Design Advantages of Solid State Batteries versus Supercapacitors

Introduction

This paper details the important differences between Rechargeable Solid State Battery technology and legacy Supercapacitor technology. Understanding these differences will enable electronics designers to leverage the advantages of Solid State Batteries in their new products. As shown in Figure 1, there are four Key Technology Drivers for product innovation:

- Ultra Low Power Electronics
- Wireless Smart Devices
- Integration and Miniaturization
- Eco-Friendly Renewable Energy

Legacy Supercapacitors and coin cell batteries do not have the characteristics to meet the requirements of new products. To leverage these technology trends in new product designs, a new type of energy storage device must be used.

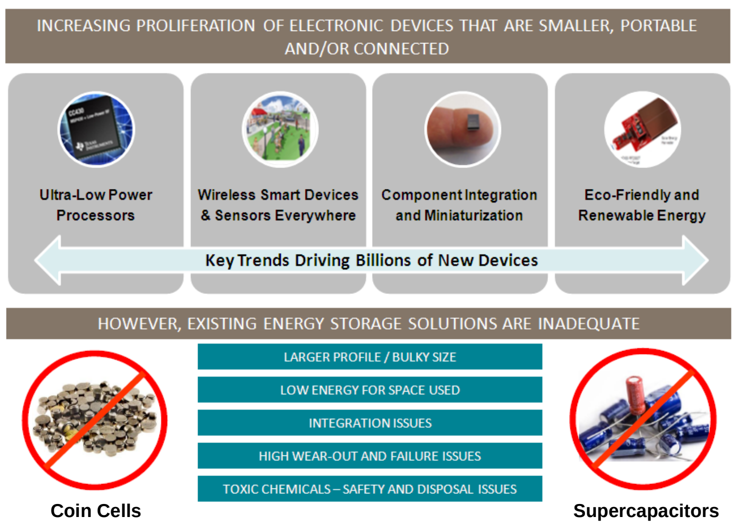


Figure 1: Key Innovation Trends Drive the Need for Solid State Batteries

Unique EnerChip Rechargeable Solid State Battery Construction

EnerChip Solid State Batteries are fabricated on silicon wafers using semiconductor processes as shown in Figure 2. As will be demonstrated later in this paper, Cymbet customers use EnerChip bare die or packaged parts as shown in the mobile phone application in Figure 3.

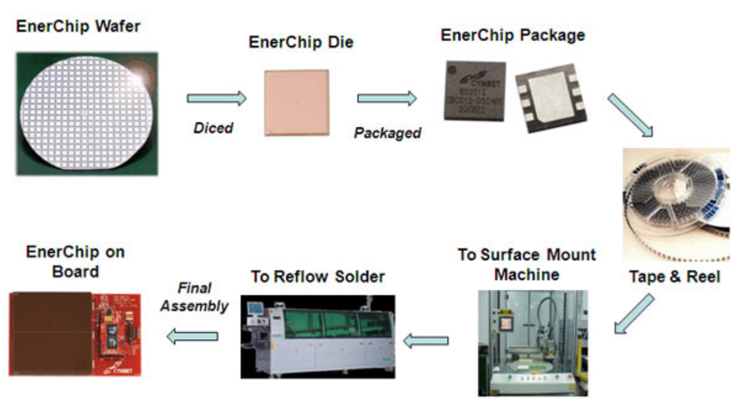


Figure 2: EnerChip Wafer Fab to Bare Die to Packaged Parts to SMT/Reflow to Board

Identifying Product Power Backup Requirements

In order to calculate the energy storage requirements in the various power modes of a new product design, it is important to ask the following questions:

a. Is the energy storage device backing up time and/or data registers?
b. What is the current draw of the Real Time Clock or MCU device?
c. What duration of backup time is required? Note that 99.7% of customer applications require < 4 hours.
d. Is a small footprint, thin package important?
e. Are there existing reliability, assembly, or warranty issues with Supercapacitors or coin cell batteries in a current design?
f. Is WEEE Directive product disposal or battery replacement important?
g. Is SMT, RoHS, REACH and automated assembly needed?

Having answers to these questions often indicates that the power backup solution can be solved by an EnerChip Rechargeable Solid State Battery or a Supercapacitor. Figure 3 shows how an EnerChip CC CBC3105 could be used in a mobile handset power backup secondary battery application. The CBC3105 is priced competitively to typical Supercapacitors used in this application.

Figure 3: EnerChip CBC3105 used in a Mobile Phone Secondary Battery Application

Many technical considerations that were design requirements for the mobile application in Figure 3 are described in the next section.

12 Technical Advantages of Solid State Batteries vs. Supercapacitors

When choosing an energy storage technology, it is important to identify the total cost of ownership that takes into account product requirements such as: assembly costs, PCB footprint, component height, external circuitry, service life, storage capacity, and other factors in addition to the base component purchase cost. The following key technical requirements must be reviewed and prioritized in order to optimize energy storage device selection for new product designs. *In each area, Solid State Batteries have unique advantages over Supercapacitors:*

1. **Low Self-Discharge** – EnerChip batteries have minimal self-discharge – on the order of 1-2 percent per year as opposed to the 10-20% per day of a supercapacitor. The high daily energy loss of supercapacitors requires the entire power system to be over-designed to compensate for these losses, which in turn increases cost and requires additional components.

2. **Small Footprint, Low Profile** – With the miniaturization of new products, a small size or thinner energy storage device is required. Packaged EnerChips are as small as 4mm x 5mm x 0.9mm. EnerChip bare die are only 150 microns thick. Many Supercapacitors are much thicker or larger, occupying more board space and volume within the end system.

3. **SMT/Reflow Solder Assembly** – EnerChips are delivered on tape-and-reel and are compatible with Pb-free reflow soldering processes. This eliminates hand soldering or using SMT sockets and assembly often required with Supercapacitors, which adds material and labor cost and reduce reliability. Supercapacitors are generally de-rated in capacity if they've been soldered at high temperature; also Pb-free tolerant supercapacitors can cost as up to twice that of devices not rated to Pb-free reflow temperatures.

4. **Minimal Device Aging** – This is a critical feature when long cycle-life is a requirement. EnerChips provide high charge/discharge cycle life and stable performance over time. After 5,000 cycles at 10% depth-of-discharge, EnerChips retain 80% of specified capacity. Supercapacitors are affected by temperature, voltage, age, cycling, and other factors, and this information is not typically specified in Supercapacitor datasheets. Typical vendor specifications for capacitors identify 1000 or 500 hours of service life for a Supercapacitor at elevated temperature.

5. **Higher Output Voltage** – EnerChip batteries provide a level output voltage – 3.8V from the EnerChip and 3.3V from the EnerChip CC products – until the device is completely discharged down to 3V at cutoff. This voltage profile allows nearly all of the stored charge to be delivered to the load at a useful voltage. Many Supercapacitors are specified at 2.6V output voltage, and this voltage decays with discharge. As a result, the narrow *usable* voltage range limits the operating margin for designers.

6. **Flat Output Voltage** – Many product designs require all the energy from a storage device to be delivered at a stable output voltage. EnerChips provide most of their energy capacity at 3.6V and higher (3.3V for the EnerChip CC products). Even with 95% of the capacity exhausted, the EnerChip delivers charge at an output voltage of greater than 3.6V! Supercapacitors produce an output voltage that is linearly proportional to their charge. For example, a Supercapacitor fully charged to 3.3V will deliver 3.3V at 100%; but at 50% charge, the voltage will be only 1.65V, which is below the level at which many processors and other devices will operate. If this cannot be tolerated, a boost circuit on the backup power rail might be needed, adding cost and circuit complexity.

7. **Faster Charge Time** – EnerChips charge quickly – just 10 minutes to 80% rated capacity – using simple constant voltage charging, with no constant current phase or safety circuit required. Conversely, many Supercapacitors are charged with a recommended current-limiting series resistor that results in a long charge time.

8. **Safe Non-Cytotoxic Biocompatibility** - Gamma sterilized Cymbet EnerChip™ bare die batteries were found to be non-cytotoxic (0% cell lysis) using both the Medium Eluate Method Eluation Test and Agar Diffusion Test feasibility screening procedures. The lack of any adverse biological responses in these very sensitive in vitro cell culture assays is indicative (although not a guarantee) of biocompatible test results in the other in vitro and in vivo aspects of biocompatibility as suggested by the ISO 10993-1 and FDA G95-1 guidelines.

9. **Temperature Range Documentation** – There are similarities in the effects of temperature on the long term performance of both Supercapacitors and EnerChips. However, the effects of the EnerChip under these conditions are well understood and documented in Cymbet's data sheets and Application Notes. This is not true for many Supercapacitors on the market today. Clarity of EnerChip temperature specifications enables designers to create a power solution that is robust and meets the system requirements.

10. **Long Term Energy Storage** – Supercapacitors were designed to filter out short term voltage transients and have high self-discharge; consequently, they are inherently ill-suited for long term storage of energy for backup or energy harvesting applications. This affects many customer applications ranging from: A microcontroller or RTC that needs several hours/days of backup time; an Energy Harvesting solar-powered thermostat in a conference room that needs to operate at a reduced level of functionality for several days before the lights are turned back on; or a device that stores energy when it is manufactured and might sit on a shelf for many years before it is activated and used. To compensate for the leakage and losses in a Supercapacitor-based energy storage system, designers are required to "over-engineer" the power solution, which adds significant cost and device footprint size to the system.

11. **Enhanced Integrated Functions** – Designers often have requirements for a supply supervisor with brown-out detection or other power management functions. If so, the power management features of the EnerChip CC 31XX product family with integrated battery management can provide some of these capabilities and reduce the cost of the Bill of Materials by removing a power supply supervisor chip or other power management device.

12. **Energy Density Increases & Cost Reductions** – Supercapacitors are built using many of the same fabrication techniques used for many years. Fabricating EnerChips using IC processing and packaging enables Cymbet to realize cost reductions and density improvements in the same way the entire semiconductor industry has enjoyed for years. Cymbet will utilize chip-scale packaging, innovative attach methods, new materials and advanced processing technologies to significantly reduce the EnerChip cost structure while dramatically increasing its energy density to compete with the more mature capacitor technologies.

Important Component Size and Cost Comparisons

When choosing an energy storage device, it is important to compare two key criteria:

- <u>Compare the size</u> of the energy storage devices in terms of board footprint and height: Footprint x thickness = device volume. Figure 4 shows the comparison of a variety of commonly used Coin Cells, Supercapacitors and EnerChips that would be used in power back-up applications. Each of the devices has the energy storage capacity to perform the energy transaction required by the back-up application. **Note that EnerChips have smaller physical volume compared to Supercapacitors.**

- <u>Compare the normalized cost</u> of the energy storage devices. Figure 5 shows the comparison of a variety of commonly used Coin Cells, Supercapacitors and EnerChips that are used in power back-up applications. Each of the devices has the energy storage capacity to perform the energy transaction required by the back-up application. **Note that in almost all comparisons, EnerChips have a cost advantage compared to Supercapacitors.**

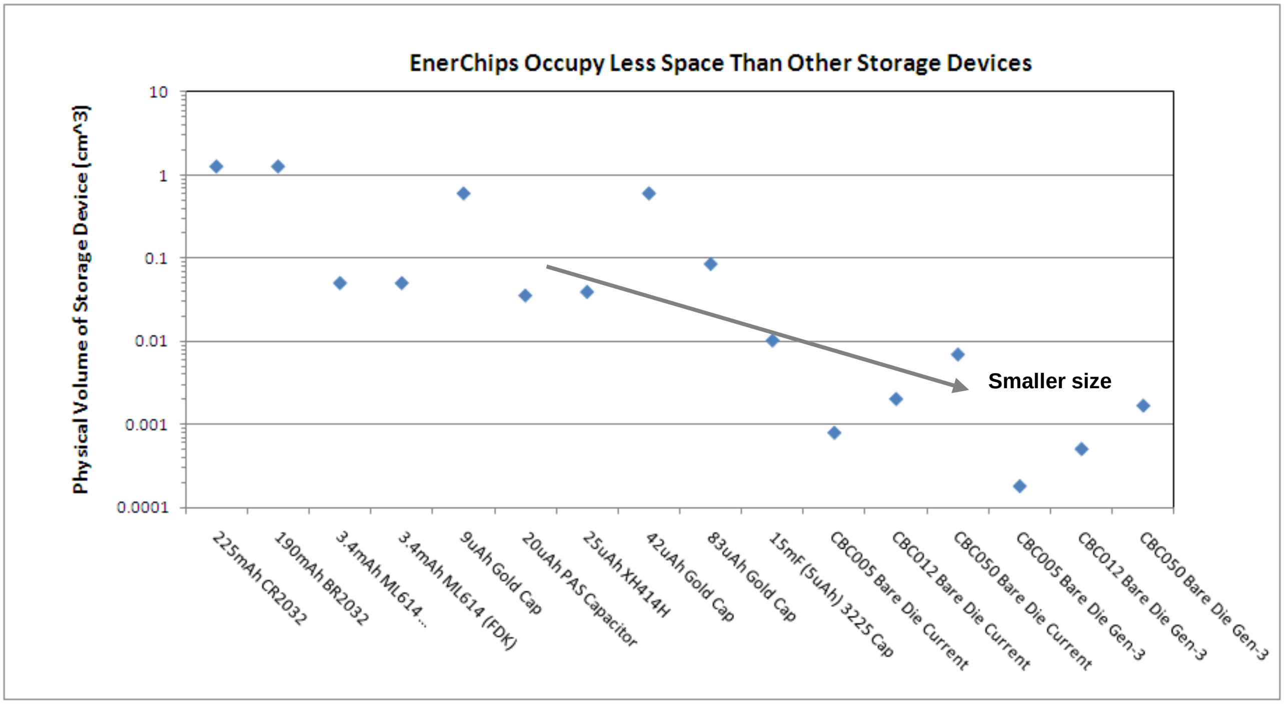


Figure 4: Comparing Device Volume (cm^3) of Coin Cells, Supercapacitors and EnerChips

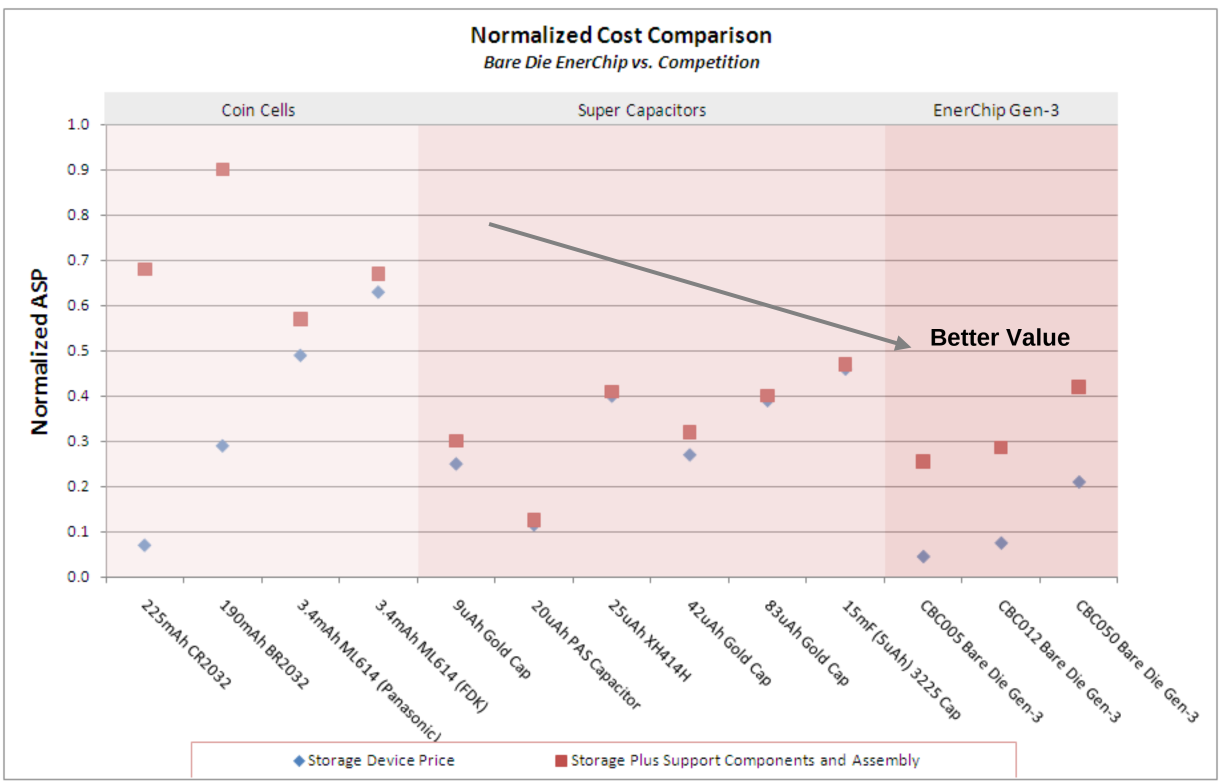
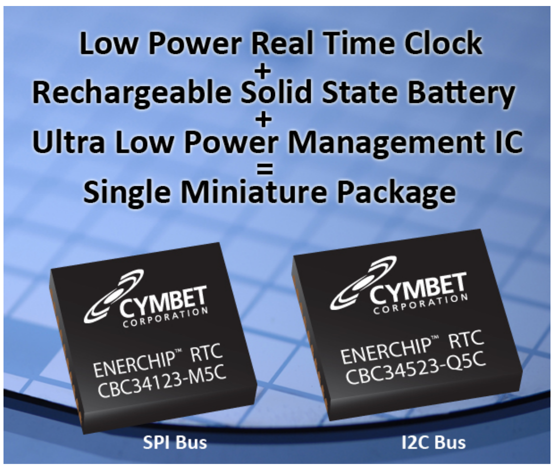


Figure 5: Comparing Normalized Average Selling Price

Advantages of Integrating Solid State Batteries into Co-Packaged Devices

One area where EnerChips are significantly different from Supercapacitors is the construction of the device. EnerChips are built on silicon wafers as bare die and can be co-packaged with other IC devices to create extremely small and dense system solutions for medical, sensors, commercial, consumer and industrial applications in innovative packaging solutions that Supercapacitors and conventional coin cell batteries cannot match.

An excellent example of this "Embedded Energy" capability is shown in Figure 6, where an EnerChip 5µAh bare die battery is co-packaged with the NXP PCF2123 Real Time Clock chip and the Cymbet CBC910 Power Management ASIC into the EnerChip RTC Cymbet CBC34123.



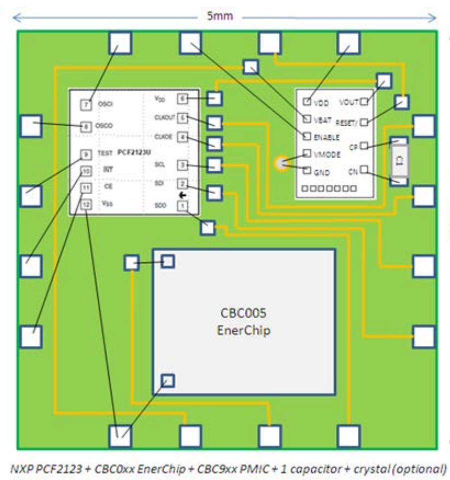


Figure 6: EnerChip Bare Die Integration in the Cymbet CBC34123 RTC with Integrated Battery

Final Thoughts

This white paper has provided electronic designers important technical background for making an informed energy storage device selection decision. It is critical that the following device selection criteria are reviewed:

- Identify the energy transaction requirements for all the operating states of the product design. There are differences between primary (non-rechargeable) batteries, rechargeable Supercapacitors, and rechargeable Solid State Batteries.
- List and research all of the device requirements – footprint, height, assembly techniques and costs, environmental standards, temperature range, voltage output characteristics, current output, charging methods and charging times, life expectancy of product, device aging, storage device component cost, and implications to warranty cost.
- Understand how the key technology drivers listed in the Introduction affect the new product design. Choose energy storage components that support these trends.

When all product design requirements are identified and the characteristics of energy storage devices are completely reviewed, the resulting conclusion is rechargeable Solid State Batteries offer unique advantages over Supercapacitors and should be utilized in new product designs.