July 25, 2021
Dr Craig Scratchley
School of Engineering Science
Simon Fraser University
Burnaby, BC
V5A 1S6

Re: ENSC 405W Proposal for Sort-e

Dear Dr., Scratchley,

This document outlines the proposal for Sort-e, a revolutionary automated waste sorting system for effective and efficient sorting. Using artificial intelligence, Sort-e will identify and transfer waste material to their designated waste bin. The Sort-e may be adjusted to attach to existing waste bins to benefit the environment and to encourage sustainable practices.

This document will provide an overview of the scope and purpose of the project, highlighting the risks and benefits, and risk management. The document will explore the current market and competition. An estimated budget and timeline for the project will be provided in the Proof-of-Concept to the final prototype.

Our team consists of four senior SFU engineering students who strive for environmental sustainability: ChinHo Wan, DongYue Shi, TianXiao Liu, and ChenXi Wang. Our diverse skill set allows for our confidence in the success of Sort-e.

BGreen would like to thank you for reviewing our proposal document. If you may have any questions or concerns, please do not hesitate to contact our Chief Communications Officer, DongYue Shi, via email at dongyues@sfu.ca.

Sincerely,

ChinHo Wan
CEO
BGreen Inc.

Proposal

Sort-e

Team Members	ChinHo Wan	CEO
	ChenXi Wang	CTO
	TianXiao Liu	COO
	DongYue Shi	CCO
Submitted to	Dr. Craig Scratchley	ENSC 405W
	Dr. Andrew Rawicz	ENSC 440
	School of Engineering Science Simon Fraser University	
Contact	DongYue Shi dongyues@sfu.ca	
Issue Date	July 25th, 2021	

Executive Summary

Global climate change is a contentious environmental issue. With recent observable effects of global climate change on the environment such as wildfires, drought, heatwaves, and storms, climate change is evident. The range of evidence published indicates that damages of climate change will be likely to increase over time [1].

Managing the amount of waste incinerated and disposed in landfills and to renew materials protects the environment and the health of the population. Recycling materials is the best option if waste cannot be prevented. Implementing waste management strategies such as waste sorting systems, reduces the amount of waste sent to landfill, moving towards a sustainable future. Canada has multiple waste management programs across the nation; however, emphasis on waste literacy supports advocacy and change for recycling intentions [2].

To support and move towards a sustainable future, BGreen is developing our prototype, the Sort-e, an add-on accessory that may be adjusted to fit current existing waste bins to encourage and promote sustainable practices. This device is intended to be used in schools and public areas where users may require assistance in sorting waste material effectively and efficiently. The Sort-e machine uses artificial intelligence technology to identify and transfer waste material to their designated waste bins.

The Sort-e machine is composed of the following three subsystems: the controller and the input/output (I/O), used for image processing; the camera, to capture images as input; the mechanical component, to dispose of waste which includes a frame for waste bin attachment.

In 2019, the global green technology and sustainability market size is valued at $8.79 billion and is projected to reach $48.26 billion by 2027 with a compound annual growth rate of 24.3% from 2020 to 2027 [3]. The rising awareness of the detrimental effects of greenhouse gas emissions on the environment drives the global green technology and sustainability market.

Sort-e provides a solution in mitigating the adverse effects of global climate change by reducing municipal solid waste and providing waste literacy. BGreen will continue to make improvements to Sort-e throughout the duration of this project, and advocate towards a sustainable future.

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1 Introduction

As global climate change accelerates, measures of waste management and waste reduction must be in place to mitigate the adverse effects. According to the Fourth National Climate Assessment (NCA4), the global annual average air temperature has increased by 1.0°C from 1901-2016 [4]. The last few years have been the warmest years on record for the globe, where records of climate-related extreme weather have been broken. Landfill gas comprises approximately 50% methane gas and 50% carbon dioxide gas [5]. Methane gas is 25 times more potent than carbon dioxide, trapping heat in the atmosphere for over a 100-year period [6]. Emissions from landfills in Canada account for 20% of the national methane emissions [6]. To control pollution and address the oversaturated landfills, waste management and diversion efforts must be considered [7]. Sustainable practices in waste management aims to minimize the amount of waste incinerated and disposed of in landfills and to renew materials. To protect our environment, waste management and waste literacy is important as it involves processing, recycling and disposing of waste material. In Canada, there are garbage and waste bin systems implemented to encourage recycling waste materials; however, only 9% of recycling materials are actually recycled [8]. As waste management practices differ from country to country, public areas such as airports and schools, new immigrants, tourists and students may incorrectly classify waste. When recycling is done incorrectly, more harm is being done than good. Placing items that do not belong in the recycling may contaminate the entire bin, which may result in contamination of the entire load of recyclable materials. If waste classification is implemented, many components of waste may be reused as renewable raw materials, enhancing the national economic capacity [9].

BGreen is introducing the Sort-e, a waste sorting device designed to educate and to promote a sustainable future. Sort-e is designed for public areas such as malls, airports and schools, targeting the public. To develop and maintain successful recycling, recovery and reprocessing waste materials, public education is crucial. The Sort-e provides education to users with the benefit of keeping materials out of the landfill. Sort-e's powerful image recognition and mechanical devices gives users a touch-free experience when disposing and classifying waste materials.

BGreen advocates for a sustainable future by addressing contamination of recyclable materials and increasing waste literacy. Sort-e aims to educate users, emphasizing on newcomers and students regarding waste classification and promoting recycling education. By recycling and renewing materials, energy consumption is reduced, pollution of air and water is reduced, waste is kept out of the landfills, and natural resources can be conserved. Sort-e fosters sustainable and positive behavior changes towards building a zero-waste future.

This document details Sort-e's proposal, including background, high-level overview of equipment, scope, risks and benefits, and analysis of current marketing trends. Financial management will also be discussed, detailing costs and funding sources. The proposal will end with a Gantt chart, which details the timeline of the project.

2 Project Overview

2.1 Background

Artificial intelligence (AI) has become increasing integrated into our daily lives and is used for image processing. Improvement in AI allows technology to perform image recognition and deep learning [10]. Advancements in AI enables a shorter processing time, with high accuracy. In 1997, AI beat the best human chess player, and in 2017, beat the best human Go player [10]. This demonstrates that AI is a powerful tool suitable to use for image classification of waste materials. AI's accuracy addresses issue of contamination of recyclables. Contamination may result in contamination of the entire load of recyclable materials, directing more waste to the landfill. Minimizing contamination in recycling materials improves the recycling process by ensuring that it is effective; hence, conserving natural resources. Sort-e can increase waste literacy by classifying the type of waste material, promoting proper waste disposal. Sort-e is not only a waste sorting device – it is an educational tool to inspire future generations.

2.2 Scope

The scope of Sort-e details the design, assembly and testing of the prototype. The prototype will be able to collect and process real-time and historical data for the following reasons:

- Capturing images of waste products continuously
- Continuous analysis and train AI models from images in the dataset
- Extract feature values from unsortable waste effectively
- Retain processed image data for future reference

Sort-e will be able to do so in an efficient and accurate manner because of the following features:

- Accelerated linear algebra may accelerate the TensorFlow models without changing the source code
- Latency is reduced by decreasing the size of the model
- Use quantization-aware training as the quantization model

2.3 System Overview

The hardware design of Sort-e will use motors to control the mechanical part for waste disposal, directing waste material to their designated bins. The design of the hardware focuses on the torsion calculation from Newtonian mechanic's formula. In terms of software, Sort-e will use TensorFlow's mechanical learning platform for artificial intelligence (AI) training. The AI models allow for analysis and classification of waste materials. Figure 2.3.1 shows the system overview of Sort-e.

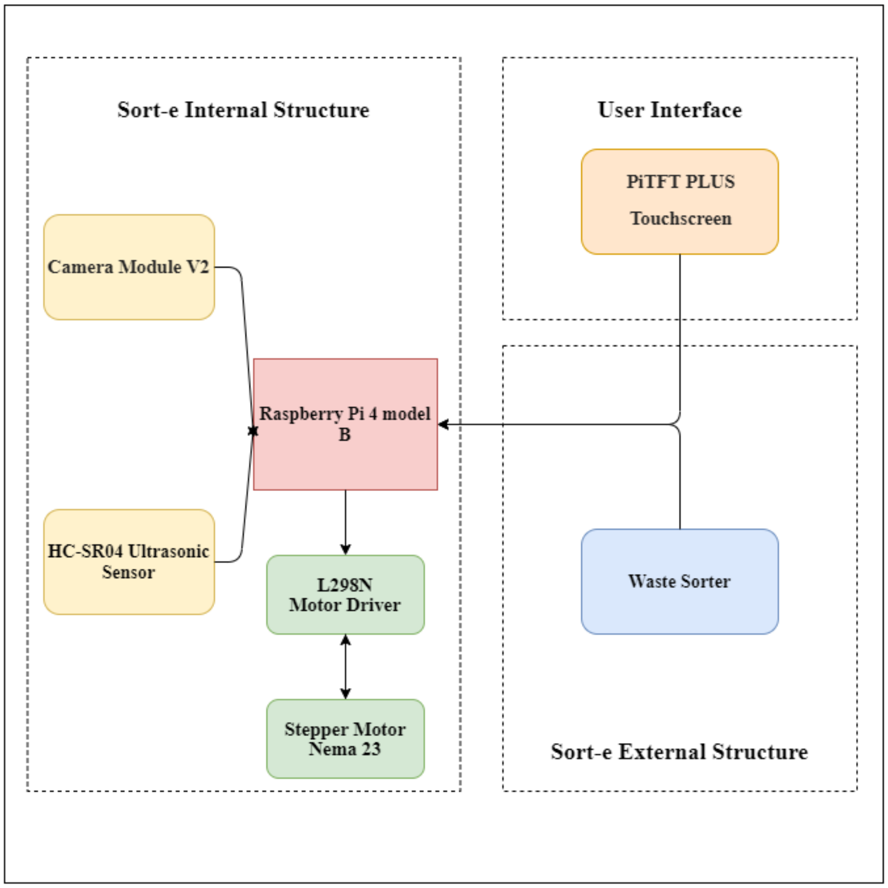

Figure 2.1: Sort-e Overview

2.3.1 Hardware Components

The hardware component in Sort-e is used to collect data and display feedback for users. The Raspberry Pi 4 Model B (Figure 2.2) will act as the microcontroller to control the whole system. The camera module (Figure 2.3) will capture images of waste material for image analysis. The motor driver (Figure 2.4) will be used for power management, to power the stepper motor to perform the following actions: the cover opening system, waste disposal system, and gate operation. The ultrasonic sensors (Figure 2.5) collect data to determine the distance between objects. This data will be used for the bins monitoring system and the cover opening system. To provide feedback for users, the LCD monitor (Figure 2.6) will display related information and system status.

Figure 2.2: Raspberry Pi 4 Model B [11]

Figure 2.3: Camera Module V2 [12]

Figure 2.4: L298N Motor Driver [13]

Figure 2.5: HC-SR04 Ultrasonic Sensors [14]

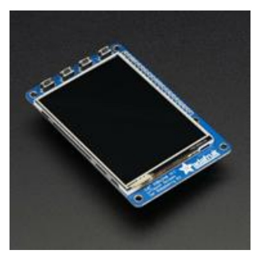

Figure 2.6: LCD Monitor [15]

2.3.2 Software Components

The software system processes waste images taken from the camera. Images will undergo the AI model, trained by an imported waste image dataset. The dataset contains five waste classes: compost, metal, glass, plastic, landfill. Upon waste classification, the software will signal the motor driver to control waste delivery according to the prediction.

To train the AI models for waste classification, the convolutional neural network (CNN) will be implemented (Figure 2.7). This process involves convolutions, allowing extraction of features from images (Figure 2.8).

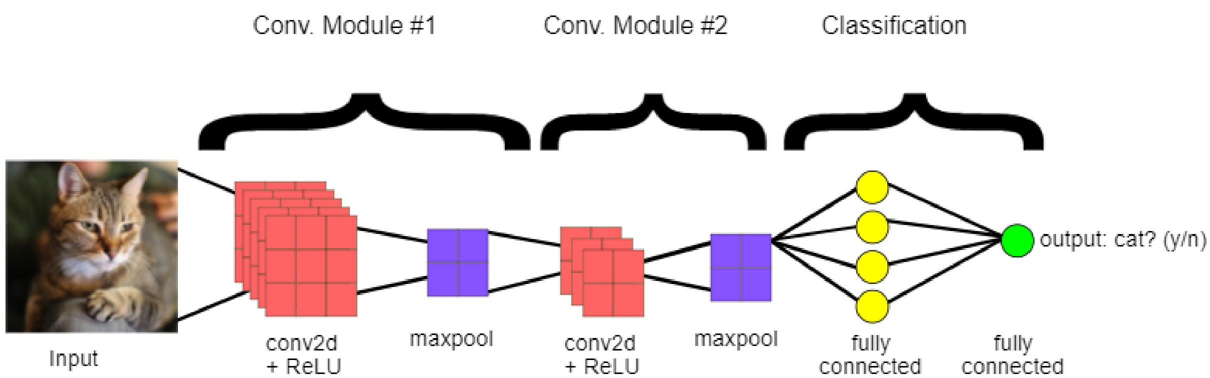

Figure 2.7: End-to-end Structure of a Convolutional Neural Network (CNN) [16]

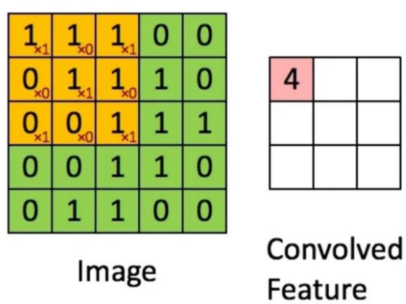

Figure 2.8: Illustration of Convolution [17]

2.3.3 Application

The proof-of-concept prototype consists of a main controller and a scanning area. The main controller is Raspberry Pi which is responsible for image processing and data communication between electronic components. The AI models will be built on the TensorFlow Lite platform. TensorFlow Lite optimizes execution for embedded devices such as Raspberry Pi. The scanning area contains a camera module, ultrasonic sensors, and a cover opening mechanism. The camera module and ultrasonic sensor is controlled by Raspberry Pi, but the cover opening mechanism will be operated by the motors which are connected to motor drivers. Figure 2.9 shows the scheme for the final functional prototype.

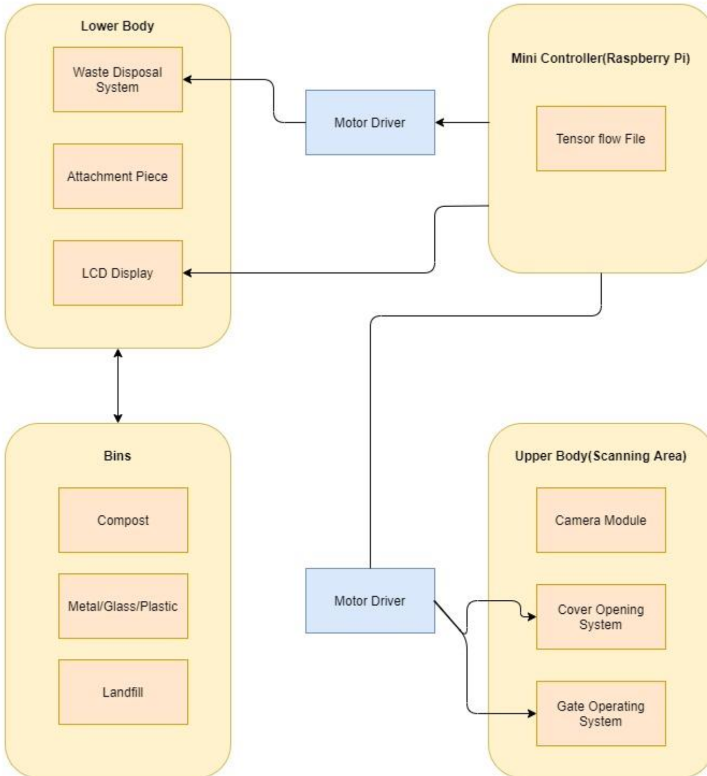

Figure 2.9: Overview of Sort-e Functional Prototype

2.4 Risk

Based on tests conducted by BGreen using TensorFlow, results of waste classification may be inaccurate. For instance, a crumpled can may be identified as compost. To minimize the risk of contamination, our team will compare predicted percentages between each class and select its best match. If the percentage does not meet the minimum requirement, the waste will be placed in the landfill bin.

Overfitting is a common problem that will obscure the model accuracy. The model may take noises or unwanted details from the sample images. Data augmentation method will make a difference when a large amount of dataset is not imported. Data augmentation is a technique that generates additional training data from existing examples by augmenting them with a random rotational transformation. This allows the model to learn from more aspects of the data. Figures 2.10 and 2.11 compare the accuracy of the AI model with data augmentation.

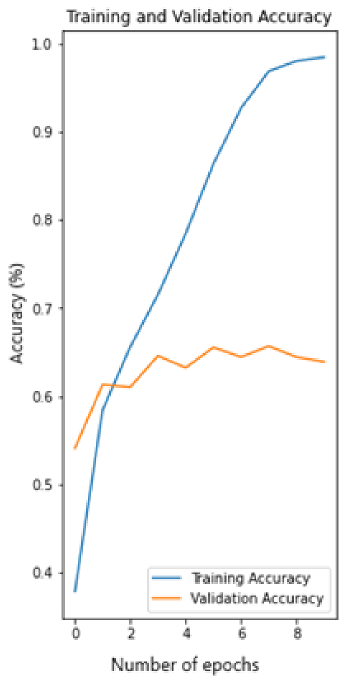

Figure 2.10: Accuracy without Data Augmentation [18]

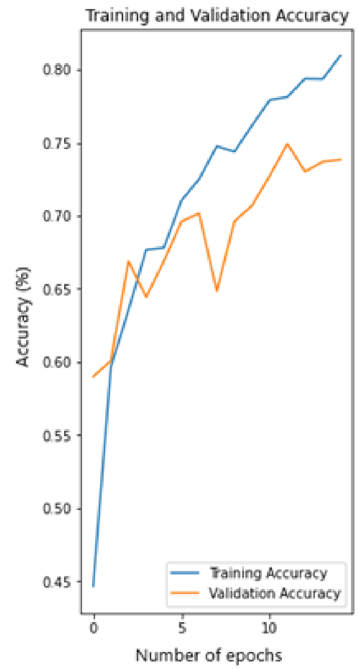

Figure 2.11: Accuracy with Data Augmentation [18]

Packaging of international products may differ, resulting in a higher chance of failure to identify the waste material. BGreen will implement different datasets for countries and regions to minimize the risk of inaccurate classifications.

To operate Sort-e, the motors within the system may require a high torque. Due to this circumstance, the current and voltage must be large, which may potentially overheat the circuit, leading to system failure. A motor driver with better power management and prevention of the reverse current is required for this device.

2.5 Benefits

The Sort-e aims to educate users, emphasizing on newcomers and students regarding waste classification and promoting recycling education. Sort-e fosters sustainable and positive behavior changes towards building a zero-waste future. BGreen indicates a series of benefits of Sort-e to provide justification for its production.

Stakeholders

The Sort-e is made from affordable materials (wood and acrylic plastic) which significantly reduces the cost of manufacturing the device. As a sustainability advocate, BGreen aims to make Sort-e accessible and affordable to the general public.

Schools

Poor waste management contributes to economic inefficiencies and environmental pollution. Increasing waste literacy in the classroom empowers students to impact and inspire others as well as to develop positive environmental habits. Sort-e's role in the school system is to provide inquiry-based learning by emphasizing curiosity, observations, and ideas. By making observations and being curious about the device, students are encouraged to discuss the positive impacts of recycling materials. Introducing Sort-e in the school system allows students to bring their knowledge into their own home and community to build a zero-waste future. Sort-e will serve as a functional device to foster independence especially for younger students that may be new to the recycling system, and those with learning differences. To avoid confusion, Sort-e can classify their waste item for them. The classification of the waste material will be displayed on an LCD screen for future reference. Whether or not students require future assistance, Sort-e will be an option to support waste classification. In implementing Sort-e in the schools, waste literacy among students will increase. BGreen hopes to inspire future sustainable projects, awareness and discussions for a sustainable future.

Environment

A step to minimize the adverse effects of climate change is for proper waste management. Using Sort-e encourages recycling waste materials such as plastics, bottles and metals. When less waste is created, the environment thrives. Recycling reduces carbon emissions by reducing methane releasing waste in the landfill. By decreasing greenhouse gases and carbon dioxide in the atmosphere, adverse effects of climate change may be reduced.

Tourists

As countries have different methods of waste management, Sort-e will be able to assist users who are not familiar with the waste management system in place. Categories of waste products may be grouped differently from country to country, so with the help of Sort-e tourists and new immigrants are able to become familiar with the waste management system in place.

Government

To reduce pollution and waste, the government of Canada works with all levels of government, industry, non-government organizations and Canadians to take action on pollution and plastic waste. BGreen's vision aligns with the government of Canada's values. Together, we may strengthen the economy and protect our environment.

Recycling Industry

One contaminated item may lead to multiple bins of recyclable materials to end up in the landfill. When a certain percentage of recyclable material is contaminated, the entire batch is considered not usable. With Sort-e, image classification is used to accurately categorize waste materials to minimize contamination of recyclable materials. Addressing contamination of recyclable materials moves the world closer towards a zero-waste future.

General Public

Sort-e's user-friendly interface creates an effortless experience for all users. Sort-e also provides a touch-free experience, potentially attracting more attention. The classification of the waste material will be displayed on an LCD screen for users to learn and apply for future encounters.

3 Market Analysis

Sort-e is a waste sorting system device for effective and efficient sorting of waste materials into the following categories: compost, metal, glass, plastic, and landfill. The Sort-e is targeted towards newcomers and students regarding waste classification and promoting recycling education.

3.1 Potential Markets

By 2027, the global green technology and sustainability market is expected to reach $48.36 billion, with a compound annual growth rate (CAGR) of 24.3% [19]. Green technology is intended to mitigate effects of human activities on the environment which include eco-friendly solutions to achieve social and economic sustainability. The goal of green technology is to protect and restore the environment. Governments across the world are heavily investing into green technology to conserve natural resources and to minimize the adverse impacts on the environment [19]. The increase in environmental awareness along with increased concerns among individuals and organizations brings growth of the market. Government and private sectors have taken initiative to address global climate change and air pollution make green technology a favourable and opportunistic factor for market growth [19]. Increased awareness of these solutions by the public and government agencies, as well as a surge in demand for the development of waste-to-energy solutions, is expected to provide market participants with profitable growth opportunities. Revenue from environmental and clean technology exports in Canada from 2015 to 2019 is displayed in Figure 3.1.

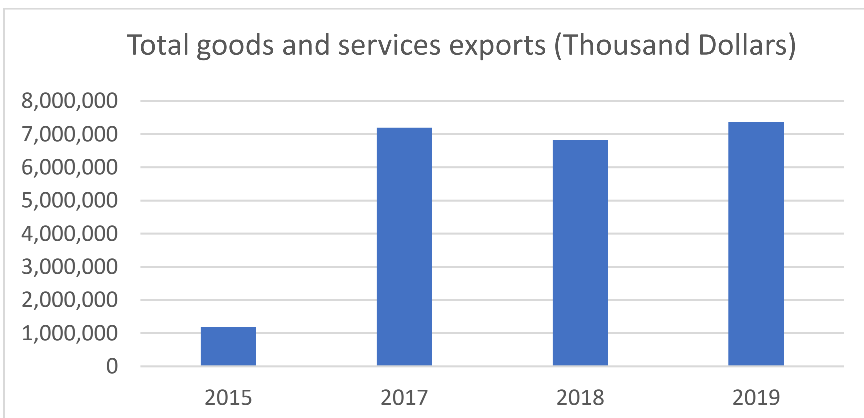

Figure 3.1: Revenues from Environmental and Clean Technology Exports (Canada) [20]

The global waste management market in 2019 was valued at US$2,080.0 billion USD and is expected to reach US$2,339.8 billion by 2027 [21], with a CAGR of 5.5% from 2020 to 2027 (Figure 3.2) [21]. The growth of the global market is driven by active government measures to reduce illegal dumping. In addition, the rapid population growth and globalization have resulted in an increase of total waste produced. The urban population generated approximately 1.3 billion tons of municipal solid waste (MSW) in 2012, which is expected to increase to 2.2 billion tons by 2025 [22].

Figure 3.2: Global Waste Management Market Forecast [21]

In 2019, the global smart waste management was valued at US $1.5 billion, and expected to reach US $9.53 billion by 2027, at a CAGR of 26% from 2020 to 2027 [23]. With the rise in volume of waste created (Figure 3.3), logistical concerns of waste collection must be met by environmental authorities and the government to seek better waste management solutions. Smart waste management is suitable for both urban and rural areas as incorrect methods of waste disposal pose environment hazards and health concerns.

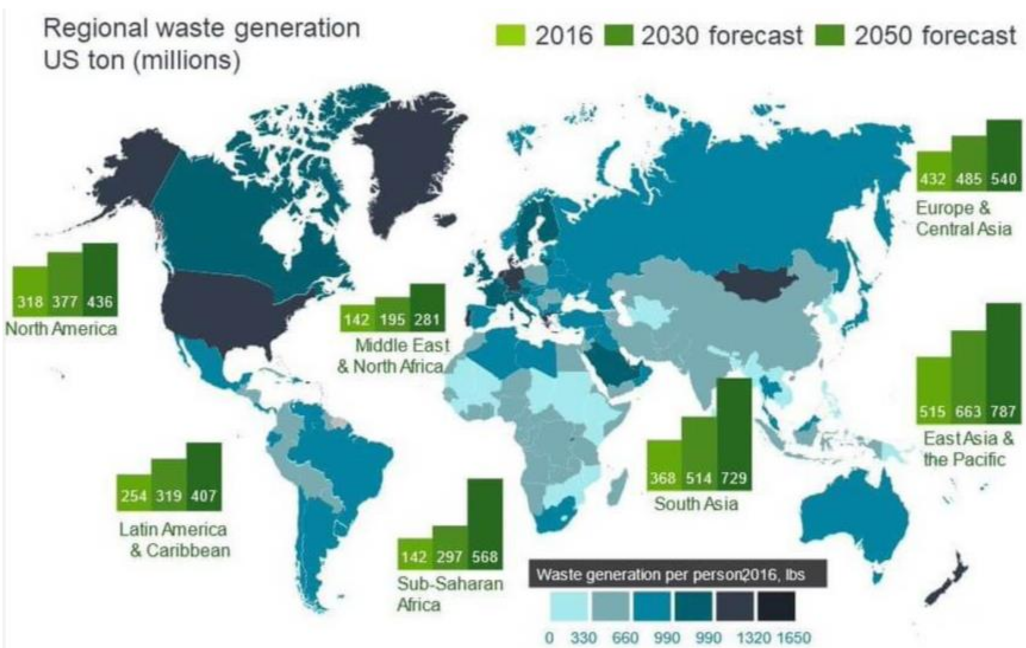

Figure 3.3: Regional Waste Generation [24]

3.2 Competition

There are waste sorting systems in place globally. However, these waste sorting systems require manual sorting of waste material. Manual sorting of waste material poses a risk of contamination as when an item is placed into the incorrect bin, the entire batch may be deemed unusable. This results in more waste material to be sent to the landfill than intended. Many waste bins have examples of images of items that belong in each bin. That being said, users may be flustered when they are not familiar with the composition of the material, which leads to confusion as to which bin it belongs in.

The Sort-e is an automated waste sorting system for users to make waste sorting more effective and efficient. Using image classification with artificial intelligence, Sort-e is able to identify the category of waste material, and transfer the waste item into its corresponding bin. Compared with manual sorting, Sort-e allows more accuracy in identifying waste material and minimizes contamination of recyclable items. Since Sort-e is an add-on accessory item, it is not necessary to purchase an entire new bin system. Sort-e is created to accommodate diverse needs, while minimizing the generation of waste. Sort-e also offers a touch-free experience for users to avoid touching potential unsanitary waste covers, further encouraging eco-friendly habits.

Figure 3.4: Product of Intuitive AI - Oscar Sort [25]

The Oscar Sort by Intuitive is a device that has many similarities in function as the Sort-e. Like Sort-e, Oscar Sort also aims for a zero-waste future. One advantage of the Oscar Sort is the user interface. The Oscar Sort features a large, attractive LCD monitor which users may find more compelled to use. This advantage becomes a disadvantage as the estimated overall cost of production is higher than Sort-e. In addition, the LCD monitor of the Oscar Sort may not be suitable for outdoor environments, while Sort-e is. Like Sort-e, the Oscar Sort eliminates manual sorting. That being said, when using the Oscar Sort, users still need to manually dispose of their waste, which poses a risk of contamination. Both the Oscar Sort and Sort-e are educational and provide solutions in addressing the environmental crisis. In terms of accessibility and inclusion, Sort-e is more accessible and more inclusive than the Oscar Sort. BGreen's value is to create an accessible and inclusive environment while fostering a sustainable future. Sort-e is an add-on accessory, so the production of the device is estimated to be much lower than the Oscar Sort. This makes Sort-e much more accessible, especially for areas that need the assistance and guidance in sorting waste material. BGreen advocates for those who have learning difficulties, and those who experience visual and hearing impairments by creating a device that assists individuals in sorting waste, increasing their autonomy and confidence. Sort-e creates an inclusive space, building a strong sense of community and environmental awareness.

4 Cost Considerations

4.1 Estimated Cost

The tables below display the breakdown cost of each of the required components for proof-of concept prototype and final functional prototype. All prices are listed in the Canadian Dollar.

Table 4.1: Proof of Concept Prototype Estimated Cost

Components	Description	Subtotal ($)
Raspberry Pi 4 Model B	Main processor and controller	90
Stepper Motors	Nema17 stepper motor (x2) for cover operation and gate operation	23
Ultrasonic sensors	HC-SR04 ultrasonic sensor (x3) for scanning area	10
Motor driver	L298N Dual H Bridge Stepper Motor Driver (x2) for motor power management	17
Camera module	Camera module for Raspberry Pi	25
Power Supply	12V DC Power Supply (x1)	25
Materials	Wood and plastic material for Proof-of-Concept	50
Others	Tools and parts	120
Total	-	360

Table 4.2: Functional Prototype Estimated Cost

Components	Description	Subtotal ($)
LCD Display	7-inch 1024 x 600 HDMI Screen LCD Display for Raspberry Pi	70
Ultrasonic sensors	HC-SR04 ultrasonic sensor (x3) for bin monitoring system	10
Stepper Motors	Nema23 stepper motors (x2) for flaps operation	55
Materials	Wood, plastic, stainless steel material for prototype	80
Others	Parts and paint	50
Total	-	265

4.2 Funding

Development expenses of Sort-e will be funded by two sources of funding:

1. Engineering Science Student Endowment Fund (ESSEF), also known as the Engineering Science Undergraduate Student Project Award managed by Simon Fraser University's Engineering Science Student Society. The funding consists of four categories, our team is eligible for Category B (Entrepreneurial) and Category C (Class).

2. The Wighton Development Fund is awarded by Dr. Andrew Rawicz for projects that satisfy Wighton's requirement of practicality. BGreen will submit our project proposal to apply for the Wighton Development Fund.

3. Our team of four has agreed to self-fund the remaining expenses to cover the funding of the development of Sort-e. The funding from our team members will be equally distributed.

5 Project Planning

Figures 5.1-5.4 shows the Gantt Charts for Sort-e's development timeline throughout ENSC 405W and ENSC 440. Figures 5.1-5.3 outline events occurring in Semester 1 (ENSC 405W) for the proof-of-concept prototype, Figure 5.4 outline tasks to be completed for Semester 2 (ENSC 440) for the functional prototype. The name for each major event indicates the tasks to be completed.

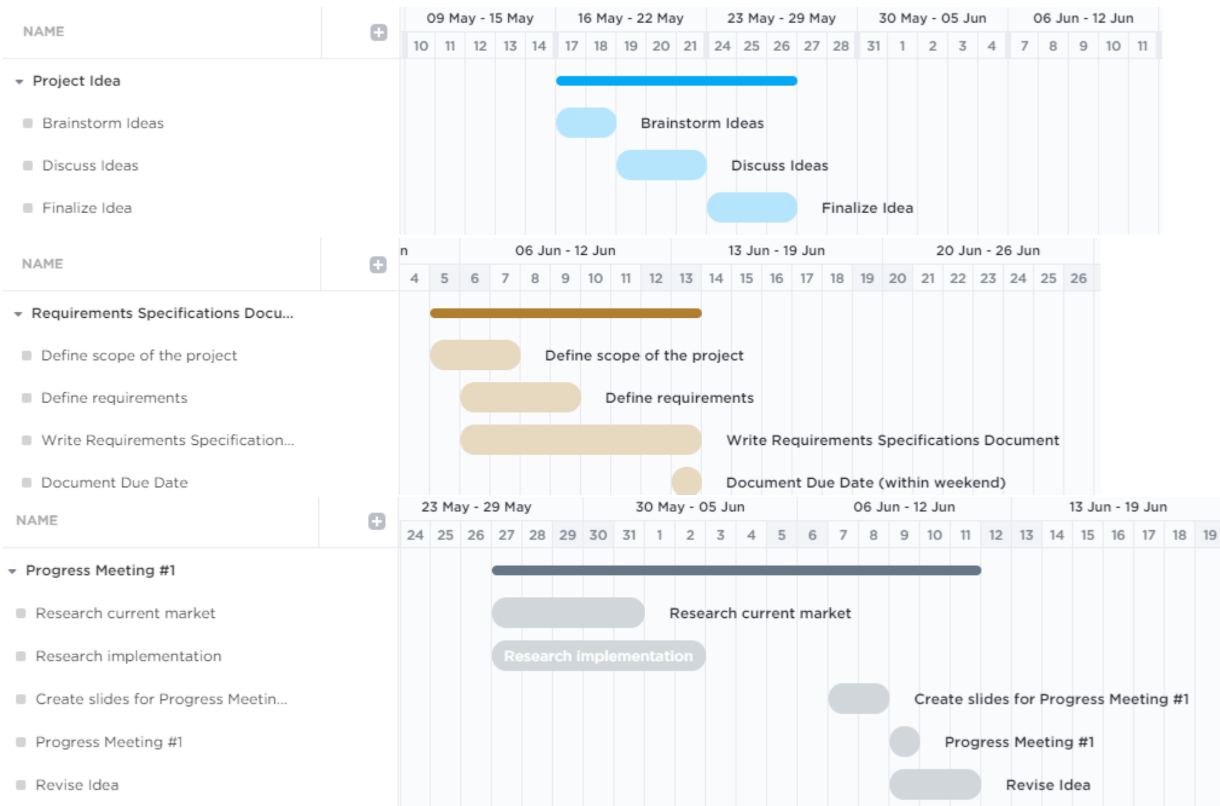

Figure 5.1: Gantt Chart for Semester 1 of Sort-e (Part 1)

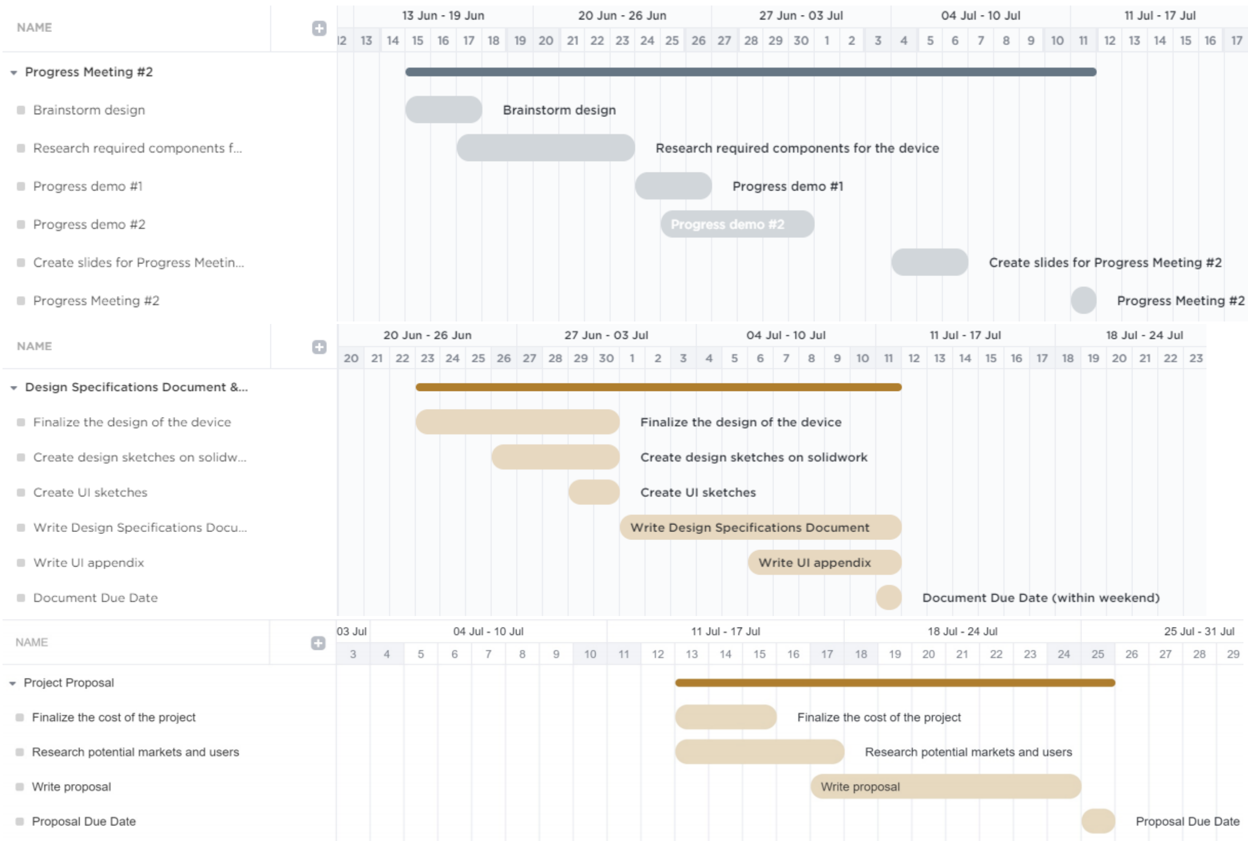

Figure 5.2: Gantt Chart for Semester 1 of Sort-e (Part 2)

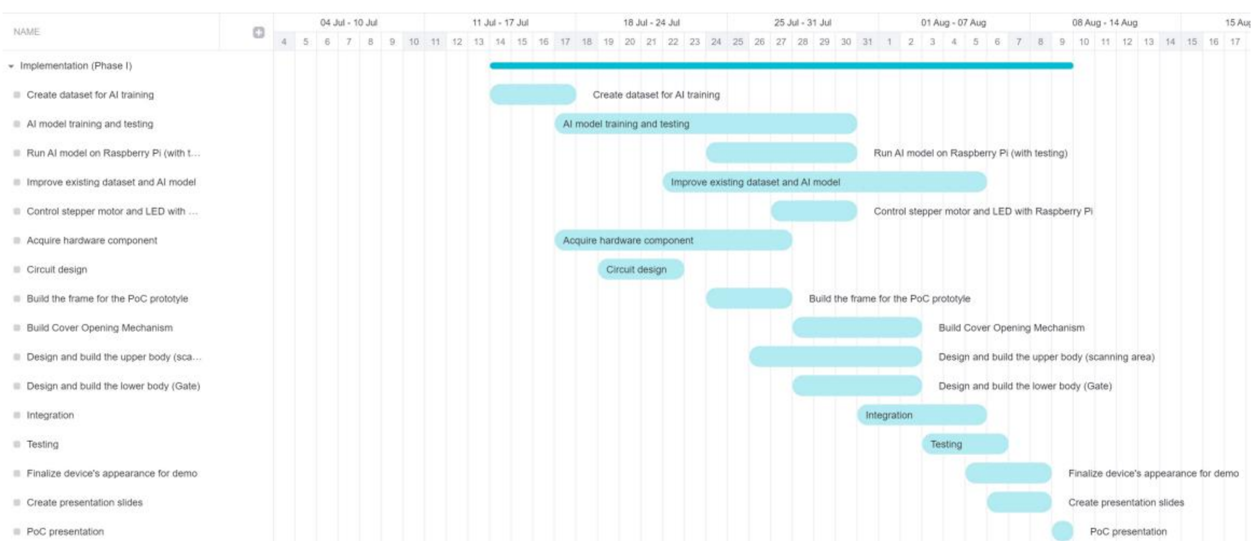

Figure 5.3: Gantt Chart for Semester 1 of Sort-e (Part 3)

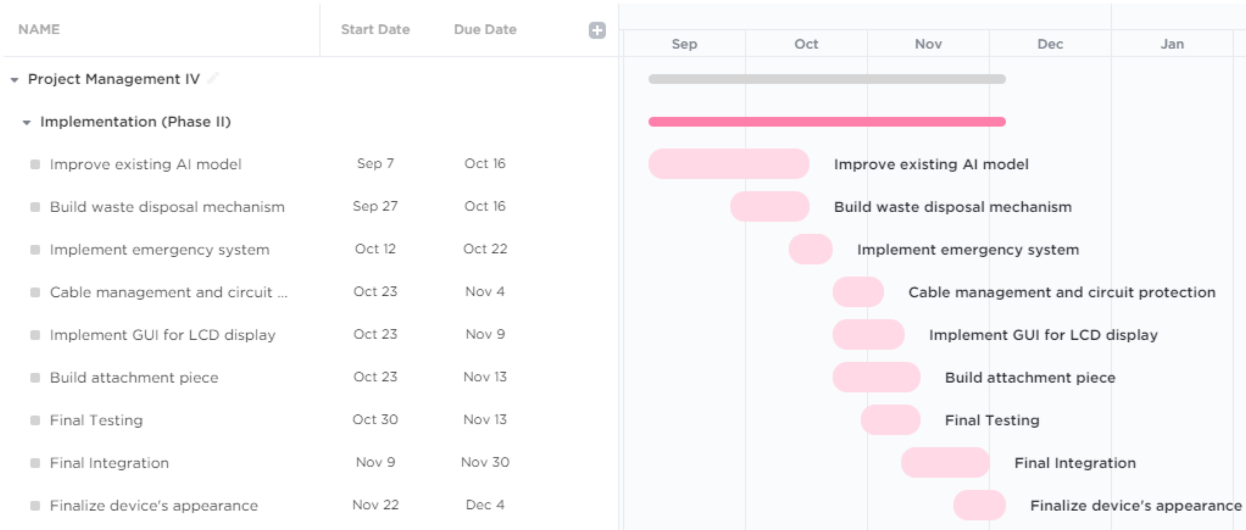

Figure 5.4: Gantt Chart for Semester 2 of Sort-e

6 Company Details

6.1 ChinHo Wan – CEO (Chief Executive Officer)

ChinHo is a fifth-year Computer Engineering student with a passion for robotics and artificial intelligence (AI). ChinHo has completed his co-op as a software developer at Change Healthcare (formerly Mckesson). At the facility, he specialized in developing internal tools for the team, identifying and fixing software defects. ChinHo has also taken part in the research team for pneumonia detection using AI. With ChinHo's research and practical experiences, ChinHo is suitable to be leading the planning and implementation process of BGreen.

6.2 ChenXi Wang – CTO (Chief Technical Officer)

Charlie is a fifth-year Computer Engineering student. He has work experience as a web developer with front-end and back-end experience. He is interested in machine learning and embedded systems. Charlie will apply his interests and knowledge to the Sort-e to ensure image classification and on-board system works as expected.

6.3 TianXiao Liu – COO (Chief Operating Officer)

TianXiao is a fifth-year Computer Engineering student with interest in embedded system development and mechanical design. TianXiao has completed his co-op as an embedded engineer at Star Solutions International Inc and as a software system engineer at Hisense Group Co., Ltd. He focused on base station development and driver development under the Linux system environment of TV. TianXiao participated in the product's hardware design. TianXiao's work experience allows him to engage in the hardware part design and circuit design related parts of the product.

6.4 DongYue Shi – CCO (Chief Communications Officer)

DongYue is a fifth-year Computer Engineering student. DongYue has co-op experience in software development including AI learning and system building. His main job is to build the application with the team by using AI learning tools. In the BGreen, he will focus on managing the IT plans and managing the IT resources. DongYue will lead the team in the field of software in BGreen.

7 Conclusion

BGreen strives to protect our ecosystem, preserve natural resources for future generations, and improve the quality of life. BGreen achieves this by addressing the oversaturated solid municipal wastes in the landfill and providing waste literacy to the general public through the Sort-e device. Sort-e is an add-on accessory, automated waste sorting system for users to make waste sorting more effective and efficient. This device accurately identifies and sorts waste materials. With Sort-e, users are able minimize contamination of recyclable materials, creating a sustainable future. Sort-e's powerful image recognition and mechanical devices brings users a seamless, touch-free experience. Introducing this accessible and inclusive device will foster environmentally friendly decisions and support recycling intentions.

This document has outlined the Sort-e device which included a background and introduction detailing of the relevancy and significance of the device. Current market trends for global green technology and sustainability have been evaluated and show rapid increase in growth due to current global climate change. The cost analysis of the device indicates that Sort-e is a low-cost device to develop.

Engineers of BGreen hope to spread awareness of the current global climate crisis and to support environmentally friendly decisions. With Sort-e, BGreen aims to redefine waste.

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