

## SIMULATION FOREGROUND READING

## Back Bay Battery, Inc.

### Overview

The battery industry is enormous, with worldwide revenues of approximately \$45 billion. It is highly fragmented with at least 20 manufacturers in each technology segment. Because of the wide range of applications of batteries, companies have tended to specialize in a particular technology or market application. Disposable batteries, such as the widely available carbon-zinc and alkaline cells, are available in standard sizes such as AA, C, and D, and they are a fast-moving consumer-good category with emphasis on manufacturing efficiency and scale, marketing and branding, and distribution efficiency.

One of the earliest forms of rechargeable battery was the wet lead-acid battery, the chemistry for which was invented in 1859. The application that drove this battery into prominence was to power a starter motor for vehicles, but today lead-acid batteries are commonly used for uninterruptible power supplies—in forklift trucks, golf carts, boats and submarines, and vehicles for indoor operation. They are inexpensive, albeit heavy. A variant on the lead-acid battery is the Gel Cell, which is a sealed lead-acid battery with a gellified electrolyte, allowing a higher degree of portability.

Smaller rechargeable batteries began as size-compatible replacements for disposable batteries and used technologies such as nickel-cadmium (NiCd), nickel-iron (Ni-Fe), nickel metal hydride (NiMH), lithium ion (Li-ion) and lithium polymer. As demands for portable electronic devices such as laptop computers, music players, and cellular telephone handsets rose, makers responded with new sizes and custom packaging to meet the unique needs of customers.

### Battery Performance Criteria

Important battery performance criteria include:

- **Energy Density:** The amount of charge stored within a battery. A battery with a higher energy density can store more charge, and thus can power a device for a longer time or deliver more power in the same time period. As laptop computers took on larger screen sizes and more powerful processors, the demand for higher energy density drove a switch from NiMH to Li-ion batteries.

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- **Recharge Cycles:** The number of times a battery can be recharged. Most batteries can go through only a limited number of deep discharge – recharge cycles. Many batteries can typically only stand around 500 cycles and then need to be replaced. This is a challenge for portable device designers; the first failure mode is often the battery's inability to hold a charge.
- **Self-discharge to 50%:** The time it takes for a battery to self-discharge. Most rechargeable batteries lose some amount of their charge just sitting on a shelf. This limits their application in devices such as safety equipment that might sit for unpredictable time periods between use. A longer time is better.
- **Recharge Time:** How quickly a battery will recharge. Fast recharge time is usually a consumer benefit, especially for things like mobile phones or music players. A typical NiMH battery can be recharged in two to four hours; a shorter time is better.
- **Price:** The cost variance of different battery types. Since small rechargeable batteries tend to come in standard form factors and output voltages, they are a fungible commodity with almost no barriers to substitution. Different battery types might require different chargers, but in general the low substitution costs make batteries a highly competitive commodity, where price is a major factor driving purchase decisions.

Interestingly, battery makers have tended to focus in relatively narrow product segments and technologies. Disposable-battery makers have typically not become major players in rechargeables, and rechargeable-battery manufacturers tended to stick with a particular technology or product focus (laptop computers, mobile phones, portable power tools, etc.)

## Back Bay Battery, Inc., in 2008

Back Bay Battery is one of over 20 major manufacturers of NiMH batteries. The field is crowded, but manufacturers have been riding rising a tide of demand from consumers for portable electrically powered devices.

The company is anticipating continuing strong volume-growth rates, primarily due to rapid consumer adoption. The worldwide market is projected to grow from 1.1 billion units in 2005 to 1.6 billion units in 2010—a compounded annual growth rate of 9.0%. Pricing pressure is significant, though, as more East Asian competitors continue to drive commoditization of NiMH cells. Back Bay's sales manager has learned to track the market pricing closely, as being out of step with the market can cause dramatic market share changes in a relatively short time.

Li-ion batteries have pretty much replaced NiMH in the market for laptop computer batteries. The first commercial Li-ion battery was produced by Sony in 1991. Li-ion batteries are favored for mobile devices because they can store a high density of energy for a given weight. They can be fabricated in many shapes, though most manufacturers focus on cylindrical cells the size of standard AA cells, which then can be stacked and repackaged for specific applications. The cells contain a lithium-salt electrolyte carried in an organic solvent.

The lithium polymer battery is a variation on the Li-ion design. Rather than use an electrolyte, these batteries employ a solid polymer composite such as polyacrylonitrile. This has the advantage of a lower manufacturing cost and is more robust against physical damage. These batteries also use a flexible, foil laminate case, so they can be fabricated in a wider variety of shapes. Lithium polymer

batteries started appearing in consumer electronics around 1996, and their popularity increased when designers started to exploit the capability of making them in form-fitting shapes, as in Apple's iPod and iPhone.

Li-ion and lithium polymer rechargeable batteries have many advantages over NiMH. They do not have any "memory effect" which causes them to hold less charge depending on what kind of charging cycle was used, but they do degrade over time.

Lithium batteries also have some not-so-well-known disadvantages. Typically they lose some percentage of their capacity every year, and they only can be recharged approximately 400 times. Newer technology is on the horizon to enable the number of charging cycles to be increased by three-fold, but this will require continuous R&D investment. They also have some well-known safety issues such as a rash of fires and other safety concerns.

Back Bay Battery failed to make timely investments in Li-ion or Li-polymer batteries. Its NiMH business was solid at the time, but continuing price pressures forced it to maintain a very lean business model with tight reins on R&D spending. The scale and learning curves of the lithium battery business are such that it would be virtually impossible for Back Bay to enter at this stage. But Back Bay was fortunate to have chosen market segments that truly benefited from some of the unique strengths of NiMH technology, namely the ability to sustain high drain rates, durability for far more charging cycles than lithium types, and their ruggedness (and absence of safety issues). The three main segments Back Bay Battery sell-into are:

- **Power tools.** Power tools have to operate in rugged environments, and they draw high current from the battery packs. NiMH batteries share the market with the older NiCd type, but have been increasing their share. Back Bay has been very competitive in this segment, and it is their largest source of revenues and profits. Lithium batteries are considered too fragile for this environment.
- **Two-way radios.** These units have not switched yet to Li-ion because of their high current-draw needs and use in harsh conditions.
- **Portable power packs.** These provide for emergency back-up power, industrial products, medical equipment, small electric appliances, and more. These have been used in all kinds of applications, many of which Back Bay is not familiar with, as they sell modular units that are incorporated by others into final applications. Market research suggests that this is an expanding opportunity.

While Back Bay management is quite confident of these three market segments, there continues to be risk that improvements in Li-ion or other competitive technologies start to cut into its market position, much as the company lost to Li-ion in earlier years.

## Enhancing NiMH Technology

Back Bay Battery spends approximately 2%-3% of revenues on R&D. It benefits from some of the improvements and learning curves resulting from investments made by both itself and others in the technology. R&D investments can be in things like self-discharge or process improvement. They can also be in "applications engineering" which is focused on finding new applications for a particular technology. Back Bay has not historically spent much in applications engineering, though, as NiMH batteries simply have to fit standard cell sizes and produce standard voltages and currents.

Freshly charged NiMH batteries lose about 5%-10% of their charge on the first day, and stabilize around 0.5%-1% per day after that. A new technology that can reduce self-discharge was developed at a major university and has become available. The technology employs a new kind of internal cell separator. The resulting improvement means that 70% to 85% of charge capacity can be retained after one year. The new cells are otherwise equivalent to normal NiMH batteries of comparable capacity and can be charged in standard NiMH chargers.

Back Bay Battery has been spending to reduce this self-discharge, leading to substantial improvements over the last two years. Not making the investment would potentially cause the company to be disadvantaged relative to its competitors. It could spend R&D money in other areas as well. **Process improvement** is most likely to lead to manufacturing-yield improvements and lower-product costs. If Back Bay Battery wants to keep improving energy density, that is probably one of the more expensive and longer range R&D programs to invest in. Price competition is getting increasingly intense, so the company has to be very careful how it spends its R&D budget.

## Capacitors: an Alternative Energy Storage Device

A capacitor is a device that is made of two electrodes separated by an insulator (a dielectric). When attached to a voltage source, it can store up charge (energy). If the charging source is removed, it will then discharge back into the circuit. How much charge a capacitor can store depends on the quality of the dielectric, the voltage that is applied, and the surface area of the electrodes.

The energy stored in a capacitor is proportional to the capacitance,  $C$ , and to the square of the voltage,  $V$ , that is applied:

$$E_{\text{stored}} = \frac{1}{2} CV^2$$

To increase the energy stored, one simply needs to increase the capacitance. The most common capacitors are composed of thin metal foil plates separated by an electrical insulator, which are then stacked or rolled and placed in a casing. Increasing the capacitance is the major technical challenge.

Capacitors could be wonderful energy-storage devices. They charge much more quickly than any kind of battery, and they don't have the problem of battery memory or limitations on the number of charging cycles. This is because there are no chemical reactions that go on inside a capacitor; the capacitor simply stores charge. The challenge has been the physical size that is required to store a given amount of energy.

## The Arrival of the Ultracapacitor

Over the last several years, scientists at several universities have been working on new classes of nanomaterials that have great potential to increase the performance of capacitors. Researchers at several universities have produced samples of ultracapacitors—small, lightweight capacitors that have a surprising amount of stored energy. The researchers demonstrated them by powering tiny LED flashlights, radio-controlled toy racing cars, and other portable devices (**Exhibit 1**).

The major advantages of ultracapacitors, when used as a battery, are their extremely rapid recharge time, and their very long life (thousands of charge/discharge cycles). Unlike most other rechargeable batteries, they do not degrade noticeably over time. Another advantage is that they provide huge current surges without ill effect. In fact, a NASA demonstration project showed a portable drill powered by ultracapacitors (**Exhibit 2**). The drill would charge in one minute and

provided three minutes of continuous operation, or enough power to drive about 30 wood screws. The drill could be recharged thousands of times without degradation.

The major disadvantage of ultracapacitors is their lower-energy density. Current technology ultracapacitors would only be able to hold slightly over 15 watthours/kg, but they have very high-power density (4000 Watts/kg).

Ultracapacitors are thought to be ideal for applications that require bursts of power. Several groups are also looking at hybrid applications. By pairing an ultracapacitor with a battery, one would be able to reduce the duty cycle on the battery and prolong its life. Thus in an emergency back-up power supply, the ultracapacitor could be used to provide short spikes of power, prolonging the life of the battery that would take care of longer outages. Similarly, in a hybrid car, an ultracapacitor could collect the energy from dynamic braking and then feed it to the battery.

The technology for ultracapacitors is available for licensing from the leading university research group. Considerable commercialization work has yet to be done, but some early promising product applications include emergency lighting, back-up power supplies, and portable power tools.

For Back Bay Battery, required R&D investment would be considerable as projects can cost anywhere in a range of \$1 million to 7 million a year for four to over seven years. This reflects the nature of most R&D projects which are people- and time-intensive. Worse yet, there are five major fronts to invest in, and it is difficult to assess what competitors are setting as their R&D spending priority.

## Planning R&D Investments

Market pressures on pricing mean that Back Bay Battery never has quite enough R&D money to spend on everything its research staff would like to do. On the one hand, the team gets daily pressure from the sales organization to improve the company's NiMH offerings, for in this commodity business, small performance or technical advantages can swing a large order since pricing is pretty competitive. The company can "tweak" its demand a bit by adjusting prices, but one always has to be careful not to lose a big customer in the process. It also has to factor in how long it will take for those investments to bear fruit. While some of the scientists wax poetic about the potential of ultracapacitors, the technology has major shortcomings for Back Bay's core markets today, and the company has to be careful not to dig too deep a hole financially.

The product manager at a major power tools manufacturer, who happens to be one of Back Bay's largest customers, has been encouraging the company to focus on its specific needs for an upcoming refresh of its consumer power tools line. The customer is looking for higher power density and lower unit battery costs, as it is feeling market pressure from Asian competitors as well. He has been shopping for competitive NiMH batteries sourced in China, and has made clear to Back Bay the importance of remaining price competitive. The NASA demonstration of an ultracapacitor-powered drill caught his attention, and the rapid recharge time for ultracapacitors was very appealing if only the storage capacity was much larger. Focusing on this customer would consume essentially all of the company's limited R&D resources.

## Operational Decisions

In addition to budgeting for R&D projects, management has to set its pricing strategy annually. The standardization of battery cell sizes makes NiMH batteries a virtually interchangeable

commodity, so competitive pricing relative to the market is closely tied to sales volumes. Back Bay also sees continuing competitive encroachment from Li ion batteries, with the losses of volumes dependent on segment. Customers frequently play NiMH battery vendors off against each other, demanding lower prices. The newer ultracapacitor technology is also price sensitive, but having better feature performance is a good way to maintain differentiation and higher pricing.

Sales volumes have been on an upswing in recent years, driven by demand for the finished products that incorporate Back Bay's products. But sales forecasting is tricky. Even if the company maintains competitive pricing, industry cyclicalities as well as technology substitution make it difficult to forecast beyond one to two year market trends. The division manager's predecessor was fired for grossly inflating his sales estimate one year and then overspending on R&D. When sales didn't materialize fast enough, earnings of the division took a severe hit.

**Exhibit 1** MIT News Release on Ultracapacitors

[massachusetts institute of technology](#)

[news office](#)



## Researchers fired up over new battery

Deborah Halber, News Office Correspondent  
February 8, 2006

Just about everything that runs on batteries -- flashlights, cell phones, electric cars, missile-guidance systems -- would be improved with a better energy supply. But traditional batteries haven't progressed far beyond the basic design developed by Alessandro Volta in the 19th century.

Until now.

Work at MIT's Laboratory for Electromagnetic and Electronic Systems (LEES) holds out the promise of the first technologically significant and economically viable alternative to conventional batteries in more than 200 years.

Joel E. Schindall, the Bernard Gordon Professor of Electrical Engineering and Computer Science (EECS) and associate director of the Laboratory for Electromagnetic and Electronic Systems; John G. Kassakian, EECS professor and director of LEES; and Ph.D. candidate Riccardo Signorelli are using nanotube structures to improve on an energy storage device called an ultracapacitor.

Capacitors store energy as an electrical field, making them more efficient than standard batteries, which get their energy from chemical reactions. Ultracapacitors are capacitor-based storage cells that provide quick, massive bursts of instant energy. They are sometimes used in fuel-cell vehicles to provide an extra burst for accelerating into traffic and climbing hills.

However, ultracapacitors need to be much larger than batteries to hold the same charge.

The LEES invention would increase the storage capacity of existing commercial ultracapacitors by storing electrical fields at the atomic level.

Although ultracapacitors have been around since the 1960s, they are relatively expensive and only recently began being manufactured in sufficient quantities to become cost-competitive. Today you can find ultracapacitors in a range of electronic devices, from computers to cars.

However, despite their inherent advantages -- a 10-year-plus lifetime, indifference to temperature change, high immunity to shock and vibration and high charging and discharging efficiency -- physical constraints on electrode surface area and spacing have limited ultracapacitors to an energy storage capacity around 25 times less than a similarly sized lithium-ion battery.

The LEES ultracapacitor has the capacity to overcome this energy limitation by using vertically aligned, single-wall carbon nanotubes -- one thirty-thousandth the diameter of a human hair and 100,000 times as long as they are wide. How does it work? Storage capacity in an ultracapacitor is proportional to the surface area of the electrodes. Today's ultracapacitors use electrodes made of activated carbon, which is extremely porous and therefore has a very large surface area. However, the pores in the carbon are irregular in size and shape, which reduces efficiency. The vertically aligned nanotubes in the LEES ultracapacitor have a regular shape, and a size that is only several atomic diameters in width. The result is a significantly more effective surface area, which equates to significantly increased storage capacity.

The new nanotube-enhanced ultracapacitors could be made in any of the sizes currently available and be produced using conventional technology.

"This configuration has the potential to maintain and even improve the high performance characteristics of ultracapacitors while providing energy storage densities comparable to batteries," Schindall said. "Nanotube-enhanced ultracapacitors would combine the long life and high power characteristics of a commercial ultracapacitor with the higher energy storage density normally available only from a chemical battery."

This work was presented at the 15th International Seminar on Double Layer Capacitors and Hybrid Energy Storage Devices in Deerfield Beach, Fla., in December 2005.

The work has been funded in part by the MIT/Industry Consortium on Advanced Automotive Electrical/Electronic Components and Systems and in part by a grant from the Ford-MIT Alliance.

*A version of this article appeared in [MIT Tech Talk](#) on [February 8, 2006 \(download PDF\)](#).*

URL: <http://web.mit.edu/newsoffice/2006/batteries-0208.html>

## **Exhibit 2** Ultracapacitor Powered Portable Electric Drill



Source: NASA