BetaBattery™ Market Summary

Introduction

The BetaBattery™ is designed to meet the needs of both unserved and underserved markets for long-life, low power batteries. More specifically, the long-life requirements are for batteries that last for 10 to 25 years without recharging, well beyond the capabilities of any battery currently available. Potential markets are shown in Table 1.

Table 1. BetaBatt Potential Markets

Government and Military	Anti-Tamper and Security, Sensors and Detectors, Health Monitoring of "Smart" Electronics, Covert Operations
Medical and Human Health	Pacemakers, Defibrillators, Micro stimulators, Drug delivery, etc.
Subsea	Valves, Actuators, Sensors, Controls, Telemetry
Subsurface	Real-Time Measurements, 4D Seismic
Outer Space	Space Vehicles, Satellites
Micro-Electronics	Microelectronic Mechanical Systems (MEMS), Self-Powered Electronic Circuit Boards
Communications/Sensors	RFID Tags, Implanted Microcircuits

The first commercial products will address a $200 million portion of the estimated $1 billion long-life battery market. Continuing reductions in the power requirements of microelectronic devices will further enlarge the available market. Entering these markets will be slow. Based on input from potential customers, one to three years will be required for product testing and application qualification by each customer before acceptance into full use.

An example of the unserved market is the Department of Defense (DOD) anti-tamper program (http://at.dod.mil) which requires a battery life on the order of 20 years to deter the reverse engineering and exploitation of our military critical technology. This market and other DOD applications must have a power source which can instantly perform when needed despite having been inactive for many years.

An example of the underserved market is medical device implants which currently use both rechargeable and long-life conventional batteries. Pacemaker batteries, for example, are replaced as needed (3 to 6 years) by either out-patient procedures ($1000s) or full surgical ("replant") procedures ($10,000s). A long-lived power source that doubled or tripled the replant time would have obvious benefits for human health and cost savings.

BetaBattery Characteristics

The BetaBattery is essentially a self contained power supply consisting of a betavoltaic charger, a charging control board, and a thin-film lithium rechargeable battery in a hermetically sealed case. The voltage, current, power, energy, duty cycle, and lifetime characteristics are designed for each specific application. In general, the three key characteristics of the BetaBattery are:

- Long life: 10 to 25 years
- Low power: < 5 volts, < 100mW
- Small size: coin to standard 9v battery

The long-life, self-recharging feature is the differentiating characteristic of the BetaBattery. Only markets with a long-life requirement without recharging will be addressed by the BetaBattery. A long-life, no-recharge requirement may be driven by one or more of the following factors:

- The battery must function for its entire lifetime (25 years) even if it is not available for replacement or recharge (e.g. US military systems in the hands of third party users, stored "smart" munitions and missiles)
- The cost to replace or recharge the battery is significantly greater than the cost of using a BetaBattery to extend the life time of the application (e.g. medical implants)
- Accessing the battery is difficult and/or dangerous (e.g. dispersed micro sensor systems)

Although there are several potential markets for long-life batteries as noted in Table 1, only two will be considered to estimate market size. This is mainly due to the fact that many possible markets are not mature enough to develop volume, size, or price point estimates. However, it should be noted that such markets are developing and will grow as the power requirements and size for micro devices continue to decrease. One example is the wireless sensor market, such as environmental or structural sensors in civil applications and battlefield sensors in which the sensors are widely distributed and essentially impossible to locate for battery replacement or recharge. This market has been estimated to grow to over $1B in the next several years.

The two markets to be discussed below are (1) the defense/military market and (2) the medical device implant market.

Defense/Military Market

The primary directives for the DOD anti-tamper program were released in 2000 and have been expanded and enhanced since. Elements of the program are contained in numerous directives for both DOD and the various service branches including:

- DOD Missile Defense Agency Anti-Tamper Policy Directive 5200.05
- DOD Directive 5200.39, Security, Intelligence, and Counterintelligence Support to Acquisition Program Protection, July 2001

The Anti-Tamper mission is to deter the reverse engineering and exploitation of the US military's critical technology in order to impede technology transfer, stop alteration of system capability, and prevent the development of countermeasures to US systems. Opportunities from exploitation of US systems are increasing and include:

- Foreign military sales, direct commercial sales, and international co-production
- Exposure during the global war on terrorism, contingency operations, and cooperative activities
- System loss on the battlefield

A critical element of anti-tamper systems is a long-life power supply. Since the anti-tamper directive is very broad in scope, most of the larger defense systems contractors (Lockheed Martin Corporation, Boeing, General Dynamics, Northrop, Raytheon, SAIC, etc.) are potential customers. The table below describes a number of application requirements. In all cases the voltage requirement is 3 to 5 volts DC, and the life expectancy is 20 years.[1]

Table 2. Anti-Tamper Applications

Application	Power	Comments
Field Programmable Gate Array (FPGA, NVRAM) Crypto Key Voltage; hold number in register	50nW	10nA at 3V after 15 years
Volume Protection: power for op amps monitoring volume fence or actuators	50µW	10 seconds, 25µW per channel
Volume Protection: single channel	30mW	1% duty cycle
Impulse power: detection response	500mW	Burst power
Impulse power to actuate response	50mW for 1 second, once a lifetime	
Power MEMS: sensors and RF/IR links	50µW	
Impulse power to activate response; performance health monitoring	50mW for 1 second, once per year	

For the two volume protection applications, Lockheed Martin estimates 10,000 to 20,000 units per year at a price of $1000, resulting in a market size of $10M to $20M for these applications alone. Given the broad range of uses for the other applications it is reasonable to expect similar or greater volumes; although, at lower prices. This would at least double the market size. In addition there are numerous other applications that fall under the anti-tamper mandate.

[1] Information provided by a large defense contractor.

Although the above discussion has focused primarily on the first anti-tamper applications for the BetaBattery™, there are other defense related applications with different operating envelopes. Some of these are listed below:

- Intelligence gathering sensor networks
- Small devices located remotely, unattended and maintenance free
- Smart Munitions, including monitoring and alarm activation
- Hazardous materials (biological and nuclear) backup monitoring

Activity in the long-life battery development area is further evidenced by the Micro Isotope Power Sources (MIPS) and RadioIsotope Micropower Sources (RIMS) programs at the Defense Advanced Research Projects Agency (DARPA). These programs investigated a range of approaches to achieve compact, mW-level power sources including alphavoltaic, betavoltaic, and thermoelectric strategies leading to 35mW/cm^3 of continuous power output devices. Uses for such devices are critical for a large array of military unattended sensor applications, including perimeter defense networks, detection/monitoring of weapons of mass destruction, and environmental protection sensors.

The entire defense related long-life battery market is estimated to exceed $400M.

Medical Implant Market

The estimated worldwide combined market for implanted electrical and neurological stimulation devices is $13.6B with a steady compound annual growth rate of 5.4%. This market is dominated by cardiac rhythm management (CRM, 79.2%), followed by spinal cord stimulation (SCS, 11.6%) and deep brain stimulation (DBS, 3.9%). Implantable bone growth stimulation, sacral nerve stimulation, gastric electrical stimulation, and vagus nerve stimulation account for the remaining 5.4%.[2]

This analysis will focus only on the $10.8B cardiac rhythm management (CRM) market, which is dominated by Medtronic (33%), St. Jude Medical (22%), and Boston Scientific[3] (19%). Each of these companies has launched several new products in the past two years and continues to advance the technologies. Several communications with Medtronic have confirmed its interest in a long-life battery.

[2] Electrical and Magnetic Nerve Stimulation. Kalorama Information Market Briefing, Mountaintop Medical, February 2010.
[3] Guidant Corporation, the manufacturer of artificial pacemakers and implantable defibrillators, was acquired by Boston Scientific in April 2006.

The purpose of CRM is managing cardiac arrhythmias. The market includes two general segments:

- Implantable pacemakers and cardiac resynchronization units
- Implantable cardiac-defibrillators

The cost of the CRM devices ranges from $5,000 to $15,000, with the current battery cost ranging from $50 to $200 per unit. The cost of the surgery to implant or replant these units ranges from $30,000 to $60,000. Replants are mostly driven by battery life with an average replant time of 7 years. A replant surgery costs about 75% of the initial surgery. If the time between replants can be doubled by a long-life battery, the devices themselves can be designed for a longer life and the cost of the battery and device can be significantly increased (doubled). The longer life capability will reinforce the current trend for increased functionality through external programming to modify the CRM therapy regimen as patients age. Thus, even with fewer units sold, revenue for the manufactures could remain the same. For that portion of the market that could benefit from a long-life battery, the cost savings in the avoided surgery alone will support a premium price for the battery of $1,000 to $2,000.

<u>Pacemakers</u>

In 2007, 740,000 pacemakers[4] were implanted worldwide for a market of $3.8B. Each unit costs approximately $5000 with a battery cost of approximately $100. If only10% of this market could benefit from a long-life battery and would support a premium price near $1,500 for the battery, this would result in a $100M market for long-life batteries.

<u>Defibrillators</u>

An implantable cardioverter-defibrillator (ICD) is a small battery-powered electrical impulse generator which is implanted in patients who are at risk of sudden cardiac death due to ventricular fibrillation. These devices also can perform pacemaker functions. Typical devices cost approximately $15,000 with an average battery cost of $150. In 2007, the number of worldwide implants was approximately 350,000 leading to a market size of $5.2B. If only 10% of this market could benefit from a long-life battery and would support a premium price near $2,000 for the battery, this would result in a $70M market for long-life batteries. At present, the “shock” power requirements for defibrillators is beyond the capability of BetaBatteries but it may not remain so as development of both the charging component and rechargeable battery improves performance.

---

[4] Market size for pacemakers and defibrillators was provided by a medical device manufacturer.

Table 3 below lists some general specifications for CRM medical implant devices.[5] All require approximately 3 volts.

Table 3. Example Battery Requirements for Medical Implant Devices

Application	Current	Duty Cycle	Peak Current	Duty Cycle	Cycle-on Time
Cardiac Shocking	3µA (circuits off) 175µA (circuits on)	2.7%	3000µA	0.0011%	30 sec/month
Cardiac Shocking	0.5µA (circuits off) 175µA (circuits on)	0.0228%	1A	0.0004%	8 to 15 sec
Pacemaker	10µA	16.7%			
Monitoring			0.01mA		10 sec

Although it is difficult to quantify how a long-life battery will penetrate the medical implant markets, the above estimates clearly show a significantly large market potential that could be as much as $1B if the 10% estimates above are low and other segments of the market adopt the long-life battery as well. Furthermore, it is clear that the industry is interested in long-life batteries and, if such a battery were available, could easily incorporate it into its products. However, it is also clear that acceptance of these “new” batteries will be subject to rigorous and time consuming qualification and verification. Penetration into this market should not be expected for several years.

Summary

There is a market for the BetaBattery. At the low end of the specific estimates above, that market is approximately $210M ($40M Anti-Tamper, $170M medical devices). As these small-sized, low-power batteries become available and the power requirements of micro electronic devices decline, the markets described above will grow and new markets will develop. The available market for BetaBatteries could become as large as $1B in 10 years.

BetaBatt’s first products will address the low power requirement (nW and µW) applications. The next products will address the ~50mW burst power requirement applications. Medical implant products will start with pacemaker applications. All medical implant products will be have lengthy (2+ years) development, testing, quality, and approval cycles. Final design and packaging will be done according to customer guidelines.

[5] Data sourced courtesy a large medical battery company

APPENDIX: BetaBattery™ Market Issues

Price market will accept

The BetaBattery™ and other betavoltaic micropower devices are being designed to have useful life spans in the range of 10 to 25 years. No other power technology on the market or in development will last for this time period without having an external supply of energy. This unique feature means that the BetaBattery is suited for a variety of applications in which inaccessibility and an associated very high value for performance are keys to the success of the mission. These are the markets that are targets for the BetaBattery, and they are somewhat price insensitive. Based on information BetaBatt has gathered (see also the Market Summary), prices ranging from $200 to $2,000 depending on application and power seem to be acceptable. Currently no betavoltaic devices have been successfully commercialized and therefore, the price the market will accept can only be estimated.

Production cost

BetaBatt has estimated the BetaBattery production cost by accounting for the contributions of materials, services and labor. The total power generated by tritiated 3D silicon diodes is estimated to be 1500 μW per 150 mm diameter silicon wafer. It is convenient to suppose that BetaBatteries will be produced with power outputs in multiples of 100 μW. Therefore the Table below shows the estimated costs of initial production runs in terms of this unit.

Wafer Count	***Cost/(100 μW)***
100 - 399	$1,062
400 - 700	$885

These wafer quantities are quite small by standards of the semiconductor industry. However, as the BetaBattery gains market acceptance, fabrication costs will decline with increased quantity in the usual fashion. It should be noted that the power output of the diodes is the charging component of the BetaBattery and not the instantaneous power output of the BetaBattery itself. As noted in the Market Summary, some applications will require only nanoWatts. In such cases, the basic chip size, power output, and charger circuit will be designed to fit the application

Almost half the cost of the diodes is related to Tritium. The raw cost is at least an order of magnitude greater than the cost of the materials in a chemical battery. In addition, because tritium is radioactive, facilities and handling costs are significantly higher than required for chemical batteries. Finally, the present market for tritium is small and the supply is greater than demand. The overall cost of tritium is dominated by the very small number of suppliers who are able to handle it and can thus impose a premium for this service. For example, raw Tritium sells for about $4 per Curie; however, the handling and processing services increase the cost to around $25 per Curie. It is clear that market acceptance of betavoltaic power sources will increase tritium demand resulting in more suppliers, competition and economies of scale. However, the cost of tritium is likely to remain high for a number of years.

Current market solutions - cost and deficiencies

Chemical batteries are the current solution to long-life power needs and will continue to dominate this portion of the market. Replacement of primary batteries or recharging of secondary batteries is by far the least expensive option when the applications are accessible or when alternate power sources are conveniently available. There is continuing effort by battery manufacturers to improve lifetime, particularly for medical implant applications for which the useful life is nearly 10 years. However, improvements are incremental and likely to remain so unless developments in nanomaterials result in unanticipated improvements.