Executive Briefing

Avoiding an Energy Storage Crisis:

The 8 Key Competitive Advantages of Solid State Batteries

By Steve Grady

Introduction

If electronics manufacturers have a motto, it's probably this: *Innovate or Die*.

For years, the industry's rapid rate of innovation and consumers' insatiable demand of for greater capability and convenience have driven each other in a relentless upward spiral. Products that don't meet customer expectations are quickly replaced. Companies that don't heed those expectations rapidly lose market share.

For the most part, the electronics industry has done an amazing job of maintaining a high rate of capability increase and cost reduction. From wafer size to memory density to processor speed… capacity has doubled every two to three years and will continue to do so for many more. Innovations in system design, chip packaging, wireless and other technologies are bringing additional gains.

But one domain has failed to keep pace: Energy Storage.

For years, electronics manufacturers have relied on just two technologies for offline energy storage: conventional cell batteries and supercapacitors.

But both of these technologies are decades old and hold marginal promise for further efficiency gains. Plus, they each have limitations that make them unsuitable for some applications, complicate power supply design and interfere with the latest manufacturing processes.

The challenges have become so great that the authors of the latest *International Technology Roadmap for Semiconductors*[i] say, "power management is now the primary issue across most application segments."

Fortunately, a new energy storage technology has emerged, one which overcomes the deficiencies of chemical cell batteries and supercapacitors, and which promises to solve the electronics “energy storage crisis.” That technology is the **solid state battery**.

This paper will demonstrate the 8 key competitive advantages solid state batteries offer electronics manufacturers.

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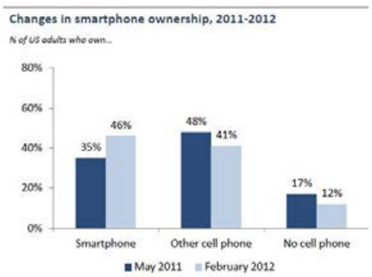

Fig. 1: Smartphones now outnumber other cell phones in the U.S.

Source: Pew Research Center's *Internet and American Life Project*, Apr-May 2011 and Jan-Feb 2012.

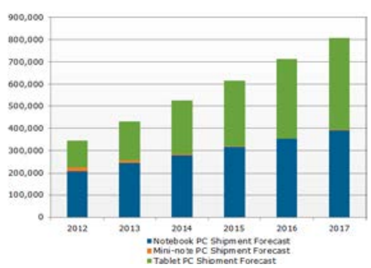

Fig. 2: Tablet PC shipments set to surpass laptop PC shipments by 2016

Source: NPD DisplaySearch *Quarterly Mobile PC Shipment and Forecast Report*, July 2012.

Ten Key Trends Driving Electronics Innovation

The following trends have been driving electronic product design – as well as consumer and industrial demand – for the past several years:

1. **Miniaturization.** Scale reductions continue to improve device economics.
2. **Integration.** System-on-chip (SoC) and system-in-package (SiP) solutions are compounding gains from scaling.
3. **Smart Devices** are adding greater capability and convenience to more and more products.
4. **Ultra-low Power** processors are creating a boom in micro-scale embedded systems.
5. **Wireless** connectivity is transforming networking and mobility.
6. **Sensor Networks** are revolutionizing industrial control, medical monitoring, asset tracking, and other product domains.
7. **High Reliability** is increasingly important in most purchase decisions and a major concern in safety-critical applications.
8. **Renewable Energy** is becoming a key issue in high-reliability and zero-maintenance applications.
9. **Eco-Friendliness** is increasingly important as safety and environmental regulations tighten.
10. **Lower Cost** improves profit margin and market share.

Consumer appetite for “smaller, thinner, lighter, smarter and more mobile” is fuelling many of these trends: Smartphone users in the U.S. already outnumber users of more basic cell phones.[ii] Wireless devices now outsell PCs.[iii] By 2016, shipments of tablet PCs are expected to top those of laptops.[iv]

And all these trends continue to accelerate. Rather than tapering off, they are expected to drive our industry for many years to come.

While some pundits have begun predicting the end of Moore’s Law, the latest *International Technology Roadmap for Semiconductors* (ITRS) contends continued research and development "have brought about reacceleration and diversification of scaling. MPU density should continue to double on a two-year cycle through 2013 and on a three-year cycle afterwards. Flash device scaling will sustain bits/chip doubling on a two-year cycle. And DRAM is on a three-year cycle."[v]

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- The International Technology Roadmap for Semiconductors: 2011

Integration of system-in-package (SiP) solutions will become increasingly important, say the *ITRS* authors. Embedded components, integrated passive devices and 3D stacking will be used more extensively to integrate off-chip components.[vi]

Even greater advances are expected in wireless connectivity, sensor networking and smart systems.

Wi-Fi, even after enormous recent expansion, seems set to explode with the introduction of Next Generation Hotspots (NGH) and Wi-Fi roaming, starting in 2013. The Wireless Broadband Alliance says NGH and Wi-Fi roaming will allow users to seamlessly connect to Wi-Fi hotspots without the need for usernames and passwords. These advancements will help operators “establish relationships with each other, so their users can access a wide variety of Hotspots in their own country and around the world.”[vii] As a result, the Wi-Fi Alliance expects the number of nonresidential Wi-Fi hotspots to grow rapidly, at least through 2015 (Figure 3).[viii]

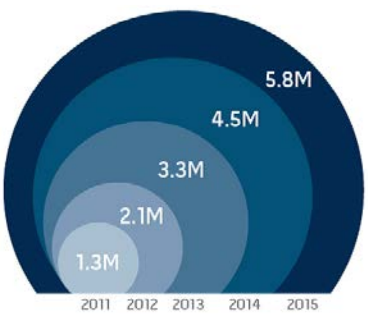

Fig. 3: Projected global growth in Wi-Fi hotspots through 2015

Source: Wi-Fi Alliance, *Wi-Fi Certified Passpoint*™, February 2012

Wireless sensor networks (WSN) “will eventually enable the automatic monitoring of forest fires, avalanches, hurricanes, failure of country wide utility equipment, traffic, hospitals and much more over wide areas, something previously impossible,” says technology research firm IDTechEx. They expect a *four-fold increase* in the WSN market over the next 10 years.[ix]

And network technology consultancy Harbor Research believes the “smart device boom” has just begun. In their recent market overview, *Machine-To-Machine (M2M) & Smart Systems Market Opportunity 2010-2014*, they conclude, “Smart systems will drive a multi-year wave of growth based on the convergence of innovations in software architectures, back-room data center operations, wireless and broadband communications, and smaller, powerful, and numerous client devices connected to personal, local and wide-area networks.”[x]

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- Harbor Research

These are just a few examples of how the trends listed above are accelerating and converging. Obviously, they represent enormous opportunity for electronics manufacturers. But they also present enormous challenges.

Current Energy Storage Systems Can't Keep Pace

One of our biggest challenges for the next several years will be finding new ways to assure continuous power to increasingly smaller and more isolated (mobile or remote) devices. Current methods for MCU, RTC and SRAM backup, for power smoothing, and for self-sustaining (zero-maintenance) applications will not keep pace with current trends and will have to be re-thought.

The ITRS calls power management "a dominant concern in electronic products" and "the primary issue across most application segments." Its authors assert that, "Power management challenges need to be addressed across multiple levels, especially system, design, and process technology."[xi]

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Power management is especially critical in small, lightweight embedded systems, like those in medical monitoring devices, object tracking systems and other applications requiring low-profile, cost-effective, mobile computing solutions.

"Power issues become a major concern in the design phase due to the unique properties of such systems," says Majid Sarrafzadeh, a professor of computer engineering at UCLA. "Optimization of power consumption in light-weight embedded systems is no longer just an objective function that is to be minimized. Power optimization is a tight constraint that must be accommodated to deliver a practical system."[xii]

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- Dr. Majid Sarrafzadeh, Professor of Computer Engineering UCLA

Legacy Energy Storage Solutions Becoming Obsolete

A major impediment for electronics designers has been the limited choice of technologies available for cost-effective on-board energy storage. Until recently, these technologies have been just two: chemical batteries and supercapacitors.

But both of these technologies are decades old. There's little margin left in either for further improvements in power density. And both have numerous drawbacks which, in the light of the trends just discussed, are making them increasingly unsuitable for many applications.

Drawbacks of Chemical Batteries

- Large size
- Require SMT sockets and hand assembly
- Low charge-cycle life
- Require external charge circuit
- Contain hazardous chemicals
- Possible explosion hazard

Chemical batteries – usually coin cells in the applications mentioned – are relatively large for the amount of power they deliver, due to the packaging needed to contain their chemicals. They are incompatible with reflow soldering methods, require SMT sockets and hand assembly for PCB mounting, and also require external charging circuitry. All of these factors inhibit product miniaturization and increase manufacturing costs.

The hazardous chemicals batteries contain create the potential for reduced product reliability (in the event of corrosion), add to regulatory compliance expenses (for disposal & recycling) and can even limit shipping options (due to explosion hazard).

They also create a liability risk. Two recent studies published in *Pediatrics,* using different sets of data, both showed a rise in the rate of serious poisonings from battery ingestion among children over the last 25 years. This increase corresponded to the growing use of lithium ion coin cell batteries in consumer electronics, with the most dramatic increase coming since the introduction of larger, more powerful 20-millimeter coin cells.[xiii, xiv]

Rechargeable conventional batteries are also limited by low charge-cycle life. They typically need to be replaced several times over the life of a product. This increases customer maintenance costs, lowers reliability, and makes conventional batteries unsuitable for zero-maintenance applications, such as remote monitoring sensors that employ energy harvesting techniques.

Drawbacks of Supercapacitors

- High self-discharge rate
- Slow charging
- Spark hazard
- Output voltage proportional to charge
- Capacity adversely affected by temperature, voltage and age
- Generally ill-suited to reflow solder assembly

Supercapacitors have a different set of drawbacks.

Among these drawbacks are high self-discharge and spark hazard. Very low internal resistance results in self-discharge on the order of *10 to 20% per day*, and extremely rapid discharge (sparking) if shorted. Power systems employing supercapacitors end up being over-designed to compensate for losses and for safety, resulting in a larger device footprint and added cost. The high self-discharge rate also makes supercapacitors a poor component choice when long-term energy storage is required.

Another drawback: supercapacitor output voltage is linearly proportional to charge (i.e., voltage decays with discharge). For example, a 3.3V supercapacitor delivers 3.3V when fully charged, but only 1.65V when charged to 50% capacity. That's well below the level at which many devices will operate. As a result, a boost circuit on the backup power rail is often needed, which adds to circuit complexity, device volume and cost.

Yet another limitation of supercapacitors is that their capacity is usually degraded by exposure to high temperatures, making them generally ill-suited for reflow solder assembly. Reflow tolerant supercapacitors can cost as up to twice as much as those not rated to reflow temperatures. Non-rated supercaps require SMT sockets and hand soldering, which adds to material and labor costs and reduces product life and reliability.

Chemical batteries and supercapacitors are ***becoming obsolete*** *for many applications in the face of continued miniaturization, integration and sophistication of new electronics products, as well as more stringent customer demands.*

In short, chemical batteries and supercapacitors are becoming obsolete for many applications in the face of continued miniaturization, integration and sophistication of new electronics products, as well as more stringent customer demands.

As mentioned earlier, both are decades-old technologies. Their fabrication processes are changing very little. Their evolution has failed to keep pace with recent trends and seems unlikely to do so in the near or distant future.

Electronics manufacturers need a new energy storage technology… one that can promise to keep pace with the trends driving our industry… a technology that possesses none of the limitations of supercapacitors or conventional batteries.

The Solution: Solid State Batteries

Fortunately, such a technology exists today. That technology is the solid state battery.

Solid state batteries are rechargeable energy storage devices manufactured on silicon wafers using semiconductor fabrication processes. They can be packaged as stand-alone components or co-packaged with other integrated circuits.

Solid state batteries are built on semiconductor wafers using standard processes.

They can packaged as standard components or – in bare die form – co-packaged with other devices.

Solid state batteries are fully compatible with automated SMT and reflow soldering processes, and need no sockets or hand assembly for PCB surface mounting.

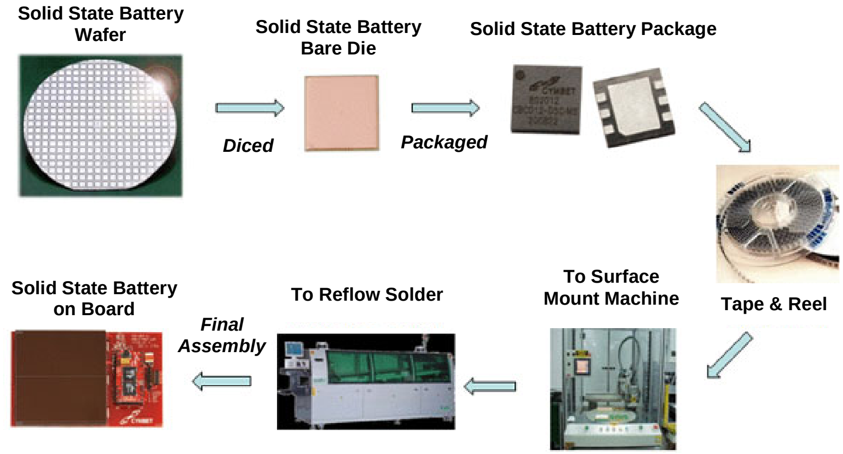

Figure 4: Solid State Batteries – from wafer to circuit board

Originally conceived at the Oak Ridge National Laboratory, solid state batteries have been available on the commercial market since 2008. Energy densities are already competitive with those of supercapacitors and coin cells. And more powerful versions are on the way.

Burdened with none of the deficiencies of supercapacitors or conventional batteries, solid state batteries are ideal for embedded energy, backup power, and energy harvesting solutions. As you are about to see, early adopters of these devices will enjoy numerous advantages over competitors who adhere to legacy energy storage systems.

8 Competitive Advantages of Solid State Batteries

1. Greater product miniaturization potential.

Solid state batteries have a smaller device footprint and lower profile than either supercapacitors or coin cell batteries. Even in packaged form, they take up less board space and volume.

And, thanks to the unique properties of solid state batteries, many components that are typically used in electronics power systems can be eliminated, creating additional space savings.

Even greater miniaturization can be achieved by co-packaging these devices with other IC components (Fig. 5), or by using advanced attachment methods. In bare die form, solid state batteries can be stacked with system-on-chip (SoC) ICs in the same package (Fig. 6), either to save space in larger products, or to provide embedded energy for tiny system-in-package (SiP) devices (Fig 7).

Here's an example. The photo to the left (Figure 8) is of a millimeter-sized solar energy harvesting sensor. The solar cell sits on an ultra low power microcontroller, which sits on a rechargeable solid state battery. The devices are wire bonded to one another. An important attribute of solid state batteries is that they can be soldered to the circuit board surface using a “flip chip” technique (Fig. 9). The flip chip and other 3D attachment mechanisms open up many new miniaturization options.

Note that none of the techniques just described can even be considered when using coin cell batteries or supercapacitors, because of the individual packaging those devices require.

Fig. 5: A rechargeable solid state battery bare die packaged side by side with an integrated circuit.

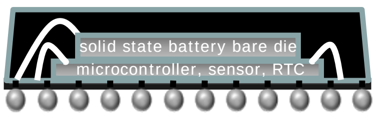

Fig. 6: A rechargeable solid state battery bare die co-packaged in a "wedding cake" die stack.

Fig. 7: A rechargeable solid state battery bare die in a system-in package (SiP) module.

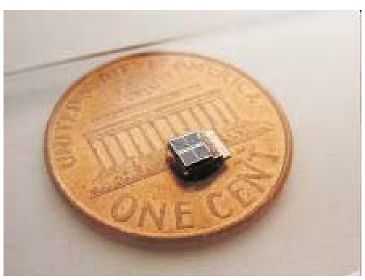

Fig. 8: A millimeter-sized solar energy harvesting sensor.

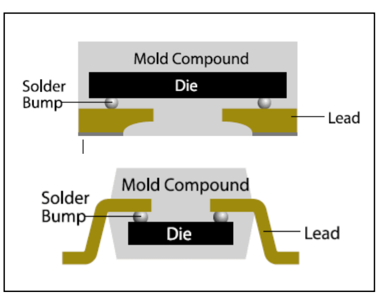

Fig. 9: Two attachment configurations using the "flip chip" technique.

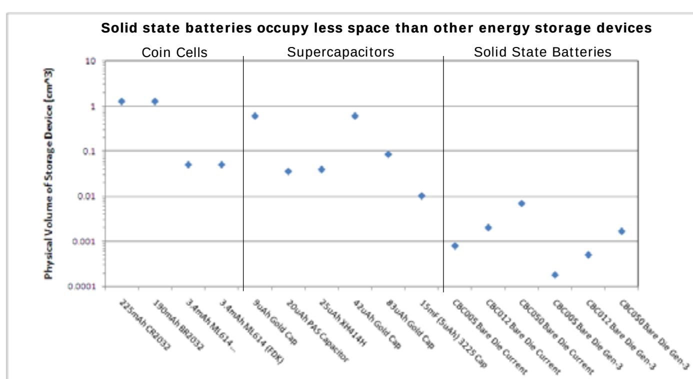

Figure 10: Device volume (cm^3) comparison of coin cells, supercapacitors and solid state batteries.

2. Lower design and component costs.

The superior voltage characteristics of solid state batteries simplify power system design and reduce the number of components in the products in which they're used.

Many product designs require all energy from a storage device to be delivered at a stable output voltage. As mentioned earlier, supercapacitor output voltage decays with discharge. And many supercapacitors are specified to only 2.6V, leaving little margin for decay. This often forces designers to add a boost circuit on the backup power rail, adding to cost and circuit complexity.

In contrast, solid state batteries provide a high, level output voltage. Most solid state batteries are rated at 3.8V or 3.3V. And even with 95% of their charge exhausted they maintain an output voltage of greater than 95% of their rated capacity. These characteristics eliminate the need for a boost circuit and give designers more voltage budget.

Plus, self-discharge from solid state batteries is very low – only 1 to 2 percent *per year* – compared to the 10-20% *per day* of a supercapacitor. Circuitry and components employed to compensate for the high daily energy loss of supercapacitors can also be eliminated when using solid state batteries.

3. Lower manufacturing costs.

Unlike conventional batteries and most supercapacitors, solid state batteries can be surface mounted using reflow soldering techniques. And they lose none of their capacity in the reflow process.

By eliminating the SMT sockets and hand soldering required with coin cells and most supercapacitors, solid state batteries reduce labor and material costs while improving reliability.

4. Increased product life and reliability.

Minimal device aging is critical when long cycle-life is required. Solid state batteries provide high charge/discharge cycle life and stable performance over time. After 5,000 cycles at 10% depth-of-discharge, they retain 80% of specified capacity.

These characteristics make solid state batteries a superior choice over conventional batteries in zero-maintenance applications, or when maintenance cost (battery replacement)

Case Study:

Intra-Ocular Pressure Sensor

Solid state batteries made possible the creation of the millimeter scale intra-ocular pressure monitor (IOPM) shown in Fig. 11, below. It is used to monitor the eye health of glaucoma patients.

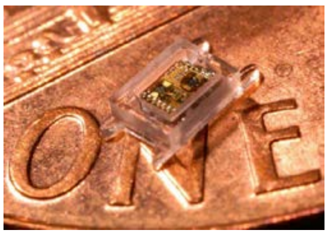

Fig. 11: Intra-Ocular Pressure Sensor (courtesy of University of Michigan)

This tiny intelligent sensor uses ambient energy harvesting to power the device autonomously. Light is converted to electricity, stored in rechargeable solid state batteries and delivered to the sensor system. There are no traditional batteries to change out and the devices can be placed anywhere.

The IOPM contains an integrated solar cell, a Cymbet EnerChip™ solid state battery, MEMS capacitive sensor, and integrated circuits vertically assembled in a biocompatible glass housing, as shown in Figure 12.

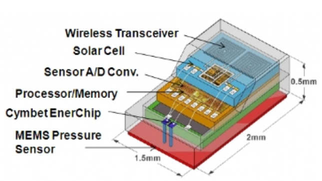

Fig. 12 IOPM Layers Block Diagram (courtesy of University of Michigan)

is a concern. A solid state battery is usually good for the entire life of the product in which it's installed.

Solid state batteries are...

Eco-Friendly

RoHs compliant for US & UK

China RoHS compliant

REACH compliant for EU

WEEE compliant

Free of all toxic heavy metals

Fig. 13: Solid state batteries lower regulatory compliance costs.

5. Lower regulatory compliance costs.

Unlike supercapacitors and coin cells, solid state batteries contain no liquids, gels or harmful chemicals. They are made solely from semiconductor materials.

This means no possibility of leakage, corrosion, harm to the environment, or worries about shipping or disposal.

For example, Cymbet's EnerChip solid state batteries have been shown to be non-cytotoxic in *in vitro* biocompatibility studies. These tests showed solid state batteries to be safe enough for use in implanted medical devices, and highlight their intrinsic health and environmental safety properties.

Solid state batteries are REACH compliant, as they contain no hazardous substances on the *Substances of Very High Concern* (SVHC) candidate list published by the European Chemicals Agency. And they have tested fully compliant with the EU's *Restriction of Hazardous Substances Directive* (RoHS), as well.

Easier compliance with environmental regulations naturally results in lower costs for manufacturers.

6. Superior value proposition.

The superior properties of solid state batteries enhance the value proposition of the products in which they're used.

For example, solid state batteries charge faster than either coin cell batteries or supercapacitors. And they require no constant current phase or safety circuit for charging. This not only simplifies power system design and lowers component count and cost. It also means less product downtime and, therefore, greater customer convenience.

Solid state batteries also offer better value in applications requiring long-term energy storage. Their low self-discharge rate lowers customer acquisition cost through device simplification, lowers customer maintenance costs and – combined with their high charge/discharge cycle life – greatly improves product reliability.

The characteristics just mentioned also make solid state batteries ideal for self-recharging using energy harvesting techniques.

7. Higher profit margins.

While the cost of an individual solid state battery may be higher than that of a comparable supercapacitor or coin cell, the *use* of solid state batteries will often **lower overall product cost** in new designs.

Figure 14 compares a variety of commonly used coin cells, supercapacitors and solid state batteries used in power back-up applications. In almost all comparisons, solid state batteries present a cost advantage compared to competing technologies.

Lowering product cost while increasing capability leads to bigger profit margins for electronics manufacturers.

The use of solid state batteries will often ***lower overall product cost*** *in new designs.*

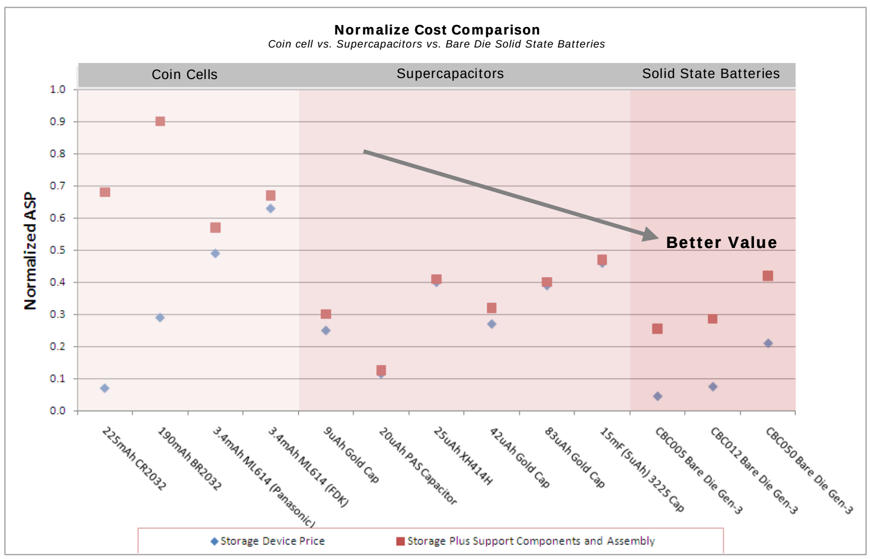

Fig. 14: A normalized cost comparison of coin cells, supercapacitors and solid state batteries

8. Ever-increasing capability at ever-decreasing cost.

Thanks to the semiconductor nature of these devices, manufacturers will be able to realize cost reductions and density improvements in the same ways the rest of the semiconductor industry has done for decades.

Advances in wafer fabrication, device scaling, chip-scale packaging, innovative attachment methods, new materials and advanced processing technologies will significantly reduce cost while dramatically increasing energy density for years to come.

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Conclusion

The superior characteristics of solid state batteries, compared to legacy power storage systems, offer electronics manufacturers a wide variety of competitive advantages.

When designed into new products, solid state batteries allow designers to reduce product size and cost while increasing product life, reliability, eco-friendliness and performance.

Electronics manufacturers should consider employing solid state batteries in their new product designs.

For More Information…

If you would like to further explore the advantages of solid state batteries or how they can benefit a specific application, I encourage you to check out the Cymbet Design Center (www.cymbet.com/design-center) where you'll find library of white papers, case studies, application notes, videos and other resources.

If your design team would like to gain hands-on experience with solid state batteries and evaluate their characteristics for themselves, Cymbet provides a number of evaluation kits aimed at various applications. You can learn more about them at www.cymbet.com/products/evaluation-kits.

You can also register to win a FREE evaluation kit. Sign up at www.cymbet.com/win-a-free-enerchip-evaluation-kit.

About the Author

Steve Grady is an expert in technical marketing, hardware and software engineering and strategic planning. He has an MSEE and BSEE from University of Illinois and has professional experience in networking, semiconductor and software companies. Currently, he is Vice President of Marketing at Cymbet Corporation.

About Cymbet

Cymbet Corporation, a privately held clean technology company, is the leader in solid state energy storage solutions for microelectronic systems. The company is the first to market eco-friendly rechargeable solid state batteries that provide electronic systems designers with new embedded power capabilities.

The company's EnerChip™ devices enable new concepts in energy storage application for ICs and new products for medical, sensor, RFID, industrial control, communications and portable electronic devices.

Founded in 2000, Cymbet has fabrication facilities in Elk River MN and Lubbock TX.

For more information about Cymbet and our EnerChip™ products, please visit our website: www.cymbet.com.

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