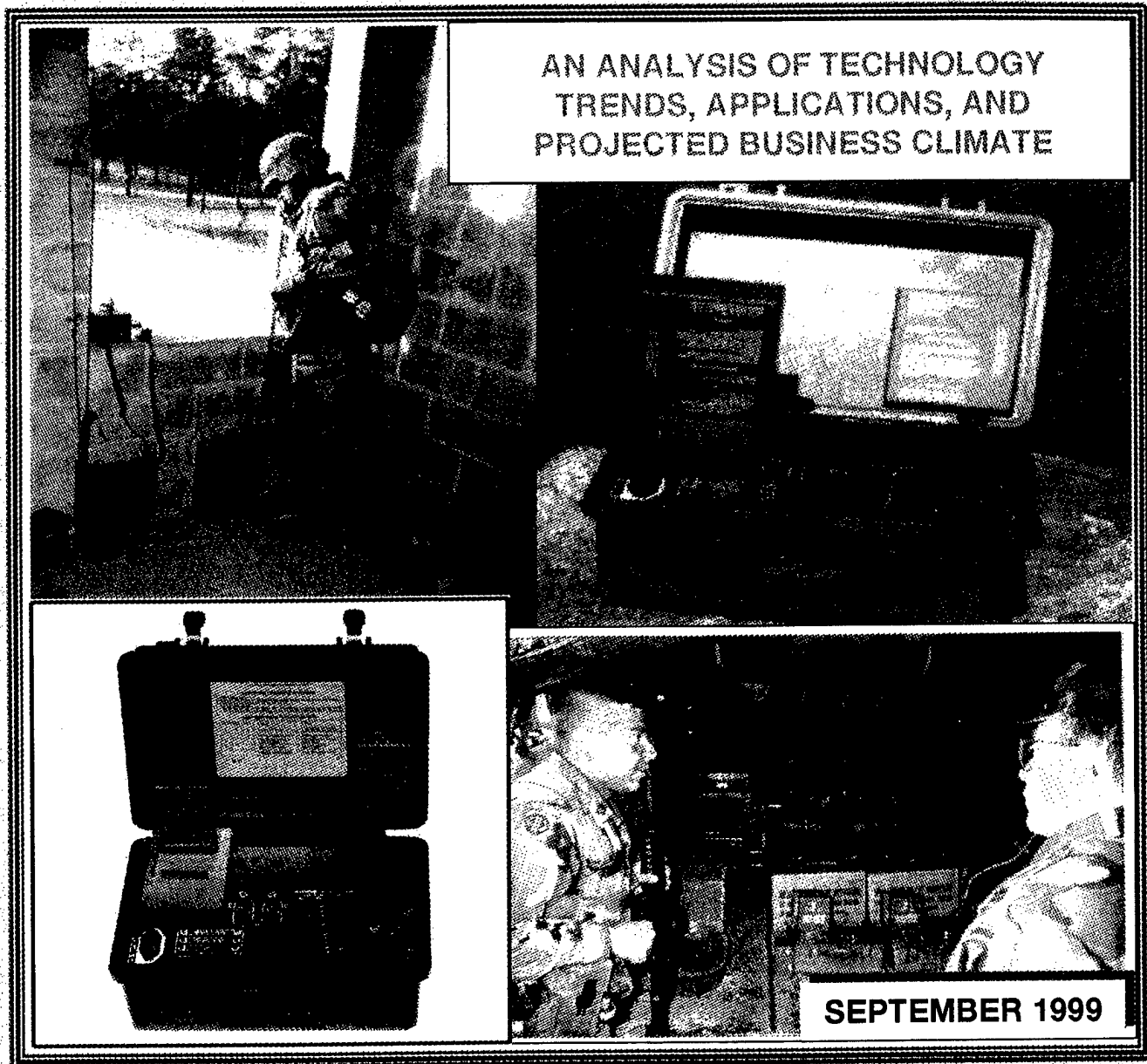
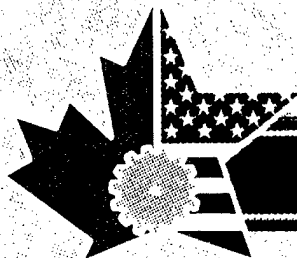


RECHARGEABLE BATTERY/SYSTEMS FOR COMMUNICATION/ELECTRONIC APPLICATIONS



INDUSTRIAL BASE STUDY



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Rechargeable Battery/Systems for Communication/Electronic Applications Industrial Base Study

Abstract

The North American Technology and Industrial Base Organization (NATIBO) study of the rechargeable battery and battery charger technology and the associated industrial base highlights the state-of-the-art and future trends of this technology and industrial base as well as the ability of industry to meet future military communication and electronic requirements.

The objective of the study was to compare the current trends in the commercial rechargeable battery and battery charger markets to the requirements of the military. The study gives an analysis of battery chemistries (sealed lead acid, nickel cadmium, nickel-metal hydride, lithium-ion, lithium polymer) and technology trends, an overview of current and potential defense and commercial applications of the rechargeable batteries. It assessed which battery and battery charging technologies will be required/desired for military communication and electronic equipment and analyzed the North American technology and industrial base capability to produce the type and quantities of rechargeable batteries required by the DoD and DND. The report identifies a number of recommendations that could facilitate a successful full-scale transition to rechargeable batteries for fulfilling military communication power needs.

**RECHARGEABLE BATTERY/SYSTEMS
FOR
COMMUNICATION/ELECTRONIC APPLICATIONS**

*An Analysis of Technology Trends, Applications,
And Projected Business Climate*

INDUSTRIAL BASE STUDY

FINAL REPORT

**Prepared for the North American Technology
And Industrial Base Organization (NATIBO)**

Prepared by TRW Systems & Information Technology Group

September 1999

FOREWORD

In April 1998, the North American Technology and Industrial Base Organization's (NATIBO) Steering Group commissioned a study of the rechargeable battery industrial base.

This report provides the results of the rechargeable battery/battery charger industrial base study, which was conducted between April 1998 and November 1998. It gives a complete and thorough analysis of rechargeable battery chemistries and technology trends; an overview of current and potential defense and commercial applications of the rechargeable batteries; highlights rechargeable battery/battery charger demographics, provides information on cell producers, repackagers, and charger manufacturers; identifies the defense and commercial institutions currently active in research and development in the rechargeable battery/battery charger field; and pinpoints facilitators and barriers effecting more widespread use of rechargeable battery technologies. From this analysis, the report provides a roadmap of recommendations for government and/or industry action to eliminate barriers and address issues hindering expanded use of these chemistries.

This report was prepared for the NATIBO by TRW Systems & Information Technology Group, 12902 Federal Systems Park Drive, Mail Stop 1275/D, Fairfax, Virginia 22033.

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BatteryPro Systems, Inc.	McDowell Research Corp.
BlueStar Advanced Technology Corp.	Moli Energy Ltd.
Bren-Tronics	National Semiconductor
Cadex Electronics, Inc.	Rayovac Corporation
CECOM RDEC	Saft America, Inc.
Cell-Con, Inc.	Ultralife Batteries, Inc.
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Rechargeable Battery/Battery Charger Industrial Base Report

Table of Contents

EXECUTIVE SUMMARY	ES-1
1.0 INTRODUCTION.....	1
1.1 Background.....	1
1.2 Purpose.....	2
1.3 Objectives	2
1.4 Scope.....	2
1.5 Methodology	2
2.0 TECHNOLOGY OVERVIEW.....	4
2.1 Battery Parameters and Factors	6
2.2 Battery Chemistries.....	7
2.2.1 Sealed Lead Acid	8
2.2.2 Nickel Cadmium	8
2.2.3 Nickel-Metal Hydride	9
2.2.4 Li-ion.....	10
2.2.5 Lithium Polymer	11
2.2.6 Direct Comparison	13
2.3 Battery Chargers	14
2.3.1 Battery Charger Elements	15
2.3.1.1 Input Source	16
2.3.1.2 Direct Current (DC) Sources	16
2.3.1.3 Switching Element.....	16
2.3.1.4 Control Element.....	18
2.3.1.5 Indicators.....	19
2.3.2 Charger Types.....	19
2.3.2.1 Integrated Chargers	19
2.3.2.2 Stand-Alone Chargers	20
2.3.2.3 Multi-Port Chargers	20
2.3.2.4 Adapters	21
2.3.3 Charging Methods.....	21
2.3.3.1 Constant Current Charging	22
2.3.3.2 Constant Potential Charging	22
2.3.3.3 Constant Current/Constant Potential Charging.....	22
2.3.3.4 Pulse Charging.....	23
2.3.3.5 Smart Charging	23
2.3.3.6 Maintenance Charging	23

3.0 RECHARGEABLE BATTERY/CHARGER APPLICATIONS	24
3.1 Commercial Rechargeable Battery Applications.....	24
3.1.1 Current Markets	24
3.1.1.1 Portable Communications.....	24
3.1.1.2 Portable Computers.....	25
3.1.1.3 Portable Entertainment.....	26
3.1.1.4 Portable Tools	26
3.1.1.5 Portable Lighting	26
3.1.1.6 Portable Medical Devices	26
3.1.1.7 Portable Scientific and Testing Devices	26
3.1.2 Potential Future Markets.....	27
3.2 Defense Rechargeable Battery Applications	27
3.2.1 Future Defense Applications.....	28
3.3 Battery Charger Applications	30
4.0 RECHARGEABLE BATTERY/CHARGER DEMOGRAPHICS	31
4.1 Defense Market Factors	34
4.2 Cell Producers.....	36
4.2.1 Rayovac.....	36
4.2.2 Moli Energy Ltd.....	37
4.2.3 Sanyo.....	38
4.2.4 Sony	38
4.2.5 Hitachi Maxwell, Ltd.	39
4.2.6 Matsushita Battery Industrial (MBI) Company	40
4.2.7 Toshiba Battery Company	40
4.2.8 GP Batteries International Limited	41
4.2.9 Duracell.....	41
4.2.10 VARTA.....	42
4.2.11 Battery Engineering	42
4.2.12 Other Producers.	42
4.3 Repackagers	43
(Companies Known to Conduct Business with DoD and DND for C/E Equipment)	
4.3.1 Bren-Tronics	43
4.3.2 Lynntronics	45
4.3.3 Alexander Technologies, Inc.	47
4.3.4 Kaycom Incorporated.....	48
4.3.5 Other Potential Repackagers.....	49

4.4 Hybrid Companies	49
4.4.1 Yardney Technical Products, Inc.	49
4.4.2 BlueStar Advanced Technology Corp.	52
4.4.3 Alliant Techsystems Power Sources Center	53
4.4.4 Ultralife Batteries, Inc.	55
4.4.5 Saft	57
4.5 Charger Manufacturers	58
4.5.1 Alexander Technologies, Inc.	58
4.5.2 AlliedSignal Inc., Defense & Space Systems	59
4.5.3 BatteryPro Systems, Inc.	61
4.5.4 Bren-Tronics	62
4.5.5 Cadex Electronics, Inc.	63
4.5.6 Cell-Con, Inc.	65
4.5.7 KB Electronics, Limited	65
4.5.8 McDowell Research Corporation	68
5.0 RESEARCH AND DEVELOPMENT ACTIVITIES.....	69
5.1 Defense Rechargeable Battery R&D Activities.....	70
5.1.1 U.S. Army CECOM.....	70
5.1.2 U.S. Army Research Office (ARO)	72
5.1.3 U.S. Navy Office of Naval Research (ONR).....	72
5.1.4 U.S. Navy – Naval Surface Warfare Center, Crane Division.....	73
5.1.5 U.S. Air Force Research Laboratory (AFRL).....	73
5.1.6 National Aeronautical Space Administration (NASA) Jet Propulsion Laboratory (JPL).....	75
5.1.7 Canadian DND.....	75
5.2 Commercial Rechargeable Battery R&D Activities	76
5.2.1 Bellcore.....	76
5.2.2 Valence	77
5.2.3 3M/USABC/U.S. Dept of Energy (DOE)/Argonne National Laboratory/ARGO-TECH.....	77
5.2.4 Lithium Technology Corporation	78
5.2.5 Battery Engineering	78
5.2.6 Moltech Corporation.....	79
5.2.7 PolyPlus Battery Company	79
5.2.8 Energizer Power Systems	80
5.2.9 Massachusetts Institute of Technology.....	80
5.2.10 Energy Research Lab of Japan.....	80
5.2.11 AEA Technology	80
5.2.12 Eveready/National Semiconductor	80

5.2.13	Duracell/Intel Architectural Labs	81
5.2.14	ARGO-TECH Productions, Inc.	81
5.3	Defense Battery Charger R&D Activities.....	81
5.3.1	Defense Advanced Research Projects Agency (DARPA).....	82
5.3.2	U.S. Army CECOM.....	82
5.3.3	U.S. Air Force Research Laboratory (AFRL).....	83
5.3.4	U.S. Navy –Naval Surface Warfare Center, Crane Division.....	83
5.4	Commercial Battery Charger R&D Activities.....	84
5.5	Power Management and Low Power Electronics	84
5.5.1	Low Power Electronics (LPE)	85
6.0	BATTERY AND CHARGER AS A SYSTEM.....	89
6.1	Smart Technology.....	90
6.1.1	SMBus	91
6.2	Charging Logistics for Military Applications.....	94
7.0	FACILITATORS ENABLING MORE WIDESPREAD USE OF	
	RECHARGEABLE BATTERY TECHNOLOGIES	95
7.1	Reduced O&S Costs	95
7.2	Leveraging of Commercial Batteries.....	95
7.3	Increase Rechargeable Battery Life.....	95
7.4	Reduction of Battery Weight	95
7.5	Smart Technologies	95
7.6	LPE and Power Management.....	95
8.0	BARRIERS AFFECTING MORE WIDESPREAD USE OF	
	RECHARGEABLE BATTERY TECHNOLOGIES	96
8.1	Power Source Logistics.....	96
8.2	Military Unique Applications	96
8.3	Commercial Trend to Small Cells.....	96
8.4	High Initial Cost.....	96
8.5	Soldier Acceptance	96
8.6	Performance (Temperature Extremes).....	97
8.7	Shelf Life	97
9.0	CONCLUSIONS	98
9.1	The LiSO ₂ Industrial Base Is Deteriorating	98
9.2	Power Source Logistics Are Not Being Thoroughly Addressed	98
9.3	Commercial Trend To Smaller Cells Is Not Optimal For Military Applications	98
9.4	Batteries and Chargers Are Not Being Considered As A Single System.....	98
9.5	Battery Capacity Is Approaching Its Realistic Limits (Technology Limits Of Chemistries)	98

9.6	Use of Rechargeable Batteries Reduces O&S Costs For Military Applications	99
9.7	DoD And DND Are Increasing The Use Of Rechargeable Batteries For C/E Applications	99
10.0	RECOMMENDATIONS.....	100
10.1	DoD/DND Should Start Planning to Use Rechargeable Batteries In Combat Situations	100
10.2	DoD and DND Need To Analyze The Impact Of Wide Spread Use Of Rechargeable Batteries.....	100
10.3	DoD and DND Should Develop and Provide Tools To Fully Utilize The Energy In Rechargeable Batteries	100
10.4	DoD and DND Should Focus R&D Efforts On Optimizing Commercial Technologies For Military Applications	100
10.5	DoD and DND Should Address Battery and Charger As A System	101
10.6	DoD and DND Should Emphasize The Use of Power Management And LPE	101
10.7	DoD and DND Should Develop and Standardize Smart Chargers For Use In C/E Equipment.....	101
Appendix A	Acronyms	A-1
Appendix B	Points of Contact	B-1

LIST OF TABLES

Table 2-1	Comparison of Battery Parameters	13
Table 2-2	Comparison of Mission Requirements and Cost	14
Table 4-1	Portable Electronic Products.....	31
Table 4-2	Rechargeable Battery Sales.....	33

LIST OF FIGURES

Figure 2-1	Basic Elements of a Battery Charger	15
Figure 2-2	Series Pass Current Limit Transistor Switch	16
Figure 2-3	Pulse Width Modulated Switching Circuit	17
Figure 2-4	Saturable Reactor Charger	17
Figure 2-5	SCR Controlled Charger	18
Figure 6-1	Typical Smart Battery Smart Charger Block Diagram	93

EXECUTIVE SUMMARY

The North American Technology and Industrial Base Organization (NATIBO) study of the rechargeable battery and battery charger technology and industrial base highlights the state-of-the-art and future trends of this technology and industrial base and the ability of this industry to meet future military communications requirements. It gives a complete and thorough analysis of rechargeable battery chemistries and technology trends, an overview of current and potential defense and commercial applications of the rechargeable batteries; highlights rechargeable battery/battery charger demographics, providing information on cell producers and repackagers; identifies selected defense and commercial institutions currently active in research and development in the rechargeable battery/battery charger field; and pinpoints facilitators and barriers effecting more widespread use of rechargeable battery technologies. From this analysis, the report provides a roadmap of recommendations for government and/or industry action to eliminate barriers and address issues hindering expanded use of these chemistries.

Previously, the military was heavily dependent on the sole use of nonrechargeable batteries in peacetime and war. This study became a necessity due to several significant developments that have occurred influencing the military unique nonrechargeable battery production base. This production base has eroded as a result of reduced peacetime demands caused by the downsizing of the forces and the high operating and support (O&S) costs associated with using nonrechargeable batteries. These costs caused Canada's Department of National Defence (DND) to implement a program to use rechargeable batteries several years ago. More recently, these costs have driven the U.S. Department of Defense (DoD) to significantly increase the use of rechargeable batteries during Operations Other Than War (OOTW). This increase is also partly attributed to the substantial advances in rechargeable battery technologies that make their use in tactical situations more practical.

FACILITATORS ENABLING MORE WIDESPREAD USE OF RECHARGEABLE BATTERY TECHNOLOGIES

The NATIBO Rechargeable Batteries/Chargers Working Group identified a number of facilitators enabling the successful full-scale transition to employing rechargeable batteries of the U.S. and Canadian Defense Departments.

- Reduced O&S costs
- Leveraging of commercial batteries
- Increased rechargeable battery life
- Reduction of battery weight
- Smart technologies
- LPE and power management

BARRIERS AFFECTING MORE WIDESPREAD USE OF RECHARGEABLE BATTERY TECHNOLOGIES

A number of barriers were uncovered inhibiting the two governments' abilities to capitalize on advances being made in the battery/battery charger technology arena and to fully implement policy directing greater use of rechargeable batteries.

- Power source logistics
- Military unique applications
- Commercial trend to small cells
- High initial cost
- Soldier acceptance
- Performance (Temperature Extremes)
- Shelf life

CONCLUSIONS

The conclusions of this study are based on observations of the current technological and business environment associated with the rechargeable battery technologies.

- The Lithium Sulfur Dioxide (LiSO_2) industrial base is deteriorating
- Power source logistics are not being thoroughly addressed
- Commercial trend to smaller cells is not optimal for Military applications
- Batteries and chargers are not being considered as a single system
- Battery capacity is approaching its realistic limits (technology limits of chemistries)
- Use of rechargeable batteries reduces O&S costs for Military applications
- DoD and DND are increasing the use of rechargeable batteries for Communication/Electronic (C/E) applications

RECOMMENDATIONS

Based on the conclusions reached as a result of this analysis into the technology and industrial base for rechargeable batteries/chargers, the NATIBO Rechargeable Batteries/Chargers Working Group has outlined the following recommendations. These recommendations fall into two categories: those that could be implemented in the short term and those that could be implemented over time. These recommendations highlight a roadmap of actions that the U.S. and Canadian governments could embark upon to help ensure a successful full-scale transition to rechargeable batteries for fulfilling their communications power needs.

- DoD/DND should start planning to use rechargeable batteries in combat situations
- DoD and DND need to analyze the impact of wide spread use of rechargeable batteries
- DoD and DND should develop and provide tools to fully utilize the energy in rechargeable batteries
- DoD and DND should focus R&D efforts on optimizing commercial technologies for Military applications
- DoD and DND should address battery and charger as a system
- DoD and DND should emphasize the use of power management and LPE
- DoD and DND should develop and standardize smart chargers for use in C/E equipment

1.0 INTRODUCTION

1.1 Background

The North American Technology and Industrial Base Organization (NATIBO) completed a sector study assessment of the overall battery industrial base in August 1994. Since then, several significant developments have occurred influencing the military unique nonrechargeable sector of the battery production base. This production base has eroded due to reduced peacetime demands, caused by the downsizing of the forces and the high operating and support (O&S) costs associated with using nonrechargeable batteries. These costs have driven the U.S. Department of Defense (DoD) and Canadian Department of National Defence (DND) to increase significantly the use of rechargeable batteries during OOTW. This increase is also partly attributed to the substantial advances in rechargeable battery technologies that make their use in tactical situations more practical. The DoD and DND anticipate the use of rechargeable batteries and chargers to expand in the future due to the potential cost savings and the growing use of manportable equipment.

Faced with increasing costs associated with the use of batteries, specifically nonrechargeable batteries, U.S. Army Deputy Chief of Staff for Logistics established a requirement, effective 1 October 1998, that rechargeable C/E batteries will be used for all military OOTW, including training and garrison duty. It is anticipated this direction will significantly reduce consumption of nonrechargeable batteries. Of the C/E batteries purchased by the U.S. Army in Fiscal Year (FY) 1995, 91 percent were nonrechargeable batteries. The U.S. Army estimates that the increased use of rechargeable batteries and chargers will save 25 percent or more than spent currently for nonrechargeable batteries for the same purpose.

In the U.S. and Canada, each Military Service conducts Research and Development (R&D) on rechargeable batteries and chargers to fulfill their respective missions with leveraging of these efforts to optimize value and minimize redundancy. Within the U.S., the majority of rechargeable batteries are procured by U.S. Army Communications-Electronics Command (CECOM) and the Defense Logistics Agency (DLA). Within Canada, the Director General Land Equipment Program Manager has primary responsibility for the procurement of the vast majority of rechargeable batteries. In each country, chargers are primarily procured separately by each Military Service.

In Canada, the Canadian Forces have used rechargeable batteries for a number of years as a reliable cost effective source of power. The Canadian Forces have also determined that they will increase the use of rechargeable batteries to power their portable communications equipment for many of the same reasons outlined by DoD. At present, the Canadian Forces are using rechargeable Nickel Cadmium (NiCd) to power their equipment. By contrast, the DoD is deploying the nickel metal hydride (NiMH) technology and pursuing the rechargeable lithium technologies. The Canadian decision is based on concerns regarding the reliability and service life of NiMH batteries. In all likelihood, the Canadian Forces will wait to procure the rechargeable lithium batteries and associated chargers as these technologies mature, foregoing the use of NiMH batteries altogether.

1.2 Purpose

The NATIBO study of the rechargeable battery and battery charger technology and industrial base (an area not addressed in detail in the 1994 NATIBO study) will highlight the state-of-the-art and future trends of this technology and industrial base as well as the ability of this industry to meet future military C/E requirements.

1.3 Objectives

The objective of this study is to compare the current trends in the commercial rechargeable battery and battery charger markets to the requirements of the military. It will also assess which battery and battery charging technologies will be required/desired for military C/E equipment and to analyze the North American technology and industrial base capability to produce the type and quantities of rechargeable batteries required by the DoD and DND.

1.4 Scope

The rechargeable batteries and battery chargers studied are only those used in the C/E industry and similar applications. Battery chemistries to be addressed are sealed lead acid, NiCd, NiMH, lithium ion (Li-ion), and lithium polymer. Batteries used for starting, lighting, or ignition, and propulsion were not studied. Types of chargers studied include integrated, stand-alone, and multi-port, and their charging methods. The study focused on those representative companies who currently provide, or are expected to provide in the near future, rechargeable batteries and chargers to the DoD/DND.

1.5 Methodology

The rechargeable battery/charger industrial base study required a clear, concise, and well-defined methodology to survey government, industry, and academia effectively and compile military, commercial, political, marketplace, and academic perspectives. The data collected and analyzed for this study were drawn from previously published reports, conference proceedings, journal articles, Internet home pages, and other on-line sources, as well as from discussions with U.S. and Canadian representatives from industry, government, and academia.

The study group's goal was to meet with or contact a representative sample of rechargeable battery/charger researchers, rechargeable battery/charger suppliers, end users, proponents, and policy makers. Factors taken into consideration in selecting sites to visit or contact included volume and business with DoD and DND, battery chemistries produced, chargers manufactured, state of the technology, applications, and new technology development. Site visits were conducted in the U.S. and in Canada. Data collection guidelines were developed and used to facilitate obtaining data from all points of contact either through telephone interviews and/or site visits.

Data collected from relevant documents, World Wide Web sites, site visits, and phone interviews were analyzed and incorporated into key sections of this report. This report functioned as a working document throughout the data collection and analysis phases of this study.

2.0 TECHNOLOGY OVERVIEW

All batteries produce electricity by converting chemical energy to electrical energy through oxidation-reduction reactions at the electrodes. Batteries fall into two major categories, nonrechargeable (primary) and rechargeable (secondary). A rechargeable battery system has the ability to convert electrical energy back into chemical energy. During the discharge of a cell or battery, electrons flow from the anode to the cathode through an external circuit. The anode acts as the negative electrode and the cathode as the positive electrode. Anions (negatively charged ions) flow from the cathode to the anode and cations (positively charged ions) flow from the anode to the cathode. During charge, electron flow is from the former anode to the former cathode, however, the anode is now the positive electrode and the cathode is negative. Anions and cations still flow toward the anode and cathode, respectively. Another way of saying this is that oxidation (loss of electrons) always occurs at the anode, while reduction (gain of electrons) occurs at the cathode.

The device used to transfer energy back into a rechargeable battery is called a battery charger. The charger forces current into the cells, thereby partially reversing the oxidation and reduction chemical reactions that occurred when the battery provided power. Several methods of charging exist. The method that the charger uses to determine when charging is complete is called the charge algorithm. The method specified is designed to optimize the return of energy back into the battery.

As battery usage has become more pervasive in recent years, the demands placed on the battery have increased. This is due to the trend toward more and more powerful portable applications, from beepers to cellular phones to computers, which has increased the demand for portable electric power. Perhaps the most demanding commercial application today is for a portable laptop computer that can operate continuously on a transcontinental flight. This application establishes stringent requirements for a battery that can operate for extended periods between charges (more than five hours) and be of small size and light weight. This application has driven much of the recent R&D in this field, due largely to the size of the market for laptop computers and their relatively expensive batteries.

The battery industry is traditionally an area where innovation comes slowly. Battery life has become an important criteria for buyers of portable electronic products. The most prevalent battery technologies in use today are NiMH and NiCd, with increasing applications of the Li-ion and lithium polymer.

Of the advanced technologies (NiMH and the various types of rechargeable lithium), each is at a different stage of development, and each promises greater energy storage, lighter weight, lower costs, and a safer environment than the baseline NiCd. In the short term, NiMH batteries are gradually replacing NiCd. Over the next several years, the rechargeable lithium technologies are expected to replace NiMH, especially in applications where weight and operating time are worth a premium in price.

When portable electronics applications first became popular, the size of the battery pack was not critical since the size of the end item was dictated by the electronics inside. This is no longer true, and in many instances the battery itself is the single largest component. With the increasing miniaturization of electronics, the ability of the battery to physically "fit" into the application is crucial. This has led to battery configurations that in

most instances are unique to the end item application. Battery level design will always be driven by the physical configuration constraints placed on it by the overall system design. Therefore, there has been and will continue to be little standardization at the battery level.

Even with a lack of standardization at the battery level, there was significant standardization at the cell level. Every battery was comprised of multiples of standard cell sizes ("AA" or "AAA"). With the current design trend away from cylindrical cells and to the pliable lithium polymer technology, even this level of standardization is projected to disappear. The ability to "mold" the lithium polymer technology into any shape will facilitate the lack of standardization in the future.

Operational requirements for an electronic device are established primarily by the users, based both on the military mission and what technology can reasonably fulfill their power needs. The system developer will establish a power requirement to be met by the battery developer. The battery developer will assess that power requirement and work with the system developer to develop a battery that meets the operational usage scenario. The "Holy Grail" of battery design is always greater capacity at less weight, volume, and cost.

The final system configuration will usually represent a compromise between the competing interests of costs and capabilities. From the system perspective, the goal is longer operational life before recharging or replacement. This goal can be advanced both by improving battery performance and by reducing power requirements in the application. The key fact is that there is a direct relationship between end item performance and battery power, therefore, the end item/battery combination must be viewed as a single system. This relationship applies to both commercial and military applications. However, the military adds other factors, such as high and low extreme temperature performance and shelf life that are not as restrictive in commercial applications. What is a matter of inconvenience for a commercial application can be a life-or-death matter in a military application. Normally, mission requirements take precedence over battery requirements.

Battery chargers must be included in the systems concept discussed above. Battery chargers either can be built into the application or consist of a separate unit. Built-in units imply that the end item must be connected to an external power source during the recharging process, and therefore limited in use and mobility during the charging of the battery. Separate charging units provide the operator with the ability to replace a discharged battery with a recharged one and continue portable use of the application.

A battery charger will typically consist of the charger unit and an interface between the battery and the charger. The charger also has control circuits that are typically programmed to monitor such parameters as time of charging, voltage, voltage change, temperature, and temperature rate change (for batteries with internal temperature sensing). The charger also has some form of indicator that displays when the battery is fully charged. More sophisticated chargers may have displays that indicate the level of charge, float/trickle charge, and charge parameter displays.

2.1 Battery Parameters and Factors

The relevant parameters and factors used for comparison of the many different battery types and chemistries are:

- **Voltage:** Voltage (or volts) expresses the difference in electrical potential between two conductors. Voltage is an indication of the potential of the electrical energy to overcome electrical resistance. In the simple fluid flow analogy, voltage equates to pressure. Voltage is only one of several indicators of battery performance. A single battery may have several contacts to deliver different voltages as needed by the application.
- **Current:** Current is a measure of the total electron flow in an electrical circuit and is expressed in amperes (abbreviated amps) or, in low power situations, milli-amperes (milli-amps). In the fluid analogy, current equates to volumetric flow (quantity). Current is also expressed as battery drain. An automobile battery is designed to provide a high current for a short period of time. Conversely, a watch battery provides an extremely low current for a very long period of time.
- **Power:** Electrical power is the ability to do a certain amount of work in a certain period of time, and is normally expressed in Wh (watts being the product of volts times amps). Wh (or, in larger units, kilowatt-hours) are the familiar units that appear on one's electric bill, for example. For a particular application, a certain level of voltage and current is required to make the application components function properly for a desired period of time. Thus, each type of battery will be rated both for its delivery voltage and for its current delivery capability.
- **Capacity:** The total energy that a battery can deliver is referred to as capacity. Capacity is a measure of the length of time that a battery can deliver a design amperage at or near a design voltage. Since all applications require a useful time of performance, the latter is normally expressed in current-time terms, for example, ampere-hours (Ah) or milli-ampere-hours (mAh). Power (or energy-time) rating of a battery is the second indicator of battery performance, the first being voltage, discussed above.
- **Energy Density:** Energy density is an efficiency measure and can be expressed either as a volumetric measure (power per volume) or as a gravimetric measure (power per weight). With nonrechargeable batteries, which come in standard sizes, volumetric energy density is usually considered more important. Rechargeable batteries tend to be larger (due to their inherently lower efficiency) and gravimetric energy density, expressed as Wh per pound or kilogram, becomes the more meaningful measure. Energy density is especially important in the design of portable systems where weight is an important consideration, with a high energy density being desirable.
- **Discharge:** Batteries have different discharge characteristics. These are typically plotted as voltage versus power, with power expressed either in terms of percentage of total or absolute current-time. This measure also allows for the important comparison at different temperatures of the battery's ability to deliver the desired

total performance under a wide range of temperature conditions that may be a requirement, especially in military applications.

- **Operating Temperature:** The temperature range within which the battery will deliver its stated capacity is called its operating temperature. The military typically establishes operating temperature requirements for both arctic and tropical conditions that exceed typical commercial requirements.
- **Recharge Time:** Recharge time is a measure of how long it takes a particular chemistry battery to be restored to a fully charged state.
- **Cycle Life:** Cycle life refers to how many times a particular battery chemistry can be discharged with satisfactory results. Obviously, the more times that a battery can be discharged, the more cost-effective that battery will be. The ideal would be an indefinite number of discharges. Cycle life data is normally obtained from laboratory tests. Real cycle life is dependent also on actual user and environmental conditions.
- **Cost per Cycle:** A method by which the cost effectiveness of different chemistries can be compared. The standard method is to divide the battery unit cost by a commonly accepted number of cycles. This number is usually found in some form of specification (a military performance specification, for example). The costs associated with the actual charging (i.e. cost of the charger, power, and associated manpower) are usually insignificant on a per cycle basis and therefore normally disregarded.
- **Safety/Environmental Factors:** Disposal of used batteries has become more important in recent years. Most battery materials are toxic (lead and cadmium) or hazardous/reactive (lithium, nickel, zinc). Rechargeable lithium batteries can explode if burned. The logistics "tail" associated with the proper disposal of batteries is a significant concern. However, new technologies will not require the same restrictions for disposal.

2.2 Battery Chemistries

The total amount of electrical energy the battery produces is limited by the amount of chemical energy stored by the materials involved in the reactions. Battery research has focused on finding the best combination of materials (cathode, anode, and electrolyte) that will store and release the greatest amount of chemical and electrical energy. The combination of these materials is what distinguishes the various rechargeable technologies. The differences tend to manifest themselves in such areas as weight, capacity, temperature range, the time it takes to recharge, and the number of times they can be recharged.

All batteries tend to exhibit gradual deterioration in performance over time. This manifests itself in two factors - shelf life and cycle life. All rechargeable batteries self discharge when in storage - some of which may be irreversible if the battery is not properly maintained. All rechargeable batteries also lose a minute amount of capacity each charge/discharge cycle. This characteristic limits the number of times that it can be recharged.

Batteries are made up of one or more cells. Each cell is capable of producing only a certain voltage, based not on its size but on the internal chemistry. To achieve the higher voltages required in many applications, cells are connected in series. The relative size of the surface area in each cell will determine the current producing capability while the chemistry determines the electrical potential or voltage.

Rechargeable battery technology for C/E applications began with sealed lead acid batteries. It eventually migrated to the nickel based chemistries, first NiCd, then NiMH. The next major technology is the rechargeable lithium chemistry, which is just currently entering widespread use.

2.2.1 Sealed Lead Acid

The typical lead-acid battery consists of lead-oxide plates, alloy grids, a porous separator, and a sulfuric acid electrolyte. Lead-acid portable product batteries are available with capacities ranging from 2.5 Ah to 27Ah, and range from cylindrical flashlight cells to automobile-sized rectangular designs. Both high-pressure and gelled electrolyte versions are used. In cylindrical units, sulfuric acid is injected into the cell between the coiled plates at 50 pounds per square inch and capped. In rectangular designs, the electrolyte is gelled with any of several polymers. Sealed batteries are less expensive than comparable NiCd designs, but are heavier, have shorter cycle lives, and run hotter.

Developments in lead-acid battery technology tend to center on increasing the exposed area of the plates relative to their weight. This has been approached through woven plate designs and increased porosity, providing over 60 percent active mass as opposed to 25-40 percent with conventional plates. Sealed designs allow inverted operation in applications, such as portable power tools.

- Advantages: Relatively low cost. Mature technology.
- Limitations: Heavy weight. Relatively low energy density. Environmental problems associated with lead and sulfuric acid.

2.2.2 Nickel Cadmium

Nickel Cadmium (NiCd) battery technology was one of the earliest rechargeable chemistries developed after lead-acid. Most power-consuming devices, such as power tools, video camera, laptop/notebook computers, and cellular phones, would never have been commercialized in portable form without NiCd batteries, which at the time were the only sealed small rechargeable cells available.

In sealed NiCd designs, the most common design used in C/E applications, two very thin plates of sintered carbonyl nickel are rolled into a cylindrical cell. Each plate is impregnated with the appropriate active material (either nickel or cadmium). Between the leaves of this coil is an alkaline-impregnated separator. The plate coil is a very stable configuration allowing a high number of cycles. Vented designs use a safety vent to allow gases to escape. Completely sealed designs, including most commercial designs, must be

charged at low rates to minimize gassing and the buildup of internal pressure. NiCd cells have the potential to rupture if charged too quickly.

NiCd batteries are much less bulky than previous (lead acid) batteries, and thus, more suitable for portable use. The main advantage of NiCd chemistry is that it provides a high level of power and charging efficiency. NiCd batteries also provide a cycle life of 300 to 700 charges. NiCd batteries exhibit good low temperature properties. NiCd chemistry has a proven track record and is a well established technology.

The drawback of NiCd when compared to newer rechargeable chemistries is that these batteries have relatively low energy density, which limits their use in weight-sensitive applications. NiCd batteries also have a characteristic known as memory effect. If the battery is not fully discharged before recharging, it develops a memory and cannot deliver full capacity upon discharge. In addition, the battery has a self discharge rate of about one cent per day when not in use. Finally, cadmium is a toxic heavy metal that is harmful to the environment.

NiCd batteries deliver approximately 1.2 volt (V) per cell and have an energy density rating on the order of 60 Wh per kilogram.

- Advantages: High current at stable voltage. Relatively high cycle life. Electrically interchangeable with nonrechargeable battery systems. Good low temperature performance.
- Limitations: Relatively heavy. Environmental problems associated with cadmium. Self discharge rate. Memory effect. Relatively low energy density.

2.2.3 Nickel-Metal Hydride

Nickel-Metal Hydride (NiMH) batteries entered the commercial market in the early 1990s. The NiMH battery provides 30-40 percent more capacity over an equivalent NiCd battery. However, the price of the NiMH battery is about 50 percent higher than that of an equivalent NiCd battery. NiMH batteries do not have as significant a memory effect as NiCd batteries; they can be recharged to their full potential even if they are not fully discharged. Whereas a NiCd battery can be safely recharged in about 90 minutes, the NiMH battery needs about three hours to charge, under the same conditions. NiMH is also more environmentally friendly than NiCd due to the absence of cadmium.

NiMH batteries are a modification of nickel-hydrogen technology that avoids some of the disadvantages of NiCd batteries and allows the fabrication of small cells with a nickel-hydrogen electrode couple. The key to NiMH technology is a multiphase, polycrystalline alloy of vanadium, zirconium, titanium, nickel, and chromium acting as the cathode with a nickel hydroxide anode. A potassium hydroxide electrolyte is used. The electrolyte is electrolyzed into hydrogen and hydroxide ions during charging. The hydrogen ions are absorbed by the cathode to form a hydroxide. Nickel hydroxide at the anode is oxidized during charging to form nickel oxyhydroxide. This reaction is reversed as the battery discharges. Since cadmium is eliminated, the battery is much lighter than NiCd cells.

NiMH batteries are formed of cylindrical cells filled with a liquid electrolyte. NiMH batteries have a high cycle life (as high as 1000 recharge cycles), no memory effect, and good temperature stability (however, without NiCd's performance at very low temperatures).

NiMH batteries currently have a lower unit price than lithium nonrechargeable batteries and have potentially 70 percent greater energy capacity than NiCd batteries of the same size and weight. NiMH batteries deliver approximately 1.2 V per cell and have an energy density rating on the order of 80 Wh per kilogram. NiMH and NiCd batteries can use the same rechargers and are usually interchangeable in most applications.

- Advantages: Relatively high cycle life. High current at stable voltage. Lighter than NiCd.
- Limitations: Slow recharge time compared to NiCd. Low power break-in period. Short shelf-life due to self-discharge.

2.2.4 Li-ion

The rechargeable lithium technology is relatively new and still emerging. The basic technology was developed as a result of the search for a battery that could be recharged a nearly unlimited number of times, would generate little heat during recharging, and could be fabricated into almost any shape. The first variation of the rechargeable lithium technology to be widely used in the commercial industry comes under the generic heading of Li-ion. Note that all batteries, lithium or otherwise, are based on "ions." In the case of Li-ion technology, the use of the term "ion" emphasizes the fact that the lithium component is always in an ionic state and never in a metallic state.

Li-ion batteries, already used in cellular phones, camcorders, and computers, are smaller and lighter than both NiCd and NiMH batteries of equivalent capacity. Li-ion battery weighs about half of the equivalent NiCd battery, with the potential to be more cost effective. Li-ion technology also has the potential for extremely long cycle life: the total number of charge/discharge cycles can exceed 1000.

Lithium, a soft but reactive alkali metal, is the least dense of all metals. Li-ion for batteries assures stable voltages and high energy density. However, Li-ion batteries are sensitive to overcharging, which has led to the development of several safety features and smart rechargers.

Anodes in Li-ion batteries consist of cobalt-acid lithium, while the cathodes employ carbon material. In operation, the cathode absorbs the Li-ions during charge periods and emits them to the anode during discharge periods. In theory at least, this permits continuous circulation of the same Li-ions between the cathode and the anode, enabling a long service life.

Li-ion cells come in two forms, cylindrical and prismatic (rectangular). Both are filled with a liquid electrolyte but differ in external shape. Both can be used in virtually any battery configuration; however, prismatic cells enable thinner batteries and more efficient use of battery space. For example, Li-ion rechargeable batteries offer up to a 250 percent

increase in energy and a 30 percent reduction in weight as compared to nickel cadmium batteries of the same case size.

Li-ion batteries deliver approximately 3.6 V per cell (versus 1.2 V for NiCd and NiMH batteries) and have an energy density rating on the order of 120 Wh per kilogram. Comparing NiCd and NiMH batteries to Li-ion batteries of identical volume shows that Li-ion models have twice the capacity over both NiCd and NiMH. A Li-ion battery that weighs 30 percent less than a NiCd model will deliver 2 ½ times the electrical energy. This makes it advantageous to use Li-ion batteries in portable applications.

- Advantages: High energy density. High number of recharge cycles. No memory effect. Low self-discharge rate (longer shelf life between recharging).
- Limitations: Higher priced. Requires protective circuitry to assure safe use. Limited discharge rate.

2.2.5 Lithium Polymer

The lithium polymer battery is another emerging chemical system that is a further refinement of the Li-ion technology discussed above. The most significant difference is the use of a polymer rather than a liquid electrolyte. Lithium polymer batteries are constructed of thin, flat cells. This enables construction of thinner batteries and more efficient use of allocated battery space in compact applications as compared to Li-ion batteries that are constrained to shapes that will accommodate the liquid electrolyte.

A lithium polymer battery is a complex assembly of components. The basic building block is typically a bi-cell composed of two flat cathodes on either side of an anode separated by the electrolyte-impregnated separator made of plasticized resin. The bi-cell is produced in a continuous strip process and is cut and sized to provide the basic voltage and current. A stack of bi-cells are connected in parallel to form a pack - or packaged cell - that will provide a desired current at the design voltage level. Several packs are then connected in parallel and series combinations to form the finished battery and provide the various voltage and current combinations needed by the application. The finished battery will include the contacts, sensors, indicators, and supervisory circuits necessary to interface with a battery charger for smart control.

Lithium polymer ion rechargeable batteries use almost the same anode and cathode material as their conventional lithium counterparts. However, they employ a solid gel polymer electrolyte instead of a liquid electrolyte. The voltage and cycle characteristics are equal to those of conventional Li-ion rechargeable batteries. But, the solid electrolyte eliminates leaks and ensures better safety characteristics than liquid versions. In addition, these batteries can adopt a metal sealing film that is just several tens of microns thick, reducing overall size and weight.

Thin models of lithium polymer technology can bend to 90° F and have the potential to be formed into flexible pouches that can conform to, for example, a person's body. The use of the solid polymer electrolyte eliminates the needs for cases and lids, thereby lowering material costs.

Solid-state lithium polymer rechargeable batteries are safer than liquid filled Li-ion, offer greater design flexibility, may cost less, and are as environmentally friendly as liquid filled Li-ion. However, lithium polymer currently has a limited cycle life of about 175 recharge cycles.

- Advantages: Expected to exhibit longer life, reduced size and weight, and improved recharge characteristics when compared to nickel or lead based technologies. Safer than Li-ion, greater design flexibility, lower life cycle cost.
- Limitations: Problem associated with the mass production of an emerging technology. Lithium polymer batteries cannot produce large currents, which will limit their use to relatively low-drain applications.

2.2.6 Direct Comparison

In the military, parameters other than cost - such as weight, capacity, and the number of batteries to complete a mission - have an impact on the battery/technology selection process. Currently, the baseline to which all rechargeable batteries are held is the BA-5590/U Li/SO₂ battery. The BA-5590/U battery is used in over 50 different pieces of U.S. Army equipment, including the Single Channel Ground and Airborne Radio System (SINCGARS) tactical radio. The following comparison illustrates the ability of rechargeable batteries to meet military requirements. Table 2-1 compares parameters of specific rechargeable batteries to the nonrechargeable Li/SO₂ battery used by the military.

Table 2-1, Comparison of Battery Parameters¹

Chemistry/ Military Designation	Nominal Voltage	Energy Wh/L	Operating Temp. (Centigrade)	Cycle Life ²	Weight/ Compared to BA-5590/U	Capacity Amp Hours Compared to BA-5590/U ³	Disposal
LiSO ₂ / BA-5590/U	3.0	415	-55 to +70	1	1.0	1.0 (7.2 Ah) ⁴	Hazard
Sealed Lead Acid/ BB-490/U	2.0	90	-20 to +55	250-500	2.04	0.30	Hazard/ Recycle
Sealed NiCd/ BB-590/U	1.2 V	80-105	-30 to +40	300-700	1.8	0.39	Hazard/ Recycle
NiMH/ BB-390/U	1.2 V	175	-20 to +40	1000	1.73	0.75	Non Hazard
Li-ion/ BB-XX90/U	2.9	200	-30 to +55	>1000	1.32	0.78	Non Hazard
Lithium Polymer/ BB-XX90/U	3.2	350	-20 to +55	Unknown	1.45	0.89	Non Hazard

¹Energy Wh per liter, Operating Temperature, and Cycle Life were taken from:

Linden, David, Editor in Chief, Handbook of Batteries, Second Edition, New York: McGraw-Hill, Inc.

² The number of cycles (the discharge and subsequent or preceding charge) under specified conditions, which are available from a rechargeable battery before it fails to meet specified criteria as to performance.

³ Capacities based on BA-5590/U Lithium Sulfur Dioxide.

⁴ Basic Lithium Sulfur Dioxide series configuration capacity.

Table 2-2 is a comparison of how the major rechargeable battery technologies compare to the baseline nonrechargeable Li/SO₂ technology. In all cases, the capacity is less and the weight is greater. However, the cost per cycle of all the rechargeable batteries (on the order of \$2 to \$3, given that one may not get the total cycle life) is substantially less than the single use baseline battery cost of approximately \$68.00 per mission.

Table 2-2, Comparison of Mission Requirements and Cost

Chemistry/ Military Designation	Weight (lbs.)	Batteries/ Mission ¹	Mission Weight	Battery Unit Price (dollars) ²	Cost/ Mission ^{3,4} (dollars)
LiSO ₂ / BA-5590/U	2.2	1	2.2	68.00	68.00
Sealed Lead Acid/ BB-490/U	4.5	4	18.0	155.00	2.76
Sealed NiCd/ BB-590/U	4.0	4	16.0	153.00	2.73
NiMH/ BB-390/U	3.8	2	7.6	293.00	2.61
Li-ion/ BB-XX90/U	2.9	2	5.8	⁵	⁵
Lithium Polymer/ BB-XX90/U	3.2	1	3.2	⁵	⁵

¹Based on a 24 hour mission using the SINCGARS

²BB-490/U and BB-590/U prices from Mathews Associates; BB-390/U and BA-5590/U prices from U.S. Army CECOM

³Based on price paid by user and 224 cycles

⁴Cost of charging equipment and charging not included in this estimate.

⁵Not yet in military inventory.

2.3 Battery Chargers

The main function of any battery charger is to cause current to flow back into a battery in the opposite direction from which current flowed during discharge. A battery on charge is not a fixed or static load. It has a voltage of its own and is connected to the charger so that the two voltages oppose each other.

Thus, the current that flows is the result of the difference between the voltages of the charger and the battery and a function of the low ohmic resistance of the battery. The voltage

of the battery itself rises during the charge, further opposing the flow of current as the charge progresses.

Some of the key considerations when developing a charger are the battery chemistry(ies) to be charged, the market to which it will be sold (i.e., the commercial market may not pay for the ruggedized design required by the military), the number/types of batteries to be charged, durability, and physical constraints (if applicable).

From a design standpoint, the key parameters that must be considered are the form of input power, the changing of the input power to a direct current (DC), switching elements, control elements, and indicators.

The basic requirements of a charger as they relate to the battery are:

- A safe value of charging current throughout the entire cycle
- Protection against conditions (i.e. temperature, battery faults, etc.) that would result in overcharge and outgassing
- Accurate termination of the charge when complete or reduction of the current to a level which provides a safe charge maintenance value.

The desired characteristics of a charger as they relate to the user are:

- Maximum reliability
- Automatic operation to the degree practical in the application
- Simplicity in design and construction
- Good efficiency and power factor
- Ease of operation
- Reasonable cost
- Rapid charging.

2.3.1 Battery Charger Elements

Every charger design incorporates all of the components shown in Figure 2-1, with the exception of the indicator. In the simpler and cheaper chargers, the indicator is normally just an indicator light. Indicators are used more extensively in the more sophisticated chargers.

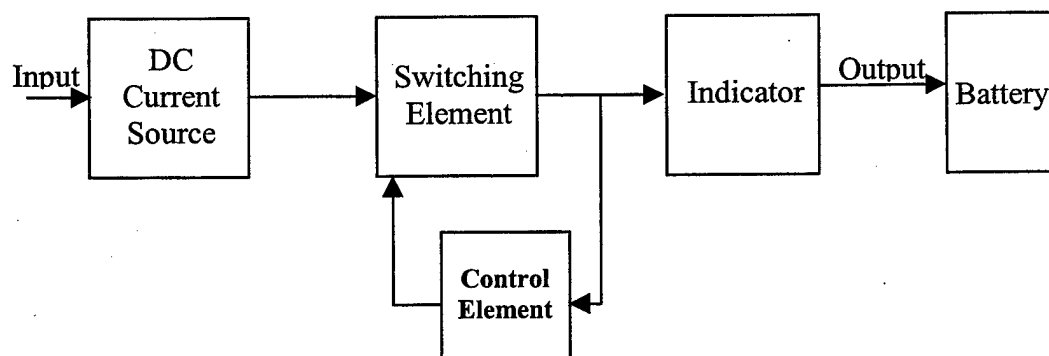


Figure 2-1, Basic Elements of a Battery Charger

2.3.1.1 Input Source

All chargers require some form of external energy source. In the vast majority of instances, this is normal commercial alternating current (AC) power. Many chargers used by the military have the ability to use alternative power sources, such as a 24 V DC from a vehicle, hand cranked generators, or solar panels.

2.3.1.2 Direct Current (DC) Source

In order for a charger to return energy back to the battery, it must convert the input source to DC current. Under normal circumstances, this input source is an AC waveform that is applied to a transformer/rectifier combination. Along with this conversion, the voltage and current are optimized to match the requirements of the battery chemistry. This optimization is more critical with the newer NiMH and rechargeable lithium chemistries than with lead acid or NiCd. It is most commonly handled by using low voltage rechargeable transformers and solid-state rectifiers.

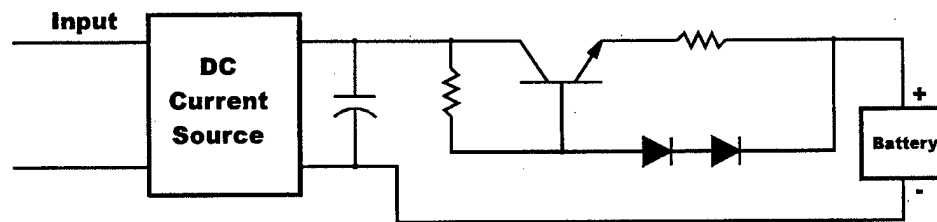


Figure 2-2, Series Pass Current Limit Transistor Switch

The most elementary type of charger has only a DC current source (similar to Figure 2-2) with the transformer rechargeable voltage set to a value appropriate for the battery being charged. In this style of charger, there are no switching elements or control circuitry. In these chargers, control of the charging current is usually maintained by rectifiers with high forward voltage drop (such as selenium) or by the addition of some discreet resistance in the output line.

2.3.1.3 Switching Element

The purpose of the switching element is to control the current and voltage that is applied to the battery. The switching element takes on many forms, ranging from simple series pass transistors to complex pulse-width modulated switching circuits. There are also circuits that include the switching element as part of the DC current source. These circuits generally use Silicon Controlled Rectifiers (SCRs) or saturable reactors. The following figures show some examples of these approaches.

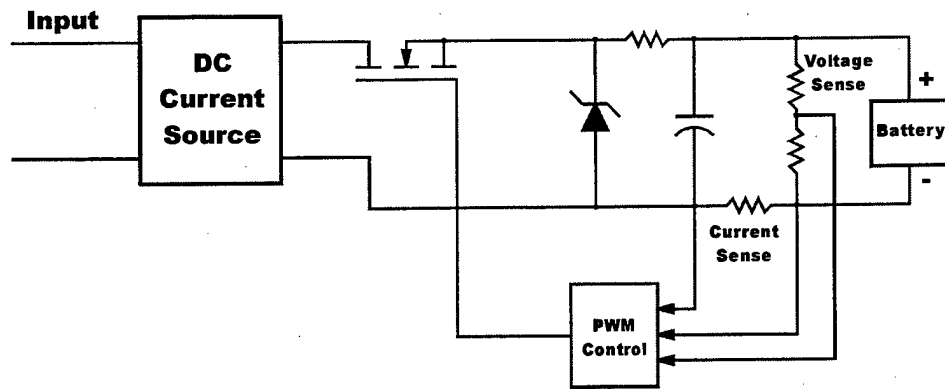


Figure 2-3, Pulse Width Modulated Switching Circuit

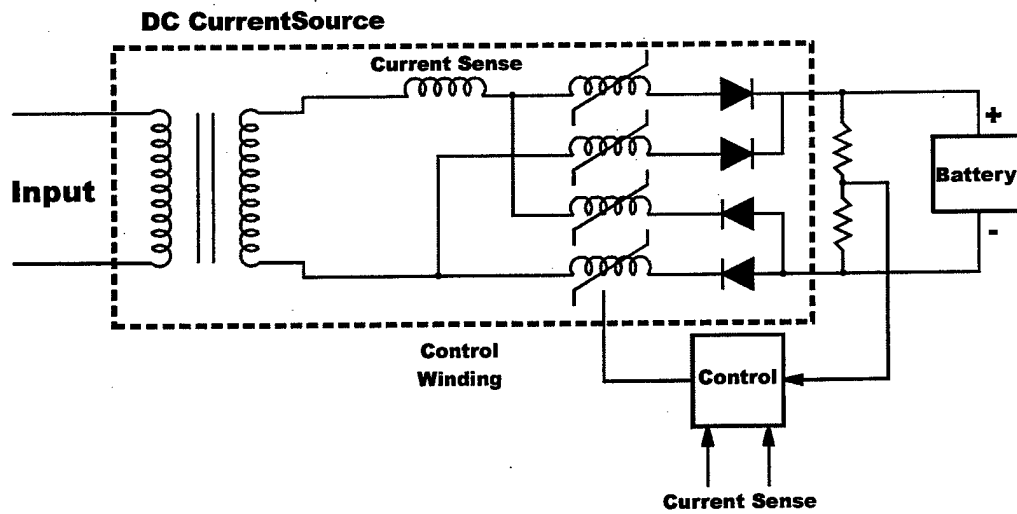


Figure 2-4, Saturable Reactor Charger

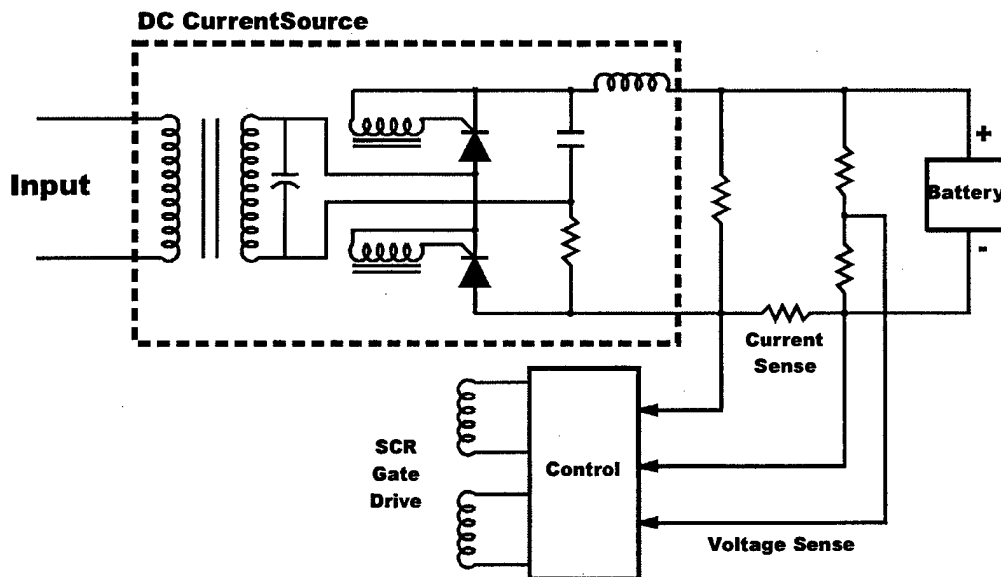


Figure 2-5, SCR Controlled Charger

Figures 2-3, 2-4, and 2-5 are intended to provide only the basic concepts of each circuit type and are not intended to include every circuit detail. There are, in fact, countless permutations of these approaches to achieve the switching action required for the particular charger application.

2.3.1.4 Control Element

The control element usually defines the complexity of the charger and is where individual manufacturers provide features that distinguish their product from those of competitors. In small applications, controls may consist of just selectable transformer taps or series resistance in the DC current source. For the more precise control required for the more sophisticated charging algorithms and regulation, magnetic amplifiers, transistorized control units, and microprocessor-based smart charging control functions are utilized.

All chargers accomplish output current limiting in one form or another, and many chargers directly control output voltage regulation. Any of the other control functions listed will be available depending on the application requirements of the individual charger.

To some extent, all chargers control the following parameters. The extent of the control is dependent on the battery chemistry being charged:

- output current limiting
- output voltage regulation
- output over voltage clamping
- output voltage compensation for temperature
- output voltage compensation for cable drops
- short circuit protection
- charging current profile
- smart charging based on battery chemistry and size
- thermal limits for batteries and charger circuitry
- protection against reversed polarity connections
- timing
- built-in-test and status indicators
- shorted-cell detection
- battery interrogation including impedance measurements
- soft start during charger turn-on
- open sensor detection and shutdown
- charger fault protection and shutdown.

2.3.1.5 Indicators

All chargers contain some form of indicator. The sophistication of the indicator ranges from a single indicator light denoting that the battery is being charged to digital displays of various parameters. In measuring the current to batteries on charge, both the type of indicator used and the waveform of the current must be taken into consideration. While any charging current is necessarily unidirectional, its waveform can vary considerably, depending on the charging source.

2.3.2 Charger Types

Battery chargers are available in two basic types - those that are integrated into the appliance and stand-alone chargers that are independent of the appliance powered by the battery.

2.3.2.1 Integrated Chargers

Integrated chargers are chargers that restore the charge to the battery without removing it from the equipment. An integrated charger system is one where the charger (with the exception of the power supply) is actually built into the end item with the battery itself. An example of this type of charger is the laptop computer. These chargers are not commonly used in military communication equipment at the present time, since military end items were designed around the use of replaceable, nonrechargeable batteries. However, it is

possible that the use of integrated chargers will increase in military applications as use of commercial off-the-shelf (COTS) items proliferate.

- Advantages: The charger is designed to maintain the specific battery used in the equipment. This enables a precise charge algorithm that maximizes the battery life. No external equipment other than the DC current source is required. This facilitates the actual charging since charging may be performed anywhere external power is available. Since no adjustments are required by the user, they are very easy to use. These units are supplied as a part of the system, thus relieving the consumer of the responsibility of procuring and maintaining a separate charger.
- Limitations: Because the battery is not removable, the equipment needs to be connected to the power source throughout the recharge process. This limits the time that the end item can be used without being connected to an external power source. This is a significant disadvantage to the military, where mission times and mobility are critical. Built-in chargers increase the weight of the equipment they are used in, due to the added weight of the charger circuitry. This is an important consideration for manportable military applications where weight is critical.

2.3.2.2 Stand-Alone Chargers

Stand-alone chargers are independent of the battery used in the equipment. The rechargeable battery is removed from the equipment and charged "off-line". These chargers are available in two distinct formats - those that only charge batteries and those that analyze/charge/maintain a battery. The configurations can be dedicated to a unique battery, such as those for cellular phones, pagers, and portable phones and, to some extent, communications equipment used by the military.

- Advantages: Equipment that uses a removable rechargeable battery is usually lighter in weight and smaller in size because there is no circuitry in the equipment to support charging. The equipment can be kept in service by removing the depleted battery and replacing it with a fully charged unit. This increases the mission time and mobility of the end item.
- Limitations: The charger is an additional expense and may require its own set of maintenance procedures and spare parts. If the charger is dedicated to a specific battery, it requires replacement with the end item. A proliferation of dedicated chargers may also pose a logistics problem to the military.

2.3.2.3 Multi-Port Chargers

A variation of the stand-alone charger is the multi-port charger. The multi-port charger is a charger that has the ability to have multiple batteries connected at one time. The design of the charger influences whether the batteries are charged simultaneously or sequentially. The key design influences are the power required to charge the battery and the capacity of the charger and the controls.

- Advantages: The major advantage of these chargers is that multiple batteries can be left on charge unattended. This vastly enhances the throughput of batteries while minimizing the associated manpower. The more complex of these chargers can be user programmed to charge various battery configurations and chemistries.
- Limitations: These chargers tend to be expensive, which limits their commercial market potential. Due to the plethora of different battery configurations, the charger requires a unique adapter for each configuration. This increases the overall cost, logistics support, and, to an extent, the overall utilization of the charger.

2.3.2.4 Adapters

Each stand-alone battery/charger combination requires some form of interface. This interface enables the battery to be electrically and mechanically connected to the charger. The interface may or may not have monitoring electronics incorporated. One end of the adapter is unique to the battery configuration, while the other is unique to the charger manufacturer. These adapters come in three general forms: direct connection, cable, and "cup" adapters.

- Direct Connection: The adapter is simply a mating connector that is battery-unique and built into the charger. When the battery is placed in the charger, the contacts of the battery match the contacts of the charger. These chargers are used to charge cellular phones, camcorders, police two-way radios, medical emergency equipment etc.
- Cable Connections: This adapter has mating connectors on each end of the cable. The battery is not physically connected to the charger. One end of the cable is unique to the battery connector whereas the other is common to the charger output. This is the method by which various battery configurations can be charged on a single charger.
- "Cup" Connections: This adapter is designed to fit the battery in both size and shape, thus giving the battery a more secure connection. The "cup" has a standard connection on one side that will plug into the battery charger and the other set of contacts match the battery.

2.3.3 Charging Methods

The charging method is the process that dictates the method by which energy is returned to the battery. The goal of the charging method is to return this energy in the safest, most efficient method possible. If the energy is not returned to the battery in a way that is compatible with the chemistry, the recharge can have detrimental effects on the battery. This will result in batteries that are not fully recharged and thus shorten the time that they operate the equipment. In the worst case, incorrect recharging can cause excessive gassing, overheating, and internal shorting, resulting in battery and equipment damage, personnel

injury, and/or environmental contamination. There are several generic charging methods, each of which is discussed below.

2.3.3.1 Constant Current Charging

Constant current charging is the simplest method of charging, employing a single low level current to the discharged battery. The current is set at a fixed rate that is usually selected at ten percent of the maximum Ah rated capacity of the battery. For example, a battery rated at 1000 mAh would be recharged at 100 mA. Constant current charging is best suited for use on lead acid and nickel cadmium batteries. The type of charger for this method is usually small, lightweight, and relatively inexpensive. The only disadvantage of this charging method is that, if the battery is inadvertently overcharged, gassing, and overheating of the battery may occur. This results in shorter performance and frequent battery replacement.

2.3.3.2 Constant Potential Charging

Constant potential charging allows the maximum current of the charger to flow into the battery until its voltage reaches a preset voltage limit. This system allows for higher charging currents, thus returning the battery to a full state of charge quicker. Once the voltage limit is reached, the current starts to taper to a minimum value. As the current tapers to minimum, the maximum energy has been transferred into the battery. At this point, the battery can be left on the charger until needed in what is referred to as a "Float Charge", which compensates for the normal self-discharge that occurs in any battery. This system works well with batteries that exhibit a voltage rise at the end of charge, such as the lead acid battery. Constant potential charging is detrimental to NiCd batteries, which exhibit a drop in voltage when the battery goes into overcharge and begins to heat up, causing the voltage to drop. Some other chemistries, especially Li-ion, are not able to absorb additional energy once fully charged and must be removed from the charging source. "Float Charging" is not recommended for these chemistries.

2.3.3.3 Constant Current/Constant Potential Charging

Constant current/constant potential charging is a combination of the two methods above. The system is designed to limit the maximum charger current until the battery voltage reaches the set limit. Then, the voltage control takes over, allowing the current to taper to a minimum value as the battery voltage nears full charge. The combination of constant current and constant potential allows for fast charging without the problems of gassing and overheating due to charging at high rates. This method is especially useful for sealed lead acid batteries. It is particularly detrimental to NiCd batteries that begin to heat up near the end of charge, causing the voltage to drop. This results in an increase in charge current at a time when the battery does not need high current charging.

2.3.3.4 Pulse Charging

Pulse charging applies a series of charge/discharge cycles until the battery is fully charged. The charge current pulse is larger than the normal charging value and may be followed by a rest period rather than a discharge cycle. Using this method, a battery can be fully recharged, with less gassing and heating, over a shorter time period than could be realized by any of the above methods. This method of charging has been used on NiCd batteries to restore capacity lost due to "memory effect".

2.3.3.5 Smart Charging

Smart charging adjusts the voltage and current supplied to the battery based on the monitoring of critical battery parameters (temperature, cell balancing). Battery charger operation can be optimized by using a micro-controller to carefully monitor and adjust the charging rate, the time, and, in some cases, the voltage. This optimization is used to increase charging efficiency, reduce charging time, or extend cell life. Use of smart charging is critical to charging rechargeable lithium chemistries to prevent the activation of the battery's internal safety features, which, if activated, render the battery useless. The charge rates and times are optimized to the specific battery chemistry and internal conditions during charging. This system does require special circuitry. The chargers that utilize this method tend to be larger and more expensive. They usually require higher levels of power to support the rapid recharge that the system may select based on the battery's state of charge.

2.3.3.6 Maintenance Charging

All battery chemistries, and especially NiCd, benefit from proper maintenance in order to maximize battery life and performance. A maintenance charger combines the functions of battery maintenance and charging into one unit. This method first determines the health of the battery and whether a discharge cycle is required before charge initiation. The discharge cycle is used primarily to equalize the state of charge in each cell before recharging. Once the discharging step is completed, the appropriate charging method is applied. These units tend to be larger than the single application unit, more complex in design, and, therefore, more expensive.

3.0 RECHARGEABLE BATTERY/CHARGER APPLICATIONS

3.1 Commercial Rechargeable Battery Applications

Rechargeable batteries are normally found in one of three generic formats. The oldest format is individual standard-size rechargeable commercial batteries (such as "AA", "C", and "D"-size batteries). These batteries were normally marketed independent of the charger, which itself was a basic version of the multi-port system. Many consumers find it cost-effective to buy individual rechargeable batteries and their associated rechargers to power common items like flashlights, radios, and electronic toys and games.

The second format is product-specific battery packs. This format is where standard cells are combined to form a battery pack that is removable from the using end item. This application normally has a separate, stand-alone, dedicated charger. An example of this would be cellular phones and pagers.

The third format is those commercial devices where the rechargeable battery and charger are integrated into the actual device. For example, many laptop computers employ this technique, as did some of the older portable power tools. Another example is cordless telephones, which are constantly charging when placed in their base-station receptacles. This is convenient when one component of the total system is normally connected to commercial power sources (household current).

As a general rule, those applications that require high current drains, such as portable power tools, utilize NiCd batteries. For the normal commercial electronics market, the NiMH battery seems to be the technology of choice by developers due to its improved capacity and reduced weight as compared to NiCd. For those applications where light weight and high capacity are desired, rechargeable lithium is usually the technology of choice. However, it should be noted that as NiMH and rechargeable lithium battery technologies have improved, these distinctions have become less obvious.

3.1.1 Current Markets

3.1.1.1 Portable Communications

The applications in this segment of the market include cordless telephones (analog and digital), cellular telephones (analog and digital), Pagers (one- and two-way), personal communication systems (combines telephone, pager, etc.), and two-way radios (generally hand-held).

These devices tend to be used in cycles consisting of charging during non-working hours and use during working hours. Use can be in either a standby or an active mode. The major use of power occurs during transmission. The receiving, or standby modes, are not power intensive. Thus, the run time for these devices is limited by the amount of time they are used in the transmission mode.

3.1.1.2 Portable Computers

The applications in this segment include laptop computers, notebook computers, personal digital assistants (PDA), address books, bar code readers, and smart cards. These applications typically require relatively low voltages (3 V or less). However, in the case of portable computers, the displays and mechanical disk drives demand much greater power than the electronics.

It is notable that there is industry standardization at the cell level, but virtually none at the battery level. An example of this is in the laptop and notebook computer areas. Cell-level standardization has occurred largely by default. This is due to the fact that rechargeable batteries were initially seen as an alternative to nonrechargeable batteries. Ergo, they were designed to meet the electrical and physical constraints of the nonrechargeable battery, which already had standardized characteristics. Standardization of multi-cell battery packs has been more elusive. This has occurred because each computer manufacturer designs the battery to fit the company's own unique computer configuration rather than focusing on standardizing on an industry-wide battery design. As the market moves toward lithium polymer technology, even the standardization at the cell level may diminish due to the relative ease of crafting unique cell sizes.

The proliferation of unique batteries for these applications has worked against the economies of scale that would reduce the cost of both original equipment and replacement batteries. A further problem may be the loss of the production base for batteries for which there is not a large replacement market. Thus, it can be difficult to find replacement batteries for portable computers that are only a few years old.

There was an effort by the battery industry several years ago to standardize on a relatively small number of different batteries for portable computers. This effort was a failure, as each computer manufacturer chose a unique battery to physically fit the particular application, seeing the differences in batteries as a sales factor. While this optimized the battery for each application, it precluded the economy of scale that might have resulted from standardization of form, fit, and function within a family of batteries. The use of lithium polymer technology has the potential to make flexible manufacturing concepts economically feasible, i.e., short production runs of relatively unique batteries. It also promotes the proliferation of unique battery configurations.

The portable computer segment of the battery market is currently tending to drive the technology. Computers are fairly expensive devices, and consumers are willing to pay a premium for a battery that will operate a portable laptop or notebook computer for many hours (for example, the length of a coast-to-coast flight). As portable computers become common business tools, the marketplace for lighter and longer life batteries will continue to expand. Most of these applications use the more recent NiMH and Li-ion batteries.

3.1.1.3 *Portable Entertainment*

Applications in this segment include radios, tape players, CD players, televisions, toys, and games. These applications are typically built around standardized and commonly available battery types. Convenience tends to be the major factor in battery selection as opposed to life cycle cost. As a result, most consumers use nonrechargeable disposable batteries for these products and avoid the minor complexity of recharging.

3.1.1.4 *Portable Tools*

There is a rapidly growing market segment in cordless tools, which inherently are high drain applications. These tools include small hand-held vacuum cleaners, drills, screwdrivers, sanders, saws, and even lawn mowers. Personal grooming tools include shavers and tooth brushes. Kitchen tools include mixers, blenders, and carving knives. Virtually all of these items come with a separate AC charger for recharging the embedded or replaceable batteries. The batteries themselves tend to be unique to each manufacturer and unique to each application. For example, cordless drills are available ranging from 7.2 V to 18 V, the higher voltages representing the heavier-duty applications. These products are typically sold with at least two batteries and a charger so that one battery can be charging while the other is in use. Therefore, a recharge time similar to the typical discharge time becomes an important factor. These products are intended for both household and commercial use. Most of these applications use NiCd rechargeable batteries.

3.1.1.5 *Portable Lighting*

The portable lighting segment is comprised of flashlights and lanterns, and is characterized by the use of standardized batteries. Battery chargers are not often purchased specifically for recharging portable lighting products. Rather, rechargeable lighting product batteries are charged in general purpose NiCd or alkaline recharging units.

3.1.1.6 *Portable Medical Devices*

Portable medical devices include hearing aids, heart products (pacemakers and defibrillators), and other products such as portable X-ray machines and portable medical test equipment. Medical test equipment batteries include nonrechargeable, rechargeable alkaline, NiCd, NiMH, lead-acid, and lithium.

3.1.1.7 *Portable Scientific and Testing Devices*

Portable scientific products include a variety of industrial, electronic, chemical, and physical monitors, analyzers, testers, and measuring devices. As better batteries become available and are integrated into scientific instruments, the effectiveness of these instruments should be improved.

3.1.2 Potential Future Markets

A major trend in portable electric and electronic devices is continuously increasing functionality with attendant increases in power requirements. A new generation of satellite-based personal communications systems went into operation in 1998. For example, the Iridium employs a handset that communicates with either the compatible local cellular phone system or, if that is not available, with a constellation of low-earth-orbiting satellites that connect the call. Clearly, the power requirement to connect with a satellite hundreds of miles away is greater than that required to connect to a cellular tower perhaps two miles away.

The continued growth in size and function of the Internet will lead to new applications. With increasing demand for portability, these applications will make even greater use of wireless communications. Connecting to the Internet through a wireless modem and a satellite communications system is planned by at least one developer (Teledesic, in conjunction with Boeing). These applications will increase the demand for rechargeable, portable electric power.

Personal navigation devices based on the Global Positioning System are now becoming affordable to the average consumer, some as low as \$100. This decrease in price will lead to new applications beyond the specialty applications (yachts, airplanes, hikers, etc.) that now exist. Current systems provide about 12 hours of use using nonrechargeable disposable batteries. As precise location becomes a component of future commercial products (such as vehicle navigation systems), the market for more cost-effective portable power will increase.

The improvements in rechargeable battery technology are driven by this rapid growth of the portable electronics market. Virtually all portable electronic product developments seek increased functionality (marketable features) at reduced weight. As these electronic devices become more miniaturized, the battery becomes a larger fraction of the overall item volume and weight. Therefore, the incentive for future advances in battery technology is greater stored power with reduced volume and weight.

3.2 Defense Rechargeable Battery Applications

DoD and DND have very demanding requirements for rechargeable batteries when compared to those of the commercial market. In addition to mission critical applications, high current requirements and long hours of continuous operation, the military has temperature and environmental (i.e. vibration and shock) requirements that exceed most civilian applications.

The U.S. and Canadian militaries have many generic C/E applications that can or would make use of the rechargeable batteries examined in this study. These include:

- Communications, Navigation, and Identification
- Computers
- Remote Sensors, Range Finders, and Laser Target Designators

- Night Vision Devices
- Mine Detectors.

When selecting a battery chemistry to meet the requirements of either commercial or military applications, certain engineering and logistics factors are considered, to include:

- Cost (the unit price for commercial applications and life-cycle cost for the military applications are the driving influences)
- Weight
- Safety (especially overheating during recharging)
- Operational requirements
- Shelf life (including loss of charge over time)
- Operating environment
- Human factors engineering
- Disposal.

The military also has some unique requirements imposed on the selection process. These include:

- Battery open circuit voltage
- Packaging to meet the existing configuration
- Mechanical shock
- Vibration
- Immersion
- Thermal shock
- Low temperature discharge
- High temperature capacity
- Long term storage
- High temperature storage.

The diversity of the military requirements precludes the use of a single battery technology meeting all military applications. Therefore, many different batteries and battery types will likely be required in all future portable defense electronic systems.

3.2.1 Future Defense Applications

Although the impact of the digital battlefield is being felt throughout the U.S. Military Services and the Canadian Forces, nowhere is the impact more profound than on the individual soldier. This is the Digital Battlefield concept applied at the lowest level – the soldier in the field. This concept regards the individual soldier as a self-contained weapons platform. The trend for the individual soldier is to have more and more electronic systems on his/her body. The soldier as a weapon systems platform is termed the LandWarrior System in the U.S. and Soldier Systems in Canada. These programs will have a profound impact on military rechargeable battery requirements in the future.

The challenge presented by such a concept as the LandWarrior/Soldier Systems is the ability to provide sufficient power in a small, lightweight package. Capabilities considered for inclusion in the LandWarrior/Soldier Systems include:

- Laser flash protection
- Microclimate conditioning system
- Chemical detection
- Mine detection
- Medical sensors
- Helmet mounted display
- Mobility sensor
- Voice communications (individual)
- Combat identification
- Image transfer systems
- Individual positioning/navigation systems
- Thermal weapon sight
- Forward observer/forward air controller communications systems
- Aiming light
- Small arms fire control
- Data network connectivity for situation awareness, command and control, and target handover.

Providing power to all the subsystems listed above will require a significant power pack, and innovative solutions will be demanded.

Some of the emerging issues impacting rechargeable battery applications in the military include:

- Requirements for rechargeable batteries are moving the military away from commercially available cells.
- Emerging technology is expected to fall short of the projected power demand. This is due to the fact that battery technology, both rechargeable and nonrechargeable, are reaching the limits of their practical energy levels. No significant breakthroughs in capacity are on the immediate horizon.
- The execution of military missions is being redefined by the technology limitations associated with the use and deployment of rechargeable batteries for OOTW. For example, the logistics support required for recharging batteries.
- The availability of cells for military applications that are no longer required by the commercial market becomes an obsolescence issue.

In light of the above, the military of the future will be faced with three main challenges. The first challenge will be to develop rechargeable batteries with better capability than current technology will allow. The second challenge will be to utilize low

power electronics in concert with power management in order to reduce the power requirements of the system. Power management is the collection of tools, both hardware and software, that minimizes energy consumption without any loss of system performance. The third challenge is to develop strategies dealing with military battery obsolescence.

3.3 Battery Charger Applications

As noted in the rechargeable battery applications section, there are a number of commercial applications that use rechargeable batteries, and hence, the chargers to recharge them. Many commercial products employ the same or similar type of chargers being used or targeted for use by the operators of defense C/E equipment. These are two-way radios, global positioning systems, remote sensors/recorders, laptop computers, target designators (laser), and night vision devices.

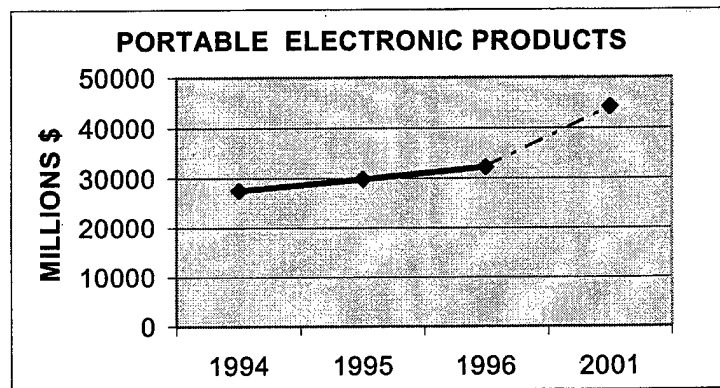
The battery charger is more closely aligned with the battery chemistry as opposed to how or where the battery will be used. Lead acid and NiCd batteries have been in use as portable power for a long time (lead acid, 100 years; NiCd, 60 years). These batteries have been recharged by "dumb" chargers (those that supply current at a maximum voltage) for most of their history. This is true for portable electrical hand tools and police, fire, and rescue two-way radios that use lead acid and NiCd batteries.

Recently it has been shown that by using "smart" chargers (electronically optimized), the performance of these lead acid and NiCd batteries can be improved. Many times, the selection of a "smart" or "dumb" charger is a matter of cost and convenience. More advanced chemistries generally require smart chargers. The need for "smart" chargers has increased because cell phones, laptop computers, and personal digital assistants use NiMH and Li-ion batteries.

4.0 RECHARGEABLE BATTERY/CHARGER DEMOGRAPHICS

As can be seen from Table 4-1, the use of portable electronics is continuing to climb, which is fueling the need for improved portable power sources. Demand for rechargeable batteries will continue to rise, driven by the pure cost effectiveness of the technology. This is especially important when one considers the energy requirements of portable electronic equipment such as laptop computers, pagers, and cellular phones. Battery manufacturers continue to strive to find ways to put more energy density in the same size battery while reducing costs. Overall, the worldwide commercial rechargeable battery market is expected to grow from \$2.94 billion in 1996 to \$6.55 billion in 2003.

Table 4-1, Portable Electronic Products



The industrial base for rechargeable batteries is driven by the demands and trends of the commercial market. The production required to meet this growing market is measured in millions of cells per month, with large production runs of a given cell to support the various battery configurations demanded by the consumer. These "cell producers" (companies that produce the cell in-house) are mainly located in the Pacific Rim, and dominate the production of batteries for the commercial market.

In comparison, the military requirements are measured in thousands of cells per month and divided between a multitude of battery configurations. Because of this, the military market is considered a small, or niche, sector and is not of interest to the major cell/battery producers. This military niche market is dominated by repackagers. A repackager is a company who buys the same cells used in commercial applications and configures them into a battery. As a rule, the cell producers and repackagers do not compete for the same customers.

An emerging source of batteries is known as the hybrid producers. These are small companies that produce "specialty" batteries such as those required by the military based on commercially available technologies. The major difference between a hybrid company and a repackager, is that the hybrid company produces the cell in-house. It is projected that the

introduction of the emerging lithium technologies, such as the polymer batteries, into the military inventory will be accomplished through the hybrid companies.

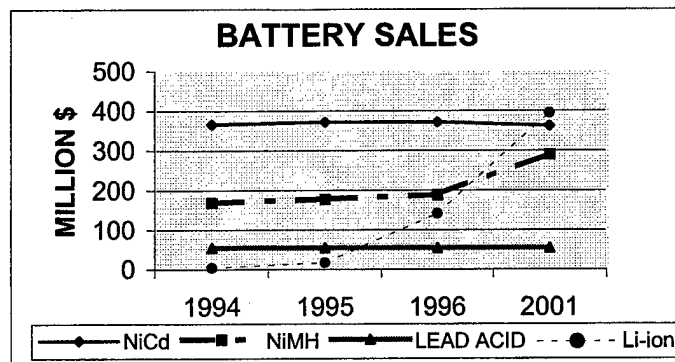
At present, the military is employing commercial technology. However, the commercial world is working to make even smaller lithium cell sizes (micro amps). They are striving to use cheaper raw materials (moving away from cobalt) in order to reduce the battery costs as a response to an increasing competitive marketplace. These more inexpensive batteries, however, have less capacity. The military may not be able to use these commercial rechargeable lithium cells in their communications equipment due both to mechanical (i.e. intercell connections and heat generation of small cell sizes) and electrical obstacles (reduced capacity resulting in shorter mission times). Coupled with this is the fact that the military is such a small consumer of rechargeable batteries as compared to the commercial market, cell manufacturers are not inclined to produce the larger cell sizes desired by the military.

Should the military begin to use lithium polymer cells, the same would hold true. The size of the cells used by the military would be larger than those used in the commercial world. It is projected that these cells would be manufactured by the hybrid producers on the same production lines as their commercial batteries using flexible manufacturing techniques.

Many analysts believe that manufacturers will continue to enhance the performance of NiMH and Li-ion chemistries in the short term, and project that these cells will continue to dominate the portable computing battery market for the next few years. Production of both NiMH and Li-ion is increasing, though growth is shifting in favor of Li-ion cells. Shipments of Li-ion batteries rose to 198 million cells in 1997, up from 116 million cells the year before. In 1998, shipments are predicted to expand to 288 million cells. NiMH, on the other hand, expanded to 607 million cells in 1997, up from 380 million cells in 1996. This was expected to drop to 517 million cells in 1998.

The trends to more energetic chemistries is illustrated in Table 4-2. The market for rechargeable NiCd chemistries is on the decline, partially due to North American and European environmental regulations as they relate to the toxic nature of cadmium. The initial replacement for NiCd was NiMH and that is rapidly being replaced by Li-ion batteries for most portable electronic applications. The NiCd market will shrink, but not disappear anytime soon. This battery chemistry, which has powered electronic equipment for more than 30 years, is the least expensive chemistry and, for some applications such as power tools, the most viable.

Table 4-2, Rechargeable Battery Sales



Note: Sales for 1997 - 2001 are estimated.

The first rechargeable lithium battery was based on metallic lithium and initially commercialized in the 1980s. Even though this technology offered higher energy density, it was abandoned due to safety concerns. However, several companies, including Tadiran Electronic Industries, now claim to have solved the safety problems. Analysts predict that by the year 2000, technology breakthroughs could allow developers to announce creation of a rechargeable battery using metallic lithium as the negative electrode.

The Japanese dominate the lithium battery market at present because of their preeminence in the commercial portable electronics market. Oftentimes, the battery company and portable electronics company are part of the same parent company. This symbiotic relationship is ideal for optimizing the battery/end item system. It allows laptop computer makers to manufacture their own special models and unique battery configurations. Hence, their volume is dictated by the number of equipment sales made and their market is established. The commercial battery producers are the driving force behind keeping batteries unique as a follow-on market to laptop computer purchases. By sticking with their own product specific components, customers have to come back to them for the batteries to power their systems.

Competition is stiff in the commercial lithium market. Those battery manufacturers producing batteries for the commercial electronics industry are entrenched. Companies hoping to compete with these already established producers would face approximately \$5 million in start-up costs to merely establish a small assembly line and investments in the tens of millions of dollars if they plan to compete in the commercial market.

The lithium battery market is experiencing a major growth in demand. Li-ion batteries have been in commercial production since 1993 and were first introduced in small video camcorders. The price of lithium batteries is expected to decrease due to increased production volumes, which will make them more price competitive.

Analysts have projected that the Li-ion rechargeable battery market will increase its market share to 79.8 percent in 2004, due to its position as the preferred battery chemistry choice for use in portable computer and cellular phone applications. Li-ion batteries are forecast to experience a declining growth rate in 2003-2004 as lithium polymer batteries begin to secure market share.

Analysts predict that the lithium polymer chemistry could drastically alter the global rechargeable battery market over the next five to ten years. Several battery manufacturers are beginning to make cells based on the new lithium polymer technology, which offers more flexible cell design, easier fabrication, and increased safety. Coupled with this is the fact that they can deliver greater volumetric efficiency because they can be assembled as stacked prismatic packages rather than cylindrical cells packed into a flat container. Analysts have forecasted that most Personal Computer (PC) manufacturers will move to lithium polymer because the chemistry delivers the same specifications as Li-ion, but is lighter and moldable.

As the technology matures, it is projected that lithium polymer batteries could cost as little as \$1 to \$2/Wh. This is due in part to the inexpensive metal oxide used as the cathode (instead of the relatively costly cobalt oxide found in liquids) and the fact that every component of a solid polymer cell is fabricated in rolled sheet form, which enables high-speed, high-volume battery production. In comparison, the mature technology of NiCd batteries will cost just under \$1/Wh.

The lithium polymer battery market has passed the preliminary R&D stages and is poised for full-scale production. Japanese companies are shipping full-scale production units, while U.S. companies are beginning to ship production samples for testing and evaluation.

Researchers believe that, early in the next century, all polymer batteries may emerge as a pliable, easy-to-manufacture successor to the cells currently in use. This battery technology (of which laboratory prototypes have been developed) employs an all polymer design in place of conventional electrode materials.

4.1 Defense Market Factors

A number of factors are critical to influencing the growth of the two countries Defense Departments' rechargeable battery market. The military places exacting demands on its power sources. In general, the following requirements form a standard basis for future, widespread use of rechargeable batteries in OOTW. Factors that are facilitating the use of rechargeable batteries are:

- Cost Effectiveness: The use of rechargeable batteries offers a significant reduction in weapon system life cycle costs.
- Increased Rechargeable Battery Life: Rechargeable batteries now offer 60 percent of the equivalent nonrechargeable battery capacity.

- Reduction in Battery Weight: Although not as light for the capacity delivered as a nonrechargeable battery, significant improvements - mainly due to advances being accomplished in the Li-ion technology - have been realized.
- Smart Chargers and/or Smart/Adaptive Cables: These automatically interrogate batteries as to type, state-of-charge, and condition, and automatically set the charging parameters according to preloaded manufacturers' specifications which minimizes user involvement.

The following are some of the barriers hampering a more pervasive use of rechargeable batteries:

- Mission Unique Applications: The applicability and use of rechargeable batteries in high-risk, low support airborne and reconnaissance missions is untested and unproven. Environmental concerns are more of an issue in military applications, such as operation in blowing dust or sand; reliability both short and long term, in salt fog and spray; and the impact of chemical or biological agents on systems.
- Soldier Acceptance: Overcoming the individuals' resistance to changing to rechargeable batteries will require significant field level efforts to ensure all soldier needs are met with rechargeable batteries. Rechargeable batteries add a new layer of complexity to fulfilling a soldier's power needs in that the battery now has to be charged and transported back to the battlefield.
- Power Sources Logistics: Using rechargeable batteries will require additional logistics support for recharging. Some of the additional logistics considerations are:
 - Soldier will need to carry two rechargeable batteries for every one non-rechargeable battery they currently carry.
 - Soldier will need access to a charger and adapters.
 - Soldier will need access to a power source to recharge.
 - Rechargeable batteries would add some weight, depending on the technology compared to the nonrechargeable lithium sulfur dioxide equivalent battery. The additional weight may range from being significant (for nickel based chemistries) to insignificant for lithium technologies.
 - A longer logistics "tail". For every rechargeable battery in use, up to three rechargeable batteries are required in the logistics "tail". For example, one in the radio, the one being charged, and one in transit. This requires a more complicated logistics structure than using nonrechargeable batteries.
- Performance: When using rechargeable batteries in areas where they are subjected to low temperatures, they do not provide the same capacity and service life as nonrechargeable batteries. Nonrechargeable batteries can function at acceptable levels whether they are used in temperatures ranging from -40° F to 150° F.

This does not hold true for rechargeable batteries, which do not fare as well as nonrechargeable batteries in extreme temperatures, particularly when subjected to the cold.

4.2 Cell Producers

Approximately 75-90 percent of the cells used in military batteries are obtained from Japanese companies, though some of these cell producers manufacture their cells in the U.S. The commercial market is the driving force in cell demand. The quantities required by the military do not justify unique or dedicated production. The most popular commercial Li-ion cell, the "18650", is also used in the only rechargeable lithium C/E battery to date, the BB-2847/U. Cell manufacturers are driven by their corporation's need to maximize profits and have targeted the commercial marketplace because it is so huge and allows them the greatest potential to maximize revenues. The military market, on the other hand, is very small in comparison and is not a real focus of cell manufacturers because the quantities ordered do not provide them with an adequate return on investment.

The following companies are representative of the industry and not considered to be all inclusive. The information provided below has been furnished by each of the respective companies.

4.2.1 Rayovac

Rayovac is a manufacturer of cells and batteries. Rayovac is the third largest U.S. manufacturer of batteries and battery-operated lighting products and the world's largest manufacturer of zinc air and silver oxide button cell batteries for hearing aids, watches, and calculators. Their corporate headquarters are in Madison, Wisconsin. Rayovac's manufacturing base is in the U.S. and England. Their primary customer base is in North America. They are in the process of introducing their products in Europe.

Rayovac recorded net sales of \$432.6 million for all product lines for FY1997. They currently employ 2300 people, of which 1680 are in Wisconsin. Though they build commercial battery systems, Rayovac is primarily a cell manufacturer of nonrechargeable and rechargeable cells. They call their rechargeable battery, the "Renewal". Less than five percent of their business is with the government.

Rayovac has teamed with 1-800-Batteries on a hotline system that will allow consumers who cannot find the batteries and accessories they need in their regular retail store to order for next day delivery using their credit card.

Rayovac manufactures ZnMnO_2 cells of all sizes and shapes and builds commercial batteries using the same chemistry. Rayovac will build batteries using other chemistries, but the cells are purchased from other suppliers. In the event a need arises for a battery system that does not use their ZnMnO_2 cells, Rayovac has a number of options for alternate cells. The three major non-manufactured cells Rayovac uses are NiCd, vented, and sealed; NiMH;

and Li-ion. Rayovac buys vented NiCd cells from Saft and Marathon; sealed NiCds from Saft; NiMH and NiCd from Eveready; and Li-ion from PolyStor.

Rayovac has three primary R&D initiatives currently in progress: Li-ion wound cells, Li-ion prismatic cells, and high rate Rechargeable Alkaline Manganese (RAM), or as they call it, the "Renewal". The currently used cell manufacturing technique is called the bobbin technique. Rayovac is in the process of developing a spiral wound technique designed to replace the bobbin methodology.

The spiral wound technique is being used in a contract with the U.S. Army. Rayovac has been under contract to CECOM since 1992 and to the U.S. Army Research Laboratory since 1993. Rayovac is building 25 batteries and 20 cells in the "fat" "D" size (a larger version of the standard "D" cell) using the spiral wound method which will be provided to the U.S. Army for evaluation.

Rayovac is also doing some R&D work on a control device that will regulate charging rates. Rayovac's developmental programs, both commercial and government, are aimed at the 5590 series cells. The current goal is 60,000 cells/year at \$350/battery.

4.2.2 Moli Energy Ltd.

Moli is a private company that was founded in 1978 and now employs 260 people. Moli is a Canadian company whose major shareholder (about 70 percent) is Nippon Electronic Control (NEC), a leading manufacturer of electronic components, with minor holdings in the hands of Mitsui and Yuasa Battery (whose primary business is rechargeable lead acid automobile batteries).

The Moli Energy group of companies produces MoliCel Li-ion rechargeable batteries, battery packs, and chargers. It conducts R&D, cell manufacturing and battery pack assembly from its plants in Maple Ridge, British Columbia and Toyama, Japan. Their Canadian manufacturing facility has production capabilities of two million Li-ion cells per month. Production is concentrated in Li-ion cells of 18mm x 65mm and 17mm x 65mm Li Cobalt (LiCo) chemistry and in 18mm x 65mm Li Manganese Dioxide (LiMn₂O₄). The latter chemistry is from Nippon Moli Energy, a sister company in Japan.

Moli had assembled custom battery packs but no longer pursues this market. The company worked with the U.S. Army in the 1980's and developed rechargeable metallic lithium in the BB-590/U format, but these were never delivered due to safety reasons and no further work for the military is anticipated. Moli hopes, though, that MoliCel will continue to be chosen by the repackagers of cells for U.S. Military applications. Presently, 80 percent of the MoliCel product is supplied to Asia and 75 percent of that goes to Taiwan for laptop computer battery packs.

The current production level of cylindrical cells is about 1.2 million per month with a capacity of two million per month. It would take Moli approximately three months to ramp up to full capacity. The Canadian company only produces cylindrical cells whereas the

prismatic cells are made in Japan and are exclusively LiMn_2O_4 cells. Production capabilities of the prismatic cells are 700K per month.

The marketing of the MoliCell is handled totally by NEC. Sales in North America are handled out of the Santa Clara, California, head office.

4.2.3 Sanyo

Sanyo Electric Co., Ltd. supplies three types of rechargeable battery cells - NiCd, NiMH, and Li-ion. Sanyo has a large share of the NiCd market and has the capacity to make 60 million NiCd cells per month. It has production facilities in Japan, Hong Kong and Indonesia.

In regards to NiMH batteries, Sanyo is exploring ways to improve capacities, discharge characteristics, cost, and weight. Three of the latest NiMH batteries that Sanyo has developed are the HF-B1, which has an 880 mAh capacity; the HF-C1, which has a 600 mAh capacity; and the HF-B2, which has a 1200 mAh capacity. The HF-B1 offers a 26 percent improvement in electrical capacity compared with the previous version. The HF-C1 is a 50 percent improvement over previous models and the HF-B2 is a 36 percent improvement over previous cell versions.

Driven by the adoption of Li-ion batteries for use in mobile phones, PCs, and notebook models, Sanyo started producing Li-ion batteries in 1994, and today produces about five million cells per month. They supply approximately 30 percent of the world market for Li-ion rechargeable batteries. They offer seven different designs - three cylindrical and four prismatic cell sizes - which are primarily produced at their Tokushima and Sumoto plants. They have recently developed a very thin cylindrical model with a 14mm diameter and a 50mm height and have just released a prismatic cell that is 6mm thick and offers a 600 mAh capacity. Sanyo just increased the capacity of its rechargeable lithium batteries, extending the average usable time by about 20 percent when used in personal digital assistants and cellular telephones. Sanyo representatives envision their monthly output will increase to eight million units with these new additions. They plan to install another line at their Tokushima plant and build a fourth facility in that same compound. With these new production facilities, they project that their monthly output will climb to 12 million units. Sanyo has targeted the personal computer market for their Li-ion cells and hope to raise their sales of these cells from 25-33 percent of total battery sales.

4.2.4 Sony

Sony has targeted its rechargeable battery development and production solely on Li-ion models, which they believe will be the leading models of the future. They have a monthly capacity of ten million cells. Sony markets twelve Li-ion cell configurations. Ten of these models are of cylindrical and prismatic design. They deliver 3.6V and have hard carbon for the carbon material. Two models are coin shaped and are used in electronic watches and similar products. They have just released three new models that have graphite for the carbon material. Sony uses many of its batteries in its own portable audiovisual

equipment, including notebook computers, cellular telephones, camcorders, minidisk players and digital still cameras. It incorporates their batteries in the equipment and products it manufactures at its production bases around the world.

Sony plans to raise its monthly production capacity with a goal of producing 30 million cells per month. They are considering assembling battery packs abroad and expanding their overseas supply system. They are using their Kaohsiung, Taiwan subsidiary, Taiwan Toyo Radio Co. Ltd., to supply products like the notebook computer.

Although most of Sony's battery output is used in their own electronic equipment, Sony does offer batteries on an Original Equipment Manufacturer (OEM) basis to other manufacturers. Sony Electronics, Inc. in California handles sales in the U.S and Canada.

The company is working to develop new materials and to improve load characteristics of Li-ion batteries in an effort to meet increasingly strict user requirements and use conditions of portable and mobile equipment.

4.2.5 Hitachi Maxell, Ltd.

Hitachi Maxell is a relatively new cell provider of NiMH and Li-ion batteries. They began supplying these cells in 1996, and offer four models of each. In addition, the company is adding an ultra-thin, polymer Li-ion rechargeable battery to its showcase. Their current monthly production capacity is three million Li-ion cells and three million NiMH cells.

Hitachi Maxell produces its batteries in Japan at their Ibaraki factory in Osaka and their Yamazaki factory in Kyoto. These cells are then shipped abroad, primarily to mobile phone and personal computer manufacturers in the U.S., Europe, and Asia. Most of their products are shipped from the factory in the form of battery packs with protective circuitry.

Their polymer Li-ion rechargeable cells use almost the same anode and cathode materials as their conventional lithium designs but have a solid polymer electrolyte instead of a liquid electrolyte. Hitachi Maxell has stated that the voltage and cycle characteristics are equal to those of conventional Li-ion rechargeable batteries but that the solid electrolyte ensures better safety characteristics than the liquid version. This battery can withstand one hour of overcharging at up to ten times the normal capacity. Hitachi Maxell supplies Li-ion polymer rechargeable batteries in thicknesses from 0.3 to 20mm depending on customer specifications. The models can bend 90° F.

The company's NiMH models include a "AAA" battery with a 10.5mm diameter x 44.5mm height, and offering 580mAh capacity; a 30mm height model that offers 350mAh capacity; a 50mm height model that offers 680mAh capacity; and a 67mm height model with 900mAh capacity. These cells are used extensively in the European Global System for Mobile Communications phones. Hitachi Maxell is conducting R&D aimed at raising the capacity of its NiMH batteries and expanding its lineup of batteries.

Hitachi Maxell is considering supplying electrodes and other battery components on an OEM basis.

4.2.6 Matsushita Battery Industrial (MBI) Company

MBI is one of the leading cell manufacturers. The company is expanding its business activities for development, design, manufacturing, and package production. It is concentrating on Li-ion rechargeable batteries, anticipating strong demand for them in notebook computers and portable phones. In response to this growing demand, Matsushita has expanded its production capacity of Li-ion batteries to six million per month at their Moriguchi factory. MBI is investing \$2 billion in their Wakayama factory to add an extra production line to produce an additional one million Li-ion cells per month. Combined with the production of Li-ion cells at their Moriguchi factory, the two facilities will be able to produce seven million cells per month. MBI plans to be able to produce 20 million Li-ion cells.

MBI plans to expand its product lineup as well. Currently, the company offers three cylindrical models with 780, 1400, and 1170 mAh capacities, plus a prismatic model with an 850 mAh capacity. The company expects to add other square models to their product line and is targeting sales in the cellular phone market. They are projecting a six percent sales gain annually.

MBI is also offering NiMH batteries with greater capacity than previous models. The cylindrical battery in their Super 350 series offers one of the largest energy densities per volume – 4500mAh capacity – surpassing that of Li-ion batteries. Its size is compatible with Li-ion batteries; however, the company claims that it costs only half as much as the lithium models. They are mass producing NiMH rechargeable batteries for notebook computers, among other applications, and can produce 1.5 million cells per month.

While continuing their effort to develop progressively better Ni-MH and Li-ion batteries, the company is also working to improve the energy density of NiCd batteries and expanding the uses for this battery chemistry as well as other rechargeable batteries.

4.2.7 Toshiba Battery Company

Toshiba and its subsidiary, A&T Battery Corporation, manufacture a number of different kinds of rechargeable batteries. Toshiba makes NiMH batteries and A&T Battery produces Li-ion batteries. Toshiba is aiming to achieve a 30 percent share of the market for NiMH batteries and a 20 percent share of the market for Li-ion batteries. Most of their manufacturing and marketing efforts are focused on their NiMH batteries.

Regarding NiMH batteries, Toshiba has eleven cylindrical and five prismatic NiMH batteries. Their lineup includes two cylindrical models with 10.5mm diameters “AAA”, two with 14.5mm diameters “AA”, and seven with 17mm diameters “A”, all with different heights. These batteries range in capacity from 550 mAh to 4000 mAh. They are focused on upgrading the capacity and performance levels of these models. Monthly production

capacity is 13 million cells. Approximately 80 percent of what they produce is exported to other countries – 20 percent to Europe, 30 percent to the U.S., and 30 percent to Asia. They are currently conducting research into ways to add extra capacity.

Their Li-ion lineup includes two cylindrical models with 17mm diameters and one with an 18mm diameter. They also have three prismatic Li-ion batteries measuring 6.33, 8.6, and 14mm thick. Their Li-ion R&D work involves analyzing ways to raise the energy density-to-volume ratios of their Li-ion cells.

The company is also considering marketing packing cases for battery packs, as well as on battery cell supplies. Approximately 35 percent of their total NiMH batteries are currently shipped in the form of battery packs.

4.2.8 GP Batteries International Limited

GP Batteries International Limited is the Battery Division of Hong Kong's Gold Peak Industries (Holdings) Limited. GP Batteries is one of world's major suppliers of nonrechargeable and rechargeable batteries with manufacturing operations and distribution centers in over ten countries, employing over 6500 people. Cells they produce are NiCd, NiMH, and Li-ion. Its combined production output is over 500 million pieces annually.

The company has major plans to increase production of NiMH battery packs and Li-ion cells. It recently completed the acquisition of Duracell Inc.'s rechargeable Li-ion battery production facility in Waterbury, Connecticut. This acquisition was their way to gain entrance into the Li-ion market. GP Batteries also signed a technology agreement with Duracell that will give it access to future lithium product development and enhancements. The company hopes that, in the future, as a result of continuing Li-ion battery R&D, they will be able to begin production of prismatic cells and enhanced formulations for greater mAh ratings and to move into different lithium chemistries and form factors.

In addition, GP Batteries purchased Duracell's NiMH battery pack business for laptop computers and industrial applications such as handheld scanners and portable printers.

The company anticipates accelerated growth as a result of its entry into the Li-ion market and the addition of the NiMH pilot line.

4.2.9 Duracell

Duracell Inc., a wholly-owned subsidiary of the Gillette Company, is backing out of the Li-ion battery business. Company representatives have stated that Duracell has decided to get out of that business because there wasn't a retail opportunity materializing for replacement computer batteries. That line was specifically dedicated to building 4/3 "AA" cells used in larger battery packs for notebook computers.

Duracell sold its Waterbury, Connecticut plant to GP Batteries International Ltd. GP officially took over the Li-ion cell and battery-pack assembly operation in early 1998.

Duracell continues to concentrate on NiMH, but with a new focus on handheld communication devices such as cellular or GSM telephones that use smaller battery packs. Company representatives pointed out that the challenge is in combining high-energy density into smaller packages. Their big push right now is working with OEMs to develop interchangeable designs for NiMH and alkaline batteries.

4.2.10 VARTA

VARTA is a German company that produces Li-ion button cells. VARTA supplies Siemens with coin-sized Li-ion batteries for telecommunications products. They also offer a comprehensive range of NiMH batteries and are the number one supplier of PowerPacks for camcorders. VARTA is increasing the capacity of its NiMH cells.

4.2.11 Battery Engineering

Battery Engineering, a subsidiary of Japan-based Hitachi Maxell, Ltd, (see para 4.2.5) is developing a flexible, credit-card-sized lithium polymer cell. New facilities in Canton, Massachusetts include high-capacity manufacturing lines, R&D labs, and testing facilities.

4.2.12 Other Producers

A new entry into the rechargeable lithium battery market is GS-Melcotec Co., Kyoto, Japan. A joint-venture between Japan Storage Battery Co. and Mitsubishi Electric Corp., they are producing small rechargeable lithium batteries for portable telecommunications and audio equipment. Nippon Electronics Corporation's production of Li-ion rechargeable batteries at the end of FY1996 was one million cells/month. Production at the end of FY1997 was four million cells/month. In NiMH batteries, the production rate at the end of FY1996 was 5.5 million cells/month. Production rate at the end of FY1997 was six million cells/month. PolyStor Corporation purchased a fully automated assembly line from Sony Factory Automation and Itochu Corporation that is capable of producing 500,000 prismatic Li-ion batteries per month. The assembly line is designed for mass production of PolyStor's new Nickel-Cobalt prismatic Li-ion cells. Panasonic, a Japanese company, is a major cell producer of NiCd and NiMH cells. Though late to enter the lithium market, the company is now shipping Li-ion cells and is developing lithium polymer. Furukawa's planned production rate is for 20 million Li-ion cells per month. Production in NiMH cells at the end of FY1996 was 2.4 million units/month, while production at the end of FY1997 was three million cells/month.

4.3 Repackagers (Companies Known to Conduct Business with DoD and DND for C/E Equipment)

The designation "repackager" refers to a company who does not manufacture the specific cell in house, but rather obtains them from an outside source, configures, or "repackages" them into a battery and then sells them to the military, or other customers. These companies wire together the cells, along with battery electronics (safety devices, connectors, and state of charge for rechargeable batteries), and insert them into the packaging of various sizes. Repackagers switch cell manufacturers frequently, based on which cell manufacturer offers them the better price. The cell chemistries determine the cell voltage and this, along with power requirements, requires various numbers of cells to be wired in a combination of series and parallel connections to meet customer's requirements. As stated previously in this report, repackagers provide the majority of unique battery configurations procured by the military. Information on some of the major repackagers for defense C/E is highlighted below.

4.3.1 Bren-Tronics

Company Background

Founded in 1973, Bren-Tronics is a private company located in Commack, New York that employs 120 people, making them one of the larger repackaging companies doing business with the military in fulfilling its communication equipment power requirements. The company had a total of \$21 million in sales in 1997. They manufacture over 600 different battery types for both military and industrial markets and specialize in custom designed batteries for special applications. Bren-Tronics manufactures batteries for three generic applications – military, underwater, and instrumentation.

The military makes up approximately 90 percent of the company's sales, with the U.S. Army being their largest customer. The commercial market clients are primarily defense companies purchasing these batteries for defense systems. They do have some international clients as well, including Turkey and Australia, meeting their demand requirements for legacy systems. The Computing Devices Corporation, a Canadian company, purchases batteries for Canadian programs.

Bren-Tronics has been awarded a major U.S. Army contract for a family of rechargeable batteries and battery chargers for use in such systems as the SINCGARS radio, Night Vision Sight, hand held radio, Thermal Weapons Sight, and Mini-Eyesafe Laser Infrared Observation Set (MELIOS).

Once again however, the cells are typically "AA", "A" or "D" size and these are repackaged by Bren-Tronics. The cells themselves are built mostly offshore in the Pacific Rim by Panasonic and Sanyo. The size of these cells tend to be driven by the commercial marketplace and they come as spiral wound electrodes encapsulated in a metal can (e.g., typical K-Mart "AA" cell) which, in the military configuration, adds much weight to the

resulting battery. Also, the military battery packs tend to be rectangular and the cells are round, which results in wasted packaging space or reduced power density as well.

R&D

Bren-Tronics conducts most of their R&D work internally, funded by the company in anticipation of future marketplace demands. The focus of their R&D is on enhancements to the current military battery pack's performance and does not entail cell design and equipment fabrication.

Bren-Tronics is under a U.S. Government contract to:

- Deliver an improved version of four existing batteries in the military inventory
- Develop and produce a new rechargeable Li-ion battery, BB-2847/U, to substitute for the BA-5847/U lithium sulfur dioxide nonrechargeable battery
- Develop and produce a low cost, portable charger capable of charging two batteries in two hours or less.

One of the new products that Bren-Tronics has under development is the BB-2590/U. The BB-2590/U is a Li-ion construction that offers equivalent capacity to the BB-390A/U, reduced weight of 25 percent as compared to the BB-390A/U, and increased cycle life (capable of 700-1000 cycles but actual physical abuse in a tactical environment may limit the usable cycles).

Cell Providers

Bren-Tronics' NiCd cell providers are Panasonic, a Japanese company; Sanyo, a Japanese company; Saft, a French company; VARTA, a German company; and Eveready, a U.S. company. These companies also provide Bren-Tronics with their NiMH cells. The company representatives pointed out that Sanyo, the cell manufacturer for the NiCd BB-516A/U cell used in the MELIOS system, discontinued making this cell and that Bren-Tronics had to find other sources.

Their Li-ion cell providers are Panasonic; Sanyo; Sony, a Japanese company; Gold Peak, a Hong Kong company formerly part of Duracell; Moli, a Canadian company that is part of Nippon Electronic Control; and PolyStor, a U.S. company.

Bren-Tronics receives its lithium polymer cells, which are currently under R&D and not yet mass-produced, from Ultralife, a U.S. firm; Saft; and Yardney, a U.S. company.

General Marketplace Observations

Bren-Tronics representatives stated that the commercial market is the driving force in cell demand. The quantities required by the military do not justify production of unique cell sizes or performance. The current focus of rechargeable battery R&D is on Li-ion and next generation lithium polymer. The most popular Li-ion cell, the "18650", which is used in the

BB-2847/U, is the mainstay of the commercial marketplace to power camcorders, laptop computers, and other portable electronic equipment.

Bren-Tronics representatives noted that they have applauded the government's move to performance based specifications and prefer to work with these specifications. They indicated that the fiscal reality of using rechargeable batteries is irrefutable. However, the cycle time capability of a particular rechargeable battery chemistry may not be realized unless care is taken to both handle and charge these batteries properly. The capacity of the rechargeable battery is gaining on that of a nonrechargeable but this is certainly one of the present limitations for a large-scale swap out of battery type.

4.3.2 Lynntronics

Company Background

Lynntronics is a repackager of various battery cell chemistries for primarily the military market. Located in Yaphank, New York it is a privately owned company, established in 1987, which has total annual sales of \$1.5 million. Lynntronics can be considered a niche supplier with a custom-build capability.

The company employs 12 full-time people, which makes them a small company of this type. Their employees are mostly classified as unskilled labor, and all are cross-trained in all the positions on the assembly floor, a process that takes approximately two months. Their battery repackaging work is labor intensive and deals primarily with subassembly and final assembly. Depending on their workload, Lynntronics has the capability of ramping up easily, and employing approximately 25 people to help speed their assembly process.

Products

Lynntronics' primary customer base - 80 percent - is the military. Major military customers are the Canadian government (considered the biggest customer, in conjunction with Kaycom of Montreal), U.S. Army, and the USAF. In the military market, Lynntronics work is split 50-50 between nonrechargeable and rechargeable batteries. They also have small orders from other countries. Their 20 percent commercial market base involves configuring batteries for sonobuoys and emerging locator transmitters.

Lynntronics produces a portable NiCd battery pack system to be used by the USAF in its Scope Shield program and by the Canadians in their Tactical Command Control and Communication System (TCCCS) project with the delivered IRIS communication system.

The company also produces the rechargeable NiCd BB-516/U battery used for the night vision system of the MELIOS. They also supply the rechargeable NiCd battery configurations for the AN/GVS-5 system, an older laser range finder system.

R&D

Lynntronics conducts most of their R&D in-house with company funding. They develop prototypes that meet client requirements on request. The Canadian government has provided \$5,000 (CAN) in funding to prototype a rechargeable battery for a truck mounted radio system, which is part of a relay system. Lynntronics was able to successfully assemble the battery for \$200, which the Canadians had been buying from another vendor for \$600. This cost savings was due in part to Lynntronics' reengineering of the battery configuration, reducing the battery parts from 36 down to 12 while making the prototype waterproof, increasing performance, and keeping form, fit, and function constant.

Lynntronics is analyzing the rechargeable Li-ion and NiMH chemistries to determine the different types of technologies/properties available and potential applications for these different configurations. They are working in conjunction with Saft, one of their major cell providers, prototyping different battery configurations and offering different properties for these assemblies.

Cell Providers

Cell producers that Lynntronics uses for their rechargeable NiCd cells are Panasonic, Saft America, and GP Battery. Panasonic produces their cells in the Orient and in Mexico. Saft produces their cells in the United States, Mexico, and France. GP Battery produces their cells in China.

Saft America supplies Lynntronics with Li-ion cells, which are produced in the United States.

Lynntronics representatives indicated that they have had some difficulty in obtaining rechargeable NiCd cells. They noted that when the U.S. government issued a contract for their NiCd BB-516/U battery used in the MELIOS system, Lynntronics discovered that this cell size was no longer being produced by Sanyo, and found a cell producer in China to fill the order.

This highlights a problem in the repackaging base. End items using a specific battery configuration may be required for twenty years or more. Some of these batteries require unique cell sizes or chemistries. If the commercial application for these cells shrinks, or is eliminated entirely, production of the cells eventually ceases. This makes them no longer available for military applications.

General Marketplace Observations

The Lynntronics representative stated that the trend in the rechargeable battery industry is to follow the requirements of the commercial electronics marketplace developments. Cell manufacturers are driven by their corporation's needs to maximize profits and have targeted the commercial marketplace because it is so huge and allows them the greatest potential to maximize revenues. The military market, on the other hand, is very

small in comparison and is not a real focus of cell manufacturers because the quantities ordered do not provide them with an adequate return on investment.

4.3.3 Alexander Technologies, Inc.

Company Background

Alexander Technologies, Inc., formerly Alexander Batteries, is a privately held integrated battery pack assembly company employing approximately 345 people. About 300 employees work in the Mason City, Iowa facility and 45 in their overseas division in England. The company is a supplier of battery systems and recharging units. Alexander does about \$40 million/year in commercial sales and \$2 million - \$5 million/year in military sales. Depending on the military situation, Alexander estimates 10-25 percent of their business is dedicated to military contracts. Three battery chemistries (Ni-Cd, Li-ion and NiMH) packs comprise about 50 percent of Alexander's military sales. Alexander is capable of manufacturing 12,000 battery packs per day and about 500,000 chargers per year.

Alexander's Electronics Division, which designs and builds state-of-the-art battery chargers and analyzers, is the company's fastest growing business segment. All battery pack and charger manufacturing is done in one facility. Alexander is currently running two shifts in battery pack production and one shift in electronics assembly. The electronic assembly process is in support of the smart charger production line. Full capacity can be achieved by addition of a third shift. Alexander can ramp up to full capacity rate in 16 weeks.

The company has facilities in England which perform production and product development. This operation assembles a full range of battery pack products for European and other international customers.

Alexander uses the work cell concept in the manufacturing facility. Employees are cross-trained in the battery pack and charger manufacturing areas respectively. Skill levels required to work on the manufacturing line are solder training, Electro-Static Discharge (ESD) training, blueprint reading, and other training based on position held.

Products

Alexander Technologies, Inc. manufactures a wide variety of rechargeable batteries and chargers. Rechargeable batteries include two-way communication, medical, special application, pager, and cellular telephone applications. The rechargeable battery chemistries they primarily use are NiCd and NiMH, though they have started to implement Li-ion technologies in certain applications.

Research and Development

Alexander intends to incorporate the latest chemistries into battery packs for use in two-way radios, cellular phones, OEM, and medical equipment. Alexander has no

government developmental contracts or R&D agreements. They are just starting to investigate the concept of smart battery packs.

Cell Providers

Alexander Technologies' primary sources of rechargeable cells are Sanyo and Panasonic. They use mostly NiCd and NiMH in their battery packs. However, Alexander can and will use cells from other producers. If the customer wants a Li-ion battery, they will purchase these cells from a Li-ion producer.

General Marketplace Observations

As Alexander looks into the future of rechargeable cells and batteries, they see about the same markets as today. They forecast that cell/battery products will become more generic, i.e. one size fits all. Alexander representatives believe that, five years from now, there will still be a need for NiCd and NiMH, and Li-ion will continue to grow. Alexander representatives think that the advanced lithium technology and fuel cells will be the commercial and military rechargeable battery technology five years from now. They also believe NiMH is ready to challenge NiCd, because the price of NiMH has come down close to NiCd.

On the subject of impediments and barriers to adoption of new technologies, Alexander representatives believe there are four important areas needing attention. First, if Li-ion is to be the chemistry of the future, the industry needs to be convinced that the shelf life of Li-ion cells is greater than a year. To date, no one is willing to commit to a shelf life of beyond one year. Secondly, there is concern whether the products are rugged enough to withstand military use. Third, in order for new cell/battery technologies to gain acceptance for military use, government agencies must actively participate as advocates of said technology. Lastly, to ensure maximum benefits are gained from the new technologies, the governments involved must work towards common interests and goals.

4.3.4 Kaycom Incorporated

Company Background

Kaycom is a privately held company located in Ville St. Laurent, Quebec which repackages battery "AA" through "D" cells for primarily military systems. Company sales are generally \$8 to \$10 million per year (CA). Their main customer is the Canadian DND.

Products

Currently, battery products are just five percent of their product mix. These batteries are used to power high-capacity military systems.

Research and Development

Kaycom, in conjunction with Lynntronics (see para 4.3.2), is currently investigating the performance parameters and potential enhanced properties gained by employing Li-ion cells, as well as potential applications for these cells.

Cell Providers

Kaycom purchases their battery cells from Saft and Panasonic.

General Marketplace Observations

Kaycom representatives believe that the potential lower cost offered by the use of rechargeable batteries will be a driving factor facilitating the use of rechargeable battery technologies.

4.3.5 Other Potential Repackagers

In the course of the study, industry representatives indicated that the Defense Departments may want to open a dialogue with other established battery companies who may welcome their business and have the manufacturing capability to produce these batteries along with their commercial product lines. Two companies that were mentioned frequently are Centurion and TDI Batteries. These two companies were not a part of the study.

4.4 Hybrid Companies

In the context of this document, companies that produce cells and repackage them are referred to as "Hybrid Companies."

4.4.1 Yardney Technical Products, Inc.

Company Background

Yardney Technical Products, Inc. is owned by ENER-TEK International, Inc. (ETI), a small business technology company that focuses on specialty battery technologies for R&D product development in niche markets. ETI is the successor company of Yardney International, Inc., a holding company that owned and licensed battery technology developed by Yardney Electric Corporation. Yardney Electric Corporation, now Yardney Technical Products, was acquired by ENER-TEK in 1990 from the Whittaker Corporation. The acquisition included the lithium battery operation of GTE laboratories in Waltham, Massachusetts.

A subsidiary, Lithion, was established in 1994 to commercialize Li-ion battery technology developed through Yardney's research activities. Some of the targeted markets they hoped to penetrate were consumer electronics (such as cell phones, camcorders, and cordless tools), medical instrumentation, computers, communications, and bar code scanning

equipment. Their goal is to seek niche markets for the unique prismatic cell design attributes of the technology they currently have under development.

The company currently employs 135 people and occupies a 260,000 square foot facility in Stonington, Connecticut. Their current product mix is 65 percent silver zinc batteries, 15 percent Li-ion batteries and 20 percent other batteries. Their biggest customer is the U.S. Navy. Other customers include the USAF, National Aeronautical Space Administration (NASA) and Lockheed Martin. Their current business base is 65 percent military and 35 percent commercial (one half of the commercial base is comprised of OEM that purchase batteries for defense systems). They have a growing international client base, including contracts with Germany, Greece, Korea, and Peru, primarily involving legacy defense systems.

Products

Yardney designs, develops and manufactures specialty battery technologies for the aerospace market, the DoD, and industrial/commercial applications.

The rechargeable batteries that Yardney produces are silver-zinc, silver-cadmium, Li-ion and aluminum air. They offer numerous cell sizes and battery configurations for the silver-zinc technology. Of these, only the lithium has any immediate potential for use in C/E equipment. They have two basic Li-ion cells in pilot production (a 5 Ah and a 20 Ah).

R&D

Yardney has a number of government-funded programs associated with the design, development and manufacture of lithium-based battery technologies. Clients include Wright Patterson AFB, Phillips Laboratory, U.S. Army Research Laboratory, NASA/JPL, and the U.S. Army CECOM. The program cumulatively equates to more than \$5.4 million in independent research and development funding, in addition to the installation of a pilot production facility to support CECOM's requirements. Yardney does not currently conduct any R&D for the Canadian government, however, they do work in conjunction with the Canadians through Lithium Battery Safety Meetings.

A major goal of their R&D effort is to produce a safe and reliable Li-ion cell technology for a variety of applications, both commercial and military. Their work involves tailor coating thickness, using different dopants to make their batteries more environmentally friendly, evaluating different electrolytes, examining ways to increase capacity (such as using a tin oxide anode) and designing their batteries to meet different parameters for different applications. Potential applications include military radios, satellites and a variety of commercial applications, such as heart defibrillators on helicopters, aircraft and ambulances, and automobile rental company hand held readers.

Yardney has a DoD/ManTech contract valued at \$2.6 million to develop the manufacturing technology for prismatic cells and their packaging into an equivalent rechargeable version of BA-5590/U nonrechargeable battery. The batteries will contain a

battery management circuit that provides the required safety (i.e. charge/discharge) controls and state of charge indicators. The target cost for this version of the battery is \$275. The advantage of the Yardney development effort is that larger prismatic cells not only increases power density but also potentially increases battery reliability as well. This is due to the reduction in intercell connections, since there are only eight cells versus the 24 commercial cells wired together in the Bren-Tronics equivalent battery (BB-390A/U).

Cell Providers

The company provides its own cells through in-house manufacturing.

General Marketplace Observations

Yardney executives stated that current government policies favor battery assemblers acquiring cells offshore. All Li-ion cylindrical cells are procured from overseas. There is no prismatic cell producer in the U.S. besides Yardney, though many companies are involved in R&D efforts. Because the current manufacturing base for Li-ion is offshore and produces small cylindrical cells, the larger military batteries require complex arrays of small cells with complex battery control circuitry.

The Japanese dominate the lithium battery market at present because of their preeminence in the commercial portable electronics market. Oftentimes, the battery company and portable electronics companies are part of the same parent company. Hence, the number of equipment sales made dictates their volume and their market is established.

Company representatives perceive that the major emphasis in R&D rechargeable battery work will be in the areas of lithium polymer and zinc air. Potential payoffs that could be realized through Li-ion R&D programs for high energy density, lightweight power sources are lower acquisition costs, better low temperature performance, and higher rate capability.

To ensure more widespread use of the Li-ion technology, the company representatives indicated that lower cost production capability in sizes applicable for military batteries would be needed.

One of the biggest hurdles to be overcome in transitioning to rechargeable batteries is addressing the perceptions and winning the acceptance of the soldier. The logistics of the move also will need to be sorted out.

When questioned whether industry would continue to develop these technologies without DoD/DND investment, company representatives stated that they believed industry would continue to pursue these technologies but not for military applications. The demand is not there to justify a high level of investment in this activity. They indicated that the DoD and DND would in all likelihood need to continue to support development for military specific needs, especially in low temperature operations where electrolyte changes can make a significant gain in power output given the same battery type. COTS and operational

impacts must be traded off if the military is to continue to operate in environments different than that for which the commercial demand exists and if the military continues to support legacy systems for long periods of time.

4.4.2 BlueStar Advanced Technology Corp.

Company Background

BlueStar Advanced Technology Corp. (BATC), located in Vancouver, British Columbia is the R&D division of a publicly owned company, BlueStar Battery Systems International Corp., established in 1993 with estimated 1998 annual revenue of \$121 million (CA). BATC has the mandate to develop the company's next generation of rechargeable and nonrechargeable power cells for future production. Efforts are presently concentrated on the nonrechargeable LiMn_2O_2 technology cell batteries and the larger Li-ion rechargeable cells required by the aerospace, vehicle, and space sectors. These larger cylindrical cells are up to 150 Ah rated. Commercial market derivatives of this work are anticipated to support electronic mobile devices such as video cameras and notebook computers.

BATC employs 17 full time people. The employees are mostly classified as chemists and engineers with technician support in the pilot assembly area. All of the products developed and produced in this facility are hand assembled and tested using qualified test equipment and software packages.

BATC's primary customer base is government, which includes the military, National Aeronautical Space Administration (NASA), and the Canadian Space Agency. Major military customers are U.S. Army CECOM and the USAF. They also have small orders for cell testing from other agencies.

R&D

BATC was awarded a five-year Industry Canada and USAF jointly sponsored project valued at about \$5 million (CA) in 1991 to develop an assortment of Li-ion cells of different sizes and ratings and with different chemistry constituents. The first cells developed for testing were the size of a tuna can (3.5 in dia x 2.5 in) and were rated at 20 Ah. Later designs resulted in 25 Ah cells that were the size of soft drink cans (2.5 in dia x 7 in). These were delivered to the USAF/NASA. The project was completed with the delivery of 40 units for testing by both Lockheed and the Jet Propulsion Laboratory (JPL) in August of 1998.

Ten much larger 37.5 Ah cells were delivered to the USAF Philips Lab as a separate program. In addition, BATC has developed a double "D" size cell that delivers about 6 amp-hrs. Three of these units have been delivered to the U.S. Army CECOM for testing. The

majority of cells consist of a metal LiCo (or Ni or Mn)O₄ cathode and a graphite/coke anode that are formed by thin film deposits on thin metal foils. The foils are wound tightly and packaged in the cylindrical metal containers that are crimped or welded closed. An organic electrolyte activates the cell and is the medium for the exchange of Li-ions. BATC has found that they can achieve a higher specific energy in the cylindrical format than in the prismatic format and thus efforts have been concentrated on cylindrical forms.

The company is also working on an initiative sponsored by the Canadian Space Agency to address development of low temperature cells that are able to function in space at temperatures less than -20° C.

Interestingly enough, as the commercial market is moving towards the cell packs made up of many smaller "A" size Li-ion cells, the aircraft and space applications are also moving toward the Li-ion cells of larger size due to the weight savings that can be realized by the high specific energy in this type of rechargeable cell. Costs are always an issue but there is work to transition the cathode material to the more common LiMn₂O₄ (Spinel), which is much cheaper and environmentally friendly.

BATC's goal is to have their cells selected for the MARS 2001 project. They will continue to work on higher energy anodes and cathodes. They will also continue their efforts to develop specialty space application cells and more "F" sized cells (1.5 "D" size) for military applications.

General Market Observations

The military requirement for high rate cells will likely always remain. The high rate requirement cannot be satisfied by using commercial cells. As a result, the specific military requirements will require R&D funding to continue and programs such as Manufacturing Technology (ManTech) will be necessary to transition the laboratory cell developments to the production situation where costs are minimized for these military unique high rate cells.

4.4.3 Alliant Techsystems Power Sources Center

Company Background

Within the battery arena, Alliant Techsystems (a \$1.1 billion aerospace and defense company) has a Power Sources Center in Horsham, Pennsylvania that produces nonrechargeable, reserve batteries (electrolyte encapsulated in a reservoir to extend shelf life for such applications as missiles) and rechargeable batteries for the aerospace and military market. They are a vertically integrated lithium battery developer and manufacturer. In their 55,000 square foot facility, they offer computer modeling for design work and automated high volume production.

Products

Alliant Techsystems produces lithium batteries for advanced mine, artillery fuzing, aerospace, underwater, and medical applications. In 1992, they were selected by Aerospatiale and the European Space Agency as a supplier of batteries for the Huygens space probe that was launched to explore Saturn's moon, Titan.

R&D

In October 1996, the Power Sources Center group formed a joint venture with Valence Technology, Inc. to develop and manufacture gel polymer batteries for military markets. Teaming with Valence allows Alliant Techsystems access to Bellcore's licensed technology and high volume manufacturing expertise. In exchange, Alliant Techsystems offers the team access to military and aerospace markets and manufacturing expertise in this area.

Valence is manufacturing both the rolls of the polymer component materials and the cells themselves. Valence is establishing high volume manufacturing capability at their production facility to target the telecommunication and portable computer markets. They plan to introduce a portable computer battery in 1999 and have a current production capability of 1.5 million cells per year. They also plan to introduce a telecommunications battery.

Alliant Techsystems' business strategy is to develop military application specific batteries from either Valence commercial cells where appropriate or using Valence materials to manufacture custom military cell sizes. Bi-cells (the basic building block for this technology) are packaged in a lightweight multi-layer foil pouch that is sealed after the electrolyte is added to activate the cell and thus, the weight of a metal can is not present. Weight reduction is one of the major benefits of this technology for both the commercial and military markets.

In January 1997, Alliant Techsystems was awarded a U.S. Government ManTech contract valued at \$1.2 million to develop and implement flexible manufacturing processes for lithium polymer batteries.

Cell Providers

Alliant Techsystems produces its own cells for their ManTech program and R&D initiatives.

General Marketplace Observations

Alliant Techsystems representatives stated that the commercial battery producers are the driving force behind keeping batteries unique as a follow-on market to laptop computer

purchases. They noted that the laptop computer makers typically provide the batteries used in their specific laptop computers.

4.4.4 Ultralife Batteries, Inc.

Company Background

Ultralife Batteries, Inc. is a \$20 million U.S. small business that manufactures and markets a comprehensive line of high-performance lithium batteries. The company's advanced solid polymer rechargeable batteries are being developed for specific applications with leading manufacturers of cellular telephones, notebook computers, and many other portable electronic devices.

Ultralife maintains a manufacturing facility and research and development laboratory at its headquarters in Newark, New York. The company also has a production and research center in Abingdon, England. They have a staff of approximately 300 people at their U.S. facilities and about 80 people are employed at their United Kingdom facility.

Ultralife was formed in 1991 to acquire certain assets, technology and patents from the lithium battery division of Eastman Kodak. This acquisition positioned the company as a major contender in the development and manufacture of advanced-technology lithium batteries. In 1992, Ultralife became a public company. Their primary cell chemistry is LiMn_2O_4 .

The company is running a pre-production pilot line for its flat polymer battery, which Ultralife calls a "Solid State System." Ultralife's Solid State System[®] Li-ion rechargeable batteries are in the process of being commercialized for high-volume consumer electronics products like cellular telephones and laptop computers in the near future and potentially powering electric vehicles projected for the future. Ultralife is also targeting these batteries for such applications as powering electric shavers, cordless telephones, and many other portable electronic products. There are also opportunities for satellites and space vehicles. The battery is now being sampled to selected customers.

Ultralife is also putting the finishing touches on its automated assembly line, and expects to begin producing its polymer batteries later this year. Ultralife is working closely with their original equipment customers towards the commercialization of a cellular telephone battery. The company has stated it expects the price per Wh of its lithium polymer batteries to drop from \$3.50 to \$2.00 when they begin mass production.

Products

In 1997 and into 1998, Ultralife Batteries Inc. supplied Mitsubishi Electric with a lithium polymer battery for its new ultra-thin notebook computer. The computer weighs 3.1 pounds, is 18 mm thick and incorporates a 233-MHz Pentium MMX processor. Measuring approximately 4 in. x 6 in. x 1/4 in., Ultralife's flat, rectangular battery contains three cells, each with a typical operating voltage of 3.7 V. The fully charged voltage is 12.6 V, or 4.2 V per cell. The lithium polymer battery has an average run time of about 1.8 hours in the new notebook computer. An optional external battery containing three lithium polymer batteries in parallel will provide more than 5.4 hours of run time. The basic battery is rated at 1,700 mAh, while the external or optional battery, which is comprised of three batteries, is rated at 5,100 mAh.

Ultralife also manufactures Solid State System[®] Li-ion rechargeable batteries for advanced-technology aircraft maintenance computers, military aircraft sub-systems, missile guidance systems, and other military applications.

R&D

Ultralife's R&D efforts are directed at the commercialization of the company's advanced solid polymer rechargeable battery. Their R&D investment in the second quarter of 1998 was \$2,180,000. Ultralife scientists are conducting extensive research to improve the performance of its solid electrolyte battery as well as to evaluate alternative electrode materials. They are examining higher capacity materials in an effort to expand the operating temperature range of the system. The company has patents pending on the formulation of electrodes to enhance performance capacity.

Their first high-speed production line for solid polymer rechargeable batteries is in the final stage of qualification at their manufacturing plant in Newark, New York. As part of their strategy for future growth, they have acquired their Newark facility and the surrounding property through a lease/purchase agreement. The facility is located on 65 acres, about 25 miles east of Rochester, and consists of approximately 250,000 square feet of manufacturing and office space.

Ultralife Batteries, Inc. was awarded a contract by CECOM to test the company's solid polymer rechargeable batteries for safety and environmental impact in military applications. This contract was valued at \$200,000. The U.S. Army has indicated that results from these tests would be used to make final cell and battery design modifications prior to high volume production. The U.S. Army is intent on reducing its battery costs by equipping all new battery-powered systems with safe, environmentally acceptable rechargeable batteries. As a result, the U.S. Army is currently developing rechargeable solid polymer versions of some of its most widely used batteries.

4.4.5 Saft

Company Background

Saft is an international manufacturer of portable power sources, industrial and advanced batteries, and power systems. Though company headquarters are in France, the North American division, Saft America, has manufacturing plants in Valdosta, Georgia (NiMH and NiCd), Valdese, North Carolina (Li-ion), and Tijuana, Mexico (Li-ion). A research facility is located in Cockeysville, Maryland.

Products

Saft offers NiCd, NiMH, and Li-ion portable batteries for mobile phones, laptop computers, professional terminals, video, medical, and military radio-communications equipment. Their latest product offering is a medium prismatic rechargeable Li-ion cell. The company states that this cell provides the highest capacity on the market in a single cell, enabling the replacement of several cylindrical cells in parallel and an active volume gain of 20 percent. Saft mass produces two ranges of NiCd batteries and manufactures NiMH and Li-ion cells upon demand. The NiCd and NiMH cells are produced at their Valdosta, Georgia and Poitiers, France production centers. To meet demand, Saft recently added a production line at its Tijuana plant with a second expansion underway and a third planned.

R&D

The company allocates five percent of sales dollars to R&D aimed at developing batteries that offer the following performance characteristics: higher performance, more durable, greater autonomy, faster to recharge, smaller, lighter, and less expensive. Researchers at Saft's two research centers - Marcoussis, France and Cockeysville, Maryland - are developing batteries for portable, space, and electric vehicle applications. Li-ion is one of the main focuses of the company's research.

The team of researchers at Marcoussis consists of 50 scientists working solely on batteries. Research focuses on the electrochemical couples that Saft develops and produces. Their primary objectives are improving battery performance, reducing the cost of their constituent materials, and incorporating environmental protection features. Research on new technologies includes developing polymer and electrolyte batteries, super capacitors, and zinc negative electrode batteries.

The Cockeysville team of 50 scientists is involved in research programs in the following initiatives:

- Li-ion batteries for portable communications and electric vehicles
- polymer electrolyte lithium batteries
- NiMH batteries for electric vehicles
- battery control systems.

The Cockeysville research center's clients include: NASA, the U.S. Army, the U.S. Navy, the USAF, the U.S. Department of Energy, the Jet Propulsion Laboratory (JPL), the U.S. Defense Advanced Research Projects Agency (DARPA), the U.S. Advanced Battery Consortium, and a Chrysler, Ford, and General Motors partnership.

Major Cell Providers

Saft produces its own cells in-house.

4.5 Charger Manufacturers

There are a large number of manufacturers that build chargers, ranging in size from the small plug-in units that are available in stores that have electronic products to those that are sold exclusively with the electronic equipment they support. At the present time, the U.S. Government has 1,193 National Stock Numbers (NSN) listed under Item Name Code (INC) 00480, (charger, battery). For INC 00480, there are 238 companies listed that have or will sell battery chargers to the U.S. government. Many of these chargers are for dedicated applications such as charging forklifts, shipboard, aircraft engine starting, and Swimmer Delivery System batteries. These chargers exceed the C/E requirements and are usually "dumb"- that is, designed to charge a specific battery (size, capacity, voltage, and chemistry) from a fixed location.

The study group contacted 65 of 238 charger companies in both the U.S. and Canada. Of those contacted, the responses ranged from those eager to supply chargers for the military to those that only manufacture units for their own product lines.

Since chargers are made up of commonly available component parts, there is a healthy industrial base to supply the manufacturers with the needed component parts. There are a number of companies who are relatively stable and willing to work with the military in developing chargers to fulfill the militaries' needs. In fact, several manufacturers that were contacted indicated that they are expanding their production capacity to meet the growing need for chargers. As noted in our disclaimer statement, the following companies are representative of the industry and not considered to be all-inclusive.

4.5.1 Alexander Technologies, Inc.

Company Background

Alexander Technologies, Inc. designs and manufactures chargers and state-of-the-art battery analysis equipment for NiCd, NiMH, Li-ion, and lead acid chemistries. A more extensive write-up of this company can be found in Section 4.3.3.

Of the company's 300 employees, 45 work in the battery charger section. These people are classified as skilled and unskilled labor with the mix based on the amount of development and production that is going on at a given time. They have the capacity to produce over 500,000 chargers per year.

Alexander's primary customer base – 90 to 95 percent – is commercial. The commercial market base involves the telecommunication industry and law enforcement worldwide. They sell to DoD and DND.

Products

Chargers are available in one, two, three, four, and six-bay applications for industrial and consumer users. They assemble electronic circuit boards in-house and utilize state-of-the-art equipment to help meet current demands. Engineers work closely with customers to design maintenance systems to accommodate NiCd, NiMH, Li-ion, and sealed lead acid battery packs. Their battery maintenance systems utilize the latest technologies to determine a battery's full charge point. Alexander manufactures over 1,000 battery adapters, including custom-made and hard-to-find models. These adapters allow them to produce a standard charger console and then customize it to meet the specific needs of the end-user.

R&D

Alexander's R&D efforts are directed towards keeping their product line ahead of their competition by designing and developing the best products at the best cost and quality.

General Marketplace Observations

Future battery chargers will have real-time analysis on-board the battery pack and have fully interchangeable charging platforms that can be used for all chemistries.

4.5.2 AlliedSignal Inc., Defense & Space Systems

Company Background

AlliedSignal Inc., Defense & Space Systems (D&SS) is located in Teterboro, New Jersey, and is a publicly held company started in 1928 as Bendix. They have combined annual sales of \$283 million. The company has been supplying chargers for approximately 15 years. They have technology and equipment to support the following battery chemistries: lead acid, NiCd, silver zinc, and Li-ion. They have two types of analyzer/charger systems: portable and stationary. The portable units are single channel systems while the stationary units can support up to four batteries.

The company employs 1400 people. Their employees are classified as skilled and unskilled labor with the mix based on the amount of development and production that is going on at a given time.

Their primary customer base – 85 percent – is military. The military market base involves the aircraft industry for the USAF, U.S. Navy, U.S. Army, and NASA.

Products

The AlliedSignal equipment is based upon several patents, which they have been awarded over the last 15 years. AlliedSignal owns all patents used on the smart chargers. Only one product falls in the size and application that would be of interest to the C/E community. This is the Intelligent Battery Analyzer Charger (IBAC) smart charger, which is capable of charging, analyzing and recovering lead-acid batteries with a wide voltage and capacity range. This product can be easily adapted via a software modification to meet NiCd and Li-ion batteries.

AlliedSignal has the technology to meet new battery chemistry requirements. Prior to performing the charge operation, the unit performs extensive battery analysis. This is accomplished by applying specific test signals to the battery and measuring the battery terminal voltage response. The observed data is input into the algorithms, which provides state-of-charge, capacity, and state-of-health data. As a result of the foregoing analysis, the system can determine the battery gassing points. The gassing point data is used to establish the proper charge regime for the battery. The charger charges batteries in the shortest possible time without generating hydrogen gas.

R&D

The company has multiple programs targeted to extend the current technology to newer battery chemistries/sizes. On the average, they spend \$1 million per year in this area. In the future, they plan to concentrate their efforts in Li-ion and NiMH. They have already addressed the lead acid, NiCd and silver zinc chemistries. The methods used to determine these algorithms will be used on new chemistries. They have received funding for and are pursuing research initiatives for the following two programs:

- the Advanced Battery Analyzer/Charger with funding supplied by the Naval Surface Warfare Center, Crane Division, Crane, Indiana
- the Li-ion Program with funding supplied by the U.S. Air Force Research Laboratory (AFRL), Dayton, Ohio.

General Marketplace Observations

The battery marketplace for portable communication electronics is migrating towards NiMH and Li-ion technologies. In 1998, the Li-ion battery applications were expected to grow by 50 percent. AlliedSignal has already developed Li-ion analysis and charge algorithms for batteries (up to 5 Ah capacity) which are used in the portable computing and communication equipment. In 1999, they expect to complete similar algorithms for the NiMH chemistry. They will be able to supply advanced analyzer/chargers for all major chemistries: lead acid, NiCd, NiMH, and Li-ion.

4.5.3 BatteryPro Systems, Inc.

Company Background

BatteryPro Systems Inc. was established as a privately owned company in 1985. It developed a corporate alliance with Kenonic Controls Ltd. of Calgary, Alberta, Canada and in 1998 was bought by Kenonic Investments Ltd. The relationship between the two companies is symbiotic in nature, where Kenonic Controls, being a much larger company, provides backup as necessary with financial, administration, and technical staff in a matrix support type of arrangement. BatteryPro has annual sales of about \$6.0 million (CA). The company has a line of three systems that cover multiple applications. These systems are the Recharging, Analyzing & Maintenance System (RAMS), the RAMTech Conditioning Charger, and the RAMS Smart Battery System (SBS). These systems will meet a customers' needs for maintaining from one to 252 batteries that include both the standard rechargeable chemistry batteries and the newer Li-ion batteries with the System Management Bus (SMBus) electronics.

The company employs 12 people of whom seven production/assembly employees are a mix of Certified Electronics Technicians and those generally classified as unskilled labor. Where appropriate, the employees are cross-trained in positions on the assembly floor.

BatteryPro's primary customer base - 60 percent - is the military. Major military customers are the USAF and the Canadian DND. Their 40 percent commercial market base involves mostly the power and telecommunication industries and governmental agencies, such as law enforcement and fire fighting/rescue units in both Canada and the U.S.

Products

BatteryPro's product line addresses the equivalent of two levels of rechargeable battery maintenance. The number of batteries to be serviced at one time also plays a part in the equipment selected.

RAMS can recondition and maintain up to 252 batteries under the direction of a master controller/processor. Each battery has a custom designed holding fixture with an individual "charge card" complete with a microprocessor. This design feature reduces processing time and eliminates "lock-up" problems that can occur when sequential analyzers get stuck reconditioning a defective battery, leaving the rest of the batteries waiting to be attended. This system monitors the performance, handles capacity problems, isolates faults, minimizes downtime and significantly extends the life of the batteries placed on the system. It provides a full battery maintenance capability. When combined with the optional bar coding equipment and the RAMWin software package (a Windows-based software system to help track and analyze battery capabilities and histories), the user will have a complete inventory control and management system.

The RAMTech Conditioning Charger is a battery charging and reconditioning system for small or remote sites where the advantages of the RAMS does not require the

programming or expansion capabilities of the more sophisticated maintenance system. It comes configured with one, four, and six battery adapter (cup) units. The unit conditions the battery by first discharging it automatically and then charging it and maintaining the charge over time. On a weekly basis, the unit automatically cycles the battery to ensure the battery doesn't degrade. User instructions can be provided to the unit to change both the recycle period (preset at the factory to occur every ten battery cycles) and to define the minimum battery capacity below which the unit will notify the user that the defined mission time will not be met.

The SBS has all the features and components of the RAMS, but it also offers compliance with the Duracell/Intel Smart Battery Charger specifications as a level three charger. This system ensures complete compatibility with the latest Li-ion rechargeable batteries that use the SMBus fuel gauge and control electronic components.

R&D

BatteryPro has an ongoing R&D program that is focussed on equipment improvements based on feedback and requirement demands received from customers. Their latest efforts were to make their systems compatible with the SMBus technology.

General Marketplace Observations

The BatteryPro representative stated that the trend in battery charger development is to follow the commercial market cell and battery evolution. The battery manufacturers have the responsibility to define the charge profile that is best for their battery. This profile is then installed into the individual battery adapters with their "charge card" chipset, which can be reprogrammed or replaced as the need arises.

4.5.4 Bren-Tronics

Company Background

Bren-Tronics builds state-of-the-art high performance batteries and lightweight portable chargers designed for field-deployment or use in a shop environment to provide fast reactivation of various types of rechargeable batteries. A more extensive write-up of this company is provided in Section 4.3.1.

The military makes up approximately 90 percent of the company's sales, with the U.S. Army being their largest customer. The balance of their business base consists of supporting major subcontractors on other defense programs and also commercial ventures for consumer applications. These ventures are for both domestic and international customers. Chargers are purchased separately when not supplied with the original equipment purchase.

Products

Bren-Tronics builds the Universal Portable Battery Charger (PP-8444A/U). This charger is built into an impact-resistant molded equipment case that is watertight when the cover is securely latched and the pressure equalizer relief valve on the bottom of the case is closed. The system is programmed to automatically charge BB-388/U, BB-390A/U, BB-503A/U, BB-516A/U, BB-2847/U batteries, the battery for ITT SINCGARS, and the Laptop Computer Battery DR35.

Bren-Tronics designs and builds specific battery adapters for the charger, so that the various batteries can be mated to the charger. The charge and float/trickle cycles are automatically programmed for each battery type. Battery status is continuously displayed on the charger by the panel light emitting diode indicators. Two automatic cycles occur during a typical battery charge: a fast rate charge cycle and a low-current trickle charge which maintains the battery until it is removed from the charger.

R&D

Bren-Tronics conducts most of their R&D work internally, funded by the company in anticipation of future marketplace demands. In addition to company sponsored R&D, Bren-Tronics has received some contracts for R&D type programs. Other new products and systems under development at Bren-Tronics are a series of charger/maintainers. For example, a vehicle/maintainer (a charger capable of being mounted under the hood of a vehicle to keep the battery charged), a bench/maintainer (a laboratory charger capable of charging two lead acid vehicle batteries) and lastly a C⁴I charger/maintainer. This charger is referred to as the "Charger-on-the-Move" and can be mounted in a variety of military wheeled vehicles (i.e. High Mobility Multipurpose Wheeled Vehicle (HMMWV), etc.). Once mounted in a vehicle, batteries can be charged while the vehicle is in motion. A unique adapter compartment houses a number of batteries and the electronics scans for battery identification and will then sequentially charge the batteries.

General Marketplace Observations

Bren-Tronics representatives noted that the cycle life capability of a particular rechargeable battery chemistry may not be fully realized unless care is taken to both handle and charge these batteries properly. The cost savings of the rechargeable batteries far exceeds nonrechargeable batteries when the number of charging cycles are taken into account.

4.5.5 Cadex Electronics, Inc.

Company Background

Cadex Electronics Inc., Burnaby, British Columbia is a privately owned company established in 1980. It has annual sales of \$9.0 million (CA). The company specializes in the research, development, and production of battery maintenance equipment. The company

produces a line of basic systems that cover the maintenance requirements of NiCd, NiMH, sealed lead acid and Li-ion batteries.

The company employs 45 people. Their employees are classified as skilled and unskilled labor with the mix based on the amount of development and production that is going on at a given time.

Cadex's primary customer base - 90 percent - is commercial. The commercial market base involves the telecommunication industry and the law enforcement community worldwide. Their major military customers are the U.S. and the Canadian Air Forces.

Products

Cadex's product line falls into three levels and is based on the number of batteries to be serviced at one time.

The C7000 Battery Analyzer is a four-station analyzer that can accommodate NiCd, NiMH, sealed lead acid, and Li-ion batteries up to 15 V. They have over 600 battery adapters available at the present time. This product is used worldwide in public safety, mobile communications, cellular/PCS, emergency response, biomedical technology, broadcast, mobile computing, and avionics. The C7000ER Battery Analyzer is similar to the C7000 but can accommodate higher power batteries, up to 30 V, in order to service flight navigational batteries on the F-16 and F-22 fighter planes.

The Battery Support System is an intelligent battery charger and reconditioner for NiCd and sealed lead acid batteries that are smart battery compatible. This unit was developed specifically for the largest manufacturer of defibrillators.

The R2000 Battery Analyzer and the CV1600 Battery Charger were supplied to the USAF to maintain the battery supplies in the OEM equipment for the ScopeShield (electronic soldier) project.

Cadex has developed BatteryStat and Battery Shop which is a PC-based software that, when networked, facilitates data collection from 128 batteries simultaneously. The PC-based software can be used to analyze battery history, print service reports, generate labels, and automate battery maintenance programs.

R&D

Cadex is spending about \$1 million (CA) in R&D to develop the next generation battery analyzers with two-way communication, intelligent chargers, and chargers for smart batteries. They are also studying new battery chemistries, battery impedance, and ways of measuring state-of-health and state-of-charge.

General Marketplace Observations

Future battery chargers will be able to accommodate a wide variety of battery types and automatically apply the correct algorithm to optimize the charge. Fast-charging of different chemistries will be made safe because a memory chip embedded in the battery pack will configure the charger to the correct settings when the battery is connected. Batteries for critical applications will be made "smart" to enable measuring state-of-charge. Chargers for batteries will be able to provide information such as battery identification, manufacturer's name, date of manufacture, date battery entered service, date of last service, capacity reading of the last service, number of cycles delivered and remaining service life. With such information on hand, these chargers will be able to evaluate the condition of a battery, advise when service is needed, and send a message when a battery should be retired.

4.5.6 Cell-Con, Inc.

Company Background

Cell-Con, Incorporated, Coatesville, Pennsylvania, is a privately owned company established in 1982. They are a relatively small company that has primarily served the commercial market. They have started doing business for the U.S. Navy and the USAF by supplying products through prime contractors.

The company employs 50 people. Their employees are classified as skilled and unskilled labor with the mix based on the amount of development and production that is going on at a given time.

Products

The Multi-Position Fast smart charger is capable of charging ten separate battery packs, which can be either NiMH or NiCd. The product lets the user know when the battery is ready for service and when the battery needs to be discarded, because it cannot be reconditioned.

Charger/Power Supply is a single position charger that is custom made to meet the specific needs of speed-of-charge, number of cells and chemistry. The "brains" of this product is a commercially available microprocessor chip that monitors the charge process and ends it via negative voltage change or peak voltage detection.

4.5.7 KB Electronics, Limited

Company Background

KB Electronics Limited (KBE), Bedford, Nova Scotia, is a privately owned company established in 1989. It has annual sales of \$7.0 million (CA). KBE is involved in all facets of research, prototyping, development and production of battery maintenance equipment. A specific battery charger system that KBE developed in conjunction with its British associate,

Charge Electronic Design (formerly Widney Aish Limited), is the Intelligent Battery Management System (BCS(T)-201), which is capable of charging, analyzing and reconditioning simultaneously up to eight batteries of NiCd and NiMH chemistry in the voltage range of 4 V to 24 V and capacity range up to 6 Ah.

The company employs 60 people. Their employees are classified as skilled and unskilled labor with the mix based on the amount of development and production going on at a given time.

KBE's primary customer is 95 percent military with the U.S. Army having the largest share, the U.S. Navy next, followed by the USAF and Canadian DND.

Products

The BCS(T)-201 is fully hardened to military standards and qualified for use in tracked and wheeled vehicles in a tactical environment. The charging function of BCS(T)-201 is automatic once the battery is installed and includes positive identification of battery type, provision of optimal charging current based on initial estimate of state of charge, estimated battery temperature conditions, and fault or memory conditions of the battery. The maximum charge rate chosen is aimed at safe charging and ensuring long cycle life of the batteries. The analyzing function includes precise estimation of the charge capacity; detection of fault conditions such as open, shorted or high impedance cells; and memory effect. The capacity estimation is based on the battery's voltage response to charge and discharge probe signals. The reconditioning function is automatic once a potentially recoverable fault condition (e.g., memory effect) is detected and includes several (deep) discharge and charge cycles.

The BCS(T)-201 can be powered from either the vehicle's 28 V Direct Current (VDC) source or the 115V, 60 Hz / 230V, 50 Hz single phase AC source. The power section of BCS(T)-201 consists of eight sets of highly flexible independent charging and discharging channels, so that up to eight batteries can be independently and simultaneously serviced. Each charging and discharging channel can be operated in constant current or current limited regulated voltage mode with high precision under command from the central microprocessor. Hence, effective charging of batteries of any of the three major chemistries - NiCd, NiMH, and Li-ion - can be easily accomplished.

The discharge circuits of BCS(T)-201 are designed to provide controlled discharge of batteries during capacity estimation and reconditioning cycles. The discharge circuits can also be used under program control to measure the stored capacity in batteries, which enables BCS(T)-201 to be used as a battery test station.

R&D

Development activities are currently underway to extend the capability of BCS(T)-201 to charge Li-ion batteries. The major thrusts of the R&D program are:

- to develop new charging algorithms for high speed charging of multiple battery chemistries,
- to model charge and discharge profiles of multiple battery chemistries and types using emerging techniques such as artificial neural networks,
- to automatically identify battery chemistry and type (with minimal sensing requirements), and
- to develop high density power circuit topologies that allow for regenerative discharging.

The R&D budget is about \$350,000 (CAN) per year, to be expended over a three year period, for a total above \$1 million (CAN).

General Marketplace Observations

With increased demand for faster recharging of batteries, it becomes imperative that new techniques should be developed to complement the conventional constant current or current limited voltage control techniques that will substantially increase the speed of charge without compromising the battery's cycle life or safety. Techniques such as pulse-charging, dynamic charging and adaptive charging will find new prominence in battery management. The use and applicability of these techniques will, however, depend on the parallel advancements in the battery chemistry and construction techniques. Currently, it is necessary that positive battery identification be accomplished using external means prior to the application of appropriate charging algorithms. For example, battery identification means are inherently provided in the mechanical adapters or application-specific battery tray configurations that house only specific battery types.

Company representatives also suggested that, for future batteries and chargers, positive battery identification can be facilitated by bar-coding each battery and providing a barcode reader in the charger. Ideally, however, the charger should automatically identify a connected battery without such special "sensor" requirements. Such automatic identification facilitates true universalization of battery charging by eliminating special requirements for battery smartness, any safety concerns related to the potential for subjecting batteries to wrong or inappropriate battery charging methods, and logistic need for sorting the batteries prior to installation on chargers.

Automatic battery chemistry and type identification using only the positive and negative battery terminals for sensing is feasible (and already a subject of several ongoing research works), due to distinctive electrochemical reactions to stimulus signals that batteries of different chemistries and types exhibit. New non-linear modeling techniques such as artificial neural networks have been proven to accurately model such dynamics. The challenge is to ensure that such modeling takes into account all potential charge/discharge

characteristics under normal operating conditions, temperature extremes, varied battery state of charge conditions, and all battery fault conditions.

4.5.8 McDowell Research Corporation

Company Background

McDowell Research Corporation (MRC) is a privately held company that was founded in 1992. The company had \$2.5 million in sales in 1997. They have one manufacturing facility located in Waco, Texas and employ 25 people. The company designs and manufactures battery chargers supporting the BB-390/U NiMH; BB-590/U NiCd; BB-490/U; and BB-690/U sealed lead acid chemistries.

MRC produces items exclusively for the U.S. Military. The USAF makes up 80 percent of the company's sales, with the U.S. Navy next at ten percent of the business and the U.S. Army and U.S. Marine Corps each at five percent.

Products

MRC has developed single unit chargers as well as multi-unit chargers for all of the above listed batteries. All of MRC's multi unit chargers allow the operator to charge multiple chemistry types at one time. All of the chargers are termed smart chargers in that they monitor the battery health prior to the start of charging and automatically terminate charge to prevent overcharge. MRC-38 and MRC-54 have discharge functions that the operators can use to recondition batteries when needed. Multi-unit chargers operate from 95 to 260 V Alternating Current (VAC) and/or 11 to 36 VDC for worldwide operation or vehicular operation. No programming is required by the operator, who must only set one toggle switch to indicate the battery type to be charged and the charger will safely and completely recharge the battery. Each battery is separately charged to assure a more effective recharge.

R&D

MRC is continuously working on new chargers for different battery chemistries. They have developed all of their chargers in-house without any government funding. They are presently working on a charger that can be installed in a vehicle and charge batteries while on the move. They are also working on a charger for rechargeable lithium battery chemistries (both Li-ion and lithium polymer).

General Marketplace Observations

Company representatives see the need for multi-chemistry chargers for use in the field to: 1) support communication systems and 2) for training organizations to realize greater cost savings than they would achieve through the use of nonrechargeable batteries, taking into account their associated disposal costs.

5.0 RESEARCH AND DEVELOPMENT ACTIVITIES

Rechargeable Batteries: The Defense Departments of the U.S. and Canada are involved in numerous research activities for rechargeable batteries. The R&D projects are examining rechargeable battery developments for a number of applications, running the gamut from space applications to aircraft to communications equipment. Specialized batteries such as those used on satellites and space probes have a very limited market that does not present an industrial base issue relevant to this study, and therefore, is not addressed. The R&D for specialized applications normally comes from the sponsoring agency, i.e., NASA for space applications. Though recognizing that there are crossover benefits from some of the ongoing R&D work, for purposes of this study, we have highlighted the most relevant R&D efforts underway that pertain to C/E equipment.

Although considered a mature technology, NiCd manufacturers continue to increase energy density. They are accomplishing this by working to improve electrodes and the construction of a very thin wall can that allows more material to be packed into the can. Engineers are also concentrating on ways to make full use of the strong current discharge and rapid recharge characteristics, helping to solidify NiCd batteries strong position in motor-driven tools.

As for NiMH battery technology advances, developers are examining hydrogen-occluding alloys in the negative electrode and are seeking improvements in cycle performance. Engineers are striving to improve the rate of discharge, by heightening the functions of the alloy surface and improving the effectiveness of the current-collection system.

Within the commercial rechargeable battery arena, the vast majority of R&D is focused on Li-ion and next generation lithium polymer. Extensive research is being conducted to improve the conductivity of solid electrolyte materials and evaluations of alternative electrode materials. Manufacturers are continually improving the cell designs so that they can pack more energy into the container itself. They are working with new higher-capacity carbonic anodes and metal-oxide cathodes and are wrapping these new cells in lightweight packages such as aluminum and plastics.

Within the rechargeable battery technology arena, the vast majority of the rechargeable battery fundamental R&D is driven by the commercial marketplace. The trend in the defense rechargeable battery industry is to follow, or adapt, commercial marketplace developments, where the emphasis is to find ways to improve energy density while reducing size, weight, and cost. The military R&D is focusing on those unique requirements (extreme cold weather performance, large cell sizes) that are not design drivers in the commercial market.

There is no incentive for commercial producers at the cell level to develop their technology for DoD uses. The big cell manufacturers do not want to be bothered with the military for a number of reasons. The quantities required by the military do not justify a major investment in R&D or tooling by the larger companies, who have targeted the ever-

growing commercial marketplace. Coupled with this is the fact that the military's technical requirements of operating temperatures, resistance to shock, and vibration are harsher than that of commercial industry, so there is minimal synergy realized between the two R&D communities. Without military funding, the specific improvements required to take commercial rechargeable battery technology and optimize it for military systems will not move forward.

As the Military Services transition to lithium polymer technologies for their rechargeable battery needs, the military will be able to capitalize on an emerging commercial technology. The very nature of the polymer technology will allow commercial and military unique cells to be produced on the same production line with a minimal amount of retooling. Lithium polymer batteries can be formed into many sizes and shapes due to their prismatic construction and lack of a rigid cell container. This enables the battery to be shaped to the design of the end item, rather than the battery shape dictating the design.

Chargers: Battery charger R&D differs from battery R&D. Whereas battery R&D is based on research for a new compound or combination of chemicals that will improve battery performance, charger R&D falls more in the area of putting together circuits that have specific features that can be applied to battery charging. Charger R&D is focused on developing the electronics required to match the charger algorithm developed by the cell manufacturer. These circuits depend on speed of electronics, software, power, input signals, and output signals and how they are used to control the recharging current and voltage for any given battery chemistry.

5.1 Defense Rechargeable Battery R&D Activities

DoD and DND have sponsored a number of separate research efforts involving rechargeable batteries for C/E equipment. There does not appear to be much coordination between the two governments on their respective research initiatives at this time, though it was acknowledged that both countries could benefit by stepped up communication regarding research findings and directions. DoD is encouraging research into rechargeable lithium technology more than any other single area. Concurrent with research into the specific chemistries, there is substantial interest in the manufacturing technology necessary to provide a production base for military batteries using commercial battery production lines.

Some of the ongoing programs are highlighted in this section.

5.1.1 U.S. Army CECOM

The CECOM Research, Development and Engineering Center (RDEC) has embarked on a number of new rechargeable battery R&D efforts to improve performance, reduce weight, lower the overall cost of batteries, assess alternative power sources, and implement innovative low-power electronics.

The major thrust of the CECOM R&D is in the adaptation of the commercial rechargeable lithium technology to military applications. This effort is divided into two

separate initiatives: (1) developing large cell configuration using commercial technologies and (2) adapting commercially available cells to military unique battery configurations. In regards to the use of rechargeable Li-ion batteries for military applications, CECOM is developing designs that package the lithium systems using solid cathodes into polymer-lined foil pouches as well as large prismatic stainless steel cans. These efforts offer both economic and strategic advantages to the military. Commercial rechargeable lithium batteries generally use "AA" or smaller size cells. The military, on the other hand, desires large high-power cells, which are more costly due to their size and the lack of commercial demand for such a cell.

The development of lithium polymer cells will allow the military to capitalize on a production base that can be sustained by a commercial market. Manufacturers would be able to use one production line that can cut both small lithium polymer cells for commercial batteries and large military lithium polymer cells. The polymer technology would allow for the production of military batteries on the same manufacturing lines as commercial batteries, with minimal change in tooling, thereby ensuring a readily available domestic production base with the potential for cost savings through manufacturing economies of scale.

CECOM awarded two major ManTech programs to Alliant Techsystems/Valence and Yardney Technical Products to set up flexible, low volume production lines for the fabrication of U.S. Army batteries. The goals of these programs are:

- to evaluate and demonstrate novel approaches to packaging a rechargeable battery in a man-wearable configuration for integration into specific military applications
- enable large cell rechargeable lithium technology to be competitive for future rechargeable battery procurement.

Realizing that battery technology is reaching the end of its practical limit to provide energy, CECOM is working on methods to utilize the energy provided in the most efficient means possible. This effort falls under the generic umbrella of power management. CECOM has embarked on a number of efforts in the area of power management and one of its main elements, Low Power Electronics (LPE). CECOM is assessing future LPE, smarter integrated circuit designs, and energy-efficient chips that can reduce power usage by 80 percent or more in future circuits. Capitalizing on work being funded by DARPA, CECOM plans to transition these new technologies to advanced field demonstrations.

CECOM is working on a DARPA Technology Reinvestment Program in conjunction with AFRL, JPL, Saft, Covalent, Inc., and Ohio University. CECOM's research involves:

- developing optimized battery configurations for military applications
- studying electrolyte formulation and optimization for acceptable cell performance at temperature extreme outside of those required for commercial batteries
- designing a test plan and conducting a test evaluation for the Saft BB-X590/U batteries and the proof-of-principle prototype cells and batteries, including the charge/safety internal controls and charger.

5.1.2 U.S. Army Research Office (ARO)

The ARO funded InvenTek Corporation of Illinois to develop a high power lightweight portable rechargeable thermal battery for U.S. Army field applications. Working in cooperation with Argonne National Lab, the company used an advanced molten-salt battery chemistry, (Lithium Aluminum/Iron Sulfite - Copper Iron Sulfide ($\text{LiAl/FeS}_2 - \text{CuFeS}_2$) with Lithium Iodide (LiI) additive, to demonstrate the enhanced rate capability achieved through this chemistry. The new chemistry also had a broad operating temperature range, $460^\circ - 340^\circ \text{C}$. A 25-year shelf life can be anticipated. The ARO envisions that this sealed bipolar Lithium Iron Sulfide (LiFeS_2) battery could be used as a lightweight rechargeable replacement for larger high power nonrechargeable batteries. They anticipate it could be used in the U.S. Army's soldier systems. Potential commercial prospects include heavy-duty portable power tools, battery-powered lawn care equipment, electric motorbikes, emergency power and recreational equipment.

5.1.3 U.S. Navy Office of Naval Research (ONR)

The ONR sponsored Northwestern University in Illinois to research new fabrication strategies for polymer electrolyte batteries. The objective of this research was to fabricate lithium polymer batteries by techniques that may produce thin electrolyte and cathode films with minimal contamination during fabrication. Ultrasonic spray and casting techniques were used. The new lithium cells that incorporate the new polymer electrolytes and polyelectrolytes developed at Northwestern were synthesized, analyzed, and tested in lithium cells. They discovered that ultrasonic spray did not lead to the fragmentation of the polymer. Performance of cells prepared by ultrasonic spray was slightly better than that of cells prepared by casting. Primary limitations to cell performance were high cell resistance, apparent interfacial reactions between polymer-electrolyte and lithium, and dimensional instability. The researchers determined that improvement in cell performance could be achieved by the use of spacers or crosslinking polymers to improve the dimensional stability of the electrolyte and by the addition of cryptands and plasticizers to increase ambient-temperature conductivity of polyelectrolytes.

5.1.4 U.S. Navy – Naval Surface Warfare Center, Crane Division

The Power Systems Department at the Naval Surface Warfare Center, Crane, Indiana is a technology leader providing a broad spectrum of support for electrochemical power systems including batteries, battery chargers, fuel cells, and ancillary equipment. Cooperative teaming agreements are in place between Crane Division, industry, universities, and other government agencies to provide a network of knowledge and enhanced capabilities. These agreements are complementary and provide for sharing of resources and expertise to reduce program costs and attain solutions to complex battery problems. Areas of support include applied research, requirements definition, design, development, prototyping, and limited manufacturing, standardization, test and evaluation, safety certification, technology evaluation and insertion, production engineering, in-service engineering, depot maintenance, and system retirement.

Naval Surface Warfare Center, Crane Division is participating in a lithium battery development for electric vehicles. The technology lessons learned in this program should be applicable and transferable to C/E batteries.

Unique relationships allow new technologies to be evaluated for possible military applications before long term investments have been made. An example of this is the agreement with CINergy (the local electrical utility company), Ballard (the battery manufacturer), and Indiana University to install, test, and operate a 250 kW proton exchange membrane or polymer electrolyte membrane fuel cell at the Naval Surface Warfare Center, Crane Division in late FY1999.

Other facilities include a unique High-Energy Battery Evaluation and Abuse Complex for test and evaluation of the latest technology batteries in a safe and ecologically suitable manner. This facility contains ten fully contained high energy test cells (rated for five and ten pounds TNT explosion), air scrubbing systems, chemical detection system, chemical containment system and other features which allow the safe evaluation of high energy battery systems while protecting the local ecology. The facilities also include a state-of-art rechargeable test complex to test lead-acid, NiCd, lithium, silver-zinc, and other rechargeable technologies.

5.1.5 U.S. Air Force Research Laboratory (AFRL)

The AFRL is active in a number of rechargeable battery research efforts. In a 50/50 cost share arrangement with Ballistic Missile Defense Organization, the AFRL is developing and testing environmentally friendly bipolar NiMH rechargeable batteries for various USAF applications. They are working with Electro Energy, Inc. under a Small Business Innovation Research (SBIR) contract to conduct this research and are in Phase II of the program.

The AFRL has R&D underway in a number of rechargeable lithium battery programs. These include:

- Develop carbon (graphite) fiber anodes capable of reversible operation with lithium in order to develop an environmentally friendly, high energy density, long-life lithium battery with improved performance and safety characteristics – Contractor: Redox Batteries, Inc.; Subcontractor: Florida Atlantic University
- Develop a high voltage, inexpensive LiMn_2O_4 and establish pilot plant design to ensure a cathode material source for commercial and military rechargeable lithium batteries - Contractor: Covalent Associates; Subcontractor: Saft
- Design and test Li-ion cells with room temperature molten salts for use in the development of lightweight batteries that are safer, have a long cycle life, offer higher electrolyte conductivity, and use a nonflammable electrolyte - Contractor: Electrochemical Systems, Inc.
- Establish the technical base to permit the development of prismatic and bipolar Lithium Carbon/Lithium Nickel Oxide (LiC/LiNiO_2) cells for use in aviation, tactical, and strategic weapons - Contractor: Yardney (AFRL is working in conjunction with JPL on this effort.)
- Develop and produce a rechargeable, high energy density Li-ion battery on a prototype production line for military and commercial use - Contractor: Saft America, Inc.
- Investigate the failure mechanism of polymer electrolytes as a function of time to determine capabilities for rechargeable lithium battery for dual-use applications - Contractor: Indian Institute of Science (This is a cost sharing venture between the USAF and the Government of India)
- Develop a highly stable inorganic electrolyte suitable for a 4 V Li-ion battery - Contractor: Covalent Associates, Inc.
- Develop a single ion lithium conductor polymer electrolyte for use in rechargeable Li-ion polymer or metallic lithium batteries for dual use applications - Contractor: Tel Aviv University
- Develop polymer electrolytes for lithium rechargeable batteries that offer high ionic conductivity, high transport number, and good electrode/electrolyte stability for dual use applications - Contractor: University of Dayton Research Institute
- Develop polymeric organometallic composites as electrolytes for rechargeable lithium batteries to be used in dual use applications - Contractor: Warsaw University of Technology (This effort is jointly funded by the Government of Poland and the USAF.)

Recognizing their common need for aerospace Li-ion batteries, AFRL and NASA have entered into a joint NASA/USAF program for the development of a Li-ion battery. By leveraging their resources, expertise, and capabilities, they hope to build on existing commercial technologies and government technology development effort and programs. They intend to coordinate the efforts of universities, battery industry, and prime contractors, involving both prime contractors and users from the project start and develop two manufacturing sources. Their goal is to develop high specific energy, long life Li-ion cells,

and smart batteries for aerospace and DoD applications. Their research also involves developing electronics for smart battery management.

5.1.6 National Aeronautical Space Administration (NASA) Jet Propulsion Laboratory (JPL)

JPL is conducting research into rechargeable micro-batteries with lithium anodes formed in situ. Their work has involved the replacement of the anodes formed by chemical vapor deposition or sputtered lithium metal anode in a rechargeable thin-film micro-battery. They are used with a metallic current collector anode alone or a metallic current collector mixed with a fully lithiated oxide where the lithium source is completely supplied from a lithiated oxide cathode. The JPL researchers have found that by doing this, they were able to improve the safety of the battery, while improving the usable lithium capacity and manufacturability of the integrated power sources on a microchip. These micro-batteries would be used for advanced microelectronic device applications such as miniature spacecraft and portable C/E applications.

JPL is also working in conjunction with CECOM on a DARPA supported program for development of an environmental energy harvesting power system. JPL's portion of this effort is to develop the technology for a 100 mW and a 5 W micro-thermoelectric generator and the associated energy storage device. The micro-thermoelectric generator will be based on solid-state thermoelectric energy conversion. The energy storage device will also be developed by JPL and be based on either Li-ion polymer electrolyte or Li-ion thin film electrolyte battery technology.

5.1.7 Canadian DND

The Canadian DND is researching ways to make use of lower cost rechargeable batteries to replace nonrechargeable batteries in some applications. The main requirements for advanced power sources in DND over the next five years will continue to be in the following areas: portable electronic equipment, weapon platforms, silent portable field power, low temperature high energy density power sources for emergency devices, new power packs for advanced sonobuoys, and specialty power sources such as those for electric propulsion and for standby power. Canadian Forces operators are requesting the development of low cost power supplies with reduced detectability, Arctic operations capability (in Canada, the need for low temperature performance is important – more so than in the U.S.) and low maintenance burdens. Safe, reliable high performance power sources will be required to support the CF in several major development projects, including Integrated Protective Clothing & Equipment (IPCE) Technology Demonstration (Canada's Soldier Systems Program).

Part of DND's rechargeable battery R&D is being conducted under the Advanced Power Sources for Military Applications Project – AVRS 4 – funded for about \$500,000 (CA). Primary factors for their rechargeable batteries are that it must be as light as possible, have as much power as possible, and yet be safe and reliable to the operator. Another major consideration is the battery's durability, since it faces more abuse than a normal consumer product.

5.2 Commercial Rechargeable Battery R&D Activities

Every cell manufacturer has an on-going R&D program. These programs tend to be closely guarded industrial secrets and are not widely shared in the industry. As noted previously, Japanese battery makers are fulfilling most of the global commercial demand in the rechargeable battery market. Recognizing that improved battery performance will enhance the performance of the products that use batteries, which in turn will increase demand for both the products and the batteries, the battery makers are actively developing new batteries, improving existing batteries, lowering battery costs, and streamlining production and supply systems. Commercial industry has focused its research efforts on reducing power usage of consumer appliances and is the frontrunner in power management R&D. They are exploring ways to shrink the size of the batteries and their weight while maintaining or increasing energy capacity and adding advanced functions. Battery producers envision that uses for such batteries will expand as personal computers begin incorporating successively larger liquid crystal display panels and color screens.

Many battery manufacturers have focused their efforts on developing lithium polymer technologies. Touted as the next generation of batteries, developers believe that this battery chemistry will revolutionize the battery industry by its ability to be designed around the available space of the device itself, a vastly different redesign from traditional batteries. The next questions in the evolution of lithium polymer batteries concern how soon they will reach mass production and if their energy density will continue to improve. Many battery companies are exploring improving the conductivity of solid electrolyte materials and evaluating alternative electrode materials. In addition, Integrated Circuit (IC) makers are designing new battery-management chips and improving the precise cell-by-cell monitoring. Through improved and more efficient circuitry, the power requirements are expected to drop, thereby increasing the desirability of polymer systems.

A number of companies are in the development stage of these lithium polymer chemistries, with a few companies at the commercialization stage. Some of the major Li-ion cell producers - including Sanyo and Panasonic - are involved in lithium polymer research efforts. There are also a number of companies who have been licensed to develop Bellcore's lithium polymer technology. Analysts have estimated that there are about ten licensees in the U.S. Though information on licensees is closely held, industry experts believe that the other licensees are from France, Japan, Thailand, Malaysia, Hong Kong, China, and Taiwan. Of the approximately 17 licensees of this technology, it is estimated that nine to 12 companies are very active in pursuing development of the Bellcore technology. Analysts have projected that lithium polymer will in all likelihood replace Li-ion and NiMH in certain applications.

5.2.1 Bellcore

Bellcore is developing a high-power plastic Li-ion (PLiON) battery. The PLiON battery is manufactured using industrial-lamination processes, and is made up of an anode, a separator, and a cathode. Pliable, thin-plastic-film sheets allow the battery to be as narrow as 20 mils. The technology allows the OEM to tailor the battery for its specific applications. It can be made into any shape, capacity, or size.

The PLiON technology offers 120 Wh of power for 800 grams of weight, compared with 40 Wh for 400 grams of weight for conventional battery technologies. The battery uses an established dielectric, is nontoxic, and its active components are commercially available. Applications vary from high-tech consumer products to space projects that require specific power requirements and are under extreme conditions.

Bellcore has several licenses for the PLiON technology, which is expected to be commercially available in the near future. The company has demonstrated prototypes in cell phones, laptop computers, and toys. The PLiON laptop battery measures 6 in. x 10 in. x 0.4 in., and provides more than 100 Wh. For cell phones, a credit-card-size (2 in. x 3 in. x 40 mil) battery provides two hours of talk time and 20 hours of standby time.

Bellcore believes the new chemistry may be the enabling technology for the electric vehicle. This is due to the battery's design flexibility where they can not only design the power needs, but can place the battery anywhere in the vehicle. It opens up the design possibilities for electronic components and equipment.

5.2.2 Valence

Valence is engaged in R&D to produce advanced rechargeable batteries based upon Li-ion and polymer technologies. The company has a license to develop the plastic lithium battery technology from Bellcore and has been working to integrate the Bellcore technology with its own lithium polymer battery technology. At the same time, the company has continued the redesign of its manufacturing equipment in Northern Ireland to support the potential future commercial introduction of this new battery design.

In the event that the company's R&D activities lead to commercially viable products, the company's strategy is to accelerate the introduction of its batteries into the portable consumer electronic and telecommunication markets by providing prototype batteries to a limited number of potential OEM customers. If the company's prototype batteries meet customer requirements, batteries employing this technology will be incorporated into advanced product designs. The company expects that customers will require an extensive qualification period once they receive their first commercial product off a production line. In working with OEMs, Valence will seek to obtain technical assistance in designing its batteries for industry-specific applications. To date, the company has delivered small quantities of handmade prototype batteries to OEMs for their inspection.

5.2.3 3M/USABC/U.S. Dept. of Energy (DOE)/Argonne National Laboratory/ARGO-TECH

A team led by 3M is conducting research into lithium polymer chemistries through a \$27.4 million contract from the U. S. Advanced Battery Consortium (USABC) for the second phase of development on a lithium polymer battery. In 1993, 3M was awarded a \$32.9 million contract by USABC to conduct the initial research. That phase was successfully completed in late 1995. Now, the 3M team is continuing its efforts to create a power source

that would permit an electric vehicle to match the performance of a conventional, gasoline-powered car. The second phase of research, like the first, is being jointly funded by 3M, USABC, the DOE, Argonne National Laboratory and Canada's Hydro-Quebec electric utility, Argo-Tech. Beyond the automotive applications, the team believes that any industry that relies heavily on batteries may benefit from future lithium polymer battery technology, including telecommunications, medical equipment, measurement devices, aerospace, and defense.

5.2.4 Lithium Technology Corporation

Lithium Technology Corporation (LTC), located in Plymouth Meeting, Pennsylvania, together with its wholly-owned subsidiary Lithion Corporation (Lithion), is an advanced development stage publicly held company in the process of commercializing a solid-state lithium polymer rechargeable battery. The company is engaged in R&D activities to further develop and exploit this battery technology and also holds various patents relating to such batteries. They believe that their battery technology, which is currently in the prototype development phase, is capable of providing up to four times the performance of current rechargeable batteries. The company's objective is the commercialization of this technology, inclusive of moving from laboratory-scale product prototypes and related prototype processes to full scale market introduction, achieving cost competitiveness, and constructing a manufacturing plant. Their commercialization focus is on the portable electronics market segment (notebook computers and wireless communications handset devices). The company's patented and proprietary composite cell construction and low-cost manufacturing process are applicable to both lithium metal polymer technology and Li-ion polymer technology. They intend to pursue both chemistries for specific portable electronics applications.

5.2.5 Battery Engineering

A new series of rechargeable Li-ion polymer batteries that can be custom engineered for applications such as smart cards, laptop computers, cellular phones, and consumer electronics is being introduced by Battery Engineering, Inc. of Canton, Massachusetts.

Battery Engineering's Li-ion polymer rechargeable batteries provide 125 Wh/kg energy density, which they claim is four times better than NiCd, and weigh one fifth as much. Featuring a flexible and thin prismatic package, they provide 500 charge cycles with no memory effect and can be custom engineered for a wide range of applications.

Manufactured using a Li-ion and cobalt oxide cell, with a proprietary polymer electrolyte, Battery Engineering's Li-ion Polymer Rechargeable Batteries are 3.7 V nominal, with a five percent per month self-discharge, and can be assembled in series and parallel styles.

5.2.6 Moltech Corporation

Moltech Corporation is a private company founded in 1988. The company began its research to develop advanced rechargeable lithium polymer batteries at the Long Island High Technology Incubator in Stony Brook, New York. In 1995, it relocated to Tucson, Arizona and now operates at The University of Arizona Science and Technology Park with more than 90 employees. The company has intellectual property rights in lithium polymer battery technology developed by its own scientists and through global research agreements. Moltech has developed a new generation of high capacity rechargeable lithium polymer batteries, which deliver twice the energy per unit weight of conventional Li-ion battery cells. The company claims that superior performance is achieved through a combination of proprietary elements, which include new classes of high sulfur content cathode materials, cathode protective membranes, polymeric electrolytes, and protective polymer coatings for the lithium anode.

Moltech's proprietary high sulfur content cathode materials provide high storage capacity for Li-ions -- as much as five times the specific energy of metal oxides used in Li-ion batteries -- and close to that of elemental sulfur. Proprietary membrane coating technology is used to stabilize the cathode against self-discharge and for enhanced cycle life performance. The electrolyte is polymerized from liquid precursors, resulting in enhanced safety compared with liquid electrolytes.

Another unique aspect of Moltech's battery is its voltage, which is 2.1 V versus 3.6 V for Li-ion. This lower voltage is matched to the next generation of electronic chips, with a power supply voltage of 1.8 V, that will enter the marketplace in 1999. Moltech's technology provides a single-cell solution to the new generation of electronics.

Moltech's first batteries are being designed to meet the needs of the mobile phone industry for thin, prismatic cells of approximately 800 mAh. They claim that the key advantage versus Li-ion and other lithium polymer cells is the low weight, which is about half that of Li-ion products of comparable energy. They are also targeting batteries for notebook computers.

5.2.7 PolyPlus Battery Company

The PolyPlus Battery Company is a privately held development stage company, incorporated in California in January 1990. Operations started in May of 1991. PolyPlus is the exclusive, worldwide licensee of a class of electro-active polymers invented at the Lawrence Berkeley National Laboratory. The PolyPlus Battery Company is developing an advanced lithium polymer battery. The objectives of the company are to develop and commercialize advanced batteries based on its proprietary technology for the electric vehicle battery and consumer electronic battery market.

5.2.8 Energizer Power Systems

Energizer Power Systems (Gainesville, Florida), a division of Eveready Battery, has invested \$75 million in a new factory in Gainesville to further develop Li-ion technology. The first product manufactured there was a 4/3 "A" cell, which is now being sampled by select customers. Full production occurred in the third quarter of 1997. They are also developing a flexible, credit-card sized lithium polymer cell, which is undergoing life-cycle testing.

Energizer Power Systems is also focusing on the power-tool potential of NiMH. Energizer scientists have tailored a NiMH battery for power tools. They have also introduced two NiMH cells for use in PCs, cordless phones, two-way pagers, and PDAs.

5.2.9 Massachusetts Institute of Technology

A group of professors is adapting a technique used by the pharmaceutical industry, called rational drug design, to identify promising battery materials. Instead of randomly testing thousands of possible combinations, the process calculates the optimum characteristics for the cathode. This process has led to testing of a cobalt-aluminum mixture that could replace an expensive lithium-cobalt compound that is widely used in Li-ion batteries. The cobalt-aluminum cathode is claimed to have the potential to reduce the price of batteries by approximately 25 percent. Other compounds and concepts are under study as well.

5.2.10 Energy Research Lab of Japan

Energy Research Lab of Japan is focusing on improved electrodes for rechargeable lithium batteries. They have developed an electrode that the company said boosts the discharge capacity of current commercial NiMH batteries by 40 percent. The electrode is made of zirconium-titanium alloy and is said to offer weight and cost reductions for all sizes of NiMH batteries.

5.2.11 AEA Technology

AEA Technology, along with Japan Storage Battery Company, Ltd. and Mitsubishi Materials Corporation, has embarked on a joint venture to design and produce Li-ion rechargeable batteries for the communications, defense and medical markets. The new company is called AGM Batteries, of which AEA, which held the original patent on Li-ion, will have a 55 percent stake. Production will take place in their Scotland factory, which is geared to handle the needs of specialized markets, such as military communications devices. The group is concentrating its R&D efforts on developing rechargeable batteries based on lithium polymer technology.

5.2.12 Eveready/National Semiconductor

Eveready and National Semiconductor have teamed up to develop 'smart' NiCd and NiMH batteries for notebook computers and cellular phones. The intent is to simplify

charging and fuel-gauging of rechargeable batteries to enable development of longer-lasting, easier-to-use battery packs. The smart battery will control its own charging, thus eliminating overcharging. Fuel gauging allows immediate determination of the state-of-charge. Team representatives noted that this has been difficult in the past because of the non-proportional relationship between terminal voltage and remaining capacity.

5.2.13 Duracell/Intel Architectural Labs

Duracell and Intel Architectural Labs are working on a Smart Battery Data (SBD) and SMBus (see para 6.1.1). SBD specifications define the kinds of data to be transferred between the smart battery, the computer host, and other peripherals/circuits. Designed for NiMH applications, representatives have stated that it is nevertheless generic with respect to battery chemistry, pack voltage, capacity, and packaging.

5.2.14 ARGO-TECH Productions, Inc.

ARGO-TECH, located in Boucherville, Quebec produces lithium polymer batteries comprised of a thin lithium foil anode, a dry solid polymeric film electrolyte, and a vanadium oxide composite cathode in three different battery module configurations. Targeted applications for these batteries are telecommunication standby power, electric vehicles, and down hole drilling.

ARGO-TECH is a wholly owned subsidiary of Hydro-Quebec, an electrical utility owned by the Quebec Government. All manufacturing activities are done at 3M and ARGO-TECH. 3M produces the cathode and electrolyte film laminates. ARGO-TECH produces the lithium foil, winds the cells together, and assembles the modules and the final battery packs, including the thermal management system and monitoring and control system. Currently, their pilot plant capacity is 2 MWh per year, with one shift per day. This can be increased to 5 MWh per year by adding more personnel.

ARGO-TECH is pursuing R&D activities in the lithium polymer battery technology area, hoping to increase its performance. Their goal in regard to Li-ion polymer batteries is to have these batteries function at room temperature versus the elevated temperatures that their configuration presently demands for efficient operation. They hope to be able to meet the USABC battery performance goals for the medium and long term, in order to be ready for commercialization in 2001-2003. In regards to their Li-ion polymer battery, their objective is to develop cells and modules from 100 to 2000 Wh, for commercialization in 2001-2003. They have received \$85 million in funding from the USABC (DOE funds about 50 percent of the USABC) and an additional \$50,000 (CA) from the Canadian Space Agency.

5.3 Defense Battery Charger R&D Activities

In the military, battery performance is of paramount importance and the performance of the charging equipment is less of a consideration. If the Defense Departments are to reap the benefits of changing from nonrechargeable batteries to rechargeable batteries, the charger

must give the best maintenance possible to keep the battery in service for as long a time as possible. The Defense Departments R&D efforts are focused mainly on achieving this.

The "R&D" conducted by the military is divided into two major areas. The first is adapting commercial chargers to military applications. The second is efforts to improve the efficiency of the various charging algorithms.

Life cycle cost is a better method for assessing the benefits of a particular combination of battery and battery charger. Having a battery/charger combination that will give the user ten years of expected performance under normal conditions may not be realized because the batteries may be lost, damaged, or superseded by a new chemistry before the full service life can be realized from the original battery.

5.3.1 Defense Advanced Research Projects Agency (DARPA)

DARPA has been working with Mid-South Industries, Gladsen, Alabama on charger technology. Mid-South Industries has been involved with battery charger development, design and production for several years. The focus of their efforts is in pulse charging technology that was licensed from Advanced Charger Technology. The licensing agreement is mainly focused on chargers of less than 5KW for the military customer or potential military customers. They have designed and produced chargers that will charge the BB-590/U, BB-390/U, and the BB-490/U (BB-690/U). These chargers are designed in bench top and suitcase models, both capable of charging multiple batteries and chemistries at once.

Test results indicates a tremendous increase in cycle life with the use of this technology, during testing at the Naval Surface Warfare Center, Crane Division. Cycle life exceeded 2000 cycles on the BB-590/U at the 60 percent depth of discharge to 40 percent of rated capacity, with minimal increase in battery temperature. With this technology, as with any battery charging technology, temperature is of the utmost importance. Battery pulse chargers are a new line of products for Mid-South.

5.3.2 U.S. Army CECOM

The U.S. Army's effort is presently directed toward getting chargers that can be used in a field environment. CECOM has developed a new, portable, smart charger, PP-84444 A/U, which can recharge most batteries in two hours. The new rapid charger is designed to charge NiCd, NiMH, and Li-ion batteries. It is a major improvement over the older PP-7286/U charger, which required 10 to 12 hours to recharge batteries and was by no means portable.

In order for rechargeable batteries to be widely and effectively used in the field, the ability to charge the batteries must be "brought forward". There are two approaches that are being pursued: Charger-on-the-Move and smart charger cable. Both approaches will be using smart technology that is available in industry at the present time. It will be repackaged to meet military specifications.

- "Charger-on-the-Move": The first prototypes of this type of charger are based on the design used for the PP-8444A/U that has been ruggedized for mounting in a vehicle. This charging unit would be installed in various vehicles such as the HMMWV. It would charge two batteries using the power from the vehicle. These units would have to withstand the effects of the environment that the vehicle is exposed to.
- Smart Charger Cable: In this design, the charger would be housed in a small, lightweight box that is between the connector for the source of power and the other end that connects to the battery being charged. The technology for charging would be the same as with any other charging system except this one would be limited to charging one battery at a time. The power could come from either standard AC power derived from commercial sources or mobile generators or from DC power from electrical generators, solar panels, or nonrechargeable batteries. One primary battery being considered is the zinc air battery. It would recharge one battery while the other one is in the equipment. When the battery is charged, it would be placed back into service and the other battery would take its place on the charger.

The final solution will probably be a combination of all of the above options; each one being used where it makes the most sense in terms of life cycle cost and troop performance. All of the above options are based on the assumption that batteries of the same voltage, capacity, and chemistry are being used in all of the equipment that each soldier is carrying.

5.3.3 U.S. Air Force Research Laboratory (AFRL)

AFRL has a program to develop a family of rechargeable Li-ion batteries. Each battery manufacturer will team with an electronic company to develop a charger for the batteries that are delivered on the contract. Saft America will team with TRW and Yardney Technical Products will team with AlliedSignal. The results of the effort should generate charger methods that can be applied to batteries in the capacity range used in C/E equipment.

5.3.4 U.S. Navy – Naval Surface Warfare Center, Crane Division

The Power Systems Department has a \$10 million program funded jointly by ONR and the DLA that will deliver charging algorithms for lead acid, NiCd, and silver zinc batteries. There are three contractor groups working on a program to develop smart chargers: AlliedSignal; Eagle-Picher Technologies and Lockheed-Martin; Neptune Science, Inc and Battery Institute of Electrochemistry. All are investigating different approaches to identify the chemistry, state-of-charge, capacity, and state-of-health of the battery as soon as it is connected to the system. This information will be used to control the charging process for each battery chemistry. The next phase of this effort will have both stationary and portable units built that will cover the range from C/E batteries to forklift batteries.

5.4 Commercial Battery Charger R&D Activities

Commercial charger R&D is in reality product development based on battery technology. Those companies conducting "R&D" are really attempting to find ways to make their product different from their competitors and attractive to battery manufacturers/users. The majority of this effort is on the control element of the charger.

For example, a lead acid battery could be recharged by applying any type of current, ranging from half-sine waves to pure DC. As the performance improved with sealed lead acid batteries, the charger had to have better controls, the current had to be closer to pure DC, and the voltage limits needed to be controllable within a few milli-volts. This could be attained by using regulator circuits made of more sophisticated electronics. Today, a battery charger can have a microprocessor that will process millions of bits of information about the battery and its present condition. This information is compared to data that is programmed into the chip and the charging profile is adjusted to get the best performance from the battery when it is put back into service.

Best performance parameters can include the quickest recharge, greatest capacity returned, lowest gassing conditions, and least amount of heat generated, among other considerations. Many times, the final outcome of the design is a compromise between performance, cost, length of use, and convenience. In the commercial world, cost and trouble free performance are the two major factors that drive the design. The user's environment is fairly benign and the level of urgency to get the battery recharged and back into service is something that can be tolerated. As you move into the public service area of police, fire and rescue, the conditions start to change. Performance of the battery becomes more important and the cost of the charging equipment less important.

Many of the OEMs have internal research programs. They are reluctant to discuss any specifics on their development because it is difficult to patent and the effectiveness of their algorithms give them a competitive edge. Coupled with this is the fact that many of the algorithms that are used in the chargers are supplied by the cell/battery manufacturer under license agreements.

5.5 Power Management and Low Power Electronics

Power management can be used to extend the operating time of battery-powered equipment by the efficient utilization of the energy provided. Power management begins with the design of the system and focuses on the elimination of excess power usage. A common example of power management is the display units on computers. Users of laptop computers are reminded of power management when, after a period of inactivity, the screen goes dark and the hard disk drive stops spinning. These measures reduce power consumption and are taken to extend battery life by putting the computer in a state of suspension and temporarily shutting down non-critical functions. Usually, the computer is reactivated by any control input. Power management requires centralized control within the application with detailed information about the state of the battery (a smart battery).

More sophisticated power management is under study. In addition to the measures described above, it may be possible to shut off power to parts of a sub-system or even parts of an IC dynamically to achieve the largest possible power savings. There is a trade-off here, as additional hardware and software, and therefore power, will be necessary to implement such power-saving functions.

The pursuit of advanced power management has led to the development of additional system design rules imposed by some manufacturers. These rules include:

- Establishing power drain and battery life as key design parameters
- Monitoring power drain throughout each phase of a system's development
- Driving for continuous improvement in power drain for each new design
- Setting goals for reducing supply voltage for each successive generation of products
- Driving the use of power efficient design techniques.

The latter would include low voltage logic, highly integrated application specific integrated circuit functions, optimized hardware versus software design decisions, and establishing a power budget for software development. Motorola and Intel have been industry leaders in this area.

5.5.1 Low Power Electronics (LPE)

The commercial market is leading in LPE and power management techniques. Although engineers have made great strides in battery technology in recent years, hardware vendors continue to introduce notebooks with power-draining features such as 14.1-inch displays, high-speed CD-ROM drives, and support for new technologies such as Universal Serial Bus. This increase in the power and capabilities of today's multimedia computers has heightened the power requirements. But, while power consumption of a multimedia computer has jumped, the capacity of the rechargeable battery pack has stalled. The amount of energy that can be expected from a battery is approaching the practical limits. The only other method to continue supporting the advances in portable electronics is to reduce the power requirements put on the battery.

The commercial market has placed much greater emphasis on this than the military, which has lagged behind. Commercial vendors are designing new battery-management chips and improving the precise cell-by-cell monitoring. The demand for intelligent batteries is driven by the need to control charging and to provide the user with an accurate fuel gauge to monitor power consumption and remaining usage time. Smart battery chips are available from Benchmarq Microelectronics, Inc.; Microchip Technology, Inc.; and National Semiconductor Corporation, among others.

DARPA is sponsoring a LPE program. The goal is the development of technologies that will enable a hundred-fold reduction of power usage in electronics while maintaining the same functionality. The main areas addressed are LPE circuit design techniques, and

Computer Aided Design (CAD) tool development. The circuit techniques include energy recovery, ultra-low power image sensors, high efficiency low voltage DC/DC converters, and mixed swing logic. CAD tool development addresses power estimation, power minimization, and power management software.

The LPE program includes work in two areas that can be described as general architecture independent and technology independent. The first category encompasses the materials and fabrication tools and processes to implement a circuit design. Here the industry is already following a trend toward decreasing power supply voltages, with 1.5 V expected by the year 2001. Power management, on the other hand is technology independent and is often an ad-hoc, point solution within a particular system design that has little application to future generations. This is where design rules embedded in CAD systems are expected to provide the most benefit.

Power management at the sub-system and at the component level has the potential to significantly reduce power requirements in portable electronic devices in the near term. In the far term, low power electronics could make major reductions in power requirements. Both of these approaches would greatly reduce the strain on battery designs, and both are alternatives to increasing battery capacities through different chemistries and packaging approaches.

The promises of LPE are multiple, including the commensurate reduction in the size and weight of power supplies and power sources. The LPE program is planned to develop a technology base that will enable a new class of electronic systems that dissipate less than one percent of the power of current systems while delivering the same performance. The program will work in the following five technology areas:

- Silicon-on-insulator (SOI) substrates,
- New device structures,
- Manufacturing processes for low voltage circuits,
- Architectures for low voltage circuits, and
- Applications that demonstrate capabilities.

The need for low power electronics is driven by the trend in the miniaturization of personal systems. Over the past few years, system volumes have decreased while system functionality has vastly increased. In the near term, electronics that are optimized for low power will be of increasing importance. Portable devices will experience the most growth.

In the longer term, the trends in miniaturization will lead to the monolithic integration of nearly all functions, including digital, analog, radio frequency, opto-electronic, mechanical, display, human interface, and energy. These components will form truly integrated systems. A new microelectronics design and manufacturing paradigm will be needed to enable this revolution.

Perhaps the biggest driver behind system miniaturization is increasing integration levels of the transistors within monolithic ICs. Line widths of 0.35 micron are now common and 0.25 micron feature sizes are not far away. Reduction of minimum feature sizes has allowed roughly a 4X expansion in the number of transistors per chip in each succeeding generation. Coupled with smaller feature sizes, chip areas have increased, leading to ever increasing manufacturing complexities. The Intel Pentium II microprocessor has approximately seven million transistors on a single chip. Research is underway that could lead to as many as 700 million transistors in the same size chip. The power requirements of such a device must be reduced by a corresponding amount for the system to be practical. The producibility challenges of such complex devices are enormous, and the LPE program will address these challenges and others.

Functionality and performance increases in microprocessors have always been accompanied by increases in power dissipation. Substantial improvements in miniaturization and portability will require a similar reduction in the relationship between power dissipation and performance/functionality. The LPE program anticipates that this reduction will come about through a reduction in the voltage necessary to trigger a change of state in a Complementary Metal-Oxide Semiconductor (CMOS) transistor. As the number of transistors increases, it becomes even more important to make progress in this area. Accordingly, the LPE program will seek ways to achieve the goal of 1.5 V ICs for portable devices by the year 2001. Research into silicon-on-insulator substrates, as an alternative to CMOS, is expected to lead to achieving this goal.

Power management activities have, in the past, approached the problem through activity management of functional blocks. This approach is effective for a particular system design, but is not necessarily applicable to succeeding generations of designs. Circuit designs themselves are rarely optimized for low power consumption. A key element of the LPE program is to develop CAD tools to answer power/performance trade-off issues and to optimize designs for minimum power. Power management techniques that are rigorous and include efficient and accurate power dissipation calculations are to be developed.

The LPE program will take a fresh look at power management itself. A portable system is likely to consist of a battery and a number of sub-systems - digital, analog, and mixed signal - that may require multiple power supply voltages and currents. An advanced energy-dense battery of the future may have an end-of-life voltage of around 1.0 V or so. Low voltage transistors may become more voltage sensitive, thus exacerbating the problem. Efficient, well regulated DC-DC converters are required to convert the battery voltage to the level needed by the various ICs in the system. The LPE program will examine several approaches to solve this problem, to include switched capacitor converters.

Power management will be implemented in both active and passive forms. Passive techniques are common in present products and include software extensions that stop spinning hard drives and dim monitors after some preset time of inactivity. Active management refers to shutting off power to parts of a sub-system or even parts of an IC dynamically to achieve the largest possible power savings. The impact of the additional

software and hardware necessary to implement these functions must be traded off with the expected reductions in power consumed.

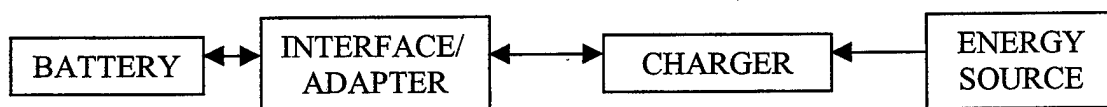
To summarize, the LPE program will address four main areas: material, devices, circuits, and power management. Several initial applications are planned to demonstrate and drive technology development. The program will include a broad range of participants from all areas - industry, academia, and government. The program anticipates that advances in the commercial realm will be directly beneficial to specific military applications as well.

6.0 BATTERY AND CHARGER AS A SYSTEM

For years the application of batteries was viewed as almost an afterthought in the system design process. And for years that philosophy was supported by the use of nonrechargeable batteries with known, fixed performance envelopes. Currently, rechargeable batteries and chargers are not considered as a system, however, the increased use of rechargeable batteries mandates a change in this philosophy. Rechargeable batteries and chargers should be treated as a system, rather than individual entities. There are several significant reasons for this approach. First, for any rechargeable battery chemistry it is imperative that the battery be charged in the safest, most efficient manner possible. Second, for the advanced chemistries, special charging circuits are required. Where these circuits are located determines the cost and complexity of the battery, interface, or charger. Finally, the logistics related to the use and charging of rechargeable batteries must be adequately addressed.

Although any user of rechargeable batteries faces the issues related to integration, the magnitude and complexity varies enormously. On one end of the spectrum is the individual consumer with a laptop computer or cellular phone. The issues related to integration are simple and transparent to the user. The battery has a dedicated charger that will provide energy in a safe and efficient manner. No interaction with the charging process is required other than to plug it into the appropriate power source (i.e. electric outlet). At the other extreme is the military, where there are multiple battery configurations and chemistries, being charged by one or more types of chargers under tactical and remote locations. In some instances the user may be required to "program" the charger.

The battery/charger system comprises three major components - the battery itself, the charger, and an interface (or adapter) that electrically and mechanically connects the battery to the charger. This is represented below:



The connection between the battery and interface has been limited to less than a dozen different types for military unique batteries. This has been accomplished through the U.S. Army's ongoing policy on standardization as documented in CECOM's "Guidance for the Approval and Use of Army Power Sources" which implements Army Acquisition Executive Policy.

The connection between the interface and the charger is more problematic. This is due to the fact that each charger manufacturer has its own unique mechanical and electrical interface. This presents a significant problem for the military as it tries to implement such technologies as the "smart cable" where its widespread application is dependent on its ability

to be used with any DC power source. This can only be accomplished if the connection between the smart cable (i.e. interface) and multiple charging sources is standardized.

One solution to the safe and efficient charging of a battery is found in what is generally termed "smart technology".

6.1 Smart Technology

The next leap forward in the electronics associated with battery usage/monitoring is the integration of battery and battery chargers via the concept of "Smart Technology." As battery technology has evolved and rechargeable batteries have been used in more and more applications, users have demanded enhanced performance in terms of longer battery life, high cycle life and fast charging of the batteries. In many ways, the only method to implement these requirements is through the proper integration of the battery and charger.

The basis for Smart Technology is already being applied, in the context of the amount of capacity remaining in the battery, or the battery's state of charge. An example of such an application would be a laptop computer, where abrupt loss of power could result in loss of an important file for a businessman. For a businessman, the loss of power may mean the loss of a file, and an inconvenience. During combat, if the laptop computer was attached to a tactical radio, the unexpected loss of power can represent a life or death situation for military personnel.

Many batteries, or end item applications, now incorporate some sort of display capable of indicating the state-of-charge (often referred to as a fuel gauge). The degree of sophistication varies from simple pilot lights to actual digital read outs or liquid crystal displays. This device indicates to the operator the amount of energy remaining and when to have the battery recharged. It also tells when a battery has completed the charge cycle and eliminates recharging good batteries that will shorten their life. In addition to the fuel gauge, many rechargeable batteries also have some form of circuit, which aids in an overall safe and efficient charging cycle.

The rechargeable batteries currently being used in both commercial and military communication applications provide only state-of-charge information. Advanced smart systems can not only provide usage information for the battery, but can also control the battery avoiding unsafe battery conditions which can occur due to overcharge, over discharge, or extreme temperature conditions.

The most prevalent utilization example to date of smart technology is the rechargeable lithium technologies. While the rechargeable lithium chemistries bring not only greater energy density, they also have special requirements relating to their use. Lithium batteries require that during both the discharge and charge cycles, the amount of current and the voltage is monitored. If these batteries are discharged too rapidly or too deeply, safety concerns due to excessive heating arise. During the charge cycle, current must be limited and the voltage monitored to ensure no over voltage is applied. As a result, rechargeable

lithium batteries contain circuitry to assure the battery operates safely even when subjected to abusive conditions.

There are two basic approaches to introducing "Smart Technology" into a battery/charger system. The first involves circuitry incorporated into the charger. This circuitry can serve one or more of the following functions:

- Ascertain the current state-of-charge of the battery
- Determine the capacity of the battery
- Analyze the chemistry of the battery
- Tailor a recharge cycle based on the previous listed three functions
- Interrogate special purpose integrated circuits within the battery itself.

The second approach is to embed electronics into the battery. Special purpose ICs have been developed and are used to perform one or more of the following functions:

- Measure the number of cycles the battery has experienced
- Determine the capacity of the battery
- Report the state-of-charge of the battery
- Identify the battery's chemistry
- Identify the battery's date code, serial number or other manufacturing data.

A hybrid of the two approaches is a "Smart Cable". In theory a "Smart Cable" combines some of the functions of the smart charger and the smart battery. This is attractive because of the ability to use any DC power source to charge the battery.

The embedding of complex ICs into batteries, the integration of complex electronics into chargers and the increased use of high energy chemistries all have contributed to the need to understand rechargeable batteries and their chargers from a "Systems" viewpoint. One industry approach to viewing batteries as an integral part of a portable electronics system is the development of the SMBus.

6.1.1 SMBus

Developed jointly by Intel and Duracell, the SMBus acts as the control bus for Smart BatteriesTM. Through the SMBus, end-users can be apprised of present state and calculated battery information and command a battery recharge through a simple software interface. Ideal for portable equipment, the SMBus also allows the simple connection of a large array of other devices, like Electronically Erasable Programmable Read Only Memory (EEPROMs), temperature sensors, digital potentiometers, etc. Because the SMBus is based on Inter-IC architecture, it provides multiple master support, allowing bi-directional communication between these devices.

The SMBus specification is supported by companion specifications for both chargers and batteries as well as a specification for a smart battery selector that allows for multiple batteries and multiple chargers. The Smart Battery Data Specification contains 34 data

values representing the operating conditions, calculated predictions, and characteristic data of a Smart Battery. These data values are the core components of the specification for the Smart Battery. These 34 data values can be divided into six key areas of functionality: Measurements; Capacity Information; Time Remaining; Alarms and Broadcasts; Mode, Status, and Errors; and Historical and Identification. A brief description of each is as follows:

- **Measurements**: The direct environmental measurements of the Smart Battery are: Voltage (mV); Temperature (0.1°K); Current (mA); and Average Current (mA).
- **Capacity Information**: The Smart Battery's capacity information includes not only state-of-charge information but also the actual capacity values in multiple representations. The capacity values include: Relative State Of Charge (%); Absolute State Of Charge (%); Remaining Capacity (mAh or 10 mWh); and Full Charge Capacity (mAh or 10 mWh).
- **Time Remaining**: The time remaining at present and predicted rates are calculated using the previously discussed capacity information and the Smart Battery's ability to predict when the capacity will be depleted, based on both measurements and knowledge of the battery cell's performance. These data values are: Run Time To Empty (minutes); Average Time To Empty (minutes); Average Time To Full (minutes); At Rate (mA or 10 mW); At Rate Time To Full (minutes); At Rate Time To Empty (minutes); and At Rate OK (Boolean flag).
- **Alarms and Broadcasts**: The ability of the Smart Battery to respond even when not being addressed is critical to the safe and reliable operation of the complete system. Additionally, the ability to instruct a Smart Charger to control charging voltage and current also contributes to system safety and ease of use. The broadcast data values are: Alarm Warning (bit flags); Remaining Capacity Alarm (mAh or 10 mWh); Remaining Time Alarm (minutes); Charging Current (mA); and Charging Voltage (mV).
- **Mode, Status, and Errors**: Understanding the operational parameters and error conditions of the Smart Battery is key to maintaining a reliable system, particularly when more than one device may be involved. The Smart Battery can provide additional system information through use of the mode, status and error functions such as: Battery Mode; Capacity Mode; Charger Mode; Max Error; Battery Status; and Manufacturer Access.
- **Historical and Identification**: Background information and identification of the Smart Battery can be used when multiple battery systems are employed and when battery life has dropped to a point of poor performance. Historical information can then be used by the system to determine the best moment to replace the Smart Battery for a fresh one. The data values are: Cycle Count (integer count); Design Capacity (mAh or 10 mWh); Design Voltage (mV); Specification Information (coded); Manufacture Date (coded); Serial Number (integer number); Manufacturer Name

(string); Device Name (string); Device Chemistry (string); and Manufacturer Data (string).

The above is provided to give insight into the wide variety of data that is available within the specification. The importance of implementing the smart battery specification is multi-faceted. The specification can offer benefits to those who adopt it. Of primary importance is the issue of inter-operability between components, manufacturers, and systems. Following the smart battery specifications insures a safe, reliable, high-performance power management system. Care must be exercised as various battery manufacturers may not design a full implementation of the SMBus. If a partial implantation is used by a vendor, some of these goals may be compromised.

Figure 6-1 shows the inter-relationship between the host system, smart battery and smart battery charger.

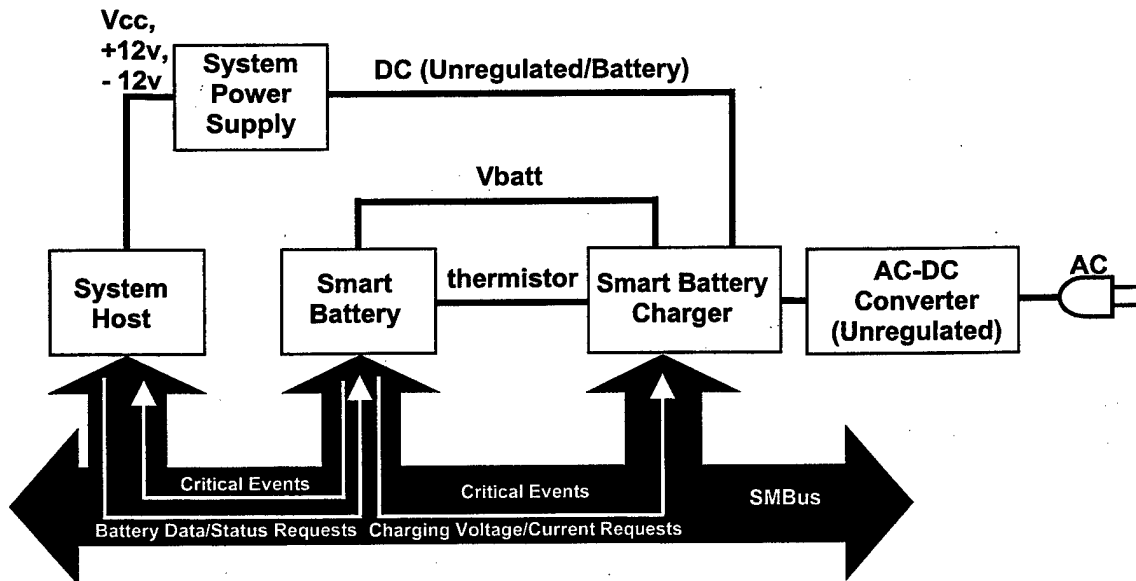


Figure 6-1, Typical Smart Battery Smart Charger Block Diagram

Currently multiple vendors provide integrated circuits which implement the various functions of the SMBus specification. BENCHMARK, POWER SMART, and USAR all offer products that can be integrated directly into Lithium or NiMH batteries.

With the advancement of battery technology and the adoption of the SMBus by industry, there exists the opportunity to revolutionize the use of portable electronics.

While rechargeable batteries hold the promise of much reduced cost, they require a thorough understanding of their performance characteristics including their behavior both during discharge (use) and recharge. If the recharge portion of their performance envelope is ignored, costs will be incurred due to shortened life cycle and may reduce the safety of personnel and equipment. The SMBus should be viewed as an enabling technology that will aid in the effective use of rechargeable battery technology. It provides low cost access to battery "health" data that allows for optimization of the battery during its entire life cycle.

6.2 *Charging Logistics for Military Applications*

Integrating the use of rechargeable batteries into the military is no trivial matter. The military doctrine of today revolves around rapid movement of forces with a logistics support system to match. To an extent, this concept is built around a ready source of portable power, i.e. nonrechargeable batteries. These nonrechargeable batteries do not require much of a logistics support system: they are shipped to the front and discarded when depleted.

The use of rechargeable batteries requires a fairly extensive logistic infrastructure, one that does not entirely exist today. Current U.S. Army policy states that rechargeable batteries will be resupplied to forward units in the same manner as nonrechargeable batteries. Batteries not only must be moved to the forward units, but must be returned to the rear echelon for charging. Furthermore, areas must be set up where the batteries can be charged, and power must be provided to these areas. Additional manpower is required to monitor the charging of batteries, with an increase in the overall amount of equipment to be maintained.

Of additional concern is the shelf life of these batteries. Nonrechargeable batteries can be stored in warehouses for up to five years with no significant degradation in capacity. They can be taken directly from inventory and successfully utilized. The same is not true of rechargeables. Although the rate of capacity loss varies by chemistry, and some of it may be irreversible, all the rechargeable batteries require some form of charging on a periodic cycle to assure minimal capacity is lost. Rechargeable batteries require a full charge before use.

Another concern is the integration of the battery and battery charger as a system. DND has been using chargers that support multiple battery configurations for several years. The U.S. Army has only one truly portable battery charger that can charge a variety of battery configurations. The real barrier to integration of the charger and the battery is the unique battery connector. This creates another problem, the proliferation of unique interface adapters that will need to be provided with either the charger or battery.

7.0 FACILITATORS ENABLING MORE WIDESPREAD USE OF RECHARGEABLE BATTERY TECHNOLOGIES

7.1 Reduced O&S Costs

As the Defense budgets of the U.S. and Canada continue to decrease, DoD and DND will continue to look for cost savings in all areas. The U.S. Army has already shown that the use of rechargeable batteries can reduce operating cost for training exercises. The attraction of reducing costs should help increase the future use of rechargeable batteries in all types of military applications and equipment.

7.2 Leveraging of Commercial Batteries

By taking advantage of what the commercial sector has done with rechargeable batteries and chargers, DoD and DND can avoid the expense of R&D for military unique cells and cell technology. By using the commercial industrial base, the U.S. and Canada can avoid the development of a military unique industrial base for rechargeable batteries.

7.3 Increased Rechargeable Battery Life

As shown in Table 2-2 (Comparison of Mission Requirements and Cost), rechargeable batteries can have enormous cost savings because they can be used and reused over several different missions when recharged.

7.4 Reduction of Battery Weight

C/E applications of rechargeable batteries will increase in the future as battery weight decreases. The LandWarrior/Soldier Systems programs depend on sources of power the individual can easily carry. The effort needed to carry power would be better utilized carrying additional combat capability.

7.5 Smart Technologies

The smart technologies will enable a more efficient use of rechargeable batteries. Batteries will be charged faster and safer to the optimum level without degrading the battery or shortening its life. The increase in efficiency will lower life cycle costs and improve the effectiveness of the batteries.

7.6 LPE and Power Management

The use of LPE and Power Management will increase the mission time supported by batteries thus increasing the attractiveness of rechargeable batteries.

8.0 BARRIERS AFFECTING MORE WIDESPREAD USE OF RECHARGEABLE BATTERY TECHNOLOGIES

8.1 Power Source Logistics

As rechargeable batteries and chargers are introduced into military units, a new logistics tail will be developed. Currently nonrechargeable batteries are consumed similar to ammunition. Rechargeable batteries will not be treated as consumables, but will require a back up supply that is continuously rotated for charging purposes, an area where the batteries can be recharged, a power source, manpower for recharging batteries, and transportation.

8.2 Military Unique Applications

The applicability and use of rechargeable batteries in high risk, low support airborne and reconnaissance missions is untested and unproven.

8.3 Commercial Trend to Small Cells

The military will substitute rechargeable batteries for the current nonrechargeable batteries. The use of large cells is more efficient than connecting several times as many small cells. Besides the complexity of connecting small cells, heat generated by the small cells becomes a problem, which can affect battery life and performance if not managed properly. As commercial products (cell phones, PDAs, etc.) become smaller, the need increases for smaller, lighter rechargeable batteries. Commercial producers will respond by facilitating production capabilities for small cells - not large cells. The niche market the military creates will cause the costs of rechargeable batteries to increase.

8.4 High Initial Cost

As shown in the battery chemistry section, the initial cost of a rechargeable battery is higher than the comparable nonrechargeable battery. However, the total life cycle cost of the rechargeable battery is lower than the nonrechargeable. With current resources scarce, the decision to expend them in anticipation of future savings is difficult.

8.5 Soldier Acceptance

Some units within the U.S. Army are reluctant to switch to rechargeable batteries due to perceived reduced performance when compared to nonrechargeables. Not only does the unit have to deal with a new battery, but also with the charger that accompanies it. The logistics within the unit to assure portable power is available is an additional task the unit must perform with no increase in resources to accomplish the task.

8.6 Performance (Temperature Extremes)

The military requirement for C/E equipment to operate at extreme temperature conditions (-40° and 150° F) eliminates the use of nearly all current rechargeable chemistries.

8.7 Shelf Life

Rechargeable batteries require charging during storage to compensate for the inherent self discharge.

9.0 CONCLUSIONS

9.1 *The LiSO₂ Industrial Base Is Deteriorating*

The use of rechargeable batteries in most operational scenarios short of full combat will have the effect of reducing the consumption of nonrechargeable batteries in peacetime. This reduction could be rather large. The result could further erode an already weak military unique nonrechargeable battery production base.

9.2 *Power Source Logistics Are Not Being Thoroughly Addressed*

There are a number of logistical considerations that need to be thoroughly examined such as movement of batteries, manpower dedicated to charging the batteries and providing power to the battery chargers. In addition, rechargeable batteries require charging during storage to compensate for the inherent self discharge.

9.3 *Commercial Trend To Smaller Cells Is Not Optimal For Military Applications*

Commercial industry is moving towards smaller cell sizes in response to the trend for smaller and more energy efficient commercial electronics (i.e., cellular phones and beepers). However, the battery configurations for existing military applications are predetermined. If the Military Services use these commercially available cell sizes, it will require putting more cells into the battery configuration in order to achieve their capacity requirements. This would cause other design issues, such as increased internal heating (heat management), increased weight and additional inter-cell wiring. There also would be a loss in the total available capacity that could be packaged into the battery.

9.4 *Batteries and Chargers Are Not Being Considered As A Single System*

In the past, the military procured rechargeable batteries and chargers separately. This approach was considered feasible due to the relative limited use of rechargeable batteries. However, as the use of rechargeable batteries increases and new technologies utilized are sensitive to a specific charge algorithm, this approach is no longer valid.

9.5 *Battery Capacity Is Approaching Its Realistic Limits (Technology Limits Of Chemistries)*

As highlighted in the R&D section, the rechargeable battery technology is beginning to level out in terms of the capacity of the various chemistries. Although advances will still be made in improving the performance of rechargeable batteries - in the short term, in regards to lithium polymer and in the longer term, solid state batteries - no "silver bullets" are seen on the horizon. This necessitates the increased emphasis on power management techniques and the use of LPE.

9.6 Use of Rechargeable Batteries Reduces O&S Costs For Military Applications

Rechargeable batteries offer significant reductions in battery related O&S costs. Even after the costs associated with the procurement of chargers and the additional resources required to operate and power the chargers are accounted for, the savings both in procurement dollars and disposal costs have the potential to be significant.

9.7 DoD And DND Are Increasing The Use Of Rechargeable Batteries For C/E Applications

Faced with increasing costs associated with the use of nonrechargeable batteries and decreasing budgets, DoD and DND accelerated the use of rechargeable batteries in C/E applications. The Canadian Forces have used rechargeable batteries for a number of years as a reliable cost effective source of power. Within DoD, the U.S. Army has been aggressively pursuing the use of rechargeable batteries to reduce battery related O&S costs.

10.0 RECOMMENDATIONS

10.1 DoD/DND Should Start Planning To Use Rechargeable Batteries In Combat Situations

When peacetime demand for nonrechargeable batteries diminishes, production capability may disappear leaving DoD/DND dependent on rechargeable batteries. As rechargeable batteries become more prevalent in peacetime operations, their use in combat situations becomes inevitable. Planning needs to start now related to the procurement of resources, training of personnel, and making the appropriate changes to combat doctrine for wartime scenario.

10.2 DoD And DND Need To Analyze The Impact Of Wide Spread Use Of Rechargeable Batteries

DoD and DND need to analyze in-depth the impact that wide spread use of rechargeable batteries will have on current logistics systems. Using rechargeable batteries in OOTW environments may be different than incorporating the batteries into combat use. As the U.S. becomes more involved in peace keeping missions, similar to Canada, the use of C/E equipment using rechargeable batteries will have an impact all the way down to the individual level. This impact needs to be described to assure mission capability is not impaired.

10.3 DoD And DND Should Develop And Provide Tools To Fully Utilize The Energy In Rechargeable Batteries

DoD and DND can increase the efficiency of using rechargeable batteries by developing and providing products such as smart chargers, SMBus, state of charge indicator, and power management algorithms. By efficiently charging batteries, the life of the battery will be extended thereby lowering O&S costs.

10.4 DoD And DND Should Focus R&D Efforts On Optimizing Commercial Technologies For Military Applications

DoD and DND should refocus their rechargeable battery R&D into areas of no or little interest to the commercial producers. A specific interest would be such areas as low temperature, electrolytes, and large cell designs. As the commercial industry continues to strive for smaller, lighter, and cheaper rechargeable batteries, the Military Services will need the same chemistries, but in larger cells. The lithium polymer technology has the promise to satisfy military needs without major changes to commercial production techniques. Tooling changes to allow for larger cells needs to be addressed if and when the lithium polymer technology becomes widely accepted by the commercial industry.

10.5 DoD And DND Should Address Battery And Charger As A System

Procurement and development of rechargeable batteries need to consider follow-on acquisition and deployment logistics of their associated chargers to realize optimum field use.

10.6 DoD And DND Should Emphasize The Use Of Power Management And LPE

The use of LPE and power management should be a significant evaluation criteria in the source selection of all power using applications. Current efforts underway are just the beginning of what will be needed in the future. DoD and DND should leverage advances in the commercial market in this area and conduct R&D for military unique applications. The combination of LPE and power management will increase the efficiency and capability of future systems.

10.7 DoD And DND Should Develop And Standardize Smart Chargers For Use In C/E Equipment

DoD and DND need to develop a standardized family of smart chargers (i.e. benchtop, charger on the move, smart cables) with special emphasis on the standardization of the interface to the charger.

APPENDIX A: ACRONYMS

AC	Alternating Current
AFRL	Air Force Research Laboratory
Ah	Ampere-hours
ARO	Army Research Office
BATC	BlueStar Advanced Technology Corporation
C ₄ I	Command, Control, Communication, Computers & Intelligence
C/E	Communications/Electronics
CAD	Computer Aided Design
CASCOM	Combined Armed Services Command
CECOM	Communications-Electronics Command
CMOS	Complementary Metal-Oxide Semiconductor
COTS	Commercial Off-the-Shelf
CuFeS ₂	Copper Iron Sulfide
DARPA	Defense Advanced Research Projects Agency
DC	Direct Current
DLA	Defense Logistics Agency
DND	Department of National Defence (Canada)
DoD	Department of Defense (United States)
DOE	Department of Energy
EEPROMS	Electronically Erasable Programmable Read Only Memory
ETI	ENER-TEK International, Inc.
FY	Fiscal Year
HMMWV	High Mobility Multipurpose Wheeled Vehicle
IC	Integrated Circuit
INC	Item Name Code
IPCE	Integrated Protective Clothing & Equipment
JPL	Jet Propulsion Laboratory
K	Kelvin
KBE	KB Electronics, Limited
LiAl/FeS ₂	Lithium Aluminum/Iron Sulfite
LiC/LiNiO ₂	Lithium Carbon/Lithium Nickel Oxide
LiI	Lithium Iodide
Li-ion	Lithium Ion
LiMn ₂ O ₄	Lithium Manganese Oxide
LiSO ₂	Lithium Sulfur Dioxide
LPE	Low Power Electronics
LTC	Lithium Technology Corporation
mAh	Milli-ampere-hours
ManTech	Manufacturing Technology

MBI	Matsushita Battery Industrial Company
MELIOS	Mini-Eyesafe Laser Infrared Observation Set
MRC	McDowell Research Corporation
NASA	National Aeronautical Space Administration
NATIBO	North American Technology and Industrial Base Organization
NEC	Nippon Electronics Corporation
NiCd	Nickel Cadmium
NiMH	Nickel Metal Hydride
NSN	National Stock Numbers
O&S	Operating and Support
OEM	Original Equipment Manufacturer
ONR	Office of Naval Research
OOTW	Operations Other Than War
PC	Personal Computer
PDA	Personal Digital Assistant
PLiON	Plastic Lithium Ion
R&D	Research and Development
RAMS	Recharging, Analyzing & Maintenance System
RDEC	Research, Development and Engineering Center
SBD	Smart Battery Data
SBIR	Small Business Innovation Research
SBS	Smart Battery System
SCR	Silicon Controlled Rectifiers
SINCGARS	Single Channel Ground and Airborne Radio System
SMBus	System Management Bus
SOI	Silicon-on-insulator
TRADOC	Training and Doctrine Command
USABC	United States Advanced Battery Consortium
USAF	United States Air Force
V	Volt
VAC	Volts Alternating Current
VDC	Volts Direct Current
Wh	Watt hour
ZnMnO ₂	Zinc Manganese Dioxide

APPENDIX B: POINTS OF CONTACT

Point of Contact		Company Name	Company Address				Phone Number
Last Name	First Name		Address	City	State/Prov.	Zip Code	
Andrukatitis	Ed	DND NDHQ/CRAD	101 Colonel By Drive	Ottawa	Ontario	K1A 0K2	613-990-0638
Au	George	CECOM RDEC	AMSEL-RD-C2-PS-B	Ft. Monmouth	NJ	07703	732-427-4886
Baker	Bill	SPAN	7745 E. 88th St	Indianapolis	IN	46256-1231	317-347-2656
Barella	Joe	Ultralife Batteries, Inc.	1350 Rt. 88 South, P.O. Box 622	Newark	NY	14513	315-332-7100
Barnhill	Sandy	KB Electronics, Limited	150 Bluewater Road	Bedford	NS	B4B 1G9	902-835-7268
Bela DeCastro	Maria	Yardney Technical Products, Inc.	82 Mechanic Street	Pawcatuck	CT	06379	203-599-1100
Bowling	Glen	Saft America, Inc.	313 Crescent Street	Valdese	NC	28690	828-879-5014
Brenna	Leo	Bren-Tronics	10 Brayton Court	Commack	NY	11725	516-499-5155
Brockel	Donald	CECOM Power Sources Team	AMSEL-LC-P-PST	Ft. Monmouth	NJ	07703	732-532-4948
Bruce	Gregg	BlueStar Advanced Technology Corp.	1155 15th St. W.	N. Vancouver	BC	V7P 1M7	604-986-4020
Buchmann	Isidor	Cadex Electronics, Inc.	111-7400 MacPherson Ave	Burnaby	BC	V5J 5B6	604-451-7900
Butler	Jon	Eldec	16700 13th Ave	Lynwood	WA	98646-9727	425-743-1313
Clark	Dennis	OSD, Technology Transfer	Two Skyline Place, Suite 1401	Falls Church	VA	22041	703-681-5448
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Dils	Eric	Xenotronics	26074 Ave Hall, Suite 10	Valencia	CA	91355	800-624-9366
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Hall	Margo	Linear Tech	1630 McCarthy Blvd	Milpitas	CA	95035-7417	408-432-1900
Hamlen	Robert	CECOM RDEC	AMSEL-RD-C2-PS	Ft. Monmouth	NJ	07703	732-427-2084
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Jochnowski	Ed	Eveready	Checkerbd Sq	St. Louis	MO	63164	800-323-8177
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Letourneau	Claude	ARGO-TECH Productions, Inc.	1560 de Coulomb	Boucherville	Quebec	J4B 7Z7	514-655-3161
Mains	Donald	NSWC, Crane Division	300 Highway 361	Crane	IN	47522-5001	812-854-3112

March	Brian	Kaycom	5800 Thimons Blvd	Ville St. Laurent	PQ	H4S 1S5	514-745-5000
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Mauch	Conrad	STAT Power	7725 Lougheed	Burnaby	BC	V5A 4V8	604-420-1585
Messing	Terry	Rayovac Corporation	P.O. Box 44960	Madison	WI	53744-4960	608-275-4806
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Moran	Scott	CECOM Power Sources Team	AMSEL-LC-P-PST	Ft. Monmouth	NJ	07703	908-532-9016
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Sikura	Jim	East Penn Manufacturing	Deka Road	Lyon Station	PA	19536	610-682-6361
Singh	Harmohan	AlliedSignal, Inc. D&SS	699 Route 46	Teterboro	NJ	07608	201-393-2573
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