Market Feasibility for Nickel Metal Hydride and Other Advanced Electric Vehicle Batteries in Selected Stationary Applications

Technical Report

Market Feasibility for Nickel Metal Hydride and Other Advanced Electric Vehicle Batteries in Selected Stationary Applications

1000292

Final Report, December 2000

EPRI Project Manager
R. Graham

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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PHB Hagler Bailly, Inc.

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CITATIONS

This report was prepared by

PHB Hagler Bailly, Inc.
520 S. Grand Ave. Suite 500
Los Angeles, CA 97001

Principal Investigator
J. Meurice

This report describes research sponsored by EPRI and SMUD.

The report is a corporate document that should be cited in the literature in the following manner:

Market Feasibility for Nickel Metal Hydride and Other Advanced Electric Vehicle Batteries in Selected Stationary Applications, EPRI, Palo Alto, CA, and SMUD, Sacramento, CA: 2000. 1000292.

REPORT SUMMARY

Governments in the United States and other countries, as well as the automotive, battery and utility industries, have spent millions to demonstrate the viability of next generation of batteries for electric vehicles (EVs) and hybrid electric vehicles (HEVs). An important question remains unanswered: "What value might these EV and HEV batteries add when employed in stationary and secondary use applications?"

Background

Advanced electric vehicle (EV) battery prices are an issue for the industry and a range of efforts are underway to bring those prices down. This study assessed the potential for three advanced EV battery technologies — Nickel Metal Hydride (NiMH), Lithium Polymer, and Lithium Ion — to compete in three stationary market applications: utility applications, telecommunications back up power and uninterruptible power supply (UPS) systems. The underlying assumption is that additional battery sales into these markets will bring the price of the batteries down faster than if only the EV market were served and also lower the overall cost curve.

Objective

To conduct an in-depth assessment of three high-growth stationary applications — telecommunications, electric utility industry, and UPS— to determine each market's receptivity and "fit" with the characteristics offered by advanced EV and HEV batteries.

Approach

The project team conducted a qualitative evaluation of market opportunities for advanced EV and HEV batteries in stationary applications. The team undertook a standard market opportunity assessment based largely on information gained from primary market sources. They interviewed both competitors and customers in the target market segments along with industry observers and other participants to assess the feasibility of selling advanced EV battery technologies into stationary markets. Interviews focused on what battery technologies were now in use, problems with existing technologies, other technologies being tested, and willingness to try a new technology. In keeping with industry practice, many of the sources will remain confidential.

Results

Overall, utility, telecommunications, and UPS applications comprise a substantial market with projected sales revenue in 2004 on the order of $1 billion. Several substantial market niches may provide opportunities for EV battery technology, including nickel cadmium (NiCd) applications, which competitor comments suggest are from 3% to 5% of the market. Valve regulated lead acid (VRLA) batteries used in stationary applications, about 20% of all sales, also appear to have weaknesses under certain circumstances that may create opportunities for the EV battery.

Some segments of the telecommunications market appear to present particular opportunities for EV battery technologies. These segments experience extreme operating temperatures that shorten the nominal life of the batteries currently in use as well as increase maintenance costs. The EV battery technologies have the potential to offer longer life and lower maintenance cost under extreme temperature conditions. They may well also have the advantage, due to their higher energy and power characteristics, of offering reductions in weight and space for the same application. This market is estimated to total about 11% of the telecommunications market, or $34 million today, growing to $80 million in 2004. This niche is presently being pursued by NiCd battery manufacturers, which seems likely to limit the near term potential of NiMH batteries in these applications. Lithium technologies, though still largely unproven in larger scale applications, are judged by market participants to have greater potential in this and other telecommunication niches than NiMH batteries.

The utility market is unlikely to be receptive to any of the new technologies in most of their current applications, though there could be potential for the lithium technologies in emerging energy storage and remote power applications. The UPS market's needs are currently being adequately met by existing lead acid batteries, and the power and energy density advantages of the new EV batteries seem unlikely to outweigh their initial cost premium and their current lack of proven reliability. To compete in this $34 million to $80 million niche, the EV batteries need to deliver more value to customers than the current flooded, VRLA, and NiCd competitors.

EPRI Perspective

This study focuses on alternate market opportunities for new EV and HEV batteries. In markets where new EV and HEV batteries show promise, it is possible that with lower costs, solid warranties, and reasonable calendar lives, used EV and HEV batteries may also have some penetration potential. More research is needed to validate this hypothesis.

Keywords

Electric vehicles
Hybrid vehicles
Batteries
Market research
Uninterruptible power supply

ABSTRACT

EPRI conducted a study assessing the technical and market feasibility of using three types of advanced electric vehicle battery technologies, nickel metal hydride, lithium polymer, and lithium ion, in stationary applications. Based on an initial evaluation of potential markets where batteries of this type might provide the highest, near-term value, the study targeted three application arenas: electric utility, telecommunications, and uninterruptible power supply (UPS) systems. The study also offers suggestions on how an assessment of the business case for secondary use of EV batteries might be approached.

EXECUTIVE SUMMARY

EPRI, supported by several electric utilities, conducted a study assessing the technical and market feasibility of using three types of advanced electric vehicle battery technologies (EV batteries), nickel metal hydride (NiMH), lithium polymer (LiPoly) and lithium ion (LiIon), in stationary applications. Based on an initial evaluation of potential markets where batteries of this type might provide the highest, near-term value, the study targeted three application arenas - electric utility, telecommunications and uninterruptible power supply (UPS) systems. It is believed in principal that if the market for EV batteries was expanded beyond just EV applications, battery production volumes would be greater and the cost of each battery produced, regardless of its ultimate application, would be reduced. Under this scenario, EVs would drop in price and reach commercial viability faster. Additionally, the study cursorily examined the prospects of how and whether a business case might be made for extracting, refurbishing, and reusing EV batteries at the end of their useful EV life in other or secondary applications. If feasible, this strategy could also contribute to the overall cost reduction (over their life) of EV batteries. In addressing this issue, the study determined that research far in excess of the scope of work for this effort would be required to derive meaningful conclusions. This study offers suggestions on how an assessment of the business case for secondary use of EV batteries might be approached.

EV BATTERIES FOR OTHER APPLICATIONS

Overall, utility, telecommunications, and UPS applications of batteries comprise a substantial market with projected sales revenue in 2004 on the order of $1 billion. From the perspective of EV battery technology opportunities, several substantial market niches appear interesting, including applications in which nickel cadmium (NiCd) is currently bei g used. This research suggests that NiCd technology makes up from 3% to 5% of the market in these applications now. Valve regulated lead acid (VRLA) batteries used in stationary applications, about 20% of all sales, also appear to have weaknesses under certain circumstances that may create market opportunities for EV battery technologies. Flooded lead-acid batteries represent the vast majority of the rest of the market.

Some segments of the telecommunications market appear to present particular opportunities for EV battery technologies. These segments experience extreme operating temperatures that shorten considerably the nominal life of the current lead-acid batteries being used as well as increase maintenance costs. EV battery technologies have the potential to offer longer life and lower maintenance cost under extreme temperature conditions. They may well also have advantages, due to their higher energy and power characteristics, of offering weight reduction and space consumption for the same application. Next generation NiMH batteries (currently in the lab) are purported to do well 50 – 60 degree C temperatures, and current NiMH do well in cold temperatures. There is potential for NiMH operation without air conditioning or heating, but this needs to be proven in demonstration programs.

This extreme temperatures segment is estimated to total about 11% of the telecommunications market, or $34 million today, growing to $80 million in 2004. This market niche is presently being pursued by NiCd battery manufacturers. NiMH batteries have potential to compete in this market, but they must first address several issues to be able to achieve significant penetration. These issues are more fully explained in the report. Briefly, among other things to become competitive in this market niche, NiMH manufacturers must first demonstrate that the technology has good quality high-temperature characteristics (field testing was deemed a critical component of the demonstration) and then the manufacturers must aggressively market this and NiMH's other attributes to potential customers. Lithium technologies, though still largely unproven in larger scale applications, are judged by market participants to have greater potential in this and other niches over NiMH. This holds true for EV applications as well, but the lithium technologies are considerably farther from proving themselves and commercial scale production than NiMH. This affords NiMH an early market entrant opportunity, but manufacturers must respond quickly.

The utility market is unlikely in the near-term to be receptive to any of the new technologies in most of their current applications. Their current needs are primarily being met with both flooded and VRLA batteries. As presently structured, the utility industry is very conservative and first-cost conscious when it comes to backup power applications. Market penetration by EV batteries could take place over time as the newer technologies become more widely demonstrated and prove themselves capable for utility use. Like the utility market, the UPS market's needs seem to currently be adequately met by existing lead acid, both flooded and VRLA, technologies. The power and energy density advantages of the new EV battery technologies seem unlikely to outweigh today's cost premium and their current lack of proven reliability in stationary applications.

To be truly competitive, the EV batteries need to deliver more value to customers than the current flooded, VRLA, and NiCd technologies. Competitiveness is primarily derived from initial price, which ranges from $150 to $500/kWh in these applications. Of course, if the EV battery price were to decline to $200 - $300 /kWh and below, the size of the niches in which they would be competitive would grow substantially. Growth of the EV NiMH battery market as a result of the California ZEV program would have a strong impact on lowering NiMH prices (possibly to less than NiCd prices). (But the size of the ZEV program and the number of lead-acid EVs is not known.) Additionally the NiMH and lithium batteries need to offer long life and less (zero would be optimal) maintenance under extreme temperature conditions while meeting the specific capacity and duty cycle requirements of the applications. Both of these issues have the prospects of being overcome with anticipated cost reductions as battery production ramps up and experiments conducted by manufacturers and third parties demonstrating the technology's capabilities in strategic applications. Substantially increased market development efforts by the EV battery manufacturers would also be necessary to develop this potential market. Because of various uncertainties, the study was unable to determine the impact of NiMH EV batteries in other first–use applications on the price of EV batteries in vehicles. The study team did not have enough information to predict the timing of the ramp-up of EV batteries in each application. For example, if NiMH EV batteries for telecommunication and other applications occurs during the steep part of the NiMH volume/ cost reduction curve, the impact could be significant and desirable. The study recommends that more investigation of the stationary market for EV batteries be done, including

- an effort to develop a strategy to grow the market,
- encouraging NiMH suppliers to consider stationary markets (first-use),
- encouraging users to test NiMH batteries in pilot stationary applications,
- more in-depth understanding of the telecommunications market (detailed life-cycle costs including air conditioning costs, the role of European and Asian markets, etc.),
- more understanding of other stationary markets (especially where NiCd exists)
- more understanding of the role of NiMH batteries for HEVs in stationary markets

Exploitation of the secondary market opportunities for advanced EV batteries may have potential to further lower the cost of EV batteries for their owners, but additional research needs to be done to understand the used battery's likely price, capacity and operating capabilities before that potential can be understood. Whether a solid business case can be determined that would support this concept remains uncertain. However, recent USABC studies are encouraging. Suggested follow-on research work for this is offered in the study (e.g., answering various technical questions, testing of batteries).

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1
INTRODUCTION

1.1 Background to the Feasibility Assessment

Millions of dollars have been spent by the United States government and other countries, as well as the automotive, battery and utility industries to demonstrate the viability of next generation (advanced) electric vehicle (EV) and hybrid electric vehicle (HEV) batteries. An important question remains unanswered: "What value might these EV and HEV batteries add when employed in stationary and secondary use applications?"

Like most new technologies, advanced EV and HEV batteries are anticipated to carry a high initial cost. High battery costs are viewed as a major impediment to the market success of EVs and HEVs. Volume production and economies of scale offer the potential of lowering battery costs and, correspondingly, enhancing the market viability of EVs, HEVs, and the advanced batteries. If additional markets, especially in high growth stationary applications, prove to be suitable targets for the deployment of new EV and HEV batteries, it would be reasonable to expect higher volumes and lower cost advanced batteries on the market sooner than otherwise.

This study undertakes an in-depth assessment of three high-growth stationary applications — telecommunications, electric utility industry, and uninterruptible power supply (UPS) — to determine each market's receptivity, competitive concerns, and potential "fit" with the unique characteristics offered by advanced EV and HEV batteries. Greater emphasis was placed on the evaluation of advanced EV batteries (rather than HEV batteries), in large part because they are further developed and their attributes can more accurately be compared with existing technologies.

Secondary use applications of advanced EV and HEV batteries pose intriguing possibilities. Since an advanced EV battery may reach the end of its useful "EV" life with about 70% to 80% of energy and power intact, it is fair to hypothesize that there may be market potential for a "secondary use" of used EV or HEV batteries. However, because there will not be a large supply of used batteries for several years, and hence key battery features (such as calendar life) will not be demonstrable for quite some time, it is much more difficult to assess market potential for used EV and HEV batteries.

This study focuses on alternate market opportunities for new EV and HEV batteries. In markets where new EV and HEV batteries show promise, it is possible that with lower costs, solid warranties, and reasonable calendar lives, used EV and HEV batteries may also have some penetration potential. More research is needed to validate this hypothesis.

1.2 Assessment Methodology

This assessment was conducted under the direction of EPRI Project Manager Michael Lechner with the direct input throughout the project of a team of outside experts. The key members of this team included Naum Pinsky, Ed Kjaer, and Dean Taylor of Southern California Edison; Jeff Molander of Sacramento Municipal Utility District (SMUD), and John Dunning on behalf of SMUD.

The assessment was conducted in two phases, Phase 0 and Phase 1. The key Phase 0 objective was to identify research that addressed the issues of the feasibility of advanced EV batteries being deployed in stationary applications. At the same time, the team sought to identify research concerning the target markets and emerging technologies targeting those markets. Phase 1 built on the findings of Phase 0 to reach the ultimate objective of understanding the competitiveness of the advanced EV battery technologies in selected stationary applications.

The findings of Phase 0 established the necessary approach for Phase 1 and helped define its scope as well. Phase 0 established that no research had been done that specifically and comprehensively addressed the issue of the feasibility of advanced EV batteries in stationary battery applications. Considerable research was identified that addresses energy storage applications of advanced battery technologies, with selected EV technologies among those assessed. Other research identified during this stage addressed some of the related issues: the stationary battery market size and its key segments, emerging technologies targeting selected stationary market segments, an analysis of the UPS market segment, and an analysis of emerging battery technologies in applications of all sizes and types.

Market size information gathered in Phase 0 provided the basis for the market segment focus in Phase 1. The team planned from the beginning of the project to focus the project efforts on a select set of market opportunities so as to enable the team to research the larger, higher potential opportunities more deeply. The identified market information indicated that the telecommunications and UPS stationary markets were two sizable and high growth markets, while the utility market was also a sizable segment. Consequently, Phase 1 efforts were focused on those three market segments: telecommunications, UPS and utility applications.

Phase 1 focused on filling the information gaps uncovered in Phase 0. To do so, interviews were conducted with selected battery and UPS manufacturers, potential purchasers in target segments, battery system packagers, and industry observers. The identities of most of the respondents are confidential, although a list of the companies contacted is provided as Appendix A to this document. In addition, team members' expertise was drawn upon, while material was drawn from numerous websites and from the studies identified in Phase 0.

Phase 1 efforts essentially were comprised of two types: one to understand the markets these technologies would be sold into and the second to understand the technologies and how they fit technically into the market. The market-focused research relied largely on external interviews. Competitors were interviewed to understand what technologies were currently on the market and what was emerging, their strengths and weaknesses, their target markets and relative technology prices and market support structures. Competitors offering products employing advanced battery technologies were also queried about their choices in marketing one or another in their various technologies. Industry observers were asked for their impartial assessments of the strengths and weaknesses of existing and emerging technologies as well as the related structure for sales, service and recycling. Customers were asked about the technologies they deployed in different applications, their purchase process, their satisfaction with their existing technologies, and issues they may have that could be addressed. Where a potential market opportunity was identified, specifications of a dummy NiMH product were provided to obtain feedback from those who were willing to respond.

In contrast, technical research was based largely on team member input, with some input from battery manufacturers who were familiar with both EV and stationary battery products. Consideration was also given to recent public reports regarding the status and potential of advanced EV batteries.

Only limited research was undertaken directly addressing the issues of hybrid battery and secondary EV battery feasibility in these markets. The study does propose a course of research that will enable the effective assessment of secondary battery use in stationary markets as well as recommendations for manufacturers to capitalize on this market.

1.3 The California ZEV Market — CARB ZEV Requirements, 2003

As additional background to this study, it is helpful to gain an appreciation for the potential size of the EV battery market and how it compares to the targeted stationary markets. This provides some sense for the magnitude of the market opportunity that may be necessary to affect the volume/cost relationship for these batteries.

One approach is to simply calculate the revenues associated with NiMH modules to meet the California Air Resources Board's (CARB) zero emission vehicle mandate for 2003. If 4% to 10% of vehicles sold in California were electric vehicles, then 23,000 to 56,000 battery packs containing thirty 30kWh modules would be sold. At $200 to $250 per module ($300 per kWh or $9,000 per pack), this would yield battery module sales totaling $173 million to $336 million per year in California alone. Of course, any sales in Massachusetts and New York would be yet additional sales volumes, as would any hybrid electric vehicle battery sales to the degree they do not displace an electric vehicle. Over the longer term, replacement batteries would be expected to add to the volumes as well. Note this assumes 100 percent of the Evs produced would use NiMH batteries exclusively. This would obviously be reduced by whatever percentage is met by other, e.g., lear-acid, battery technologies.

As the foregoing numbers show, in and of itself the California EV battery market is a large market. In order to significantly affect battery prices, it will be necessary to identify market opportunities that considerably increase production volumes of EV batteries.

2
STATIONARY BATTERY MARKET OVERVIEW

2.1 Background

Batteries are typically classified into two categories: primary batteries, which are not rechargeable, and secondary (or storage) batteries, which are rechargeable. Secondary batteries are also organized into two categories: SLI (starting, lighting and ignition) batteries and industrial batteries. SLI batteries are found in cars, trucks, farm equipment, pleasure boats and applications using small internal combustion engines. These batteries provide power for cranking or other small loads. Industrial batteries can also be divided into two groups: those providing motive power and those in stationary applications. Motive power includes forklifts, railcars, locomotives, electric vehicles and the like.

Batteries in stationary applications, the subject of this research, typically provide back up power to the application to which they are connected. They may act as a bridge to a back up generator, which is incapable of providing instantaneous power in the event of a power outage as well as other features such as continuous power quality. Alternatively they may displace a generator as a direct alternative. Stationary batteries are used in many applications, including telecommunications, electric power, uninterruptible power systems, industrial control, emergency lighting, photovoltaic systems and energy storage systems.

Back up and UPS power systems use secondary batteries that provide electricity during power failures and brownouts and are recharged during periods of normal electricity supply. A typical configuration includes a rectifier/charger that converts utility AC into DC power and float-charges banks of batteries. In UPS systems, a solid state inverter converts DC back into AC, which is necessary for electronics equipment. When there is a problem with utility power, the batteries feed DC directly into the solid state inverter where it is converted into AC. A typical large system is installed in a battery room. Smaller units can require several cubic feet and protect an individual workstation.

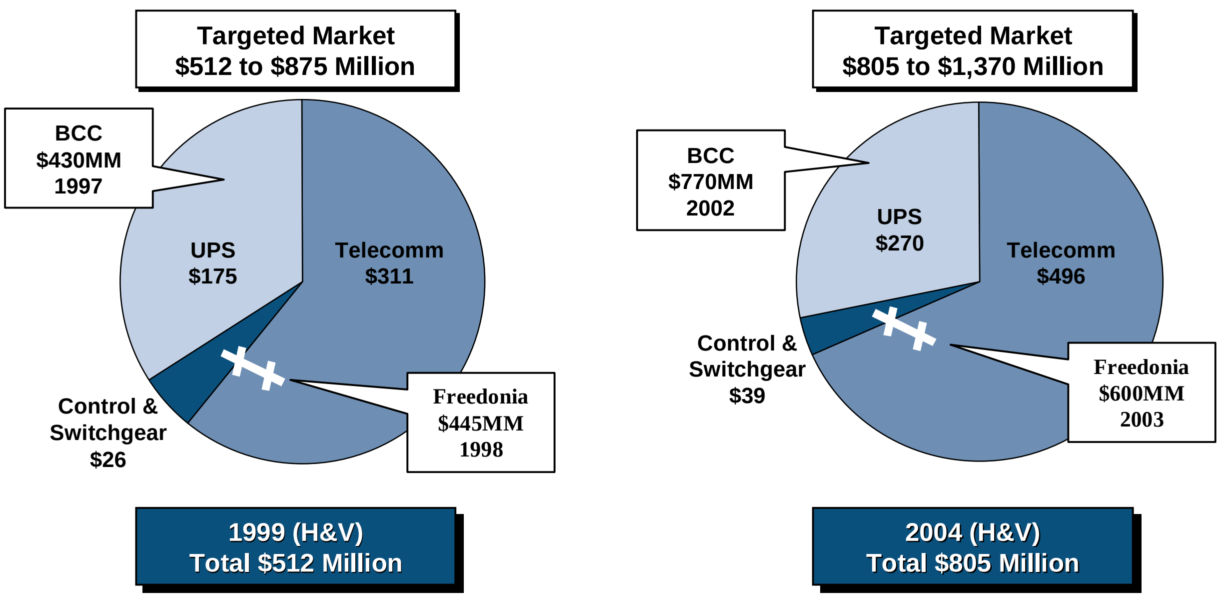
Stationary batteries are rated based on the capacity of a cell in Ampere-hours (Ah) or Watt-hours (Wh). This rating depends on a number of standard conditions, including discharge rate, end-of-discharge voltage, cell temperature, and, for lead acid cells, the full-charge density of the electrolyte. The standard discharge rate for lead-acid stationary batteries is 8 hours in North America, and 10 hours in other parts of the world. UPS batteries are generally rated at the 15-minute rate. Nickel cadmium batteries can be rated at the 5-, 8- or 10-hour rate. The standard end-of-discharge voltage used for lead-acid cells is 1.75 volts and for nickel cadmium, 1.0 volts per cell. The standard cell temperature in North America is 25 degrees centigrade.

2.2 Stationary Market Size and Composition

Back up power and UPS systems have been in existence for decades. The major blackout on the East Coast of the U.S. in 1965 caused significant increases in sales of these systems. Brownouts in the early 1970's made UPS systems attractive to most industrial and commercial operations.

Today, the stationary battery market in total is a sizable one that is expected to grow rapidly for the foreseeable future. There is considerable disagreement both about its precise size and likely growth rate, however. One reliable, though conservative, industry source puts the 1999 stationary battery market sales at $627 million, with projected sales growing to almost $1 billion by 2004.

This study focused on three of the more sizeable segments of the stationary battery market as shown in the chart below: telecommunications, UPS, and control and switchgear applications. These three segments alone account for about 79% of the total market in 1999 and are projected to grow to 85% of the total in 2004.



Sources: Hollingsworth and Vose presentation at BCI, April 2000; Freedonia; BCC

Figure 2-1
Targeted Stationary Battery Market Size

As shown above, the largest stationary battery market that we targeted is for telecommunications applications, which account for over half of all targeted segment sales. These applications include back up power to telecommunications companies' central offices, microwave repeater stations, cell sites, cable signal amplifier stations, and other sites where power to equipment needs to be backed up. Battery Council International (BCI), an industry trade group, projects that estimated telecommunications battery sales revenues of $311 million in 1999 will grow to $496 million in 2004.

The second largest market segment is uninterruptible power supply systems, which account for about one-third of total 1999 sales revenue for the three segments. These on-line systems provided back up power primarily to computer, office telecommunications and Internet service provider systems. BCI projects that UPS battery sales revenue will increase from $175 million in 1999 to $270 million in 2004.

Control and switchgear applications, the third segment assessed in this study, account for only about 5 percent of the targeted market. These applications are largely with utility power generating plants and substations. Revenues for this segment are projected to increase form $26 million in 1999 to $39 million in 2004. This segment was targeted in spite of its smaller market size because of the customers' relationship with electric vehicle operations and potential openness to new battery technologies. The balance of the stationary market, which is not investigated in this analysis and not shown in the above chart, includes lower volume applications in miscellaneous standby, railroad, mining, security, lighting, electronics and medical applications.

Other battery market projections suggest that the Battery Council International market estimates are conservative. As shown in the foregoing pie chart, one vendor's UPS market estimates would place the 1997 UPS battery market alone $255 million larger than BCI does the 1999 market. This estimate is based on the industry rule of thumb that, on average, battery costs are one-third the price of UPS systems. Looking to the future, the first vendor's implied UPS market projection is $770 million, or $500 million greater than BCI's.

A second vendor puts the 1998 telecommunications and control and switchgear markets together at $108 million more than BCI's 1999 estimates. Similarly, the second vendor's 2003 projection of $600 million in telecommunications and control and switchgear sales is $65 million higher.

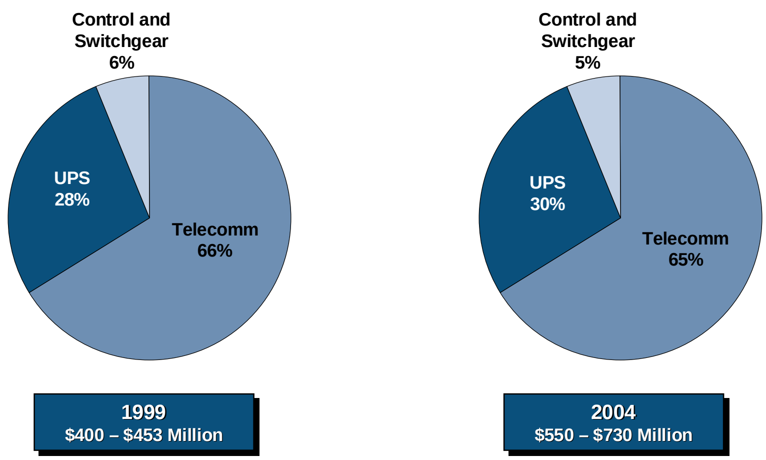
Consequently, there is some reason to think that the 1999 market may be up to about $363 million larger than BCI's estimate of $512 million, while the 2004 market could be $600 million larger than the conservative projection. These differences in forecasts likely relate at least in part to sales of imported batteries, which the lower forecast tends to exclude. These imported batteries tend to be smaller and are growing in number as more manufacturers move some battery production to lower cost locations.

Taken together, these projections place 1999 stationary battery sales in the targeted telecommunications, UPS and control and switchgear segments at between $512 million and $875, while five-year projections range between $805 million and over $1.4 billion.

There are two major forces driving the strong growth of the U.S. battery market. The first is the rapid increase in spending on telecommunications equipment as deregulation and wireless services permeate the market. Personal communications systems vendors are rapidly building out their networks, while the local exchange companies and cable companies enhance their high-speed services. Additionally, competitors to the incumbent telecommunications service providers are continuing to build out their networks while the incumbents are seeking ways to operate more efficiently as demand for their services is growing rapidly. Altogether, factors yield projections of 12% annual rates of growth in equipment spending through 2004.

The second factor is the high growth rate in UPS systems, and particularly the larger systems manufactured in the U.S. The growth in the use of the Internet and in data networks is fueling rising spending on UPS systems, as is the increased use of electronic equipment on the factory floor and in medical facilities. Growing problems with power quality and the reported higher incidence of brownouts and blackouts are also fueling sales of UPS systems.

To better understand the potential for advanced batteries leveraging EV technology, the market was further narrowed to focus on large battery applications only. As shown in the chart below, the three targeted segments account for over 85% of large battery sales in the U.S. when large batteries are defined as greater than 25 Ah. Sales of large batteries in the three target sales are estimated to range between $400 and $453 million in 1999, growing to between $550 and $730 million in 2004.



Source: Hollingsworth and Vose presentation at BCI; BCC

Figure 2-2
Large Battery Markets

The existing battery technologies for larger stationary batteries are limited in number. Lead acid batteries account for the majority of sales today, about 81%. Nickel cadmium batteries dominate the balance of the worldwide market, with a reported 16% share. Nickel metal hydride played a very minor role in the market (and predominantly in smaller battery applications), as did other technologies that were introduced in pilot applications in 1999, including aluminum air according to BCC.

Both lead acid and nickel cadmium batteries are available in vented (or flooded) and valve regulated designs. Nickel cadmium is available in sealed designs as well. The different flooded and valve-regulated batteries are variously designed for long duration, general purpose or high performance. Key differentiating features include the plate type, and in lead acid cells, the plate alloy.

Forecasts in market shares of the competing technologies disagree on which technology will increase its market share at the expense of the other. Over the next five years, a shift away from lead acid batteries is projected by BCC, with lead acid share falling to 76% of sales. NiCd's share is also projected to shrink, while Lithium Ion, nickel metal hydride and others are projected to grow to account for 15% of the market altogether. Lithium Polymer is notably absent from projections for these applications during this timeframe. A competing projection shows no slippage of lead acid's hold on the market, but rather a slight decline only in the share of all nickel technologies through 2003.

For the purposes of this study, a key distinction in the batteries currently marketed is between sealed and flooded lead acid batteries. Sealed lead acid batteries were introduced in the 1980's with the objective of reducing the risk of spillage, lowering the cost of battery maintenance, and increasing energy density to achieve a more compact size. In flooded lead acid batteries, the electrolyte can move around and spill if the cell is tipped. In a VRLA battery the electrolyte is immobilized and the battery operates under pressure with oxygen recombination. The cell is sealed and water cannot be replaced. A valve is used to reduce any pressure build-up, which occurs under abnormal operation only.

This distinction is of particular note for this research since the advanced battery technologies will be competing for use in many of the same applications as valve regulated lead acid batteries. The advanced batteries are in a better competitive position relative to the sealed lead acid batteries due to both price and performance characteristics of the technologies as discussed later in this paper. Market analyses by one industry association suggest that sealed batteries accounted for 22% of all applications in 1999, including 18% of telecommunications and 23% of UPS. They are projected to decline to 21% of the total in 2005. UPS sealed batteries are projected to decline in importance, accounting for 20% of battery sales, while in telecommunications applications they are projected to rise to 20%.

In the U.S., the lead acid battery has become the industry standard. In Europe and in other overseas markets, NiCd batteries have a much stronger position in stationary applications.

2.3 Existing Technologies' Strengths and Weaknesses

Each of the existing battery technologies has strengths and weaknesses relative to the others and these differences have resulted in their use in different stationary applications. As can be seen in the following table, flooded lead acid batteries have low initial cost, high reliability, industry standard status, size and weight disadvantages, spill risks, emissions problems in enclosed spaces, and relatively high maintenance costs. VRLA batteries were designed with the objective of addressing many of the weaknesses of the flooded lead acid batteries; however, they have some shortcomings of their own. These shortcomings include higher price, shorter life, need for additional tools and training for the new technology, and maintenance requirements above expectations. NiCd batteries have a still higher initial price than VRLA batteries — reputedly three times VRLA prices — have similar size, weight and emissions advantages over flooded options, and in addition, offer superior life under uncontrolled temperature conditions. It should be noted that there are lead-based technologies that have higher initial prices and lower maintenance costs than basic VRLA batteries. These higher cost lead technologies are not described in the following chart or discussed throughout this report because industry respondents did not cite them as technologies that they currently use.

Table 2-1
Current Technologies' Strengths and Weaknesses

Technology	Strengths	Weaknesses
Flooded Lead Acid	Low price, high reliability, industry standard (base of training in place at customer; politically low risk)	High maintenance cost, weight, size, emissions
VRLA	Smaller size, lighter weight, potentially lower maintenance cost, lower emissions than flooded, spill-proof	Higher cost than flooded, short life under high temperature conditions, reliability concerns due to history of failures
NiCd	Broader operating temperature range than VRLA, resistance to vibrations, lighter weight, more compact than flooded, lower emissions than flooded; high one minute operating rate (so smaller capacity required in utility operations)	Higher priced, unfamiliar technology

Source: PHB Hagler Bailly analysis

The reliability weakness of VRLA batteries has created a significant market opportunity for NiCd battery manufacturers, and at least one of them has invested over the last two years to take advantage of this opportunity. Looking specifically at the NiCd technology, information in Saft's ALCAD marketing literature is fairly typical:

- Best operation in extreme temperatures: -50 degrees C to +60 degrees C
- No risk of sudden death or thermal runaway
- Excellent resistance to overcharge and over-discharge
- Low life cycle cost
- Easy visual checking of electrolyte levels
- Minimal topping up requirement – up to 20 years' interval in some standby applications

Another recent issue with battery purchasers has been delivery time. Many lead acid battery manufacturers are reportedly quoting delivery times of 40 weeks to a year. Saft expects to bring the delivery time for its NiCd batteries down to 8 weeks from 20 weeks currently.

In the past, the typical duration of the duty cycle or back up time for a standby power application was eight to ten hours. Currently, shorter times of even two or three hours have become more common than previously in back up applications. UPS applications typically require 15 minutes or less since emergency generators typically back up these installations for longer outages. In some instances, government regulations or codes may mandate minimum back up times. Some states, for example, dictate minimum back up times depending on the presence or absence of a generator on the site. Florida requires five hours without generator back up and three hours with generator availability in selected telecommunications applications.

In contrast, the system nominal voltage may be set by the individual company or by industry standards, such as the nominal 48 V system for the telecommunications central office. Specific requirements for each segment will be discussed in that chapter.

2.4 Existing Battery Suppliers

Some of the leading stationary battery manufacturers include GNB (formerly Gould and recently purchased by Exide), Liebert, Hawker, Yuasa, C&D and East Penn. Significant consolidation has been underway in this industry with Gates being bought by Hawker, Johnson Batteries by C&D, Trojan's Industrial Division by Hawker, Hawker by Invensys (formerly British Tire & Rubber), among others. Some examples of their battery product line and selected specifications from their web sites are presented in Appendix C. As detailed in the Appendix, their products range from 2V to 12V battery modules with capacities of between 2.5 Amp hours and 6,000 Amp hours. The listed products are mostly lead acid batteries. Purchasers commented that delivery times for lead acid batteries can run as high as 40 weeks, which is becoming an issue for them.

Suppliers of nickel cadmium batteries are more limited, with Saft of France the industry leader in the U.S. Nickel cadmium battery supply has also consolidated considerably recently as Saft has bought many of its competitors worldwide. Nickel cadmium batteries are much more common in stationary applications overseas than in the U.S., although in Europe there is an effort to ban marketing of NiCd batteries in industrial and consumer applications beyond 2008. Details on selected Saft batteries are presented in Appendix C as well.

Looking to the future, Saft sees significant potential for NiCd batteries in outside plant applications in the U.S. telecommunications market. Saft has been marketing their batteries to this market for two years and has reportedly won some major contracts. Based on these contracts, the company is now in the process of converting a production line at its Georgia facility to produce batteries for this market, and they plan to increase their workforce by over 35% to meet the need. Saft is anticipating about $20 million in sales to this market segment next year, or about 20,000 units. They will be offering two products to the market, one that fits directly into the standard power racks and has the same charger requirements, and another that is bulkier and uses pocket plate technology.

The batteries that Saft is marketing to the telecom industry are supposed to last over 20 years at 25 degrees centigrade where the float charge is 1.43 volts. The service interval for electrolyte watering is fourteen years and the battery can be deep discharged without ruining it. Saft will offer lease deals on the batteries and expects the payback to be between 18 months and six years. More detail on life cycle costs is provided in the utility and telecom market sections.

Most of the battery manufacturers market their products directly to their large end-use customers and to the UPS manufacturers, and also maintain a sizeable network of distributors. Equipment manufacturers for the telecommunications and utility industries will also purchase batteries from the manufacturers for their systems, such as a turnkey power plant project built by GE. The distributors will sell batteries alone, or with racks or other equipment for the total back up system, or a custom back up system for the customer's application.

Distributors have historically served customers with DC applications, like telecommunications and utilities companies. Those with AC applications, that is the UPS systems for computer center and Internet service providers, turn to the UPS providers for their systems. The structure of the industry may look different in the future. Invensys is in the process of pulling together all disciplines with its ownership of Best Power (UPS), Hawker (batteries) and two international DC systems packagers.

Service support is available from both the battery OEM and the distributor. Some customers outsource much of their battery system maintenance usually as part of a maintenance contract for the equipment being backed-up. All battery manufacturers have in-house technical service capabilities to back up their network of representatives. The extent of those capabilities varies depending on the manufacturer and its service strategy, however. The OEMs typically provide support on more sophisticated problems.

Lead acid batteries are typically sold with a full one- or two-year warranty, prorated thereafter based on expired versus design life. Warranties are subject to specific conditions around temperature, cycle conditions, and maintenance requirements. Design lives run from 20 to 25 years for flooded lead acid batteries in float applications and 10 to 20 years for VRLA batteries. Reported battery lives vary considerably, with VRLA batteries offering shorter 10 year lives and flooded lead acid 20 years and more. As discussed in the telecommunications market section, in selected telecommunications applications, VRLA battery lives run between 2 to 5 years. Useful service life is considered to have expired when the battery cannot deliver 80% of its rated capacity.

One NiCd battery manufacturer commented that NiCd battery design lives vary from 10 to 15 years in the hotter climates to 20 years in the northeastern U.S. The minimum guaranteed performance is three years, with a maximum of ten years and an average of five. There are no disqualifiers for temperature as there are in flooded lead acid and VRLA batteries.

2.5 Emerging Competitive Technologies

Given the significant growth potential of the UPS and telecommunications back up power market, a number of competitive technologies are being tested and honed with the objective of replacing or supplementing the existing battery systems. The majority of the technologies, but not all, have relatively high initial prices, relatively short durations, and relatively wide operating temperature ranges. A number have begun to penetrate the full range of telecommunications and UPS markets, with a particular focus on industrial UPS applications. Given the uncertainty around pricing and performance of these technologies as well as the advanced EV battery technologies, it is difficult to predict the degree of competitive threat offered by these emerging technologies.

E Source in its May 1999 study "Storage Technologies for Ride-Through Capability" identified five emerging technologies that are pursuing the telecom, utility and UPS markets as well as other power quality applications (see Appendix B). They are low-speed flywheels, high-speed flywheels, zinc-flow batteries, super-conducting magnetic energy storage and ultra capacitors. As shown in the following list, a number of these technologies are reportedly available in the market today and offer longer life, lower maintenance costs and other improvements over existing chemical batteries. Contacts with industry participants, however, did not turn up any significant purchase activity in any of the market sectors.

Low speed flywheels operate at up to about 10,000 rpm. There are a number of competing systems on the market which have been installed in place of chemical batteries or, perhaps more commonly, to extend the lives of the batteries by protecting them from some of the voltage sags. Active Power's product combines motor generator and flywheel into one unit as a direct competitor to chemical batteries. The product has a power density of 80kW per square foot. The company signed a marketing agreement with Exide in 1999. At least 30 units had been installed by mid-1999, primarily in industrial sites and data centers, and protecting PC networks. The flywheels are designed for short durations, a long life, and low maintenance, and are compact enough to fit in a battery-based UPS.

High-speed flywheels rotate as fast as 90,000 to 100,000 rpm, offering higher energy and power densities that the low-speed alternatives can not. They are lightweight, small and have high energy density, but applications were still at the beta test phase in 1999. One manufacturer, Beacon Power Corp., began delivering beta units to cable and telecommunications providers in September 1998. It has been designed as a direct replacement for chemical batteries in cable TV, telecommunications, and wireless back up power applications. The system can operate at temperatures up to 140 degrees Fahrenheit and are designed to be maintenance free for seven years. The operating life is expected to be more than 20 years and will be available on a lease. They reportedly have a payback of two to six years versus a chemical battery system in which batteries are replaced every one to three years. These systems ultimately look to target power quality, utility load leveling, and remote power applications.

A **zinc bromide flowing electrolyte chemical battery system** is offered by Powercell and distributed through Williams Distributed Power Services. The batteries have no memory effect and can operate at a temperature range of 20 degrees to 100 degrees Fahrenheit, preferring the 90 to 95 degree range. Energy density is about 75 Wh/kg, about twice that of the conventional lead acid battery. Williams plans to combine the Powercell system with Capstone microturbines to offer an integrated package to industrial customers.

Superconducting magnetic energy storage (SMES) stores energy within a superconducting magnet, using liquid helium to keep the coil of superconducting niobium-titanium metal at just above zero degrees Kelvin. The coil has no moving parts so it does not degrade over time with many deep discharges. A second-generation product has been installed in three sites, including one plastics extrusion plant and a foundry.

Ultracapacitors store energy as an electrostatic charge rather than as a chemical reaction. They resemble high power, low energy batteries, and have quite short duration times, making them most attractive for power quality applications. Their principal target market is adjustable speed motor drives. They last from 10 to 15 years and can withstand thousands of deep discharge cycles.

In addition, conversations with one manufacturer of Lithium Polymer batteries indicated that they have several beta tests underway at remote telecom sites in the Southern U.S. and expect to put in place another two by year-end 2000. This battery technology is reputed to offer longer life at higher temperatures, remote monitoring capabilities and reduced maintenance costs.

Still additional battery technologies are being researched and developed for many of the target applications. Research (BCC) cites continued study of the sodium sulfur technology in load leveling applications. Battery technologies cited as having potential future use in UPS applications as well as remote power systems include nickel-iron, nickel-zinc and lithium technologies.

2.6 Conclusions

The three targeted segments make up a large potential market, estimated to range from roughly $512 million to $875 million in 1999 to $805 million to $1.4 billion in 2004. Of those totals, large batteries of 25Ah or greater account for up to $453 million in revenue in 1999 and $730 million in 2004, predominantly in telecommunications applications. The dominant technology is the flooded lead acid battery, which competes based on low price and reliability. Valve regulated lead acid batteries also have a strong position in these segments, estimated by one source to be about 20% of the market. This technology offers smaller size, a spill-proof design, purportedly lower maintenance costs and lower emissions than the flooded lead acid battery at a higher initial price and shorter life. NiCd batteries also have their niches in these segments, typically where high reliability is essential or rugged operating conditions merit their even higher initial price.

Although the battery industry has experienced significant consolidation in the recent past, there remain a number of sizable battery manufacturers, particularly those with a strong lead acid product line. Saft dominates the NiCd battery market, particularly in Europe. All of these manufacturers are supported by extensive sales and service networks, largely through regional distributors.

A number of new technologies are emerging to compete in some of the applications, particularly remote telecommunications applications. Cost and performance are still being proven in the market, with low speed flywheels having been most effective at penetrating the market.

2.7 Published Sources

"Industrial Battery Forecast Report", presented to the 112th Convention of the Battery Council International, April 2000, Bob McCullen, Hollingsworth and Vose.

"Large and Advanced Battery Technologies and Markets", May 2000, Business Communications, Co.

"Batteries", December 1999, The Freedonia Group

"Uninterruptible Power Supply Systems: Continuous Data and Network Systems", Business Communications Co.

"Storage Technologies for Ride-Through Capabilities, The Power Quality Series", E-Source, May 1999

Handbook of Electric Power Calculations, 3rd Edition, 2000, McGraw-Hill Publications

3
UTILITY MARKET OPPORTUNITY

The utility market is one of the smaller market segments assessed. And while it appears to be a solid, easily targeted segment, in fact there are numerous purchasers involved in the specification and purchase decisions inside the utility. This section focuses on those purchases made by the utilities. In addition, batteries to start and to back up certain equipment, such as back up diesel generators and new turnkey power plants, will often be specified by the equipment manufacturers.

3.1 Applications

Applications for larger batteries at utilities typically fall into five types, three of which dominate the market today and are expected to in the near future. The three dominant applications are for distribution and transmission substation back up, power plant back up, and telecommunications system back up. Looking to the future, potential additional applications include load leveling and remote applications, such as the supplementing of photovoltaic power sources.

3.2 Current Technologies

As shown in Table 3-1, the battery technologies that are currently used by utilities are predominantly lead acid, including some VRLA. In some utilities, nickel cadmium has penetrated substation back up applications, typically where vibration resistance is necessary or tempera-true fluctuation is high and the location is remote. Among the utilities contacted, NiCd battery use was still very limited.

Table 3-1
Utility Battery Applications

Application	Technology	Relevant Characteristics
Power Generation	Predominantly flooded lead acid; some VRLA	Low cost, reliable, long-lived
Sub-station back up	Predominantly flooded, few VRLA and NiCd	High reliability, low cost. Occasional need for vibration resistance (NiCd) or compact size
Telecommunications	About half flooded, half VRLA	VRLA has smaller size, lighter weight, limited harmful emissions and arguably lower maintenance costs
Load Leveling	Most existing plants are flooded lead acid, new technologies in pilots	Flooded lead acid lowest cost but still not commercially viable
Remote Applications	Lead acid	Few current commercial applications, including storage for solar powered radio transmitters, oilfield injection pumps, and irrigation

Source: PHB Hagler Bailly analysis

The technical requirements and operating conditions of the various applications vary considerably. Capacity requirements can range from 50Ah to 5,000Ah, while the thermal environment can be either controlled or uncontrolled. Voltage requirements are typically 48V to 130V, though it can be lower in some applications. Additional battery characteristics are detailed in Appendix C. The Table below presents these factors for the existing utility applications.

Table 3-2
Current Utility Applications Specifications

Application	Ah Capacity	V	Duration Requirements	Temperature
Substation	50-560Ah	Largely 48 – 130v	8 hours	Uncontrolled environment in smaller stations. Use exhaust fan.
Generation	1,200-2,400Ah	125v	8 hours	Uncontrolled environment; manned stations.
Telecom	Up to 5,000Ah	48 – 130v	8 – 32 hours	Mostly controlled environment. Some microwave repeater stations uncontrolled.

Source: PHB Hagler Bailly market research

Few utility battery installations are connected to generators for additional back up power. One exception is for nuclear power plants, which are required to have back up generators in addition to the batteries. As can be seen in the duration requirements, batteries are typically specified for long durations.

In addition, the duty cycles differs between the three utility control and switchgear back up applications and the telecommunications applications. In the telecommunications applications, the battery performs float service, where the demand is steady and the battery charger does everything. In the utility applications, there are multiple peaks each time the battery is drawn upon for use. Two typical duty cycles for control and switchgear applications are shown below.

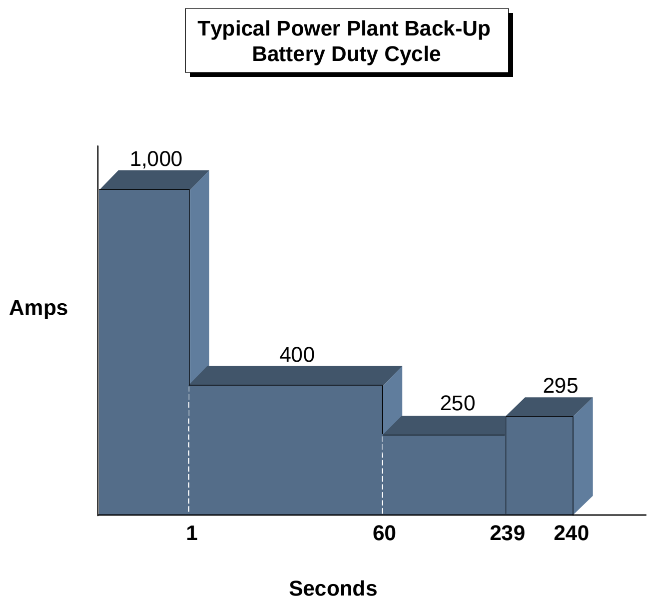
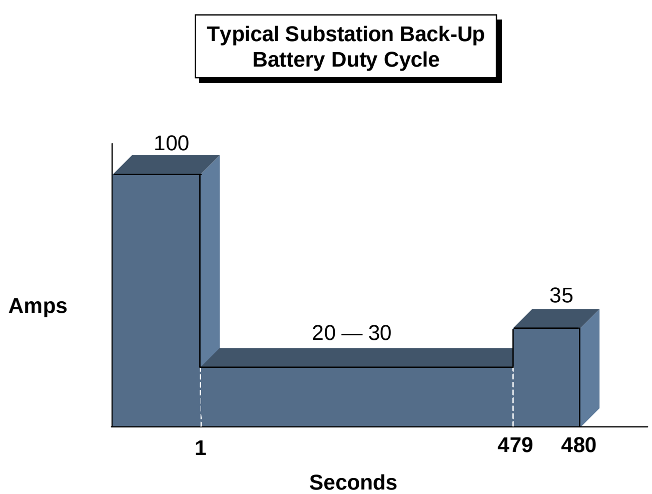


Figure 3-1
Typical Power Plant Back up Battery Duty Cycle



Source: Marco Migliaro, FP&L

Figure 3-2
Typical Substation Back up Battery Duty Cycle

The duty cycles of both load leveling and remote applications are more in keeping with those of electric vehicles — frequent, deep cycling.

Applications for electric generating stations and substations have typically used single strings of batteries because their battery duty cycle usually includes large brief current requirements at the beginning and/or the end of the cycle, as shown in the duty-cycle graphs. Where high reliability is required, such as in selected nuclear power plant applications, customers will opt for a redundant string of batteries.

3.3 Key Buying Characteristics and the Buying Process

The key buying criteria in most applications in the utility industry are reliability and low initial price. The monetary cost of battery failure would be considerable due to collateral equipment damage as well as regulatory repercussions, so proven product reliability is a key factor in a buying decision. Reliability is particularly important in generation and substation applications, where continued operation is essential. Only selected telecommunications are not mission-critical, such as those backing up office phones and computers.

In selected applications, size and possibly weight are important. Some microwave repeater stations have only limited space for battery back up while some office building applications are limited by size, weight and emissions concerns. Some applications are also housed in remote locations where the temperature may or may not be controlled by more than an exhaust fan.

The buying process can vary from utility to utility, as does the organization or organizations responsible for battery specification. Most commonly, there are three or four organizations that are involved in specifying batteries for a utility: substation engineering; power plant engineering; nuclear power plant engineering; and telecommunications. Engineers in these organizations, either alone or as part of a team, develop the specifications for a particular need or set of needs. Different battery manufacturers and their representatives are then identified as authorized vendors and put on a list. Some purchasers will have blanket orders and can customize the specifications depending on the applications. Purchases are typically made based on lowest price that meets the specifications, though some utilities are beginning to consider life cycle cost. Purchases are typically made directly from the manufacturer when volumes are high or from the sales representatives when lower volumes or a custom order is required. Quoted discounts for volume orders are considerable, ranging from 40% to 45% among the utilities contacted. Quoted prices, including discounts, are presented in the following chart.

Table 3-3
Sample Utility Battery Prices

Type	Capacity	Voltage	Quoted Price	Equivalent ($/kWh)	Comments
Flooded Lead Acid	560Ah (60 cells)	125v	$14,700	$210	Reflects 40% discount for bulk purchase
Flooded Lead Acid	200Ah	6v cell	$129	$108	Reflects 45% discount
NiCd	461Ah (Comparable to 560Ah flooded)	125v	$21,600	$375	Reflects 40% discount
VRLA	200Ah	6v cell	$175	$146	Reflects 45% discount

Source: PHB Hagler Bailly market research

At present, delivery times for lead acid batteries range up to 52 weeks, a major issue with buyers.

In addition to the staff that specifies the batteries there is a team of personnel in operations that are responsible for ongoing maintenance. Required maintenance will vary depending on the battery technology and the approach of the utility. One utility commented that they had trained about 300 operations personnel in how to maintain batteries at the sites they were responsible for, including substations and telecommunications. At those sites, for example, the substation operations personnel and telecommunications technicians are responsible for on-going maintenance while a separate battery group undertakes annual testing and troubleshooting.

One manufacturer’s representative provided an estimate of comparative life cycle costs in utility applications. Looking at a 25 year life, this representative, who sells nickel cadmium batteries into stationary applications, estimates that the average annual cost of a sealed NiCd battery runs 43% of that of a comparable sealed lead acid battery, assuming only two replacements of the lead acid battery in that period. The analysis assumes a 25-year life for the NiCd battery and a 10-year life for the VRLA battery. Other details supporting these calculations are provided in Appendix D.

Table 3-4
Supplier Estimated Life Cycle Costs

Cost Component	VRLA	Vented NiCd	Sealed NiCd
ISEE Sizing	75Ah	58Ah	119Ah
Number of Cells	20	95	32
First Material Cost	$5,348	$11,692	$12,290
Total Replacement Cost (25 years)	$13,260	0	0
Maintenance Cost (25 years)	$20,504	$9,183	$4,628
Total Cost	$39,112	$20,675	$16,918
Average Annual Cost	$1,564	$835	$677

Source: Industry Distributor

3.4 Competing Technologies and Attitudes Toward New Technologies

In the leading utilities contacted, lead acid technologies appear to be firmly entrenched in current applications in spite of selected failures of VRLA batteries and the high maintenance costs of flooded batteries. By and large, the contacted utilities were comfortable with the technologies they are currently using, have had good experiences with the batteries over long periods, and could identify few areas needing improvement. A couple of utilities were looking at NiCd batteries for telecommunications and substation applications, but a decision in favor of that technology appeared distant at best. One other had replaced all of their VRLA batteries in substations with flooded lead acid and was satisfied with their performance. Still another utility commented that the cracking and bulging of batteries in two VRLA installations (one in a microwave repeater station and one in an office building) after three years or so had caused them to begin to think about reducing the assumed life of the batteries to five years. In reaction to the sample NiMH module, one utility employee commented that the 85Ah capacity was too small for their substation applications.

A widely respected utility battery expert commented that they had a significant investment in personnel training around the lead acid batteries that would be costly to replicate with a new battery technology. In substation applications alone, they had 300 substation operators responsible for day to day maintenance of the battery systems. In addition there were the telecommunications systems technicians who were responsible for telecom system back up and the power plant operating personnel. To supplement this operating staff, the utility has a small group of battery experts who handles major annual maintenance and trouble shoots the battery systems. He commented that in part because of this cost he would not install a new technology battery if it were given to him at no cost.

In the utilities contacted there was no evidence that many newer technologies had been tried in current applications. The general attitude expressed was that new technologies are inherently risky and unless the benefits of the new technology are substantial, the new technology would not even be tested. Even with substantial benefits, if the initial price is much higher than current battery prices, then it is unlikely to survive the purchase process, which still focuses almost exclusively on first cost. One utility that had analyzed the numbers for NiCd batteries in substation operations commented that the high initial cost simply could not be overcome when the flooded lead acid batteries were achieving a 12- to 15 year life.

Lead acid batteries were also most commonly deployed in pilot load leveling and remote power applications. Since these pilots generally proved not to be commercially viable with lead acid technology, there is an apparent opening for advanced EV technologies in such applications. In fact, one manufacturer commented that they expected to have two pilot load leveling projects on line at two utilities using their Lithium Polymer technology before year-end 2000.

3.5 Conclusions

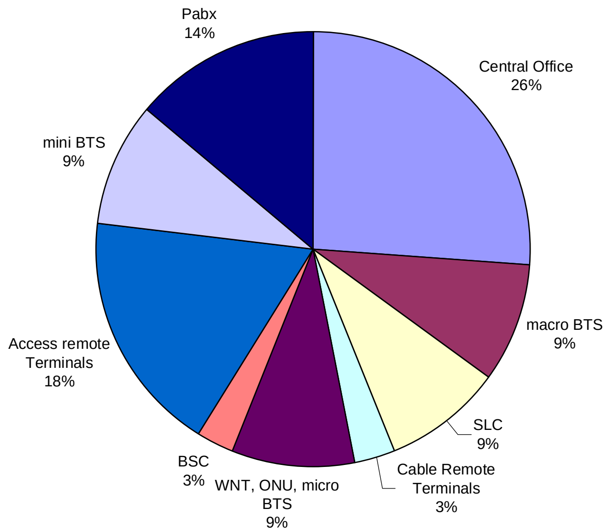
Customer research suggests that utilities are generally satisfied with the batteries they are currently using and are having no major problems that need addressing. The particular opportunities for advanced EV battery technologies — limited space, high or low operating temperatures in a remote location without temperature control — are relatively limited in utilities, where flooded lead acid batteries can often be used and meet their performance requirements. Further, the corporate environment is generally not conducive to experimenting with new technologies in these applications because of the significant downside risk from battery and equipment failure. To penetrate most applications in this segment, a technology would need to offer significant performance improvements over existing applications and a proven track record, preferably at a lower price.

4
TELECOMMUNICATIONS MARKET OPPORTUNITY

The telecommunications market for stationary batteries is the largest market segment and one of the fastest growing. Competition in local exchange markets, increased demand for high speed services, and growth in wireless telecommunications services have all combined to create growing requirements for telecommunications equipment. Furthermore, rising customer expectations for service quality and reliability and pressure on maintenance budgets to enhance profitability are changing the stationary battery market in these applications.

4.1 Applications and Current Technologies

Batteries are sold to a wide range of telecommunications services providers for a number of different applications. Telecommunications services providers include long distance carriers, cellular service providers, local exchange carriers, high-speed service providers, competitive local exchange providers, personal communications services (PCS) providers, and cable systems. As shown in the following graph, their applications can be grouped into about nine types: central office; macro base transceiver station (BTS); subscriber line carrier (SLC); cable remote terminal; wireless network terminal (WNT), optical node unit (ONU), and micro BTS; base controller station; access remote terminal; mini BTS and customer premise equipment (PABX). WNT, BTS and BCS applications are wireless, with micro-BTS related to limited cellular coverage, such as in malls. Cable remote terminals support the cable television infrastructure, while access remote terminals include street cabinets in fixed networks or ADSL (advanced digital subscriber line) terminals.

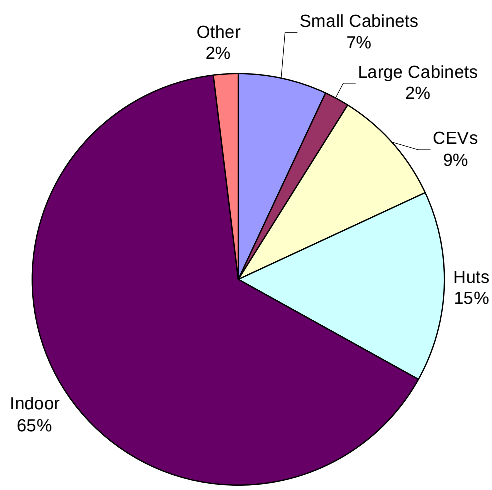


Source: Saft Alcatel

Figure 4-1
Telecommunications Market Stationary Battery Applications

Each application has its own requirements for capacity and duration, which will be discussed shortly. The duty cycles are all fairly continuous, with no major peaks.

Perhaps equally importantly from the perspective of advanced battery technologies is how the applications are housed (see figure below). The majority are indoors in temperature controlled environments. Others are in controlled environment vaults (CEVs), huts (which may or may not be temperature controlled), and large and small cabinets, which usually are not temperature controlled.



Source: Saft America

Figure 4-2
Telecommunications Battery Locations

One source estimates that at least 100,000 units are located in remote locations with extreme variations in temperature.

Key technologies employed in the various telecommunications sectors are identified in the following table. Most applications rely on VRLA batteries because of space constraints and maintenance issues. Others, like central office applications and many cable TV amplifier stations, still use lead acid batteries. As shown in the Issues column, there are always minor issues that can be better addressed. There is one general type of application, however, that has significant issues, and that is outdoor plant where there is no temperature control and temperatures vary considerably. VRLA batteries lives shorten dramatically under uncontrolled temperature situations. Sources reported that in order to assure reliability of the batteries, in these applications VRLA batteries were being replaced as frequently as every two to three years. Obviously this puts a high cost premium on the use of VRLA batteries in such applications. Further, a customer with this type of problem is actively looking for a solution.

Table 4-1
Telecom Applications for Stationary Batteries

Application	Technology in Use/ Application Characteristics	Issues
Office System UPS	Lead Acid, both flooded and valve regulated, but predominantly VRLA; usually room temperature with air conditioning; larger systems have separate rooms and AC.	No major issues. Space constraints, leaks, maintenance.
Cell PCS Sites	VRLA predominates usually housed in huts. Backed up by generators. PCS requires smaller capacity batteries.	Temperature variability in micro sites, space constraints generally.
Microwave Repeater Stations	Valve Regulated Lead Acid. Batteries and electronics housed in huts.	No major issues. Space constraints; some without temperature control.
Fiber Repeater Stations	Similar to microwave repeater stations.	Similar to microwave repeater stations.
Cable TV Amplifier Cluster Locations	Flooded Lead Acid. In cabinets with little protection; sometimes with thermal protection.	High maintenance costs, temperature variability, leaks.
Central Office/Hubs and Head-End Office	Traditionally flooded. Some increase in VRLA use. Temperature controlled.	No major issues. Construction costs, space constraints, and maintenance
Outside Plant	VRLA. Some thermal protection and water channeling in larger cabinets.	Major issues around battery life in outdoor applications with high temperatures.

Source: PHB Hagler Bailly market research.

Capacities and runtimes required by customers varied widely across the various applications as shown in the chart below. Capacities run from 25 Ah to 4800 Ah depending on the load they are serving. Run-times in DC applications range from 5 minutes to 8 hours, with 4 to 8 hours more typical. Voltage requirements are standardizing around 48 volts.

Table 4-2
Telecommunications Applications Specifications

Telecommunications Site	Ah Capacity Required	Voltage	Run Time	Temperature Range
Outside Plant*	25 – 4,800	48 – 54	3 – 8 hours	Up to 140° F
Central Office	200 – 6,000	48	3 – 8 hours	68 - 78° F
Office System UPS	250 – 4,000	48 – 540	4 minutes – 1 hour	68 - 78° F
Cell Sites (single phase and three phase)	30 – 150	48	2 – 4 hours	0 - 40° C
Microwave Repeater Stations	105 – 4,800	24, 36, 48	5 minutes - 3 hours	Most 70° F Some -10 to 113° F (Micro)
Fiber Repeater Stations	3 – 100	24, 36, 48	5 minutes - 3 hours	Depends on site
Cable TV Amplifier Cluster Locations	10 – 15 Amps of Load	48	4 - 8 hours	As high as 110° F

Source: PHB Hagler Bailly market research

A very important feature of battery applications is the operating temperature of the applications since batteries' lives are affected by these conditions. Several applications appear to face a wide range of temperatures, including most notably outside plant, but also cable TV amplifier clusters, some cell sites and some microwave repeater stations. One local exchange carrier commented that they see VRLA in high temperature cabinets (outside plant) lasting from 1.5 to 3.5 years, while in temperature controlled battery boxes they can last from 4 to 5 years. In contrast, NiCd battery life expectancy in high temperature applications is ten to fifteen years though having tested them for only three years they do not know what will actually happen.

Some of the applications are backed up by generators, like the office system UPS and the cell sites, while other applications are sized to have a back up generator brought in if necessary. Most applications will use parallel strings because they will provide flexibility in load service; e.g., the entire load will be able to be served for part of the time when one of the strings is out of service.

4.2 Key Buying Characteristics and the Buying Process

In most applications, buyers prefer an established track record and low initial cost. Many of the installations are centrally located and have enough space that flooded lead acid batteries are the best choice. Other installations are space constrained, in unvented facilities or are located more distant from central operations so maintenance becomes a consideration. In still others, where temperatures vary widely and are not controlled in the facility housing the batteries, robustness of the battery under a range of operating conditions is a buying concern.

There appears to be a different attitude towards reliability in the various services providers. Perhaps because of their long history of regulation, the incumbent local exchange companies and long distance companies appear to be most concerned about reliability, while cable and cellular companies are somewhat less concerned, or more accepting of service outages.

The buying processes of these companies are not dissimilar to that of the electric utilities. An Evaluation Team, principally composed of engineers, creates an approved products list. The Evaluation Team will be different for different applications within the same company. Some companies will rely on subcontractors to assess the batteries in field tests as input to their evaluation. Some Teams include procurement staff. When a purchase needs to be made, a purchase requisition is sent to Purchasing, which then solicits bids from the approved vendors and, in most cases, chooses the lowest cost vendor meeting the purchase request specifications. Some vendors also agree to take back and recycle the used batteries as part of the purchase agreement.

Historically, final purchase decisions have been made largely based on initial cost. However, with battery lives under certain circumstances so short and the corresponding maintenance costs high (at a time when staff are being cut), life cycle cost analysis is increasingly part of the purchase process. Local exchange companies appear to be embracing this approach earlier that others, followed by cellular carriers. Over time, it is anticipated that at least for remote installations and/or installations in uncontrolled high temperature environments, life cycle cost analysis will become more widespread in the industry.

As with the large purchasers in the electric utility industry, volume purchases are typically made from the battery manufacturers. Smaller amounts go to their distributors. Smaller buyers will tend to deal more with the distributors, who will also assemble custom systems for their applications.

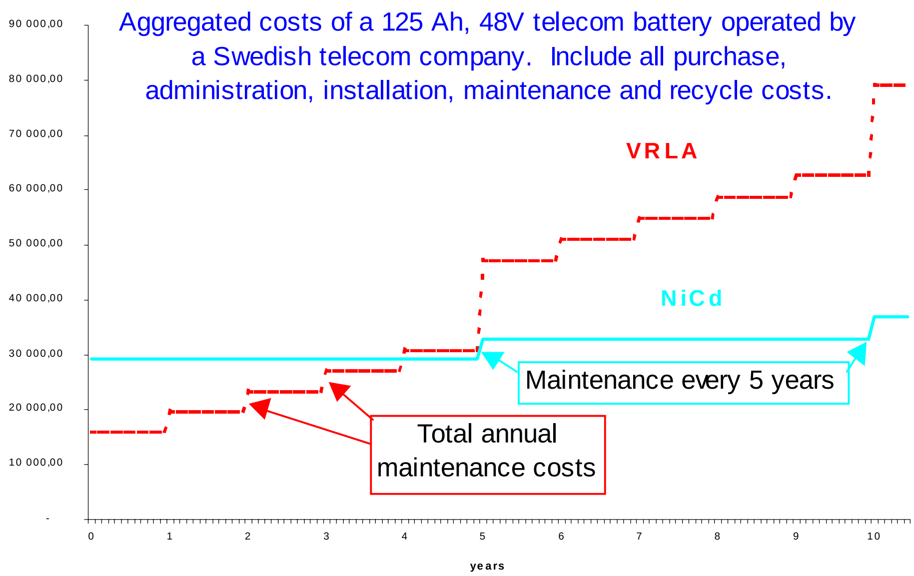
Battery prices provided by respondents are provided in the following chart. As shown below, flooded lead acid prices tend to be among the lowest on a per kWh basis, with VRLA falling in the middle of the range and NiCd at the high end of the range. NiCd quotes between two manufacturers varied widely, from $500 to $600 on the one hand to $800 to $900 on the other. The lower quotes were provided by Saft, which has a market leadership position in this technology.

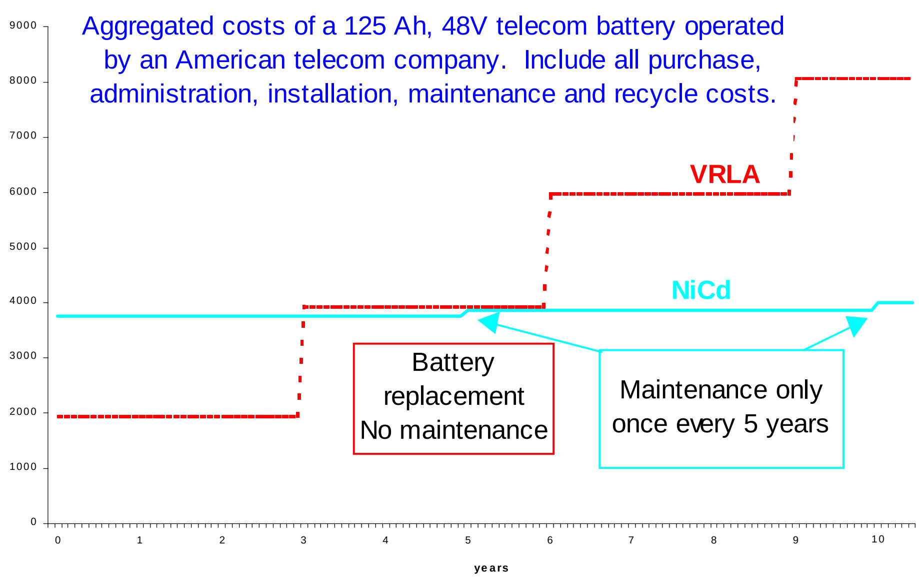
Table 4-3
Sample Telecom Battery Prices

Type	Capacity	Voltage	List Price	Equivalent (List) $/kWh	Comments
Flooded Lead Acid	2020Ah	48V	$15,906	$164	30-40% discount is added for volume sales.
	4000Ah	48V	$32,000	$167	Price for cell system plus rack.
VRLA	100Ah 70Ah 25Ah	24V 12V 2V	$410 $240 $25	$171 $286 $500	10-40% discount is added for volume sales.
NiCd	98Ah	48V	$3,852	$819	Large cell site. Hawker quote.
	125Ah	48V	$3,500	$583	Saft quote
	500Ah	48V	$12,000	$500	Saft quote

Source: PHB Hagler Bailly market research.

Battery life cycle costs are, of course, a related question. Unlike prices, they vary depending on customer and application specific criteria. One vendor provides the following life cycle costs for NiCd and VRLA technologies assuming in one instance on-going maintenance of the VRLA batteries, and in the other, no maintenance. In the former instance, batteries must be replaced in 5 years, while in the later replacement in three years is necessary. As shown in the following graphs, NiCd cumulative ten-year costs are about one-half those for their VRLA counterparts, although the initial cost for the NiCd batteries is about twice that of the VRLA equivalents. Other industry participants have suggested still lower life cycle costs for NiCd relative to VRLA batteries, on the order of one-third. Presumably, this relationship varies considerably depending on the operating temperature of the application.





Source: Saft America

Figure 4-3
Comparative Life Cycle Costs for Telecom Use of NiCd and VRLA Batteries

4.3 Competing Technologies and Attitudes Toward New Technologies

Most of the telecommunications companies contacted had considered other technologies (see the following Table 4-4). Respondents in the cable, local exchange, and long distance industries commented that they had looked at lithium batteries. The cable company respondent indicated that there may be a potential fit for lithium in applications on the sides of houses. The long distance respondent commented that NiCd could have applications in outside plant. One local exchange carrier commented that he thought the NiMH capacity proposed by the particular vendor was inadequate for their applications. No mention was made of flywheels.

Table 4-4
Telecom Review of Other Technologies

Customer Type	Technologies Used	Others Tested
Local Exchange Carrier (LEC)	Flooded Lead Acid VRLA NiCd	Nothing looked at seriously. Thought NiMH capacity inadequate.
Cable	Flooded Lead Acid VRLA	Have looked at lithium and "NiMH." Only potential fit is for lithium on sides of houses. Thinking about using NiCd batteries in remote terminals.
Long Distance	VRLA	Have looked at Lithium polymer for some applications; no very positive reaction. Possible NiCd uses in outside plant.
Cellular	VRLA	Exploring a fuel cell for potential use.

Source: PHB Hagler Bailly market research.

Where feasible in the interview process, the interviewee was given the hypothetical specifications of a NiMH battery module to comment on. The specs of that module, which are based on GM Ovonic's product literature, are detailed in the following table.

Table 4-5
NiMH Module Specifications Tested

- 13.2 Volts
- 85 Ah
- 409mm length
- 102mm width
- 178mm height
- 17.7 kg weight
- 10 year design life
- 1,000 deep discharge cycles
- Energy density: 63 Wh/kg
- Power level: 2,124 W for 1/2 hour at room temperature, 200 W/kg peak
- Energy content: 1,122 Wh
- Operating temperature range: -8°C to 40°C
- Sealed, no customer maintenance
- Warranty: full first year, prorated thereafter
- Price: $336 per module or $300/kWh

Source: John Dunning and Ovonics Product Literature

Respondents' reactions were mixed (see table below). Some felt the price was reasonable, while others commented it was too high for a new technology. A couple of respondents commented that the capacity was inadequate, while others felt it was adequate. A local exchange carrier observed that the design life is usually 20 years and that, because it was a new technology he would expect a better warranty, like eight to ten years. One respondent commented that the operating temperature needs to go up to 65 degrees centigrade.

Table 4-6
Telecom Reactions to NiMH Module Specifications

Positive	Negative
• Price ok (cable, long distance, local exchange)	• Price too high for a new technology (local exchange, long distance)
• Capacity ok (local exchange, long distance, wireless)	• NiMH capacity typically too low (local exchange); too low (cable)
• Good design life (cable, local exchange, wireless)	• Design life too short, usually 20 years (long distance, local exchange)
• More deep discharge capability than needed (local exchange, cable); ok (long distance)	• More deep discharge capability needed (cable)
• Energy density good (long distance)	• Expect better warranty (local exchange, wireless, local exchange)
• Operating temperature ok (long distance)	• Needs to go up to 65°C (local exchange)
	• All in all would rate a 7 out of 10; C&D batteries perform better (long distance)

On the whole, telecommunications services providers appeared open to considering new technologies. One commented that he would consider the technology based on how it performed under test conditions. Another commented that he would expect superior performance at comparable if not lower cost. Still another commented that he would consider the new technology but would focus primarily on initial price and performance.

One manufacturer commented that after extensive field tests of their NiCd battery in outside plant applications, one local exchange carrier now plans to purchase NiCd batteries for all of their remote terminal applications.

4.4 Conclusions

There are many different applications of stationary batteries in the telecommunications field, and changes in customer needs and technology deployment are creating opportunities for new technologies to solve battery-related problems. There are particular issues with outside plant applications, presently with the local exchange carriers, that offer an opportunity for smaller-sized, low maintenance batteries with a greater resistance to high temperatures. Similar opportunities appear likely to develop in selected cellular and cable applications.

These particular opportunities are being actively targeted by a number of competing battery and non-battery technologies. Saft in particular has targeted the telecommunications market with its NiCd product and marketing efforts over the last two years have reportedly lead to significant contracts from customers and expansion of the company's U.S. production capacity. In the instance of NiCd batteries, initial prices are estimated to run about three times VRLA prices, while product life is two to three times as long. One manufacturer's example puts the average annual life cycle cost of NiCd batteries at one-half that of VRLA over a 25 year period and with VRLA replacement at ten years.

The telecommunications market appears to generally be open to new technologies, contingent on performance and price. A focus on initial price in the purchase decision will make the penetration of new technologies slower and more difficult than otherwise. Target initial prices will need to be in the $175 to $500/kWh range, while performance will need to be superior to capture significant market share.

4.5 References

"'Phone(y)' war opens on battery technologies," *Batteries International*, April 2000, p. 79-82.

"Lies, Damn Lies, and Longevity Studies," *Batteries International*, January 1999, p. 52-57

5
UNINTERRUPTIBLE POWER SUPPLY SYSTEMS

5.1 UPS Overview

UPS (uninterruptible power supply) systems are designed to provide clean continuous AC power against utility power and changes in frequency. These systems protect against small duration decreases in voltage levels (sags), small and large duration increases in voltage (spikes and surges), and loss of utility power (blackout). When there is large load surrounding equipment, UPS systems also serve to eliminate electromagnetic interference (noise) and harmonic distortion.

There are basically three UPS system topologies: off-line, line-interactive and on-line applications. Offshoots of these three topologies, sometimes considered under the umbrella term line-interactive, include standby on-line hybrid UPS, on-line without bypass UPS, and the standby-ferro technology.

A typical UPS system has four basic components: the charger/rectifier, battery, inverter, and transfer switch. The charger/rectifier changes utility AC power to usable DC power, and when power is available, supplies power to the inverter and maintains a float charge for the battery. When there is no source power available, the inverter provides AC power for a specified amount of time, which is called the run-time.

The battery in UPS systems must provide power to the inverter once AC power is removed. The typical battery cell in UPS applications is 2 volts, with a cell voltage range of about 1.7 to 2.2 volts. Batteries are strung together in series or parallel to obtain higher voltages and capacities. For a larger load, a larger inverter must be used. Consequently, a larger battery is needed.

This chapter provides a brief overview of the UPS markets, describes the general characteristics of these markets, and concludes on the implications for advanced battery technologies in UPS systems applications.

5.2 UPS System Topologies

A standby or "off line" UPS only provides outage protection, that is there is no line conditioning and no correction for voltage fluctuations. When the outage is noticed, the UPS switches to back up power provided by the battery and inverter. The off-line unit does not protect from certain voltage and frequency deviations. Some off line units have tightened input parameters to decrease this, but this puts more stress on the battery. Most of the batteries are UPS batteries that are sensitive to cycling, so off line UPS Systems are not the best product for all specifications.

With these systems, there is transfer time (for the inverter to take over as a power source) that can be an issue for critical applications. For example, motherboards and hard drives may lose data unless the UPS system comes on within several milliseconds of a power outage. Off-line UPS systems are usually supplied with trickle chargers that are not designed to quickly recharge the system's battery after a discharge. If the batteries are being discharged frequently, then the batteries may not recover their full charge in-between outages. This may develop to the extent that the required current can no longer be provided to critical loads.

A typical standby UPS system has a capacity range of 100 VA to 1.4 kVA. The price for these systems ranges from $140 to $1000. Standby UPS systems have a runtime of 5 to 100 minutes, and approximately 2 to 4 milliseconds of transfer time. Batteries in these UPS designs are VRLA and are "hot swappable." Hot swappable refers to the modular configuration of the UPS system, which allows for parts replacement to occur while still operating the other system components. These systems can be used for small, medium, and large computer and workstation applications, although there are disadvantages to using it for very critical applications.

An on-line UPS system is also known as a double conversion unit. The on-line UPS system is on all the time, constantly converting AC power to DC power back to AC power. There is no transfer time for utility power loss, but there may be minimal transfer time when the power from the primary battery charger/battery/inverter power path fails.

A line-interactive system is in essence an on-line system with a different configuration. Line-interactive systems have the AC power converter always connected to the output of the UPS. It is comprised of the same components as an on-line or standby system, but functions differently. Battery charging occurs by operating the inverter in reverse, and when there is an input power failure, the transfer switch opens and provides output power. Since the inverter is not on all the time, there is less heat and noise created.

The typical on-line and line-interactive UPS system has a larger capacity than a standby system, with system capacity ranging from 500 VA to 75 kVA. The price typically ranges from $525 to $4500. The systems have runtimes of 3 to 6 hours, no transfer time, and also house VRLA hot swappable batteries. The battery packs are comprised of two to eight batteries. Like offline systems, these systems can be used for computer and workstation applications of all sizes. The largest applications for these systems are in data centers, large telecommunications installations, industrial process control systems, and laboratories. Most systems have programmable parameters for alarms, and offer remote monitoring capability.

Off-line designs are usually manufactured in small capacities, for one-on-one usage. Line interactive UPS systems, including hybrid technologies, have the lion's share of the market. Although the line-interactive system is basically an on-line system, it is configured differently so that it is considered an entirely separate product. There are fundamental differences between standby and on-line UPS systems, noted here**:**

Table 5-1
Standby and On-line UPS System Features

Feature	Stand-By	On-Line
Lightning and surge protection	Yes	Yes
EMI/RFI Noise filtering	Yes	Yes
High voltage protection	Some	Yes
Continuous no break power	No	Yes
Switch mode power supply	Most	Most
Communications interface port	Most	Yes
Telephone and modem protection	Most	Yes
Status indicator and alarm	Most	Yes

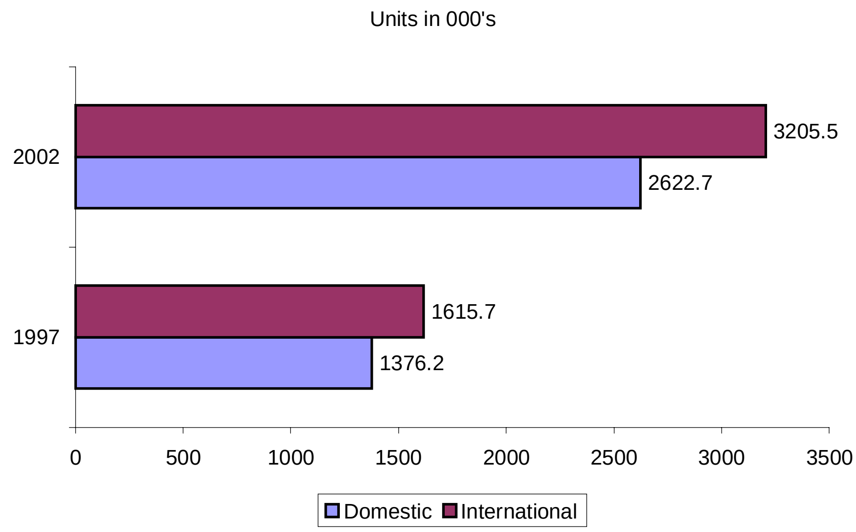
Source: "Uninterruptible Power Supply Systems: Continuous Data and Network Systems", *R.* Moran, Business Communications Company Inc., Norwalk, CT, 1998.

Most on-line UPS systems are backed up by a generator to enable continued power supply in the event of a longer power outage.

5.3 UPS Market

Because advanced EV batteries would have greater potential in the larger and more costly on-line and line-interactive UPS systems, this market analysis focuses on UPS systems other than the less expensive standby systems. As indicated previously, standby systems are designed to keep computers or other electronic devices running only long enough to store data to the hard drive or allow an orderly shutdown of the system, and thus do not offer much market potential for batteries designed to deliver maximum energy at a high unit price.

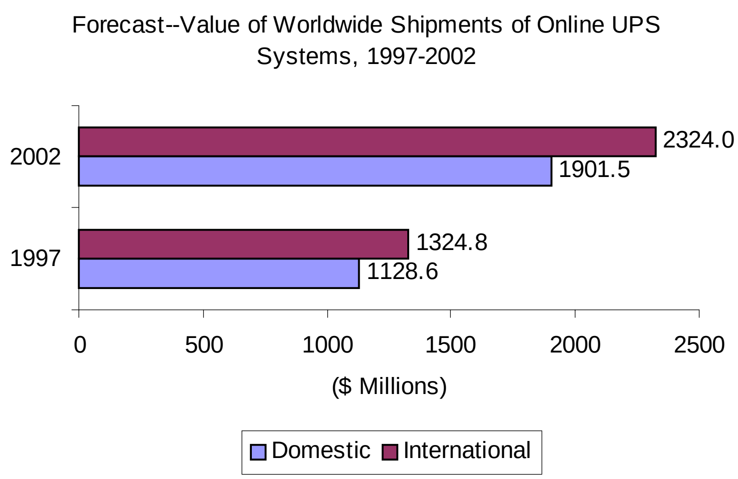
The worldwide on-line UPS market is projected to grow at a 14.3% compound annual rate through 2002, reaching 5.8 million units sold according to a BCC report. The domestic market will grow from 1.4 million units in 1997 to 2.6 million units by 2002. Demand is fueled by a growing requirement for on-line UPS systems in larger computer systems, networks, mainframe computers, and data centers. Communications systems also represent a growing UPS market, particularly in PBX systems and other telecommunications equipment.



Source: "Uninterruptible Power Supply Systems: Continuous Data and Network Systems", *R.* Moran, Business Communications Company Inc., Norwalk, CT, 1998.

Figure 5-1
Forecast of Worldwide Shipments of On-line UPS Systems — 1997 and 2002

Revenues from on-line systems sales are projected to grow to $4.2 billion worldwide by 2002, with the growth rate of line-interactive sales exceeding that of the traditional on-line system. In addition, sales of replacement batteries are expected to double from $0.2 billion in 1997 to $0.4 billion five years later. Domestic on-line system sales are projected to reach $1.9 billion in 2002.



Source: "Uninterruptible Power Supply Systems: Continuous Data and Network Systems", *R.* Moran, Business Communications Company Inc., Norwalk, CT, 1998.

Figure 5-2
On-line UPS System Revenues Worldwide — 1997 and 2002

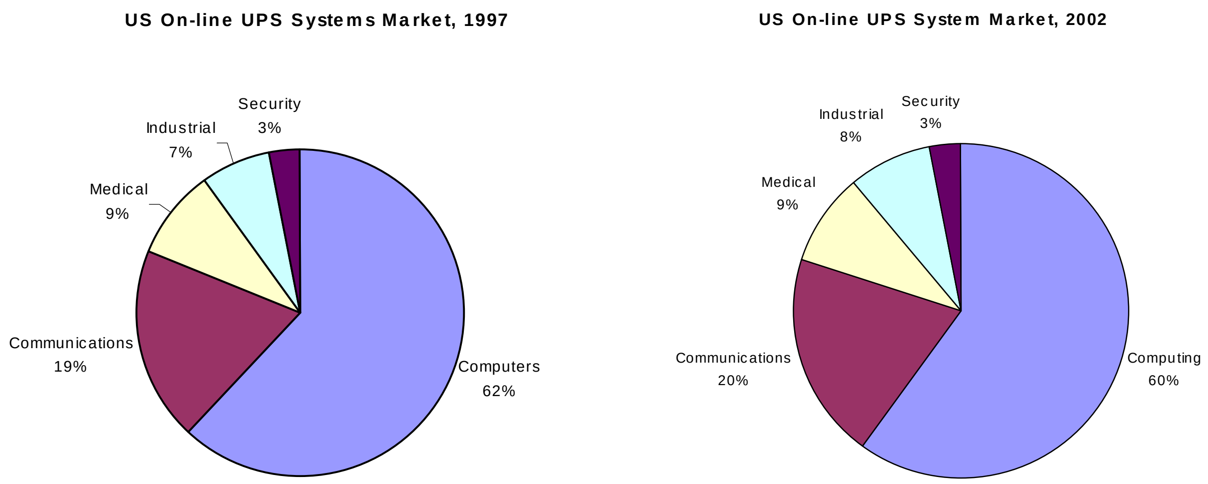
On-line systems of all sizes are expected to experience high growth, with five-year growth rates through 2002 ranging from 13.9% annually for 1 kVA to 5 kVA systems to 15.7% annually for systems over 5 kVA in capacity, as shown in table below.

Table 5-2
Worldwide Shipments of On-line UPS Systems by Capacity, 1997-2002 (Units 000)

Size Range	1996	1997	CAGR% 96-97	2002	CAGR% 97-02
< 1kVA	296.2	344.1	16.1	705.2	15.4
1 to 1.9 kVA	973.5	1092.1	12.1	2092.3	13.9
3 to 5 kVA	1098.0	1232.6	12.2	2360.5	13.9
Over 5 kVA	277.7	323.1	16.3	670.2	15.7
Total	2645.4	2991.9	13.0	5828.2	14.3

Source: "Uninterruptible Power Supply Systems: Continuous Data and Network Systems", *R.* Moran, Business Communications Company Inc., Norwalk, CT, 1998.

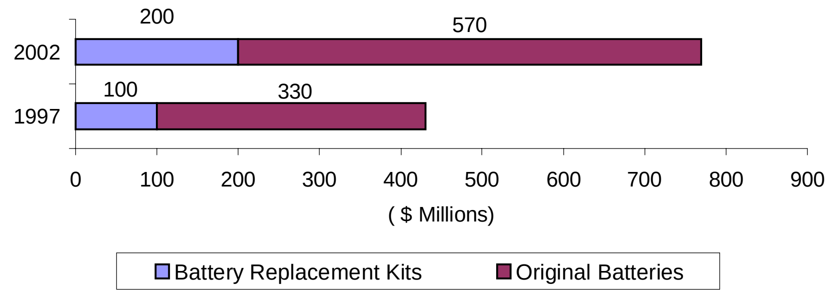
The majority of on-line systems have been sold into computer-related applications. In 1997, computer-related UPS systems accounted for an estimated 62% of systems worldwide. Communications was the second largest application for UPS systems, followed by medical, industrial, and security applications. Looking onto the future, communications and industrial applications growth is projected to be more rapid than applications in the other segments.



Source: "Uninterruptible Power Supply Systems: Continuous Data and Network Systems," R. Moran, Business Communications Company Inc., Norwalk, CT, 1998.

Figure 5-3
On-line Systems Market Segments, 1997 and 2002

The foregoing forecasts of UPS systems provide one basis to estimate the size of the domestic UPS battery market. Industry experts indicate that on average the cost of the battery is 30% of the system price. In addition to sales for initial use, replacement batteries are also required. As shown in the chart below, domestic UPS related battery sales are projected to reach $770 million by 2002 based on the BCC UPS market projections.

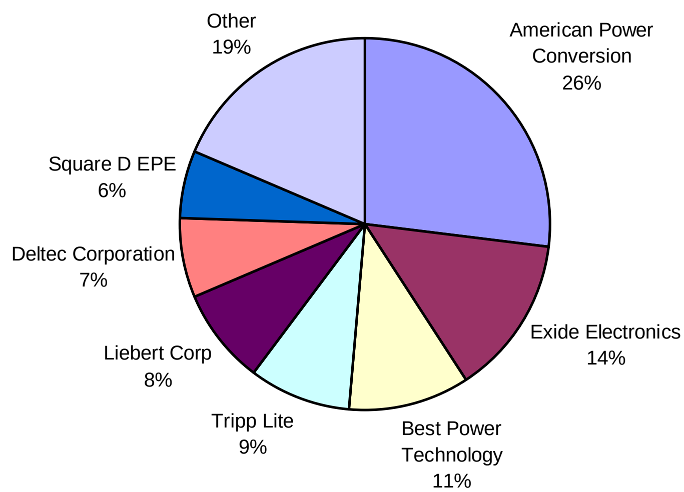


Source: "Uninterruptible Power Supply Systems," BCC; PHB Hagler Bailly Analysis

Figure 5-4
Projected Domestic Battery Sales for On-line UPS Systems

5.4 UPS Manufacturers

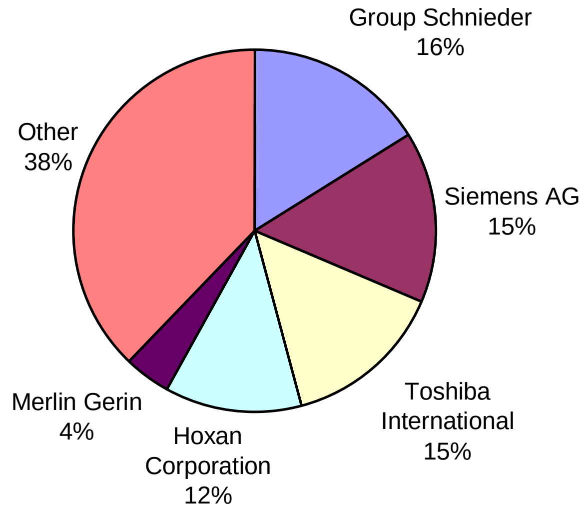
The leading domestic UPS system manufacturers are American Power Conversion (APC) and Liebert Corp., followed by Best Power Technology. APC held an estimated 27% of the total UPS market and was particularly strong in smaller systems. Liebert and Best had estimated domestic market shares of 14% and 11%, respectively.



Source: "Uninterruptible Power Supply Systems: Continuous Data and Network Systems", *R.* Moran, Business Communications Company Inc., Norwalk, CT, 1998.

Figure 5-5
Domestic Market Share of Leading U.S. Manufacturers (%)

Other major international competitors include Group Schneider (French) and Siemens AG (German.)



Source: "Uninterruptible Power Supply Systems: Continuous Data and Network Systems", *R.* Moran, Business Communications Company Inc., Norwalk, CT, 1998.

Figure 5-6
International (non U.S.) Market Share of Key Overseas Competitors (%)

UPS system manufacturers may use several brands of batteries, depending on the individual product line. Battery manufacturers and brands cited by interviewees include Johnson Controls, SAFT, Varta, Yuasa-Exide, C&D Battery Systems, East Penn Manufacturing, Hawker, and Chloride Power.

UPS systems are essentially sold through three channels: direct to application user, to an electronic vendor or OEM, and to an electronic parts supplier. Typically the electronic parts supplier handles only the smaller and simpler systems. Many telecommunications companies purchase from both a distributor and the OEM. This depends on availability of the product, as well as any contract agreement between the buyer and seller.

Service networks vary depending upon the type of UPS applications. Small UPS systems are self-diagnostic, so manufacturer field service is limited. A network of authorized service representatives provide field service for larger UPS systems for most manufacturers.

5.5 Battery Technologies, Key Buying Criteria and Customer Satisfaction

UPS batteries normally operate in full-float mode, supplying all the load requirements plus the power needed to keep the battery at full charge. Batteries for use in UPS systems usually must deliver high currents for short periods of time. Some manufacturers characterize these cells as high performance cells. These cells typically are modifications of the traditional electric utility and telecommunications cell designs, which are designed to deliver moderate discharge over long periods. The modifications are designed to minimize internal cell resistance and enable the chemical reaction to occur as rapidly as possible. At the same time, they tend to shorten the life of the battery from about 20 years to something less than ten years.

There are two basic types of batteries used in UPS systems: lead acid and nickel cadmium. Lead acid use predominates because of its lower cost and wide availability. VRLA batteries are generally favored over flooded lead acid in applications around other electronic equipment because of the risk of acid-mist from the battery damaging the electronic equipment. Nickel cadmium used to be favored for such applications. Many industrial applications use large flooded lead acid batteries for their low costs and good cycling capability.

Lead acid batteries come in two plate-material versions, lead calcium or lead antimony grids. Lead calcium dominates in UPS applications overall because of its ability to deliver the better short-time performance. Lead antimony can be preferable in high-frequency cycling applications. The least expensive UPS system uses sealed VRLA batteries containing grids of lead and antimony and an electrolyte of sulfuric acid. In temperature controlled environments, these batteries last from three to six years.

VRLA batteries have two basic types, gelled electrolyte and AGM, or Absorbed Glass Mat. Gelled batteries are general purpose batteries. They contain acid that has silica gel added to it, which turns the acid electrolyte into gel. It makes it impossible to spill acid when the case is broken. The disadvantages are that they must be charged at a slower rate to prevent excess gas from damaging the cells. They must also be charged at a lower voltage then flooded or AGM batteries. If overcharged, there will be a loss in capacity. In hot climates, water loss can limit a battery’s life to only several years. AGM batteries are high-performance batteries and have very fine boron-silicate glass mats between the plates. These batteries are more durable than gel cells, and also do not spill. AGM batteries are considered to be recombinant in that the oxygen and hydrogen combine inside the battery, which prevents water loss. This process is over 95 percent efficient.

VRLA batteries are usually used in smaller UPS where voltage and current demands are at a lower level. Lead calcium batteries have wider recharge tolerances, longer life, and lower maintenance.

Nickel cadmium batteries offer high energy density at higher cost. They are also reputed to offer greater reliability and can be found in some highly sensitive customer applications. Nickel cadmium is also a better fit when operating environments are cold and there are physical space constraints. Additionally, some flooded NiCd UPS Systems are being used in lieu of lead acid because of their greater durability at higher temperatures. Typical industry standards indicate that VRLA batteries lose 50% of their capacity for every fifteen degrees in electrolyte temperature above 77 degrees Fahrenheit. A NiCd battery, on the other hand, will only use 15% of its capacity under the same conditions.

All of the top ten UPS suppliers use lead acid batteries in their UPS systems. The batteries are generally of flat-plate construction, with nickel cadmium using the pocket plate design. According to one source, less than 3 percent of larger UPS applications use NiCd batteries. These applications are reportedly primarily those with high power reliability requirements and include banks and air traffic control.

At least one advanced battery technology is sold into UPS applications today. Industry contacts report that NiMH batteries are sold into very small desktop UPS systems, but have not moved into the larger sizes because of their cost. Out of 4 manufacturers of larger NiMH batteries (Hawker, Panasonic, Sanyo, and Saft battery,) none reportedly sell to UPS systems manufacturers.

Cost remains a key buying criteria for the UPS systems manufacturers, all other technical specifications being equal, as well as for the end users. Size and safety needs are generally being met by the available VRLA products, which also offer varying degrees of reliability and life depending on the battery construction.

Customer satisfaction remains high for the lead acid UPS systems. The satisfaction is not only with the battery, but also with the sophisticated electronics that monitor the performance of the UPS system in general.

Most UPS systems operate in temperature-controlled environments, so shortened battery life is less an issue in these applications than in others. These customers perceive additional value from smaller and lighter batteries and systems, but generally are not willing to pay much more for them. Cost analyses done by the end user typically do not provide a cost credit for the real estate space savings associated with smaller, more powerful batteries, so any space savings would need to come at a comparable price and reliability. The willingness of these customers to try new technologies is a function of how critical the application is. Where it is not critical, willingness is high. Otherwise, the perceived benefits from the new technology must be significant for any risk to be taken.

5.6 Conclusions

The UPS battery market is a large, rapidly growing market for batteries of all sizes. Most applications are indoors in temperature-controlled environments and often are around electronic equipment. VRLA lead acid batteries predominate in this market, and users are generally satisfied with their current technology. System and battery cost is usually a major consideration, with life, maintenance, size and run-time also important considerations. Run-times tend to be shorter than for other applications because many UPS systems are backed up by generators.

Some UPS system manufacturers are open to new battery technologies and would be quite interested in smaller, lighter batteries that cost less. Other system manufacturers are tied to supply from an affiliated battery manufacturer and limit purchases to those supplied by the affiliate.

5.7 References

"Uninterruptible Power Supply Systems: Continuous Data and Network Systems", *R.* Moran, Business Communications Company Inc., Norwalk, CT, 1998.

"Large and Advanced Battery Technology and Markets", D. Saxman, Business Communications Company Inc., Norwalk, CT, 2000.

"Specifying Batteries for UPS Systems," M.W. Migliaro, *Plant Engineering*, March 21, 1991, p. 100-102.

6
ADVANCED BATTERY TECHNOLOGIES

The advanced battery technologies assessed for stationary application feasibility in this analysis were nickel metal hydride, lithium ion and lithium polymer. While there is a fair amount known about nickel metal hydride capabilities and potential costs, less in known about lithium ion and lithium polymer.

6.1 EV Batteries

In electric vehicle applications, NiMH batteries are the only advanced battery technology currently in use in electric vehicles. Recognized EV battery experts have recently concluded that both lithium ion and lithium polymer are quite far from commercialization for electric vehicle use. Current planned battery modules reflect significant improvements in Lithium battery specific energy over their NiMH counterparts; however, many uncertainties remain about their ultimate performance and price characteristics. Appendix E presents the current specifications of the three technologies in electric vehicles as well as their projected development timeline, as reported in “Advanced Batteries for Electric Vehicles: An assessment of Performance, Cost, and Availability” prepared by the Year 2000 Battery Technology Advisory Panel.

Table 6-1
Advanced EV Battery Comparisons

	Comparison to NiMH Batteries	Time to Commercialization
Lithium Ion	• Likely to be more expensive (initial cost) • Operating life only 2 to 4 years now	• 4 to 6 years from commercial production
Lithium Polymer	• Potential to be cheaper – $200/kWh or less initial cost • In pre-prototype cell stage of • development	• Possibly 7 to 8 years from commercialization

Source: “Advanced Batteries for Electric Vehicles: An Assessment of Performance, Cost and Availability,” Year 2000 Battery Technology Advisory Panel.

6.2 Advanced Batteries in Stationary Applications

When assessing the feasibility of new technologies, it is essential to focus on those product characteristics that are of critical importance to the customer. While in stationary batteries critical characteristics vary depending on the applications, the critical differentiating characteristics in general are price, reliability, size, and operating temperature range, with maintenance requirements a more distant issue. Of course these product characteristics need to be supported by other manufacturer capabilities, such as service and recycling support, but the latter are generally not critical issues in purchase decisions today.

One note on research approach in this section. Our research into the applicability of the technologies at this point did not delve into the technical detail, but rather rests on the opinions of selected individuals that are knowledgeable about the technologies and electric vehicle and stationary applications. There is, of course, potential for further qualitative and quantitative research in this area.

Overall, when compared to existing technologies, advanced EV batteries can be expected to have qualitative characteristics that are largely similar to the characteristics of NiCd batteries and to a lesser extent to VRLA batteries. NiCd and VRLA batteries generally have a higher initial price, smaller size, and potentially lower maintenance costs. NiCd batteries distinguish themselves from VRLA batteries in their higher operating temperature range and purported greater reliability, as shown in the table below. Like these two battery types, advanced batteries typically have higher initial costs, smaller size, and higher operating temperatures, and some promise lower maintenance costs as well.

Table 6-2
Distinguishing Characteristics of NiCd, VRLA, and Advanced EV Batteries vs. the Industry Standard Flooded Lead Acid

Characteristic	VRLA	NiCd	Advanced EV Batteries
Initial Cost	Higher	Higher than VRLA	Higher than VRLA
Size	Smaller	Smaller	Smaller than VRLA and NiCd
Maintenance Requirements	Lower or Equal	Lower than VRLA	Some lower than NiCd with remote monitoring
Operating Temperature Range	Lower	Higher than VRLA	Some higher than NiCd. NiMH unclear

Source: PHB Hagler Bailly market research

Because of the similarities between the strengths and weaknesses (from a customer's perspective) of these technologies, opportunities for the new technologies would most likely rest with those where NiCd and/or VRLA batteries are currently the favored technology. Further, the competitiveness of the advanced technologies will hinge first on whether they can deliver greater value to the customer than these two existing technologies.

6.3 NiMH vs. NiCd

NiMH batteries are in commercial use today in small portable applications, and their scaling up for use in EVs has been largely accomplished. Yet, there are no apparent applications of NiMH technology in stationary applications. Speculation suggests that this reality stems from the fact that primary ownership of the NiMH technology rests in the hands of automotive companies and that they have not seen the benefit of expansion into stationary markets. On the other hand, one of the leading Japanese battery manufacturers with the NiMH technology is only considering expanding into emergency lighting batteries with the NiMH technology.

In comparing NiMH and NiCd technologies, the industry contacts commented that NiMH technology does not offer more customer value than the existing NiCd battery and has some significant drawbacks. A comparison of NiMH and NiCd technologies offered by one manufacturer of both battery technologies is shown in the following table. This manufacturer considers lithium technologies to have more potential to outperform their current NiCd products. This manufacturer has a long history with NiCd batteries, primarily in stationary applications.

Table 6-3
NiMH vs. NiCd Batteries in Stationary Applications

- Higher Energy Density but More Expensive Than NiCd
- More costly to recycle
- Equally toxic
- No Track Record vs. an Established NiCd Record
- More Temperature Sensitive, Requiring Cooling at High Temperatures
- Lower Charging Efficiency
- NiMH is also Inferior to Lithium on Weight and Energy Density

Source: Industry Manufacturer

For the reasons cited in the above table, this manufacturer has chosen to continue to manufacture and market NiCd batteries for stationary applications, and to consider developing a lithium ion product line for stationary applications as that technology matures.

As cited earlier in this report, in customer research for this project, customers who appeared likely to have applications suitable for NiMH batteries were asked to react to a sample NiMH product. The selected customer reactions were generally mixed across the board. Of course, a true customer reaction would require actual field tests in customer applications, none of which are currently underway with the NiMH technology.

There are a number of scenarios under which NiMH could achieve a share of this market, but the scenarios' probabilities are not very high. Under one scenario, cadmium supply becomes an issue and prices and availability become problematic. This scenario appears highly unlikely given the current availability and trends in cadmium use as well as current cadmium prices. Another potential scenario is a ban on cadmium batteries similar to that proposed in Europe. In the U.S., industry contacts were unaware of any momentum against cadmium use and, in fact, with the removal of cadmium batteries from hazardous waste status within the last several years, any momentum appears to be in the opposite direction. Industry reports suggest that nickel cadmium recycling facilities are in place and that health and environmental issues are around the batteries' use are minimal. Finally, one potential scenario would have bans on European use of stationary, consumer and EV NiCd batteries. In this scenario, there may be potential to drive NiCd battery prices up into the $900/kWh range. Under such circumstances, and if NiMH prices were lower because of their use in EVs, there could be potential for NiMH batteries to penetrate NiCd's market niches. This would only happen, however, with a concerted marketing effort by the NiMH battery manufacturers and would likely happen quite slowly as NiMH technology is largely unproven. It should be recalled that many of these purchasers recently had bad experiences with the proven VRLA technology that delivered two- year life in these targeted applications.

6.4 Perceptions of Lithium Technologies in Stationary Applications

Interestingly, in stationary applications there is already a fair amount of discussion of lithium technologies and their potential attractiveness in stationary applications. Lithium technologies were perceived by several in the industry to be the natural successor to NiCd batteries in stationary applications. One manufacturer involved with all four technologies (NiCd, NiMH, Lithium Ion and Lithium Polymer) indicated that they had no plans to develop NiMH product for large stationary applications, but that Lithium, probably lithium ion, products had some potential to outperform NiCd in similar applications. They were not yet, however, testing these products in the U.S. These batteries are now reportedly about eight times the cost of VRLA batteries.

A competing battery manufacturer, however, considers there to be at least two significant problems with the lithium ion technology. Two issues are safety issues: first, the technology is flammable and, second, that thermal runaway can occur under certain conditions while charging. A third stated concern is that the calendar life will never be lengthened to a competitive length.

This same manufacturer that raises concerns about the lithium ion technology, Argotech, is investing in and researching Lithium Polymer in stationary applications. Argotech is now pursuing development of the telecommunications market, principally outside plant in cellular and local exchange companies, the same markets into which nickel cadmium is being sold. Argotech plans to also target peak shaving and load leveling applications as well as nuclear power plant sites over the longer term. They anticipate having in place a couple of load leveling pilot sites by year-end as well. They consider Lithium Polymer a tougher sell against VRLA in UPS applications and industrial applications because of shorter UPS run times and greater industrial cycling requirements.

The company is planning on developing one Lithium Polymer product that they believe will cover 70% of the applications covered by 200 VRLA products. In their two pilot sites, they are testing a 24v 80 Ah battery, but plan to move to a 48v 40 Ah battery by year end. They plan to package and market their products on their own, without using any sales representatives for the foreseeable future. Their two current pilots are in local exchange company outside cabinets, while their additional two pilots are expected to included one cell site in addition to another outside cabinet. Argotech has announced plans to begin production of their lithium product for the stationary market in 2002.

According to Argotech the Lithium Polymer technology's strengths relative to VRLA batteries far outweigh their weaknesses. Essentially, the lithium polymer product is projected to be four times the cost of VRLA batteries, have a 10-year life, lower maintenance costs and have a wider operating temperature range.

Table 6-4
Lithium Polymer Characteristics vs. VRLA

- Four times the initial cost of VRLA
- One-fifth the weight of VRLA
- Expected life of 10 years vs. actual VRLA life of 2 years
- Wider operating temperature range, -40 degrees C to 65 degrees C
- A preference for warmth, and costs to heat a battery are much lower than cooling costs
- No maintenance
- Have a remote monitoring capability that cannot be replicated in VRLA batteries

Source: Argotech

A number of telecom customers commented that they had looked at lithium products and concluded that they may have potential in some of their applications. A couple limited the potential to small outside applications, while others spoke more generally about its potential.

6.5 Conclusions

In summary, the advanced battery technologies appear likely to have at least a technical fit with those applications that NiCd can penetrate, and potentially other VRLA applications. NiMH does not appear to be an attractive alternative to NiCd from either a technical or marketing perspective although under certain circumstances it can be envisioned that NiMH would be the successor to NiCd batteries. Lithium technologies are generally considered to have more potential for delivering more value to customers than existing technologies and than NiMH, and the lithium technologies are being pursued seriously for outside telecommunications applications already by at least one manufacturer. The ultimate success of the lithium technologies is, of course, highly uncertain at this time.

6.6 References

"Advanced Batteries for Electric Vehicles: An assessment of Performance, Cost, and Availability," Year 2000 Battery Technology Advisory Panel.

7
SECONDARY USES FOR EV BATTERIES

The term secondary use refers to the deployment of used batteries in other applications than the first vehicle in which they were installed. The basic concept is that the used batteries may have significant value and that this value may be more profitable to exploit than the value obtained by classic battery recycling. By exploiting the value of the batteries at the "end of life" in the first electric vehicle, one can imagine that the actual cost of the batteries to the first user may be reduced and therefore that the electric vehicle may become more economically feasible.

This issue is complex and analysis involves a number of assumptions. It is the purpose of this chapter to frame the issues and to suggest further research that will enable good business decisions and reasonable policy decisions to be made.

The simplistic argument is as follows. Nickel metal hydride batteries, in production volumes of 100,000 battery packs per year, will be priced to the auto makers at $300/kWh. They will provide 70 Wh/kg and will degrade to 80% of their initial capacity in 1000 cycles in an electric vehicle. The 80% of initial capacity is defined as the end of life. This means that an EV-1 for example, will suffer a range degradation from 140 miles to 112 miles and that the customer will no longer be satisfied with this range and will want a new battery and will be willing to pay about $300 per kWh for the new battery. The arithmetic and logic get a bit more interesting when one considers time. The 1000 cycles listed above might be considered to be 80% depth of discharge cycles. That is, 112 miles per cycle. If this is so, the vehicle will have traveled 112,000 miles by the end of the battery's life. At, say 12,000 miles per year, this represents 9.3 years of use. Perhaps the vehicle will be at the end of its life at that time. No one knows what the life of the EV-1 might be, but it is likely that the vehicle will not be in the hands of the original owner at that time. On a cost per mile basis, the 30 kWh purchased with the original $300/kWh cost $9,000. Amortized over 112,000 miles, the cost per mile was $.08/mile.

Now what is the value of the batteries at this point in time? If the batteries are decaying in capacity (and energy) in a linear manner with cycle number, we have a battery pack that has not 70 Wh/kg, but 56 Wh/kg specific energy. If we take as a benchmark a lead acid battery in a fork lift application, it has about 35 Wh/kg initially and we might assume that it reaches the end of life at 80% of this or 28 Wh/kg. The market is willing to pay about $150/kWh for this lead acid battery new. Its cycle life to 28 Wh/kg might also be 1000 cycles . Our nickel metal hydride battery has 56 Wh/kg and is decaying at a rate of 0.014 Wh/kg per cycle. It will decay to 28 Wh/kg in (56-28)/.014 cycles or 2000 more cycles. On a life cycle and specific energy basis, a customer should be willing to pay twice as much for the used nickel metal hydride battery as she is willing to pay for the lead acid battery. Thus the value of the $300/kWh battery is still $300/kWh after 9.3 years and 112,000 miles of use in an EV-1! Now the battery amortization cost is $0.00/mile.

Except for the time value of money. At 8% return, without considering taxes, one would have to pay an investor $9000 x (1.08)^9.33 or about $18,000, so the cost is still .$.08/mile. If the residual value of the battery were zero, the cost per mile would be $.18, because one does not realize the value of the investment for 9.33 years.

What factors comprise the residual value of the battery? Can the entity owning the battery expect to get $300/kWh net for it? Three factors influence the answer to this question. They are logistics, market, and finance. Logistics refers to the fact that the batteries must be collected, transported, analyzed for suitability, warehoused, maintained, redistributed, and installed in the new application. Market refers to the technical requirements of various applications and the technical capabilities of the re-used batteries. Finance refers to the warranty provisions and the assurance to the customer that he will get that for which he pays. To some extent, the market for used electric vehicle batteries might be similar to the market for used cars themselves. In the latter case, the customer looks at mileage, condition, past experience, personal testing, and salesmanship to assess the value of the product. There is a wholesale and retail market for used vehicles, and one could be expected to develop for used batteries. The logistic factors mentioned above would be similar as those for the used vehicle markets. The batteries might be collected by automobile dealers or at specialty battery replacement shops, which would then assess the condition of the batteries and make an offer to the seller, knowing the cost structure in the value chain following this transaction. If the batteries are distributed to new applications, then warehousing and transportation will be important. The length of the pipeline and the costs associated with inventory will have to be carefully managed.

From a technical point of view, considerable gaps exist in our knowledge about used nickel metal hydride batteries coming off of electric on-road vehicles. For example, in the above discussion, it was assumed that degradation was linear with cycles. It might turn out to be non-linear, or associated with time and temperature of operation more than with cycling. It is known, for example, that nickel metal hydride batteries degrade in the laboratory by mechanisms such as corrosion of the negative plate alloys used to store hydrogen and the associated use of water in the electrolyte to sustain the corrosion reactions. Therefore the batteries may dry out over time. One needs to characterize laboratory-tested batteries and compare them with field used batteries to identify various degradation mechanisms and to classify the batteries as to their suitability for next-use. One would need to characterize not only capacity on a standard test cycle, but also power capability, current and energy efficiency, float characteristics (for standby power applications) and other parameters which relate to next-use requirements. This implies that the next-use requirements are clearly known and specified. These issues must be dealt with in technical research which to date has not been done, or even started. Most laboratory tests of electric vehicle batteries are done in an accelerated mode (for example, the “dynamic stress test” run at higher than normal temperatures) but no one has much data on actual fleet degradation. It is expected that high temperatures of operation, for example in the southern and southwestern states, will degrade nickel metal hydride batteries more quickly than in cooler regions. However, some vehicle manufacturers have active battery cooling systems in their vehicles to counteract this effect. Further development of chemistry and alloy compositions will probably affect this degradation, so it will be important to know which generation of battery one is dealing with. This will complicate the valuation of used batteries.

Simple tests of used batteries must be developed to assess their condition and to predict their remaining life. Very little research has been done in this area, because the market is still developing and battery makers are still trying to modify formulations to cut costs. A few tests are underway in selected laboratories to condition batteries in vehicle like conditions, which will provide test articles for further characterizations. For example, DARPA and DOT have sponsored co-funded research on Saft nickel metal hydride deliverable from the USABC development program, along with Sacramento Municipal Utility District. These tests will provide sample batteries for tear down and failure analysis and for characterization tests of suitability for extended life in secondary applications. Such well-documented tests need to be supplemented with extensive statistical analysis of returned batteries from, for example the California fleet of MOA vehicles now being deployed by General Motors, Toyota, Honda, Daimler Chrysler, and Ford. It would be very helpful if a central analysis and evaluation program were initiated now to accept and sample the used batteries in the next few years and to create a systematic database of failure modes and life extension predictions, both in the laboratory and using field returns. Normally such activity is beyond the scope of the business community because of the uncertainty of the market, and the possibility of obsolescence in the technology (i.e., the emergence of lithium batteries to replace nickel metal hydride batteries). Without such a program, however, business decisions must be made in a vacuum and high-risk will probably inhibit much investment in re-use scenarios. In the end, the introduction of electric vehicles and the economic analysis of used batteries is a very risky business. A mechanism needs to be found to fund research into this important aspect of the business.

8
STATIONARY BATTERY SYSTEMS AND EV BATTERY COST IMPACT

8.1 Stationary Battery Systems

NiMH Use Study

A typical outdoor enclosure used for supplying non-stop DC power telecommunications or other applications is shown in Figure 8-1.

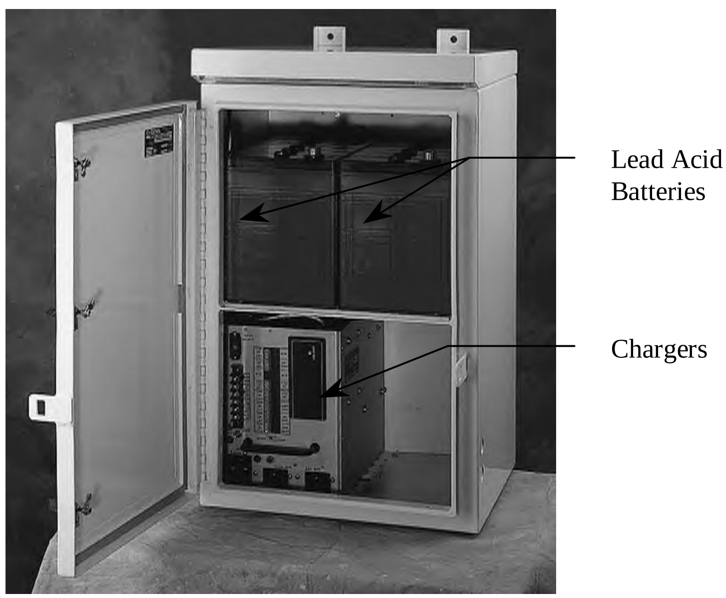


Figure 8-1
Typical Commercially Available

Figure 8-2 provides general dimensions for the enclosure shown in Figure 8-1.

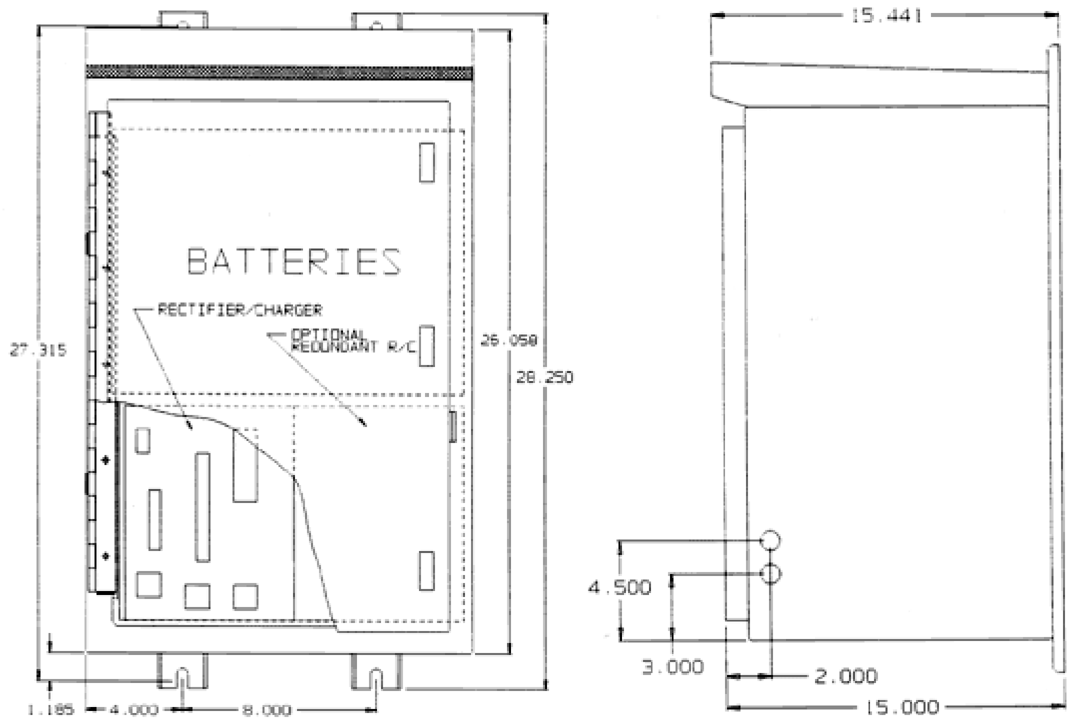


Figure 8-2
Dimensions for Commercially Available Enclosure

The outdoor enclosure shown in Figures 8-1 and 8-2 normally uses 12 V lead-acid batteries. These batteries can be used in many different configurations to accommodated different voltage, current, and capacity requirements. The lead-acid module offered for this enclosure had a rated capacity of 82 Ah. If used in parallel, 164 Ahs could be obtained. The above-mentioned enclosure can house 4 batteries of this size in series or parallel configurations (12 V, 24 V, or 48 V nominal).

The standard charger supplied with this system (collocated with the modules in the weather proof enclosure) can supply charge in any of the above-mentioned configurations. It also comes standard with a load disconnect that can be set to disconnect a minimum voltage and reconnect when the modules are above a set voltage limit. However, the above-specified system does employ a float style charge that may not be compatible with current NiMH modules. For this reason a different style charge may need to be specified.

Proposed use of NiMH Modules

Figure 8-3 provides a general look at two of the NiMH batteries being considered.

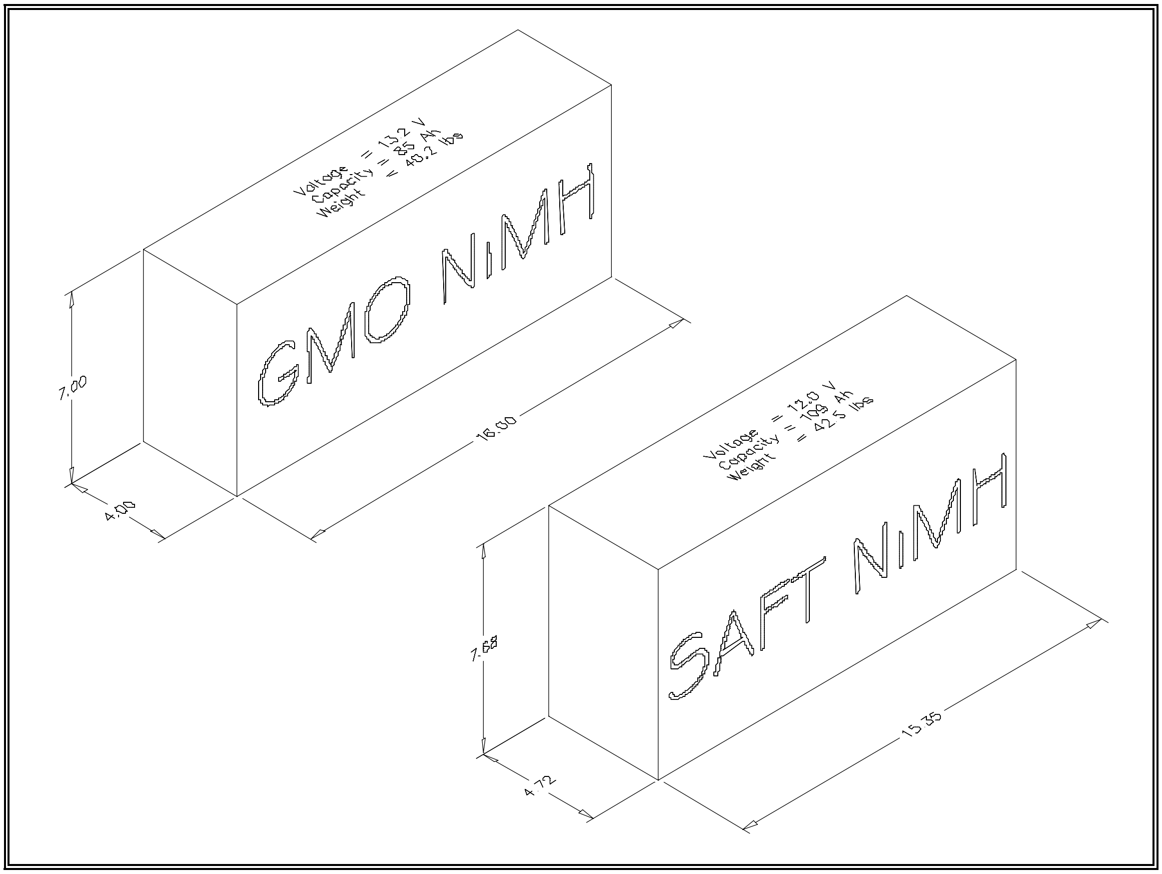


Figure 8-3
NiMH Modules Being Considered

In the absence of further (more specific requirements), the following layout is proposed. The proposed layout shown in Figure 8-4 represents a possible configuration in which the NiMH modules could be installed into a similar commercially available enclosure.

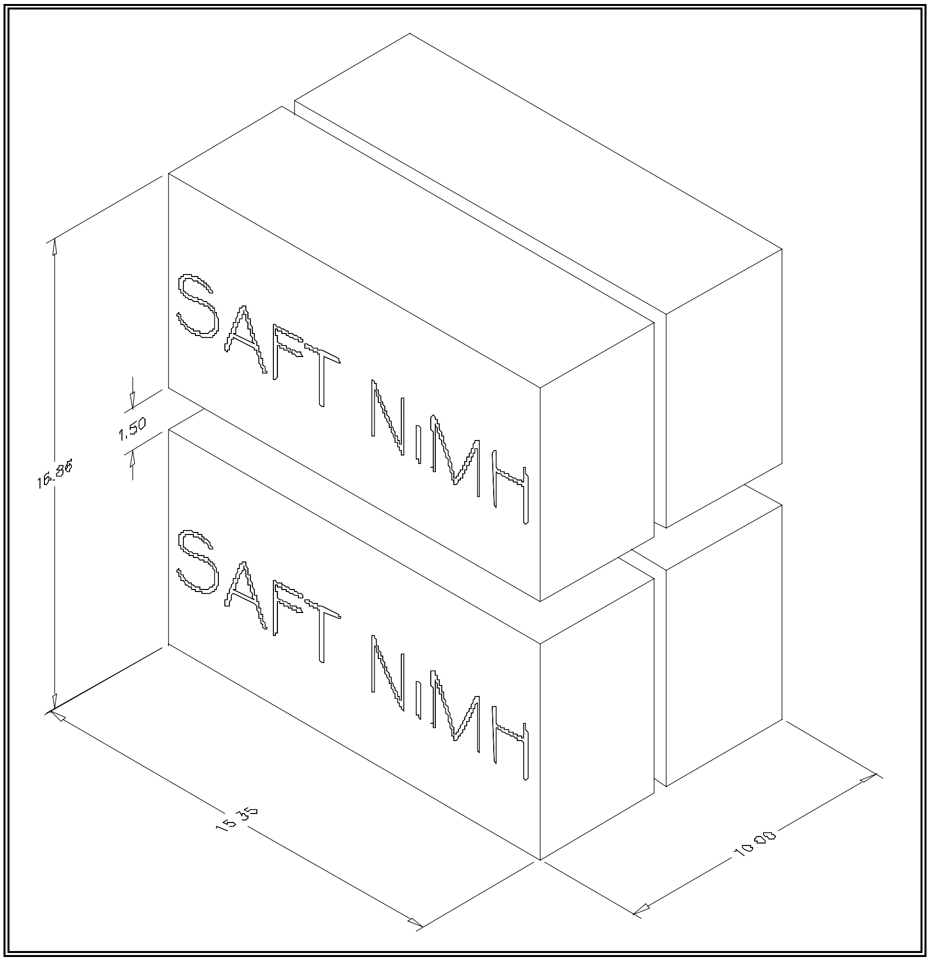


Figure 8-4
Proposed 12-Volt Module NiMH Module Layout

The module layout proposed in Figure 8-4 will fit into an enclosure similar to the one shown in Figures 8-1 and 8-2. The NiMH option will offer the same power configurations and safety options while offering longer back up times, and greater cycle life.

8.2 Cost Estimates for NiMH EV Modules

This section assesses the impact of incremental battery production/sales volume on EV battery costs. The CARB-sponsored Battery Technology Assessment Report provided the following summary of the costs of battery modules versus production volume.

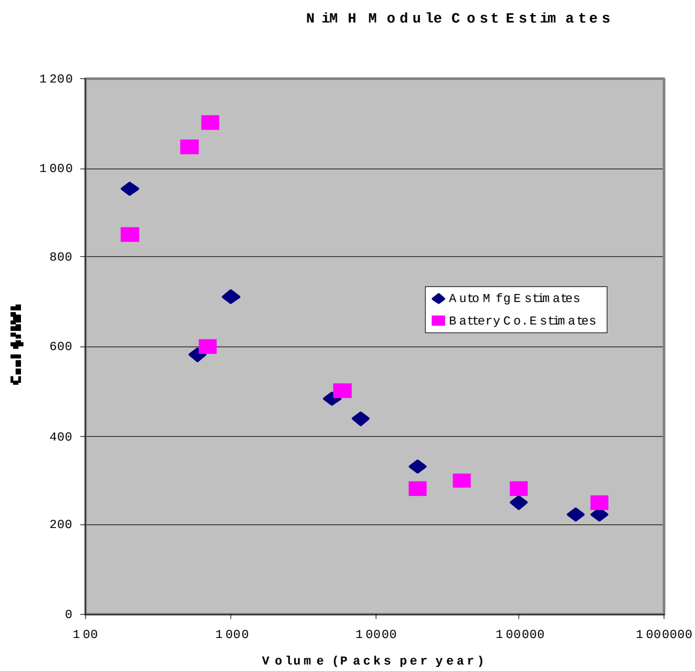


Figure 8-5
NiMH Module Cost Estimate

If significant volumes of batteries were produced for a stationary market, what would be the effect on this curve? For example, are we simply talking about getting down the cost curve sooner on a one-stationary-to-one-EV-battery basis? Or are we talking about lowering the cost curve at a given EV volume production because of opportunities to spread fixed or semi variable costs?

Where did the above curve come from? It was the collected (not collective) knowledge of battery companies and automobile manufacturers, which is based on a set of assumptions about raw materials costs and processing costs. Fixed costs such as plant and equipment are amortized over the total annual production volume. If one looks at a product such as the nickel cadmium battery for stationary applications, one would expect a similar curve to exist. Variations in the data at low volumes may depend on specific compromises that the companies have had to make to ensure delivery of product to near-term users. The analogy to a lead acid battery manufacturing activity should be considered. In the case of a modern lead acid plant, product moves through the plant completely by automation. The labor force never touches the product. The labor force only feeds components to the high-speed machinery that assembles the product and serves to maintain the machines. A reasonable sized starter battery factory can produce up to 5 million modules per year. At 30 modules per pack, this would mean that a single plant could provide the equivalent of 166,000 packs per year. So the flat part of the above chart reflects fully automated mass production. One might be able to achieve larger economies of scale, but in the case of batteries, plants are often located near markets to avoid excessive shipping costs, and global production demands that new plants be built rather than ever expanding single plants.

Various nickel metal hydride manufacturing processes involve some differences in materials processing up to the electrode manufacturing stage, but these variations do not affect the overall cost of materials. Differences in design, which may emphasize specific energy over cycle life, may also influence costs, and the technology must still be considered under development. Without breakthroughs in nickel utilization, and assuming that present levels of cobalt will be reduced through additional product development, raw materials costs of $150 per kWh appear to reasonable for high levels of manufacturing associated with more than 100,000 packs per year. It may be necessary to consider what chemical modifications could be made for very long-lived batteries. For example, we have considered secondary use scenarios in one section of this report. This assumes a lifetime of 10 years in the EV and perhaps 10 more years as a second use battery. No one knows yet if achieving this life will cause the introduction of costly materials. If the stationary application requires tolerance of high temperatures, which is not needed in the EV application due to system level cooling in the vehicle, then new materials, adding cost, may be necessary. However, in any case, if we assume $150/kWh for materials, then the remaining costs of production at high levels will be about $50/kWh with a margin to cover profit and expenses of and additional $50/kWh for a selling price (fob factory) of $250/kWh in line with the above chart. The chart below summarizes these components of battery factory module costs.

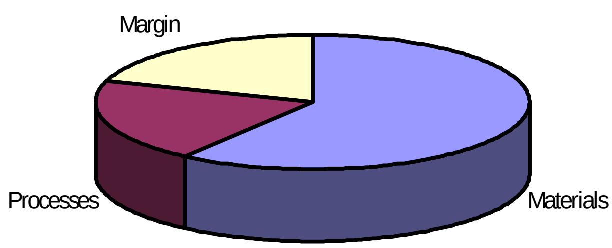


Figure 8-6
Cost Components for Nickel Metal Hydride Module

How would postulated stationary market applications impact the above calculations? In the case of lead acid plants, many models can be produced with the same bricks and mortar and much of the same processing equipment, provided the plate width is a constant. Without more information to the contrary, one may assume that plate width for EV and for stationary use batteries might be able to be made common. Note that this is not the case with large industrial lead acid batteries. They are not generally built on high-speed assembly lines alongside starting batteries. However, if we give ourselves this assumption, then the production of stationary batteries alongside the EV batteries will not affect the cost curves shown above.

The introduction of a large quantity of nickel metal hydride battery modules to the stationary market would change the rollout timetable for lowering the cost of EV batteries. At present, there is not an apparent market for such batteries, because the cost of lead acid alternatives seems to be below the threshold for competition from nickel metal hydride. With EV mandates that transfer the high costs of producing the early numbers of batteries to a party other than the normal buyer, a windfall of cost lowering might occur. This windfall might make it possible for nickel metal hydride to pass up nickel cadmium and to threaten the lead acid high-end batteries.

To illustrate this point, we have taken the estimates presented in the Battery Technology Assessment Panel report and re-plotted them as a single set of estimates, then forced a fitting equation through the points. We plotted in linear coordinates instead of logarithmic, and used a power curve y=x^p as the fitting function. The following chart shows the result:

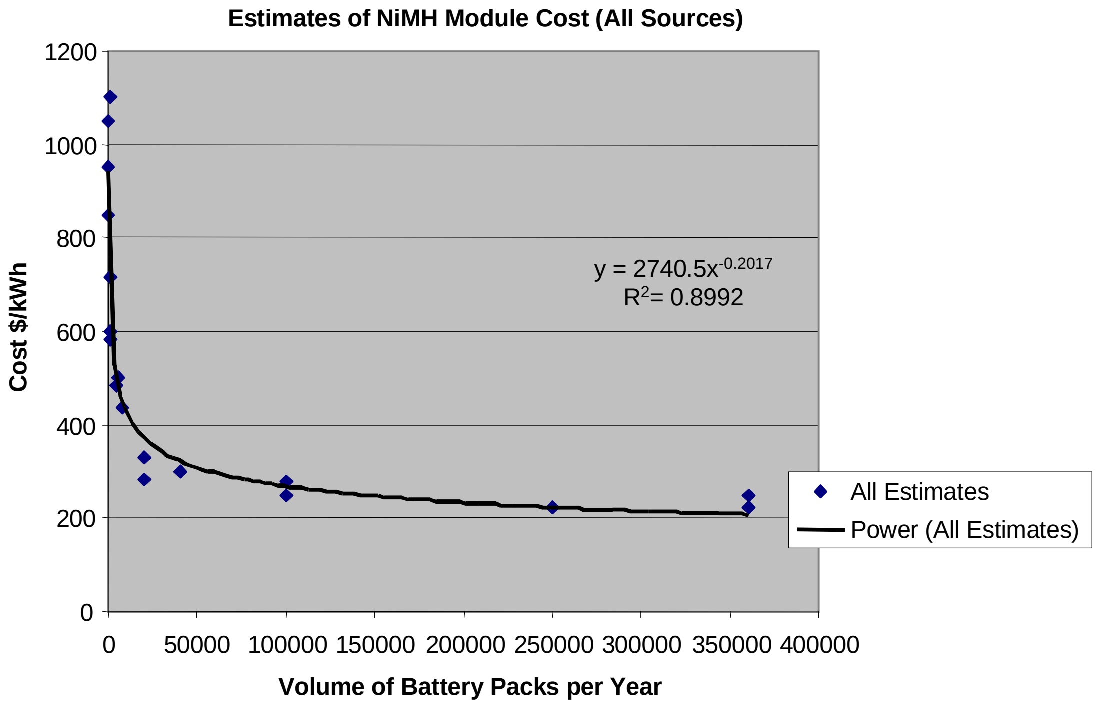


Figure 8-7
Estimate of NiMH Module Cost (All Sources)

The resulting power curve equations allows us to estimate "what if" an EV battery market of 20,000 packs per year were somehow to come into existence. Then we estimated that a small fraction of that market could penetrate the stationary power market. If the stationary power applications market grew to the same volume as the EV market within seven years, then the cumulative savings to the EV market due to the presence of the stationary market would be $141 million, as shown in the following example.

Table 8-1
Assumptions

Assumptions: 30 kWh EV Battery Pack
Mandated Sales of 20,000 EVs per year (assumes all batteries for EVs meeting mandate are NiMH, no lead-acid)
Power Curve Relationship Between Cost and Volume (Cost =2740.5 * Vol ^ -.2017)
A Free Market for Stationary Batteries at that Power Curve cost

Year	Number of Battery Packs for EVs	Number of kWh for Stationary Application	Equivalent Number of EV Packs From Stationary Application	Total EV Packs Equivalent	Cost per kWh (from Power Curve)	Cost per kWh Differential Due Having Stationary Applications	Net Savings to EV Industry from Having a Stationary Market	Total Size of NiMH Stationary Market
2003	20000	30000	1000	21000	$368	$4	$2,184,572	$11,044,840
2004	20000	60000	2000	22000	$365	$7	$4,247,572	$21,883,380
2005	20000	120000	4000	24000	$358	$13	$8,054,642	$43,005,346
2006	20000	240000	8000	28000	$347	$24	$14,637,428	$83,377,578
2007	20000	480000	16000	36000	$330	$42	$24,940,147	$158,512,980
2008	20000	600000	20000	40000	$323	$49	$29,106,463	$193,974,909
2009	20000	600000	20000	40000	$323	$49	$29,106,463	$193,974,909
2010	20000	600000	20000	40000	$323	$49	$29,106,463	$193,974,909

Simply put, without the development of a stationary market, an EV battery, based on the calculations presented in Table 8-1, would cost $372/kWh in 2003 and be expected to cost about the same in 2010. This is because production volume is assumed to remain constant. If an effective doubling of production occurred to supply an expanding EV or even new stationary market, the battery cost could be on the order of $323/kWh in 2010.

Note also on Figure 8-7 that, again based on the curve, that major cost reductions come in going from say a few thousand packs per year to tens of thousands. As the production volumes increase from say 50,000 packs per year to double that (100,000), the same kinds of cost deltas are not as great.

9

SUMMARY AND CONCLUSIONS

Overall, telecommunications, utility and UPS applications comprise a substantial market with projected revenue in 2004 on the order of $1 billion. From the perspective of advanced battery technology opportunities, several substantial market niches appear interesting, including NiCd applications, which competitor comments suggest are from 3% to 5% of the market. VRLA stationary applications, about 20% of all sales, also appear to have some weaknesses that may create opportunities for the advanced vehicle technologies.

Customer and manufacturer input indicates that customers are currently purchasing primarily flooded lead acid and VRLA batteries for most applications. Nickel cadmium batteries are receiving increased attention for use in high temperature applications. A new battery technology, lithium, has sparked interest in the telecommunications market and it is in the early pilot stages in stationary applications in that market. Flywheels have been integrated into existing UPS systems to extend the batteries' lives; however, market penetration still appears to be low and no other emerging technology appears to be a near-term threat.

Current technologies each have their comparative advantages and disadvantages that determine in which applications they are prevalent. Flooded lead acid batteries are sold primarily based on first cost and reliability, and they are prevalent in large telecommunications, industrial, power plant and substation applications. VRLA products are typically found in smaller footprint applications and where weight, emissions, maintenance cost, and leakage resistance are important. Other competitors, including NiCd batteries, typically aim to leverage a life cycle cost advantage over VRLA, primarily in high temperature applications where VRLA product lives have been unexpectedly short and NiCd's life cycle cost advantage is comparatively large.

Customer and manufacturer input suggests that the most attractive of these stationary markets is in telecommunications applications. While the advanced batteries are not likely to be competitive in temperature-controlled central offices or controlled environment vaults, in outside cabinets and huts where temperatures fluctuate significantly they could be competitive with the VRLA technology. The telecommunications industry is beginning to incorporate life cycle costs into their purchase decisions, and the short life of the VRLA batteries currently in these applications has created an opening for a more responsive product. At present, NiCd batteries appear to be successfully stepping up to this opportunity, thereby possibly limiting the potential for the advanced technology batteries. Over time as NiCd or the advanced technologies prove their life cycle cost advantages, there may be opportunities to expand their penetration of the telecommunications market into other VRLA applications. This high temperature market niche accounts for about $34 million in sales currently, based on an outside cabinet and hut market of $68 million (22%) and assuming that 50% are subject to significant temperature fluctuations. There appears to be a potential that these opportunities may grow to an $80 million market domestically in five years.

The utility market is less attractive. Not only is it smaller, but a significant unmet need does not exist in this market. Furthermore, life cycle costs are being incorporated in purchase decisions only marginally, if at all, and the risks of failure for a buyer are perceived to be quite high in most applications. Even at a low product cost, it is unclear that a new technology would be rapidly adopted in this market segment.

Like the utility switchgear and control market, the UPS market does not appear to have any major unmet needs that require the capabilities of the advanced technologies. The high initial cost of the advanced technologies could potentially be offset to some degree by the benefits of longer battery lives, smaller size, and reduced maintenance cost, but NiCd batteries offer many of the same advantages and are not a major player in this market segment. It is conceivable that once the batteries are proven there will be opportunities in this segment, but only if prices are competitive with existing technologies.

The advanced EV battery technologies with the greater potential for these telecommunications applications presently appear to be the lithium technologies. According to industry personnel, NiMH is less attractive than NiCd in these applications, while lithium products have the potential to offer more value than NiCd batteries. One manufacturer with NiCd, NiMH, and lithium capabilities commented that they plan to develop lithium ion, not NiMH, products to succeed their current NiCd stationary batteries. At least two lithium polymer pilots are operating successfully in outside plant applications and one battery manufacturer has announced plans to produce lithium polymer batteries for telecommunications applications in 2002.

NiMH batteries, in contrast, have not made it out of EV applications into the market although there are applications where the technology could be attractive with customers if the issue of recharging at higher temperatures is effectively addressed. The NiMH technology would need to compete well on price with NiCd, and ideally VRLA, to penetrate this niche. And even before this, significant effort would need to be made to develop the market for this technology through product development and pilot plants at customer sites.

Manufacturers contacted in this study are now focusing on the potential for their EV batteries in stationary markets and not their hybrid EV batteries. EV batteries are designed as energy, as opposed to power, batteries, and energy batteries are a better fit with standby applications. In contrast, hybrid batteries are a power battery and therefore appear to have less potential in the market. The UPS market may be the better fit with hybrid batteries, though further research into this opportunity would be needed.

NiMH appears to have limited potential in larger stationary battery applications as long as NiCd batteries are an attractive alternative and there is limited market development by NiMH battery manufacturers. The future for NiCd batteries in the U.S. appears good as cadmium supplies are reported to be more than adequate. In fact, producers are seeing the lowest prices they have in a long time, according to the U.S. Geologic Service. Efforts a few years ago to ban or reduce cadmium usage in batteries seem to have dissipated and there appears to be no resistance to its use in stationary batteries today. In fact, U.S. legislation within the last few years made it easier to recycle the NiCd batteries making them less of an environmental threat than previously. Perhaps the one uncertainty is the risk of a potential ban in Europe on all NiCd battery sales and its potential impact on NiCd batteries in the US.

Secondary battery use appears to have a great deal of potential for advanced EV batteries, but their value is highly uncertain. Selected research necessary to market the product has not yet been undertaken and the necessary infrastructure is not yet in place.

9.1 Related Issues and Next Steps

This study concludes that over the near term NiMH EV batteries would find it difficult to compete with NiCd batteries in stationary applications if NiMH battery manufacturers were to pursue these markets. One key assumption is that prices for the two battery technologies would not be widely dissimilar. With a potential NiCd EV or NiCd industrial battery ban in Europe, this situation could change. This situation should be monitored.

Another assumption behind NiCd superiority is that NiMH batteries may have issues around recharging at higher temperatures and consequently no life cycle cost benefit. Current laboratory findings that suggest this may no longer be an issue should be followed to see how they are applied in manufacturing and what the implications are for NiMH battery performance and price.

A final key assumption is that NiCd batteries are successful in their current targeting of the outdoors telecommunications market. Other battery technologies have not faired well and opened the door to a competitor, so the NiCd market results should be followed carefully. At the same time the performance of lithium polymer batteries in pilot test should be monitored to gather competitive intelligence.

Potential additional market research could be undertaken to understand the overseas, and particularly the European, market for advanced technology stationary batteries. The potential bans on NiCd stationary batteries would appear to open the market to NiMH alternatives, though probably not before 2008 by which time the lithium technologies may have proven themselves in applications.

Additional research should be undertaken to study carefully the potential for secondary use of EV batteries. One critical question is what the life of these batteries would be under varying conditions after eight to ten years in an electric vehicle and with 80% of their original capacity remaining. Design life can be a critical issue in the current stationary market, as evidenced by the fact that VRLA batteries are being displaced in spite of their lower price by an alternative technology because of design life problems.

Secondary battery use appears to have a great deal of potential for advanced EV batteries, but their value is highly uncertain. Selected research necessary to market the product has not yet been undertaken and the necessary infrastructure is not yet in place.

A
LIST OF COMPANIES CONTACTED

- Utilities
  - SCE
  - PG&E
  - NYPA
  - Boston Edison
  - VEPCO
  - Southern
  - FP&L
  - Puget Sound
- Telecommunications Services Providers
  - GTE
  - Sprint Local Exchange
  - Sprint Long Distance
  - PacBell
  - AT&T Broadband
  - AT&T Long Distance
  - Cox Communications
  - Charter Communications
  - Nextel
  - PacBell Wireless
- UPS Manufacturers
  - Best Power
  - APC
- Battery Manufacturers/Sales Reps
  - SAFT
  - Argotech
  - S&C Electric
  - GNB
  - Power Cell
  - ALCAD
  - McLaren, Inc.
  - M&M
  - Strikalite
  - Hawker
- Others
  - ENRL
  - USGS
  - International Cadmium Association
  - Batteries International
  - European Commission
  - Powercell

B
COMPETING TECHNOLOGIES

Supplier	Status	Price	Target Segments	System Capacity	Duration of Ride-Through	Expected Lifespan	Technology Features
Low Speed Flywheel							
Active Power	Intro in 1998	$100 to $200/kW	Telecom	200 to 600 kW	5 sec to 3 min	20 years (bearing change every five years)	– Operates under wide range of temperatures
			Data Centers	.67 to 1.67 kWh			– Unaffected by cycling and high power discharges
			Industrial UPS				– Requires 20% of space required by chemical batteries
Precise Power Corp.	Available	(With $20,000 to $150,000 generator)	Industrial Medical Computer Installations	10 to 150 kVa	15 sec at full load		
	Beta Units	$29,000 to $110,000 before discounts (with IC engine)	Cell Towers	10 to 80 kVa			
Zinc-Flow Batteries							
Powercell Corp	Available	System-dependent (<$2000/kW)	Utilities	100 kW/100 kWh modules	Can be configured to supply any duration required	20 years	– Operates at -20 to 100 degress F
		Lease-only	Industrial Distributed Generation				
High Speed Flywheels							
Beacon Power Corp	Beta Units	$3,000 to $5,000	Cable	1 kW/2 kWh	10 seconds	20 years	– Operates up to 140 degrees F
			Telecommunications			7 year maintenance interval	– Can be leased
			Power Quality (Future)				– No hazardous waste disposal issues
			Utility Load leveling (Future)				– Can be droped into a hole in the ground
SMES							
American Superconductor	Available	$200 - $600/KVA	Industrial UPS	1.4 MVA	3 or more seconds	20 years	– No degradation with use – Annual maintenance required
Ultra Capacitor							
Maxwell Technologies	Available	$350 - $450/kw	Industrial UPS	100kw/100kWh up to several MWs	5, 20 and 60 seconds	10 years	– High power density 1/10 the energy of a ??? battery – Low maintenance – Up to 104 degrees F

C
BATTERY CHARACTERISTICS

Electric Utility

Electric Utility (Switchgear and Power Generation)	Volts	Capacity	Length	Width	Height	Weight	Design	Energy Density
GNB								
Absolyte IIP	6V or 12V	105AH - 4800AH	437 - 1080 mm	217 - 218 mm	412 - 670 mm	71 - 361 kg	20 years	
Marathon	6V or 12V	28AH - 180AH	173 - 306 mm	167 - 174 mm	150 - 224 mm	11.8 - 33.6 kg		
Flooded	2V or 4V	200AH - 3700AH	105 - 383 mm	283 - 438 mm	464 - 638 mm	32 - 268 kg		
Saft NiCD								
SPH		11AH - 320AH	46.5mm - 202 mm	86mm - 166mm	196mm - 339mm	1kg - 16.5kg	Over 20 years	
Sunica	1.2V - 6.0V	35AH - 1,070AH	63mm - 437mm	195mm	349mm	5kg - 48kg	Over 20 years	
Ultima	1.41V - 1.45V	55 - 200	66mm - 93mm	121mm - 192mm	270mm - 352mm	3.4kg - 10.6kg	Over 20 years	21.6-33.8Wh/1

* Sources Include World Wide Web and Interviews w/ Battery Manufacturers

UPS

UPS Systems	Volts	Capacity (AH)	Length	Width	Height	Weight	Temp	List Price Per Unit
GNB								
Absolyte IIP	6V or 12V	105Ah - 4800Ah	437 - 1080 mm	217 - 218 mm	412 - 670 mm	71 - 361 kg		
Sprinter	6V or 12V	117 - 746Ah	173 - 306 mm	167 - 174 mm	150 - 224 mm	11.8 - 33.6 kg		
Flooded	2V or 4V	200Ah - 3700Ah	105 - 383 mm	283 - 438 mm	464 - 638 mm	32 - 268 kg		
Hawker								
Cyclon	2V or 4V	2.5Ah - 25Ah	79.5 - 139.2 mm	46.0 - 54.1 mm	69.9 - 101.6 mm	.36 - 1.43 kg	-65C to 80C	
Genesis	12V	13Ah - 70Ah	175.51 - 330.71 mm	83.36 - 168.15 mm	129.87 - 176.02 mm	4.9 - 24.3 kg	-40C to 45C	
Best Power								
Ferrups	500 VA to 18 kVA							$949.00 - $5965.00
Yuasa Exide								
DX / DXC	2V	.594 - 5.089 kw per cell @ 15 minute rate	241 - 424 mm	406 mm	558, 576 mm	119 - 143 kg		
Saft NiCD								
SPH		11-320	46.5mm - 202mm	86mm - 166mm	196mm - 339mm	1kg - 16.5kg		
Ultima	1.41 - 1.45	55 - 200	66mm - 93mm	121mm - 192mm	270mm - 352mm	3.4kg - 10.6kg	-50 to +70°	

* Sources Include World Wide Web and Interviews w/ Battery Manufacturers

Telecommunications

Telecommunications	Volts	Capacity (AH)	Length	Width	Height	Weight	Temp	Design Life	Discharge Cycles	List Price Per Unit
Hawker										
Cyclon	2V or 4V	2.5Ah - 25Ah	79.5 - 139.2 mm	46.0 - 54.1 mm	69.9 - 101.6 mm	.36 - 1.43 kg	-65C to 80C	10 years at 25C or 15 years at 20C	300 cycles	$2.50-$29.62
Genesis	12V	13Ah - 70Ah	175.51 - 330.71 mm	83.36 - 168.15 mm	129.87 - 176.02 mm	4.9 - 24.3 kg	-40C to 45C	10 years at 25C or 15 years at 20C	400 cycles	$70-216
Yuasa Exide										
DGX (High Cycling Cells)	2V-12V	170 - 4080Ah	660 - 1080 mm	585 mm	220 mm	136 - 355 kg				$38.00 - $1700.00
Telcom 30/ Telcom 40	12V	28, 40Ah	170 - 201 mm	128 - 168 mm	175 mm	9.3-13.6 kg	-20C to 80C			
DD/DDV	8V	120Ah - 1,360Ah	130 - 378 mm	379 - 629 mm	923mm	53 - 436 kg				
Phoenix-Float Service	12	90 - 200 @ 20 hours	169 - 178 mm	305 - 358 mm	244 - 302 mm	29.6 - 106 kg				
PL-110 / PL-150	12	110Ah-150Ah	542 mm	127 mm	305 mm	48 - 68 kg				
Central Offices										
GNB										
Absolyte XL	4V	2,000Ah - 6,000Ah	967 mm	543 mm	291 - 396 mm	315 - 447 kg	-40C to 50C	20 years	1,200 cycles to 80% DOD	For 3 XL (3000 AH) Batteries, costs will be $92,000
Absolyte IIP	6V or 12V	105Ah - 4800Ah	437 - 1080 mm	217 - 218 mm	412 - 670 mm	71 - 361 kg		20 years		
Flooded	2V or 4V	200Ah - 3700Ah	105 - 383 mm	283 - 438 mm	464 - 638 mm	32 - 268 kg				
All Other										
GNB										
Absolyte IIP	6V or 12V	105Ah - 4800Ah	437 - 1080 mm	217 - 218 mm	412 - 670 mm	71 - 361 kg		20 years		
Marathon	6V or 12V	28Ah - 180Ah	173 - 306 mm	167 - 174 mm	150 - 224 mm	11.8 - 33.6 kg				
SPH		11Ah-320Ah	46.5mm - 202mm	86mm - 166mm	196mm - 339mm	1kg - 16.5kg		Over 20 years		
Sunica	1.2V - 6.0V	35Ah - 1,070Ah	63mm - 437mm	195mm	349mm	5kg - 48kg	-50 to +60°	Over 20 years		
NCX	3.6V - 9.6V	93Ah - 186Ah	15mm - 420mm	171mm	257mm	11.4kg - 30.0kg	-50 to +70°	Over 20 years	57 - 65Wh/l	57-65Wh/1 (energy density)
Ultima	1.41V - 1.45V	55Ah - 200Ah	66mm - 93mm	121mm - 192mm	270mm - 352mm	3.4kg - 10.6kg	-50 to +70°	Over 20 years	21.6 - 33.8 Wh/l	21.6-33.8Wh/1 (energy density)

* Sources Include World Wide Web and Interviews w/ Battery Manufacturers

D

LIFE CYCLE COST

		VANTAGE NI-CAD	VENTED NI-CAD	LEAD VALVE REGULATED
	IEEE SIZING:	119Ah	58Ah	75Ah
	# CELLS:	32	95	20
MATERIAL COST				
Cells		$ 9,861	$ 9,633	$ 2,412
Seismic Rack		$ 750	$ 750	$ 1,134
Charger		$ 1,679	$ 1,309	$ 1,802
Initial Material Cost (First Cost)		$ 12,290	$ 11,692	$ 5,348
REPLACEMENT COSTS				
Reliable Life (yrs)		25	25	10
# of Replacements		0	0	2
Material Cost*		--	--	$ 8,855
Labor Costs*		--	--	$ 4,405
Total Replacement Cost (25 years)		--	--	$ 13,260
MAINTENANCE LABOR **	HRS/EACH			
Gen. Visual Inspection	0.1	9.90	9.90	29.90
Float Voltage-Battery	0.025	2.48	2.48	7.48
Float Voltage-all Cells	0.0042/Cell	6.57	19.60	4.12
Specific Gravity	0.0157/Cell	N/A	N/A	N/A
Temperature	0.025/Cell	2.48	2.48	49.50
Connection Resistance	0.0028/Conn	N/A	N/A	4.39
Connection Torque	0.0053/Conn	8.16	24.00	N/A
Impedance/Conductance	1	N/A	N/A	96.00
Discharge Capacity	4	32.00	32.00	112.00
Electrolyte Topping ***	0.025/Cell	0.00	38.00	N/A
TOTAL MAINT/TEST HRS. ****		61.59	128.46	303.39
TOTAL MAINTENANCE COST (25 YRS) *****		$ 4,628	$ 9,183	$ 20,504
25 YEAR TOTAL COST OF OWNERSHIP **		$ 16,918.00	$ 20,875.00	$ 39,112.00
AVERAGE ANNUAL COST =		$ 676.72	$ 835.00	$ 1,564.48

Notes:

* Material and labor costs inflated at 4%/year. Labor O/H burden rate is 100%.
Labor rates: Purchasing & Admin = $20/hr, Maintenance tech $20/hr, Engr = $30/hr.

** Maintenance labor is computed from estimated times to perform maintenance.
Based on IEEE/ANSI standards and industry experience.

*** Topping labor is based on manufacturer's recommended interval of 18 months.

**** Maintenance costs are computed on inflated labor costs in the year used.

E
EV BATTERY INFORMATION

NiMH Batteries

	Unit	GMO	PEVE	SAFT
Design Characteristics				
Nominal Capacity	Ah	90	95	96
Anode Chemistry	--	AB_2	AB_5	AB_5
Nominal Module Voltage	V	13.2	12	12 or 24
Number of Cells in Module	#	11	10	10 or 20
Nominal Module Energy	KWh	1.2	1.2	1.2 or 2.4
Performance Characteristics				
Specific Energy C/3	Wh/kg	70	63	66
Energy Density C/3	Wh/liter	170	150	140
Specific Power (80% DoD, 25°C, 30 sec.)	W/kg	200	200	150
Power Density (80% DoD, 25°C, 30 sec.)	W/liter	485	476	315
Cycle Life (100% DoD to 80% of initial capacity)				
at 20°C to 25°C	Cycles	~800 (80% DoD)	>1200	~1250
at 35 to 40°C	Cycles	~600	~1100	600

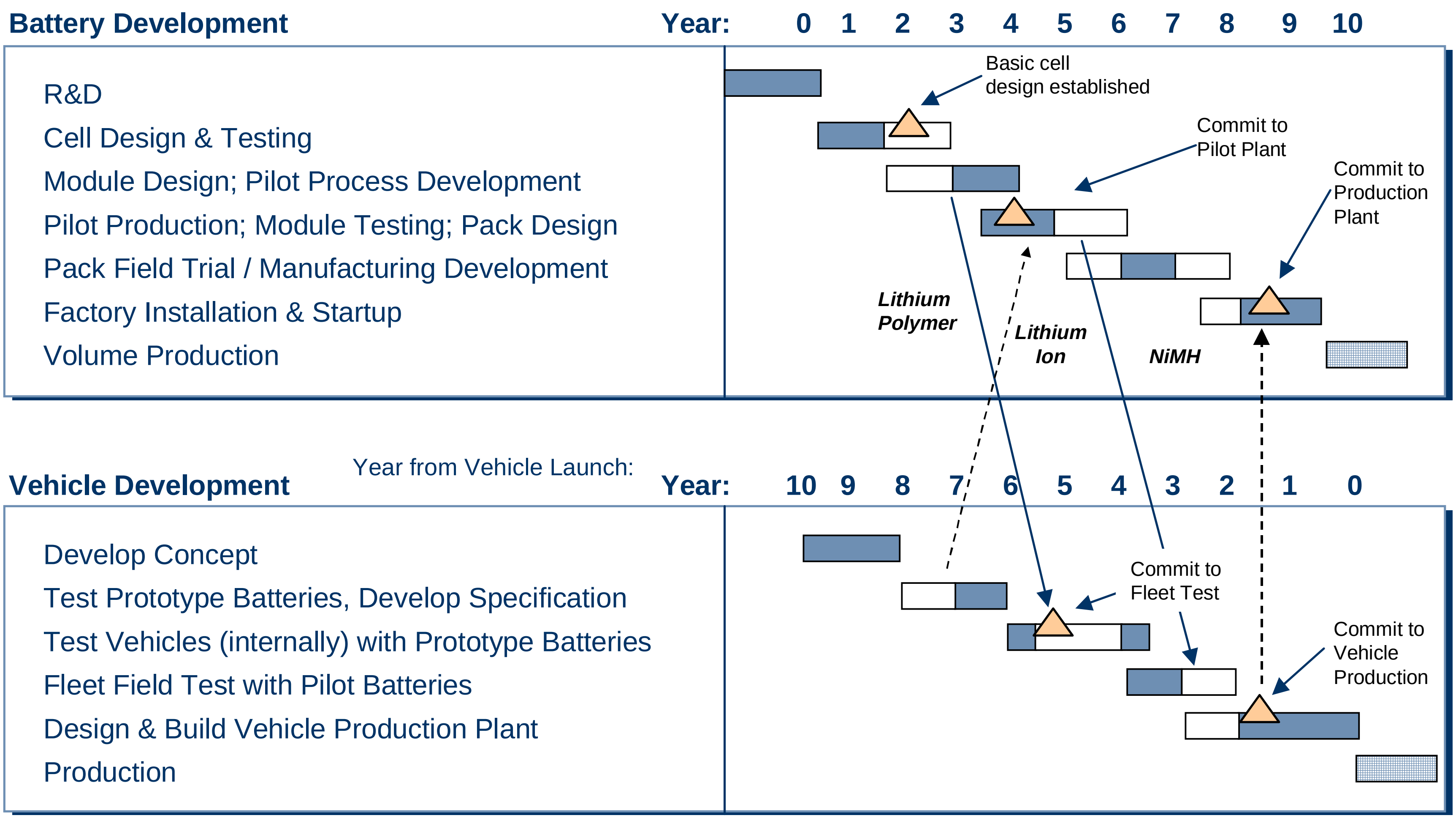
Source: "Advanced Batteries for Electric Vehicles: An Assessment of Performance, Cost and Availability," Year 2000 Battery Technology Advisory Panel.

Lithium EV Batteries

	Unit	JSB	Shin-Kobe	SAFT	Argotech
Design Characteristics					
Nominal Cell Capacity	Ah	88	90	90	119
Cell Design	--	Prismatic	Cylindrical	Cylindrical	Prismatic
Positive Electrode Chemistry	--	$LiMn_20_4$	$LiMn_20_4$	LiNiM'M"O_2(*)	LiV_20_5
Nominal Module Voltage	V	15	30	10.5	21
Number of Cells in Module	#	4	8	6	8
Nominal Module Energy	KWh	1.32	2.7	1	2.5
Performance Characteristics					
Specific Energy C/3	Wh/kg	97	93	138	110-130
Energy Density C/3	Wh/liter	168	114 (136)**	210	130-150
Specific Power (cell level)		50% DoD, 20 sec.	50% DoD, 10 sec.	80% DoD, 30 sec.	80% DoD, 30 sec.
at 20°C or 25°C	W/kg	810	750 (25°C)	430	300 (80°C)
at low temperature	W/kg	125 (-20°C)	328 (-15°C)	296 (0°C)	N/A
Cycle Life (100% DoD to 80% of initial Capacity)					
at 20°C or 25°C	Cycles	750 (25°C)	600	≥550	N/A
at 40°C	Cycles	230 (45°C)	<500	510	250-600 (80°C)

Source: "Advanced Batteries for Electric Vehicles: An Assessment of Performance, Cost and Availability," Year 2000 Battery Technology Advisory Panel.

Development Timeline



Source: "Advanced Batteries for Electric Vehicles: An Assessment of Performance, Cost and Availability," Year 2000 Battery Technology Advisory Panel.

Target:
Energy Storage Systems

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EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com