Super Battery

By: *LaToya Babbs, Laura Dionisio, Patrick Figaro, Nathan Hursh, Holly Krutka*
Capstone Design Project- University of Oklahoma - Spring 2003

INTRODUCTION

From entertainment purposes such as personal walkmans and Nintendo Gameboys to today's only version of communication featuring cell phones and laptops, batteries are essential to today's lifestyle. The most used batteries right now are very compact and split 50/50 between rechargeable and non-rechargeable. Today's commonplace batteries present the consumer with many problems. Either batteries that cost a fortune and must be replaced every few months, or they are relatively inexpensive, but quickly run out of energy and add harmful. Batteries should add convenience to the life of the consumer, instead of adding inconvenient and expensive problems.

A question was posed as to whether higher capacity batteries based on unusual stabilized iron (VI) chemistry could meet the growing need of consumers (Licht). These super-iron batteries boast a 50% energy advantage over conventional alkaline batteries or the rechargeable batteries out on the market today. Also, because of their makeup, these batteries are more environmentally safe than those on the store shelves. This makes this battery enticing to penny pinchers as well as the environmental groups that seem to have a large influence in many important circles.

Super Battery has then drawn up a plan to go about the construction and design of the components of this proposed Super-Iron battery. Justification is also presented as to why this makeup of a AAA is better than the original AAA batteries made by companies such as Duracell and Energizer.

BASIC COMPONENTS

The cathode is the section of the battery between the outside shell casing and the separator paper. During cell discharge, which is the reaction that occurs when the battery is in use, the cathode goes through a reduction reaction where it gains electrons. In the super-battery, a unique iron (VI) compound acts as the cathode. This substance is reduced from iron (VI) to iron (III) when it gains three electrons.

The anode consists of the positively charged material, making up the interior part of the battery. It is made up of a zinc paste made in the production plant based primarily on zinc oxide and the metallic oxide chosen as calcium oxide.

The final battery is constructed using a 304 stainless steel casing. In addition, a separator paper is used to keep the anode and cathode materials from coming into direct contact, while allowing the flow of KOH electrolyte solution. Finally, a brass current collector is necessary in order for the battery to use the flowing electrons for the various battery applications.

CATHODE SYNTHESIS

The increased storage capacity of the super-battery is due to the iron (VI) compound, which is missing six valence electrons. This material is Na_2FeO_4, and its synthesis is one of the main challenges in the process. Figure 1 is a PFD that details the equipment and different steps involved with the production of Na_2FeO_4, as well as the mixing of the components that comprise the cathode of the battery. *Since no iron (VI) compound has ever been synthesized on an industrial scale, the main challenge of the project was to find a way of making a suitable iron (VI) cathode material that would still allow the process to be profitable.*

The final battery cathode is comprised of the following solid state components: 65 wt % Na_2FeO_4, 5 wt % $KMnO_4$, and 35 wt % CF_x. In addition to these solid components, 1 mL of saturated KOH (13.5 M) is added for every gram of solids that are in the cathode. The total mass of the cathode is approximately 3.66 g, which comprises 49 % of the total battery volume.

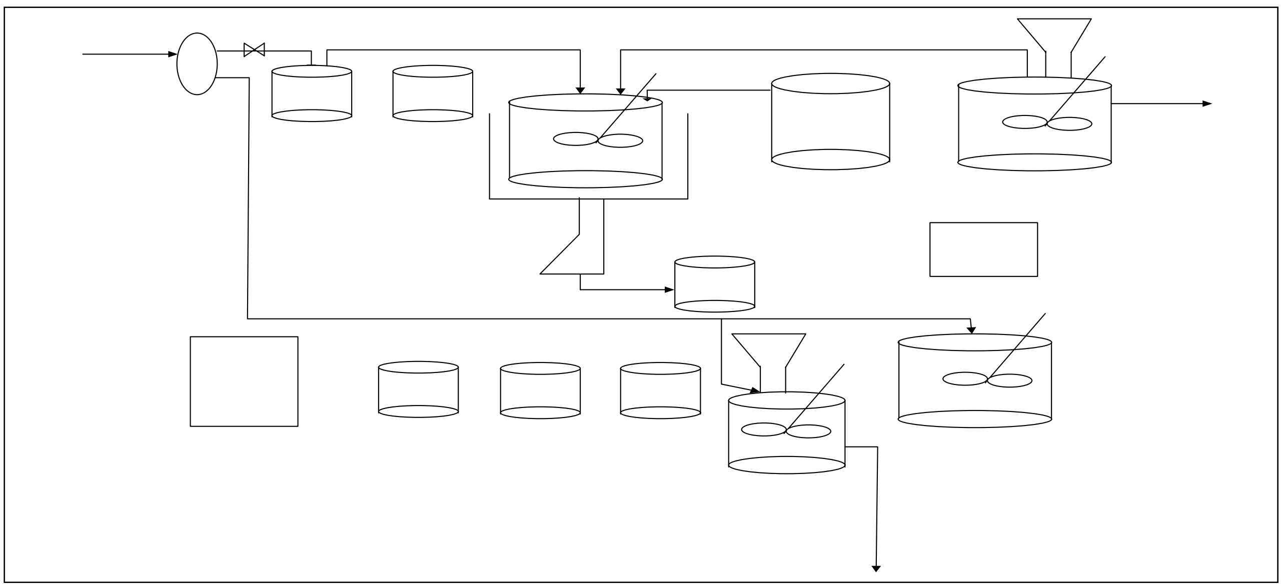

Figure 1: Cathode Synthesis PFD

Most of the vessels in Figure 1 are storage containers where the different components are stored until they are used. The main reaction occurs in the batch reactor R-1. In M-1, NaOH pellets and de-ionized water are mixed in order to create a 13.5 M solution that is used in the reaction and precipitation of Na_2FeO_4. M-2 is used to create the 13.5 M KOH electrolyte solution, which is used in both the cathode and anode. Finally, M-3 is a mixer where the solid cathode components are thoroughly mixed before they are inserted into the battery.

The main reaction in the production of the Na_2FeO_4 occurs inside the reactor R-1 in Figure 1. This reaction uses the different raw materials to produce the iron (VI) compound via the following reaction:

$$Fe(NO_3)\cdot 9H_2O + \tfrac{3}{2}NaClO + 5NaOH \rightarrow Na_2FeO_4 + \tfrac{3}{2}NaCl + \tfrac{23}{2}H_2O$$

After the above reaction is completed, more NaOH is added to the system in order to precipitate the Na_2FeO_4 out of the solution. This compound is collected and dried. Next, the iron (VI) compound, $KMnO_4$, and CF_x are mixed thoroughly before they can be inserted into the battery. M-3 in Figure 1 is the mixer where the different solid cathode components are mixed. Finally, when the solid cathode mixture is inserted into the battery, the specified amount of KOH is added to the top of this mixture.

The process described above is a modification from a process, which produced a cathode $BaFeO_4$ solution, and was scale-up directly from laboratory procedures. The development of the process described above was a continuous evolution from the extremely unprofitable direct scale-up. The first change that was made was the decision to use Na_2FeO_4, instead of $BaFeO_4$. Next, NaClO was purchased instead of synthesizing KClO at the battery production plant, which also removed the need to use Cl_2 inside the plant. Next, NaOH was used instead of KOH in the synthesis of the iron (VI) salt, since the sodium compound was less expensive than the potassium hydroxide. Finally, inorganic experts were consulted in order to estimate the necessary amounts of NaOH that would be needed to precipitate the Na_2FeO_4 out of the solution. Most of the waste and weekly costs in the direct scale-up originated with the over use of KOH to precipitate and wash the iron (VI) salt. These are the most important modifications to the direct scale-up process that allowed the production of the Super Battery to be economically feasible.

ZINC ANODE

Zinc electrodes are used in primary alkaline batteries predominately due to the ability to provide low cost negative electrodes at a high voltage and low weight. Different methods of preparation of this zinc paste were proposed, although only one showed the highest potential. The method proposed by Phillips may be mass produced and shows a high cycle life, good rate capability, and excellent mechanical characteristics. The following are the steps taken to mass produce the zinc paste anode for one day's production level:

1. Create a suspension by adding 5540 g of calcium oxide to 108.8 L of water and stir vigorously in the mixer.
2. Add 13500 g of zinc oxide to the mixture (about 2.5 times the weight of the calcium oxide) and stir overnight at room temperature.
3. The solid mixture was then filtered and dried at 60^0C.
4. Approximately 1174 g of zinc oxide is then added to the powder mixture of zinc oxide and calcium oxide, so that the volume fraction of zinc oxide to calcium oxide becomes 0.51:0.32.
5. Bismuth oxide is also added to the solid mixture in the amount of 1523 g.

The smooth paste is finally prepared by the addition of 2547 g of hydroxyl-ethyl cellulose, about 10% wt. and polytetrafluroethlyene (PTFE) in the amount of 1274 g (Miller, Journal of Electrochemistry). As well the electrolyte, potassium hydroxide, will be added once the anode is placed in the battery can and a formation voltage will be applied to convert zinc oxide to the required metallic zinc for the discharge reaction. Furthermore, the zinc electrode is used rather than the cadmium-based electrode to cut down on toxicity provided to the environment through the life cycle considering that zinc is a common metal found in the earth and does not cause harm.

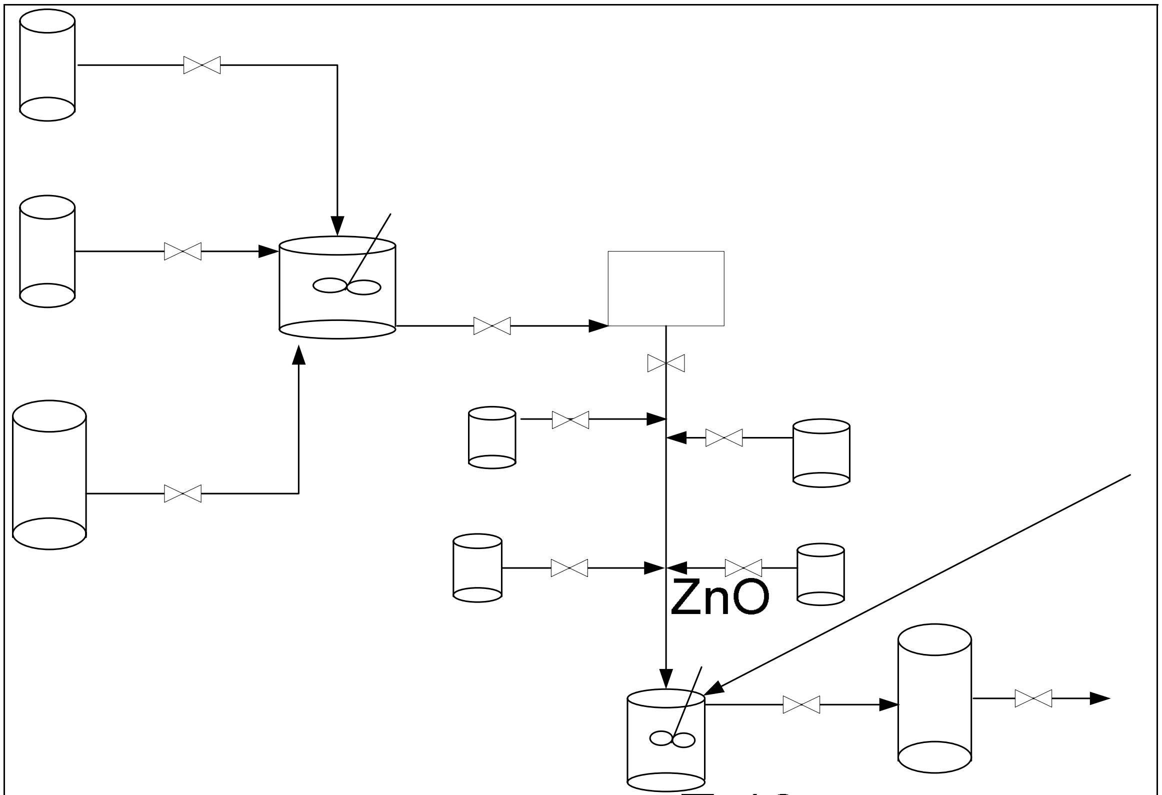

Figure 2: PFD of Anode

CONSTRUCTION COMPONENTS

Casing

When considering the type of material to enclose the battery, one must consider several factors such as durability, safety, availability and cost. 304 stainless steel is a common alloy that is used because it has excellent corrosion resistance in a wide range of media, it resists ordinary rusting, it can be cleaned, and it resists organic chemicals, It is available is a wide range of sizes and specifications. It is better than other forms of stainless steel because it contains the lowest amount of nickel possible. Nickel is reactive with the components found in the cathode material.

CaO

Figure 3: Casing

H2O

Separator
The separator is a porous material between the anode and the cathode that prevents internal shorts while allowing ions to move freely between the electrodes. The separator is a NFWA membrane which is a dimensionally stable separator membrane that consists of a uniform dispersion of carboxylic ion exchange material in a microporous acrylic copolymer matrix. The membrane will be supported on a woven nylon substrate that will quickly absorb the electrolyte solution. The separator material will be 43.5 mm long and have a 6.5 mm diameter once rolled and inserted into the battery casing.

Collector
The collector is a metal current collector that provides the electrical connection between the porous cathode and the positive terminal of the battery. The collector will be a 20 mm long brass pin. The diameter will be 1.5 mm. Brass is usually one of the first choices of metals for components for equipment made in the electrical industries. Brass has good strength and ductility along with excellent machinability. Brass is a high purity homogeneous alloy with uniform chemical composition over the entire wire length. It has very good corrosion resistance and a very high surface quality that minimizes the formation of hydrogen inside the battery cell due to faulty coating.

Packaging
The basic role of packaging is to ensure the product quality. The packaging of the batteries will also be important in regards to the marketing strategy. Not only should the packaging be eye-catching, it should be simple and convenient for customer handling. The new line of super- iron batteries will be sold in transparent, sleekly designed cylinders rather than the traditional wasteful blister packs. These tubes are manufactured by Tulox Plastics using a cellulose propionate resin. The plastic cylinder that mimics the shape of a battery is made from ecologically friendly recyclable and reusable materials. The round containers are 1.027'' I.D. x 3-15/16'' long with clear sealed bottoms and natural plug closures. The packaging is designed to appeal to modern customers.

Figure 4: Packaging

MARKET ANALYSIS

A market analysis allows a company the tools to build strong and profitable connections with consumers. The consumer should always be held as the most important person in a company that specializes in producing a product. The total market should first be identified, but then divided into smaller segments. The company then selects the most promising segment and focuses on serving and satisfying this segment. This segment is then further analyzed and becomes the niche or the target audience of the company.

There are two main selling points for the Super-Iron battery:

1. 50% more energy capability than other AAA batteries on the market and 200% more energy in higher drain applications.
2. The components of the Super-Iron battery are considered environmentally friendly and are easily disposed of without harm to the earth.

These two attributes help the company set its position. A product's position is the place the product occupies relative to competitors' in the minds of the consumers.

Marketers rarely limit their segmentation analysis to only one variable. Saying that the Super Battery is setting their sights on environmentalists is very presumptuous. Multiple segmentation bases aid to identify smaller, better-defined target groups. Super Battery has not only identified environmentalists, but more specifically those with active lifestyles, have a mid range to higher range income, and those within the particular age group of 24-50 years of age.

Deciding on an area to market the battery was the next step in the process of marketing. Due to one major selling point, cities denoted as the "most environmentally friendly" were targeted. Demographics were then considered along with prices of competitor's batteries in all the different areas in order to narrow the market down to one. Cost of living index, battery prices, population segmentations, and median income statistics all pointed to one city, San Francisco. The following table shows the 5 most environmentally friendly cities as noted by Green Peace, as well as New York City, the trend setting city in the US, and Washington, DC, which is the headquarters of Green Peace.

POPULATION CHARACTERISTICS				
City	**Population**	**Pop. Density (per sq.mile)**	**Population Change**	**Median Age**
National Average	52,000	3012	11.26	34.3
Austin, TX	587,873	2479	18.93	29.6
Seattle, WA	537,150	6417	4.03	36.2
Portland, OR	503,637	3558	3.61	35.8
San Francisco, CA	746,777	15,344	3.15	36.3
Charlotte, NC	520,829	2522	2.2	33
NYC, NY	7,428,162	25,464	1.44	35.4
Washington, DC	519,000	8567	-14.48	34.2

Table 1: Population Characteristics for the Top City Choices

The numbers all show San Francisco's popularity as the target audience as well. The desired demographics are as follows:

- 8.2% children ages 5-14
- 48% ages 20-45
- 44.3% of all families having children
- 45.6% of all families young and single
- 1.7% unemployment rate
- 56.8% making $50,000 and over per household

San Francisco has been at the forefront of clean-environment programs for years, and is well noted for it's efforts. Therefore, San Francisco is chosen as the target market location above all other cities in the United States.

Plant Location

The plant location for SuperBattery was limited to the continental US. To narrow the search, the US was broken into six geographical districts. In each of these districts, the state with the highest percent of industrial manufacturing was determined. The search was then narrowed again by determining the city with highest percent of industrial manufacturing in each of these six states. These cities were found to be: Wichita, KS; Indianapolis, IN; Philadelphia, PA; Charlotte, NC; Oakland, CA; Portland, OR. It was found that the largest difference in cost of each of these cities would be the cost for transportation of raw materials and final product. Transportation cost were found by consulting EZ Freight Trucking corporation and receiving price quotes for the transportation of raw materials from their sources and transporting the final product to the market in San Francisco. Automatically, Oakland and Portland were eliminated. This is because of the large amount of raw materials received from the East Coast. The remaining four cities were very close in cost. In order to decide between the four cities, other city attributes were considered such as individual state transportation costs, utility cost, property tax, and future job growth. Once these four characteristics were considered, one city was the most cost effective. That city was Charlotte, NC.

LIFE CYCLE ANALYSIS

The life cycle of the battery begins with the raw components. For the cathode, the raw components are as follows: NaOH, NaClO, $FeNO_3$ $9H_2O$, $KMnO_4$, CF_x, and KOH. The raw materials are shipped from different manufacturers throughout the United States. The raw materials for the anode are as follows: ZnO, CaO, Bi_2O_3, Et-hydroxy cellulose, PFTE, and KOH. These materials all originate from KL Trail in Columbus, Ohio. In addition, the header, brass pin, and separator paper are also needed for battery construction. These raw materials are shipped to the battery-production plant where they are used to compose the final super-battery, using the methods described previously. The shipping of the raw materials as well as the finished batteries is completed by LTL Trucking and Cargo Company.

The batteries are produced, and then are shipped to the market. The consumer is able to purchase these batteries. When the batteries are used in electronic devices, the following reaction occurs:

$$Na_2Fe(VI)O_4 + Zn \rightarrow Fe(III)_2O_3 + ZnO + Na_2ZnO_2$$

When the battery is used, the compounds on the right side of the above equation remain inside the batter. Therefore, when the consumer discards the used battery in the trash, these are the components of the battery that will eventually be placed into a landfill. Fortunately, $Fe(III)_2O_3$, which is a main difference between the super-battery and conventional alkaline batteries, is an environmentally benign substance that poses little threat.

ECONOMIC ANALYSIS

The tables below shows equipment sizes and costs as well as profitability.

Cathode Equipment	Volume (gal)	Cost ($)
Deionizer		$2,526
Tank-1 Carbon Steel (Distilled H2O)	5.28	$20
Tank-2 Carbon Steel (NaClO)	16.09	$25
Tank-3 Carbon Steel (Fe(NO3)3 9H20)	36.60	$30
Tank-4 Carbon Steel (NaOH pellets)	16.58	$25
Tank-5 Carbon Steel (Na2FeO4)	11.64	$20
Tank-6 Carbon Steel (KMnO4)	0.90	$20
Tank-7 Carbon Steel (CFx)	5.58	$20
Tank-8 Carbon Steel (KOH pellets)	17.95	$25
Tank-9 Carbon Steel (Waste Storage)	74.21	$1,426
Reactor-1	69.27	$5,048
Filter-1 Cast iron	69.27	$87
Mixer-1 Steel bhp=2.7 (NaOH)	2.22	$2,259
Mixer-2 Steel bhp=2.7 (KOH)	2.40	$2,259
Mixer-3 Steel bhp=2.7 (Cathode)	4.82	$2,259
Vacuum Dryer-1		$12,000

Table 2: Cathode Equipment

Anode Equipment	Volume (gal)	Cost ($)
Mixer-4 stainless steel – 6 hp	24.95	$3,312
Stirrer-1 stainless steel – 2 hp	10.82	$2,259
Tank-10 Carbon Steel (ZnO)	3.59	$20
Tank-11 Carbon Steel (CaO)	2.15	$20
Tank-12 Carbon Steel (Et-hydroxy)	3.74	$20
Tank-13 Carbon Steel (Bi2O3)	0.23	$20
Tank-14 Carbon Steel (PTFE)	1.12	$20
Tank-15 Carbon Steel	10.83	$20
Vacuum Dryer-4 carbon steel		$12,000

Table 3 Anode Equipment

Total weekly Cost	**$41,431**
Capacity	**50,000**
Total Processing Cost ($ / battery)	**$0.83**
Total Capital Investment	**$413,071**
Fixed Capital Investment	**$359,192**
Return of Investment	**114%**
Net Present Worth	**$3,645,631**
Purchased Equipment	**$72,101**
Yearly Cash Flow	**$471,294**

Table 4: Economic Criteria

RISK ANALYSIS

In order to see the sensitivity of the project due to varying costs, a risk analysis was made. After varying the product costs, product sales, and fixed capital investment, the net present worth was calculated in order to see if the project would still be profitable. The three criteria were varied from + 20% to – 20% of their mean value. From the analysis, it is seen that product sales have the greatest affect on the profitability of the project. A 20% decrease in product sales will actually bring the project to a negative net present worth and therefore an unprofitable project.

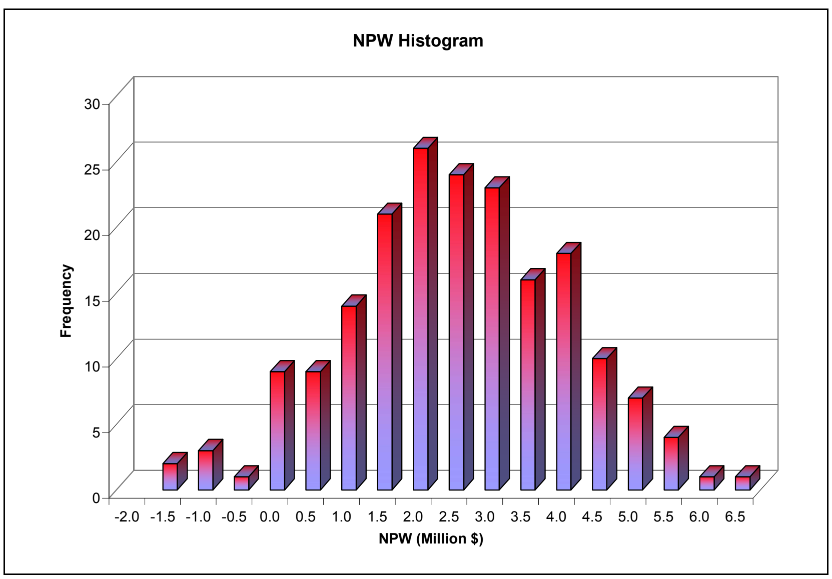

Figure 1: NPW Histogram

CONCLUSIONS

The major challenge in this project was engineering a process to be profitable when the only available scale up information was from a chemist. Production of the super batteries is both economically feasible and environmentally friendly. Due to the new iron (VI) cathode, the energy increased capacity and lifetime of the batteries will also serve as a selling point to investors and customers.