MTAPP
Taking Manufacturing to New Heights

MTAPP FOCUS PAPER

Small Business Support of Air Force and Department of Defense

Weapon Systems Battery Requirements

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DoD Supply Chain Constraint
Portable Power Sources

The Challenge

The military currently uses thermal batteries in a wide range of weapon systems infrastructure to power sonobuoys, guided artillery, missiles, guidance systems and countermeasure devices. A lack of capable domestic suppliers, the high cost of thermal batteries, as well as manufacturing process problems has constrained the number of weapon systems that can be purchased and deployed. To improve the military's effectiveness without budget augmentation and to meet production requirements, thermal battery costs must be reduced and the manufacturing process and quality improved or alternative technologies advanced in order to remove this constraint. .

Since 2003, the DoD SBIR program has invested more than $22 million, across 120 separate SBIR projects, on advancing battery technologies.

MTAPP believes that successful R&D is only a part of the solution to this problem and that focused technical assistance provided to current MTAPP members attempting to solve these problems could increase the probability of the DoD successfully addressing these challenges.

What MTAPP found:

- Battery usage in the DOD is prolific with over 1,300 different battery parts for over 110 weapons and equipment platforms.
- These portable power requirements are met with batteries utilizing a wide range of technologies (Thermal, Lithium, Silver Zinc/Silver Cadmium, Lead Acid, and Nickel-Cadmium Magnesium) all of which share the fundamental challenge of being difficult and costly to produce.
- The military specification for batteries is highly stringent. Batteries must work in extreme weather, disperse voltage at a high rate have long shelf lives (20 years) and be able to withstand extreme G forces.
- The demand for these non renewable resources has grown near 70% annually from 2001-2005. This demand has choked a supply chain optimized to expand capacity at only 20%.
- Despite the demand surge and the requirement for new suppliers, there remains a critical shortage of domestic suppliers of DOD batteries.
- Initiatives to address this challenge include attacking the problem from many angles:
    - Process efficiency for current technologies
    - New less expensive battery technologies
    - New more capable battery technologies
    - Power management systems to maximize power received per dollar invested
- MTAPP's supplier development efforts can be focused to assist current member companies within this area as well as bring support to other SB innovators trying to commercialize their technology based solutions.

Battery Basics: Two Critical Categories

Thermal Batteries

The term *thermal battery* does not refer to any one type of battery chemistry but to a group of electrochemical systems using different chemistries. The most common configurations are lithium based systems. These types of batteries are for one time use and provide power for mines, missiles, guided artillery, fuses, countermeasure devices, and guidance systems. Activated pyrotechnically, the electrochemical reaction cannot be stopped and has duration of a few seconds to a few hours. Thermal batteries are used exclusively by the military, though R&D is underway to address commercial applications.

Thermal batteries have several advantages over other batteries. Their shelf life is longer than ten years without degradation in performance. They can be activated instantly to provide power within fractions of a second, and their high peak-power density exceeds 10 watts per square centimeter. Thermal batteries are resistant to harsh environments, operate at many temperatures, are reliable after long-term storage, and require no maintenance. They are hermetically sealed, so they do not outgas, and most importantly, they are custom designed for acute voltage, start time, and configuration requirements. Their disadvantages include a very short activated life (usually under 10 minutes), low energy density, a surface temperature of 230 degrees Celsius or higher, nonlinear voltage, and a one-time usage.

Eagle-Picher's Joplin, Missouri facility and Electro Energy's Colorado Springs, CO facilities are the only remaining North American sites for producing thermal batteries. SAFT America in Cockeysville, Maryland ceased thermal battery production in December of 1993 and became a R&D facility. Two other companies, Martin Marietta and Westinghouse, recently have shown thermal battery production capabilities for R&D and prototype batteries.

Lithium Batteries

Lithium batteries are used primarily in military applications, though there is some spin-off into the commercial market. Lithium primary batteries offer performance advantages well above

the capabilities of conventional aqueous electrolyte battery systems. They have the highest gravimetric energy (watt hours/kilogram), highest volumetric energy (watt hours/liter), and one of the best storage lives of any electrochemical battery system.

The lithium chemistries used by the military include primary lithium sulfur dioxide, lithium thionyl chloride, and lithium manganese dioxide. At present, the most widely used of these chemistries is lithium sulfur dioxide. Defense applications include global positioning systems, silo batteries, SINCGARS radios, sonobuoys, and torpedoes. The commercial market uses lithium batteries in a small number of applications. Commercial applications of primary lithium thionyl chloride batteries include animal tracking devices, oil drilling electronics, timing devices, and life support systems. Primary lithium manganese dioxide batteries are used commercially in watches, calculators, laptop computers, cellular telephones, and cameras, and lithium sulfur dioxide batteries in medical devices, animal tracking devices, and lighting on mining helmets.

There are four major North American lithium battery producers - Ballard Battery Systems, Battery Engineering Inc. (BEI), Power Conversion Inc., and SAFT America Inc. (Valdese). A fifth company, Yardney Technical Products, is a potential supplier of lithium systems to the military but, to date, has not produced any batteries. The present market for lithium batteries represents a small fraction of the overall battery market. The lithium marketplace has been driven by military sales, with commercial sales accounting for only a small portion of the overall demand.

Battery Demand within the DoD:

MTAPP research interviews revealed the sourcing of rechargeable and non-rechargeable batteries for weapon systems as a critical supply chain constraint. Battery demand impacts virtually all major aircraft platforms and equipment **(Exhibit 1)**. In addition to presenting real time challenges to the warfighter, the inability to cost effectively produce batteries impacts the speed at which the services can deploy new technologies including smart munitions and unmanned systems.

EXHIBIT 1 The Scope and Impact of the Battery Challenge

Type	Number of Parts	Number of Platforms
Aircraft	255	30
Communications & Elec.	47	24
Strategic Weapons Systems	12	16
Fire Control Systems	4	11
Helicopter	81	7
Ship	9	6
Sonar	4	4
Generators	2	4
Support Equipment	34	3
Material Handling	6	3
Missile	26	1
Aircraft Engine	19	1
Torpedo	11	1
Fire Pumps	7	1
Truck Tank Personnel	6	1
Unknown	787	1
Grand Total	1310	114

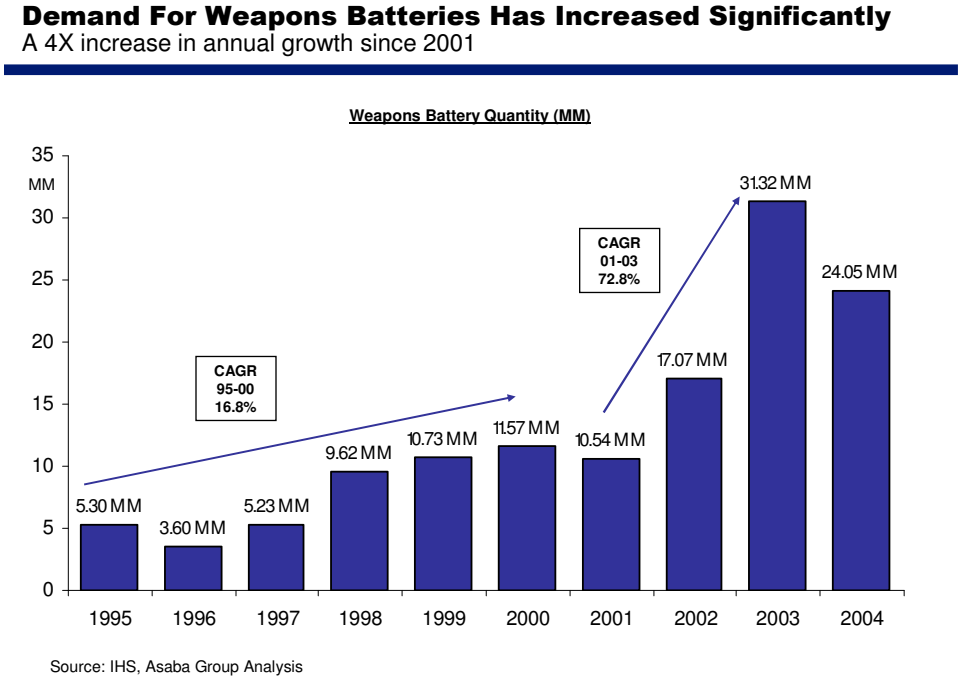
In addition to weapons platforms, Soldiers today also rely on batteries to power: laptop computers, night vision goggles, laser finders, GPS receivers, radios, and target designators. Powering this core survival infrastructure requires that batteries operate in extreme conditions and perform reliably under all conditions. These parameters drive the wide range and complexity of batteries types and configuration used in the military and limits the ability to make commercially viable in a large scale manufacturing model.

Surging Demand for Weapon System Batteries

From 1995 until 2001, demand for batteries used on weapons systems grew at an annual rate of 16.8%. In 2003, as the services began military actions in support of the Global War on

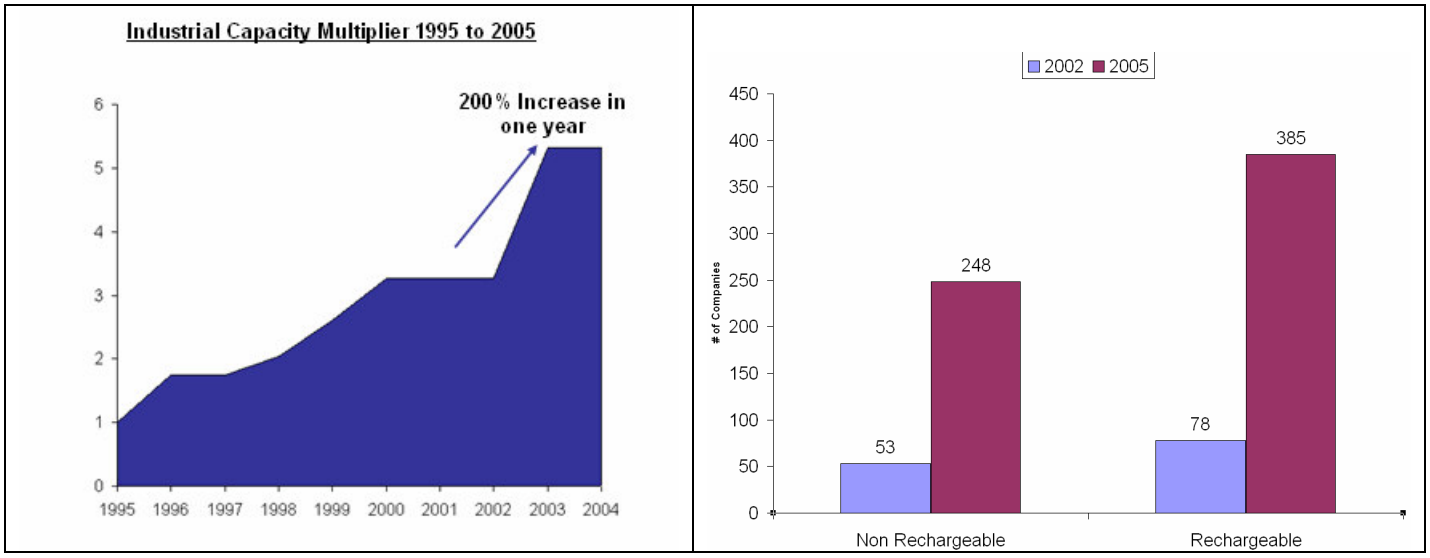
Terror (GWOT) the procurement data show a spike in contract awards that increased capacity requirements within the industry at 78%.

EXHIBIT 2 Surge in Battery Contract Awards with GWOT



The surge in demand in overwhelmed the domestic supply base and consumed both known and new sources of supply (Exhibit 3) at levels never seen before in the industrial base. The tooling up of 200% increase from 1995 production capacity occurred over a five year period from 1995 to 2000. The industrial base remained constant with the same number of companies – the manufacturing economics from 2000 to 2002 was not attractive to encourage new suppliers. From 2002 to 2004, the graph indicates that the industrial base needed a 200% capacity demand increase in less than twelve months. The adjustment to this shift most likely has not fully occurred. During this period, a 2003 report by the North Technology and Industrial Base Organization titled, "An Assessment of Battery Technologies, Trends and Projected Business Climate" also highlighted batteries as critical constraints in military readiness.

EXHIBIT 3 Dramatic Demand Surge within Battery Supply Chain



Barriers of Entry to New Battery Suppliers

While the spike in demand for batteries detailed above certainly demonstrates the limitations within the Supply Chain, more concerning from the DoD's perspective is the supply chains inability and unwillingness to adapt to meet this demand.

The reasons for both the limited number of domestic suppliers available to scale to meet this demand (for each of the two main types of weapon batteries—liquid electrolyte reserve and thermal batteries—there are only two or three manufacturers. The only makers of liquid electrolyte batteries are Alliant Techsystems, EaglePicher Technologies, and KDI Precision Products. For thermal batteries, the two manufacturers are EaglePicher and Enser Corporation) and the lack of suppliers willing to enter into the market to fill this gap include both demand side and cost side factors.

MTAPP identified the following factors that must be addressed in order for a supply side solution to be successful:

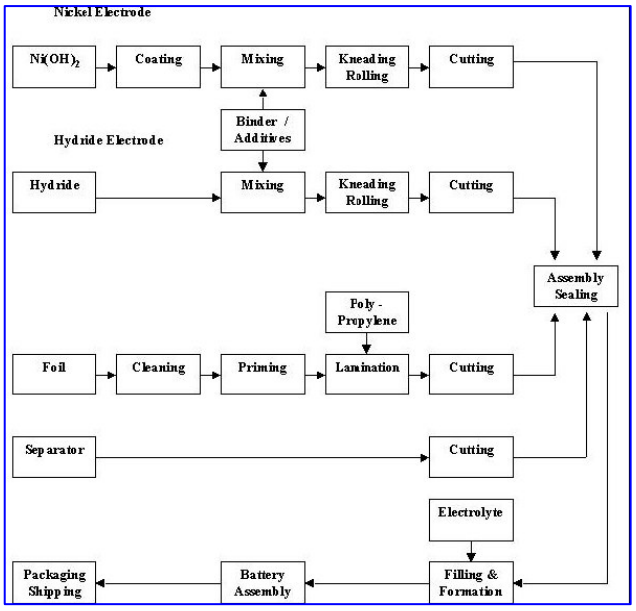
1. **Economic Drivers**: Many U.S. battery companies "opted out" of volume manufacturing of weapon batteries, primarily because of a low return on investment compared with their existing business. The total volume of custom batteries for all of the Defense Department munitions applications is very small compared to commercial battery production, where one commercial brand manufacture about 4.2 billion batteries a year. In addition to the low volumes, the production of weapon batteries consists of both unit-cell production (which can be automated to a high degree) and battery pack assembly (which is most cost effective as a manual process). Establishing an automated production facility requires a minimum investment of about $120 million. The current volume and margins makes it difficult to justify the investment.

2. **Technical and Manufacturing Constraints**: In addition to these economic factors, the requirements for military grade batteries also present unique commodity challenges to suppliers. Weapons/munitions batteries come with unique requirements not found in any other industry. They are small in size and must be capable of lying dormant with a shelf life of 20 years, and then discharge their power in a fraction of a second. They must function in temperatures ranging from minus 45 degrees F to a 145 degrees F, and withstand being fired out of a cannon that subjects them to as many as 100,000 Gs [the

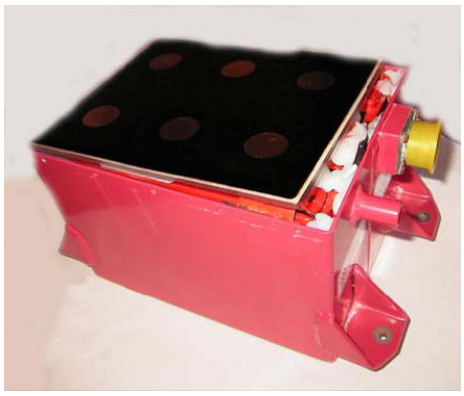
force of gravity][1]. There is difficulty of manufacturing such small batteries munitions batteries. The production line nozzles can clog when forced to rapidly insert minute amounts of electrolyte into liquid reserve batteries. These components must have a quick rise time or the ability to generate power quickly to detonate the munitions. Other military devices require high-performance, highly specialized batteries such as communications equipment, night vision, thermal imaging, chemical agent monitors, landmine detectors, GPS and satellites. Most of these devices depend on reliable, high-energy lithium batteries. High-performance military batteries are on the cutting edge of battery technology and it is a challenge to design and manufacture military batteries that will safely perform demanding tasks under extreme environmental conditions.

The diagram below shows a simplified battery manufacturing process.

EXHIBIT 4



Battery Manufacturing Process



Example: F-16 Thermal Battery

One very stark example of the economic realities facing domestic manufacturers within the Battery Industry is provided by Eagle-Picher. Eagle-Picher is the largest manufacturer of

[1] National Security Assessment, *Gun-Fired Munitions and Sub Munitions Power Source Industry* (June 2004)

Thermal Batteries in the world and the only viable domestic source for these batteries. Despite having this virtual monopoly on the military thermal battery market, Eagle-Picher filed for bankruptcy protection in 2005. At present, Eagle-Picher has emerged from bankruptcy and will continue to be a major source for DoD thermal batteries.

Potential Small Business Roles Within the Battery Market

At present, the DoD is investing significant resources into identifying and implementing a long term solution to their anticipated portable power requirements. Their approaches vary but include:

- Process efficiency for current technologies
- New more capable and less expensive battery technologies
- Power management systems to maximize power received per dollar invested

Developing Lower Cost Thermal Solutions:

One approach executed by the AFRL and ongoing within the AF and Army SBIR programs is the development of less costly processes for the manufacture of Thermal batteries. In 2005, AFRL awarded a $10 million cost plus fixed fee contract to Enser Corp. of Pinellas Park FL to create over the next six years a manufactory to produce cobalt disulfide base thermal batteries. Materials like cobalt disulfide have been found to be more attractive in producing thermal batteries - typically installed in munitions, cockpit ejector seats and other such applications - because they have lower melting points. The project focuses on the development of manufacturing techniques for a power source exploring the use of unconventional methods for electrode fabrication that may substantially reduce the cost of thermally activated batteries and significantly improve performance.

MTAPP is also active in this area through its development efforts with MTAPP member company Electro Energy, Inc. (EEI). EEI is currently in Phase II SBIR development on a project for the development of low-cost thermal batteries through the use of novel and

unconventional methods for electrode fabrication. EEI believes that this solution could drastically reduce the cost of thermal batteries and dramatically improve performance. Preliminary tests have been carried out to show the feasibility of the preparation of the cathode electrode by painting. The capacity of the cell with the painted electrode was better than the standard PP cell. The cell also showed lower polarization during phased transitions due to improved mechanical bonding between cathode particles. The data presented substantiates the contention that painted electrodes offer equivalent performance as standard PP electrodes but at a much lower cost.

In order to address potential obstacles to the commercialization of this technology and process, MTAPP is working with EEI on both Lean Manufacturing concepts and achieving AS9100 quality system certification.

Developing Lower Cost Alternative Solutions

While Lithium and Nickel Cadmium batteries provide cost advantages to the Thermal battery, performance equivalency has not yet been achieved. Within SBIR, there are currently 72 ongoing projects looking at advancing the capabilities of these batteries.

Here MTAPP member EEI is working with the support of the Air Force MANTECH program to further develop a bipolar nickel-metal hydride (Ni-MH) wafer cell design that has the advantages of reduced size, weight, and cost, with increased high power capabilities, over conventional Ni-MH and competing technologies. These advantages make the EEI bipolar Ni-MH the battery of choice to replace main aircraft batteries. To meet the demands of the DOD, and commercial interests, while providing a cost competitive battery, it is necessary to scale-up EEI's manufacturing processes. EEI has begun this scale-up process, focusing on three critical process steps. These include: 1) EEI's $Ni(OH)_2$ electroless nickel coating process; 2) EEI's plastic bonded positive and negative electrode rolling process; and 3) EEI's cell sealing process. This paper describes the scale-up of these key manufacturing process steps, with particular focus on reducing the cost of EEI's bipolar Ni-MH aircraft battery.

MTAPP member Custom Manufacturing and Engineering, Inc. has won a grant to develop an integrated in situ hydrogen production and Micro Fuel Cell (MFC) for Micro Air Vehicle (MAV) Power. The system can replace conventional battery powered MAVs, with the added benefit of longer range. The system will also be capable of recharging or replenishing fuel. This system consists of four parts: (1) An in situ hydrogen generation subsystem, (2) a power generation subsystem, (3) a thermal management system, and (4) a power management system. The novelty of this research lies in the fact that the entire system is being considered from a systems engineering viewpoint with realistic constraints. Past work has typically focused on only one subsystem and the interaction between systems has been ignored. At the end of this research, a virtual prototype of an integrated in situ hydrogen production and fuel cell system that is capable of operating onboard a MAV will be developed. The virtual prototype developed in this research project will provide the key systems integration parameters necessary for building a prototype vehicle as part of a Phase II SBIR effort. The Phase I will develop a model prototype for simulation.

ACTION PLAN FOR MTAPP

As mentioned above, in October 2005, the Air Force Research Laboratory (AFRL) at Wright-Patterson AFB began a program to rebuild some of the factory capacity to produce cobalt disulfide base thermal batteries for weapon system. Enser Corp. of Pinellas Park FL was awarded a $10 million cost plus fixed fee contract to create over the next six years a factory to produce a type of weapons battery - cobalt disulfide base thermal batteries. Materials like cobalt disulfide have been found to be more attractive in producing thermal batteries (typically installed in munitions, cockpit ejector seats and other such applications) because they have lower melting points. This initiative is part of the Air Force Mentor Protégé program. MTAPP proposes that a collaboration with AFRL to audit the progress of Enser Corp. on the development of the manufacturing capabilities necessary to achieve AFRL objectives for use in working with MTAPP member companies EEI and Custom Manufacturing and Engineering.

MTAPP must also investigate how the few military battery manufacturers can leverage the network of small manufacturing companies to meet current requirements. An US manufacturer, Ultralife Batteries, Inc. was awarded in 2005 a five-year battery production contract by the DoD. This DoD acquisition major objective was to maintain a domestic production base of sufficient capacity to meet peace-time requirements and surge quickly to meet any deployment needs. However, the low volumes, profit margins, and technical requirements may be a hurdle in utilizing small manufacturers. Most of the principal suppliers are vertically integrated companies.

Lastly, MTAPP will have to conduct some specific research into areas where the next likely demand for batteries will come from – identifying potential emerging needs that will significantly impact the production capacity of the available sources of supply. These areas may be the future soldier systems, infantry radio applications, and other portable military devices. This knowledge will help provide direction on how current MTAPP companies can participate in addressing the critical shortage issue impacting the military.