no known hazardous materials by design and all reoccurring by-products are at recognized non hazardous levels.
- There is no special material handling or process management due to hazardous material or process exposure in the work environment.
- All metal constituents are candidates for resource conservation recycling.
- Product meets specifications established in ***Ro HAS*** in the EU.
- All cell constituents are non combustible and will not set fire.

5 NICKEL-ZINC TECHNOLOGY OPTIMIZATION FOR HEV APPLICATIONS

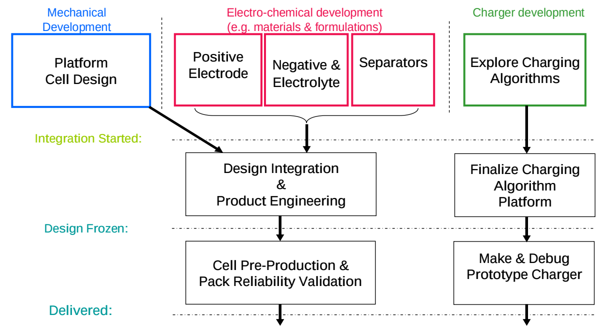
- Dominant failure mechanisms that limit life, and operational restrictions desired/required to maximize the life of the system.

Failure Mode Analysis: NiZn



6 DEVELOPMENT PROGRAM OUTLINE

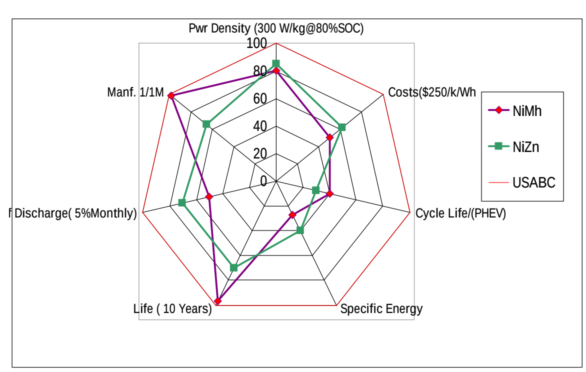
Nickel Zinc Cell Development Program



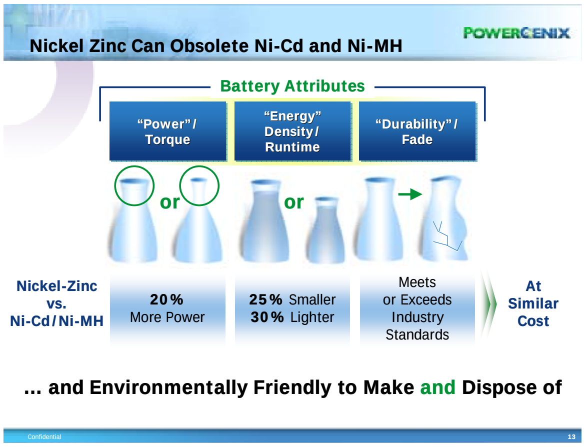
7 POWERGENIX SEALED NICKEL-ZINC TECHNOLOGY GAPS

- Cycle life/Calendar life
  - Cell design: Increase cell reserve charge Positive capacity
  - Reduction of oxidation of metals
  - New Separator materials
  - Electrolyte reformulation to address life targets
- Manufacturing
  - Implementation of automation and clean/sanitized manufacturing environment to critical process
  - Separator enhancements; thickness and oxidation levels cycle life
  - Cell design: Increase cell reserve charge Positive capacity
  - Reduction of oxidation of metals
  - Separator enhancements; thickness and oxidation levels
- Specific Energy:
  - Material studies related to energy densities and activation levels.

Performance Gaps/comparison to Nickel Metal Hydride technology
Reaching the outer perimeter is better



8 SUMMARY



USABC Goals

Characteristics	Units	Power-Assist (Minimum)	Power-Assist (Maximum)
Pulse discharge power (10s)	kW	25	40
Peak regenerative pulse power (10s)	kW	20 (55 Wh pulse)	35 (97 Wh pulse)
Total available energy (over DOD range wher ower goals are met	kWh	0.3 (at C1/1 rate)	05 (at C1/1 rate)
Minimum round-trip energy efficiency	%	90 (25-Wh cycle)	90 (50-Wh cycle)
Cold cranking power at -30°C (three 2-s pulses, 10 s-rest between	kW	5	7
Cycle life for specified SOC increments	cycles	300,000 (25 Wh cycles [7.5 MWh])	300,000 (50 Wh cycles [15 MWh])
Calendar life	years	15	15
Maximum weight	kg	40	60
Maximum volume	l	32	45
Operating Voltage limits	Vdc	Max ≤ 400 Min ≥ 0.55 x Vmax	Max ≤ 400 Min ≥ 0.55 x Vmax
Maximum allowable self-discharge rate	Wh/day	50	50
Temperature range: Equipment operation Equipment survival	°C	-30 to +52 -46 to +66	-30 to +52 -46 to +66
Production Price @ 100,000 units/year	$	500	800

PowerGenix Nickel Zinc Data comparison to USABC criteria: May 7, 2007

Characteristics	Units	Power-Assist (Minimum)	Power-Assist (Maximum)
Pulse discharge power (10s)	kW	50	79
Peak regenerative pulse power (10s)	kW	20 (55 Wh pulse)*	35 (97 Wh pulse)*
Total available energy (over DOD range where power goals are met)	kWh	0.3 (at C1/1 rate)*	0.5 (at C1/1 rate)*
Cycle life for specified SOC increments	cycles	300,000 (25 Wh cycles [7.5 MWh])	300,000 (50 Wh cycles [15 MWh])
Calendar life	years	15	15
Maximum weight	kg	36	56
Minimum round-trip energy efficiency	%	90 (25-Wh cycle)*	90 (50-Wh cycle)*
Cold cranking power at -30°C (three 2-s pulse, 10 rests between)	kW	5*	7*
Maximum volume	l	25	35
Operating Voltage limits	Vdc	Max ≤ 400 Min ≥ 0.55 x Vmax	Max ≤ 400 Min ≥ 0.55 x Vmax
Maximum allowable self-discharge rate	Wh/day	25	25
Temperature range: Equipment operation Equipment survival	°C	-30 to +52 -46 to +66	-30 to +52 -46 to +66
Production Price @ 100,000 units/year (200 cell battery)	$	$6.00/cell	$6.00/cell

*** = Meets specification requirements**

Underline= Undetermined however within the scope of technology

Clean Technology 2008, www.ct-si.org, ISBN 978-1-4200-8502-0