February 15, 2016

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, BC V5A 1S6

Re: ENSC 305W/440W Project Functional Specification for a New Designed Hybrid Bicycle

Dear Dr. Rawicz,

The attached document, Functional Specification for a New Designed Hybrid Bicycle, outlines our project for ENSC 305W/440W, which intends to research and develop a new hybrid bicycle with several innovations on its driving system and some new features on its operating system.

This document provides clear description of this new designed hybrid bicycle, including generality introduction of our product, the system overview to describe how all requirements and a test plan to show the stage of development. This file will be used as a reference material for all members of this project through the entire working phase.

4E Technology consists of four talented, passionate Engineering students, Jason Li, Jim Zhang, Sheng Sheng and Coco Gong. Please feel free to contact me if you have any questions about our function specification. I will reply you as comprehensive as possible by email at yuanjiez@sfu.ca.

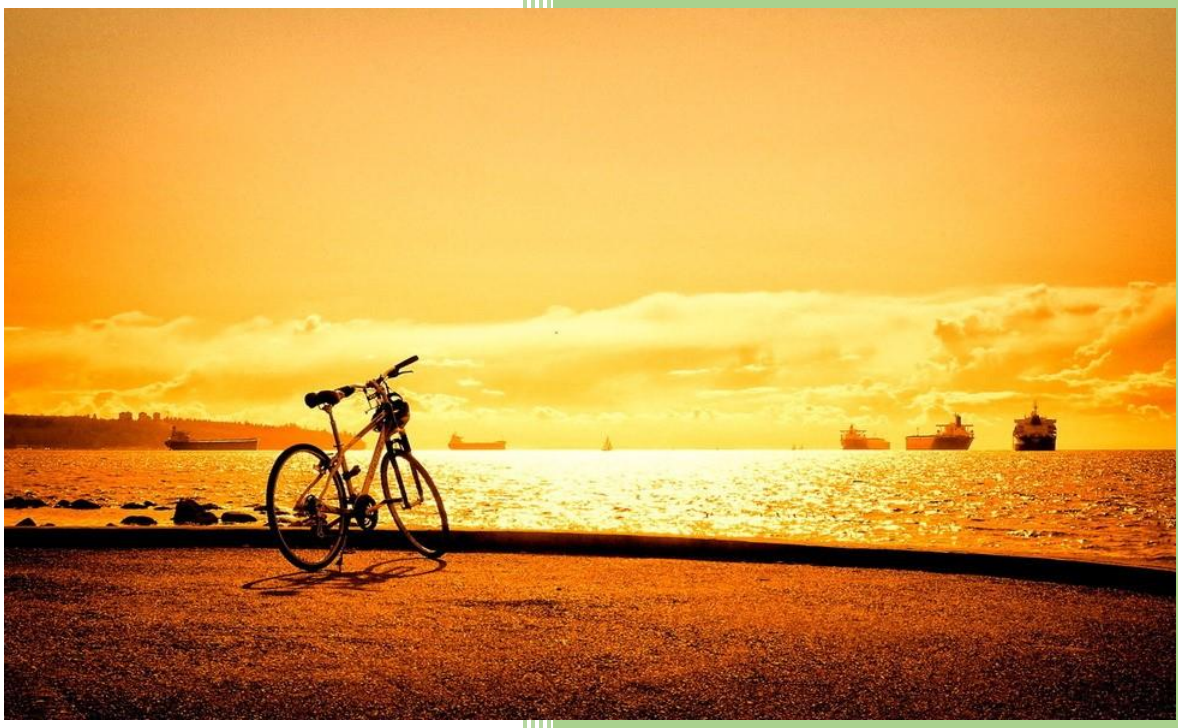
Best Regards,

Jim Zhang
COO of 4E Technology Inc.

Enclosure: *Functional Specification for a New Designed Hybrid Bicycle*

Functional Specification

For A New Designed Hybrid Bicycle



Project Team: Jason Li
Sheng Sheng
Jim Zhang
Coco Dong

Contact Person: Jim Zhang
yuanjiez@sfu.ca

Submitted to: Dr. Andrew Rawicz – ENSC 440
Steve Whitmore – ENSC 305

Issued Date: February 15, 2016

Revision: 1.1

Executive Summary

Tired of endless finding parking position? Impatient of traffic jam? Upset about the increasing price of gasoline? Due to these increasing number of social and environmental issues yielded by cars, more and more people prefer to consider one environmentally friendly and cost-effective way for daily travelling, which is the bicycle. However, some selling reports show that the sales volume of bicycles for last few years is not as large as we expected. The main reason is that the number of uphill in the city area is pretty large, and the country roads are usually rugged, which increase the cycling difficulties. The emergence of electric bicycles have figure out some of the problems, but still cannot meet the needs of all due to the limitation of its battery. Our new designed hybrid bicycle is a perfect solution to the above questions with its energy-convertible driving system.

The most attractive of this bicycle is that its kinetic energy can be converted into electrical energy and stored in battery, vice versa. The stored electrical energy can be used as a power bank. When riders encounter uphill or bumpy roads, the stored electrical energy will be converted to kinetic energy automatically in order to enhance the mobility of bicycles, which will reduce the burden on riders' muscles.

This project will be split into three phases:

Phase 1
- Obtain proof-of-concept and calculate for the effective of energy converting

Phase 2
- Design and implement drive system, energy conversion system and energy storing system.
- Assembly all separate systems together and test

Phase 3
- Install on a real bicycle and test its performance

When complete the first phase, we should be able to predict the performance of our prototype and the material to be used. The second phase is the most important stage and we will focus more on that to setup the core technology of the entire project based on all data we get from phase one. Furthermore, this new designed hybrid bicycle will conform all standards and safety guidelines to ensure the modular compatibility of our design and satisfaction of customers.

Overall, this document provides more detailed functional specifications for general requirements and other characteristic of the entire system.

Table of Contents

Executive Summary i
List of Figures and Tables iii
Glossary iii
1. Introduction 1
1.1. Background 1
1.2. Scope 1
1.3. Intended Audience 1
1.4. Classification 2
2. System Requirements 3
2.1. System Overview 3
2.2. General Requirements 4
2.3. Physical Requirements 4
2.4. Mechanical Requirements 4
2.5. Electrical Requirements 5
2.6. Environmental Requirements 5
2.7. Standards 5
2.8. Reliability and Durability 5
2.9. Performance Requirements 6
2.10. Usability Requirements. 6
2.11. Luxury Functions 6
3. Propulsion 6
3.1 Mode of operation.. 6
3.1.1 Pedal Assist Mode 7
3.1.2 Throttle Control Mode 7
3.1.3 Human Powered Mode 7
3.2. General Requirements 8
3.3. Physical Requirements 8

3.4. Electrical Requirements 8

4. Generator 9
4.1. General Requirements 9
4.2. Electrical Requirements 10
5. Control System 10
5.1. General Requirements 10
5.2. Physical Requirements 11
5.3. Electrical Requirements 11
5.4. Usability Requirements 11
5.5. Performance Requirements 11
5.6. Environmental Requirements 11
6. Sustainability and Safety 12
6.1. Sustainability 12
6.2. Safety 12
7. **User Documentation** 13
8. **Conclusion** 13
9. **Sources and References** 14

List of Figures and Tables

Figure 1: Energy Conversion Systems of Hybrid E-bicycle 1
Figure 2: High Level System Diagram 3
Figure 3: Propulsion System of Hybrid E-bicycle 8
Figure 4: Regenerative Braking System. 9

Table 1: Material Considerations 12
Table 2: Major Considerations 13

Glossary

UI: User interface.

BLDC Motor: Brushless direct current motor

M/G: Motor/generator

MCU: Micro-controller unit

1. Introduction

With a wonderful energy conversion system, this new designed hybrid bicycle is a multifunctional vehicle, which suitable for all ages of people. The functional requirements for our hybrid bicycle are described and explained in the document.

1.1 Background

Due to environmental issues generated by motor vehicles, the bicycle becomes a more popular transportation among workers and students. However, one statistics report [1] of bicycle marketing shows a very slow increasing trend of the bicycles consumption, almost a flat trend. The hybrid is the only type of bikes that purchasing amount keeps increasing. But its battery limitation will definitely affect the sales volume and this may not be very convenient to riders as well.

Therefore, we come up with the idea of a hybrid bike with energy conversion system, which can perfectly solve all these problems. This new designed hybrid e-bicycle has an attractive feature that its kinetic energy can be converted into electrical energy and stored in battery, vice versa. The stored electrical energy can be used as a power bank to charge phone and support some vehicle devices during a long travelling. When riders encounter bad road conditions, the stored electrical energy will be converted to kinetic energy automatically to enhance the mobility of bicycles. The following figure shows the basic principle of the energy conversion systems of our designed bike.

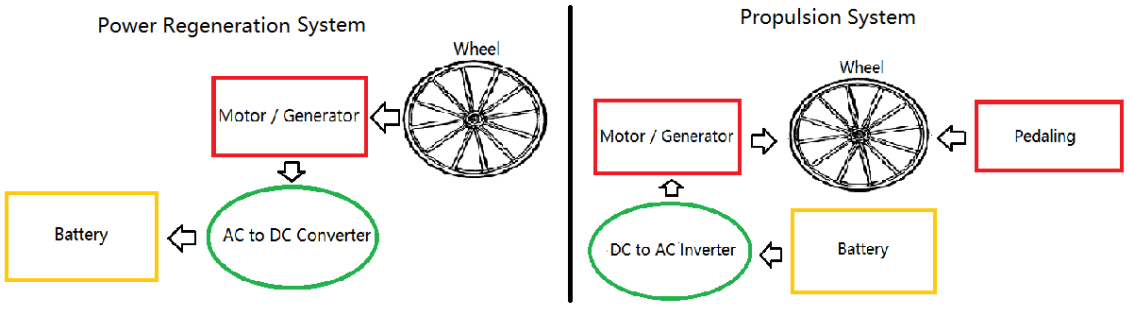


Figure1. Energy Conversion Systems of hybrid e-bicycle

1.2 scope

The document describes the functional specifications of our new designed hybrid bicycle. The requirements are divided by function and classified based on need. All requirements listed in this functional specification will be used as a reference guideline to ensure the safety and reliability.

1.3 Intended Audience

This functional specification is developed for the use of all members in 4E Technology, which will be used as the guideline and standards for designer through the entire developing phases of this project. Moreover, this document should be in very detailed as it will be used by our future audience who probably is a non-technical person.

1.4 Classification

In order to prioritize the requirements, we will use the following classification method:

[Rn-p] The Functional Requirement statement

Where ‘R’ is the abbreviation of requirement; ‘n’ represents for the functional requirement number; ‘p’ stands for the priority level of the functional requirements defined below:

A – High priority: proof–of–concept stage only
B – Medium priority: both proof–of–concept stage and final production stage
C – Low Priority: Final production stage only

For example: [R3-B] – define the requirement number 3, with a medium priority.

2. System Requirements

2.1 System Overview

The hybrid e-bicycle functions as both exercise bike and commuter bike in people's daily life. In order to make it a multi-purpose bicycle, there are three modes in the propulsion system, for instance, Pedal assist Mode, Throttle control mode and human powered mode.

In the hybrid bicycle, the propulsion system is consisted of pedals, sprockets, crank, chain, freewheel, rear axle, rear-wheel, hub motor and lead-acid batteries. Customers shall rotate the pedals to provide a human power which goes through cranks, sprockets, chain, freewheel, rear axle and eventually delivers the power to the rear wheel. In addition, the M/G provides driving force to rear-wheel to assist propelling the bike.

A rotary encoder works as a braking pedal which convert kinetic energy to electrical energy stored in the battery. The maximum speed of charging is when current following back to the battery at allowed maximum current 20A. Therefore, the braking resistance caused by regenerative brake will not allow for a current more than 20A, which is insufficient for an emergency brake. Hand operated mechanical rubber brake is still necessary for our hybrid e-bicycle.

The system that can be modeled as a high level block diagram shown below.

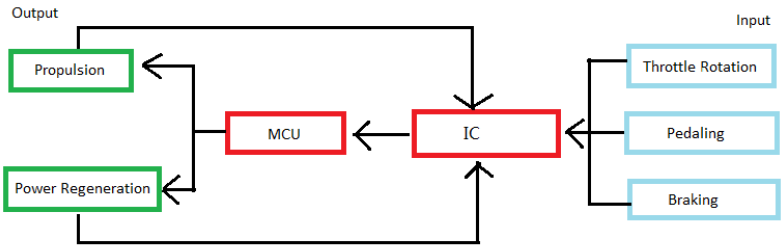


Figure 2. High level system diagram

The propulsion and power regeneration of bike are achieved by corresponding input. In throttle control mode, the propulsion of bike could be controlled by the rotation of the throttle. In the pedal assists mode, the bike could be propelled by BLDC motor when pedaling. The charging battery can be achieved by braking while cycling.

2.2 General Requirements

[R1-C] The hybrid e-bicycle is designed for outdoor usage but also capable for indoor usage

[R2-C] The retail price of the hybrid bicycle shall be under $1200.

[R3-B] Hybrid bicycle shall have 3 modes: pedal assists, throttle control and human power modes.

[R4-C] Hybrid bicycle will be able to switch to any mode smoothly while the bike is fully functioning.

[R5-C] All mechanical gears and sensors shall be safe to customers.

[R6-A] User shall weigh no more than 150 kg

[R7-B] The customers' height shall range from 140cm to 200cm with adjustable seat

2.3 Physical Requirements

[R8-B] The length of hybrid bicycle shall not exceed 140 cm.

[R9-B] The width of hybrid bicycle shall not exceed 30 cm.

[R10-B] The height of hybrid bicycle shall not exceed 60 cm.

[R11-B] The wheel size shall be 26 inches.

[R12-B] The product shall not exceed 30kg in order to ride freely with pure human power.

2.4 Mechanical Requirements

[R13-B] The propulsion system shall be controlled by pedals or throttle.

[R14-B] The power regeneration system shall be controlled by rotary encoder.

[R15-C] All propulsion and power regeneration components which are not automatically adjustable shall be only assembled/ disassembled by wrenches, pliers or other tools.

[R16-C] All controller parts shall be adjusted manually.

2.5 Electrical Requirements

[R17-B] One 36V 10Ah lead-acid battery shall be used as power supply for M/G and controller

[R18-A] The battery shall be rechargeable.

[R19-A] The battery shall be replaceable.

[R20-B] The batteries of hybrid bicycle could be charged with wall charger.

[R21-C] The battery shall survive at least 2 years of day-to-day operation before it reaches the end of its life defined as a reduction to 80% of the rated capacity. [19]

[R22-B] The batteries percentage shall be observational on the bicycle UI.

2.6 Environmental Requirements

[R23-C] The hybrid e-bicycle shall operate normally in various environmental temperatures (-30 – 45°C)

[R24-B] The hybrid e-bicycle shall operate normally in various routes such as urban, mountain and sandstone.

[R25-B] The hybrid e-bicycle shall operate normally under mild shock.

[R26-B] The hybrid e-bicycle should be able to operate normally under both rain and snow conditions.

2.7 Standards

[R27-B] The hybrid bicycle shall conform to ISO 4210:2015 standards [2].

[R28-B] The hybrid e-bicycle shall conform to ASTM F08.10 standards [3].

[R29-B] All electronic components shall conform to CAN/CSA - C22.2 NO.60335 - 1.11 standards [4].

[R30-B] All electronic components shall conform to ISO/TC 22/SC 3 for Electrical and electronic equipment [5].

[R31-B] The M/G shall conform to ANSI/NEMA MG 1 2011 standards [6].

2.8 Reliability and Durability

[R32-C] The hybrid e-bicycle shall be able to withstand daily operation.

[R33-C] The hybrid e-bicycle shall not expect any mechanical or electrical failures within the first 1 year.

[R34-C] The hybrid e-bicycle shall resistant to corrosion under rain and snow conditions.

[R35-C] The material used for the hybrid e-bike shall be recyclable and acquired through environmentally friendly means, as per the ecology requirement of C2C design.

[R36-C] Broken components shall be replaced easily by trained technicians.

2.9 Performance Requirements

[R37-B] The transmission and generation system shall response time of less than 500ms.

[R38-B] The hybrid bicycle shall travel more than 50 km on flat ground propelled by pure electric power with the battery which has been fully charged.

[R39-B] The hub motor shall provide the maximum speed up to 40km/h on flat ground.

2.10 Usability Requirements

[R40-B] The UI of product shall be easily operated and understood for customers.

[R41-C] The user manual should be comprehensive to the users.

[R42-B] Current battery percentage shall be easily accessible on the LCD display board.

2.11 Luxury Functions

[R43-B] The e-bike shall be equipped with a USB port to charge external electronic device.

[R44-B] The e-bike shall be equipped with a bottle holder.

[R45-B] The e-bike shall conform to ergonomic design

3. Propulsion

The hybrid e-bicycle functions as both exercise bike and commuter bike in people's daily life. In order to complete multiply task, multi-mode is necessary for our bike.

3.1 Mode of Operation

Three modes of operation are available for customers.

- Pedal assist
- Throttle control
- Human power

3.1.1 Pedal Assist Mode

The pedal assist mode will be accomplished by detecting the pedaling motion with an infrared sensor which will send an input signal to the system; and the motor will be turned on at maximum load regardless of the speed or torque of the pedaling. In this mode, throttle control is disabled to avoid complexity caused by multi-command. We choose not to add power control feature in pedal assist mode for the following reasons:

- Time and budget constraints
- It is hard to determine the power requested by user by processing the torque and speed of pedaling.
- The algorithm for power control cannot be as accurate or sensitive as throttle control.
- Maximum power can be achieved by our purchased hub motor is 250W. Operating at maximum load has no safety concern.

3.1.2 Throttle Control Mode

The more rotation of the throttle, the more power will be delivered to the wheel. In this mode, the pedal assist function is disabled.

3.1.3 Human Powered Mode

This mode is also known as the real bicycle or exercise mode. In this mode, all the driving force is provided manually by pedaling. Throttle control and pedal assist will be disabled for safety purpose.

The propulsion system shall utilize 2 forms of onboard energy to achieve propulsion, for example,

- **Human power,**
- **BLDC motor.**

The figure below demonstrate the overview of the propulsion system.

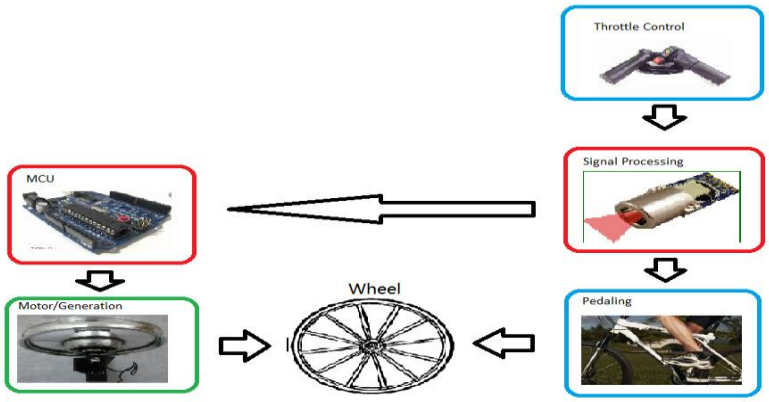


Figure 3. Propulsion system of hybrid e-bicycle [7][8][9][10][11]

3.2 General Requirements

[R46-A]Hub motor shall use 3 phase brushless DC motor

[R47-A] The pedaling human power is transmitted through mechanical system of bicycle to the rear-wheel.

[R48-B] The M/G shall be centered in the rear–wheel for better road traction since the majority of the riders weight is over the rear wheel.

[R49-B] The batteries shall be fixed on the rear bike rack.

[R50-C] The motion of the hybrid bicycle shall be smooth with motor on/off.

3.3 Physical Requirements

[R51-B] The diameter of the hub motor shall not exceed 25 cm

[R52-A] The M/G shall not exceed 2.8kg weight.

[R53-B] The M/G shall be replaced by the after-sales service technicians.

3.4 Electrical Requirements

[R54-B] The hub motor shall be 36V and 250W to provide enough power to counter gentle slopes and steeper slopes with the assistance of pedaling on the right gear.

[R55-B] The minimum supply current of 1.45A are required to move the hybrid bicycle.

4. Generator

The decided to use the BLDC motor in propelling system to function as a generator. Thus, BLDC motor works as motor and generator which is different from the initial design from our proposal. We choose the BLDC motor for our regenerative system for several reasons:

- BLDC motor has permanent magnet on the rotor; turning the rotor in the stator coil will induce 3 phase AC output. After converting AC to DC output by converter, battery charging begin.
- If we have an alternator and a BLDC motor as our regenerative and propelling system respectively, the hybrid e-bicycle will be 3 kg heavier which leads to less cruise range and unpleasant cycling experience.
- The cost of bike will increase about 20% to 30% as buy another generator for power regeneration.
- The potential market of a heavier and more expensive bike will not be as competitive as the bike with one M/G.

A rotary encoder will be needed for controlling the regenerative brake. When the rotary encoder is rotated, the current in the M/G and battery is reversed and the battery start charging in this stage.

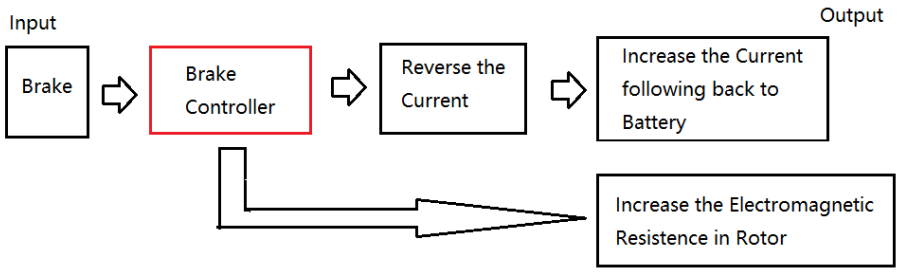


Figure 4. Regenerative Braking System

4.1 General Requirements

[R56-B]The battery shall start charging once regenerative brake is triggered.

[R57-B]The braking force shall be adjustable.

[R58-C] The efficiency of the power regeneration should be between 15% and 20%. [20]

4.2 Electrical Requirements

[R59-B] the battery shall have capacity of 10Ah to ensure the proper battery weight and size

[R60-B] The voltage provided to the battery shall be between 41.4V and 42.5V for charging 36V battery. [21]

[R61-B]The braking force shall be limited to the level which the battery would reach its maximum allowed charging current (20A), according to the limitation of the battery.

5. Control System

It is the “brain” of the hybrid e-bicycle. It receives command including rotation of throttle, mode switching, pedaling and braking, and outputs acceleration or deceleration of the bike and charging or discharging of the battery. It processes signals from battery indicator then displays in on the LCD. It also processes signals from reed switch to calculate the speed of cycling then displays on the LCD.

5.1 General Requirements

[R62-B] All sensors should be installed in different body parts of bike for detecting the corresponding change of parameters.

[R63- B] The electronic components and power connections shall be enclosed.

[R64-B] The manual switch shall be easy and intuitive.

5.2 Physical Requirements

[R65-B] The LCD monitor shall be attached closed to the handlebar grip.

[R66-B] The system and hybrid bicycle state should be monitored by the LCD

[R67-A] Size of the LCD shall be 80mm x 36mm x 12mm

[R68-B] Wires that are not enclosed shall be in perfect length to avoid hampering pedaling.

5.3 Electrical Requirements

[R69-A] The controller shall run under 5V based on Arduino board limit.

[R70-B] The battery shall share the power source to the control system.

[R71-B] The electronic components of the bike shall not cause interference with each other.

[R72-B] The controller shall be grounded

5.4 Usability Requirements

[R73-B] The infrared sensor shall be used to detect the pedal rotation

[R74-B] Rotary encoder shall manually controlled to change the brake power, thus the power of charging.

[R75-B] Throttle shall be manually controlled to change the power delivered to hybrid e-bicycle

[R76-B] The LCD on the controller shall alarm when the battery life is below 10%.

[R77-B] If the sensors malfunctions in any ways, an error message will be printed to the LCD screen

5.5 Performance Requirements

[R78-B] The throttle shall have a response time delay of less than 50ms.

[R79-B]The three-position switch shall have a response time delay less than 50ms.

[R80-B] The pedals rotation detection shall have a response time delay of less than 200ms.

[R81-B] The LCD display board response time shall be less than 200ms.

5.6 Environmental Requirements

[R82-B] Controller shall function within a temperature range of -20°C to 70°C.

6. Sustainability and Safety

6.1 Sustainability

4E Technology Inc., since its establishment, is devoted to make world a green place with the principle of sustainable development. Our products are following the “Cradle-to-Cradle” cycle design to reduce the waste of non-renewable energy. Each component selected in our product considers not only production quality standards, but also recyclability and reusability.

The specific breakdown of materials used for our products and the disposal methods are shown in the table below:

Table 1: Material Considerations

Components	Materials	Method of Disposal
Bicycle Frame, Screws, Wheels	Steel	Recyclable [12]
Tires, Wire Enclosures	Rubber, ABS	Recyclable [13] [14]
Wires	Copper	Recyclable[15]
Battery	Lead-acid	Recyclable[16]
Magnets	Permanent magnet	Recyclable [17]
Board, Sensors	PCBs, Silicon	Recyclable [18]

From table1,We can conclude that most of materials of our products are recyclable. Less waste will be produced and non-renewable natural resources will be preserved, thus protecting natural environment and future generations.

The hybrid e-bicycle, compared to normal e-bike, have better efficiency of energy conversion, thus requires less electricity. In addition, as the prevalence of hybrid e-bicycle, the use of gasoline will reduce and emission of CO2, CO and NOx will be less, which result in less pollution. The petroleum consumption will drop as well since more people choose to use clean energy for transportation. Consequently, the prevalence of hybrid e-bike will build a better environment for future generation significantly.

6.2 Safety

The manufacturing process of the bicycle body is to be carefully operated, in order to give a comfortable and convenient customer experience. The electrical and mechanical components are considered to be safe as they shall not be hazardous to users. Various tests have been done to the mechanical and electrical systems so that the hybrid e-bicycle performance shall be safe and satisfactory to every customers.

Table 2. Major Considerations

Considerations	Solutions
Water leaking into the microcontroller/battery	Apply Waterproof material
Terrain interference	Refine the circuit to minimize interference Use high quality components

The hub motor may harm customer while cycling in high speed	The hub motor shall be enclosed to eliminate potential hazard
Overheating of controller and battery	Avoid design defects that may cause short circuit. avoid direct sunshine Battery and controller shall be surrounded with heat insulating material.

7. User Documentation

[R83-C] User Documentation shall include a user manual, and technical support information

[R84-C] User manual shall be written for the customer with minimal knowledge of power regeneration and control system.

[R85-C] Technical support information shall provide the installation and maintenance guide for the technicians and vendors.

[R86-C]User Documentation shall provide the warranty with the service information.

[R87-C]User Documentation shall be provided in English, French, Spanish, German, Chinese, Japanese, and Korean to satisfy product language requirements for international markets.

8. Conclusion

The functional specification shows the requirements of the system, which is divided into 3 levels based on its priority to make sure our work will be purposive and no irreverent tasks involving. Moreover, this document provides the design specification to ensure the proper functioning of the system. This document will be a guide for our designer, also the prototype of our new designed hybrid bicycle will be based on all requirements mentioned in this file, which is expected to be completed with high quality by April 4th.

Reference

[1] '2014 - The NBDA Statpak'
Available: http://nbda.com/articles/industry-overview-2013-pg34.htm. [2014]

[2] 'ISO 4210:2015'
Available:
http://www.iso.org/iso/iso_catalogue/catalogue_ics/catalogue_ics_browse.htm?ICS1=43&ICS2=150. [2015]

[3] 'Subcommittee F08.10 on Bicycles'
Available: *http://www.astm.org/COMMIT/SUBCOMMIT/F0810.htm*.[2016]

[4] 'CAN/CSA-C22.2 NO. 60335-1:11'
Available: http://shop.csa.ca/en/canada/appliances/cancsa-c222-no-60335-111/invt/27023152011. [2016]

[5] **'**ISO/TC 22/SC 3 Electrical and electronic equipment'
Available:**http://www.iso.org/iso/standards_development/technical_committees/other_bodies/iso_technical_committee.htm?commid=46752.** [2016]

[6] 'NEMA Publishes ANSI-Approved MG 1 Motors and Generators'
Available: **http://www.nema.org/news/Pages/NEMA-Publishes-ANSI-Approved-MG-1-2011-Motors-and-Generators.aspx.** [2016]

[7] MCU
Available: http://www.instructables.com/id/Use-your-android-phone-sensors-on-the-arduino-/. [2016]
[8] M/G
Available: http://www.leafmotor.com/blog/tag/motor-controller/. [2016]

[9] Pedaling

Available: http://adventure.howstuffworks.com/outdoor-activities/triathlons/training/pedaling-technique3.htm. [2016]

[10] Inferred Sensor
Available: https://www.elprocus.com/infrared-ir-sensor-circuit-and-working/. [2016]
[11] Throttle
Available: http://www.aliexpress.com/item/Free-Shipping-High-Quality-Wuxing-Brand-Electric-Bicycle-Thumb-Throttle-Ebike-Speed-Hande-Bar/575461203.html. [2016]

[12] recycle-steel
Available: http://www.recycle-steel.org/ [2013]
[13] Alberta recycling
Available: http://www.albertarecycling.ca/tire-recycling-program[2013]
[14] Recycling & Recovery
Available: http://www.plasticseurope.org/what-is-plastic/recycling-recovery.aspx[2015]
[15] Recycling of Copper
Available: http://www.copper.org/environment/lifecycle/ukrecyc.html[2016]
[16] Battery Disposal Guide for Households
Available: http://www.ehso.com/ehshome/batteries.php#BatteryFacts. [2015]
[17] Recycling permanent magnets in one go
Available: http://phys.org/news/2015-09-recycling-permanent-magnets.html[2013]
[18] Printed Circuit Board Recycling Methods
Available: http://www.epa.gov/sites/production/files/2014-05/documents/handout-10-circuitboards.pdf [2015]

[19] 'LEAD ACID BATTERY working – LIFETIME STUDY'

Available: **http://www.power-thru.com/documents/The%20Truth%20About%20Batteries%20-%20POWERTHRU%20White%20Paper.pdf** [2015]

[20] 'Investigation of the Effectiveness of Regenerative Braking for EV and HEV'
Available: http://papers.sae.org/1999-01-2910/ [2015]

[21] '36 VOLT CHARGER TUTORIAL'
Available: http://www.chargingchargers.com/tutorials/36-volt-charger.html [2016]