Electric Motorcycle Lithium-Ion Battery System

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Abstract

This project entails the processes of design, construction, implementation, and testing of a lithium-ion battery system, including a battery management system, dedicated to converting a 1999 Honda XR100R motorcycle into a fully functional electric motorcycle. The battery system powers the motorcycle with enough voltage and amperage to sustain the needed power capability for a reasonable range [9]. Providing an estimate of the voltage needed, the two largest loads, the DC motor and controller, draw about 48 to 60 volts from the battery for proper operation. Additionally, different aspects of the design also ensure safe operation, correct sizing, and maximum lifetime of the lithium-ion cells. With the large industry movement towards fully electric vehicles, this project provides valuable knowledge, experience, and insight to the future: a world driven by electric power.

I. Introduction

In the recent past, lithium-ion battery use and application has exponentially increased in the world of battery power. Lithium-ion performance proves to rise above many other types of power, due to the fundamental characteristics of lithium like its extremely low density to power ratio [6]. In addition, in a world concerned with the minimization of pollution and the conservation of natural resources, electric vehicles have risen as popular transportation [9]. Thus, a project entertaining the application of lithium-ion battery power to convert a gas-powered motorcycle into an electric motorcycle proves to be useful and educational.

Before discussing any details of an electric motorcycle, let it be known that a collection of safety guidelines, which goes hand-in-hand with this project, is found in Appendix B. The safety documentation must be consulted first, to understand the scope and risk associated with constructing and handling a lithium-ion battery system.

The vehicle to be converted into a lithium-ion powered electric vehicle is a 1999 Honda XR100R. This project design derives from the existing lithium-ion battery designs of common electric bicycle batteries [6]. A motivation arises to develop a higher power output design: a battery system with sufficient power to operate the motorcycle. Many problems arise with the complexity and power upgrades, such as the need for battery management, thermal cooling, and strict safety considerations, leading to a challenging design process [2]. This challenge uncovers a great senior project concept, which teaches the implementation of necessary safety guidelines, design processes, production techniques, and product testing. Using extensive lithium-ion research and following similar techniques as those used in proven lithium-ion battery systems, a design for a 1999 Honda XR100R battery system becomes attainable [9].

There are two ways to connect multiple lithium ion battery cells to accomplish such a complex design—either via a series connection or a parallel connection. Connecting batteries in series requires connecting the positive terminal of one battery to the negative terminal of another battery. When cells are in series, the current through each cell stays the same, and their voltages accumulate, simply by adding all the cell's respective voltages [9].

Alternatively, cells can be configured in a parallel connection, which means connecting the positive terminals together and connecting the negative terminals together. When cells are in parallel, the voltage across the positive rail and negative rail stays the same as the voltage of each respective cell, but the total current is the sum of the currents going through each respective cell. This allows for the alteration of the range of the battery system [9]. The fundamental characteristics of series and parallel connections play an important role in the design and analysis of this project.

The following report exemplifies the assessments and processes completed throughout the design, construction, implementation, and testing of the lithium-ion battery system created.

II. Customer Needs, Requirements, and Specifications

Customer Needs Assessment

The customers served by this product include students or hobbyists interested in a learning experience that provides a stepping-stone to converting gas powered vehicles into fully electric powered vehicles. The lithium-ion battery requires safe installation, use, and care for customer satisfaction. Some additional customer needs include correct power sourcing, safe operation, accurate dimensional consideration for space available, decent range on a single charge, and environmental friendliness. Determined from popular basic needs of current electric vehicles, these customer needs hold high importance in the design [9]. Additionally, customer needs derived from talking to the direct customer: the Future Fuels Club, which owns the motorcycle. By holding a meeting, and brainstorming many possible customer needs, the needs voted most important were decided on.

Requirements and Specifications

Derived from the customer needs, the requirements and specifications add more detail, ensuring the production of a product that satisfies the customer. All requirements drive at least one specification and all specifications support one or more requirement. This creates an unambiguous and traceable specifications set, forecasting a successful product. Significant challenges and difficulties associated with this project also effected the requirements and specifications. The project is very expensive, so funding from outside sources proved to be critical. Because of the high cost, the vehicle's range needed to be decreased to minimize the total number of cells used. Additionally, the system's construction was problematic, due to the high voltage associated with it. Refer to Table I, below, for marketing requirements, engineering specifications, and justifications.

TABLE I
MARKETING REQUIREMENTS AND ENGINEERING SPECIFICATIONS

Marketing Requirements	Engineering Specifications	Justification
1	The battery must be able to properly operate the 1999 Honda XR100R without any gas usage over a range of at least 5 miles on one complete charge of the system. Proper operation entails a consistent ability to reaccelerate to reach a speed of at least 25mph after any decelerations or stops.	The product must allow the bike to work on fully electric power without any gas usage for 5 miles: a reasonable trip distance to a grocery store. Proper operation defined based on the fact that a bike with an ability to accelerate to 25 mph can legally drive on residential streets.
2	The battery, from full charge, must be able to supply at least 48 Volts and at least 18 Ah (864 Wh) at any given time and within the expected range of 5 miles.	The DC motor and controller require a minimum of 48 Volts to properly operate, according to data sheets. The range of 5 miles is low when compared to a realistic electric vehicle range, however, this project serves as a lower cost learning experience rather than a realistically marketable product.
3	The cost of producing the car battery, including all materials and tools needed, is less than $5000.	The product build must be affordable and accessible to a wider range of customers. In addition, the production budget based on donations and funding is $5,000.
4	The battery management system must discontinue charging to an individual battery module when it reaches 80% capacity +/- 5%.	Charging the battery to only 75-85% capacity will increase the lifetime of the product [10].
4	The battery management system must keep the battery module (built of 96 cells) outputting voltage at values no more than 0.2	Research demonstrates that if all battery modules exhibit similar stresses during use, then the entire system holds longer lifetime and reliability [9,10].

	Volts in difference from one another at any given time.	
5	The system must not exceed 100 °F at any point of charging, operation, or storage.	The recommended operating temperature of the battery cells is between -20 ~ 60 °C [7].
6	The dimensions of the entire car battery system do not exceed 15" by 8" by 5".	The system must fit the area where the previous gas tank was located, above the main frame and between the rider's legs. Dimensions found by measuring the 1999 Honda XR100R gas tank area.
6	The system weighs less than 30 lbs.	The battery must be lightweight to assist ease of installation and to ensure that the total load needed to be powered by the battery is as small as possible. In addition, it must be lightweight to keep the upper mass of the motorcycle as low as possible, lowering the bike's center of gravity.
7	The system charges using a 240 V wall outlet.	Most electric vehicle charging stations use 240 V to charge batteries [5].
Marketing Requirements 1. Acceptable range 2. Powers the DC motor 3. Low cost 4. Quality and reliable product 5. Safe to use 6. Fits in available space 7. Rechargeable		

TABLE II
SYSTEM DELIVERABLES

Delivery Date	Deliverable Description
12/9/19	Project Plan Report
2/28/20	Design Review
3/6/20	EE 461 demo
3/13/20	EE 461 report
5/30/20	EE 462 demo
11/4/19	ABET Sr. Project Analysis
5/28/20	Sr. Project Expo
6/5/20	EE 462 Report

III. Functional Decomposition

Block Diagram and Functional Requirements

Derived from the requirements and specifications, the block diagram gives an overall description of the battery system. The input that drives the module is power from the charging station [5]. The overall output is battery power, which supplies the necessary components of the vehicle [2]. The subsystems, the Battery Management System and the Battery Modules, ensure the correct and safe operation of the entire battery system [3,7]. Refer to Figures I-II and Tables III-IV, below, for the Level 0 and 1 diagrams, as well as the system component functionalities.

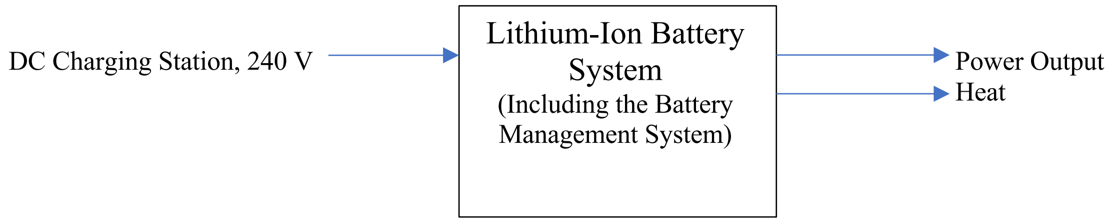

FIGURE I
LEVEL 0 BLOCK DIAGRAM

TABLE III
LEVEL 0 SYSTEM FUNCTIONALITY TABLE

Function	Description
Module	Lithium-Ion Battery System
Inputs	-Power: 240 V charging station supply [5]
Outputs	-Power: 48-60 V, 18-24 Ah(0.86 kWh – 1.44 kWh) to supply the DC Motor and Controller [9] -Heat: The lithium-ion batteries produce heat throughout discharge [2]
Functionality	Takes in charging voltage and monitors the voltage capacity of the battery cells. The output of the battery system should be sufficient to power the DC motor and controller of the 1999 Honda XR100R for a range of 5 miles.

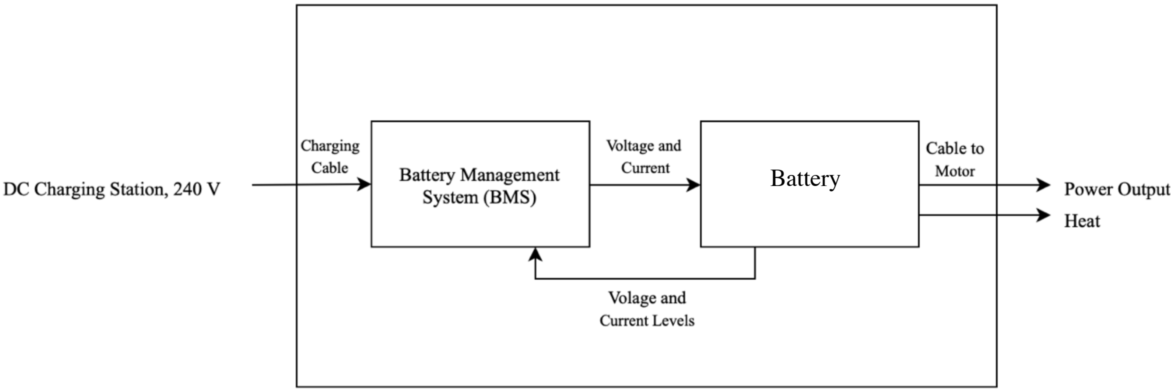

FIGURE II
LEVEL 1 BLOCK DIAGRAM

TABLE IV
LEVEL 1 SYSTEM FUNCTIONALITY TABLE

Function	**Description**
Module	Lithium-Ion Battery System
Inputs	-Power: 240 V charging station supply [5]
Subsystems	-Battery Management System: cuts power after capacity requirement fulfilled [3] -Battery: 48-60 V, 18-24 Ah (0.864 – 1.44 kWh) [7]
Outputs	-Power: 48-60 V, 18-24 Ah (0.864 – 1.44 kWh) to supply the DC Motor and Controller [9] -Heat: The lithium-ion batteries produce heat throughout discharge [2]
Functionality	Takes in charging voltage and monitors the voltage capacity of the battery cells. The output of the battery system should be sufficient to power the DC motor and controller of the 1999 Honda XR100R for a range of 5 miles.

IV. Project Planning

Derived from the total time available to complete the project, and the tasks that need completion, the Gantt Charts and Time and Cost Estimate Tables add more detail and provide a general completion dates for the various tasks. This creates an unambiguous and traceable project plan, forecasting a successful product. Refer to Tables V-VI and Figures III-V, below, for Gantt Chart estimates and Time and Cost estimates.

Gantt Charts

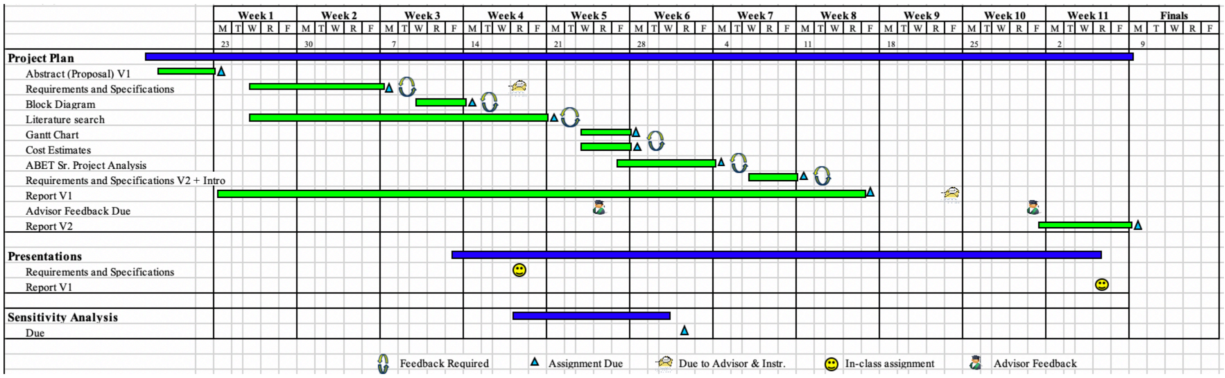

FIGURE III
FALL QUARTER GANTT CHART

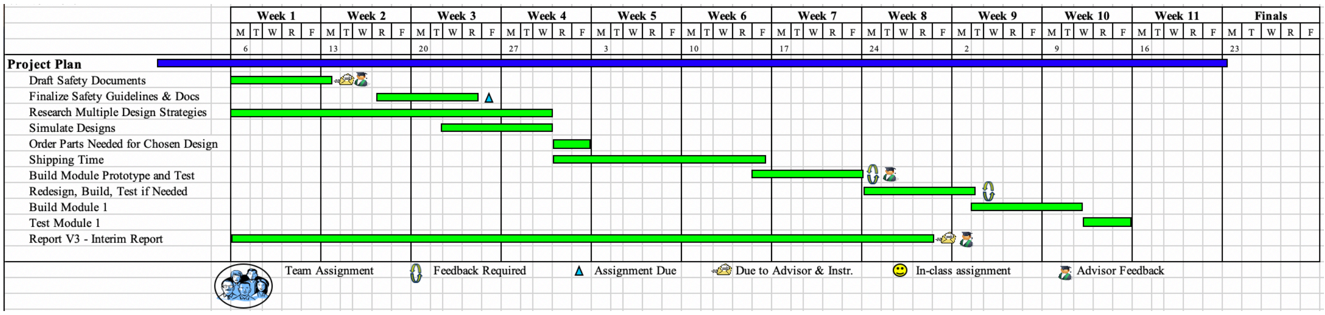

FIGURE IV
WINTER QUARTER GANTT CHART

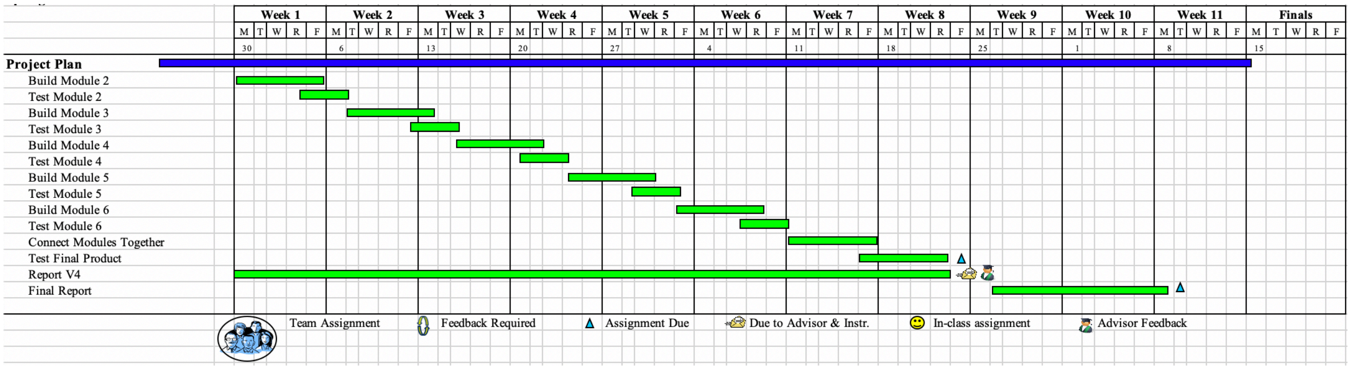

FIGURE V
SPRING QUARTER GANTT CHART

Time and Cost Estimates

Refer to Table IV, below, for the time estimated to accomplish each task outlined in the project plan Gantt Charts above (Figures III-V). Following the time estimate, a cost estimate can be found in Table V, including labor and material costs.

TABLE V
LABOR TIME AND COST ESTIMATE

Task	Optimistic Time	Realistic Time	Pessimistic Time	Tactual = (Topt + 4*Treal + Tpess) / 6	Rate of Pay	Cost
EE 460 Reports	44 hrs	75 hrs	100 hrs	74 hrs	$30/hr	$2,220
Drafting Safety Documents	3 hrs	5 hrs	10 hrs	5.5 hrs	$30/hr	$165
Simulate Designs	3 hrs	5 hrs	10 hrs	5.5 hrs	$30/hr	$165
Build Prototype and Test	5 hrs	7 hrs	15 hrs	8 hrs	$30/hr	$240
Build and Test String 1	1 hr	2 hrs	3 hrs	2 hrs	$30/hr	$60
Build and Test String 2	1 hr	2 hrs	3 hrs	2 hrs	$30/hr	$60
Build and Test String 3	1 hr	2 hrs	3 hrs	2 hrs	$30/hr	$60
Build and Test String 4	1 hr	2 hrs	3 hrs	2 hrs	$30/hr	$60
Build and Test String 5	1 hr	2 hrs	3 hrs	2 hrs	$30/hr	$60
Build and Test String 6	1 hr	2 hrs	3 hrs	2 hrs	$30/hr	$60
Connect System Together	2 hrs	3 hrs	4 hrs	3 hrs	$30/hr	$90
Test Final Project	1 hr	2 hrs	3 hrs	2 hrs	$30/hr	$60
Write Final Report	3 hrs	5 hrs	10 hrs	5.5 hrs	$30/hr	$165

TOTAL				115.5 hrs	$30/hr	**$3,465**

TABLE VI
TOTAL COST ESTIMATE

Item	Unit Cost	Quantity Needed	Overall Cost	Reasoning
Labor	$30/hr	115.5 hrs	$3,465	See Labor Time and Cost Estimate Table above, which outlines the expected time needed to finish the labor on the project.
3.7V 3400mAh NCR18650B cells	$6.20/cell	100 cells	$619.56	The number of cells needed to make a 56 V battery with the specified range is 96 individual cells.
Battery Management System	$160.00	1	$160.00	Battery needs one BMS system to meet specifications.
Pure Nickel Strips	$0.59/foot	20 feet	$11.80	Need 20 feet of nickel strips total to connect each individual cell.
Copper Wire (6 AWG)	$0.60/feet	15 feet	$9.03	About 1 foot of wire is needed to connect the battery to the DC Motor Controller.
Terminal Cap Kit	$39.99/kit	4	$159.96	Need 96 pairs of terminal caps to electrically connect cells.
DC Motor and DC Motor Controller Kit	$215.39	1	$215.39	Need to connect a load to the battery pack to confirm functionality.

TOTAL	**$4,640.74**

V. Design Implementation and Testing

Battery Pack:

The first step in designing the battery pack is to determine the design constraints. The design constraints lie within the loads that the battery pack will need to supply. The two largest loads that the battery pack will need to supply power to are the DC Motor controller and the DC motor. The DC Motor Controller has a max current rating of 45 amps and optimal voltage range anywhere from 48-60 volts. On the other hand, the DC Motor has a rated current of 42 amps and a rated voltage of 48 volts. With that, the constraints of the battery pack have been determined. In order to properly power the motorcycle with its stated controller and motor, a battery pack of at least 48 V supplying no more than 45 A is required.

The 18650 lithium-ion battery cells are the building blocks of the battery pack. Each cell has an actual voltage of 3.5 V and nominal capacity of 3.4 Amp-hours. Ultimately, the most space efficient design for the battery module came out to be a configuration of 16 cells in series by 6 cells in parallel, also denoted as 16s x 6p. With the 16s x 6p setup, the total module voltage and total module capacity is calculated below.

$$\begin{aligned}\text{System Voltage} &= (\text{number of cells in series})(\text{voltage of each cell})\\ &= (16)(3.5\ \text{V})\\ \Rightarrow &= \mathbf{56.0\ V}\end{aligned}$$

$$\begin{aligned}\text{System Capacity} &= (\text{number of cells in parallel})(\text{capacity of each cell})\\ &= (6)(3.4\ \text{Ah})\\ \Rightarrow &= \mathbf{20.4\ Ah}\end{aligned}$$

FIGURE VI
Top View and Side View of the 16s x 6p Battery Pack.

Additionally, once the voltage and capacity are calculated, the amount of energy that the battery pack can store is calculated as shown below.

$$\begin{aligned}\text{System Energy Capacity} &= (\text{Battery Pack Voltage})(\text{Battery Pack Capacity}) \\ &= (56.0\text{ V})(20.4\text{ Ah}) \\ &= 1142.4\text{ Watt hours} \\ \Rightarrow &= \mathbf{1.14\ kWh}\end{aligned}$$

For li-ion battery systems of this scale, it is common for the battery pack's efficiency to be around 5 miles per kWh. Assuming this is roughly the efficiency of the designed battery pack, the range of the motorcycle is estimated below.

$$\begin{aligned}\text{Estimated Motorcycle Range (miles)} &= (1.14\text{ kWh}) * (5\text{ miles / kWh}) \\ \Rightarrow &= \mathbf{5.712\ miles}\end{aligned}$$

TABLE VII

ENGINEERING SPECIFICATIONS AND SYSTEM RESULTS FOR BATTERY PACK.

Marketing Requirements	Engineering Specifications Goals	Actual Implemented System Results
1	The battery must be able to properly operate the 1999 Honda XR100R without any gas usage over a range of at least 5 miles on one complete charge of the system. Proper operation entails a consistent ability to reaccelerate to reach a speed of at least 25mph after any decelerations or stops.	Our battery pack has an energy capacity of 1.14 kWh (56 V, 20.4 Ah). At a standard rate of about 5 miles of range per kWh, this results in a battery pack range of about 5.7 miles. Due to the COVID-19 pandemic, we were unable to test the system on an actual motorcycle to verify the speed requirement.
2	The battery, from full charge, must be able to supply at least 48 Volts and at least 18 Ah (0.864 kWh) at any given time and within the expected range of 5 miles.	After tests, the battery pack supplied 56.3 V to the DC motor. Combining this with the nominal 20.4 Ah of the battery pack, our system provides 1.14 kWh of energy capacity.
6	The dimensions of the entire car battery system do not exceed 15" by 8" by 5".	The dimensions of the final battery system are 15" by 7" by 4". In addition, the battery pack was custom built in a shape designed to best fit the frame of the motorcycle.
6	The system weighs less than 30 lbs.	The battery system's final weight is 17.5 lbs.
Marketing Requirements Legend 1. Acceptable range 2. Powers the DC motor 3. Low cost 4. Quality and reliable product 5. Safe to use 6. Fits in available space 7. Rechargeable		

Battery Management System:

Every efficient battery pack has its own Battery Management System (BMS). A battery pack with many cells connected in series will have *fairly* identical current loads, but not *exactly* identical current loads. This natural characteristic for battery packs is also known as being unbalanced. Having even slight discrepancies in current loads between cells in a battery pack could lead to detrimental side effects in the long-run since unbalanced-ness can exponentially degrade a battery pack. That's where the BMS comes in. A BMS regulates all battery cells by constantly monitoring all cell voltages throughout charge and discharge.

The BMS we utilized is the Chargery BMS16T100 (100 amp rated charge and discharge current). Our BMS is equipped with many control-based features such as discharging protection, over-drain protection, and thermal protection. It can be programmed to meet various specifications, such as those listed in Table VIII below.

FIGURE VII
CHARGERY BMS16T100 SCREEN READ-OUTS FOR THE SYSTEM.

TABLE VIII

ENGINEERING SPECIFICATIONS AND SYSTEM RESULTS FOR BATTERY MANAGEMENT SYSTEM.

Marketing Requirements	Engineering Specifications Goals	Actual Implemented System Results
4	The battery management system must discontinue charging to an individual battery module when it reaches 80% capacity +/- 5%.	The BMS settings are configured to charge and discharge the batteries only between 20% and 80% capacity.
4	The battery management system must keep the battery module (built of 96 cells) outputting voltage at values no more than 0.2 Volts in difference from one another at any given time.	The BMS settings are configured to ensure a voltage difference of no more than 0.2 V between the lowest and highest cell voltages. Throughout testing the highest voltage difference observed was 0.102 V.
5	The system must not exceed 100 °F at any point of charging, operation, or storage.	The BMS settings are configured to shut the system down when either temperature sensor reads a temperature exceeding 100 °F. Throughout testing the highest temperature observed was 74.8 °F.

Marketing Requirements Legend

1. Acceptable range
2. Powers the DC motor
3. Low cost
4. Quality and reliable product
5. Safe to use
6. Fits in available space
7. Rechargeable

DC Controller and Brushless Motor:

In electric vehicles, the battery pack is connected to a DC Motor Controller. The controller we decided to use operates at a 48 V to 60 V range with a 45 A current rating and power of 2 kW. The battery is also connected to the vehicle's DC Motor so it can directly supply sufficient energy to allow the motor to function properly. An electric motor converts electrical energy —from the battery pack—into mechanical energy that ultimately provides power to the load. The DC Motor operates nominally at 48 V and 2 kW.

Overall System:

In summary, the key aspects of an electric vehicle's battery system have been accomplished through this project. These include the configuration of lithium-ion cells and the implementation of the battery system to the battery-dependent subsystems of electric vehicles.

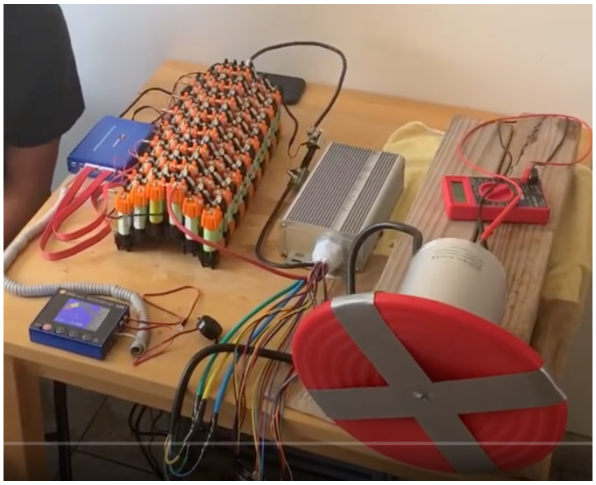

FIGURE VIII
ENTIRE ELECTRIC MOTORCYCLE LITHIUM-ION BATTERY SYSTEM.

TABLE IX
ENGINEERING SPECIFICATIONS AND SYSTEM RESULTS FOR ENTIRE SYSTEM.

Marketing Requirements	Engineering Specifications Goals	Actual Implemented System Results
3	The cost of producing the car battery, including all materials and tools needed, is less than $5000.	The total cost of the battery system comes out to be $4640.74 after adding labor and supply costs.

Marketing Requirements Legend
1. Acceptable range
2. Powers the DC motor
3. Low cost
4. Quality and reliable product
5. Safe to use
6. Fits in available space
7. Rechargeable

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APPENDIX A – ANALYSIS OF SENIOR PROJECT DESIGN

Project Title: Electric Porsche Lithium-Ion Battery System

Student's Name: Donald Alexander & Amman Asfaw **Students' Signatures:** DJA, AFA

Advisor's Name: Art MacCarley **Advisor's Initials:** **Date:**

• 1. Summary of Functional Requirements

This project entails the processes of design, construction, implementation, and testing of a lithium-ion battery system, including a battery management system, dedicated to converting a 1999 Honda XR100R motorcycle into a fully functional electric motorcycle. The battery system powers the motorcycle with enough voltage and amperage to sustain the needed power capability for a reasonable range [9]. Providing an estimate of the voltage needed, the two largest loads, the DC motor and controller, draw about 48 to 60 volts from the battery for proper operation. Additionally, different aspects of the design also ensure safe operation, correct sizing, and maximum lifetime of the lithium-ion cells. With the large industry movement towards fully electric vehicles, this project provides valuable knowledge, experience, and insight to the future: a world driven by electric power.

• 2. Primary Constraints

The significant challenges and difficulties associated with this project include cost and construction. The project is very expensive, so funding from outside sources proved to be critical. Because of the high cost, the vehicle's range needed to be decreased to minimize the total number of cells used. In addition, the system's construction was problematic, due to the high voltage associated with it. Many precautions needed to be taken throughout the design, construction, implementation, and testing of the system to ensure safety. Refer to Chapter II for more primary constraint details and how they effected the requirements and specifications.

• 3. Economic

• Economic impacts resulting from this project:

→ Human Capital – The battery system brings about many jobs for people to do. The process of design, construction, sales, installation, and maintenance provides for a wide range of created jobs.

→ Financial Capital – This project also drives financial capital. With the purchasing of the components needed, and the sale of the constructed battery system, this product positively drives the economy. The payment for labor also brings about economic capital.

→ Manufactured or Real Capital – With the need for construction, this system also creates manufactured capital. The product's creation would not be possible without workers and their manufacturing tools.

→ Natural Capital – Lastly, this project positively creates natural capital. Although the project does utilize batteries and hazardous materials in its construction, the rechargeability of the system makes it reusable. In addition, the system eliminates the need for gas, which makes for zero emissions and creates a more sustainable world in the process.

• The costs of the project accrue initially when supplies are purchased, and during labor of construction. The benefits accrue once the product is sold. Benefits continue to rise after this point as less emissions result, and a demand for system maintenance arises.

• The project requires inputs of battery cells, wires, nickel strips, silicon wire, and battery management systems [9]. In addition, it requires labor and equipment. Some equipment needed includes safety equipment, multimeters, and various tools. As seen in Table VI, which includes component parts and additional equipment costs, the project costs slightly more than $4,600. Outside donors and funding sources pay for the project.

• As of now, the project does not earn any monetary value, unless sold. However, the battery's use provides for an educational experience for the members of the Future Fuels Club. In the future, the battery system can be converted into a business operation and production costs can be reduced through increased production efficiency. The current value for a battery system with this project's specified capabilities made in the U.S. is about $1,750.

• The products emerge after about 115.5 hours of labor, shown in Table V. In the future, this timing will be decreased once the first product is proven to work and replication can take place. The product exists as long as the lifetime of the battery cells, which is currently estimated at about 3-5 years, depending on use. The need for maintenance only arises following this lifetime estimation. For estimated development time, also reference Gantt charts provided in Figures II-IV. After the project ends, the process converts into manufacturing battery systems at a faster rate.

- **4. If manufactured on a commercial basis:**
- Following the completion of the original project, the manufacturing time should decrease to about 17 hours of labor. Thus, about 120 devices could theoretically sell per year assuming 5 day work weeks, 8 hour work days, and single manned manufacturing. If more manpower arises, this number will multiply by the number of workers employed.
- Each device holds an estimated manufacturing cost of about $1,684.74 following the proof of concept for the original prototype.
- Each device holds an estimated purchase price of about $1,750.
- Per year, the profit then arises to be around $7,831 based on current estimates.
- Over a period of 1 year, the estimated cost for a user to operate the device includes the initial cost of $1,685, and an additional recharging electricity cost of about $700 per year. This electricity cost estimate arises from the recharging costs of about $5.20 per 100 miles, and the average American driving rate of about 13,474 miles per year [5]. Thus, in the first year of using the product, the cost runs about $3,200. However, in years to follow, this cost reduces to only the recharging cost of $700 per year. Keep in mind that this is significantly cheaper than the cost of using gas operated vehicles, which really means the user will be saving money rather than losing money.

- **5. Environmental**
- Many environmental impacts associate with this project's manufacturing and use. During manufacturing, the use of electricity arises as the main impact environmentally. During use, the product serves to save gas and emissions, which is a positive environmental impact. After lifetime, the product has a negative impact, as the battery cells contain hazardous materials and are difficult to recycle [6]. In fact, the common practice of "recycling" the cells is not truly recycling, but more a practice of shipping the used cells to other countries causing negative environmental impacts elsewhere. Some cathode materials from the cells can be recycled and reused, however, most of the cell's hazardous materials cause waste and pollution.
- The project directly uses electricity and materials necessary to make a battery. However, this indirectly reduces emissions.
- This project improves the use of natural materials such as oil and fuel. By eliminating the need for these resources, and lowering emissions, the environment and ecosystem will be overall better off with the use of the product.
- This product's impact on other species is seen through the reusability of the product without a large impact on the ecosystem throughout its lifetime.

- **6. Manufacturability**

Many challenges with manufacturing exist. Safety ranks as the largest challenge, as this project utilizes high voltage of around 56 V, which is dangerous to work with. Connecting the modules and the manufacturing with the use of lithium-ion cells proves to be a dangerous task as well due to their volatile characteristics [10]. If too much heat is applied to the cells, they could catch fire. Thus, many safety guidelines and precautions must be carried out throughout the process.

- **7. Sustainability**
- Not many issues arise when considering maintenance. The product's design ensures a large lifetime before maintenance is needed, based on the data sheet lifetime for the cells used and the fact that a battery management system is used to ensure proper operation of the cells [3, 7]. The only maintenance that might be necessary includes cleaning. Once the lithium-ion lifetime passes, however, the modules may need replacement depending on their state of safety.
- This project ensures a sustainable use of resources through its ability to recharge, and the decrease of the need for non-sustainable resources, such as fuel, through its use.
- Lithium-ion batteries with a larger lifetime and efficiency would upgrade and improve the project's design. The charging method used could also improve the product, as the product could use renewable energy, such as solar energy, to decrease the total non-renewable energy consumed. Lastly, adding more modules in parallel will allow for a larger range of usability.
- Upgrading the design will create some issues and challenges, as the implementation of upgrades cost much more money and increases labor time.

• 8. Ethical

• Many ethical implications relate to the design, manufacture, and use of this project. The most important ethical concern relates to the first rule of the IEEE Code of Ethics, which entails holding paramount the safety, health, and welfare of the public, while complying with ethical design and sustainable development practices. This project contains many safety concerns throughout construction and use of the product. If handled incorrectly, the hazardous materials associated with the project could cause great harm. Morally, it is most important to hold the safety of the manufacturer and the users of the battery system to high priority. Although this rule may be the most important to the scope of this project, all other rules of the IEEE Code of Ethics apply as well.

• In context of ethical frameworks, The Golden Rule proves this project's positive ethical considerations. The Golden Rule considers treating others as you would like them to treat you. The product creates minimal emissions, while also eliminating the use of nonrenewable fuel resources. Alternatively, not using this product would contribute to a more emission-polluted and less resourceful environment. Thus, by using the product, the environment is treated the way you would like others to treat it with the saving of non-renewable energy sources and the elimination of polluting emissions created.

• In addition, Utilitarianism shows that the net positives in using the product outweigh the negatives. By using the product, less emissions pollute the environment. Also, non-renewable resources are conserved. However, negative impacts of the product's use such as the hazardous material pollution created exist as well. When considering the weight of the positive impacts and negative impacts, the positives ultimately outweigh the negatives, showing the positive ethics the project holds.

• Considering all ethical challenges, it is possible to avoid many negative impacts by developing new technologies to aid and develop the lithium-ion recycling process. In addition, by following strict safety guidelines throughout design and manufacturing, the ethical consideration of health and welfare of the public can be maximized, essentially eliminating most health risks caused by the product.

• 9. Health and Safety

Many health and safety concerns arise when designing and manufacturing this product. The lithium-ion cells utilize harmful chemicals and hazardous materials that need to be handled correctly and safely [6]. In addition, the temperature range of the cells must be of concern throughout the entire process. If the cells are over stressed, the product could catch fire. Thus, the system must shut down, if the cells begin to operate outside of a safe range [2]. For more information on this project's health and safety concerns, refer to Appendix B.

• 10. Social and Political

• The social and political issues associated with the design, manufacture, and use of this project include following all legal guidelines and rules set for vehicle battery systems.

• This project impacts vehicle drivers and the entire ecosystem. Direct stakeholders include those that use the product in their vehicles, and the indirect stakeholders include those that live in the ecosystem that depend on less pollution and decreased use of non-renewable fuel resources.

• The project benefits the various stakeholders as long as the product is in use, as it employs renewable energy and creates a less polluted environment. Once the product's lifetime expires, a potentially negative social and political impact arises. As mentioned previously in the Environmental section, the process of recycling the cells involves the shipping of the hazardous materials to other countries causing pollution in those areas. The question of social and political correctness arises from this fact. As it currently stands, this process can be viewed in a bad light depending on social and political viewpoints.

• Stakeholders benefit equally, as the environment and resources saved can be used by the entire population. Inequities exist in that buyers of this product must pay the initial cost of the battery system. However, eventually, the buyers also gain the positive inequity of saving money on travel compared to others.

• In the scope of various stakeholders' locations, communities, access to resources, power, knowledge, skills, and political power, this product does hold some limitations and inequalities. The product can only be used in communities with access to electric power, as electric power is required to charge the system. In addition, some communities with extremely hot or cold climates (below -20 °C or above 60 °C) will be unfit for the use of this product, as these environments are not suitable for the volatile lithium-ion cells.

• 11. Development

We learned about many new tools and techniques through this project. First of all, we learned about the Monte Carlo simulation as part of the design process, which allows for a sweep of a range of parameters. This tool proves

useful when testing important project specifications for many different cases. In addition, we found a casing for building lithium-ion batteries that allows for safer connections without the need of high temperatures used in other techniques such as spot welding [11].
A literature search for this project can be found in the above report under the title “References”.

APPENDIX B – SAFETY GUIDELINES

A. Warnings:
(Applicable whenever handling Lithium Ion Batteries)

1. Do not disassemble or modify the battery pack without having first receiving permission to do so by the project's President, Vice President, *and* Design Lead. Insure at least two people are present at the work area, both with knowledge of these guidelines.

2. Do not connect the positive (+) and negative (-) terminals with a metal object such as wire. Do not transport or store the battery pack together with metal objects such as necklaces, hair pins, among other examples. Otherwise, short-circuiting will occur, over-current will flow, causing the battery pack to leak acid, overheat, emit smoke, burst and/or ignite, or the metal object such as wire, necklace or hair pin can generate heat.

3. Do not discard the battery pack into fire or heat it. Otherwise, its insulation can melt down, its gas release vent or safety features will be damaged and/or its electrolyte can ignite, possibly leading to leakage, overheating, smoke emission, bursting and/or ignition on it.

4. Do not use or leave the battery pack near a heat source such as a fire or a heater (+176ºF or higher). If the resin separator should be damaged owing to overheating, internal short-circuiting may occur to the battery pack, possibly leading to leakage, smoke emission, bursting and/or ignition of the battery pack.

5. Do not immerse the battery pack in water or seawater and do not allow it to get wet. Otherwise, the protective features in it can be damaged, it can be charged with extremely high current and voltage, abnormal chemical reactions may occur in it, possibly leading to leakage, smoke emission, bursting and/or ignition.

6. Do not recharge the battery pack near fire or in extremely hot weather. Otherwise, hot temperatures can trigger its built-in protective features, inhibiting recharging, or can damage the built-in protective features, causing it to be charged with an extremely high current and voltage and, as a result, abnormal chemical reactions can occur in it, possibly leading to acid leakage, overheating, smoke emission, bursting and/or ignition.

7. To recharge the battery pack, use the battery charger specifically designed for the purpose and observe the recharging conditions specified by the manufacturer. A recharging operation under non-conforming recharging conditions (higher temperature and larger voltage/current than specified, modified battery charger, among other examples) can cause the battery pack to be overcharged, or charged with extremely high current, abnormal chemical reaction can occur in it, possibly leading to acid leakage, overheating, smoke emission, bursting and/or ignition.

8. Do not pierce the battery pack with a nail or other sharp objects, strike it with a hammer, or step on it. Otherwise, the battery pack will become damaged and deformed, internal short-circuiting can occur, possibly leading to acid leakage, overheating, smoke emission, bursting and/or ignition.

9. Do not strike or throw the battery pack. The impact might cause leakage, overheating, smoke emission, bursting and/or ignition. Also, if the protective feature in it becomes damaged, it could become charged with an extremely high current and voltage, abnormal chemical reactions can occur, which can lead to acid leakage, overheating smoke emission, bursting and/or ignition.

10. Do not use an apparently damaged or deformed battery pack. Otherwise, leakage, overheating, smoke emission, bursting and/or ignition of the battery pack may occur. If a damaged or unusual battery pack is noticed, back away from the work area and call a senior club member with electrical safety training to inspect the battery.

11. Do not directly solder the battery pack. Otherwise, heat can melt down its insulation, damage its gas release vent or safety features, possibly leading to leakage, overheating, smoke emission, bursting and/or ignition.

12. Do not reverse the positive (+) and negative (-) terminals. Otherwise, during recharging, the battery pack will be reverse-charged, abnormal chemical reactions then may occur, or excessively high current can flow during discharging, leading to leakage, overheating, smoke emission, bursting and/or ignition.

13. The positive (+) and negative (-) terminals are arranged in a particular orientation. Do not force the connection if the battery pack terminals are not easily connected to the battery pack charger or other equipment. Confirm that the terminals are correctly oriented. Reversing the terminals will result in reverse charging, possibly leading to leakage, overheating, smoke emission, bursting and/or ignition of the battery pack.

14. Do not connect the battery pack to an electrical outlet, vehicle cigarette lighter, among other examples. When subjected to large voltage, over-current can flow on the battery pack, possibly leading to leakage, overheating, smoke emission, bursting and/or ignition.

15. Do not use the battery pack for a purpose other than those it was intended to by the club leadership. Otherwise, its performance will be lost and/or its service life will be shortened. Depending on the equipment the battery pack is used in, excessively high current can flow through battery pack, possibly damaging it and leading to leakage, overheating, smoke emission, bursting and/or ignition.

16. If the battery pack leaks and the electrolyte gets into the eyes, do not rub them. Instead, rinse the eyes with clean running water and immediately seek medical attention. Otherwise, eye injury may result.

17. Do not use the battery pack with primary battery packs (such as dry-cell battery packs) or battery packs of different capacities or brands. Don't hook together our Lithium Ion batteries with our Lead acid batteries. Otherwise, the battery pack can be over-discharged during use or overcharged during recharging, abnormal chemical reactions may occur, possibly leading to leakage, overheating, smoke emission, bursting and/or ignition.

18. If recharging operation fails to complete even when a specified charging time has elapsed, immediately stop further recharging. Otherwise, acid leakage, overheating, smoke emission, bursting and/or ignition can occur.

19. Do not put the battery pack into a microwave oven or pressurized container. Rapid heating or disrupted sealing can lead to leakage, overheating, smoke emission, bursting and/or ignition.

20. If the battery pack leaks or gives off an odor, remove it from any exposed flame. Otherwise, the leaking electrolyte may catch fire and the battery pack may emit smoke, burst or ignite.

21. If the battery pack gives off an odor, generates heat, becomes discolored or deformed, or in any way appears abnormal during use, recharging or storage, immediately remove it from the equipment or battery pack charger and stop using it. Otherwise, the problematic battery pack can develop acid leakage, overheating, smoke emission, bursting and/or ignition.

22. Do not use or subject the battery pack to intense sunlight or hot temperatures such as in a car in hot weather. Otherwise, leakage, overheating and/or smoke emission can occur. Also, its guaranteed performance will be lost and/or its service life will be shortened.

23. The battery pack incorporates built-in safety devices. Do not use it in a location where static electricity (greater than the manufacturer's guarantee) may be present. Otherwise, the safety devices can be damaged, possibly leading to leakage, overheating, smoke emission, bursting and/or ignition.

24. The guaranteed recharging temperature range is 0°C to +45ºC. A recharging operation outside this temperature range can lead to leakage and/or overheating of the battery pack and may cause damage to it.

25. If electrolyte leaking from the battery pack comes into contact with your skin or clothing, immediately wash it away with running water. Otherwise, skin inflammation can occur.

26. Remove jewelry items such as rings, wristwatches, pendants, etc., that could come in contact with the battery terminals. This is very important and easy to forget. Never wear anything conductive, even under our arc flash equipment.

27. All dented cells or batteries with dented cells should be disposed, regardless of electrolyte leakage. Denting of sides or ends increases the likelihood of developing an internal short circuit at a later time.

28. Cover all metal work surfaces with an insulating mat. Work areas should be clean and free of sharp objects that could puncture the insulating sleeve on each cell.

29. If cells are removed from their original packages, they should be arranged to preclude shorting. Do not stack or scatter the cells. They should be placed in non-conductive carrying trays with individual compartments for each cell.

30. Cells should be transported in non-conductive carrying trays. This will reduce the chances of cells being dropped, causing shorting or other physical damage.

31. All inspection tools (including calipers, rulers, etc.) should be made from, or covered with, a nonconductive material.

32. Measure the open-circuit-voltage (OCV) of the cell. The nominal OCV for each cell chemistry is printed on the cell label or in the manufacturer's data sheet. An open circuit voltage of 0.0 volts may be indicative of a blown fuse. However, if no fuses are present in the circuit, 0.0 volts could be a result of complete discharge.

33. After a cell has been inspected it should be returned to its original container.

34. If leads or solder tabs need to be shortened, only cut one lead at a time. Cutting both leads simultaneously can short the cell.

35. Never touch a cell case directly with a hot soldering iron. Heat sinks should be used when soldering to the tabs and contact with the solder tabs should be limited to a few seconds.

36. Exercise caution when handling cells around solder pots. If leads need to be tinned, do only one at a time. Also, guards should be in place to prevent cells from falling into solder pots.

37. Cells should not be forced into battery holders or other types of housings. This could deform the bottom of the case causing an internal short circuit. Furthermore, the terminal cap could be crushed putting pressure on the glass to-metal seal. This could result in a cell venting. Check for proper fit before inserting the cells into any housing.

38. Excessive force should not be used to free a cell or battery lodged inside the housing.

B. Cell Storage

1. Cells should be stored in their original containers.

2. Store the cells in a well ventilated, dry area. The temperature should be as cool as possible to maximize shelf-life. Observe the manufacturer's minimum and maximum storage temperatures.

3. Store the cells in an isolated area, away from combustible materials. Store depleted cells in an area separate from fresh cells.

4. Any Primary Lithium battery storage area should have immediate access to both a class D and an ABC fire extinguisher.

5. Never stack heavy objects on top of boxes containing lithium batteries to preclude crushing or puncturing the cell case. Severe damage can lead to internal short circuits resulting in a cell venting or explosion.

6. Do not allow excessive quantities of cells to accumulate in any storage area.

C. Installing Battery Packs

1. In-line fuses should be fitted external to the battery such that they may be replaced after a short circuit is cleared.

2. Thermal cutoff (TCO) or resettable polymeric, positive temperature coefficient (PTC) resistors can be used to limit cell temperature rise when that rise is caused by external current flow through the protective device.

3. Both the surrounding thermal environment and the heat output of a battery pack and/or individual cells should be evaluated. If the hazard analysis determines that a remote means of monitoring cell temperature may be needed, devices such as thermocouples, and infrared temperature sensors should be considered.

4. For larger packs or for batteries run at high rates, additional thermal management must be considered. For example, copper or aluminum heat sinks could be incorporated into the pack design to effectively conduct excessive heat away from the cells during discharge.

5. Cells connected in series should not contain a center voltage tap. This will eliminate the possibility of unequal discharge of the cells.

6. Battery pack construction should consider the need for cell vents to function (where applicable). There should be an unrestricted escape path for the fumes such that pressure does not build up in the battery pack or housing. A vent mechanism should also be incorporated in rigid housings to avoid rupture or an explosion if overpressured.

7. Shock and vibration requirements must be considered in the design of any battery pack. All cells must be protected from excessive shock and vibration.

8. Arc Flash protective equipment must be worn at all times. All jewelry should be removed so that the cell is not inadvertently shorted. Please do not forget this.

9. Loose wires should not be stripped until it is time to install a connector. If no connector is used, wire ends should be insulated.

10. Should wire trimming be necessary, only cut one wire at a time.

11. All battery packs should be labeled with the appropriate warnings as they appear on the cell label.

12. Certain potting compounds are exothermic (release heat) when they set. The maximum temperature of the cell must not be exceeded during the potting process.

D. Emergency Procedures

Releases from Cells (Vented, Leaked, or Exploded):

The electrolyte contained within the lithium cells can cause severe irritation to the respiratory tract, eyes and skin. In addition, violent cell venting could result in a room full of hazardous air contaminants, including corrosive or flammable vapors. All precautions should be taken to limit exposure to the electrolyte vapor. Review the MSDS or product information sheet BEFORE working with cells, so that you are familiar with the steps to take in the event of a release.

- Lithium may emit a colorless to pale yellow gas with a sharp, pungent odor.

- The electrolyte contained in lithium cells can cause severe irritation to the respiratory tract, eyes, and skin.

- Potential hazards may include the release of:
  - Thionyl chloride, bromine, chlorine dioxide, hydrochloric acid, sulfur dioxide and sulfuryl chloride gasses
  - Strongly acidic wastewater

  - Hydrogen from the reaction with water

In the event of an emergency:

- **Students working on car:**
  - Warn others and report the emergency.
  - Evacuate to a safe area.
  - Attend to any person that has been exposed to the material, if safe to do so.
  - Wait for further instructions from the Club Supervisor.

- **Project advisor supervising:**
  - Ensure that area personnel have evacuated, and injured personnel have been attended to.
  - Review the material safety data sheet.
  - Assess the extent and magnitude of the release.
  - Determine if further evacuation is required.
  - Determine if the emergency response authorities must be mobilized. If the extent of the hazard cannot be determined the emergency response contractor should be called.
  - Introduce additional ventilation, if possible, until pungent odor is no longer detectable.
  - Oversee response, neutralization, cleanup and disposal of released materials.

- **Cleanup Procedures (for trained/qualified personnel):**
  - Don't appropriate personal protective equipment (e.g., electrical suit, gloves, safety glasses, respirator).
  - Place leaking cell in a sealable plastic bag and cover with a mixture of neutralizing agent (soda ash or baking soda) and absorbent material (vermiculite). Double bag the leaking cell and seal the bag.
  - Absorb/neutralize any spilled electrolyte with absorbent material and neutralizing agent. Collect the contaminated absorbent into a sealable bag.
  - After removing the cells and any absorbent/neutralizing materials, the areas can be cleaned with water or an ammonia-based cleaner.
  - Place all waste materials in an appropriate container and identify contents with a red hazardous waste tag and request pickup or move to a Main Accumulation Area for hazardous waste.

E. First Aid Procedures

In case of contact with electrolyte, gases, or combustion byproducts from a lithium battery or lithium ion battery release, the following first aid measures should be considered:

- EYES: Immediately flush eyes with a direct stream of water for at least 15 minutes with eyelids held open, to ensure complete irrigation of all eye and lid tissue. Get immediate medical attention.

- SKIN: Flush with cool water or get under a shower, remove contaminated garments. Continue to flush for at least 15 minutes. Get medical attention, if necessary.

- INHALATION: Move to fresh air. Monitor airway breathing and circulation. Taken appropriate first aid and/or CPR actions, as necessary. Get immediate medical attention

F. References Used in Appendix B

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