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Strategic Innovation Simulation: Back Bay Battery Foreground Reading

Overview

Energy storage plays an important role almost anywhere electricity is used. Portable devices such as flashlights, phones, laptops, and electric vehicles are familiar to almost everyone, and they typically store energy in some type of rechargeable battery. Rechargeable batteries and other types of temporary energy storage systems also play an important role in many systems that are connected to the electrical grid. Large computer datacenters have warehouse-sized banks of batteries that keep the machines running during the 10 to 15 seconds it takes to start up backup generators. Off-grid solar and wind power systems, environmental control systems, and uninterruptable power systems (UPS) also rely on some kind of energy storage systems to bridge short term outages and provide stable power for a wide range of applications. This diversity of applications has made battery-based energy storage an enormous, but still growing, market.

One of the earliest forms of rechargeable battery was the lead-acid battery. The basic design of lead-acid batteries was a “flooded cell” with lead plates immersed in a chemical electrolyte (usually sulfuric acid). Powering the starter motor for automobiles made lead-acid batteries extremely popular, and today they are widely used in all kinds of vehicles, sometimes even as the primary power source (for example, in golf carts or fork lift trucks). They are inexpensive and can provide large surges of power on demand. Their primary disadvantage is that they are heavy for the amount of energy stored, which matters less for stationary applications. There is an important specialized class of lead-acid batteries known as valve-regulated lead-acids (VRLA). These use the same chemistry, but are packaged so that they have better reliability and performance. The most popular variants are the gel battery (“gel cell”), which uses a semi-solid electrolyte, and the absorbed glass mat (AGM) battery which uses a thin ultrafine fiberglass mat to absorb the electrolyte and separate the lead plates. Both of these types are much easier to handle and withstand vibration and extreme conditions well. They also withstand freezing better than flooded-cell batteries, which might experience case cracking.

Smaller rechargeable batteries began as replacements for disposable batteries, and used technologies like nickel-cadmium (NiCd), nickel-iron (Ni-Fe), nickel metal hydride (NiMH), lithium ion (Li-ion), and

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lithium polymer. As demands for portable electronic devices rose, makers responded with new sizes and custom packaging to meet the unique needs of customers.

Li-ion batteries have become the most popular battery chemistry for portable applications today. There are several different chemical formulations. Portable electronics mostly use a lithium cobalt oxide chemistry because of their very high energy density, albeit with some safety risks. Lithium iron phosphate, lithium ion manganese oxide, and lithium nickel manganese cobalt oxide are targeted at applications like power tools or electric vehicles. There is a fast pace of continuing innovation in different lithium battery chemistries.

Important battery performance criteria include the following:

- **Energy density**. A battery with a higher energy density can store more charge, and thus could power a device for a longer time, or deliver more power in the same time. This is important for portable devices. Sleek industrial designs for smartphones, tablets, and laptops drove increasing demand for thin conformal-fitting Li-ion batteries, while the desire for maximal driving range drove constant innovation in battery chemistry and packaging.
- **The number of times a battery can be recharged.** This is also referred to as recharge cycles. Most batteries can only go through a limited number of deep discharge-recharge cycles. Many batteries typically can only stand a few thousand cycles and then they need to be replaced. This is a challenge for portable device designers; the first failure mode of a smartphone 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.
- **Recharge time**. Fast recharge time is usually a consumer benefit, especially for things like mobile phones or electric vehicles.
- **Cost.** 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.

Historically, battery makers have focused on relatively narrow product segments and technologies. Disposable battery makers did not become major players in rechargeables, and rechargeable battery manufacturers tended to stick with a particular technology or product focus (portable electronics, electric vehicles, etc.).

Back Bay Battery, Inc.

Back Bay Battery started out as a specialist in sealed AGM-type lead-acid batteries. They focused on industrial applications where the ability to store and deliver power in short surges made them more attractive than Li-ion batteries. Though AGM batteries were about three times more expensive than standard flooded cell lead-acids, they were considerably cheaper than Li-ion batteries. They also had roughly twice the lifetime of conventional lead-acid batteries, and because they were sealed and didn't discharge fumes on overcharging, they found special favor in applications on ships and military equipment.

Back Bay built a solidly profitable business as a supplier to integrators who built uninterruptible power supplies both for large systems used in datacenters and the smaller units designed to keep back office computers or point-of-sale systems running during short outages. The other area where the company found success was power-management applications requiring many rapid charge/discharge cycles for short-term power needs.

Back Bay Battery sells into three main market segments that are organized by application type:

- **Storage for solar power systems.** AGM batteries are increasingly popular for storing energy from solar panels. They are less expensive than Li-ion or Ni based types, and they can handle high charge and discharge rates well.
- **Warehouse equipment.** Automated logistics warehouses use many pieces of equipment that use electrical power, such stackers and robots, and Back Bay has carved out a growing niche, supplying batteries for these systems. Many of these systems draw high startup power and they need to undergo frequent charging cycles.
- **Uninterruptible power systems (UPS).** This segment includes backup power systems for large datacenters. Warehouse-sized rooms are filled with batteries that are switched in to provide power in the event of an outage. The batteries only need to supply electricity for about 15 seconds, which is the amount of time it would take to spin up standby diesel generators.

While Back Bay management is quite confident of these three market segments, a widespread interest in battery technology for pure electric vehicles means large competitive investments in R&D.

Enhancing AGM Lead-Acid Technology

Back Bay Battery spends approximately 2–3% of revenue 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 increasing energy density. They can also be in process improvement, which is focused on reducing the production cost (often by improving the yield).

Freshly charged batteries of all types inevitably lose some amount of their charge over time. 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. Its AGM batteries are about 3–10 times better than gel cells, and 5–50 times better than their flooded cell counterparts. The company 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, though the company is relatively far down the learning curve. If it 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 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 because there are no chemical reactions that go on inside a capacitor, they simply store charge. The challenge has been the physical size that is required to store a given amount of energy.

Supercapacitors

Supercapacitors (also known as ultracapacitors) first emerged from research at General Electric in the late 1950s, but there were no known commercial applications at the time. They are essentially a double layer capacitor that can store far more energy than a typical capacitor, but at a lower voltage. Recently technological progress has continued to improve their properties. Materials used in making them have been the subject of intense research in universities and government research laboratories.

Supercapacitors have several major advantages compared to batteries. First and foremost, they can withstand far more recharge cycles than typical batteries. While an AGM lead-acid might withstand 1500–2000 discharge/recharge cycles, a supercapacitor would see little to no degradation over time and could still be fully recharged. The other advantage is they have the ability to deliver huge surges of power as well as recharge quickly. This is reflected in a fast recharge time—they can charge and discharge quickly.

The major disadvantage of supercapacitors is their lower energy density. Current technology supercapacitors would only be able to hold 10 watt hours/kg, which means that even though they deliver a lot of power quickly, they can't sustain this over a long time. The other disadvantage is self-discharge rate. Supercapacitors lose 40–50% of their energy over the course of a month if they just sat unused.

Supercapacitors are thought to be ideal for applications that required bursts of power. Several groups are also looking at hybrid applications. By pairing a supercapacitor with a battery, one would be able to reduce the duty cycle on the battery and prolong its life, meaning that in an emergency backup power supply the supercapacitor 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 a supercapacitor could collect the energy from dynamic braking and then feed it into the battery.

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

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

Estimated Project Investments

Available R&D Projects	**Annual Project Cost (in millions)**	**Anticipated Project Length**	**Total Cost (in millions)**	**Potential Improveme nt Range**	**Types of Projects**
AGM Lead-Acid: *Energy Density*	$3.0–9.0 M	4–6 years	$12.0–54.0 M	900–5,200 watt hours/kg	AGM battery chemistry is well established. Improvements in energy density rely on changing the formulation or internal plate and mat design.
AGM Lead-Acid: *Recharge Cycles*	$1.0–6.0 M	5–8 years	$5.0–48.0 M	530–1,050	Doubling the number of recharge cycles will greatly enhance the value proposition of AGM cells, roughly doubling their life and improving total cost of ownership. This could have a subsidiary impact on revenue as customers would not need to replace them as often. This project would entail studying the chemistry and trying to eliminate causes of degradation during deep discharge cycles.
AGM Lead-Acid: *Self-discharge Rate*	$2.0–4.0 M	5–8 years	$10.0–32.0 M	11–21 months	This will make AGM batteries more appealing for devices that do not have regular access to power. A project would probably look at separator layers and consider material substitutions to decrease internal leaking.
AGM Lead-Acid: *Recharge Time*	$1.0–5.0 M	4–7 years	$4.0–35.0 M	105–210 minutes	Rapid recharging improves value proposition. Look at the granularity and distribution of materials used in manufacturing and whether there are alternate structures or manufacturing methods that lead to faster recharging.
AGM Lead-Acid: *Process Improvement*	$1.0–6.0 M	4–7 years	$4.0–42.0 M	10–56% reduction in unit costs	Process improvement activities could include substitutions of less expensive materials in the battery casing or packaging, better utilization of

Available R&D Projects	Annual Project Cost (in millions)	Anticipated Project Length	Total Cost (in millions)	Potential Improveme nt Range	Types of Projects
					manufacturing capacity through *kaizen*-style continuous improvement, or a more efficient supply chain and materials handling. Any improvements at this point are likely to be hard work, and the sum of many small improvements rather than any large dramatic changes.
Supercapacitors: *Energy Density*	$4.0–10.0 M	5–7 years	$20.0–70.0 M	900–1,700 watt hours/kg	Energy density is limited by the surface area of electrodes and the spacing between them. This project would look at a new type of carbon nanotubes for application as the electrode.
Supercapacitors: *Recharge Cycles*	$2.0–9.0 M	5–8 years	$10.0–72.0 M	8,750–17,490	Supercapacitors can already go through an enormous number of recharge cycles. Improvement projects would have to examine the root cause of eventual breakdown and try to develop solutions around it.
Supercapacitors: *Self-discharge Rate*	$2.0–8.0 M	5–8 years	$10.0–64.0 M	32–63 months	Self-discharge tends to be through charge leakage paths, although the root cause needs to be understood. Improvement projects would seek to reduce these through substitution of materials.
Supercapacitors: *Recharge Time*	$1.0–6.0 M	5–7 years	$5.0–42.0 M	9–17 minutes	Recharge time is highly dependent on voltage. This project would examine different configurations and cell voltages to see if there is a more effective solution.
Supercapacitors: *Process Improvement*	$3.0–7.0 M	5–7 years	$15.0–49.0	10–74% reduction in unit costs	Manufacturing costs are still very high because supercapacitors are early on the learning curve. Much work needs to be done on basic manufacturing process improvements and supply chain management.

Note: Improvements come from company R&D and to some extent from key materials suppliers' R&D.

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 AGM battery offerings because, in this commodity business, small performance or technical advantages can swing a large order as pricing is pretty competitive. The company can tweak its demand by adjusting prices, but needs to be careful not to lose a big customer in the process. Back Bay 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 supercapacitors, 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 of a major solar array 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 most popular energy storage unit. The customer is looking for higher power density and lower unit battery costs as they are feeling market pressure from Asian competitors. He has been shopping for competitive AGM batteries sourced offshore, and has made clear to Back Bay the importance of remaining price competitive. The rapid recharge time for supercapacitors would be appealing if the storage capacity were much larger. Focusing on this customer would consume essentially all of the company's limited R&D resources.