Lithium Ion Battery Safety

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Abstract

This project completed at the Consumer Product Safety Commission (CPSC) in Bethesda MD, researched lithium ion batteries because the risk of fire associated with their use is a danger to consumers. Data was collected from CPSC databases, government agencies, innovative companies, and battery organizations. The research indicated four potential directions for the CPSC to follow to make batteries safer for consumer use, (1) initiate round table discussion, (2) strengthen voluntary standards, (3) consumer education, (4) regulations and (5) new technologies.

Executive Summary

The two largest safety recalls ever from the consumer electronic industry, were of mobile telephones and notebook computers using lithium ion batteries (Darlin, 2006). The mission of the United States Consumer Product Safety Commission (CPSC) is to protect consumers from safety risks posed by consumer products. The lithium ion battery is a battery technology that can result in fires; however, these batteries also have a high energy density allowing products to be lighter and run longer. Thus the CPSC wants to investigate ways to make their use safer for consumers. Lithium ion batteries have been used since the early 1990s and have persistently experienced safety issues. Most recently, lithium ion batteries have spontaneously exploded or self ignited, and in some cases have caused injury to the consumer. There is a slim probability of a lithium ion battery causing a fire or explosion, but, when a malfunction does occur, the failure mode can be extremely dangerous; therefore, it is a concern for the CPSC.

Our project goal was to provide recommendations to the CPSC about potential solutions to minimize the safety risk involved with the use of lithium ion batteries for consumers. We followed these objectives to reach our final goal:

1. Categorized hazard scenarios from in-depth investigation (IDI) reports.
2. Compared and contrasted current voluntary battery standards.
3. Researched new battery technologies as alternatives to lithium ion batteries.

The first objective allowed us to categorize the circumstances surrounding the failure of lithium ion batteries. A Fault Tree Analysis was created in order to analyze the failure data from the in-depth investigation (IDI) reports. The second objective permitted us to discover possible limitations in current voluntary standards. We created a table that compared six well-known and worldwide voluntary standards. To complete our third objective, we researched innovative battery manufacturers that are either, developing measures to increase battery safety, or developing entirely new battery chemistries. We also interviewed and contacted several representatives from government agencies, manufacturers, and standards organizations. Meetings with government agencies allowed us to gain more detailed information on incidents not included in the IDI reports. Contacting organizations provided a better understanding of testing procedures and manufacturing guidelines incorporated in voluntary standards, the possibilities of roundtable discussions, and third party certification. Discussions with manufacturers allowed for better understanding of the current technology as well as new technology.

From the analysis of the IDI reports, it was determined that when lithium ion batteries fail they may experience thermal runaway. Thermal runaway is the term used to describe an accumulation of heat within a battery, which can activate a series of heat generating reactions causing the battery's internal pressure to increase. The flammable electrolyte can then leak out and ignite a fire. From classifying all of the In-Depth Investigation reports into one table, it was determined which scenarios or dangers occurred most often. Our analysis showed that most notebook computer batteries that malfunctioned were aftermarket batteries, instead of original equipment manufactured (OEM) batteries. Also, we found that most battery failures in mobile telephone batteries occurred while the battery was in a charging state.

Industry testing standards were compared by developing a table which included the different standards with associated tests, and described the requirements each test had to follow (Appendix M). This allowed for comparison of the integrity of each standard's specified test. Putting these standards and their associated tests in a matrix format allowed us to view limitations. Standards from the Institute of Electrical and Electronics Engineers (IEEE), Underwriters Laboratories (UL), the International Electrotechnical Commission (IEC), and United Nations Economic Commission for Europe (UNECE) were studied and correlations were found between each of them. For example the low pressure test (high altitude test) is identical in each of the voluntary standards, but the temperature abuse test varies. Additional research showed that additional tests are being developed that will subject lithium ion batteries to further conditions of normal use.

Through the research of new technologies we determined that there are several safer solutions in development that could reduce the safety risk for consumers. Examples of newer technologies discovered were additives, new electrolyte solutions, and new electrode materials.

Through the research and analysis we determined there were a number of causes of failure in lithium ion batteries and each could result in fire; therefore we determined five different options in which to potentially make these batteries safer for consumers:

1. Continuing roundtable discussions with manufacturers,
2. Strengthening voluntary standards.
3. Encouraging consumer education.
4. Providing potential innovative technologies.
5. Forming regulations.

After comparing all the possible options the CPSC could use to help alleviate the current lithium ion battery problem, we decided the best course of action would be to recommend stronger voluntary standards and consumer education. Incorporated in the recommendation for stronger voluntary standards are additional tests, revised tests that reflect current consumer use and foreseeable use, and encouragement of third party certification. These additions will still allow manufacturers to choose which voluntary standards to follow but also will increase safety and performance of lithium ion batteries. Our second recommendation is to begin a consumer education plan about lithium ion batteries and aftermarket batteries. Included in this recommendation would be safety labels on the products using lithium ion batteries written and placed by manufacturers and also a product fact sheet about safe use of products using lithium ion batteries on the CPSC website.

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Acronym Page

ABDT	Abbreviated Death Certificates
ATL	Amperex Limited Technology
CAP	Children and Poisoning
CEN	European Committee for Standardization
CPSC	Consumer Product Safety Commission
CTIA	Mobile Telephone Industry Association
DOT	Department of Transportation
DTHS	Death Certificates
EEC	European Economic Community
ETFA	European Free Trade Area
FAA	Federal Aviation Administration
FMEA	Failure Modes and Effects Analysis
HP	Hewlett Packard
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
INDP	In-depth Investigations
IPII	Injury and Potential Injury Incidents
IPS	Infinite Power Solutions
LIP	lithium ion polymer
LMO	Lithiated metal oxides
LMP	lithiated metal phosphates
LTC	Lithium Technology Corporation
NASA	National Aeronautics and Space Administration
NASFM	National Association of State Fire Marshals
NEISS	National Electronic Injury Surveillance System
NSWC	Naval Surface Warfare Center
NTSB	National Transportation Safety Board
OEM	Original Equipment Manufacturer
PRBA	Portable Rechargeable Battery Association
UL	Underwriter's Laboratories
UN	United Nations
UNECE	United Nations Economic Commission for Europe
ZMP	Zinc Matrix Power

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Chapter I: Introduction

Mobile technology is essential for communication. Not only are devices such as mobile telephones and notebook computers in high demand, but the desire for them to become smaller, more portable, and have a longer operating time between charging, is continuously increasing.

One significant problem in scaling down mobile devices is reducing the size of the batteries by which they are powered. A consumer wants the battery to have a long operating time between chargers and short charge times. However, it is difficult to make batteries smaller, lighter, and more powerful without compromising their safety. When they are produced smaller and lighter problems can arise which may result in fire. Due to the large risk of fire, millions of mobile products such as mobile telephones, notebook computers, portable DVD players and power tools have been recalled over the past three years (Appendix B).

Several battery technologies have come into common use; nickel cadmium batteries were developed in the 1940's. They have a long life, but must be discharged entirely before recharging (Kantor, 2004). Around the 1990's nickel metal hydride batteries became available. While they have a 40% higher energy density, they have limited service life and high maintenance (Buchmann, 2005). These batteries were typically too big and heavy to adequately supply the amount of operating time for the electronics.

During the late 1990's lithium ion batteries were developed. Lithium ion batteries provide three times the voltage of previous batteries, and are much lighter. However, lithium ion batteries have the potential to short internally and can ignite. Due to the large risk of fire, millions of mobile products that include lithium ion batteries such as mobile telephones, notebook computers, portable DVD players and power tools have been recalled over the past three years (Appendix B). Lithium ion batteries have high power outputs because of potentially harmful chemical mixtures, and they have become a large danger to consumers due to the possibility of overheating which may lead to the potential of fire in the product. One potential failure found in the batteries is due to small metal pieces within the electrolyte. These metal pieces can pierce the polypropylene separator causing the battery to short circuit (Polloack, 2006). Additional foreseeable use and abuse of products by consumers such as dropping the battery or exposure to extreme temperatures can also cause it to short circuit and catch fire.

The Consumer Product Safety Commission (CPSC) has addressed the risk by issuing large recalls for several lithium ion batteries. The batteries are fairly new and thus, there has only been some research done on their safety. Therefore, the CPSC wants to have data about risks and injuries compiled so the problem can be addressed. There are safer products being developed and these can decrease the hazards associated with lithium ion batteries.

This project will look at the risks involved in lithium ion battery technology and provide recommendations about directions the CPSC may want to follow in order to reduce the safety risk associated with the use of lithium ion batteries. In order to formulate these solutions, we will address incident reports, standards, and innovative technologies.

Chapter II: Background

The recalls of lithium ion batteries have been some of the largest thus far. In response, the CPSC has asked for potential solutions to reduce the hazards towards consumers. In order to provide solutions, an understanding of lithium ion batteries, the problems facing them, and knowledge of what others are doing, was necessary. The following sections discuss current technologies, battery risks, recalls, analysis techniques, and work that others have been doing on this problem. The knowledge gained from this research served as background which led to the recommended solutions.

2.1 Current Battery Technology

There are many types of batteries such as nickel metal hydride, alkaline, nickel cadmium, lithium metal, lithium ion, and lithium polymer. Each type has advantages and disadvantages for specific applications. Primary batteries are non rechargeable batteries. These primary batteries can contain alkaline and lithium chemistries. Secondary batteries are rechargeable batteries. Nickel cadmium, lithium ion and lithium polymer are most commonly used in consumer products requiring high energy rechargeable batteries. Such products include notebook computers, mobile telephones, portable DVD players, and digital cameras. Each battery type has benefits and hazards. Currently the most popular battery for consumer use is lithium ion.

2.1.1 Nickel Cadmium and Nickel Metal Hydride

The first major rechargeable battery implemented in many products was the nickel cadmium battery. This battery was developed around the late 1890s, but not made proficiently until the 1940s (Kantor, 2004). At that time, it was incapable of storing a significant amount of charge and was manufactured with toxic chemicals. Another major drawback of nickel cadmium batteries was that when used the batteries had to be drained of their power completely in order to be recharged efficiently. One advantage of nickel cadmium batteries was that they were and still are one of the most inexpensive secondary batteries on the market. There has been documentation that if properly maintained and discharged entirely before charging, nickel cadmium batteries can provide over 1,000 life cycles. Another major advantage is that the nickel cadmium batteries can be heavily abused. Nickel cadmium batteries are acknowledged to be the toughest rechargeable battery. A lithium ion battery can explode from a small amount of damage, whereas the nickel cadmium battery will remain resilient under abusive conditions (Buchmann, 2005).

However, the nickel cadmium battery was far from ideal and thus the nickel metal hydride battery was developed. This battery was introduced in the 1990's and offered 40% higher energy densities than the nickel cadmium battery (Kantor, 2004). The nickel metal hydride battery became the battery for mobile technology during this time and replaced the nickel cadmium battery. The nickel metal hydride battery was also more environmentally friendly than its predecessor. The nickel metal hydride battery still had disadvantages, such as a limited service life, high maintenance, and power loss over time (Buchmann, 2005).

Overall these battery types were adequate for their intended applications; however as devices required more power and consumers required longer life between charges and shorter charge times, these existing technologies were unable to meet the performance requirements. Lithium ion batteries were developed to produce a high power output and a faster recharge time.

2.1.2 Lithium-Ion

Lithium ion batteries, developed in the early 1990's, are now the predominant technology in the battery market. Compared to nickel cadmium batteries, lithium ion batteries produce about three times the voltage (Titus, 2004). These batteries are used throughout the world in many households and industries in products such as, notebook computers, mobile telephones, or power tools. These batteries have gained popularity not only because of the size to weight ratio, but also the superior size to energy ratio. The most common form of cell is the 18650 cell.

The make up of the lithium ion battery consists of an inorganic lithium-intercalating compound as a positive electrode, a lithium-intercalating carbon negative electrode, and a lithium salt in an organic liquid, known as an electrolyte (Hammel, Ring, and Vimmerstedt, 1995). In layman's terms, the lithium ion battery consists of two metal sources, one with a positive charge, and the other with a negative charge. Both metal sources must be different types of metal and separated by some sort of thermoplastic polymer, usually polypropylene. Polypropylene has a melting point of 160°C and is very resistant to many chemical solvents, bases, and acids (Polypropylene, 2006). Also, in between the charged metal sources there is flammable lithium containing liquid (Figure 1). The ideal lithium ion battery would contain a perfectly homogenous, non-combustible liquid with no impurities. However the process to make the battery can produce small metal pieces that float around freely. These particles can cause the battery to short circuit, overheat and cause fires (Wilson, 2006).

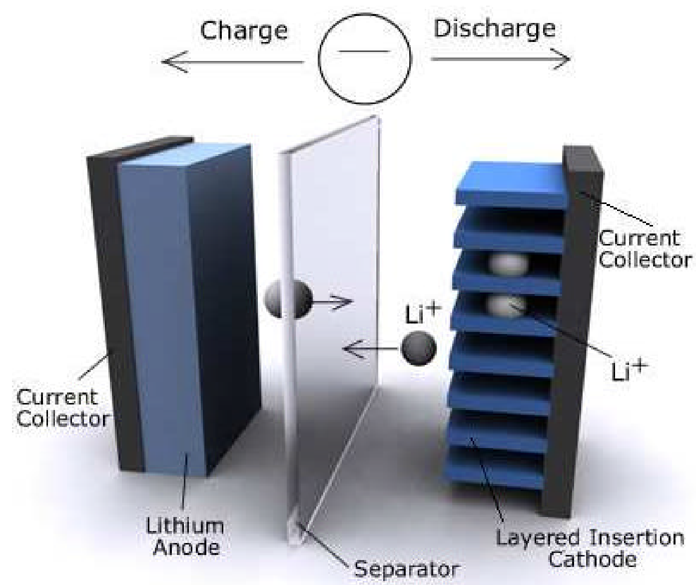

Figure 1: Lithium Ion Battery Structure
(http://www.notebook computer-batteries-guide.com/how-lithium-ion-battery-works.html)

New improvements in the battery have mitigated some safety concerns. There are two switches on the battery for automatic shut off when the battery reaches a predetermined temperature. The first switch stops the battery from recharging if the temperature reaches 71°C. Once the battery cools down, the switch will reset and allow charging to resume. This gives the battery a chance to operate and charge at a safe level. Another switch shuts down the entire battery irreversibly when the temperature reaches 90°C and the battery will be inoperable. It cannot be charged or discharged even if the battery cools down below 90°C (Cleaveland, 2006).

2.1.3 Lithium-Ion Polymer

The design of lithium polymer batteries was created in 1970, using a dry solid polymer electrolyte. The type of electrolyte used in the lithium polymer batteries are different than the electrolyte used for lithium ion batteries. The electrolyte does not conduct electricity but allows ion exchanges and looks like a thin plastic film, which allows the batteries to become very thin, as small as one millimeter (Buchmann, 2005).

One of the draw backs of lithium polymer batteries was they suffer from poor conductivity due to the dry polymer. This problem was overcome by adding a gelled electrolyte. Also, lithium polymer batteries have a lower capacity than standard lithium ion batteries. Lithium polymer batteries can be expensive making them less appealing to manufacturers (Buchmann, 2005).

2.2 Associated Battery Risk

Lithium ion batteries are used because their high energy density is beneficial for consumer products. However, they pose a large safety risk, because when they fail they will most likely go to fire, which is a danger to consumers.

2.2.1 What Goes Wrong

There can be several modes that cause lithium ion batteries to fail. One of the first occurs during the manufacturing process. Due to poor quality control during manufacturing, microscopic metal fragments can contaminate the electrolyte solution. These particles can be of varying size and number. If one of the fragments pierces the thin polypropylene separator between the negative and positively charged electrodes, a short circuit can occur (Pollack, 2006). The safety mechanism that shuts the battery down is based on the temperature of the battery and can do little to prevent this type of short circuit (Cleaveland, 2006).

Another potential cause of failure is foreseeable uses of batteries by the consumer, such as dropping or exposure to high heat environments. Batteries built using cobalt oxide in their electrodes are extremely reactive. At Valence Technology Inc., lithium ion batteries were subjected to tests involving sudden impact, puncture, crushing, and overcharging. According to Valence, the oxides in the batteries release oxygen when heated and a spark can ignite it. In one test a battery burned for four minutes and sustained temperatures of up

700°C as each cell exploded due to the heat generated by one cell exploding. This event is known as thermal runaway (Valence, 2006).

There is a complicated process that occurs within a battery that has been compromised. External thermal exposure, which can include leaving a battery in the sun or next to a source of heat, causes the cathode to breakdown releasing oxygen gas into the sealed battery. This causes pressure to build in the cell which generates more heat and makes the cathode even more likely to break down. The increased pressure makes the battery far more likely to explode from the stress. The reaction of discharging the battery is exothermic; therefore there is always a source of heat to fuel a potential combustion and it is difficult to stop the fire in one cell from spreading to the other cells (Valence, 2006).

The chance of a spark can cause the mixture of the flammable electrolytes (Ethylene Carbonate) to short circuit and catch fire, which may have been the cause of the fires that were attributed to the recall of millions of batteries (Hammel, Ring, and Vimmerstedt, 1995). Since the fires are fueled by the battery fluid within, the fires are difficult to control or extinguish.

Lithium ion batteries can fail in a number of ways besides fire and explosion. According to a presentation by NSWC Carderock, they can vent toxic electrolytes into the air, or can leak dangerous toxins and flammable liquids (Kiernan and Winchester, 2005). The presenters were able to produce a spectacular failure by exposing the batteries to extreme conditions. These tests show the potential for failure, but also show that the batteries are durable under standard operating conditions.

According to a popular writer, Tracey Wilson, as notebook computer computers get more powerful and at the same time smaller, the lithium ion batteries are more often used.

Additionally the smaller the battery gets, the thinner the separator gets, and the easier it becomes to puncture the electrolyte. Smaller batteries also have less room for safety precautions and heat up faster. All these factors lead to batteries that are more likely to malfunction (Wilson, 2006).

The chemicals contained in the lithium ion batteries are hazardous after a battery has malfunctioned. Typically there is no risk of contamination, but if the battery explodes or vents gases into the air they can have a variety of hazardous effects. From previous testing reports, lithium ion batteries have been found to contain chemicals that break down into toxins (Hammel, Ring and Vimmerstedt, 1995). Lithium Hexafluoroarsenate, the lithium salt contained in the electrolyte solution, is an arsenic compound. "ACGIH (1994) classifies arsenic compounds as confirmed human carcinogens (Hammel, Ring and Vimmerstedt, pp14 2005)." When the batteries overheat and combust, the storage procedure for the hazardous material is ruined; and the people dealing with the clean up may be exposed to these hazardous materials unless proper procedures are taken. The average consumer is unaware of the hazard and what precautions to take in the event of a failure, making it extremely dangerous to them.

2.2.2 Fire during Transportation

With lithium ion incidents happening in normal use, concern has spread to what may happen when they are shipped in bulk. The National Transportation Safety Board (NTSB), Federal Aviation Administration (FAA), and Department of Transportation (DOT) all have expressed concerns in this area. The NTSB has been keeping track of incidents that have occurred with lithium ion batteries during flights. On August 7, 2004 a fire broke out in a Federal Express airplane. The loading personnel were placing the freight onto the plane when they smelled smoke and began to take the freight out of the airplane. However, before the freight was taken out of the airplane the lithium ion batteries started a fire that cost $20,000 in damages. The lithium ion cells involved in the incident had four different safety features to prevent fire incidents from occurring, but in this case they failed (National Transportation Safety Bureau, 2005).

Additional incidents include a United Airlines flight, fifteen minutes before the flight was about to depart a passenger's notebook computer began to smoke. The notebook computer was taken out of the plane and placed on the floor outside of the gate where a full fire extinguisher was used to put out the fire. On March 3, 2006, a US-bound package of lithium ion batteries was found smoking on a cargo plane in Shenzen, China. On another passenger plane shortly before take off a burning smell filled the first class cabin. The passengers were evacuated and a bag in the overhead compartments was discovered to be smoking. The crew was able to remove the bag from the airplane before it caught on fire. The fire was determined to have been started by a notebook computer with its extra battery pack (Batteries & Battery-Powered Devices, 2006). Three more incidents occurred from August 12, 2002 to June 29, 2002. The two more serious ones resulted in fires. To view these incidents please refer to Appendix O.

These incidents are not the only reasons the FAA and DOT are concerned about lithium ion cells on airplanes. The FAA and DOT conduct series of tests to see if the fire suppression system (Halon 1301) installed on transportation category aircrafts can handle the fires. The cell that was tested was an 18650 cell with a capacity of 2700 mAh, in both its shipping charge (50%) and fully charged states. From these tests, the agencies learned that only a relatively small fire source was needed to cause an 18650 lithium ion cell to begin to vent the flammable electrolyte and ignite. From one of the cells, the flame would be hot enough to have the process of venting continue to the surrounding 18650 cells. The tests also found that Halon 1301 would be effective at extinguishing the electrolyte gas fire, even at 3% concentration. Halon 1301 concentration of 3% is equal to that of a standard cargo compartment for fire suppression in an initial lockdown. The material of the cargo liner (a single thin wall layer in the shipping crates) was also tested and lithium ion cells posed no threat to it. The one negative aspect of the tests was that the cells produce a pressure pulse when venting. It was found that four cells could raise the pressure in a sealed ten meter cube by one psi. With the pressure being raised by one psi it was found that Halon 1301 would not be as effective as it would be under normal pressure (Webster, 2006).

Even with the results of Halon 1301 being effective against lithium ion fires, pilots still do not want to transport lithium ion batteries. In a letter to NTSB on Oct. 4, 2006 from the Air Line Pilots Association, pilots rejected exceptions allowing lithium batteries onto flights. There were four main points the pilots brought up in the letter.

1. Remove Special Provisions for the transportation of lithium batteries in cargo shipments by issuing rule making (the special provisions before allowed lithium ion batteries on flights if they passed certain tests).
2. Have additional and more specific transportation requirements for lithium ion batteries. This can pertain to the case they are packaged in.
3. Ban bulk shipments of lithium metal until packaging is suitable
4. Perform tests on recalled lithium ion batteries to determine danger and whether using a notebook computer with recalled batteries is safe.

These points prove that aircraft pilots do not feel safe with lithium metal and ion batteries on board aircrafts. Yet, some batteries are permitted as long as they pass a series of requirements (Rogers, 2006). First in order for the batteries to be shipped there can be no more than 24 cells or 12 batteries together. Even under this requirement the shipment will be subject to a drop test from 1.2 meters while in the box the batteries or cells are being shipped. The box needs to be marked appropriately and weigh less than 30 kg. Lithium metal and lithium ion batteries are also subject to United Nations (UN) standards. These standards focus on the shipping aspect of the batteries and include tests ranging from altitude simulation to thermal and shock tests (Panasonic, 2005).

Only a few serious incidents have occurred. One incident even went unnoticed during the flight, but the outlook of danger of lithium ion batteries in air transport may change if one causes a fire while a passenger airplane is in-flight.

2.3 Recalls

In order to protect consumers from unsafe products, the CPSC works with companies to recall defective products. There is a specific process followed in order to recall products. In addition there is a fast track recall process. By conducting recalls the CPSC insures that products on the market will not cause hazards to consumers by either design or foreseeable misuse.

2.3.1 CPSC Recall Process

The U.S. CPSC has a clearly defined system for classifying a hazard and implementing a recall. The process for a recall can take several days or up to several months depending on the cooperation and experience of the company involved and the technical complexity of the problem being investigated. A thorough and time-consuming investigation might be necessary to determine not just if a defect exists or if a specific federal regulation has been violated, but also to determine if the problem identified presents a substantial product hazard and warrants a recall.

The CPSC can be made aware of the problem through a variety of ways. The distributors and manufacturers are required to report any hazardous products to the CPSC. They can also learn about them from consumers, medical practitioners, or safety officials. Once informed of the risk the CPSC will conduct an investigation into the hazard and classify it. If the risk is found to be substantial, that product is recalled (Clark et al., 2002).

The manufacturer of the product is then contacted and asked to develop a corrective action plan. If the product was manufactured outside of the United States, the importer of the product would be contacted instead of the foreign manufacturer. The CPSC must approve of this plan. If it does not approve, it will negotiate with the company until both sides have reached a compromise. If a company refuses to accept the CPSC's terms they could be brought to federal court and an administrative law judge could compel the firm to implement a corrective action plan. The company is required to facilitate the recommended action which always includes both a method to notify the public and distributors, and a plan to remove the defective products and compensate the consumers (Clark et al., 2002).

In addition, there is the No Preliminary Determination (also called "fast track") recall process. It is as follows: a company that reports a problem to the Consumer Product Safety Commission may request to participate in the Fast Track Recall Program if it implements a consumer level product recall within 20 business days of filing the report. If the recall proposal is satisfactory to the staff, then there will be no formal preliminary determination by the CPSC staff that the product presents a substantial product hazard. Instead the staff at the

CPSC works with the manufacturer on finalizing and implementing the firm's proposed Corrective Action Plan (US Consumer Product Safety Commission Recall Handbook, 1999).

2.3.1.1 Consumer Product Safety Commission (CPSC)

The Consumer Product Safety Commission is responsible for the safety of over 15,000 consumer products. This agency is part of the Executive branch and was established by the Consumer Product Safety Act. They have some regulatory power and work with manufacturers to conduct recalls of dangerous products. For more information on the CPSC please refer to Appendix A.

2.3.2 Notebook Computer Recalls

Lithium ion batteries are a popular high power battery on the market that are used to power many different products including notebook computer computers. Due to the problems with lithium ion batteries in notebook computers since October 2003 there have been battery recalls from several major computer manufacturers. The most recent and largest recall by Apple and Dell were of batteries manufactured by Sony.

2.3.2.1 Dell

The largest ever safety recall of consumer electronics industry was the August 2006 Dell recall of 4.1 million Sony manufactured batteries. This recall was a result of a fast track recall due to several specific incidents. One of the six incidents that spurred the recall was a notebook computer fire at a Japanese conference (Figure 2). Dell recalled these batteries because they were found to have a manufacturing defect.

Figure 2: The Dell Battery Fire at a Japanese Notebook computer Convention
http://www.voanews.com/specialenglish/images/explosion_battery_31aug06_150_se.jpg

In the Japanese conference fire it was determined by Exponent, a failure-analysis firm that the fire was caused by an internal short circuit. This short circuit was caused by small metal particles that were released during the end of the manufacturing process when the cell was crimped. The recalled batteries will be replaced by new batteries built by Sony. Dell claims they are confident the new batteries by Sony will be much safer because the manufacturing process had been refined (Darlin, 2006). Senior vice president and general manager of the product group at Dell is quoted “We are absolutely confident that when we replace the batteries that we are getting the at-risk batteries out of consumers’ hands and that there will be no more incidents” (Darlin, pg 4 2006).

2.3.2.2 Apple

The Sony batteries recalled by Dell were also found in Apple’s 12-inch iBook G4, 12-inch PowerBook G4, and 15-inch PowerBook G4. There were nine incidents that spurred the Apple recall of 1.8 million notebook computer batteries (Kirkpatrick, 2006). The same manufacturing problems were found to be a factor in these incidents and the batteries will be replaced. The details of the specific nature of replacement batteries are unclear, but it is probable that Apple will also continue to use Sony's batteries as they are the second largest manufacturer of lithium ion batteries. Additionally, these batteries are currently the cheapest form of battery chemistry and can pack more energy into a smaller space than other types of batteries (Darlin, 2006).

2.3.2.3 Other Notebook computer Manufacturers

In addition to the Dell and Apple recalls, Lenovo and Toshiba have also recalled Sony made batteries. Both these recalls occurred in the beginning weeks of September 2006. Lenovo recalled 168,500 Sony made battery packs for the IBM ThinkPad. This recall was spurred by a fire in a ThinkPad at Los Angeles International Airport and done in cooperation with the CPSC (Ferguson, 2006). In conjunction with this, Toshiba recalled 340,000 notebook computer batteries from their Satellite and Tecra notebook computers as a safety precaution. Their batteries were also made by Sony however this was a "voluntary exchange" and "completely separate" from the Dell, and Apple recalls (Moltzen, 2006). Hewlett-Packard's batteries are also manufactured by Sony, but they claim their notebooks would not be affected in the same way because the batteries were designed specifically for their products (Darlin, 2006).

2.3.3 Other Electronic Recalls

Notebook computers are not the only products that have experienced complications as a result of lithium ion battery use. Products that have been recalled include portable DVD player battery packs, cameras, flash lights, and mobile telephones (Valence, 2005). On

March 23, 2005, there were 47,000 portable DVD player batteries recalled by the CPSC. The batteries were manufactured by Thomas Inc. and there were 11 reported overheating incidents and five incidents of the batteries exploding (US Consumer Product Safety Commission, 2005). Lithium batteries have also experienced problems in flashlights. On February 3, 2004 the CPSC issued a recall of 20,000 units of Fuji lithium batteries sold with Dorcy Xenon flashlights. The batteries were known to overheat, leak, and rupture (US Consumer Product Safety Commission, 2004). Additionally camera batteries have had problems, approximately 710,000 batteries were recalled from Nikon on November 8, 2005, and 200,000 of these batteries were located in the United States. The problem with the batteries was a possibility of them short circuiting, causing them to overheat and in some cases melt. A total of four incidents were reported before the recall occurred (US Consumer Product Safety Commission, 2005).

2.3.3.1 Mobile Telephones

Two companies have experienced recalls of their mobile telephones due to lithium ion batteries: Verizon Wireless and Kyocera. The second largest ever safety recall of a consumer electronics product was the October 2004 recall of one million lithium ion batteries for Kyocera mobile telephones. This was initiated because of fourteen incidents of battery failure from counterfeit batteries (US Consumer Product Safety Commission, 2004). Additionally, Verizon Wireless experienced a recall of 50,000 units of their LG-branded TM-510 mobile telephone batteries. The recall was issued on June 24, 2002 and these mobile telephones also contained counterfeit batteries (US Consumer Product Safety Commission, 2002).

2.4 Companies, Agencies, and Organizations

There are many groups working on either correcting the issues involved with lithium ion battery use, or developing new technologies that may be safer than lithium ion batteries used in consumer products. Government agencies are working to protect consumers from the hazards of lithium ion batteries in different situations. One large issue being worked on is safe transportation of batteries. Additionally, standard organizations are working on enhancing their standards so batteries certified by the organizations will be safer for consumer use. Finally, there are many companies developing new technologies that may be safer than the lithium ion batteries in use today.

2.4.1 Government Agencies

This section provides background information about agencies that were contacted in order to gain more information on their uses, and testing procedures of lithium ion batteries. Additionally, they provided incident data and discussion about potential solutions.

2.4.1.1 National Transportation Safety Board (NTSB)

The National Transportation Safety Board (NTSB) was created on April 1, 1967 and although independent, it relied on funding from the Department of Transportation (DOT). However, after the Independent Safety Board Act in 1975, all ties to the DOT were severed. In the last 39 years NTSB has investigated over 124,000 aviation accidents and more than 10,000 surface transportation accidents. The purpose of NTSB is to investigate aviation and other civil transportation incidents, in order to issue safety recommendations that may prevent future incidents. NTSB has been involved in the investigation of lithium ion battery fires. They conducted a hearing on July 12-13, 2006 about a fire on a United Parcel Service flight. This fire was caused by lithium ion batteries in transportation (National Transportation Safety Bureau, 2006).

2.4.1.2 National Aeronautics and Space Administration (NASA)

The National Aeronautics and Space Administration (NASA) began in 1958. It was started partially as President Dwight D. Eisenhower's response to the Soviet Union's launch of the first artificial satellite. NASA's mission is to, "Pioneer the future in space exploration, scientific discovery, and astronautics research" (National Aeronautics and Space Administration, 2006). In the 1960's NASA focused on landing on the moon, but continued to research and develop applications for space technology including developing the first weather and communications satellites. In 1981 NASA built the space shuttle which has had 112 successful flights with two lost crews. NASA continues to research aeronautics, exploration systems, science, and space operations. NASA uses lithium ion batteries in many different applications including the Mars Lander and satellites. In order for NASA to use these batteries they must be tested to stringent levels, as the risk associated with their use is greater than normal consumer use (Jeevarajan, 2006).

2.4.1.3 Department of Transportation (DOT)

On October 15, 1966 an act was passed through Congress that established the Department of Transportation (DOT), but the doors did not open until April 1, 1967. The DOT's mission is to "Serve the United States by ensuring a fast, safe, efficient, accessible and convenient transportation system that meets our vital national interests and enhances the quality of life of the American people, today and into the future" (Department of Transportation, 2006). DOT held a public hearing about the safe transportation of lithium ion batteries on November 29, 2006 about new additions to the UN standards of shipping lithium ion batteries.

2.4.1.4 Federal Aviation Administration (FAA)

The Federal Aviation Administration (FAA) is now an agency of the DOT that focuses on aeronautics. The FAA began long before the DOT with the Air Commerce Act of May 20, 1926. This act began government's regulation of civil aviation through a new branch of the Department of Commerce. Initially it focused on safety, rulemaking, and certification of pilots and aircrafts. It was renamed the Bureau of Air Commerce in 1934. By 1936 they had encouraged the establishment of three air traffic control centers along airways. The Civil Aeronautics Act of 1938 transferred the responsibilities from the Commerce Department to the Civil Aeronautics Authority. The group continued work with air safety and air traffic control. In 1958, the Federal Aviation Act established the Federal Aviation Agency; the name was changed to Federal Aviation Administration after the establishment of the DOT. The DOT was established to house all major federal transportation responsibilities so the FAA became included in their organization. The investigation division of the FAA which had been previously called the Civil Aeronautics Board was transferred to the National Transportation Safety Board. FAA's purpose is to provide the safest, most efficient aerospace system in the world (Federal Aviation Administration, 2006). FAA documents all incidents of lithium ion batteries and is concerned with the safe transportation of these types of batteries.

2.4.1.5 National Association of State Fire Marshals (NASFM)

The mission of the National Association of State Fire Marshals (NASFM) is, "To protect human life, property and the environment from fire and to improve the efficiency and effectiveness of State Fire Marshals' operations" (National Association of State Fire Marshals, 2006). NASFM provides public education and advises Governors and State legislatures on fire protection. The NASFM is concerned with lithium ion batteries, because of the fires they can cause. They want to protect fire fighters from the dangers resulting from lithium ion battery fires.

2.4.1.6 Naval Surface Warfare Center (NSWC)

The Naval Surface Warfare Center (NSWC) was restructured by the Secretary of the Navy on the 12th of April, 1991. It was started as part of the Naval Sea Systems Command laboratories (NAVSEA). On January 2, 1992 the NSWC was officially established. The NSWC is housed in a number of different divisions. The David W. Taylor model Basin, Carderock in Bethesda, MD is the home of the NSWC Carderock Division. The Naval Ammunition Depot, Burns City, IN is home to the NSWC Crane Division. Both these divisions are involved in the research and development of lithium ion batteries; there are other divisions as well as numerous other research laboratories throughout the United States. "NSWC's role is to provide the right technology, the right capabilities, and the specialized research and development facilities to support all aspects of surface warfare." (Naval Surface Warfare Center, 2006) NSWC wants to make sure all lithium ion batteries used by the Navy can pass stringent tests in order to be safe for use.

2.4.1.7 Sandia National Laboratories

Sandia National Laboratories began in 1949 to develop technologies that support national security. Sandia is a national security lab that works to research and design programs to help develop a peaceful and free world through technology. Sandia has a goal of meeting the national needs in five key areas, (1) nuclear weapons, (2) energy and infrastructure assurance, (3) nonproliferation, (4) defense and system assessment, and (5) homeland security (Sandia National Laboratories, 2006).

Sandia also has a science, technology, and engineering program in order to use their laboratories to stay on the cutting edge. They run tests on hybrid cars using lithium ion batteries to try to gain a better understanding of lithium ion batteries failures (Sandia National Laboratories, 2006).

2.4.2 Standards and Certification Organizations

There are many different paths a product manufacturer can take when deciding which voluntary standards to which they want to adhere. Some respected and widely known standard organizations are the Institute of Electronic and Electrical Engineers, Underwriters Laboratories, United Nations, International Electrotechnical Commission, American National Standards Institute, and the European Committee for Standardization. These organizations have working groups that create a list of standards and tests in regards to safety measurements and performance requirements.

2.4.2.1 Institute of Electrical and Electronic Engineers (IEEE)

The Institute of Electrical and Electronic Engineers (IEEE) was formed in 1963 through the merge of the American Institute of Electrical Engineers (AIEE) and the Institute of Radio Engineers (IRE). They served as a catalyst for technological innovation and advanced theory and application of electrotechnology and allied sciences (Institute of Electronic and Electrical Engineers, 2006). This organization creates voluntary standards for all types of electronic and electrical equipment through sponsors. Many people who are in an associated field could be a part of the creation of a new standard document.

Two of IEEE's standards focus on lithium ion batteries. The first standard is IEEE 1625 "Rechargeable Batteries for Portable Computing," and the second is IEEE 1725 "Rechargeable Batteries for Cellular Telephones." These standards are only recommended practices that may improve safety. Organizations, such as the Cellular Telephone Industry Association (CTIA), have developed a certification process for IEEE 1725 to help improve safety.

2.4.2.2 Underwriters Laboratories (UL)

Underwriters Laboratories (UL) is a non-profit organization that conducts product-safety testing and certification. UL was founded in 1894 and is a leader in their industry within the United States. Products ranging from fire suppression systems to marine products are tested by UL. Products that have passed the product-safety test are marked with a well-known UL mark to prove they are certified. Over 20 billion products inside and outside the US are marked with this symbol (Underwriters Laboratories, 2006).

UL has two standards associated with lithium ion batteries. The first standard UL 1642 "Lithium Batteries," focuses more on the lithium cell, while UL 2054 "Household and Commercial Batteries," focuses on battery packs as a whole. In order to be UL certified and be stamped with the UL mark a lithium ion battery pack must adhere to both standards (UL 2054). In the near future there may be additional tests added to these standards.

2.4.2.3 Cellular Telephone Industry Association (CTIA)

The Cellular Telephone Industry Association (CTIA) is an international organization that focuses on all aspects of wireless communication. Founded in 1984 as a non-profit organization, they represent many manufacturers, service providers, and other wireless companies. Also, they ensure high quality and reliability through product certification and testing. CTIA wants to expand wireless technology, provide accurate information to consumers, and ensure safety among all users (Cellular Telephone Industry Association, 2006).

Currently, service providers in the United States, such as Verizon Wireless, Sprint Nextel Corporation, and Cingular Wireless, are providing their customers with safe products through CTIA services (Cellular Telephone Industry Association, 2006). CTIA developed a third party certification for mobile telephones based on IEEE 1725 the standard for mobile telephones. With this, CTIA makes sure that all mobile telephone batteries will comply with IEEE 1725, and then service providers who purchase the batteries to sell to consumers will be certified for system safety.

2.4.2.4 International Electrotechnical Commission (IEC)

The International Electrotechnical Commission (IEC) is a global organization that creates international standards for electronic and electrical technologies. They cover a larger geographical area than IEEE, and some IEEE tests are based on IEC standards. In addition to electrical and electronic devices, the IEC charter embraces magnetism, electromagnetism, telecommunication, and multimedia. They want to improve quality, establish test criteria, increase efficiency, improve human health and safety, and protect the environment, by developing international standards for electronic. IEC's standard is called "Secondary cells and batteries containing alkaline or other non-acid electrolyte – Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications IEC 62133, 1st addition" (International Electrotechnical Commission, 2006). As stated earlier, IEEE does refer to some IEC standards for testing procedures. Testing among these two standards is very similar and sometimes exact.

2.4.2.5 European Committee for Standardization (CEN)

The European Committee for Standardization (CEN) was founded in 1961 by the national standards bodies in the European Economic Community (EEC) and European Free

Trade Area (EFTA) countries. Every product in Europe must comply with CEN standards in order for these products to have a CE marking. This marking signifies that the product can be legally placed on the market in the European nation. It also allows the product to travel between countries in the European Union (European Committee for Standardization, 2006).

2.4.2.6 United Nations Economic Commission for Europe (UNECE)

The United Nations Economic Commission for Europe (UNECE) was founded in 1947 and includes fifty six nations located globally located. This group of countries comes together and discusses world issues which include economic and social issues. The UN also sets norms and standards to facilitate international cooperation which includes the transportation of dangerous goods (United Nations Economic Commission for Europe, 2006).

The United Nations standard is titled Committee of Experts on the Transport of Dangerous Goods. It focuses on tests lithium ion batteries must pass in order to be transported internationally. This standard is not as in-depth as some IEEE standards or UL standards, but it is a basis for transporting dangerous goods.

2.4.2.7 Portable Rechargeable Battery Association (PRBA)

The Portable Rechargeable Battery Association (PRBA) was founded in 1991 as a non-profit organization. Some of the key players in initiating this association were Energizer, Matsushita Battery International of America (Panasonic), Sanyo Energy Corporation and Varita Batteries. The PRBA works with the DOT in regards to the safe transportation of lithium ion batteries. PRBA also focuses on the safe recycling and disposal of small sealed rechargeable batteries (Portable Rechargeable Battery Association, 2006).

2.4.3 Innovative Companies

Among manufacturers of lithium ion batteries are companies developing new products. These companies are either developing additives to lithium ion batteries or developing batteries similar to lithium ion batteries, but with slightly different internal components that have designed out the problem faced in lithium ion batteries.

2.4.3.1 Quallion

Quallion was first incorporated in Delaware in 1998. It was founded by Alfred E. Mann a biotechnology entrepreneur and philanthropist. The vision of Quallion is "to develop innovative battery solutions for the improvement of life and the way we live it." (Quallion, 2006) Quallion focuses on medical, military and aerospace battery solutions.

Quallion is currently developing a number of new solutions to the lithium ion battery problems. One solution is their zero volt battery. This battery can stay at 0V for years without deteriorating, unlike a normal lithium ion battery which can corrode if it is charged below 2.0 V. Additionally, Quallion is developing an additive solution called SaFE-LYTE which is fluorine based and mitigates the hazard of thermal runaway (Quallion, 2006).

2.4.3.2 Valence Technologies

Valence Technologies was founded in 1989 as part of a research and development company and has facilities in Austin, Texas, Las Vegas, Nevada, and Suzhou and Shanghai, China. The company goal of Valence is to become a leading provider of high performance, safe, cost effective, large-format battery systems. Valence has focused on Saphion® battery technology for large-format lithium ion batteries. Valence is also looking into the possibilities of expanding into markets that may use lithium ion battery technology in the future. This includes the telecom, utility, and motive markets. Valence hopes to continue to expand as a company with its Saphion® Technology. It will offer the power of lithium ion batteries with the safety, environmental friendliness, and cost benefits of using new technologies (Valence, 2006).

2.4.3.3 3M

3M was founded in 1902 in Minnesota, and was developed from a mining company that wanted to mine a mineral deposit for grinding wheel abrasives. Roughly eight years later the company began to experience marketing and technical success in the development of waterproof sandpaper. From there, 3M began to grow and now today is a technological company involved in many different areas including: consumer and office, display and graphics, electro and communications, healthcare, industrial and transportation, safety, security and protection services. 3M applies technologies to all of these consumer needs (3M, 2006).

3M contains many different branches and has companies in over 60 different countries with roughly 69,000 employees. There are 139 plants of 3M over the world and 188 sales office locations. The branch of 3M we concerned ourselves with was the electro and communications branch. This branch provides consumers with technological solutions in the field of electrical, electronics and communication products. Their products allow consumers to clean, insulate, protect, and test electronics. In addition, the branch provides reliable sources of electrical power and high-performance electronic devices. (3M, 2006)

2.4.3.4 Amperex Technology Limited

Amperex Technology Limited (ATL) was established in October 1999. Today ATL has approximately 5,000 employees with headquarters in Hong Kong. The employees from ATL are located in China, Hong Kong, Taiwan, and the United States and possess backgrounds of battery technology, manufacturing, and original equipment manufacturers

(OEM). Currently ATL has focused their primary attention on making lithium polymer cells for the communication industry. (Amperex Technology Limited, 2006)

2.4.3.5 Zinc Matrix Power

Zinc Matrix Power (ZMP) was formed to develop high-performance rechargeable alkaline battery technology in the fields of commercial and military applications. The company holds 16 patents in the field of rechargeable batteries and there are many more patents pending. ZMP has had the Navy as a customer for years by supplying them with batteries for their submarines (Zinc Matrix Power, 2006).

2.4.3.6 Infinite Power Solutions

Infinite Power Solutions (IPS) is a private company that makes thin film batteries for micro-electronic applications in Colorado. The products IPS makes are very thin, flexible, and have the ability to be recharged in a couple minutes (Infinite Power Solutions, 2006).

2.4.3.7 A123 Systems

Founded in 2001 by research at Massachusetts Institute of Technology, A123 Systems is working towards manufacturing the next generation of lithium ion batteries, by using a different internal chemistry. The company's headquarters is in Watertown, Massachusetts, but most manufacturing work is done in Asia. A123 Systems is the first company to address the three major factors of a good high energy density battery, which are (1) high power, (2) intrinsic safety and (3) longevity. The batteries have several key advantages such as a five time increase in power density compared to competing technology, intrinsic safety, breakthrough improvements in life, and a five minute charge time (A123 Systems, 2005).

Companies, such as Motorola, have an investment in this new technology and Black and Decker announced last year that batteries made by A123 Systems will be used to power their new line of DeWalt power tools. Just recently A123 Systems was awarded $15M to continue to develop the next generation of hybrid cars (A123 Systems, 2005).

2.4.3.8 Sion Power

Sion Power was originally named Moltech Corporation and was created in 1992. The goal of the company was to develop electrochemical storage systems that would be more advanced and powerful than anything coming out at the time. In 2002, the name of the company was changed to Sion to reflect their new intentions to work with lithium sulfur batteries. As the potential for sulfur chemistry was discovered for battery applications, Sion began development of lithium sulfur batteries (Sion, 2006).

2.4.3.9 Lithium Technology Corporation

Lithium Technology Corporation (LTC) was formed in 1994 as a public company. LTC produces the largest and highest powered lithium ion cells in the western hemisphere. The company does not focus on smaller size cells since they feel the market in China can make very inexpensive batteries for smaller applications, thus larger cells are more practical for LTC. Their technological capabilities, manufacturing infrastructure and management strengths allow them to have many solutions in the fields of battery design, manufacturing, marketing, and delivery (Lithium Technology Corporation, 2006).

2.5 Analysis Techniques

There are many different ways to analyze data; graphical representations as well as Fault Trees are useful techniques because they allow the reader to gain understanding of the data and where the results have been derived from pictorially.

2.5.1 Fault Tree Analysis

A Fault Tree Analysis is a method of analyzing failure by breaking it down by its causes and further breaking those down. The entire process requires knowledge of the system in question. First, the major fault is defined and set as the first level of the tree. The highest level of the system is then looked into to determine the causes of the fault. Once they have been obtained, the levels of the system are analyzed to find the situations and cause that led to the ones above it. Logic gates are used to link a situation on a higher level with its causes on the lower level. The two most common gates are the "And" and "Or" gates (Chaponis, 1996). When the "And" gate is used a higher level failure requires all causes that are associated with it to occur, or it will not happen. An example of this is "A car can stop unless it loses its brakes, emergency brake, AND its transmission fails." The "Or" gate is used when only one of the causes occurring will cause the root failure to occur. An example of this is "A car will not start if it has no gas, OR it has a bad starter." It makes no difference how many of the branches fail only one is required. Figure 3 is an example of a fault tree.

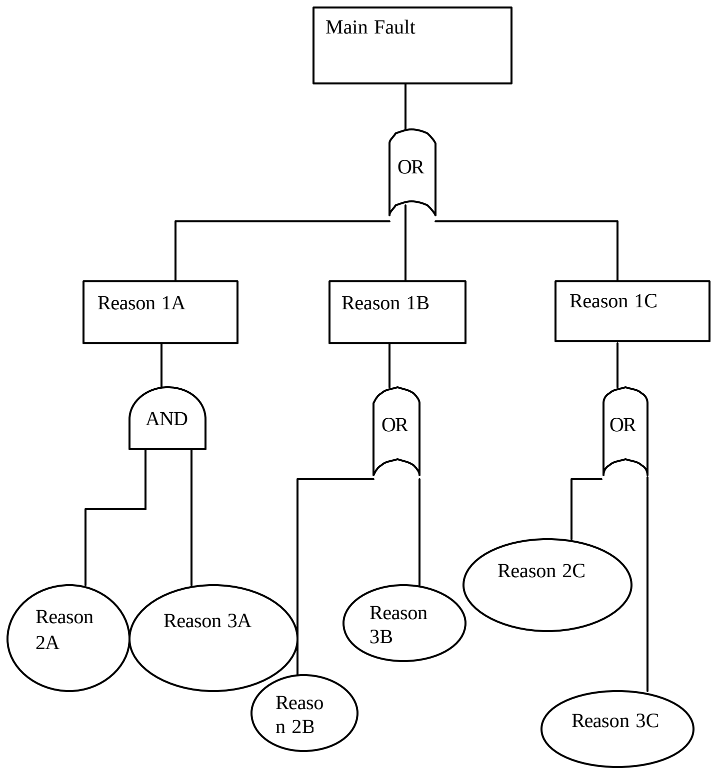

Figure 3: Fault Tree Chart Example

2.5.2 Pivot Chart

Pivot charts and tables allow one to look at data in different ways. "Pivot tables show data in headings that you can *pivot* from one axis to the other to display different relationships in the data" (Walkenbach and Underdahl, pg 421, 2006). These charts allow you to drag groups of data into axis arranging them by their order of importance. The highest priority of data is divided into as many options as are present in it. Then, for each option in the highest category, the next priority level of data is broken down. This way the pivot chart can show how a number of different factors can add up to a high failure probability. If one particular section has a very high rate of occurrence then the situation that led to it can be looked into. Figure 4 is an example of a Pivot chart for conditions surrounding car breakdowns using fabricated data. In it one can clearly see that one set of circumstances leads to a breakdown far more often than the others. The data can be rearranged to suit different needs and multiple charts can be generated for different categories. For example, in the chart below location is the primary category, time of day is present for each location, and temperature is present for each location. In this way, multiple categories for the same data can be viewed simultaneously. This versatile feature of excel makes data analysis much easier.

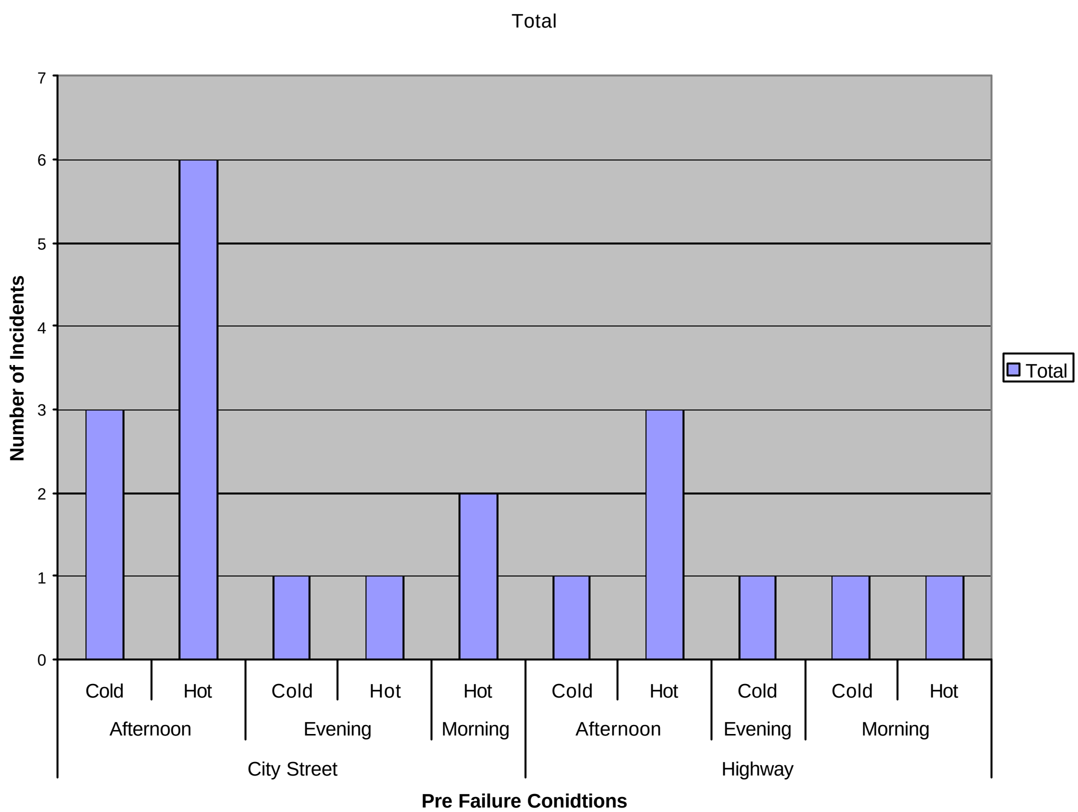

Figure 4: Example of Pivot Chart

2.6 Summary

Through this background review we gained a better understanding of how the recall process works, what the failure modes of lithium ion batteries are, how the standards organizations are run and what they have produced, and what kind of work towards the safety of lithium ion batteries has been done. It also provided a better understanding of what needs to be done to improve lithium ion battery safety for consumers. There are a few areas that will be focused on in order to close the gap in what is already known.

The first area focused on will be incident reports as they will develop the understanding of what goes wrong and how it affects consumers. The next area will be a continued investigation of battery standards organizations and what their solutions and developments to the standards will be. Finally innovative companies will be thoroughly researched in order to gain a better understanding of their technologies and how those technologies can make high energy density battery usage safer for consumers.

Chapter III: Methodology

Our project goal is to provide the U.S. Consumer Product Safety Commission (CPSC) with potential solutions that will lead to minimizing the safety risk involved with the use of lithium ion batteries. This chapter identifies the methodologies used for this study. The objectives met in order to achieve the goal were:

1. Categorize hazard scenarios with data from in-depth investigation reports
2. Develop a comparison table of lithium ion battery standards
3. Investigate potential alternative technologies to lithium ion batteries

In order to illustrate the steps taken to achieve our goal we developed a flowchart (Figure 5).

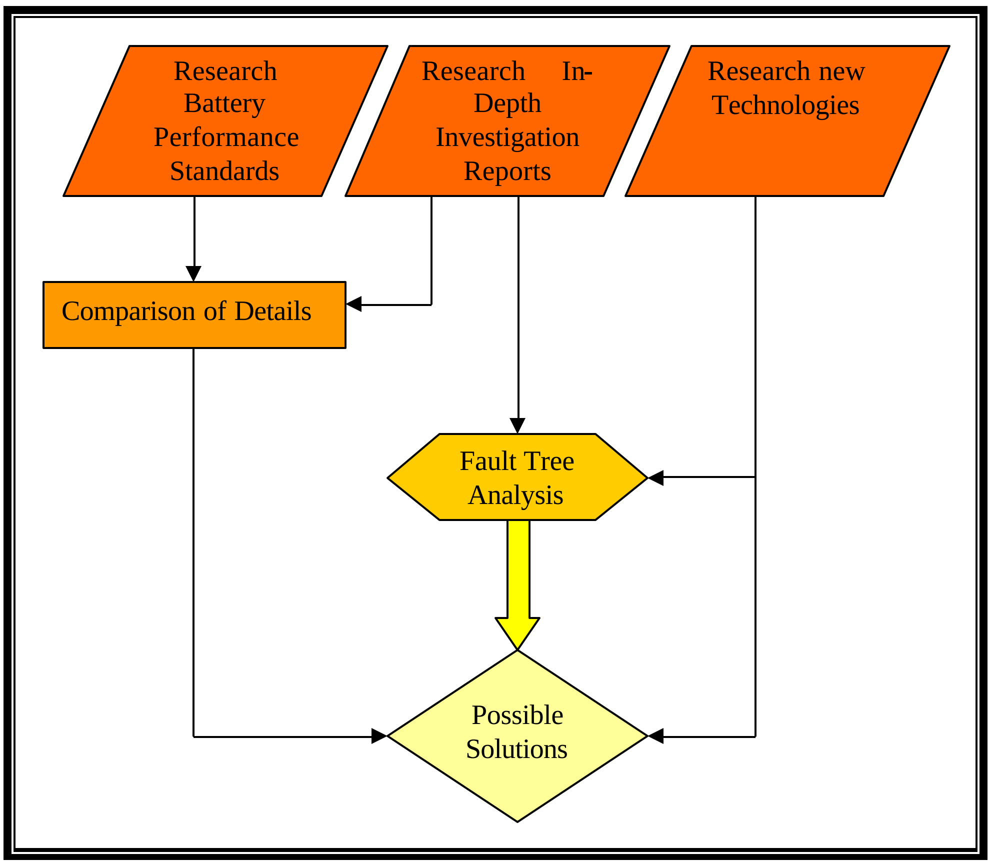

Figure 5: Flowchart of Objectives

3.1 Categorize Hazard Scenarios

Data collection was necessary to categorize hazard scenarios involving lithium ion batteries. Being able to categorize scenarios allowed further understanding of the key factors contributing to lithium ion battery induced incidents. The categorization of scenarios also allowed potential solutions for reducing the safety risk of lithium ion batteries to be more accurately identified.

At the CPSC there are numerous databases that record reports ranging from hospitals to field investigations. The databases allowed specific data relating to hazards to be gathered. With this information we categorized hazard scenarios which allowed a clearer definition of our recommended solutions. The following is a list of the six databases at the CPSC:

1. NEISS (National Electronic Injury Surveillance System)
2. DTHS (Death Certificates)
3. IPII (Injury and Potential Injury Incidents)
4. INDP (In-depth Investigations)
5. CAP (Children and Poisoning)
6. ABDT (Abbreviated Death Certificates)

The INDP database was the most useful and relevant information about consumer product injuries related to lithium ion batteries. This database is an overview of information gathered from field investigators in the form of an in-depth investigation report (IDI). Other databases looked at but were not included in the report for various reasons were: NEISS, Death Certificates, and the IPII. The NEISS database provided limited entries of consumers who went to the emergency room as a result of lithium ion battery incidents. Additionally, the reports were not as detailed as the INDP. Death Certificates was not useful because there have been no confirmed fatalities from lithium ion batteries. The CAP database was not useful because scenarios of children swallowing lithium ion batteries were not in the scope of this project. The IPII database included information that was useful but not as detailed as needed in order to categorize hazard scenarios.

When searching through the IDI files, there were key pieces of information necessary to conduct the analysis. First, we read the brief overview of the report to get the main idea of the incident before reading for details. Next, the title page of the IDI file was examined and the date the incident occurred, the type of product, the name brand of the product, model number, and manufacturer was recorded. If there was a secondary product involved, similar information was recorded if the information was accessible. When reading the actual report, key pieces of information gathered: were possible causes of the incident, what amount of damage the incident caused, the types of injuries abstained by the consumer, and if the report included any other key information that could have caused the incident. After all of this information was collected an Excel database was created listing the data under its appropriate title and categorized by the task number in case the IDI file had to be accessed again.

3.1.1 Analysis using Fault Tree

The In-depth Investigation (IDI) reports provided a considerable amount of information. In order to better understand that information, they were organized by failure modes. Then the causes of these failure modes were determined. In order to analyze this systematically a Fault Tree Analysis was chosen.

A Failure Modes and Effects Analysis (FMEA) was considered, however, due to time constraints, a full FMEA was determined to not be possible before arriving at the CPSC. However, it was still thought that a simplified version of an FMEA could be conducted, but it was then realized that the team did not have the expertise to assign values to severity, occurrence and detection of each failure mode. Additionally, it was determined that there was not enough data to determine all failure modes as most failure modes are on an internal component level. Therefore, the Fault Tree Analysis appeared to be the ideal analysis tool. In an FMEA, the product is analyzed from the component level to the system level, anticipating failure along the way. A Fault Tree Analysis begins with the failure and works its way down to the root causes. The Fault Tree Analysis was used to help us identify possible solutions and determine if they mitigated causes that would prevent a branch of causes from leading to a failure.

3.1.2 Interviews with Manufacturers and Government Agencies

In order to acquire further information on incidents and component level failures to enhance the Fault Tree Analysis we attempted to contact manufacturers that use, produce, and test lithium ion batteries. The purpose of this was to better understand the hazard scenarios at a component level that would help to design a more accurate fault tree. This proved to be an exceedingly difficult task. Failure modes are something that manufacturers keep very secure as to protect their intellectual property. Therefore, we decided to approach the companies in order to get information about standards and what they would be open to doing to make lithium ion batteries safer for consumers. Through the help of Richard Stern, Associate Director of Fueled, Electric, and Recreational Products in the Office of Compliance, at the CPSC, we were able to contact Hewlett Packard (HP) and Sony. The contacts at both companies were willing to provide any help they could while still protecting the interests of the companies. In order to protect the interests of the companies and obtain the most beneficial information for the project, the questions were kept broad. This way some generalizations could be made about manufacturers as both groups answered the same questions. The questions asked were:

1. Do you follow any specific standards such as Underwriters Laboratories (UL), Institute of Electrical and Electronic Engineers (IEEE), International Electrotechnical Commission (IEC) or United Nation (UN)?
2. Do you think batteries will change to a different form or will lithium ion batteries remain in use?
3. Do you feel that it would be better to design out or guard against the problems found with lithium ion batteries in notebook computers and mobile telephones?
4. Are your battery packs tested at all levels? Cell, battery pack and within the product?
5. Would you be willing to participate in a roundtable discussion with other shareholders to help develop ways to make lithium ion batteries safer for consumers?

Additionally, the following government agencies were contacted: National Aeronautics and Space Administration (NASA) Glenn Research Center and Johnson Space Center, Department of Transportation (DOT), Federal Aviation Administration (FAA), National Transportation Safety Bureau (NTSB), the Naval Surface Warfare Center Carderock Division (NSWC Carderock), and Sandia National Laboratories. These agencies were contacted in order to obtain information about how they use lithium ion batteries, incidents they have experienced, or any additional information they could provide. This information was applied to our recommendations because it gave further incident data and additional reasoning for why certain recommendations were provided.

3.2 Comparison of Lithium Ion Battery Standards

Standards allow products to be safer, more efficient, and have less variance. Current standards associated with lithium ion batteries are voluntary, which allow manufacturers to choose which standard they deem appropriate. Standards were studied to determine the major differences and similarities between a wide-range of common voluntary standards.

There are a dozen standards to which manufacturing companies test their products. We compared six main testing standards written by the Institute of Electrical and Electronic Engineers (IEEE), Underwriters Laboratories (UL), International Electrotechnical Commission (IEC), and United Nation (UN). These four standards organizations focus on batteries for portable applications (inter)nationally, as well as testing standards prior to transportation.

The CPSC provided each of the voluntary standards needed for the evaluation. In the voluntary standards there are construction requirements, performance requirements, cell and system considerations, and certain tests. The list of the voluntary standards used for this report is as follows:

1. IEEE 1725 – Rechargeable Batteries for Mobile telephones
2. IEEE 1625 – Rechargeable Batteries for Portable Computing
3. UL 1642 – Lithium Batteries
4. UL 2054 – Household and Commercial Batteries
5. IEC 62133 – Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications
6. UN ST/SG/AC.10/27 – Committee of Experts on the Transport of Dangerous Goods

We focused on these six testing standards since they are most commonly used by major battery manufacturers. Not only are these standards in effect to protect consumers from faulty batteries, they are also tested for safe transportation. A table, which included the six chosen voluntary standards along with their associated tests, was created. It lists all the tests and testing procedures that each voluntary standard requires. The reason a table was constructed was for an easy comparison of standards to determine differences in tests and differences in testing procedures. Also we wanted to find the voluntary standards that have a strong base in order to determine them to be adequate for consumer safety.

3.3 Investigate New Technologies

Various companies that are using innovative research and technologies to reduce the hazard of lithium ion batteries were researched. Looking at potential new technologies was important to the report because it allowed examination and research of technologies that provide possible solutions based on our Fault Tree Analysis. The research showed if the technologies were practical and able to prevent the lithium ion batteries from experiencing thermal runaway or reducing the hazard during a thermal runaway event. Internet searches were conducted to find technologies. While there are a large number of companies in these fields, this is just a small representation since we did not have time to do extensive research. When information was gathered on potential technologies for lithium ion batteries, there were two main sources used: company websites with product reviews and listings, and interviews with the companies.

The information gathered from the companies developing potential technologies was the mission statement/goal of the companies and what products are being developed for the market. Next, they were evaluated for advantages and disadvantages for consumer usage and how effective the technology would be in preventing the Fault Tree Analysis from reaching the ultimate failure. Once accomplished, conclusions were drawn on which technology may be most useful for certain products and how recommendations could be drawn from these various types of technologies.

3.3.1 Interviews with manufacturers of new technologies

In addition to researching the companies that are developing new technologies that could potentially solve the hazard with lithium ion batteries, interviews were conducted with these companies. Conversations with A123, Quallion, Amperex Technologies Limited (ATL) and Zinc Matrix Power (ZMP) helped to provide more credible reasoning for why specific technologies were suggested. Again in order to protect the interests of the companies we kept the questions broad and asked the same set of questions to every company. These questions were:

1. Can you tell us about the technology you are working on and the benefits of using it?
2. Do you follow any specific standards when manufacturing your products?
3. What makes your products safer than lithium ion batteries in consumer products?
4. What are the most beneficial uses for your technologies? (ex High energy/ high power)
5. Would it be cost effective to implement this technology into consumer products?
6. Is there any thermal runaway or failure modes associated with the technology? Can you prevent thermal runaway with your technology?
7. Does your new technology reduce energy density?

These questions helped us to determine which technologies would be best to implement based on consumer use and not a technical level. Beneficial new technologies need to address a few specific problems and these questions allowed us to determine if the companies we spoke with are developing technologies that are safer than lithium ion batteries.

3.4 Summary

By completing the objectives we were able to develop specific conclusions and recommendations for the CPSC to reduce the hazard risk of lithium ion batteries for consumers.

Chapter IV: Results and Discussion

This section details the results found through research and analysis conducted at the U.S. Consumer Product Safety Commission (CPSC). From these results, conclusions were drawn and recommendations were provided to the CPSC. The results followed the three objectives of: creating hazard scenarios from the IDI (In-depth Investigation) reports, comparing standards, and researching possible solutions of lithium ion batteries. These three objectives made identifying potential solutions that will minimize the safety risk associated with the use of lithium ion batteries possible.

4.1 Hazard Scenarios

In creating hazard scenarios, the In-depth Investigation (INDP) database was used to access the IDI reports provided by the CPSC. Lithium ion battery incidents examined were of two products, notebook computers and mobile telephones from January 2003 to December 2006. Over this period, only 27 of 46 IDI files examined were found with sufficient information to draw conclusions from. Other IDI files found in the database did not contain enough detail or was irrelevant to our study. Our results and conclusions are based on the small number incidents found and may not reflect all the scenarios in which lithium ion batteries experience failure. A spreadsheet was compiled from the useful information to allow better categorization of the hazards. Table 1 is an example from the spreadsheet.

Date of Accident	*Product*	*Cause of Hazard*	*Damages*	*Injuries*
1/11/2006	Mobile telephone	Low Battery-Put Battery in Charger Minutes later while charging battery exploded	Set papers and arm rest on chair on fire	Cut or Burn over right eye Redness to Face and right arm

Table 1: Excerpt from IDI Spreadsheet

The full spreadsheet containing the IDI data can be found in Appendix N. The spreadsheet was broken into two categories: notebook computers and mobile telephones. These were examined for similarities. The first area examined was if the consumer product was using an aftermarket battery or an original equipment manufacturer (OEM) battery. (OEM batteries are batteries that were originally purchased with the product or are recommended battery replacements by the manufacturer, while aftermarket batteries are manufactured by companies other than those who made the product and are not endorsed by the manufacturer). When observing the chart, it was found that 67% of the incidents could be attributed to aftermarket batteries for notebook computers, while for mobile telephones, 21% of the incidents were involved with aftermarket batteries (Table 2) (CPSC, 2003-2006). One possible explanation for the relatively low number of aftermarket battery incidents in mobile telephones is that they are usually replaced within one to two years with a new battery.

	Lithium Ion Battery Type	
Consumer Product	**Aftermarket (AM)** (# of Incidents)	**Original Equipment Manufacturer (OEM)** (# of Incidents)
Mobile telephone	4	15
Notebook computers	6	4

Table 2: Battery Type of Lithium Ion Battery for Notebook computer and Mobile telephone Incidents from 2003-2006

Mobile Telephones

Besides looking at the battery type, other key information examined was the pre-incident operating conditions and the type of environment in which the mobile telephones were used. The pre-incident conditions were examined to determine how the consumer was interacting with the product before the incident occurred.

For mobile telephones, the pre-incident operating conditions were “standby” and “off,” while the environment conditions were “open” or “enclosed”. “Standby” can be described as when the mobile telephone is turned on but not in use, while “off” was when the mobile telephone was not powered on. An open environment was where the battery had proper ventilation before it started to overheat. For example, a battery located on a desk or table would be considered an open environment. A “closed” environment was if the battery was being “suffocated”, for example being in a pocket or purse. The environmental factors can be seen in Table 3, while the power conditions can be seen in Table 4.

Number of Incidents for Mobile Telephones	
Open Environment	**Enclosed Environment**
13	6

Table 3: Mobile Telephone Environmental Incidents

Number of Incidents for Mobile Telephones	
Standby (Power)	**Off (Power)**
17	2

Table 4: Mobile Telephone Power Conditions Incidents

A third characteristic examined was if the mobile telephone was less than two months old. The reason for examining this pattern was to determine if manufacturing infant mortality rate could be a factor. Infant mortality rate for could play a factor since the batteries have higher charges and may be more likely to experience an incident than an older battery as the charge of the battery declines with use. These results can be seen in Table 5 (CPSC, 2003-2006).

Number of Incidents for Mobile Telephones	
Great than 2 Months Old	**Less than 2 Months Old**
14	5

Table 5: Age of Mobile Telephones Experiencing Incidents

Analyses of Tables 3, 4, and 5 show that mobile telephones were on standby 89% of the time, while 68% of the time they were in an open environment. The following information from the IDI files suggests the mobile telephones experienced normal use during the majority of the incidents. The age of the batteries was also examined, and it was found that 26% were less than two months old when they failed. The data from the IDI reports suggests that the age of the battery for telephones did not play a factor in the incidents (CPSC 2003-2006).

Secondary information was found after further searching the IDI and it consisted of whether the telephone was damaged (dropped, thrown, etc.), or in the process of charging. The reason for separating the charging category into two categories (greater than five hours, and less than five hours) was because it is impossible to tell if the safety mechanisms in the battery and cellular telephone failed and allowed overcharging to occur. Having studied the IDI file the results showed that out of 19 incidents, a total of fourteen (74%) were in the process of charging, while one (5 %) was dropped onto concrete and the other four (21 %) were not charging or damaged. (Table 4) (CPSC, 2003-2006)

Number of Incidents			
Damaged	**Less than 5 Hours on Charger**	**Great than 5 Hours on Charger**	**Not Charging**
1	11	3	4

Table 6: Secondary Factors for Causes of Lithium Ion Battery Incidents in Mobile Telephones

The IDI files suggest that mobile telephones on a charger plugged into an electrical wall outlet is a common hazard scenario.

Notebook Computers

After addressing mobile telephone incidents, notebook computers incidents were reviewed for hazard scenarios other than aftermarket battery failure. There were three different pre-incident power sources:

1. Using battery power,
2. Using AC power,
3. Notebook computer was turned off.

As seen in Table 7, four (44%) were powered by Direct Current (DC Power), two (22%) were powered by Alternating Current (AC), and three (33%) notebook computers were turned off when the incident occurred.

Number of Incidents		
Battery Power (DC Power)	**AC Power**	**Turned Off**
4	2	3

Table 7: Pre-Incident Power Source of Notebook Computers

Also the pre-incident operating conditions were examined. These conditions included:

1. Running Applications
2. Standby
3. Charging

From the IDI information found in Table 8, 33% were running applications, 33% were on standby, and 33% were in the process of charging (CPSC, 2003-2006).

Number of Incidents		
Running Applications	**Standby**	**Charging**
3	3	3

Table 8: Pre-Incident operating conditions of Notebook Computers

Analysis of Tables 7 and 8 show that for notebook computers the pre-incident conditions do not indicate any specific hazard pattern. The pre-incident conditions appear to be typical, normal use; therefore, no further conclusions were drawn from the data.

After looking at the pre-incident conditions the environment the notebook computer was in during the incident was examined for specific information, such as whether the vents on the notebook computer were obstructed. An unobstructed environment was where the vents were not covered, for example being on a hard surface, allowing proper ventilation for the fans. An obstructed vent was where proper ventilation was not occurring, for example having the vents being covered by a soft surface such as a bed or couch (CPSC, 2003-2006).

Number of Incidents	
Unobstructed Ventilation	**Obstructed Ventilation**
6	3

Table 9: Ventilation Condition of Notebook computer Incidents

The results from Table 9 show the incidents are not dependent on whether the vents of the notebook computer are open or obstructed. However incidents have occurred due to improper ventilation that led to problems of overheating (CPSC, 2003-2006).

From these results found in the initial IDI Spreadsheet, a new spreadsheet with the data from Tables 1-9 was formed. The new spreadsheet is more concise than the original and contains data that allow graphics and charts to be formed. The new spreadsheet provides a method to create pivot charts which in turn, allowed a Fault Tree Analysis to be created for lithium ion batteries. All this data is present in the pivot charts and original spreadsheets (Appendix N).

4.1.1 Fault Tree Analysis

In order to determine the effectiveness of our recommended technological solutions, we used a Fault Tree Analysis (Figure 6), as described in the background. Fire, explosion, and overheating were identified as negative effects of failure from reviewing the IDI's and various reports such as the Draft Naval Surface Warfare Center (NSWC) Crane report. Ideally, if the batteries fail, a cessation in function should be the only consequence. From the background research, it is known that thermal runaway is an event that leads to these failures. For the Fault Tree Analysis, thermal runaway was set as the primary failure. From there, research data was collected from IDI's, and reports to try to determine causes of thermal runaway, which occurs when the battery's internal temperature reaches a critical thermal point and begins to generate heat on its own. The electrode chemistry in particular was found to be a problem as it is thermally unstable (Saidi and Barker, Advantages of Saphion®). The expanding material and constant volume of the battery increases the pressure and temperature within the battery. The added heat activates the exothermic reactions between the chemicals and more heat is generated (Chen and Evans, 1996). The reports examined indicated that the causes of thermal runaway were internal short circuits, overcharging, and external heating.

Incidents involving charging were most common in mobile telephones with fourteen out of nineteen incidents involving a telephone being charged, on the charger, or recently removed from it. All of the batteries tested at NSWC Crane contained fuses that were meant to prevent overcharge; therefore, for an overcharge to occur, these circuits must fail. This test contained various aftermarket and OEM batteries (NSWC Crane, 2006). Although the relative amount of time the batteries were charging was known, the charge levels were not so it was impossible to determine if any of the batteries were overcharged, unless they were left on the charger for an extended period of time (for our purposes, over five hours). In order for an overcharge to occur a battery must be left charging past its full capacity and it must either not contain, or have lost functionality of overcharge protection circuitry.

Underwriters Laboratories provided a report containing other reasons a battery may fail and go into thermal runaway. They collected a myriad of information from their own study on manufacturing processes. Their report shows that an internal short circuit can lead a battery into thermal runaway. The primary causes of internal shorts were: particles and/or contaminants in the cells, burrs (metallic edges, left over from cutting, on the electrodes that puncture the separator) and improper alignment of components such as leads. These three root causes can be attributed to problems in manufacturing process and quality control of the batteries. Contaminants can be traced back to poor environmental controls and raw material quality control. Burrs on the electrodes may be from defects in the machinery and/or poor quality control in the manufacturing operation. These are errors in the manufacturing process, which could be fixed by better quality control practices (Underwriters Laboratories, 2006). This is the most likely explanation for batteries that fail shortly after purchase or fail when not on the charger and on standby. The internal short circuit can also be caused by damage to the system.

There is yet another way for thermal runaway to occur. NSWC Crane's testing report indicated that an external heat source, applied to the battery, can raise it to the critical temperature to start runaway (NSWC Crane, 2006). This means that heat generated by the system is not removed adequately and is getting to the battery. In some of the IDI's for notebook computers, they were left on beds. When combined with the fact that many notebook computers have their cooling fan on the bottom the chance of overheating increases. For this to happen, the temperature sensors within the system and the cell would have to fail or not be present.

From this data a Fault Tree was constructed to aid in understanding how the recommendations, proposed by the team, may solve the problems of lithium ion battery technology.

Fault Tree

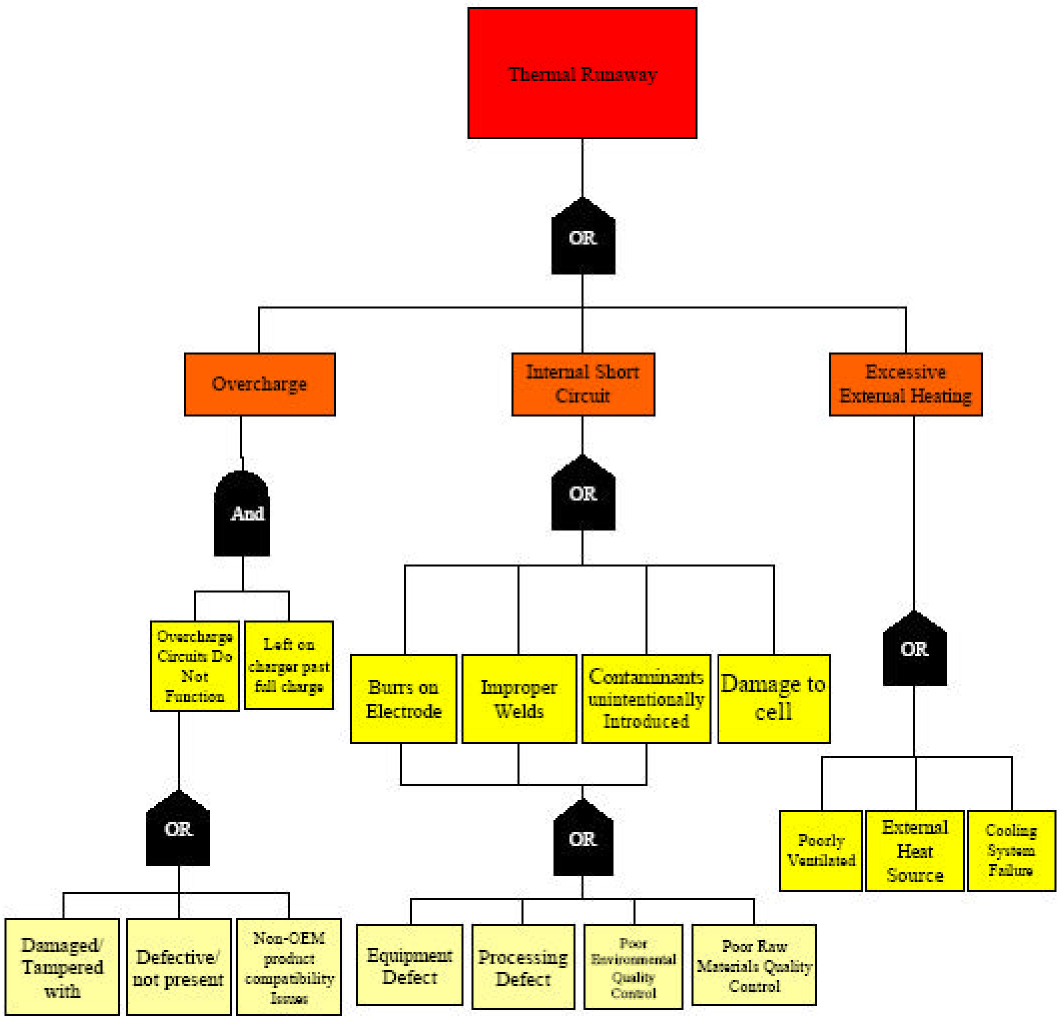

Figure 6: Fault Tree Analysis developed from IDI reports

4.1.2 Pivot Charts

To help understand and categorize the IDI data, all relevant information was placed into pivot charts. As described in detail in Background Section 2.5.2, a pivot chart allows one to see how the different types of circumstances are related to one another. IDI's were grouped by mobile telephones and notebook computers and a table for each was made. Information included was the circumstances surrounding each incident. As these two products have different components the tables varied slightly.

For mobile telephones, data was broken down and examined by battery manufacturing type, the state of the telephone prior to incidents, whether it was charging (broken into two categories, charging for more/less than 5 hours), environmental factors, age, manufacturer, and charge capacity. These factors were used to find similar patterns (based on a limited number of incident reports) in the data that could lead to pursuing different courses of action.

The pivot chart (Figure 7), for mobile telephones indicates that most failed while charging. This may indicate that either an overcharge or a short circuit is the underlying cause behind these incidents. Although the initial state of charge was not known, the chemical properties of the charging reaction are. The reaction of charging is endothermic, meaning that it requires energy input to occur (Chen and Evans, 1996). The battery gets the energy for this process from its charger. During overcharging, heat is generated from the increased impedance. The other explanation is that the batteries developed an internal short circuit and began to generate heat due to rapid self discharge, which was continuously fueled by the charging process.

Since the manufacturers were spread out among three companies, the problem is most likely a manufacturing defect, given the low amount of incident data observed. In the case of mobile telephones OEM batteries had a much greater failure rate than aftermarket batteries. One reason for this may be that consumers upgrade their mobile telephones prior to the end of their OEM batteries' lifetime, thus fewer aftermarket batteries may exist. As this data was not available, no conclusions about it could be drawn.

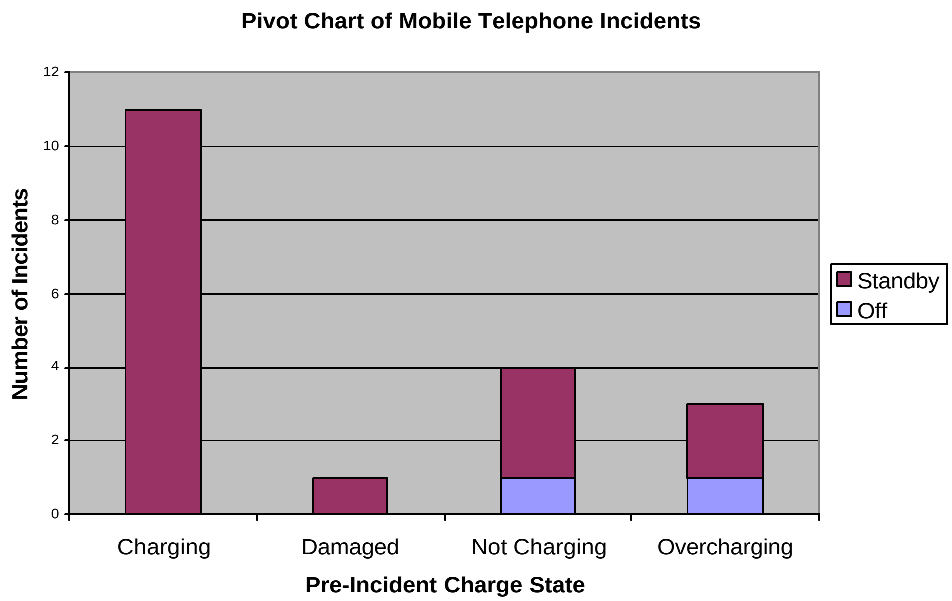

Figure 7: The Pivot Chart for Mobile telephones displaying charging state, and Pre-Incident State for X-axis compared to Number of Incidents on the Y-Axis

The issue with the notebook computer data was there were so few incidents from which to draw conclusions; therefore, the data had to be examined in simple charts such as the one in Figure 7. The aftermarket batteries involved in the incidents stand out, especially considering every notebook computer is sold with an OEM battery in it and not everyone buys an aftermarket battery. This is most likely due to the high cost of a notebook computer. Figure 7 illustrates this in a pivot chart that simply compares the number of incidents by battery type.

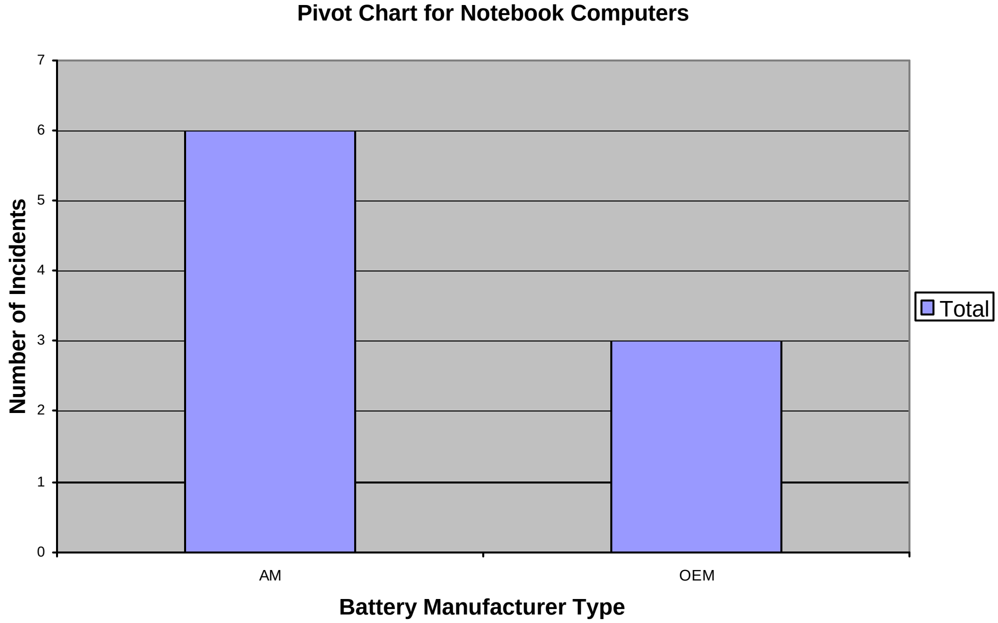

Figure 8: Pivot Chart for Notebook computers displaying Manufacturer Type on the x-axis and the number of incident on the y axis

In Figures 8 and 9 the numbers of incidents were compared by power source, pre-incident running conditions and cooling fan state. This particular chart was made to see if there were any other factors besides battery manufacturer type that had a greater number of incidents. Notebook computers running on battery power resulted in the greatest number of incidents, but because of the limited amount of incidents, no concrete results could be drawn. Figure 9 shows the data in Figure 8 represented as a pivot table instead of a chart.

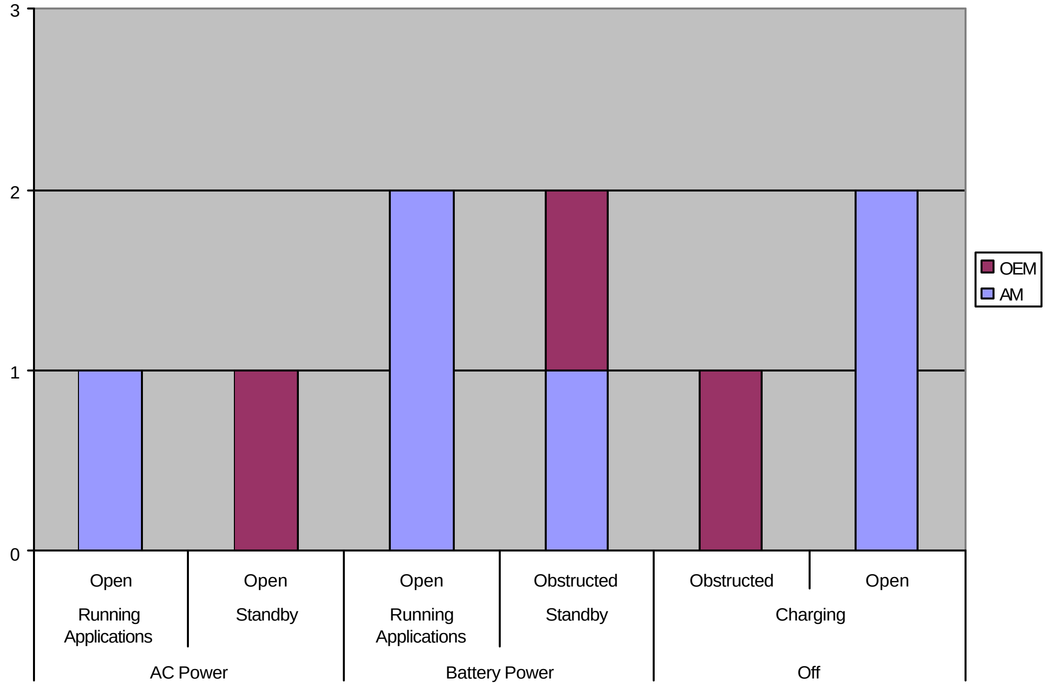

Figure 9: Notebook computer Pivot Chart Displaying Manufacturing Type, Pre-Incident Power Source and Operating Conditions, and Cooling System Status on the x-axis compared to the number of incidents on the y axis

Count of Task Number		Battery Type		
Pre-Incident Power Source	Pre-Incident Operating Conditions	AM	OEM	Grand Total
AC Power	Running Applications	1		1
	Standby		1	1
AC Power Total		1	1	2
Battery Power	Running Applications	2		2
	Standby	1	1	2
Battery Power Total		3	1	4
Off	Charging	2	1	3
Off Total		2	1	3
Grand Total		6	3	9

Figure 10: Same data represented as a Pivot Table

4.2 Standards

After reviewing standards from Underwriters Laboratories (UL), the Institute of Electrical and Electronic Engineers (IEEE), the United Nations (UN), and the International Electrotechnical Commission (IEC), two tables were developed, and comparisons were made between each organization's relevant battery standards. Results gathered were important differences in tests, voluntary standards and lack of third party certification processes.

Described in the following section are the findings in regards to battery standards and battery certification processes. Again, there are more than a dozen voluntary standards, but the ones focused on were the widely used and well-known standards.

The standards were chosen because of variety. We focused on the United Nations standards because of the requirements for transportation. The International Electrotechnical Commission was chosen for an international approach to standards; the Institute of Electronic and Electrical Engineers is widely known and referenced; and finally, Underwriters Laboratories requires third party certification for their voluntary standards and is also widely known and referenced.

4.2.1 Comparison of Voluntary Standards

Table 10 is an excerpt from the larger comparison of voluntary standards with a few chosen tests (Appendix M). These varieties of tests are to show the differences and similarities in popular standards used by a variety of manufacturers and companies. The six voluntary standards are IEEE 1625, IEEE P1725, UL 1642, UL 2054, IEC 62133, and UN ST/SG/AC.10/27. The focus of the table is mostly upon IEEE and UL standards since they are widely used in electronic products.

	Standard	*IEEE 1625 / IEEE P1725*	*UL 1642 / UL 2054*	*IEC 62133*	*UN ST/SG/AC 10/27*
	Test				
1	Overcharge	Discharged cell with power supply ≥ 10 volts (t = 2.5C / I) where I = recommended manufacturer current charge	fully discharge sample, connect in opposition to dc power supply charging with 3 times the current specified by manufacturer (I) (t = 2.5C / 3I)	Discharged cell with power supply ≥ 10 volts (t = 2.5C / I) where I = recommended manufacturer current charge	charge at 2 times the manufacturers recommended charge for 24 hours
2	Free Fall	fully charged dropped from 1m three times onto concrete floor (hardwood floor – P1725)	dropped from 1m with 3 samples onto concrete surface (UL 2054)	fully charged dropped from 1m three times onto concrete floor	
3	Temperature Cycling	75C for 4 hours, 20C for 2 hours, (-20)C for 4 hours, 20C for 2 hours	70C for 4 hours, 20C for 2 hours, (-40)C for 4 hours, 20C for min of 2 hours	75C for 4 hours, 20C for 2 hours, (-20)C for 4 hours, 20C for 2 hours	6 hours -> 75 ± 2 then 6 hours -> -40 ± 2
4	Low Pressure	Stored at pressure of 11.6 kPa for 6 hours	Stored at pressure of 11.6 kPa for 6 hours	Stored at pressure of 11.6 kPa for 6 hours	Stored at pressure of 11.6 kPa for 6 hours
5	X-ray		In Development		

Table 10: Compared Voluntary Test Standards involving Cellular Telephones and Notebook computers (IEEE P1725, IEEE 1625, UL 1642, UL 2054, IEC 62133, UN ST/SG/AC.10)

4.2.1.1 Overcharge Test

From our analysis of our IDI reports, we concluded that numerous incidents occurred when a mobile telephone was in a charging state. Our definition of a charging state is the mobile telephone is using AC power and is plugged into a wall socket, through a charger. The table above shows that these voluntary standards include an overcharge test.

In three out of the six tests, the battery is charged with a higher rate than the recommended manufacturer charging rate. The UL standards have the battery charged at ten times the recommended charge (UL 2054), at least three times the recommended charge (UL 1642) and the UN standard has the battery charged at two times the recommended charge

(UN ST/SG/AC.10). The overcharge test is very important because when an excessive amount of energy is forced into a battery, it can lead to fires.

A battery normally has some protective measures to prevent overcharge. These features can be located inside the battery, in the system using the battery, or the charger. In order to test batteries to overcharge, these fail safes must be removed or damaged. Aftermarket batteries and aftermarket chargers may have safety features omitted or are not compatible with OEM equipment. In many cases, testing is not performed to ensure safety of the system. In an OEM lithium ion battery, there are five to six wires connecting the cells in a notebook computer battery. Two of these wires are for positive and negative leads; the others are for safety measures. On examination of one aftermarket battery, there were no internal connections for safety found, or "dummy connectors" (Charles Monahan, Nov 13, 2006) were found.

4.2.1.2 Free Fall or Drop Test

The second voluntary test focuses on dropping a battery from different orientations to determine the consequences. The three organizations that require the drop test are UL, IEEE, and IEC. In most tests a battery is dropped three times, in different orientations, from a height of one meter onto a concrete floor, but the IEEE 1725 standard requires a mobile telephone battery to be dropped onto a hardwood floor. During consumer use, if a mobile telephone is dropped, it may not be always from a one meter height, it would more likely be dropped from a higher height since mobile telephones are used at head height. This is different than portable computer batteries since their application would be most likely from a desk which has a height of one meter.

In Table 7, the highlighted sections denote the difference in UL standards. UL 1642 does not incorporate the free fall test whereas UL 2054 does. These two tests are considered very important because trends were found that most battery failures occur while in a charging state or were subject to damage from being dropped. For a battery pack to be UL certified it must comply with both UL voluntary standards.

4.2.1.3 Temperature Cycling Test

The temperature cycling test subjects the battery to extreme temperature conditions (Table 10). In all the voluntary tests, it seems that temperature zones are extremely high and low, but these standards organizations must test all possible scenarios. It is rare for batteries to be subject to these temperatures, but when a notebook computer is used on a person's lap, the battery will not be allowed to dissipate heat and will heat up rapidly.

4.2.1.4 Low Pressure Test

The low pressure test is an example of the unvarying voluntary test procedures. Each one has the same procedure for this test which requires a battery to be stored in a container, which has a pressure of 11.6 kPa, for six hours. The intent of this test is to determine the stability and safety of a battery in low pressure environments, such as in air transit or high altitude facilities.

4.2.1.5 X-Ray Test

The recent incidents, recalls, and injuries have motivated UL and other voluntary standards organizations to update and rework their standards. The X-ray test is one of three new tests that UL is incorporating into an updated draft of UL 1642. The other two tests are the aging test and the dielectric test. The X-ray test identifies unwanted elements inside a lithium ion battery, such as burrs. Also the X-ray could determine any faults with the exterior or interior, which may include cracks in the shell or misalignment of the center tube. This test has issues with finding small metal particles in the interior of the battery, because it can not see most contaminants. By subjecting batteries to these new tests, they will be safer, but will still have potential to cause safety issues (Underwriters Laboratories, *Lithium Ion Batteries, 2006*).

4.2.1.6 Overall Comparison

Table 11 illustrates the tests that each voluntary standard requires. IEEE has a section for each one of its standards since each relates to a different product. The UL standards are combined into one section because battery packs and battery cells must comply with both standards. The table shows that UL standards and IEC standards have more safety tests compared to UN or IEEE. The areas highlighted are tests that UL is developing and may incorporate in the next edition of UL1642. The UN standards are lacking in many categories because they focus on the transportation of batteries, not on consumer safety.

This table illustrates a less in-depth comparison of the amount of tests a battery pack or battery cell must pass. It shows strengths in each voluntary standard as well as the basis it covers. The table shows UL has a large basis of voluntary tests and covers the problematic areas we found were the cause of incidents regarding notebook computer and mobile telephone batteries.

		IEEE 1625	IEEE 1725	UL1642 & UL2054	IEC 62133	UN ST/SG/AC
1	*Continuous Charging*	X	X		X	
2	*Vibration*	X	X	X	X	X
3	*Temperature Cycling*	X	X	X	X	X
4	*External Short Circuit*	X	X	X	X	X
5	*Free Fall*	X	X	X	X	
6	*Mechanical Shock*	X	X	X	X	X
7	*Thermal Abuse*	X	X	X	X	
8	*Crush Test*	X	X	X	X	
9	*Low Pressure*	X	X	X	X	X
10	*Overcharge*	X	X	X	X	X
11	*Forced Discharge*	X	X	X	X	X
12	*Impact*			X		X
13	*High Rate Charge*			X	X	
14	*Incorrect Installation*				X	
15	*Case Stress*	X	X	X	X	
16	*Electrostatic Discharge*	X	X			
17	*Projectile Test*			X		
18	*Aging*			X		
19	*Dielectric*			X		
20	*X-ray*			X		
21	*Limited Power Source*			X		

Table 11: Standards' Tests

4.2.2 Battery Certification

Certifications for battery packs and organizations that certify products were also analyzed. There are two paths a manufacturer can take in regards to certification; they can either self-certify or third party certify. Currently self-certification is the dominant form because it is cost effective and an easier process.

The Cellular Telephone Industry Association (CTIA) has developed a certification document which requires manufacturers to adhere to IEEE 1725. Mobile telephone service providers are only issuing mobile telephones with batteries that are certified though the CTIA (Monahan and Kerchner, Nov 13, 2006). Battery products may be certified to UL standards or another third party certification laboratory. The UL marking on lithium ion batteries identifies the product as being UL tested and certified.

On most battery packs, battery cells, and electronic products, there is a “CE” marking. This marking identifies the battery to be a battery that conforms to European Union directives with respect to safety, health, environment, and consumer protection. Products that display the CE marking are self-certified, and this marking is required to facilitate trade between countries in the European Union. The difference between the CE marking and the UL marking is that the CE marking is not a safety certification, and the marking does not signify compliance with North American safety standards or installation codes (Underwriters Laboratories, *CE Marking Info*, 2006).

The differences between self-certification and third party certification involve severity, costs, and validity. Manufacturers that self-certify their product do not have an outside agency supervising certification processes to ensure that they comply with standards. It is hypothetically possible that manufacturers can falsify data in order to have their products possess a mark of certification. Currently, the CTIA certification has allowed two companies to begin IEEE certification, Exponent and the Société Générale de Surveillance (SGS) group.

Companies like these are hired to ensure the validity of the certification process by completing the tests themselves.

4.2.3 Summary of Standards

Even though these standards cover a large base and have specific testing there could be improvements. In a recent meeting with UL, new tests were described and will be included in the next draft of UL 1642. The tests are the aging test, x-ray test, and dielectric test. These tests add an additional layer of safety testing to lithium ion batteries. Other standards organizations should consider adding additional testing procedures in order to cover every instance of normal use.

Batteries can be certified either by the manufacturer or by an outside company. Although third party certification provides more validity, it is costly because it requires hiring an outside agency. Even though self-certification is cost effective the data may not be as reliable when compared to third party certification. Each option has its advantages and disadvantages, but third party certification is important in regards to more reliable lithium ion batteries for consumer use.

4.3 New Technologies

Research was conducted on companies involved in manufacturing new types of batteries and additives. Researching these companies was necessary in order to make valid recommendations of potential solutions to the CPSC.

4.3.1 Valence Technologies

Valence Technologies, based in Texas is currently manufacturing batteries with their Saphion® technology. Saphion® technology uses a phosphate based cathode material instead of the lithiated metal oxides (LMO), usually cobalt, which are used for current lithium ion batteries. In the current lithium ion batteries thermal runaway has become a major concern, because the batteries use metal oxide-based cathode materials which when abused can release oxygen into the cell (Valence, 2005).

The Fault Tree Analysis shows that thermal runaway is the end failure for lithium ion batteries. Thermal runaway is fueled from the oxide-based cathode materials; Valence is able to reduce the chance of thermal runaway by incorporating lithiated metal phosphates (LMP) into their batteries instead of the traditionally used LMO. The metal found in the LMP consists of either a transition metal or a transition metal and a non-transition metal. Since there are no oxide based cathode materials in a LMP it has a decreased chance of experiencing thermal runaway. Another advantage of LMP over LMO is that lithiated metal phosphates use cheaper production materials (Valence, 2005).

While lithiated metal phosphates experience advantages over lithiated metal oxides, there are also disadvantages. One example is that LMP cathodes have an average voltage of approximately 3.2-3.3 V while the metal oxide cathodes experience an average voltage of approximately 3.6-3.8 V, the greater the voltage, the greater the electrical current. Another disadvantage of phosphate is that there is a lower energy density than that of metal oxides. Therefore, lithiated metal phosphates are usually not found in portable electronics and other similar devices (Valence, 2005).

Nevertheless Valence has taken LMP cathodes and found ways to have them placed in a variety of products including: external computer batteries, hybrid cars, and many different military applications. To gain some understanding of the standards Valence designs their batteries to, a table on the vehicle batteries they make, was found. The specifications can be found in Table 12 for their U-Charge RT Power Systems battery. The significance of this table is to show the wide range of tests, standards, and certifications Valence uses to make their products safe for consumer use (Valence, 2005).

Common Specifications	U-Charge RT Power Systems
Operating Temperature	-10?C to 50?C (14?F to 122?F)
Storage Temperature	-40?C to 50?C (-4?F to 122?F)
Operating Humidity	5% to 95% none-condensing
Water/Dust Resistance	IP56
Shock and Vibration	IEC61960, DIN VG96 924
Certifications	FCC Class B, CE, UL1642 (Cells)
Shipping Classification	UN 3090, Class 9

Table 12: Valence's Lithium Ion Vehicle Battery Specifications

When examining the Fault Tree Analysis, one is able to see that overcharge and charging play a role in batteries that experience thermal runaway. Valence contains one US Patent 6724173 that is related to the device charging and cell charging methods of lithium batteries. This patent explains how Valence batteries have a method to prevent overcharging and over voltage from occurring within the product. By using new battery chemistry and a patent for overcharging, Valence has developed two suitable ways to stop thermal runaway from occurring (Valence, 2005).

4.3.2 3M

3M, a company based in Minnesota is researching ways for battery manufacturers to add 30% more energy capacity to lithium ion batteries. The key aspects they use to accomplish this are with new materials and different manufacturing methods (3M, 2006).

3M uses a new electrolyte and electrode materials. The disadvantage of the new electrolyte and electrode materials is that they cost more than conventional lithium ion batteries. They are replacing the current anode material based on graphite with a silicon-based anode. The silicon-based anode would double the amount of lithium ions the anode can share. For example, a graphite-based anode takes six carbon atoms to store one lithium ion, whereas tin silicon, can store four lithium ions for each tin silicon when an alloy is formed. The benefit to this new technology is that the electrode materials increase the energy capacity of the battery, therefore balancing the increased cost (Bullis, 2006).

In the past the use of a new electrolyte and electrode materials was impractical because the material swelled up to three times its original size because of the increased number of lithium ions. This decreases the number of life cycles of the battery due to the physical changes the battery experiences. In order to resolve this problem, 3M reduces the swelling by using amorphous silicon instead of crystalline silicon. When pairing the amorphous silicon with inert materials, amorphous silicon helps to stabilize the system. These new materials reduce the expansion but do not entirely eliminate the expansion and contractions as the ions move in and out of the anode. 3M is working to fix this problem with new designs to absorb changes in size (Bullis, 2006).

The improvement of the electrolyte addresses the safety concern of lithium ion batteries by having the liquid conduct lithium ions and block the electrons, this forces them to travel to an external circuit to power the device. To deal with the incidents of over-charging, overheating, or internal short circuits for lithium ion batteries, 3M's new electrolytes will not react with the battery materials. 3M's additive can also help to prevent thermal runaway (Bullis, 2006).

Additionally, 3M's new electrolyte may have a big impact on hybrid vehicles because the new chemistries will be able to work at temperatures as cold as -40$^{?}$C. At this temperature, many other lithium ion batteries' electrolytes begin to block the flow of ions reducing the battery capacity by 80% to 90%. With a battery able to withstand these cold temperatures hybrid cars would be able to run almost anywhere in the world (3M, 2006).

4.3.3 Sandia National Laboratories

Another key research group is Sandia National Laboratories, they are trying to make lithium ion batteries work longer and be safer. Sandia researchers also focus on the effects of lithium ion batteries inside hybrid vehicles. They have a work center known as FreedomCAR where they conduct tests in the areas of battery abuse tolerance while also looking into lifetime prediction of the battery. Sandia researchers "want to develop a battery that has a graceful failure -- meaning that if it's damaged, it won't cause any more problems" (Sandia National Laboratories, 2005). This shows Sandia wants to gain an understanding of how batteries fail and why they fail, since this understanding would allow the battery to have a "graceful failure" (Sandia National Laboratories, 2005).

To do this Sandia has been working in the field of abuse tolerance and they have begun to find mechanisms that control the cell responses, such as, the effects of anode and cathode, electrolyte breakdown, and battery approaches. Sandia has improved their abuse test procedures developed at their labs which have led to lithium ion test standards; these were published in a Sandia research report. The standards that were developed are for hybrid electric vehicles and do not address the problems of mobile telephones and notebook computers (Sandia National Laboratories, 2005).

4.3.4 Thin Film Lithium Polymer

Another type of battery on the market that is attempting to address the problem of lithium ion batteries is thin film lithium polymer batteries. Thin film lithium polymer batteries contain a solid electrolyte making them safer than regular lithium ions since the solid electrolyte will never move or get bigger so there will not be a short circuit between the anodes and cathodes (Amperex Technology Limited, 2001). Currently, these batteries are being made for specialized products such as medical devices, Radio Frequency Identification (RFID) tags, detectors, and sensors and are useful for these products due to the small size and the life cycle of the battery which can last for over 10,000 cycles and only lose one percent of its capacity per year. The batteries do not contain the power needed for products such as notebook computers, but in the future thin film polymer batteries may appear in products such as ultra thin notebooks and mobile telephones. Many companies are working on this technology and it appears likely that at least one will make a breakthrough in the coming year. The companies working on thin film polymer batteries include Solicore, Cymbet, Excellatron Solid State, Great Power Battery, and Infinite Power Solutions (Bradley, 2005).

By preventing short circuiting, thin film lithium polymers have taken a step in preventing thermal runaway. While this prevents one of the paths of thermal runaway in our Fault Tree Analysis, it still does not address the concerns of overcharging and excessive external heating which are two more ways that thermal runaway may be achieved.

4.3.6 Lithium Technology Corporation

Lithium Technology Corporation (LTC) is focused on making large cells for the battery market in high powered applications. LTC also feels that their batteries are going to have a large market in military and national security areas. Standards that the company follows are International Standards Organization (ISO) compliant. They are working towards certification, in addition to conducting their own rigorous testing on the cells. LTC uses a battery monitoring system that keeps track of a number of factors in the battery while protecting the cells from potential failures. The battery monitoring system monitors the individual cells at all times, keeping track of their state of charge and health, while also preventing damage due to over voltage, under voltage, over heating, and an internal short circuit. LTC is also expecting to have a break through with the iron phosphate cells they expect to have on the market within the next year (Manning, 2006).

4.3.7 Interviews with Manufacturers of New Technologies

In addition to the above companies, A123 Systems, Quallion, Amperex Technology Limited (ATL) and Zinc Matrix Power (ZMP) are manufacturers also developing safer solutions to the lithium ion battery problem. Contact was made with representatives from each of these companies and teleconferences were conducted. The minutes from these meetings can be found in Appendixes D, G, I and K.

4.3.7.1 A123 Systems

The meeting with A123 Systems was held via teleconference on October 5, 2006, with Dr. Bart Riley, the Vice President of Research and Design. Dr. Riley was very informative not only about the structure of regular lithium ion cells, but with the differences of the cells designed by A123 Systems and the reasons they are safer. A123 Systems has developed a new lithium cell which is different from traditional lithium ion cells in the chemical structure. Instead of using an oxide on the cathode they use a phosphate material. This is more chemically stable than the traditional oxide because when the oxide is charged the cobalt goes from 3+ to 4+. Cobalt is no longer stable at 4+, thus it can cause an internal short, which leads to high temperatures and exothermic reactions or explosions. Phosphate does not have this problem and because it heats up slowly there is no possibility for thermal runaway.

Thermal runway is the end failure that appears on the fault tree analysis in this report. If a product can solve the problem of thermal runaway it can function through the damage and abuse and still be inherently safer than lithium ion batteries. The cells currently being built by A123 Systems are meant for power and not energy. This means there is a high output but the cells do not last as long. Therefore the technology is excellent for power tools and electric cars, but not as beneficial for consumer products such as notebook computers or mobile telephones that run through many cycles and do not need to be very high power. This technology is cost effective to implement into different products.

A123 Systems chose to develop cells with less energy, but a higher power. In the future they may develop higher energy cells for notebook computers and mobile telephones, but that is not the current focus.

Additionally, all A123 Systems cells are all UL certified and A123 administers their own safety tests as well. A123 Systems new technology currently has patents pending and perhaps in the future this battery will be further developed in order to operate products with a need for high energy and less power. For now it would be a good replacement for the lithium ion batteries in power tools (Riley, October 5, 2006).

4.3.7.2 Quallion

The meeting with Quallion was held with Mr. Paul Beach, Vice President of Business Development, on November 12, 2006. It began with an understanding of the focuses of Quallion, which are batteries for medical, military and aerospace industries. The discussion then moved to the new solutions Quallion is developing to make lithium ion batteries safer for consumers. Mr. Beach spoke about two different technologies. First was the Zero volt battery. This battery developed at Quallion can remain at 0V for a number of years without the battery deteriorating. A normal lithium ion battery cannot stay below 2.0 V before the battery can corrode and cause internal short circuits and other hazards. There are two patents for this technology and the reference numbers are 6,596,439 and 7,101,642. The other solution is called SaFE-LYTE.

SaFE-LYTE is an additive to impact or mitigate thermal runaway. This additive does not affect the design of the battery because it does not combine with the electrolyte and can be injected after the cells are manufactured. Thus, the manufacturers do not need to change their process rather they can add this after the battery is built. SaFE-LYTE is fluorine-based and combines well with oxygen. Therefore, if thermal runaway begins to occur the solution will absorb the oxygen that would normally fuel the fire. The solution has the ability to absorb most of the heat and the fluorine base helps to prevent thermal runaway. The solution is not 100% guaranteed because it is dependent on the nature of the thermal runaway. If the thermal runaway occurs in the very center of the cell it may have built up too much for SaFE-LYTE to entirely stop it. However, SaFE-LYTE will always help to control the amount of thermal runaway thus adding a safety barrier to consumer products. The solution is not very expensive adding just $0.10 – 0.15 per cell and the density will only decrease slightly from approximately 2.5 mAh to 2.3 mAh.

Quallion's SaFE-LYTE solution may be very beneficial to mitigate thermal runaway. For more information about the chemistry of this additive refer to Patent 6,797,437 (Beach, November 12, 2006).

4.3.7.3 Amperex Technology Limited

Amperex Technology Limited (ATL) focuses on designing lithium ion polymer (LIP) cells and batteries for mobile devices. These devices include mobile telephones, personal digital assistants, notebook computers, telephones, and smart card applications. Safety tests which ATL conducts on their batteries to ensure safety include:

- Short-circuit tests
- Overcharge and Over discharge
- 150?C oven baking test
- Vibration & Crush Tests

The products of ATL are also certified under the following Certifications:

- PRC Certification
- CE Certification
- International Standards Organization 9001 Certification
- International Standards Organization 14001 Certification
- Mobile telephone Battery Underwriter Laboratories Certification (UL 1642)
- All Products Underwriter Laboratories Certification (UL 1642)

The research and development team at ATL is active in the enhancement of cathode, anode, electrolytes, additives, and packaging with cell designs. For example, ATL batteries consist of a solid electrolyte which cannot leak liquid that may short circuit the batteries. Also, the packaging consists of an aluminum foil and not a rigid structure, allowing small expansions of pressure. Regular lithium ion batteries consist of a rigid structure that may lead to incidents. These improve: safety, energy density, temperature performance, voltage plateau, impedance, and cycle life (Amperex Technology Limited, 2001). We did speak with Mr. Anthony Wong at ATL, but the meeting was more a discussion of lithium ion battery technology in general and not specific about the technology ATL is developing. Thus, we gained more knowledge about the benefits of the technology through research on the web (Wong, November 21, 2006).

4.3.7.4 Zinc Matrix Power

Zinc Matrix Power (ZMP) has developed a new technology that is based on silver, zinc, and water. We spoke with Mr. Ross Dueber and Ms. Robin Hoffman. From both the conversation and information gathered from the website we learned about the advantages of this technology. There are three distinct advantages of this battery technology. First, the chemistry is based on silver, zinc, and water so it contains no flammable liquids or lithium. Thus, the battery is much safer than lithium ion, because it is free from the problems of thermal runaway and unrestricted pack capacity. Next, these batteries possess some of the highest power densities and energy densities of current batteries. The silver zinc battery has a very low discharge rate and can provide high discharge currents on demand. Therefore, they have an increased runtime and would be very useful for portable products. Lastly, these batteries are environmentally-friendly allowing the battery to be recycled and reused. In addition these batteries also weigh 5-10% less than lithium ion batteries. When manufacturing their batteries ZMP follows the following standards UL 1642, IEEE 1625, 1725 and ISO 9000.

The main problems facing the silver zinc battery technology are: (1) zinc is very difficult to recharge and (2) silver is relatively expensive. There are no rechargeable zinc batteries on the current market yet, because they are very expensive to make and have a relatively short life cycle, roughly fifty cycles. The reasons for the short life cycle is that as the battery charges and discharges, the zinc experiences physical changes that decrease the capacity of the cell. ZMP states that they have found a way to make zinc batteries more efficient and have increased the life cycle. They have also stated that they are going to try to implement a recycling program to help remedy the costs of the batteries and attempt to improve the life cycles of the batteries.

The method they are using to fix this problem is placing zinc granules within a conductive polymer. A professor from MIT stated, "The capital costs of this thing are going to kill you." He further went on to say if this was possible it "could be really good, but remarkable claims require remarkable proof" (Bullis, 2006). While unsure if ZMP can implement the recycling plans, if they do this battery appears to be a good alternative in the future. For more information on this process see Patent 6743548 (Deuber and Hoffman, December 1, 2006).

4.4 Interviews

The following section details the contact we made with different government agencies, organizations and manufacturers. As this material does not specifically relate to the conclusions and recommendations we made we have separated it into an additional section. Thus our results and discussion of why we interviewed each group is detailed in this section. If we gained any useful information it is also presented. Additionally, minutes for every meeting except the manufacturers can be found in the appendices. Each interview was interesting and helped to develop the background for the project. However, much of the information was not used to specifically influence the recommendations provided.

4.4.1 Interviews with Government Agencies

We contacted several different government agencies to learn how the lithium ion battery problem affects them. These organizations were the National Association of State Fire Marshals (NASFM), National Aeronautics and Space Administration (NASA), National Transportation Safety Board (NTSB), Department of Transportation (DOT), Federal Aviation Administrations (FAA), Naval Surface Warfare Center (NSWC) Carderock Division, and Sandia National Laboratories.

Meetings were held with Bill Bennett, an independent contractor working with NASA's battery investigation group at Glenn Research Center, Karen Suhr and Allison Crowley of the NASFM, Judith Jeevarajan from NASA Johnson Space Center, and Daphne Fuentevilla from NSWC.

NASFM

The meeting with NASFM was held with Karen Suhr and Allison Crowley. The information gathered from the meeting included:

- How the NASFM works
- The influence they have
- Concerns about lithium ion battery safety, such as how to put out the fire so fire fighters will be safer
- Further contacts

The most beneficial information gained was that George Kerchner the Executive Director of the PRBA had put together a book for the NASFM with numerous documents pertaining to lithium ion battery safety. As the lithium ion battery problem is fairly new, the meeting was more of an exchange of information gathered from similar research areas versus an informative meeting about solutions to the lithium ion battery problem. Thus, information gathered from the NASFM was not specifically used in order to provide reasoning for providing specific recommendations (Crowley and Suhr November 9, 2006). Minutes can be found in Appendix E.

Bill Bennett independent contractor at NASA Glenn Research Center, and Judy Jeevarajan NASA Johnson Space Center

The meeting with Bill Bennett, an independent contractor at NASA Glenn Research Center, provided information about different types of high energy density batteries on the market and what type of batteries NASA uses.[1] The meeting then moved to a discussion of other batteries. Mr. Bennett provided information about Lithium Technologies and Sion. These two companies are developing newer safer technologies. Bill Bennett gave contact information for Judy Jeevarajan during the teleconference. Judy was very helpful in informing us about the use of lithium ion batteries by NASA. Lithium ion batteries are used in many applications at NASA including the Mars Lander, satellite applications and notebook computers and other portable devices in the space shuttle. NASA uses a number of different tests before these batteries are used (Bennett November 16, 2006). The tests conducted are similar to those of UL and IEEE. However, their tests are much more stringent and all the batteries they use must come from the same lot. This means that the batteries they test and the batteries they use were manufactured and shipped together. When they perform the tests they are conducted in four categories:

(1) Engineering tests, which include tests on the battery cell and battery pack

(2) Performance tests, such as vacuum, vibrations and temperature tests,

[1] The information gathered at this meeting was the opinion of Bill Bennett and is not necessarily representative of NASA.

(3) Safety tests such as overcharge, discharge, external and internal short circuit and drop tests

(4) Qualification tests where they test 100% of batteries used in flight and these include vibration, vacuum and environment.

Finally it was learned that NASA has been using lithium ion batteries since 1999 and have not had any incidents. The only incident they had was with a lithium polymer battery that swelled up during a vacuum test. Thus this battery cell type was not used. NASA foresees the continued use of lithium ion batteries and sees value in potentially adopting UL's new x-ray test for the updated version of UL 1642.

Information from this meeting showed that if standards were more stringent then there may be a decrease in incidents related to lithium ion batteries. If information about NASA's specific tests was able to be gathered then this information could be developed into the present voluntary standards, because with more stringent tests there is the potential to be fewer incidents. However, testing consumer products to this level may not be economically feasible (Jeevarajan November 29, 2006).

NSWC Carderock Division

During the visit to the Naval Surface Warfare Center Carderock Division we watched a short circuit test be conducted on a cell used for an unmanned underwater vehicle. Additionally we were shown videos of tests that had been conducted in the past which had resulted in large fires. The Navy uses their own standard (9310) when they test batteries. The reason the Navy is interested in testing lithium ion batteries for safety is specifically because of an incident which occurred in the 1970's that resulted in one death. There have been more incidents with lithium ion batteries since then, but the data was not gathered.

The Navy uses many different types of lithium ion batteries and they are tested in equipment and conditions that replicate the actual use conditions. When the Navy tests lithium ion batteries, they are tested until they fail. In manufacturing products are typically tested to the standard in a pass fail mode. However, in the Navy they want to know exactly when the battery fails. Generally, safety is emphasized over cost in military electronics. They do use consumer type lithium ion cells (18650) in products such as notebook computers. However there are not as many incidents when compared with the number of incidents with consumer products. In fact the lithium ion battery safety group at NSWC Carderock only had one reported incident from their notebook computers in use.

The information gathered was useful, because an understanding was gained about the use of lithium ion batteries by high level consumers. The Navy uses lithium ion cells to power consumer level devices, such as notebook computers, all the way up to large scale operations, such as powering unmanned underwater vehicles. It was interesting to learn that they have not seen many incidents. Thus in the future it may be plausible for some of their tests from 9310 to be applied to UL or IEEE standards to improve the performance testing of lithium ion batteries used to ensure that cells in consumer products are safer in the system and environment in which they are used (Fuentevilla December 1, 2006).

Additional Contacts

Additionally, contact was made with NTSB, DOT, FAA and Sandia National Laboratories. The results of these contacts were numerous documents about lithium ion and lithium batteries, incidents involving these batteries, and different solutions to the lithium ion battery problem. One document gained from the FAA was a spreadsheet documenting incidents of battery fires on airplanes since March 1997 (Batteries & Battery-Powered

Devices, 2006). Not all these incidents were of lithium ion batteries, but the few that were helped to show the reasoning behind the regulations of shipment of lithium ion and lithium batteries (Appendix O). Additional documents received from the DOT provided information about the specifics of shipping lithium ion batteries. They provided a better understanding of the level of failure and what has been done to protect consumers, but they were not specifically helpful in determining the recommendations and conclusions provided.

Conclusions were not specifically drawn from these documents. Instead they were reviewed in order to get more background on incidents especially with transportation. This incident data provides reasoning for why this topic should be investigated.

4.4.2 Interviews with Organizations

While conducting research we had the opportunity to speak with Underwriters Laboratories (UL) and the Portable Rechargeable Battery Association (PRBA). Both organizations were helpful in understanding the direction different organizations are taking to make lithium ion batteries safer.

The meeting with PRBA was informative. It began with an introduction of the formation of PRBA and what they do. The meeting was held with Mr. George Kerchner, Executive Director of PRBA and Mr. Charles Monahan, Chairman of the PRBA board attended via teleconference. Information gathered included: the structure of the cells, a hands on look of the actual makeup of the battery, the design of OEM batteries versus aftermarket batteries, how PRBA works, and finally transportation issues of lithium ion batteries. Minutes from the meeting can be found in Appendix F. The information gathered from the meeting at PRBA was specifically helpful in addressing the recommendations of developing trade organizations for notebook computer companies. Trade organizations can help bring all the stakeholders into a discussion about how to make products safer for consumers. They are usually working groups of all invested parties. In the meeting it was discovered that no trade organizations for notebook computer manufacturers existed. This discovery was specifically useful in developing the recommendations of this report to further develop trade organizations and third party certifications for notebook computer companies (Kerchner and Monahan, November 13, 2006).

There was also a meeting held at the CPSC with UL. The meeting mostly detailed the forum UL had with manufacturers on November 1 and 2, 2006. The purpose of the forum was to bring industry stakeholders together in order to discuss the development of programs that can improve lithium ion battery safety. There were several different speakers at the forum. Simon Rate of Apple computers focused on the manufacturer's perspective of the end-product and what elements are needed to enhance the safety of lithium ion batteries. The other speakers were UL employees that led discussions of the following topics: gathering data on battery manufacturer initiatives to improve safety of lithium ion batteries, what UL should consider when changing the battery certification process, and learning about the quality control techniques which are thought to have a positive impact on product quality.

From the forum UL developed the following set of steps that they will implement: "UL will

- Formulate the next version of Construction Report and Recognized Component Separator Program based on feedback from this forum. Input from industry is welcome. The goal for enhancement of these aspects of the certification program is by the first quarter of 2007.
- Revise the Follow-Up Service and Production Line Test documents based on the results of this forum and will issue revised drafts in early 2007. Input from industry is required before the end of 2006.

- Undertake an internal research investigation into new safety performance tests. Participation from industry is welcome. Timing is based on sample availability but is planned for the beginning of 2007." (Underwriters Laboratories Forum)

4.4.3 Interviews with Manufacturers of Products using Lithium Ion Batteries

Contact was made with two different manufacturers of products using lithium ion batteries, Sony and Hewlett Packard (HP). Questions were presented to HP over e-mail and their responses were as follows.

Hewlett Packard

1. **Do you follow any specific standards such as UL, IEEE, IEC, or UN?**

HP batteries are designed to comply with UL, IEEE, IEC and UN transportation standards. Cells and batteries are certified to UL standards by UL. (HP provided a copy of the document "Batteries in HP Notebooks" to the CPSC which also addresses the standards topic)

2. **Do you think there is a problem with lithium ion batteries?**

(Customers say battery life is not long enough, they cost too much, and are too heavy.) A product of careful design, manufacturing and systems integration and used as intended by the manufacturer should not result in a safety problem for the consumer.

3. **Do you think batteries will change to a different form, or will they stay lithium ion?**

In the short run, batteries will be Li Ion. The technology allows manufacturers to best address the needs of customers who want mobile products.

4. **Do you feel it would be better to design out or guard against the problems found with lithium ion batteries in notebook computers and mobile telephones?**

From HP’s experience, the answer is yes. Design is primary, but both need to be addressed. If you consider the type of information in a standard such as IEEE 1625, you will see there are requirements and suggestions directed towards design and manufacturing such that the product will perform as intended, and there are other requirements that essentially address mechanisms intended to mitigate the consequences of a product failure should that unfortunately occur. (We believe most of industry is taking both the "design out" and the "guard against" approach for battery safety)

5. **Are your battery packs tested at all levels? Cell, battery pack and within the product?**

Yes, HP tests at the cell, pack and product level as part of the design process. This was made known to the CPSC through the "Batteries in HP notebooks" document

6. **Do you foresee a trade organization such as CTIA (for mobile telephones) being developed and requiring third party certification?**

We are not aware of any new trade associations being developed at the moment. Members of industry are currently working with UL on changes in their voluntary certification program for cells. We understand the certification topic will also be considered in an IEEE working group as part of the recently announced work to update IEEE 1625. We believe the industry focus for the moment should be in the standards review and update area initially.[2]

[2] These are answers from Mr. Kevin Clancy, representative of HP. They are taken directly from his e-mail.

Sony

Additionally, we conducted a teleconference with Mr. Christopher Smith and Mr. Brett Crawford who represent Sony. The same questions were asked, but as it was a conversation and not a direct e-mail we do not have word for word answers instead we have a summary of the information. It was learned that all Sony Notebook computers are UL certified. Most products carry the UL mark and thus Sony does go through the UL third party certification. Most testing is done on the finished product side versus cells. It was learned that Sony is engaged in research and development to enhance or develop new technologies to replace lithium ion technology. Sony said that they would be willing to participate in a roundtable discussion on ways to change and strengthen standards so that lithium ion battery use is safer for consumers.

Gathering information from these two manufacturers was beneficial in learning what they are doing and willing to do to make lithium ion batteries safer for consumers. Both sets of information helped to develop the recommendations for a roundtable discussion.

4.5 Summary

Overall, our results began with searching through the IDI files. With the IDI files similar patterns were found for lithium ion batteries in mobile telephones and notebook computers. For incidents in notebook computers, 66% of the lithium ion batteries were aftermarket. For mobile telephones 72% of the incidents happened while the telephone was on a charger. The information and trends from the IDI files allowed the creation of our pivot charts and Fault Tree Analysis. The pivot charts gave us the ability to pick and choose the information we wished to graph to gain a better understanding of the failure modes. Once we had a better understanding of the failure modes we then created our Fault Tree Analysis.

With this analysis we determined that the end failure for lithium ion batteries was thermal runaway.

Knowing the end result of the Fault Tree Analysis we then looked at areas where standards and technologies could prevent the thermal runaway stage. Different standards were then compared to find the similarities and differences. Comparing the standards allowed us to determine if the standards were suitable or if more tests should be added to improve quality control. Also third party certification could play a role in making lithium ion batteries safer for consumers and help to prevent thermal runaway. Lastly we looked at possible technologies that provided solutions to the Fault Tree Analysis. Companies are focusing on new types of chemistry for lithium ion batteries and are trying to stay away from flammable electrolytes and for existing electrolytes companies are trying to implement additives to help prevent thermal runaway from occurring. As potential technologies keep appearing on the market hopefully manufacturers will begin to adapt some into lithium ion batteries to make them safer for consumer use.

Chapter V: Conclusions

The overall goal of this project was to provide recommendations to the U.S. Consumer Product Safety Commission (CPSC) of ways to make lithium ion batteries safer for consumer use. Lithium ion batteries can be dangerous because they can cause fires and also injuries and property damage. Through analyzing hazard scenarios with the in-depth investigation (IDI) reports, comparing standards, and researching new technologies several conclusions were made about how to improve lithium ion batteries used in consumer products safer for consumer use. These conclusions led to the recommendations presented in Chapter VI. The following chapter details the conclusions that were made from analyzing the aforementioned topics.

5.1 Hazard Scenario Analysis

Based on our background research, literature review, interviews with industry and government experts, and from our Fault Tree Analysis we believe the primary cause of battery fires and explosions to be thermal runaway. As stated in our results section 4.1, this happens when the temperature of the batteries' internal components reach their critical thermal point and begin to generate heat. The electrode chemistry, in particular, was found to be a common problem as it can be thermally unstable. When its critical point is reached, the electrodes begin to breakdown releasing oxygen molecules into the battery. The added material increases the pressure and temperature within the battery. The added heat activates the exothermic reactions between the chemicals and more heat is generated. As a safety precaution, the battery is designed with a vent so that pressure and temperature do not build up within the battery.

Overcharging, internal short circuits, and external heating were found to lead to thermal runaway. In our Fault Tree Analysis, we determined that despite present protection measures, overcharge is still a possibility. It is has been determined that greater redundancy in safety is required to reduce the likelihood of such an event from occurring. This means adding additional protection measures at the system level, such as a sensor in the charger, host device, and/or the battery. Also since some incidents involved the use of aftermarket products, system level testing or third party system safety evaluation may be the solution.

External heating, primarily seen in notebook computers, is a problem that can contribute to battery heating which leads to thermal runaway. This can be initiated by added heat from an external source or by preventing internal heat from escaping. This problem must be addressed at the system level. The cooling systems on the notebook computers must be designed to meet foreseeable use by the consumer. That is, it must be anticipated in the design of the notebook computer that a consumer may place it on a bed, sofa, or lap that may obstruct the cooling system. Some notebook computers have their intake fans located on their base, facing downward where they may be obstructed. If for some reason the machine does not turn off due it overheats, the heat can spread to the battery cells.

The Fault Tree Analysis indicated that internal short circuits can lead to thermal runaway conditions which are most likely due to manufacturing defects. Although protection measures exist, they are designed to guard against external shorts and are not effective against internal shorts. Two effective ways of mitigating this problem would be to guard against thermal runaway itself, which would still result in the battery ceasing to function, or to strengthen the standards to improve quality control. Underwriters Laboratories (UL) is currently working on several additional tests that have been covered in the voluntary standards section of our results (section 4.2) and in our conclusions (section 5.2). Additionally, a technology that eliminates or reduces the probability of thermal runaway would be an effective means of eliminating the problem.

The pivot charts provided a way to organize the IDI data. There were several repeating circumstances found using this tool. For mobile telephones, most of the incidents involved original equipment manufacturers (OEM) batteries. Also, the majority of the batteries involved in the incidents were charging.

As discussed in the Pivot Chart results section (4.1.2), the batteries went into thermal runaway because of an overcharge or a short circuit. This supports the finding of the fault tree and also reinforces the need for strengthening the voluntary standards that were discussed in the voluntary standards section (4.2).

The number of incidents involving OEM batteries was greater in mobile telephones than in notebook computers. This inconsistency can possibly be explained by their shorter ownership life and lower cost. Mobile telephones are on average one tenth the cost of notebook computers. It is possible, that a person will upgrade their whole mobile telephone unit rather than buying a new battery when their old phone's battery begins to lose charge capacity. With a notebook computer, it is far more economical to buy a new battery when the original has lost effective capacity, than to buy a new notebook computer. This would make the population of aftermarket batteries in mobile telephone batteries lower than the population of aftermarket batteries in notebook computer batteries. Since we do not have any data on the number of aftermarket or OEM (Original Equipment Manufacturer) batteries on the market we cannot confirm this statistically, but it does merit further investigation in future studies.

The higher number of incidents involving aftermarket batteries in notebook computers was the only clear pattern that could be derived. In our meeting with the Portable Rechargeable Battery Association (PRBA) we were informed that the safety devices on the aftermarket batteries, examined by PRBA, were not present. This suggests that the voluntary standards need to be enforced with a certification program where the batteries are tested on their interactions with their intended system.

Thermal runaway is the primary cause of lithium ion battery fires. Any solutions proposed need to mitigate either thermal runaway or its causes. Voluntary standards are needed to ensure that the appropriate and redundant safety devices are in place and if non-compliance to these voluntary standards becomes an issue then regulation will be required.

5.2 Standards

The conclusion that was drawn from the comparison of voluntary standards involving lithium ion batteries was that the structure and basis of the voluntary standards proved appropriate for manufacturers to follow. The voluntary standards have a wide variety of tests, especially International Electotechnical Commission (IEC) and Underwriters Laboratories (UL) standards. They have explicit details on safety tests. Even though these standards cover a large base and have specific testing there could be improvements on voluntary standards. In a recent meeting with UL, new tests were described and will possibly be included in the next draft of UL standards. As previously stated, the new tests are the aging test, x-ray test, and dielectric test. These tests can add an additional layer of safety testing to the lithium ion battery and other types of batteries overall.

Not all tests in the voluntary standards were compared as in depth as the other tests because of relevance to failures. More testing procedures can be viewed in Appendix M.

After reviewing these standards, we concluded that even though these tests cover a wide base and cover numerous safety tests, they can be improved by either requiring additional safety tests or testing batteries to elevated restrictions. Specific recommendations are discussed in section 6.2.

5.3 New Technologies

In reference to our Fault Tree Analysis, many companies are developing potential technologies to prevent thermal runaway. These technologies range from new battery chemistries to additives. The following technologies are possible options to use in order to help prevent thermal runaway from occurring.

The most common method companies are looking to improve upon with regards to the safety and performance of lithium ion batteries is through new battery chemistries. By using different types of battery chemistries, such as lithium sulfur or lithiated metal phosphates, companies have the ability to achieve longer runtimes while further decreasing the already small chance of thermal runaway from occurring. These new battery chemistries are in their infant stage and will require more time to develop. However, it is still recommended that the CPSC remain aware of these technologies as they are further developed. Some of the companies we researched and interviewed are still in the development stages of their batteries and they are not yet in production. While they decrease the chance of thermal runaway it takes time for companies to develop chemistries and the initial cost to implement and manufacture is high.

Additives are another option in preventing thermal runaway from occurring. For the majority of cases, adding a small amount of the additive will prevent thermal runaway from occurring but it may not work if an internal short circuit happens within the center of the battery because the additive is placed towards the outside of the cell and the runaway can exceed the additive's capabilities. The additive reduces the probability of thermal runaway and thus, protects the cell from all the branches of the Fault Tree.

While costly for manufacturers and companies to safeguard their batteries from thermal runaway, it is necessary for the safety of consumers. There are proven ways to allow lithium ion batteries from reaching hazardous end-of-life failure modes in the Fault Tree Analysis and the possibilities above are not the only ones. The CPSC has the ability to run independent tests on new technologies, as they are developed. By conducting battery tests on these technologies the CPSC has the ability to evaluate them and come to their own conclusions. Using information from new technologies and test results the CPSC can bring forth a performance based requirement to address the issue of thermal runaway. Companies would then need their batteries to pass the performance based requirement to improve the safety of their batteries. Promoting a specific technology is not beneficial as different products have different requirements. Instead, giving companies broad performance guidelines allows innovation in research and the development of new technologies to reduce the hazard of lithium ion batteries.

5.4 Summary

Our conclusions were broken up into three main sections. First the Hazard Scenarios were analyzed. In this section explanations for causes of thermal runaway were concluded as well as trends in data that were found from the IDI reports. Main causes that explained thermal runaway were overcharging, short circuits, and external heating. These three causes could be seen in our analysis tool - the Fault Tree Analysis. Section 5.1 further explained ways that these incidents may be able to be prevented, such as additional cooling systems, strengthening standards, and guarding against potential problems.

The patterns in the IDI reports included a higher incident rate of aftermarket batteries in notebook computers than OEM batteries. However the data suggested this was not true for mobile telephones, where OEM batteries were more prevalent. However, mobile telephone incident data suggested a majority of incidents were found as the telephone was being charged.

Next conclusions for voluntary standards were considered. When observed the standards were found to be appropriate for manufacturers to follow. However, we believe that the voluntary standards can be and should continue to be strengthened. Voluntary standards can be strengthened for foreseeable use scenarios such as dropping a mobile telephone from a height higher than 1 meter, or leaving notebook computer in a car on a hot day with stricter guidelines in order to help prevent incidents from occurring.

Our final conclusion was related to potential technologies. Section 5.3 explained that many new technologies are being brought forth to the market such as battery electrolyte additives, new battery chemistries, nonflammable electrolytes, and new battery materials. The CPSC should take into consideration investigating each of these technologies and see if they deem it necessary to create performance tests to increase the safety of lithium ion battery for consumers.

These conclusions gave us the ability to develop recommendations for the CPSC on the safety of lithium ion batteries

Chapter VI: Potential Recommendations

The following chapter expresses the recommendations that will be made to the Consumer Product Safety Commission (CPSC). The recommendations were based on our conclusions and how effective the proposed recommendations would be in preventing thermal runaway in our Fault Tree Analysis. Another factor taken into consideration when forming these recommendations was the time period it would take to implement. With our recommendations based on these aspects, we prioritized them by the steps we feel the CPSC would follow in a normal course of action to make the product safer for consumers. Our first recommendation is to have a roundtable discussion with the manufacturers. It would be very helpful having all the manufacturers in a room discussing what they understand the problems to be and what possible solutions there are. Roundtable discussions can be scheduled around the manufacturers' convenience. The last recommendation is regulations, although they are the most effective, demanding compliance, the first options would need to have failed in order for regulations to be put in place. Consumer education could be conducted alongside each of the other options.

6.1 Roundtable Discussion

Underwriters Laboratories held a forum on lithium ion batteries on November 1-2, 2006. They invited manufacturers, and various other standards organizations to this meeting to discuss the problems and possible solutions with lithium ion batteries. This is a type of collaborative discussion where everyone with a stake in lithium ion batteries gets together to share what they know and work towards fixing a problem is highly effective.

As UL has already organized such a meeting, we encourage that they continue to hold them. However, we suggest that they include regulatory agencies and trade organizations to ensure both the pool of knowledge and expertise are substantial. The material from the UL presentation that is summed up in the results and analysis (sections 4.2 and 4.3) was the product of the first meeting. Future meetings could produce a number of outcomes: further changes to the standards, a shared technological solution, or a new trade organization. UL should continue to host these meetings, because it will improve the likelihood of manufacturers' participation and provide a higher chance of participants in offering up information. Also, having already held a meeting with good attendance UL is in a better position to continue hosting the discussions.

There are several obstacles to a roundtable discussion. The first is that no company would be required to send a representative and could therefore ignore it. Another obstacle is that manufacturers may still be reluctant to share their information with the others there, especially if there are regulatory agencies like the CPSC and DOT present. Despite the obstacles further meetings such as this would be beneficial.

6.2 Strengthening Voluntary Standards

Voluntary standards are created for a manufacturer to have some sort of idea of how to maximize safety of a product by subjecting it to tests and guidelines of manufacturing. After researching voluntary standards on lithium ion cells and battery packs, it was found that, although standards cover a large base of safety issues, they can be improved in a variety of different ways. To strengthen voluntary standards, organizations can include additional safety and performance tests, revise tests in order to make them more relevant to the environment and foreseeable use by the consumer, and include third party certification processes.

6.2.1 Additional Tests and Test Revisions

At the Underwriters Laboratories forum on November 1-2, 2006, it was determined to investigate additional tests that may be used to improve the performance testing in UL 1642. These tests are the dielectric test, aging test, and x-ray test. A recommendation would be for more standards organizations to consider these additional similar tests. Any additional tests would add further layers of safety tests in the battery certification process.

The x-ray test can determine the internal robustness of a battery after certain physical tests. It can also determine if there are contaminants or any excess burrs on the electrode. The aging test can determine the average time a lithium ion battery can be used without risking safety. The dielectric test will determine the robustness of the cell when exposed to varying voltages.

More specifically, standards organizations should adopt these additional tests as well as other tests not included in their voluntary standards. This would create a larger conformity between standards organizations and have common safety requirements for all lithium ion batteries.

Not only should organizations add additional tests to their standards, they should make the tests representative of the environment and foreseeable use by the consumers. For an example, the IEEE 1725 drop test, where a mobile telephone battery is dropped from a one meter height onto hardwood floor should be changed from one meter to 1.75 meters onto a concrete floor. This would be a more appropriate test for a mobile telephone battery.

6.2.2 Third Party Certification

From the vast amount of knowledge obtained from voluntary standards, trade organizations, and standards organizations, it was determined that a third party certification process is an important aspect of product testing. Currently only UL requires products to be certified by them or third party certified in order to carry the UL mark. No cell or battery pack can have the UL marking without third party certification. Another recommendation in regards to strengthening voluntary standards is to encourage all voluntary standards to require third party certification.

Third party certification has strict procedures and accurate results. The cost of a battery can increase, but the chance of it being faulty or counterfeit is reduced. Although this third party certification method is in the process of being adopted for mobile telephones, there should be the same for other lithium ion battery operated products. This process should also be used for other electronic equipment using lithium ion batteries, such as notebook computers, power tools and electronic video and music devices.

Another way to certify a product is through a self certification process. This has been used throughout the world in countries such as China, Japan, and the United States. It is less costly to certify a product, but it allows biased classification of data.

There are trade organizations, such as the CTIA, who are certifying products to voluntary standards. Unlike UL standards, the IEEE 1625 and 1725 standards do not require a third party certification for their standard. If voluntary standards included mandatory third party certifications for their products, then there would be no need for trade organizations.

In conclusion, our second recommendation is to strengthen voluntary standards by including additional tests, revising voluntary tests to reflect the product being tested, and encouraging third party certification processes. These would make safety requirements very similar no matter which voluntary standard a manufacturer chooses. It also would allow for more specific testing requirements and procedures depending on the product.

6.3 Consumer Education

Studies on consumer education have produced mixed results about the impact they make (Sanders McCormick 1993). However, it may be useful to educate consumers about how the use of their mobile products may result in larger safety risks. This education could be implemented in two different ways. One way would be for the CPSC to develop a safety fact sheet and the second would be to develop a warning label for products using lithium ion batteries. Both methods would inform consumers, and both could be implemented in either voluntary standards or regulations. Input should be considered by the entire industry including manufacturers, users and the CPSC.

Two product safety announcements have been made regarding lithium ion batteries by the CPSC. Both were press releases that can be found on the public website. However, these are difficult to find if the consumer does not know specifically what they are looking for. Therefore, our recommendation would be to use the same information in these press releases to develop a consumer safety fact sheet, or keep it the same but place it under CPSC publications, within the electrical safety group or make a separate battery category. The original bulleted lists (Table 10) of the releases may be the best way to communicate the safe usages of lithium ion batteries in specific products. The main concern addressed with these fact sheets would be the use of aftermarket batteries as they are not necessarily tested in the system that the consumer uses it in and therefore may not be compatible (66% of incidents observed were aftermarket batteries). A fact sheet would address the proper use of notebook computers and mobile telephones as well as the purchase of compatible batteries. The product safety fact sheets could either be general safety of lithium ion batteries or product specific.

General Guidelines for Mobile Telephones and Notebook Computers	Specific to Notebook Computers
• Do not use incompatible computer batteries and chargers. If unsure about whether a replacement battery or charger is compatible, contact the product manufacturer. • Do not permit a battery out of the phone to come in contact with metal objects, such as coins, keys or jewelry. • Do not crush, puncture or put a high degree of pressure on the battery as this can cause an internal short-circuit, resulting in overheating. Avoid dropping the cell phone. Dropping it, especially on a hard surface, can potentially cause damage to the phone and battery. If you suspect damage to the phone or battery, take it to a service center for inspection. • Do not place the phone in areas that may get very hot, such as on or near a cooking surface, cooking appliance, iron, or radiator. • Do not get your phone or battery wet. Even though they will dry and appear to operate normally, the circuitry could slowly corrode and pose a safety hazard. • Follow battery usage, storage and charging guidelines found in the user's guide.	• Computer batteries can get hot during normal use. Do not use your computer on your lap. • Do not use your computer on soft surfaces, such as a sofa, bed or carpet, because it can restrict airflow and cause overheating.

Table 13: CPSC announcements about safe use of Mobile Phone and Notebook Computers[3]

While consumer education is based on how apt consumers are to listen a study by Ursic (1984) "found that products with a warning were perceived as safer than the same product without the warning." (Sanders McCormick, pg 680 1993) Another study by Laugherty and Stanush (1989) found that products are perceived to be safer based on how explicit the warning is. (Sanders and McCormick 1993) Taking into consideration the problems with lithium ion batteries in notebook computers, it would be beneficial to use a warning label to address the safety concerns.

We have determined that notebook computers would benefit the most from a warning label, because fire damage and incidents as a result of notebook computers can be reduced if consumers heed the warnings. Also, the size of notebook computers allows the space for a

[3] Consumer Product Safety Commission, press releases September 28, 2006 and May 13, 2005

readable warning label. Notebook computers become more susceptible to fires when the cooling fans are obstructed and unable to dissipate heat. Additionally if a notebook computer does start a fire and is near combustibles the fire has the potential to be much more dangerous. Thus a warning label to address these concerns would be beneficial. These warning labels would be written by manufacturers but should include the following topics:

- Notebook computers have overheated and caused fires
- Use Notebook computers on surfaces that allow for cooling fans to operate correctly
- Do not leave unattended running notebook computers on or in close proximity to combustibles

Mobile Telephones may benefit from warning labels, but as the surface of a mobile telephone is small they would probably be placed on the box in which it is purchased in and not on the actual product resulting in a smaller likelihood that consumers would read the warnings and abide by them, because the packing is often disregarded.

Even when educated, consumers may use their products in the same way. However, product safety fact sheets and warning labels could potentially be implemented quicker than regulations, and if it can result in fewer incidents, injuries or potentially save lives, the attempt is useful. This plan would not be a solution to the large scale problem, but could be a step in the direction of making lithium ion batteries safer for consumers.

6.4 New Technologies

From analyzing the results in Chapter 4, we have determined the most beneficial new technology that will lower the safety risk of lithium ion batteries. Additives appear to be the most beneficial new technology on the market because they can be easily implemented.

Manufacturers do not need to change their manufacturing process instead it is inserted after the cells are built. Using an additive addresses the second approach for making a recommendation which is to guard against the hazard present (McCormick and Sanders 1993). An additive can reduce the impact of thermal runaway. Therefore, it is a guard against the biggest cause of failure as seen in the Fault Tree Analysis. Also it is fairly cost effective. One type of additive explored reportedly cost an additional $0.10-$0.15 per cell. Additives can lower the energy density. However, as the technology is explored in the future, there may be a method to make it even cheaper and not reduce the energy density. If a technology was presented to manufacturers as one to help mitigate the problem seen with thermal runaway in lithium ion batteries it should be the additive technology.

6.5 Regulations

The Consumer Product Safety Commission is mandated to solve problems with voluntary standards; however, if the need arises, it can impose regulations that force companies into certain actions. Voluntary standards are given time to work before a regulation is considered. The time is determined by the relative severity of the effects of failure, in this case probably one to two years. If after that time, recalls are continuing to occur, a regulation should be drafted.

Regulations, in general, can take two forms. The first is a safety standard, developed by the CPSC, that would include a series of tests that the product must pass in order to be sold in the United States of America. The second form that the regulations may take is an outright ban. Any company or individual that is found to be in deliberate violation of a regulation is subject to several penalties ranging from fines to incarceration of the individuals responsible. Regulations are generally a last resort approach and are imposed when either the voluntary standards are found to be inadequate, or there is a problem with compliance to the standards. A regulation would also remove the need for a market enforced third party certification in favor of a statutory enforcement.

A majority of the notebook computer incidents researched were batteries that were bought from aftermarket manufacturers. Upon further investigation, it was found that many of the aftermarket batteries contained no proof of a safety certification. A regulation that requires all manufacturers to follow one standard may be required. Since the standards examined were adequate, the trigger for a regulation would be a number of manufacturers failing to comply with the voluntary standards. The form this regulation would take would be a Consumer Product Safety Standard. This standard would include all tests that the CPSC determined relevant to battery safety and would require a product to pass all of them or be banned form the market.

The particular form that the CPSC safety standard should take would be very similar to the strengthened standards that are discussed in section 6.2, with particular emphasis placed on the following areas. The drop test should be standardized with a concrete floor, creating a worst case scenario for impact surface. The drop test height should also be increased for mobile telephones to a height of two meters to more accurately reflect a fall from the actual height of a person. This height is greater than average human height in order to make the test pass for all heights. For the temperature cycling test, the UN standards should be used, since the batteries will have to pass these tests in order to be shipped. In our Fault Tree Analysis and pivot charts we found that overcharging was a problem, and to help correct this we propose that the batteries be tested for overcharge circuit redundancy. There should be at least two forms of overcharge protection circuits present in the entire system.

The batteries should be tested with the system intact and then be tested with one of the safeties removed. From our standards analysis we found that UL is developing a standard for the shutdown separator and an x-ray, aging, and dielectric test. We recommend that these be included as well as they will help identify manufacturing defects such as contamination, and can also find defects that may appear over time with the aging test. The tests focused on in this section are the ones that we believe are most directly related to the problem identified in our Fault Tree Analysis and pivot charts. The regulations, like the strengthened voluntary standards would be based on the other tests that are common to all standards, in addition to those listed here.

The process for creating a regulation is a long one. The proposed rule must be drafted and made available to the public for commenting. It must be approved by the commissioners, and examined by the CPSC's general council and economics team to determine its feasibility. Once again a regulation is only recommended if voluntary standards do not solve the problem.

6.6 Summary

From the above recommendations we feel the two best actions for the CPSC to take in the near future are to strengthen voluntary standards and begin consumer education on lithium ion batteries. They could accomplish strengthening voluntary standards by including additional tests, revising voluntary tests to reflect the product being tested, and encouraging third party certification processes. Accomplishing all these tasks would allow voluntary standards to be more reliable and reduce the number of incidents.

Revising voluntary standards tests to reflect the product being used is very important. The reason is that different products are used in different ways, causing the cell to potentially be subject to stresses differently according to the product. With third party certification companies would have to send the consumer product to be tested at another organization. This allows for the tests to be accomplished without any bias and also creates a standard basis for various products using lithium ion batteries.

The next recommendation that the CPSC should strongly consider is consumer education on lithium ion batteries. The following two methods would better educate consumers. The first method is to create product fact sheets for consumer safety. These fact sheets would include information on how consumers should treat their products and what types of scenarios consumers should be aware. The second is to place warning labels on consumer products. The warning label for consumers would warn the consumer not to block the cooling fans on a notebook computer. When this complication arises fires are more likely to occur, due to the increased amount of heat within the notebook computer. These were the two recommendations that the CPSC should devote most of their time toward in regards to reducing the safety hazard of lithium ion batteries.

Appendices

Appendix A: Consumer Product Safety Commission

The Consumer Product Safety Commission (CPSC) was founded in 1972 to protect consumers from dangerous products. The CPSC is an independent agency of the United States Federal government that was founded through the Consumer Safety Act (see Exhibit 1). The CPSC is an independent agency and therefore does not report to any other department or agency of the federal government. The CPSC is headed by three commissioners, who are appointed by the President and confirmed by the Senate. They serve staggered seven year terms and the President appoints one of the commissioners to serve as the Chairman. The current Acting Chairman is Nancy Nord (Consumer Product Safety Commission, 2006).

The CPSC's mission is to protect the public against unreasonable injury risks associated with the use of consumer products, help consumers evaluate the safety between consumer products, develop uniform safety standards for consumer products, reduce conflicting state and local regulations, and promote research of product related deaths, illnesses and injuries. The commission sets its priorities by taking into consideration the number of deaths and injuries associated with a particular product, the severity of those injuries, and the likelihood of exposure to that product. Regulatory decisions are based on the hazards associated with the product and the economic costs and benefits of a regulation. The CPSC is in charge of administering four acts:

1.) Flammable Fabrics Act

2.) Poison Prevention Packaging Act

3.) Federal Hazardous Substances Act and

4.) Refrigerator Safety Act

The two key objectives of the CPSC are (1) to reduce injury risk and death associated with the use of consumer products and (2) to reach consumers with safety information so that they will be able to judge the comparative safety of consumer products (Consumer Product Safety Commission, 2006).

The CPSC has 480 employees and they are responsible for the safety of over 15,000 consumer products. Examples of products that are normally under the CPSC's control include: household appliances, electronics, toys, swimming pools, and furniture. Other products fall under the jurisdiction of agencies such as the Food and Drug Administration, National Highway Traffic Safety Commission, and the Bureau of Alcohol, Tobacco, Firearms, and Explosives (Consumer Product Safety Commission, 2006).

Consumer Product Safety Act (CPSA), 15 U.S.C. §§ 2051-2084.

This is CPSC's umbrella statute. It established the agency and defines its basic authority. The purposes of the CPSA are: 1) to protect the public against the unreasonable risks of injury associated with consumer products; 2) to assist consumers in evaluating the comparative safety of consumer products; 3) to develop uniform safety standards for consumer products and to minimize conflicting State and local regulations; and 4) to promote research and investigation into the causes and prevention of product-related deaths, illnesses, and injuries. When the CPSC finds an unreasonable risk of injury associated with a consumer product it can develop a standard to reduce or eliminate the risk. The CPSA also provides the authority to ban a product if there is no feasible standard, and it gives CPSC authority to pursue corrective actions and recalls for products that present a substantial product hazard. (Generally excluded from CPSA are food, drugs, cosmetics, medical devices, tobacco products, firearms and ammunition, motor vehicles, pesticides, aircraft, and boats) (Consumer Product Safety Commission, 2006).

Exhibit 1: Act that Founded the CPSC

The CPSC's policies are set by the Commissioners. Currently they are Thomas Hill Moore and Nancy A. Nord. Usually the CPSC has three Commissioners however, at the current time one of these positions is vacant. The two Commissioners will constitute a quorum until January 15, 200. After that no rulings will be able to be made until a new commissioner is appointed.

At the CPSC, six offices report directly to the Acting Chairman, Nancy A. Nord. These offices are Congressional Affairs, Equal Employment and Minority Enterprise, General Counsel, Inspector General, Secretary, and the Executive Director. The CPSC then categorizes the next groups under these as offices, which are comparable to departments in a corporation. The offices of the CPSC are compliance, hazard identification and reduction, field operations, administration, budget, human resources, information and public affairs, information services, and planning and evaluation. These offices report to the executive director who oversees Commission policy and administration (Consumer Product Safety Commission, 2006).

When a product hazard analysis is conducted, the CPSC staff will compile a report called a briefing package. A typical briefing package will consisted of an analysis of the injury data, adequacy of product standards, as well as human factors, health sciences, engineering and economic analysis. Once this report is written and reviewed by the appropriate Directorates, the Office of the Executive Director and the Office of General Counsel, the briefing package is transmitted to the Commission through the Office of the Secretary. Often, the staff will brief the Commission on their finding. The Commissioners then vote to determine which direction they will follow. This direction could be consumer education, rulemaking or another direction. The purpose being to make the hazardous product safer based on staff recommendations. Figure 1 shows an organizational chart that illustrates the department the WPI team is working for and to whom this department reports. At the top of the chart is the Executive Director of the Office of Hazard Identification and

Reduction (EXHR). Below her are two more executive directors. This chart then splits into the Directorate of Engineering Sciences (ES). Hugh McLaurin is the Director of the Directorate for Engineering Sciences, under which there are four divisions: (1) Division of Combustion and Fire Sciences (ESFS), (2) Division of Mechanical Engineering (ESME), (3) Division of Electrical Engineering (ESEE), and Division of Human Factors (ESHF). The WPI team reports directly to Mark Kumagai, Director of ESME (Consumer Product Safety Commission, 2006).

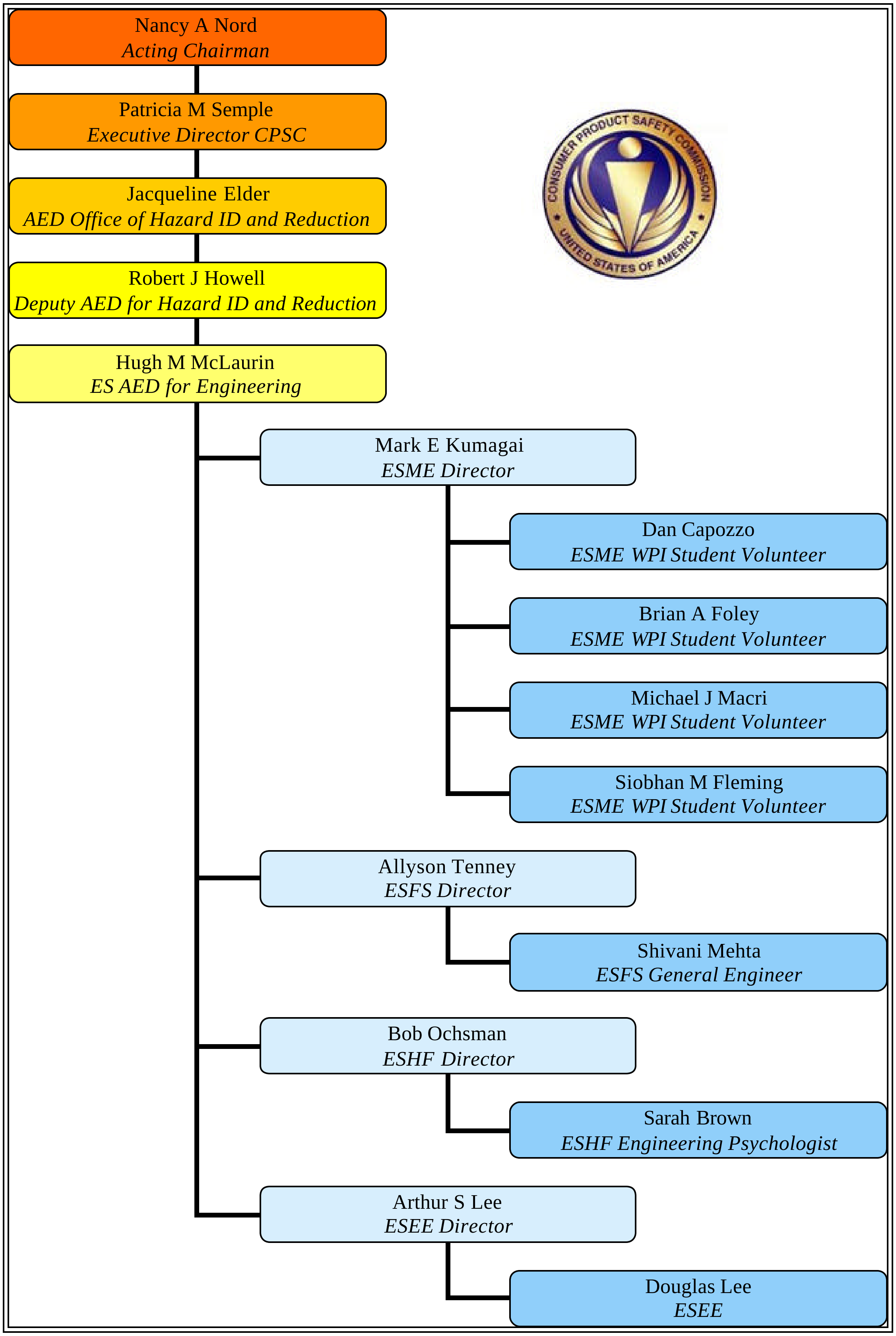

Figure 11: Organizational Chart for work at the CPSC

In 2006, the CPSC requested $62,370,000 from Congress. This amount is $286,000 more than the budget for 2005. The request for 2007 is the same as 2006. Of that amount, approximately 90% is spent on salaries and office rent, and the remaining 10% goes to identifying and reducing hazards. The budget is broken down by the amount spent toward various hazard identification and reduction areas of focus, with salaries and rent factored into each area. Table 9 gives a breakdown of the budget for 2004-2007. It includes a plan for the current year and the request for 2007 (Consumer Product Safety Commission, 2006).

Total Commission	59604	62084	62370	62370	0
Program/Activity	2004 actual amount in thousands of dollars	2005 actual amount in thousands of dollars	2006 plan amount in thousands of dollars	2007 request amount in thousands of dollars	Difference between 2006 and 2007
Reducing Product Hazards to children and families					
Reducing Fire and Electrocution Hazards	22101	24227	23193	22795	-398
Fire Deaths	19473	21907	20763	20252	-511
Electrocution	2628	2320	2430	2543	113
Reducing Children's Hazards	11456	10975	10638	11096	458
Reducing Poisoning and other Chemical Hazards	8190	7419	7465	7938	473
CO Poisoning	1629	1473	2165	2302	137
Child Poisonings and Other Chemical Hazards	6561	5946	5300	5636	336
Reducing Household and Recreation Hazards	6722	6902	8609	7654	-955
Subtotal	48469	49523	49905	49483	-422
Identifying Product Hazards					
Data Collection	9353	10600	11009	11432	423
Emerging Hazards/Data Utility	1782	1961	1456	1455	-1
Subtotal	11135	12561	12465	12887	422

Table 14: CPSC 2007 Performance Budget Request. Stratton, Hal; Moore, Thomas H

The WPI project on lithium ion battery technology at the CPSC is directly related to its mission and main goals. The incident data shows that the use of lithium ion batteries in consumer products can be a fire hazard due to component based failures. The students will evaluate the incident scenarios, battery design and technology and provide potential solutions that could be used to make the batteries safer for consumers. By providing these potential solutions the team will address three specific key points in the CPSC's mission:

1.) To protect the public against unreasonable injury risks associated with the use of consumer products.
2.) To develop uniform safety standards for consumer products
3.) To promote research of product related deaths, illnesses and injuries to gain information about causes and death.

They will address the first by categorizing the hazard scenarios from the in-depth investigation reports which will develop a better understanding of the causes of lithium ion battery incidents. The second key point in the mission will be addressed by the comparing and contrasting the different existing lithium ion battery standards such as Underwriters Laboratories (UL), the Institute of Electrical and Electronic Engineers (IEEE), International Electrotechnical Commission (IEC) and United Nation (UN). Finally the last point is addressed solely by the fact that the WPI team is conducting research that will lead to consumers being further protected from failures of lithium ion batteries.

Exhibit 2 is the initial letter that the CPSC sent to WPI students about the scope of the project. This letter was used to develop objectives and mission before the students traveled to the CPSC headquarters in Bethesda MD.

Consumer Product Safety Commission: Lithium Ion Battery Safety

The U.S. Consumer Product Safety Commission (CPSC) is charged with protecting the public from unreasonable risks of serious injury or death from more than 15,000 types of consumer products under the agency's jurisdiction. Deaths, injuries and property damage from consumer product incidents cost the nation more than $700 billion annually. The CPSC is committed to protecting consumers and families from products that pose a fire, electrical, chemical, or mechanical hazard or can injure children.

Portable electronic devices use high-energy density batteries, such as lithium ion batteries. Recent recalls include battery packs from notebook computers, portable DVD players, mobile telephones and cameras. The energy density of lithium-ion is typically twice that of the standard nickel-cadmium, and there is potential for even higher energy densities for future batteries.

Batteries that experience an internal cell short may overheat and explode, posing a hazard to consumers. Battery failure in a portable device, such as a mobile telephone, may result in a potentially more hazardous situation because of the close proximity of the telephone to the body when in use or in the pocket/side clip during transit. Larger capacity 36-volt lithium ion batteries are now being used in portable hand tools. These products are used in outdoor environments and often roughly handled and may have additional safety concerns.

The WPI team will:

- Identify all possible sources of preliminary data and information, including user groups, manufacturers, insurance sources, trade association, doctors, magazines, and consumers.

- Identify and assemble all applicable information from CPSC's data sources including the National Electronic Injury Surveillance System, In-Depth Investigation Reports, and Injury/Potential Injury Incident file, and outside sources such as the National Association State Fire Marshals, U.S Fire Administration, Underwriters Laboratories, National Institute of Standards and Technology, and state governments.

- Categorize the hazard scenario related to the various types of products using high energy batteries based on battery types and capacities, product function, consumer interaction and product environment. Discuss the societal benefits of this technology as well as the incremental risk of changing over from Ni-Cd or alkaline chemistry to lithium ion, and possibly to even higher density battery types in the future.

- Identify the technologies that can minimize or manage the safety for these products, and make recommendations on how CPSC can address the safety of lithium ion and other types of high energy batteries in consumer products.

Exhibit 2: Original letter from CPSC identifying project topic

Appendix B: CPSC Presentation

Date	Recalled Battery	Quantity	Incidents	Injuries
10/2003-9/2004	Mobile telephone	140,000	4	1 minor burn
10/2003-9/2004	Flashlight	12,500	2	No Injuries
10/2003-9/2004	Flashlight	20,000	5	4 property damage/injury
10/2003-9/2004	Mobile telephone	50,000	18	All had property damage/injury
10/2003-9/2004	Notebook Computer	28,000	4	No injuries
10/2004-9/2005	Mobile telephone	1,000,000	14	Property damage/2 minor burns
10/2004-9/2005	Headlamp	1,000	0	No injuries
10/2004-9/2005	Portable DVD Player	47,000	17	5 explosions/2 burned fingers
10/2004-9/2005	Notebook Computer	128,000	6	No Injuries
10/2004-9/2005	Water Scooter	2,200	9	Explosions/ 3 facial injuries
10/2004-9/2005	Notebook Computer	10,000	6	No injuries
10/2004-9/2005	GPS Navigation System	10,300	15	Overheating/swelling no injuries
10/2004-9/2005	Portable DVD player	116,000	10	Overheating/fire no injuries
10/2004-9/2005	Cordless Drill/ Driver	2,000	6	Rupturing 1 injury
10/2004-9/2005	Water Scooter	475	5	Explosion/ 2 Injuries
10/2005-6/2006	Notebook Computer	85,000	16	Overheating/ Melting no injuries
10/2005-6/2006	Digital Camera	200,000	4	Overheating/ Melting no injuries
10/2005-6/2006	Portable DVD player	165,000	8	Overheating/ Melting no injuries
10/2005-6/2006	Notebook Computer	22,000	3	Overheating/ Melting no injuries
10/2005-6/2006	Wireless Conference Telephone	21,000	2	Overheating/ Melting no injuries

10/2005-6/2006	Wireless Conference Telephone	4,200	9	No property damage no injuries
10/2005-6/2006	Portable DVD Player	102,000	17	Overheating/ 3 burn injuries
10/2005-6/2006	Notebook Computer	4,100	20	Overheating/ 1 burn injury

Appendix C: List of Contacts

Name	**Org/Comp/Agency**	**Details**
Allison Crawley	NASFM	Meeting (11/9)
Anthony Wong	ATL	Telephone Interview (11/21)
Bart Riley	A123 Systems	Teleconference (10/5)
Bill Bennett	Independent Contractor NASA GRC	Telephone Interview (11/16)
Bill Wilkening	FAA	Directed us towards Jon Carter
Brett Crawford	Outside Legal Council for Sony	Teleconference (11/30)
Charles Monahan	Panasonic/PRBA	Teleconference with George Kerchner (11/13)
Christopher Smith	Outside Legal Council for Sony	Teleconference (11/30)
Daphne Fuentevilla	NSWC Carderock	Visit on (11/29)
Duncan Culver	Lithium Technologies	Answered Product Related Questions
George Kerchner	CTIA/PRBA	Conference (11/13)
Jason Howard	Motorola	Directed us to George Kerchner
Jim Henderson	NTSB	Directed us to Crystal Thomas
Jim Manning	Lithium Technologies	Answered Product Related Questions
Jon Carter	FAA	Gave us documents on FAA and Li-Ion batteries
Judy Jeevarajan	NASA JSC	Teleconference (11/29)
Karen Suhr	NASFM	Meeting (11/9)
Kevin Clancy	Hewlett Packard	Answered Questions via Email
Mark Sargent	CTIA	Received Information
Mark Tisher	NSWC Crane	Trying to get contacts for us?
Paul Beach	Quallion	Telephone Interview (11/12)
Peter Roth	Sandia	Received document
Robin Hoffman	ZMP	Teleconference (12/1)
Ross Deuber	ZMP	Teleconference (12/1)
Spencer Watson	DOT	Received documents and transportation regulations

Appendix D: A123 Systems Meeting Minutes

Meeting Minutes

Consumer Product Safety Commission

Dr. Bart Riley, A123 Systems

Thursday, October 5, 2006

Meeting Participants:

WPI:	Dan Capozzo, Siobhan Fleming, Brian Foley, Michael Macri
A123 Systems:	Bart Riley

- Meeting Attendees
  - Bart Riley
  - WPI
    - Dan Capozzo
    - Siobhan Fleming
    - Brian Foley
- Discussed our IQP and mission
- Questions
  - Difference in structure
    - anode and cathode separated by ionically conductive separator
    - Two approaches
      - Wound approach – metal plate and film separator rolled like a jelly roll
      - Bobbin approach – pressed concentric, nested or stacked pellets of anode and cathode, separated by paper or film separator (example is alkaline batteries)
    - A123 first products are cylindrical (wound approach)
      - Modified manufacturing process, but looks like normal process
      - If you took battery apart would look very similar to other lithium ion batteries
    - Difference is chemical structure
      - Use phosphate material on the cathode instead of an oxide
      - Industry standards are an oxide on the cathode
      - Conductive additives
        - Polymeric binder to hold everything together
        - Carbon black
      - Use aluminum current collector on cathode

        - Anode active material is carbon synthetic graphite with copper foil for current collector
        - Separator
            - Polymeric porous membrane with 50% porosity
            - Soaked in carbonate lithium salt electrolyte
        - Big change – use phosphate instead of oxide for cathode since its more chemically stable
            - In Oxide, cobalt goes from 3+ to 4+ during charging which is very unstable
            - Internal short, high temps, external short can cause exothermic reaction/explosion
        - Temperature
            - Oxide based cell self heats at a rate of 1000C/min at temperatures > 150C
            - Phosphate based cell has a self heat rate of only a few C's per minute at > 150C
    - Safety Mechanisms
        - Phosphate has no possibility for thermal runaway (explosion)
        - Japanese use design tricks to pass nail test, manufacturing defect, which cannot guard against manufacturing quality problems
    - Standards
        - Regulating standards
            - DOT – large lithium ion batteries need to be labeled as HAZMAT
            - UL – industry expected norm over legal requirement
            - IEEE – industry convergence
        - Follow UL1642 and their own standards
        - Hard time getting out of "technical muck"
            - They have intrinsic advantage in safety but no one recognizes them differently than any other manufacturer
            - can be categorized differently – but need to educate regulators
    - Failure Rates
        - A123 cells are meant for power not energy
            - Energy is how long it lasts
            - Power is rate of energy output
            - Current cell (2.8cm diameter, 6.5cm length) capable of 200 Amps for short period of time
        - Risk associated with this
            - Small battery dumps energy very quickly it gets very hot
            - Limits max temperature and shuts off
        - Runs all UL1642 tests
            - Overcharge
            - Hotbox

        - Performance test
        - No longer need nail test
- Notebook computer and Mobile telephones
    - Making power batteries for cars and tools with much more internal porosity improve ionic conductance via electrolyte
    - Design choice, cell with less energy but more power
    - Notebook computers and Mobile telephones
        - Need high energy and less power
        - People tolerate very small risk of fire as long as they have long run time
        - First products focused on high power products
        - Developing higher energy version of phosphate technology

Appendix E: National Association of State Fire Marshalls Meeting Minutes

Meeting Minutes

Consumer Product Safety Commission

Meeting with National Association of State Fire Marshals

Meeting Date:	November 09, 2006
WPI:	Dan Capozzo, Siobhan Fleming (Discussion Leader), Brian Foley (Minutes), Michael Macri
NASFM:	Ms. Allison Crowley, Ms. Karen Suhr

The meeting began at 10:00 am.

The meeting began with introductions of the WPI Students.

- Dan Capozzo- Management Information Systems Major '08
- Siobhan Fleming- Mechanical Engineer '08
- Michael Macri- Mechanical Engineer '08
- Brian Foley- Physics Major '08

After introductions were complete we began to discuss what an IQP (Interactive Qualifying Project) project really is.

- Degree Requirement for Students at WPI
- Our project is focusing on Li-Ion batteries and to provide recommendations to the Consumer Product Safety Commission (CPSC) about potential solutions that will lead to minimizing the safety risk involved with the use of lithium ion batteries.
- When conducting our report we will be looking at IDI (In-depth Investigation) files, researching potential technologies, and examining current standards.
- Advisors for our project at the CPSC include Shivani Mehta, Mark Kumagai, Doug Lee, and Arthur Lee.

After describing the project Allison and Karen began to talk about the National Association of State Fire Marshals (NASFM).

- NASFM members are the top fire officials at the state level, ones who report to governors and advise on fire issues.
- The responsibilities of State Fire Marshals differ state to state but there are some all share such as public education, code enforcement, data collection, and fire investigation.

- These officials are contacted frequently to advise on policy issues that include fire risk (unsafe products) and have the authority to pull products off the shelf that they determine to be unsafe.
- NASFM takes on major project areas such as consumer product safety, strengthening the model building and fire codes, pipeline safety and hazardous materials safety.
- NASFM has been working with International Electrotechnical Commission (IEC) to develop a standard for the outer housings of information technology (IT) and consumer electronics (CE) equipment to protect against external ignitions by small open flame sources such as candles. Currently the outer housings of many IT and CE products are made of plastics that ignite easily and spread fire rapidly. However, the technology exists to make these products more resistant to ignition.
- The IEC standard for outer housings of IT and CE equipment is part of a larger package of safety requirements for these products. Right now the standard, known as TC 108, is going through the final adoption, which may take a couple years.
- NASFM also is working with UL on their Standard Technical Panels for IT and consumer electronics products. Industry is resistant to adopt these standards but the IT industry is more cooperative than the CE industry.
- NASFM believes that making the outer housings of products that contain lithium-ion batteries more fire-resistant, these products will be better able to withstand and contain fires involving these batteries if they do occur, and prevent a small fire from growing and spreading.
- Another of NASFM's concerns regarding lithium-ion batteries is that firefighters and other emergency responders need to know how to respond to different scenarios involving malfunctioning lithium-ion batteries.
- On Sept. 11, 2006, NASFM organized a conference call with DOT, CPSC, and manufacturers to find out what emergency responders need to know about lithium-ion batteries.
- Feedback from manufacturers was that there were only "isolated incidents" so far, so lithium-ion batteries do not pose a problem. NASFM disagrees with that assessment. An incident on an airplane in flight, for example, could cost many lives – putting consumers and emergency responders at risk.
- The Portable Rechargeable Battery Association (PRBA) provided NASFM with a book of presentations and tests that have been done on lithium-ion batteries. Was given to NASFM by George Kerchner.

The WPI students then began to talk about situations we were seeing in our work

- Lithium-ion batteries may play a part in hybrid cars, and these batteries are much bigger than the ones found in notebook computers so could potentially be much more dangerous.
- Certain new types of technology are better in different situations
- Taking a look at a Hazard Control System when you either design out the problems or guard the user against the problems.

Next the students began to ask a few questions.

- The first question was focused on the NASFM Consumer Product Fire Safety Task Force

    - The task force prefers to approach emerging issues before they become a real problem
    - Do not react just on lots of data but also red flags that may arise
    - There are active and passive protection measures and at times if you focus on one the other one is not implemented. For example if sprinklers are in a building (active), there may have been a tradeoff where fire retardant materials were not used (passive).
    - Also, including building contents that are designed to be more fire-resistant is a passive measure that is often overlooked. Recent research by the National Institute of Standards and Technology to reproduce smoke alarm tests from the 1970s found that the average time to untenable conditions in a typical residence has been reduced from 17 minutes 30 years ago to 3 minutes today. This reduction is primarily due to the difference in the building contents (more plastics, etc.) and means that occupants have that much less time to escape a fire situation.
    - Stated that you cannot rely on one type of fire protection measure. Safety redundancy, or layers of safety, is necessary because if one measure fails you need to have a backup. For example, safer contents (e.g., upholstered furniture, mattresses, computer equipment) as well as ignition sources that are designed to be safer in use (e.g., candles that don't tip or flare up; child-resistant lighters; lower ignition strength cigarettes); and active measures (e.g., sprinklers) as well as passive measures (e.g., spray-on fireproofing for structural steel)
- Next we asked if they believe public education and warning labels are an effective way to combat fire problems
    - Stated that it is necessary to do, but should not be the only thing that is relied on. Even if you have the best education you will still make mistakes if certain situations arise.

We then concluded our meeting that our final report should be around Dec. 15 and we will provide them with our final report.

Meeting was adjourned at 10:45am
Minutes Prepared by: Brian Foley
The minutes were distributed to all who attended the meeting and any additions or corrections to the minutes should be sent to the author at bfoley@cpsc.gov

Appendix F: Portable Rechargeable Battery Association Meeting Minutes

Meeting Minutes

Consumer Product Safety Commission
PRBA/Panasonic Meeting

Meeting Date: Tuesday, November 13, 2006

Meeting Participants: Dan Capozzo, Siobhan Fleming, Brian Foley,
Michael Macri (Minutes)

PRBA: Mr. George Kerchner

Panasonic Mr. Charles Monahan

The meeting began at 10:00 am.
The Meeting began with George giving out business cards and introductions. Followed by an introduction to PRBA.

- Established in 1991
- Big Contributors include Sony, Panasonic, and Sanyo.
- Concerned with environmental Issues, helped reduce regulation for Nickel Cadmium batteries allowing them to be recycled.
- Current Issues include Lithium Ion batteries and their transportation
- PRBA deals with standards frequently

George then passed around examples of Li Ion battery packs disassembled and went on to give us some information regarding cells and manufacturing conditions.

- The standard Lithium Io cell is the 18650 cell.
- Cells manufactured in very clean conditions
- There a nearly 2 billion cells worldwide

Charles Monahan entered the conversation at this point via a teleconference. The students described their project and began questioning about standards.

- Standards require a sponsor that will pay for the work of development.
- IEEE certification 1625 was the notebook computer standard made in 2004.
- 1625 is a self certification standard
- 1725 was nearly identical to 1625 but dealt with mobile telephones. CTIA sponsored it so that they can perform third party certifications on mobile telephones
- There will be further meetings in December to work on this certification
- IEEE 1825 standard is being developed for digital cameras and camcorders, but no one is sure who the sponsor is.

- Standards are voluntary

The discussion then moved to general questions about PRBA and trade organizations regulatory power.

- No trade associations have authority to impose standards
- CTIA is being enforced by service providers, who are refusing to buy telephones from manufacturers who do not get the certification.
- If notebook computer manufacturers had a similar organization and the notebook computer companies agreed to it. A similar system could work for notebook computers
- There are federal and international regulations that mandate batteries follow the UN manual testing but it is primarily vibration and harmonics, so they will be safe for shipment.

Charles discussed the structure of aftermarket batteries.

- OEM notebook computer batteries have 5 or 6 different contact points: Positive, Negative, and safety related connections
- On examination of interior of Aftermarket cells that had 5 or 6 contact points it was found that some AM had no internal connections to these "dummy" connectors.

Lastly George discussed some of the transportation issues with lithium batteries.

- Aircraft fire suppression systems cannot put out lithium metal battery fires, but can extinguish fires from lithium ion batteries
- Water can also be used to put out lithium ion battery fires
- PRBA had Exponent, an independent testing firm; conduct test similar to FAA testing to make sure the batteries would comply with FAA regulations.

During the wrap up, we asked George to send us a copy of materials he put together for the NASFM and have them sent to this address:

Michael Macri
U.S. CPSC
4330 East West Hwy.
Suite 611
Bethesda, MD 20814

Meeting was adjourned at 11:50 am
Minutes Prepared by: Michael Macri
The minutes were distributed to all who attended the meeting and any additions or corrections to the minutes should be sent to the author at mmacri@cpsc.gov

Appendix G: Quallion Meeting Minutes

Meeting Minutes

Consumer Product Safety Commission

Quallion Interview – Paul Beach

Meeting Date:	November 12, 2006
Students Present:	Dan Capozzo (Minutes), Siobhan Fleming (Discussion Leader), Brian Foley, Michael Macri
Quallion Representative:	Executive Director – Mr. Paul Beach

The meeting began at 1:00pm.

- Discussed Quallion background and focuses
  - Lithium-ion battery manufacturer primarily out of Japan
  - Focuses on medical, military and aerospace battery solutions
  - Produce thousands of battery cells per month
- Discussed differences in Quallion
  - Japanese core knowledge of lithium-ion technology
  - Focus on different applications
  - Long lasting, safe batteries
    - Extremely expensive
    - Last 60,000 cycles and have 50% retention
    - Medical applications last 25 years
  - Geared towards safety and reliability
  - Active materials and design materials are different
- Zero volt battery capabilities
  - The higher you charge a battery, the less cycles you get out of it
  - Battery can stay at 0V for years without battery deteriorating
  - If normal lithium-ion battery stays below 2.0V then corrode battery and will not last as long
- Developed extremely safe anode/cathode (battery will not combust with 400C electrode)
- SaFE-LYTE
  - Additive to impact/mitigate thermal runaway
  - Companies do not use additive because of diminished performance
  - Chemistry
    - Non-mixable compound – does not combine with electrolyte
    - Fluorine based, comes from halogen family, combines well with oxygen

            - When thermal runaway occurs, fluorine absorbs oxygen that would normally fuel the fire
    - Acts as a higher boiling point
        - Absorbs most of heat and fluorine basis prevents thermal runaway
    - Not 100% guaranteed
        - If fire initiates in center of cell, harder for additive to stop thermal runaway, compared to fire starting towards the outer area
        - Just adds another layer of protection to mitigate thermal runaway
    - Issues
        - How much safelight to use in cells
            - The more you use, the better chance to mitigate thermal runaway
            - Normally use 2g to 3g
        - Implementation
            - Adds 10 to 15 cents per battery cell
            - Does not change process too much, uses same equipment
            - Adds another step to process
            - Battery voltage drop from 2.5mAh to 2.3mAh, but have 2g of additive, or top off the battery

Meeting was adjourned at 1:25pm
Minutes Prepared by: Daniel Capozzo
The minutes were distributed to all who attended the meeting and any additions or corrections to the minutes should be sent to the author at dcapozzo@cpsc.gov

Appendix H: Bill Bennett, NASA Meeting Minutes

Meeting Minutes

Consumer Product Safety Commission

Mr. Bill Bennett -independent contractor at NASA Glenn Research Center
Information Noted is the Opinion of Bill Bennett and not NASA

Meeting Date: Thursday, November 16, 2006

Meeting Participants:
WPI: Dan Capozzo, Siobhan Fleming, Brian Foley, Michael Macri

NASA: Mr. Bill Bennett

The meeting began at 10:00 am

It started with an introduction of the WPI team and explanation of the project they are completing an Interactive Qualifying Project on lithium ion battery safety

The students then discussed their findings and who they have met with

- NASFM
- PRBA
- Quallion
- A123
- UL

Briefly discussed the new technologies researched

- Quallions additive SaFE-LYTE solution
- 3M additive, new electrolyte

Bill Bennett then discussed that he is an independent contractor for NASA

- Works with the NASA battery community looking at battery technology

He mentioned that

- Johnson Space Center is responsible for man space flight portion
- Standards questions might be better answered by contact at Johnson Space Center
- Bill Bennett said he would send the contact Judy J.'s e-mail and telephone number

The students then asked about whether lithium ion batteries were used for any NASA applications

- NASA has not qualified lithium ion for man flights
- The batteries would be highly tested before use
- Has been used on the Mars Lander because it was an unmanned mission
- If they used lithium ion batteries they would be manufactured by quality aerospace battery manufacturers
- NASA would have its own high level standards for the process
- The battery design would have many safety features

Types of batteries used by NASA
- Shuttle/ Apollo used Fuel Cells
- Silver Zinc

Other Technologies mentioned by Bill Bennett
- Lithium sulfur batteries –Sion (high energy)
- Lithium Corporation (Yardney) Aerospace quality lithium ion batteries
- Lithium metal batteries- risks, hard to stop and just as damaging as lithium ion

There was then discussion about problems with notebook computers and mobile telephones and trends of the failure
- Mobile telephone abuse can be a problem
- Overcharge, short circuit problems
- Many different things that can go wrong
- Counterfeit Cells-not up to the same quality

Additionally safety issues with other battery types was addressed
- Alkaline batteries if short circuited can also get very hot

There was a question about the Dell Notebook computer incidents
- Not to much data on it because of nature of the recall
- The foreseeable danger is the bigger problem than the actual number of incidents

Add-ons might make lithium ion batteries safer
Phosphates may have a good future if energy issue is addressed
- Not a lot of information about failures
- Heats up slowly, thermal runaway not really possible

Meeting was adjourned at 10:30 am
Minutes Prepared by: Siobhan Fleming
The minutes were distributed to all who attended the meeting and any additions or corrections to the minutes should be sent to the author at sfleming@cpsc.gov

Appendix I: Amperex Technologies Limited Meeting Minutes

Meeting Minutes

Consumer Product Safety Commission

Mr. Anthony Wong, ATL

Tuesday, November 21, 2006

Meeting Participants:

WPI:	Dan Capozzo, Siobhan Fleming, Brian Foley, Michael Macri
ATL:	Mr. Anthony Wong

The meeting began at 10:00 am
It started with an introduction of the WPI team
There was a brief explanation of the project and who the team is working with
Brian will send Anthony the contacts
There was then an explanation of the advantages and disadvantages of lithium polymer batteries

1. They do not leak liquid, which can short circuit the batteries
2. There is an aluminum foil packaging which allows small expansion of pressure. It is not confined in rigid structure which can reduce incidents
3. These cells can be bigger
4. high energy density per cell
5. cathode/ anode and separator go through a process with better interfacing
6. the better interfacing delivers higher power

The discussion then moved to the three levels of impact

1. System
2. Societal/Economical
3. Business

Anthony sent the team his notes about the discussion for the above topics. These notes cover the details of the rest of the meeting

Mr. Anthony Wong's Meeting Minutes

Re: CPSC project related to Lithium Ion Battery Safety

Date: 11/21/2006
From: Anthony Wong, V.P. Business Development, ATL
Telephone 1-216-371-2555; MP 1-216-702-5255
To: Foley, Brian; Capozzo, Daniel; Fleming, Siobhan; Macri, Michael

Summary of 11/21 (T) discussion.

The issue at hand is so complex, in my thinking it involves at least 3 levels –
(1) System level (e.g. battery, pack, electronics, device),
(2) Social-economical level (e.g. mobile society, price, consumer usage pattern)
(3) Business level (e.g. business competition, demand for longer device run-time).

We (Gov/Industries/consumer) need to come up with policy/solution(s) to mitigate further events. Battery industry has shipped billions of rechargeable lithium batteries worldwide and if we look at the # of accumulative incidences, one may say that the industry is doing quite well. However with the increased incidences in the last few years, we all need to improve and find ways/policies/education/forum to further reducing the risk exposure to consumers.

I was involved in the 1725 work-group to develop the IEEE-1725 Standard, also now with CTIA-1725 implementation. In those meetings, the 1725 group has made great progress. Still this ONLY addresses (1) – System level.

Battery is so complex comparing to other consumer products that are non-perishable. I used to tell people that battery has its own life. It is a living thing (if we may call it so?); it does change with time and depends on how it's being designed/manufactured/used/handled, etc. Just like gasoline, battery stores energy; it is a perishable product. We need to understand its "benefits vs. associated risks" and how to "manage the risk."

Let me post a few questions; of course by no means exhaustive --

- Can one achieve 100% *efficiency of energy transfer* between charging and discharging in a rechargeable lithium battery? We know that the answer is "no", otherwise it will defy physics/chemistry/nature. Then what are the implications and how to manage risk, expectation and product life?

- What are *some possible mechanisms* in rechargeable lithium battery events in the field? Internal short? External short? Breaking down of chemistry over time? Design/manufacturing (battery, pack, circuit, device) robustness? Assembly quality? Proper handling/storage?

- *Polymer battery* when packaged in a pouch format (aluminum material) does allow the cell to swell if there is gassing (chemistry break-down), not allowing excessive pressure to be built up as in a hard case; thus possibly reducing the risk of severe events. But it still is not fool-proof; it does not eliminate all events.

- Are there better *(safer??) materials* and/or manufacturing processes? Battery industry has always been developing materials that are potentially safer. However, one has to remember that it ONLY gives a wider safety window. As long as we are dealing with energy system, there is no system that is absolute safe. Suppose that there is a material which provides a wider safety margin; what about energy density, voltage level, material cost? They affect how a device is being design cost-effectively and with good value to the consumer. $LiFePO_4$ is safer, but voltage is lower and today it is not cost effective.

- What about product *non-conformance*? Can a product achieve zero ppm (parts per million) nonconformance? We also know that the answer is "no," as long as it is a product involving machineries and people, there will be nonconformance. Since battery is a system (many components/materials inside), can we ensure 100% defect free of all components? We know that the answer is "no." Even how to define all defects that could have safety implication is extremely challenging, if not impossible. Throwing on top is the element of unknown factor - degradation over time.

- Free market economy is great, but also pushes *cost down unrelentlessly at all levels* of the supply chain. Is the growth of the rechargeable battery industry (in CAGR $ and quantity) healthy enough to allow this industry to re-invest and bring in new technologies at an affordable cost? Simultaneously at the social-economic and business levels, we are pushing to have longer device run-time, cheaper and more convenience to consumer. Are we pushing the battery technology to such an extent that --- in order to make a battery with higher and higher energy density, are we start seeing compromising safety margin unbeknowingly?

- As we are dealing with a perishable and potentially dangerous product (energy source), shall we design a battery or device with *a safe-guard system* such as log-out mechanism (date timer), notification system (reminder to replace the battery), or some kind of rechargeable battery exchange program with the OEMs or service providers, or recycling,…?

- How do we *educate the public* that rechargeable battery does not last forever, and need to be handled properly? Are there things we can learn from the food industry ("best sold before xxxdate"?) such as having a perishable date requirement? Are the consumers informed and educated enough to take care of the product (device, battery) as stated in the product manual? What if one cannot read? Or device is being resold or given to someone else? What about re-furbished industry? I am sure that a lot of consumer can only afford refurbished products.

- How to *manage risk and share responsibility* in the food chain, from suppliers all the way to users? Is it even doable and how to create open dialogue from all parties? What forum?

- How do we deal with *counterfeit*, cheap batteries coming through the retail and/or internet channels? But anti-trust would demand free market and open competition.

-- END --

Meeting was adjourned at 11:15 am
Minutes Prepared by: Siobhan Fleming
The minutes were distributed to all who attended the meeting and any additions or corrections to the minutes should be sent to the author at sfleming@cpsc.gov

Appendix J: Judy Jeevarajan, NASA Meeting Minutes

Meeting Minutes

Consumer Product Safety Commission

NASA Interview – Ms. Judy Jeevarajan

Meeting Date:	November 28, 2006
Students Present:	Dan Capozzo (Minutes), Siobhan Fleming (Discussion Leader), Brian Foley
NASA Representative:	Senior Scientist, Battery Office – Ms. Judith Jeevarajan

The meeting began at 10:30am EST with introduction of the students and Ms. Jeevarajan.

Background Information
- Ms. Jeevarajan worked at NASA for 9 years, already been working on lithium ion batteries at Texas A&M
- Did extensive testing with lithium ion batteries
- Certifying batteries for flight in 1998

Questions students asked:
- NASA battery certification standards
    - NASA uses more stringent standards for space applications
    - Two fault tolerance
        - Toxic electrolyte salt
            - Highly corrosive
            - Irritant
            - Can blind user
- Certain tests NASA follows
    - Engineering tests
        - Tests on the battery cell and battery pack
    - Performance tests
        - Vacuum test
        - Vibration test
        - Temperature test
    - Safety tests
        - Overcharge test
        - Discharge test
        - External short circuit test
        - Internal short circuit test (crush test)

        - Venting tests
        - Drop tests
    - Qualification tests
        - Test 100% of batteries used in flights
        - Includes vibration, vacuum, and environment
- NASA battery manufacturers
    - Use commercial cells and battery packs
    - Does not manufacture own cells
    - Sometimes buy cells and put together
    - Whenever they buy cells they buy from same lot of batteries, which are made from the same electrode materials
- Other applications of lithium ion batteries for NASA
    - Used in Mars lander
    - Been using li-ion since 1999
    - Un-manned satellite applications
    - Being used by multiple nations
- Any incidents involving lithium ion batteries at NASA
    - No adverse effects
    - Need to go through multiple levels of control
    - One problem with lithium polymer cell
        - Cell swelled up in a vacuum
        - Did not use cell anymore
- Lithium ion battery lifespan
    - Traditional lithium ion battery will most likely be used in the future
    - Innovative technologies are traditional lithium ion, but with safety features
- Possible new tests for NASA batteries
    - X-ray test seems like a procedure NASA could adopt for their strict tests
    - X-ray test can control quality and contamination

Meeting was adjourned at 11:00am EST
Minutes Prepared by: Daniel Capozzo
The minutes were distributed to all who attended the meeting and any additions or corrections to the minutes should be sent to the author at dcapozzo@cpsc.gov

Appendix K: Zinc Matrix Power Meeting Minutes

Meeting Minutes

Consumer Product Safety Commission

Teleconference with Zinc Matrix Power

Tuesday, December 1, 2006

Meeting Participants:

WPI:	Dan Capozzo, Siobhan Fleming, Brian Foley, Michael Macri
ZMP:	Mr. Ross Deuber, Ms. Robin Hoffman

The teleconference began at 1:00pm.
Introductions were made, followed by a brief description of our project.

The students requested information about ZMP's product, the silver zinc battery

- Silver Zinc batteries are designed to meet and exceed the energy density of lithium ion batteries, while increasing safety.
    - Not prone to thermal runaway
    - Improved Energy Density over lithium ion
    - Have much greater run life
    - Use water as an electrolyte which is not flammable
    - produces 40 times less energy that Cobalt-Oxide based lithium ion batteries during electrode decomposition
- Environmentally friendly
- Recyclable
- The higher cost of silver zinc is due to their silver content; this coast can be mitigated through recycling programs that would essentially buy back the silver when the batteries died.
- Silver Zinc batteries will go into production at some point between mid to late 2007
- Expected to replace lithium ions in much the same way that lithium ion replaced Nickel Cadmium.

The teleconference moved on to questions. Reponses are summarized:

- Standards followed are IEEE 1625 and 1725, UL 2450 (2054?), and the ISO 9000 series
- Will weigh 5-10% less than a lithium ion with equivalent energy

Meeting was adjourned at 1:30
Minutes Prepared by: Michael Macri
The minutes were distributed to all who attended the meeting and any additions or corrections to the minutes should be sent to the author at mmacri@cpsc.gov

Appendix L: Lithium Technologies Questions

The following questions were sent to Donald Culver from Lithium Technologies:

1. Can you tell us about the technology you are working on and the benefits to using it?

Our basic technology is conventional lithium ion. We have certain design and manufacturing IP (intellectual property) which we do not disclose. Our particular expertise is in the areas of very large cells and very high power cells. Both of these areas were once considered impossible and very unsafe. Clearly today they are not only safe, but they are safer than small cells. One of the benefits in large cells is that you do not need lots of little (consumer 18650) cells in parallel to achieve a high capacity battery. With regard to high power, if you need high power, there are not too many companies that can provide this - for example continuous discharge at 100C. (If you are not a battery person, C rate is the current that will discharge/charge the cell in 1 hour.) Our 7.5Ah DD size cell will discharge at 750A!

2. Do you follow any specific standards when manufacturing your products?

Basically we are ISO compliant, working towards certification. Just being ISO, or employing TQM, does not in itself make the product safer. We also do a lot of testing on every cell and have very rigorous testing standards

3. What makes your product safer than lithium ion batteries in consumer products?

As manufacturers of consumer products have continued to increase the amount of energy stored in a given volume, they have continually reduced the thickness of the separator and the tolerances for manufacturing, thereby increasing the potential of defects.

Lithium Technology Corporation (LTC) manufactures a variety of large, high energy capacity and high power standard cells in cylindrical and flat formats that are assembled into custom large batteries complete with battery management systems (BMS), a critical part of every lithium ion battery that ensures systems safety and performance. The BMS monitors the cells individually at all times, keeps them in balance for best performance, reports the state of charge and state of health and prevents damage to the battery due to over voltage, under voltage, over temperature and short circuit. LTC's high power cells have low internal resistance due to its unique and patented production process. This fact in turn reduces the heat generation in the battery, hence, reducing dramatically the risk of over heating. Our cells have such a low resistance, that if the cell is shorted, the short has higher resistance than the cell causing the energy to dissipated outside of the cell.

Since, LTC's focus has been on safety and high power cells, (rather than competing for the highest specific energy,) LTC uses thicker separators and greater manufacturing margins than are employed in the typical 18650s. Further, LTC has exhaustive testing and QC to identify potentially problematic cells.

In addition, LTC is engaged with several raw material manufacturers working on new technologies – one of which is lithium iron phosphate cathode. We will introduce an iron phosphate line of cells next year. We see a great deal of effort today in the area of safety and expect several breakthroughs in the next year or two which will revolutionize the industry. We cannot discuss these for obvious reasons.

4. What are the most beneficial uses for your technologies? (ex. High energy/ high power)

Our products are geared primarily to high power as that is a niche in which we can compete effectively with Asia. High power is an emerging market within the military/national security which demands a domestic supplier. Our very large cells are extremely popular in very large capacity batteries – such as for submarines.

5. Would it be cost effective to implement this technology into consumer products?

What we do today - No. The consumer always wants more energy and lower prices. We cannot compete on price with China. Even Japan cannot compete with China. We expect some of the new safety developments to be cost effective to implement as they will make the higher energy systems (higher that iron phosphate) safe, and will therefore become cost effective.

6. Is there any thermal runaway or failure modes associated with the technology? Can you prevent thermal runaway with your technology?

Yes, our current chemistry exhibits thermal runaway and runaway on overcharge (both at significant abuse levels, not just a few degrees or a few Ah). As noted above, the BMS protects against both. Also, our low resistance reduces heat build up. (Our cells are 1 milliohm or less, conventional consumer cells are several Ohms!)

7. Does your new technology reduce energy density?

It is not new technology that makes our energy density lower – you might say it is older technology as we provide greater margins of safety as noted above. Commercially available 'new technologies' (iron phosphate), cut the energy density in half. Some of the developments we are working on have only a negligible effect.

Appendix M: Table of Standards

	Standard	IEEE 1625 / IEEE P1725	UL 1642 / UL 2054	IEC 62133	UN ST/SG/AC 10/27
	Title	*Rechargeable Batteries for Portable Computing / Rechargeable Batteries for Mobile telephones*	*Standard for Safety for Lithium Batteries / Household and Commercial Batteries*	*Safety Requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications*	*Committee of Experts on the Transport of Dangerous Goods*
	Test				
1	Continuous Charging	28 Days of continuous charge		28 Days of continuous charge	
2	Vibration	amplitude .8 mm, 1 Hz min between 10-55hz, 90 min per axis	simple harmonic motion with amplitude of .8 mm at 1 Hz per minute between 10-55hz, tested in 3 directions between 90-100 min	amplitude of .76mm between 10-55hz, 90 min in all perpendicular directions	vibration shall be a sinusoidal waveform with a logarithmic sweep between 7 Hz and 200 Hz and back to 7 Hz traversed in 15 minutes, 12 times for 3 hours
3	Temperature Cycling	75C for 4 hours, 20C for 2 hours, (-20)C for 4 hours, 20C for 2 hours	70C for 4 hours, 20C for 2 hours, (-40)C for 4 hours, 20C for min of 2 hours	75C for 4 hours, 20C for 2 hours, (-20)C for 4 hours, 20C for 2 hours	6 hours -> 75 ± 2 then 6 hours -> -40 ± 2
4	External Short Circuit	2 batteries (20C and 55C) short circuit with total external resistance < 100mO	2 batteries (room temp and 60C) connect positive and negative ends with 100 mO	2 batteries (20C and 55C) with connected + - poles with resistance < 100mO	subjected to a short circuit condition with a total external resistance of less than 100mO at 55 ± 2 °C for 1 hour
5	Free Fall	fully charged dropped from 1m three times onto concrete floor	dropped from 1m with 3 samples onto concrete surface	fully charged dropped from 1m three times onto concrete floor	
6	Mechanical Shock	3 + and - shocks of equal magnitude in different perpendicular directions, min average accel = 75g for first 3 msec, peak acceleration = 125-175g	3 + and - shocks of equal magnitude in different perpendicular directions, min average accel = 75g for first 3 msec, peak acceleration = 125-175g	3 shocks of equal magnitude in different perpendicular directions, beginning acceleration = 5g, peak acceleration = 125-175g	shock peak acceleration of 150gn and pulse duration of 6 milliseconds. 3 shocks positive, 3 shocks negative
7	Thermal Abuse	130C for 10 min with rate of 5C/min	convection oven temp. rate increasing 5C/min to 150C and remain for 10 min	130C for 10 min with rate of 5C/min	

8	Crush Test	two flat surfaces crush at 13kN	crushed b/t 2 flat surfaces, crush until pressure is 2500 psig and force is 13kN	crushed at 13 kN b/t 2 flat surfaces	
9	Low Pressure	11.6 kPa for 6 hours	6 hours in 11.6 kPa at 20C	11.6 kPa for 6 hours	Stored at pressure of 11.6 kPa for 6 hours
10	Overcharge	power supply ≥10V at recommended manufacturer	current 10 times C_5 amp rate	power supply ≥10V at recommended manufacturer	charge at 2 times the manufacturers recommended charge for 24 hours
11	Forced Discharge	discharge cell with constant current for 90 min	connect completely discharged battery in series with fresh cells of same kind	reverse charge for 90 min	in series with 12V dc power source at initial current equal to maximum discharge current specified by manufacturer
12	Impact		15.8 mm bar across battery, 9.1 kg weight dropped from 61 cm		15.8mm bar through center of battery. 9.1 kg mass falls from 61 cm
13	High Rate Charge		charging current 3 times the manufacturer specified and connected in opposition to a dc power source	charged at 3 times manufacturer recommended rate until fully charged or safety cut off switch enables	
14	Incorrect Installation			have 4 fully charged identical batteries in series with one in reverse connected with 1O resistor	
15	Case Stress	70C for 7 hours in convection oven	70C for 7 hours in convection oven	70C for 7 hours in convection oven	
16	Electrostatic Discharge	conducted on battery pack with electronic protection devices			
17	Projectile Test		no piece of exploding cell can penetrate wire screen (2 ft away)		
18	Aging		in development		
19	Dielectric		in development		
20	X-ray		in development		
21	Limited Power Source		fully charged, loaded to equivalent resistance load that provides max power using AWG 30 Nichrome wire		

Notes: Li-ion batteries must comply with both UL standards

Only in IEEE P1725	Only in UL 2054

Date of Accident	*Product*	*Secondary Prod*	*Cause of Hazard*	*Damages*	*Injuries*	*Other Key*
9/6/2006	Notebook computer	Battery	Was using the battery of the notebook computer as the only source of power, when battery caught on fire damaging the notebook computer	Plastic shell of the notebook computer suffered heat and melting damage, causing severe fumes in consumer's apartment	Headache due to the fumes for several hours	Consumer did not return telephone calls for follow ups on additional information
8/26/2006	Charger	N/A	At 11pm plugged batteries and charger into an outlet to charge. At 2:22am noticed a smell of smoke and found the garage filled with a thick black smoke. Called fire department	Limited fire to garage but structural damage was $25,000 and content damage was $25,000	No injuries	No signs of short circuiting but charger's plastic housing where power chord was connected too had melted together
8/17/2006	Batteries	DVD Player	Portable DVD player was in storage at a Pawn Shop, when person failed to pay loan on time the DVD player was taken out of storage when it was noticed the battery pack had ruptured	Damages were limited to portable DVD player	No injuries	When examining the collateral for the loan it appeared nothing was wrong with the DVD player and let it run for 5 or so minutes before placing in storage.
8/10/2006	Mobile telephone	N/A	Mobile telephone battery exploded bounced off wall landed on bed	Bed caught on fire put out himself	No injuries	Not much info no IDI
8/2/2006	Notebook computer	Battery	Consumer bought a replacement battery that was compatible with his notebook computer, was using battery for approx. 30 minutes when heard a loud pop. Saw smoke and battery laying on floor in two pieces and through out the window, burned outside and exploded again	Battery burnt a hole in duvet, sheets, and mark on mattress, the computer still functions but it has residue on the bottom and some of the key do not function	No injuries	Original battery had died and bought compatible intemet battery in Oct. 2005. Used wireless 50% and plugged in 50%

Date of Accident	Product	Secondary Prod	Cause of Hazard	Damages	Injuries	Other Key
7/10/2006	Batteries	Notebook computer	Been using battery power of notebook computer for 20-30 minutes, began to hear loud popping noises took battery out and went to make a telephone call, then battery caught on fire and exploded	Fire damaged the bedroom floor, causing black scorch marks and indentations where the battery landed, ipod cable partially burned, bedroom received smoke damage, side of desk burnt	No injuries	Notebook computer was 6-7 years old and the battery was different than the original battery. The new battery was purchased from an online website
7/5/2006	Model Airplane	Batteries	Plugged in to charge electric helicopter and went to work on computer. 20 minutes later heard a noise and went to room and saw helicopter on fire. Battery laid next to table out of helicopter	Helicopter was burnt along with table and nearby carpeting	No injuries	When arrived took for a test drive, ran into a wall and feel 1-2 feet. After the fall checked on helicopter appeared to be fine so brought inside to charge
6/26/2006	Flashlight	Countertop	Consumer purchased flashlight and tried to turn on but would not work. Set flashlight on countertop with lens facing down and battery exploded. Flashlight came with lithium ion batteries	Damages to flashlight and countertop	No injuries	N/A
6/24/2006	Mobile telephone	Batteries	Bought new telephone and was at concert when it exploded and green flames were coming from his pocket. Military who was there rushed to get water and cut pocket off of pants	Damages were to pants, shirt, cigarettes, and telephone	Immediately received minor burn to right thigh that grew to the size of a quarter. The day after hands turned a blackish green and he went to hospital where he received shots and a prescription	Went to mobile telephone store to try to get new telephone, threatened to call police on him. Went to manufacturing where they paid $7500 for him to stay quiet about incident

Date of Accident	*Product*	*Secondary Prod*	*Cause of Hazard*	*Damages*	*Injuries*	*Other Key*
6/22/2006	Batteries	Battery Charger	At 4pm started to charge Li-Ion battery for his camcorder he had bought that day. At 5pm he went in another for 5 minutes, when walked back into room saw that battery had exploded out of the charger.	Smoke covered room and there was an electrical odor. Debris and soot covered carpet, walls, and furniture.	No injuries	Bought battery that was not exactly the same for camcorder but very similar 7.2V/4000mAh for battery, 7.2V/3000mAh for camcorder
6/6/2006	Notebook computer	Electric Outlet	Notebook computers usually used without batteries and just plugged into the walls. Brought to store they fixed in installed batteries and charged them. Later that night left notebook computer plugged in and fire started, used fire extinguisher then brought outside and used second extinguisher as battery still popped	Damage contained to notebook computer, desk, chair, bedroom carpeting, totaling $4,000.	No injuries	Notebook computers previously used as ultrasound machines, brought home when outdated and always had them plugged in until store repaired them.
5/16/2006	Flashlight	Batteries	Co-worker was using flashlight for 30 minutes, when done put flashlight in his pants pocket with lens facing downwards turned off. Sitting at desk heard strange noise from flashlight took out of pocket to examine then exploded	Damages was contained to flashlight	Received small piece of glass in eye and lacerations to his face. From explosion had ringing in both ears and since report still had ringing in right ear	Flashlight was located in car console between seats since March 2006 and changed batteries on March 16, 2006 and changed them several times since he has had the flashlight
5/6/2006	Charger	Batteries	Batteries had been charging all day, left to do errand 2 to 3 hours and when he came back, smelled burning as soon as he came in. Kitchen was filled with smoke and flames approx. 1 foot high. Pack then exploded	Kitchen cabinet, walls, and counter were damage during the explosion	No injuries	Battery pack was only suppose to be used for 4 hours when charging
5/2/2006	Notebook computer	N/A	Notebook computer Inspiron became very hot	N/A	Caused daughter pain when she touched the notebook	No IDI available

Date of Accident	*Product*	*Secondary Prod*	*Cause of Hazard*	*Damages*	*Injuries*	*Other Key*
					computer	
4/20/2006	Mobile telephone	Batteries	Turned telephone off when boarding an airplane, 10 minutes later felt something burning in his pocket. Took telephone out of pocket noticed that it was hot and the lcd screen was cracked. Took battery out and problem stopped	No Damages	No Injuries	Before incident had telephone turned on 24 hours a day 7 days a week, even when charging due to his job.
4/10/2006	Mobile telephone	Battery Charger	Charger plugged into surge plugged into outlet Telephone was left charging for 24+ hours smelled odor, no smoke alarm	Battery shifted out and melted to side of mobile telephone, black soot around area, hole placed in Formica countertop	No injuries	Month before electrician examined outlet where fire was and reported nothing was wrong, also lap was connected to outlet
3/24/2006	Notebook computer	Batteries	On 3/23/2006 closed top of computer without turning off and placed into drawer. Left at 1630, fire went off on 3/24 at 0430, fire department stated that not turning off notebook computer contributed to fire	Sprinkler system dumped 5000 gallons of water reaching approx. $110,000 of damages	No injuries	Used notebook computer 8 hours a day plugged into wall. At night always closed screen but left notebook computer on to "exercise" the battery since consumer thought it would be "healthier" for the notebook computer
3/21/2006	Mobile telephone	Batteries	Replacement Li-Ion RadioShack battery placed in mobile telephone, next day smoldered in pocket	Mobile telephone in pocket released smoke and battery was charred	Consumer was not injured	Telephone worked well for years but first week of March began losing power and battery lost charged
3/17/2006	Batteries	Mobile telephone	Came home from work and began to charge her mobile telephone at 12am woke up with house filled with smoke due to battery blowing up	Fire fighters extinguished the fire in the house estimated damages were $30,000	Consumer was treated for smoke inhalation	Noticed Battery was recalled in 2004, incident happened in 2006
3/2/2006	Mobile telephone	Mobile telephone	When using telephone, overheated and caused face to become hot	Replaced battery in mobile telephone to try and fix overheating	Hot Face when using mobile telephone	After replacing battery telephone continued to overheat

Date of Accident	*Product*	*Secondary Prod*	*Cause of Hazard*	*Damages*	*Injuries*	*Other Key*
2/16/2006	Battery Charger	Batteries	At 3:30 went to charge lithium polymer pack to fly airplane. At 3:40pm battery and charger overheated, ignited bench and nearby combustibles. Went on for 40 minutes before fire department was called	Property damage was totaled at $100,000	No injuries	Perhaps thought during investigation that he put in the fully charged battery pack instead of depleted battery pack, thought charger should have mechanism to prevent overcharging
2/4/2006	Batteries	Flashlight	Lost power at work, turned on flashlight at work gave off weak light, turned off flashlight put in plastic bag and put inside jacket. About 6 hours later consumer's family noticed a loud popping noise coming from room and realized a fire was going on	Fire was in an approx. 12" diameter around the bed with flames reaching as high as 2 feet. Property damage estimated at $300.	No injuries	Consumer bought replacement batteries once and installed them in the flashlight. After incident found batteries scattered over room and only one of them appeared ruptured
1/17/2006	CELL-TELEPHONE	N/A	Mobile telephone charging in truck through cigarette lighter, battery exploded seat and other areas caught on fire	Small damages, insurance company gave a "very low estimate"	No injuries	Investigator went to home no one was there just info from basic telephone call
1/11/2006	Mobile telephone	N/A	Low Battery- Put Battery in Charger Minutes later while charging battery exploded	Set papers and arm rest on chair on fire	Cut or Burn over right eye Redness to Face and right arm	N/A
1/7/2006	Portable DVD	Battery	DVD player was charging when the consumer woke at 3:30 am to sizzling noise the player leaking a black liquid substance	No damages besides the DVD battery	No injuries	Recharged Battery 12 times before incident
12/7/2005	Mobile telephone	Battery Charger	Between 8 and 9 placed mobile telephone on charger loud popping noise and strong electrical odor	Sofa and Rug contained several burn marks	No injuries	Mobile telephone always left charging overnight 8-10 hours a night when asked for replacement telephone, received same telephone

Date of Accident	*Product*	*Secondary Prod*	*Cause of Hazard*	*Damages*	*Injuries*	*Other Key*
11/20/2005	Portable DVD	N/A	While driving in a car home from vacation plugged in DVD Player to charge. 40 to 45 minutes into charging they noticed the edge of the charger had begun to melt. Took out charger battery did not explode.	Charger experience damages	No injuries	Battery that was being charged was High Capacity Rechargeable Lithium Ion Battery
11/14/2005	Mobile telephone	Electric Outlet	Mobile telephone charger left charging with no telephone attached, lady who was in house took telephone with her as she left for errands	Fire investigator examined the scene saw much of the room where the mobile telephone was burned away, PI estimated damages at $100,000	No Injuries	Usually used car charger for charging the mobile telephone and only recently started to use the desk charger since she was not going to be driving a lot anymore, noticed when she did use desk charger it appeared hotter compared to other appliances
10/23/2005	Mobile telephone	Electric Outlet	Telephone was charging at 8pm battery caught on fire at 10pm found next too tote and receptacle	Heavy concentration of soot, couch cushion burnt minimal smoke and water damage	No injuries	Purchase Feb. 2005, noticed telephone would become hot after talking on for more than 10 minutes purchased two other telephones of same model but problem did not exist for those telephones
10/2/2005	Lithium Ion Battery	Battery Charger	Plugged battery into charger and went upstairs, 10 minutes later smelled something burning and saw smoke coming from office fire department stated battery exploded and debris landed on combustibles	Wooden floor and closet door were slightly damaged from the fire, no damage to electrical outlet and no insurance claim made	No injuries	Li-Ion had been bought off line, consumer thinks through eBay. Had problems getting battery to work when he bought it, and on the day of the incident he was able to get the battery to charge
10/1/2005	Batteries	Flashlight	Installed replacement batteries to flashlight, placed flashlight with the light bulb facing down after having it on for 10 minutes during a walk, a few minutes later the batteries overheated causing the unit to explode	Flaming batteries burnt the floor, ceiling, and the plastic dust pan used to handle the hot batteries when it exploded	No injuries	Replacement batteries were originally suppose to be used for a digital camera but ended up using them for the flashlight installing them a week before the incident

Date of Accident	*Product*	*Secondary Prod*	*Cause of Hazard*	*Damages*	*Injuries*	*Other Key*
9/30/2005	Mobile telephone	N/A	Telephone was in pocket and suddenly began very hot Took telephone out of pocket and exploded in hand battery expanded twice its size	Damages to telephone and battery	Covered hand in black soot and experienced second degree burns	Produced Smoke and intense heat for 5 to 10 minutes, had it been near anything flammable would of started a fire and caused 3rd deg burns
9/16/2005	DVD Batteries	Other Sound Recording	Battery on portable DVD player exploded while it was charging over night after daughter watched movie, walked by room and saw battery in flames	Put fire out with towel minor damages	No injuries	Product had been recalled
9/5/2005	Batteries	Electric Outlet	Plugged in battery to charge at 12am was told it was fully charged when all 3 leds were lit up, at 7am checked on battery only 3 were lit up, left at 8am for breakfast, 10am fire broke out and neighbors called the fire department	Structure damage totaled $1,500 and content damage during the fire was $2,000	No injuries	Product was 1.5 years old bought a new longer lasting battery since daughter wasn't happy with only 2 hours of battery life, bought 8 hours first night of charging incident happened.
8/1/2005	Notebook	Battery	Left notebook computer running with being plugged into the wall searching for hackers using internet, about an hour later heard popping noises and saw 2-3 foot flames coming from the computer	Fire was limited to one bedroom, damaging the notebook, friend's computer, bookshelf, desk, and carpet	No injuries	Purchased notebook computer for 5 dollars from a university that was not in working order. Fixed notebook computer bought batteries on internet, but cant remember who sold them, Sony stated only use their charger for their notebook computers
7/11/2005	Mobile telephone	N/A	Put telephone on charger, hour into charging exploded	Fire in room where was charging causing two carpets, curtains, wood floor to be on fire	N/A but pieces of battery everywhere mobile telephone 4 feet away, unharmed	Telephone contained aftermarket battery
6/10/2005	batteries	Computers	Charging replacement battery overnight with notebook computer off, heard popping noises went downstairs and saw 8-10 inches flames coming from notebook computer, took	Fire was confined to notebook computer and coffee table	Thermal Burns to right forearms and to bottoms of both feet	Used replacement battery before 2-3 hours a day and never received problems before when using it

Date of Accident	*Product*	*Secondary Prod*	*Cause of Hazard*	*Damages*	*Injuries*	*Other Key*
			notebook computer out of house and threw in lawn until died down			
5/3/2005	Mobile telephone	Batteries	Plugged telephone into charger and set and was set to wake him up at 6am, at 3am woke up to a loud pop noise and flames on his desk and the battery on the floor. Noticed battery was melted and separated from telephone	Papers were destroyed and carpet burnt	Felt light headed from smoke inhalation	Purchased telephone on 1/5/04 used daily since purchase and never had a problem
4/18/2005	Mobile telephone	N/A	Plugged telephone into charger at 9pm, 7:10 am, awoke to flames on nightstand	Smudges and ashes around nightstand with small rectangular black pattern in carpet, burn marks on nightstand	No injuries	Previous Day went too mobile telephone store receive "new" mobile telephone but appeared used didn't work when turned on but was told to charge to full
4/11/2005	Model Airplane	Batteries	Was flying plan in 6 acre field and when tried to land the plane experienced a bumpy landing and consumer noticed smoke coming from plane, next thing he noticed was a fire occurring in field	Ran to get extinguisher but fire became to big and burnt 1/2 acre before fire department could get there	No injuries	Flew motor airplanes for 5 years and first time using a lithium ion battery pack this incident happened
2/6/2005	Batteries	telephones	Prior to leaving for work she unplugged her mobile telephone and put in jacket pocket and didn't use before incident, noticed odor while at work and found it was from jacket, took battery out of jacket was burning hot and then exploded	Damages confined to mobile telephone, burns through the jacket and the carpeting where the mobile telephone landed	Received chemical burns to her chin and cheeks, also receiving burns to her hands	Used telephone 3 to 4 times a day and never experienced a problem since she got it in Oct. 2004. Telephone was completely destroyed.

Date of Accident	*Product*	*Secondary Prod*	*Cause of Hazard*	*Damages*	*Injuries*	*Other Key*
1/29/2005	Mobile telephone	Batteries	Mobile telephone battery had been plugged into charger for 2-3 hours when consumer heard an explosion, saw battery pop out of mobile telephone and land on glass nightstand with 1" flames coming from it and waited for it to sizzle out.	Property damage was too mobile telephone, battery charger, nightstand and bed sheets. The estimated cost of all this was $200	No injuries	Battery in original telephone stopped working and did not use for 8 to 12 months. Bought a replacement battery and received in first week of January
1/29/2005	Mobile telephone	N/A	While driving to work telephone popped out of holder in car. Battery was ejected from the telephone and landed on the passenger floor and began to sizzle filling the car with smoke.	Passage seat floor matt and mobile telephone were damaged	No injuries	Around Sept. 2004, bought mobile telephone from a Sprint Kiosk and used telephone 4 times a day as main telephone
5/30/2004	Mobile telephone	Batteries	Was at a friends house dropped telephone on cement porch falling from 3 to 4 feet. Place telephone in pocket, 30 minutes later felt burning sensation on leg took off pants noticed telephone burnt hole through pants	Only damages occurred to the telephone and burning holes through the jeans as it feel down his leg	Appointments with the Colorado University Burn Unit, would not require skin grafts for his 3rd degree burns on left leg, knee and hip	Dropped telephone prior to incident several weeks before but noticed no changes in the telephone after the first or second drop.
5/26/2004	Mobile telephone	Batteries	Grandmother heard popping noise and went to investigate what it was; she observed smoke and then flames coming from purse where the telephone was located. Battery blown open at origin of fire	Damages included carpeting, clothing, and the purse, the consumer also stated they repainted the room where the explosion occurred	No injuries	Mobile telephone not normally kept in the charger after it was fully charged. 7 days before incident might have been left in charger while on cruise 5 uses later the incident happened.
4/10/2004	Mobile telephone	N/A	Plugged mobile telephone adaptor into mobile telephone, four hours later the consumer heard a popping noise coming from the room noticed white smoke or powder coming from telephone. Then battery pack	Battery pack landed on the floor, burning a hole through the carpet, carpet pad, and then into the sub-floor.	The blackish-silver fluid spilt onto her 2 year old son's hand giving him minimal burns.	The telephone was used daily and recharged almost every night from March 5, 2004 up to the incident, April 10, 2004.

Date of Accident	Product	Secondary Prod	Cause of Hazard	Damages	Injuries	Other Key
			shot out of back spewing silverish-black fluid onto son's hand			
3/29/2004	Mobile telephone	Battery	Mobile telephone had low charge and started charging at 2am. Around 3:30 am heard a loud pop and saw flaming battery fly over the bed and hit the interior wall. Battery pack looked badly burned and had a silverish-blackish powder on it	Marks on carpet and smoke in room triggered the fire alarm at the hotel	No injuries	Consumer stated the mobile telephone never worked right, the battery would fade quickly and not keep its charge. Talked to salesclerk and had to buy a new battery but was not the same as old one, she still felt like it did not work right

Appendix O: FAA Incident Report

Batteries and Battery-Powered Devices
Aviation Incidents Involving Smoke, Fire or Explosion
FAA Office of Security and Hazardous Material
Note: These are recent incidents that the FAA is aware of. This should not be considered a complete listing of all such incidents
Updated October 2, 2006
The following is an excerpt from the above named document. It includes only incidents where the battery type was known to be lithium ion.

Date/ Source	Type of Battery	Device (if applicable)	Aircraft Type (Pax or Cargo)	Incident Summary
15-Sep-2006 United Airlines Report	Lithium-ion	IBM Notebook computer	Pax	Approximately 15 minutes prior to departure of a LAX-LHR transatlantic flight, the notebook computer of a passenger began to smoke. The relief pilot and the purser assisted the passenger in removing the notebook computer from the airplane. The notebook computer was placed on the floor of the gate area where is continued to smoke from the battery pack area and a small flame appeared. A customer service representative discharged a fire extinguisher on the fire. The battery pack continues to smoke for an additional couple minutes with white smoke and a strong odor. The Fire Department responded and discarded the burnt battery pack. The Passenger stated the notebook computer was an IBM belonged to his company and had been in his possession the entire time, having original parts and never having been serviced. The passenger was reportedly not using aircraft power to operate the computer. The airplane remained in service and departed on time without the incident passenger
15-May-2006	Lithium-ion	Notebook	Pax	Shortly before the flight departed,

Lufthansa DG Occurrence Report # 0001/06 DOT incident report # 2006060033	(VGP-BPL2/VGP-BPS2 or equivalent)	computer with spare batter		a burning smell was detected in the first-class cabinet of a Lufthansa ORD-MUC flight. Maintenance personnel were called to check and found it was coming from hang luggage inside an overhead luggage bin above seat 2A. The flight attendants evacuated the passengers in first class and first 2 rows of coach class. Crew used extinguishers to prevent setting off what was seen as the beginning of a slow fire. Maintenance immediately brought the bag outside the aircraft onto the ramp where it started to catch fire. Fire dept was called to assist. Fire was eventually put out after reigniting once. Fire apparently started from the extra battery pack for a notebook computer (not known if loose or attached to notebook computer). Flight departed 1 hour 18 minutes late.
03-MAR-2006 FedEx incident report	Lithium ion button cells mfr. By Lixing		Cargo	US-bound package was noticed to be smoking at outbound FedEx station in Shenzen, China. Upon inspection, the package of lithium ion batteries was discovered to be on fire
29-JUN-2005 FAA case #2005WP700218, DOT incident report #2005080470	Lithium Ion	Battery-pack	Cargo	At UPS in Ontario, Calif., during unloading of a ULD from Shanghai, it was discovered that a fire had taken place inside the ULD. A package containing a lithium-ion battery pack was identified as the source of the fire. Upon discovery, the burnt package and its contents were cool to the touch and there was no smoldering evident.
07-AUG-2004 FAA incident summary statement, DOT Incident Report	Lithium-ion	Lithium-ion batteries assembled together in	Cargo	Prototype lithium batteries shipped under a competent authority approval from California to Europe apparently started a fire in a ULD during the loading process

#2004081622		a plastic case		at the FedEx Memphis hub. The ULD had just been loaded for a transatlantic flight (Memphis-Paris). The ULD and many other packages in it were damaged/destroyed by fire. Shipment apparently was in violation of the DOT approval allowing the prototype battery to be shipped.
02-NOV-2003	Ni-Cad, Ni-Methyl Hydride, and/or Lithium (according to label on computer)	Notebook computer-Toshiba Satellite model #815-S129	Passenger	At security screening, a passenger's bag contained a computer bearing a warning label on the bottom near the battery compartment: "Warning: Hot base may cause burn. Avoid prolonged contact with bare skin." Battery compartment was hot. Screener had passenger turn off computer.

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