Benefits of ZPower's Silver-Zinc Rechargeable Batteries

Compared to Alternative Technologies

INTRODUCTION

Design engineers are continuing to innovate in the consumer electronics and medical device markets; developing smaller, yet more powerful devices. A primary challenge the designers face is how to miniaturize a device around the large batteries previously required for such applications. ZPower has developed the answer. The ZPower rechargeable cell is the smallest, high-energy density microbattery available; enabling a new generation of products by providing over 58 mWh in packages smaller than the collar button of your dress shirt. With hundreds of cycles, and no shipping or transportation restrictions, ZPower microbatteries are the safest way to power the next generation of hearable and wearable products. This white paper is intended to provide design engineers with greater detail on the benefits of integrating ZPower's rechargeable microbatteries into their own designs and how ZPower can support that effort.

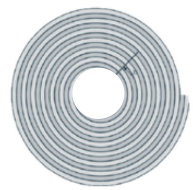
DID YOU KNOW?

ZPower batteries provide over **58 mWh** in packages smaller than the collar button of a dress shirt.

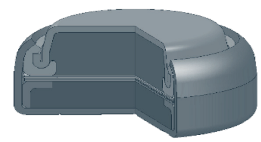
58 mWh of ZPower VS dress shirt button

HIGHER ENERGY DENSITY

ZPower has developed proprietary, silver-zinc microbatteries that offer higher energy density values than any other battery within the same volume range (< 250 mm^3). Today, ZPower microbatteries have an energy density of approximately 340 watthours per liter (Wh/L) at a size of 156 mm^3. Our cell's energy density remains high, between 320 and 370 Wh/L, even as the battery's volume changes.



Cross Section of Li-ion jelly-roll



ZPower XR41 Planar construction

Li-ion batteries maintain competitive energy densities at volumes above 625 mm^3, which is four times greater than the size of the XR41 silver-zinc battery with the equivalent energy density. But as the Li-ion cell shrinks to microbattery size, inherent constraints in the 'jelly-roll' implementation of the electrodes (smaller electrode widths, fixed separator thicknesses, shrinking jelly-roll diameters, and the volume lost in the center of cell due to the winding mandrel) all limit the amount of active material that can be placed in the cell; lowering the cell's capacity. Coupled with the significantly lower current density of the Li-ion electrodes (electrical current per unit area of electrode interface space), the Li-ion cell's performance scales down dramatically with size.

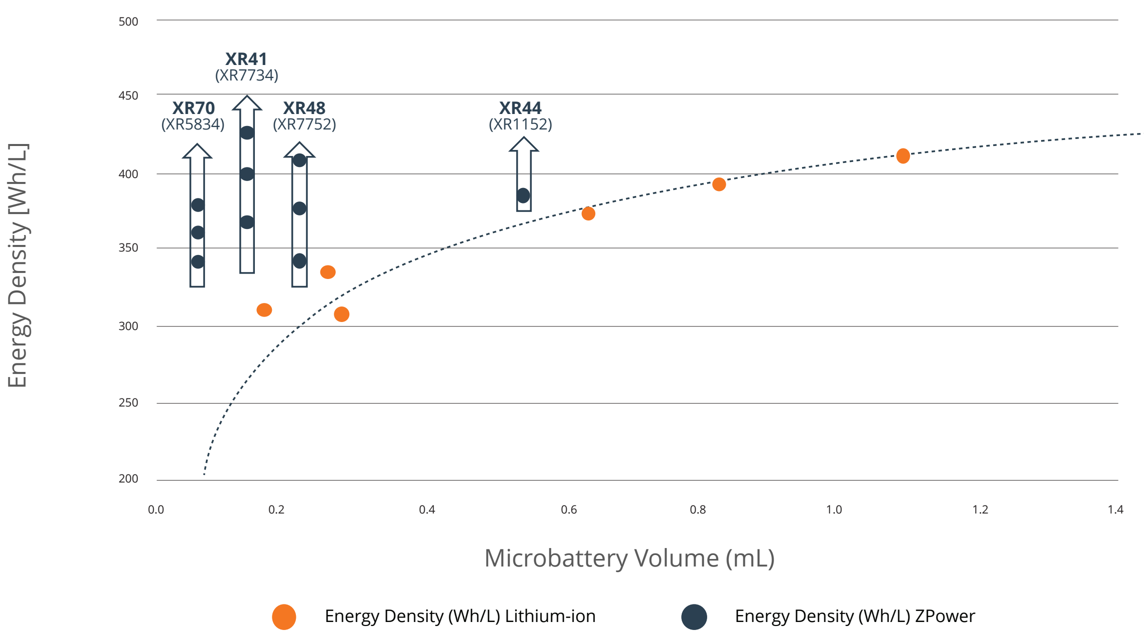


Figure 1. Energy density of AgZn compared to Li-ion.

Thanks to the significantly higher electrode current densities of silver-zinc batteries, ZPower makes the most efficient use of space in the microbattery size: planar cell construction. ZPower will be releasing products with even greater energy densities in 2019.

With respect to further improvements to energy density in the future, currently the silver-zinc cells utilize less than 60% of their theoretical capacity. This is done by design to ensure long cycle life. As improvements are made to the electrodes, electrolyte and charge algorithm; the available/rated energy density of silver-zinc cells will increase. The same cannot be said for Li-ion batteries that utilize 100% of their jelly-rolled materials.

DID YOU KNOW?

ZPower makes the most **efficient** use of space in the microbattery size.

SMALLER VOLUMES

Small volumes enable smaller devices. The cross-sectional area of a Li-ion microbattery would have to be 20% larger than a ZPower battery of equivalent height & energy. The difference is much greater when compared to batteries with NiMH chemistry, which has been the state-of-art for rechargeable hearing aids for the last several years. To provide the same energy, the NiMH battery would have to be 138% larger when compared to the soon-to-be released silver-zinc battery in 2019, please see Figure 2 for reference.

While the initial target of ZPower was the hearing aid market, where our silver-zinc batteries enabled the design of smaller, more comfortable devices; our small, high-energy microbatteries can also enable their use in and development of other miniature medical devices and wearables in the consumer electronics industry.

Figure 2. Battery diameters and relative sizes required to deliver 58 mWh of energy given a cell height of 3.35mm (size XR41) in 2019.

	XR44 Size 675 (XR1152)	**XR48** Size 13 (XR7752)	**Li-ion* Fat 48**	**Li-ion* Fat 312**	**XR41** Size 312 (XR7734)	**XR70** Size 10 (XR5834)
Capacity	130 mAh	50 mAh	25 mAh	25 mAh	35 mAh	18 mAh
Energy Density	388 Wh/L	341 Wh/L	309 Wh/L	333 Wh/L	370 Wh/L	341 Wh/L
Height (mm)	5.2 mm	5.2 mm	5.4 mm	4 mm	3.4 mm	3.4 mm
Diameter (mm)	11.5 mm	7.7 mm	8.4 mm	9.4 mm	7.7 mm	5.8 mm

*These represent non-ZPower, standard Li-ion cells.

Table 1. Overview of ZPower products in comparison to Li-ion batteries.

LONG CYCLE LIFE

ZPower has successfully tested over a full year of use at the cell's rated capacity (see Figure 3). Unlike Li-ion batteries, that lose a little capacity each cycle, the discharge capacity of the ZPower microbattery stays consistent thoughout the first 500 cycles of the device's cycle life. This provides the end user with a consistent runtime. ZPower's patented charging method is the critical part of how we extended the historically short cycle life of the silver-zinc battery.

The chart below details 500 cycles at 32 mAh of capacity. But if a design engineer's product requirements are for a greater cycle life, the charge method can be modified to provide 700 cycles or more, but at a slightly reduced capacity.

Although Li-ion batteries can be charged faster (2-3 hours) than silver-zinc batteries (<7 hours, for fully depleted); in most use cases: a) the user does not consume all of the battery's capacity and will require less time to charge and b) the device can be charged while the user sleeps, therefore charging in under 3 hours is irrelevant.

DID YOU KNOW?

ZPower microbatteries retain **>85%** capacity after **500 cycles** of the device's life.

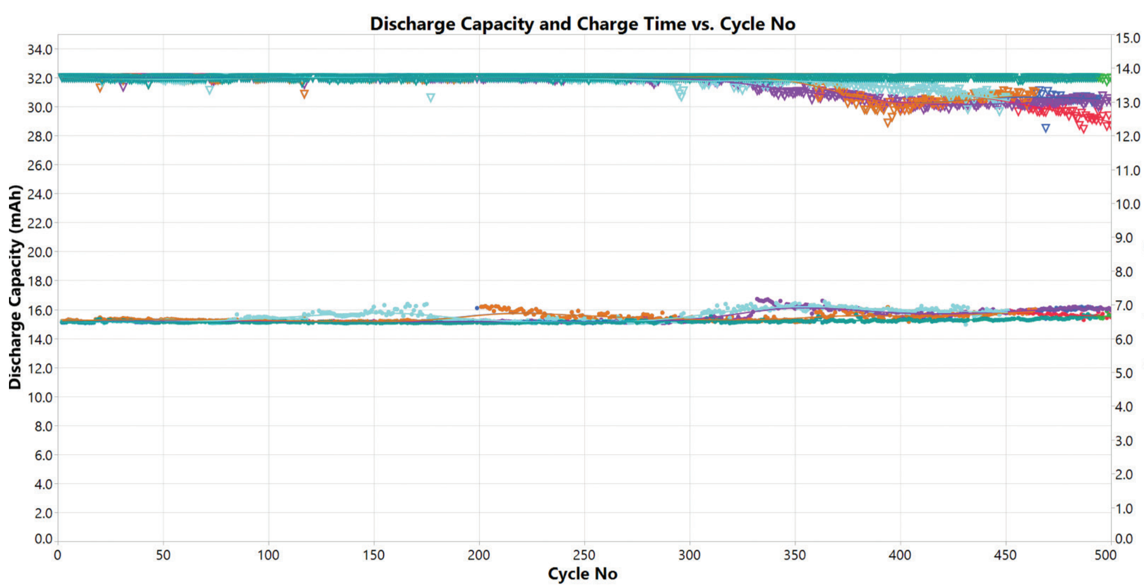


Figure 3. Example of capacity retention for over a year at one cycle a day at hearing aid application rates (~1.5mA).

SAFETY AND ENVIRONMENTAL BENEFITS

Silver-zinc batteries are aqueous (they contain water), so there is no threat of a thermal runaway or fire. Li-ion cells contain flammable electrolytes with air-sensitive lithium electrodes. Additional secondary safety circuits are required in all Li-ion designs to prevent voltage conditions that lead to the hazardous Li-ion failures seen in the media today. These secondary Li-ion safety circuits consume valuable design space and are not required in silver-zinc battery-based systems.

Another safety consideration to consider is cell ingestion. Because of the hazardous materials utilized in Li-ion batteries and because of the higher working voltages of the Li-ion chemistry (4.2-3.0V), the danger associated with ingestion of a microbattery is significantly greater with Li-ion cells. When swallowed, the saliva in the throat completes the circuit between the two electrodes of the battery, during which the pH of the water in the saliva is increased. This can result in the burning of the esophageal tissue and other internal organs. The higher voltages of the Li-ion batteries accelerate this damage and may lead to the battery opening and spilling its hazardous materials into the body.

Due to the unacceptable risk associated with ingestion, a device powered by a Li-ion microbattery must have the battery sealed into the device. As a result, any problem associated with the battery requires the entire assembly to be returned to the factory for service.

The smaller diameter and lower working voltage of silver-zinc cells mitigates the risk of harm; therefore they do not need to be sealed in the device to protect the consumer or patient. This allows for greater product design freedom. A design could allow the end-user the convenience of immediately changing the depleted silver-zinc cell with a fully charged silver-zinc or primary cell of similar size. There is no need to wait for a full charge. This feature is also beneficial in extending the device's service life. Devices with an old silver-zinc battery need only to have their battery replaced.

Silver-zinc batteries are recyclable. The water based electrolyte and the zinc anode are environmentally benign. Moreover the precious metal in the cell is a commodity and in high demand for other markets and applications; therefore, the silver puts our cell in a high-value recycling stream. Li-ion cells are recyclable as well, but they must be treated as hazardous and dangerous goods. Because of this, they are more expensive to handle and process. The flammable electrolyte of the Li-ion cells is not recyclable and must be burned off to recycle the lithium and other metals, this means that they have a greater carbon footprint relative to silver-zinc batteries. Because of these environmental and safety benefits, silver-zinc batteries should be preferentially utilized in devices that have to be worn on the human body, medical or consumer, especially within the ear or around the head and neck area.

DID YOU KNOW?

Silver-zinc batteries are aqueous so there is **no threat** of thermal runaway or fire.

TRANSPORTATION CONSIDERATIONS

Because silver-zinc batteries are aqueous batteries, they are treated and handled the same as other common alkaline batteries, there is no threat of fire. In fact, silver-zinc batteries have the analogous anode and electrolyte as with common primary AA and AAA batteries, it is the positive electrode in the silver-zinc battery that enables its rechargeability.

ZPower silver-zinc batteries do not need to be restricted from any mode of transportation. In contrast, most Li-ion cells are categorized as Class 9 dangerous goods and are restricted to cargo airlines for bulk shipments. Also, the state-of-charge (SOC) of shipped Li-ion cells is now required to be less than 30%. This can be a big drawback for consumer and other applications where there is a long delay between the production date and the day of first use. Parasitic current drains can take depleted batteries into an overdischarged / zero voltage state resulting in either poor or non-functioning products out of the box. Conversely, silver-zinc cells can be shipped at 100% SOC and not under a Class 9 designation which reduces both risk and cost, respectively. Shipping Li-ion cells in bulk is high risk and expensive; and going forward IATA and industry regulations only look to add further restrictions.

DID YOU KNOW?

ZPower silver-zinc batteries do not need to be restricted from any mode of transportation.

CURRENT MARKET APPLICATIONS

ZPower's silver-zinc rechargeable microbatteries were initially used in the hearing aid market. Hearing aids have been primarily designed for disposable zinc-air batteries that operate in the range of 1.2V to 1.45V and end of life voltage around 1V. Hearing aids are particularly sensitive to size constraints, with the manufacturers attempting to make them as small as possible. The small product size often makes the replacement of the primary battery a cumbersome process, especially for less dexterous end users. ZPower silver-zinc batteries, with their higher energy density, are an excellent rechargeable alternative. But to enable the ability to be a drop-in replacement for the existing hearing aid designs, additional circuitry was required. The incorporation of custom electronics and a battery door allowed for the efficient regulation of the silver-zinc voltage plateaus into the zinc-air operating voltage range and enacts an efficient end of discharge cycle protocol (see Figure 4).

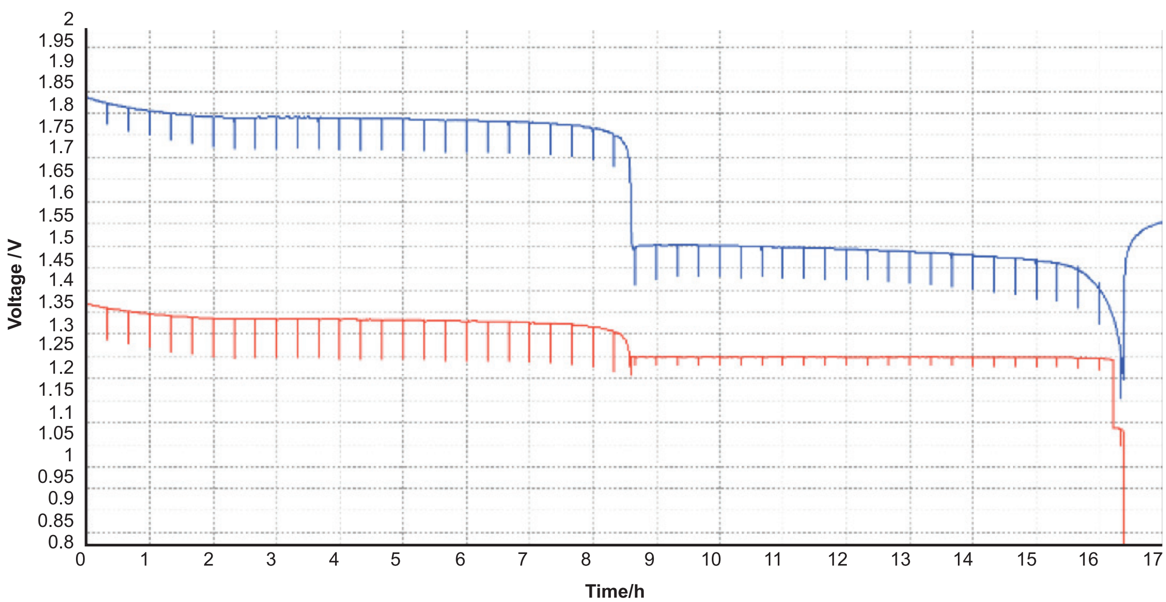


Figure 4. Silver-zinc discharge voltage profile (blue) and ASIC's regulated voltage output (red) to adapt to hearing aid electronics.

A similar strategy can be employed to accommodate Li-ion batteries in hearing aids, however the batteries must be larger to match the performance of silver-zinc batteries. This means that the hearing aids themselves must also be larger, which could cause discomfort to the wearer.

SILVER-ZINC CELL PARAMETERS

Many design engineers are familiar with the operating characteristics of Li-ion cells but have never considered using a rechargeable silver-zinc microbattery to power their design. As the chemistries differ between the two technologies, so do their operating parameters. Figure 5 provides a high-level summary of the major differences.

One of the first differences to consider between the two chemistries is working voltage. A fully charged silver-zinc cell has an open circuit voltage (OCV) of 1.85V. If the cell is discharged below 50% state of charge, the OCV of the cell becomes 1.59V. Under load, the cell's working voltage depends on many factors (SOC, discharge rate, temperature) but will typically operate in the two voltage plateaus shown in the blue curve of Figure 4. These stable plateaus provide consistent voltage rails but make simple, voltage-based gas-gauging impractical.

The silver-zinc cell is fully discharged when the battery voltage drops below 1.3V. Below that threshold, the battery's voltage drops quickly and very little energy remains in the cell. Discharging the cell below 1.2V is not recommended as over-discharging can lead to a degradation in cell performance. The ZPower microbattery can support continuous discharge rates up to 5 mA (~C/7) with pulses in the order of 18 mA (~C/2). These rates, although lower than the maximum rates of Li-ion cells, are ideal for many of the latest generation ARM microprocessors of Bluetooth Low Energy radios.

Charge times for the ZPower battery are typically twice that of Li-ion's standard charge rates. This is a result of the silver-zinc cell's construction, particularly the separator stack. Development work continues in this area, but charge times can be reduced at the expense of some capacity.

	Microbattery Size Limitations	Operating Voltage	Typical Drain Rates	Typical Charge Rates	Discharge Temperature
Silver-zinc:	None	1.85V -> 1.3V	Up to C/7 with C/2 Pulses	C/6	0 ºC to 85 ºC
Li-on:	> 200 mm^3	4.2V -> 3.0	Up to 2C with 3C Pulses	C/2 -> 2C	-20 ºC to 60 ºC

Figure 5. Comparison of miniature battery parameter ranges.

Above 0˚C, the operating characteristics of silver-zinc cells are like that of Li-ion, a minor performance hit to available capacity as temperature drops. All batteries suffer at cold temperatures; but the safe, water-based electrolyte we use in our cells is not suited for operating temperatures below 0˚C. Despite that restriction, the small size of the ZPower microbattery makes it ideal for body worn hearables & wearables where body temperature helps keep the battery in an ideal temperature zone. Figure 6 details the effects of temperature and discharge rate on the cell's available energy.

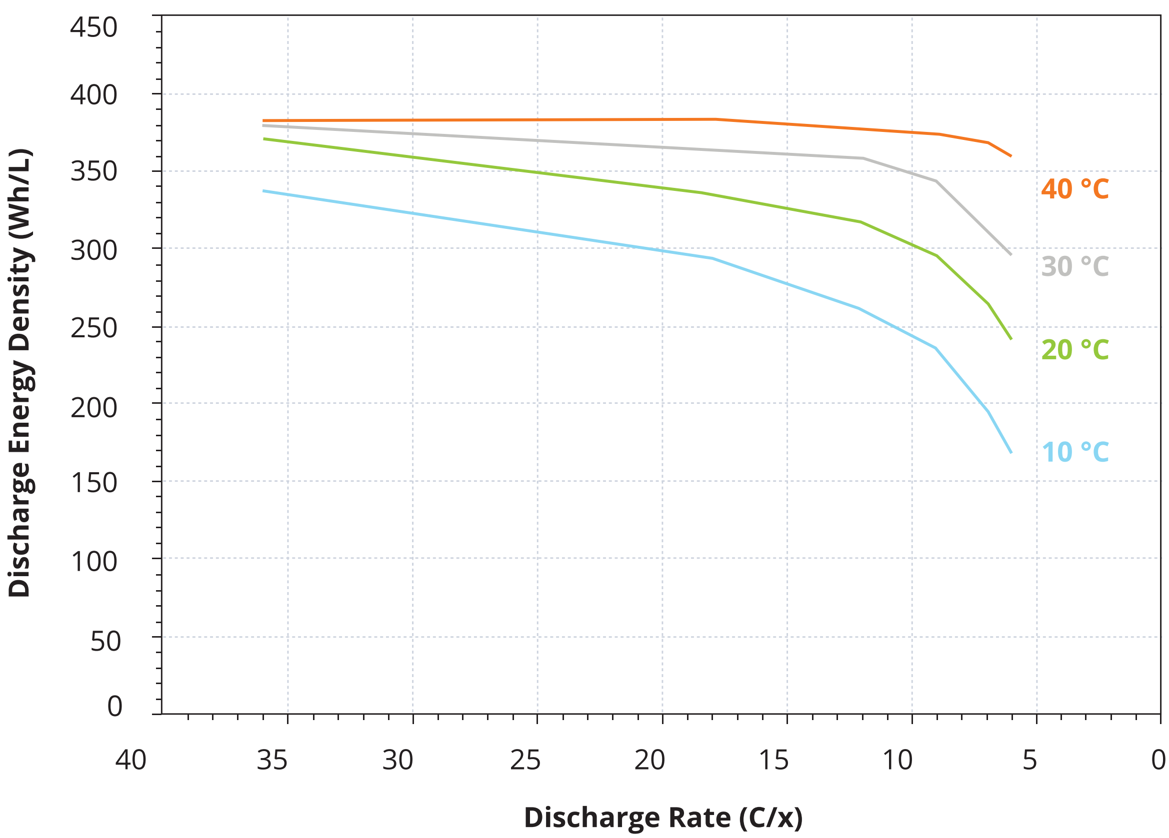


Figure 6. Average Energy Densities with respect to applied rate and temperature with a C/6 charge.

PROPRIETARY CHARGE ALGORITHM

Prior to ZPower's development efforts, the primary barrier to wide acceptance of silver-zinc rechargeable batteries in the commercial market was the short cycle life (under 20 cycles). The combination of our cell's construction and the patented charge algorithm combine to create the first silver-zinc battery to shatter that limitation, providing hundreds of cycles with the safest & smallest high energy battery on the market today.

The charge method was developed to insure a bare cell could be charged to its rated capacity without the benefit of a Battery Management Unit (BMU) providing data to the charger. The silver-zinc charger uses a similar CC-CV method to charge Li-ion cells, but with different limits. The CC limit is defined by the cell's capacity. The CV limit can vary based on the cell's SOC and other factors. The conditions at which the silver-zinc charger terminates charge is different than Li-ion chargers. The Li-ion charger terminates on a trickle current condition.

A typical CC-CV charge profile is shown in Figure 7, but the charge algorithm can be tailored to different applications or use conditions.

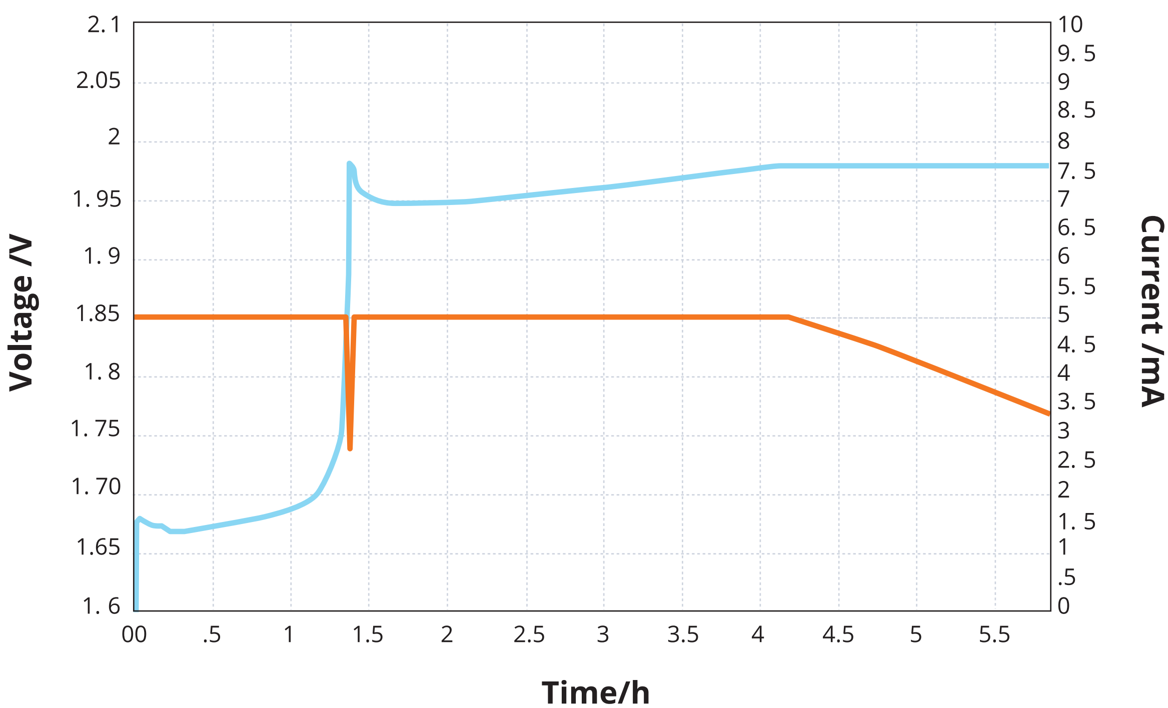


Figure 7.
Typical charge profile.

CONCLUSION

This white paper details the benefits of ZPower's rechargeable microbatteries for designers and engineers aiming to create new and disruptive products. ZPower's rechargeable cell is the smallest, high-energy microbattery available to innovators looking to shrink the next generation of consumer & medical products. Today, our safe silver-zinc battery chemistry, high energy densities and long cycle life align with the requirements of tomorrow's devices.

ZPower is one of the fastest growing companies in the United States and is ranked #82 on the 2018 Inc. 5000 list for America's Fastest Growing Private Companies. Our growth will continue next year with further expansion of our production capacity to support the growing demand. Let us know how we can help support your efforts.

	ZPower Silver-Zinc	Nickel Metal Hydride	Lithium-ion
Energy Density	●●●● Smaller Sizes Than Li-ion	●●○○	●●●○
Logistics	●●●● No Restrictions, 100% SOC	●●●●	○○○○ Hazardous Goods, <30% SOC
Regulatory	●●●●	●●●○	○○○○
Safety	●●●● Non-flammable	●●●●	○○○○ Highly Flammable
Cycle Life	●●●○	●●●○	●●●●
Eco-Friendly	●●●● Recyclable	●○○○	○○○○ Downcycled Waste
Right to Repair	●●●● Consumer Replaceable (Safe to handle)	●●●●	○○○○ Requires OEM Service

Figure 8. Summary of benefits of silver-zinc cells with respect to other chemistries.