June 13, 2021
Dr Craig Scratchley
School of Engineering Science
Simon Fraser University
Burnaby, BC
V5A 1S6

Re: ENSC 405W/440 Design Specification for Sort-e

Dear Dr., Scratchley,

This document describes design specifications for an add-on accessory, automated waste sorting system for users to make waste sorting more effective and efficient, as outlined in the Project Proposal and Requirement Specification. Our goal is to create an accessible, sustainable system that uses artificial intelligence for image processing to identify and transfer waste material to the designated waste bins. Our automated waste sorting system is adjustable and may be attached to existing waste bins to encourage sustainable practices to benefit the environment and to enhance the quality of life. This document outlines our design and specifications for both software and hardware systems.

Our team consists of 4 senior SFU engineering students who strive for environmental sustainability: ChinHo Wan, DongYue Shi, TianXiao Liu, and ChenXi Wang.

We thank you for taking the time in reviewing requirement specifications documents. 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.

BGreen

Requirement Specifications

Sort-e

Team Members	ChinHo Wan	CEO
	DongYue Shi	CCO
	TianXiao Liu	COO
	ChenXi Wang	CTO

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

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Abstract

This document describes design specifications for an add-on accessory, automated waste sorting system, Sort-e. First, the document will introduce the functionality of Sort-e, then will explain each aspect in a series of subsections. Details regarding how Sort-e meets the current engineering standards, sustainability, and safety factors will be stated. The document aims to provide a deeper understanding of the product including: the purpose, the operation, and the design details.

The Sort-e consists of three parts: the controller and the I/O, used for image processing; the camera, to capture images as input; and the mechanical component, to dispose of waste which includes a frame for waste bin attachment. A display will be installed on the product which provides feedback to the user regarding the status of the system as well as capacity status of the bins.

Requirements for Sort-e includes three main aspects: first, general requirements, which include the overall system and functional requirements; second, software requirements, which include general and performance; third, hardware requirements, which include general, power supply, mechanical requirements. The requirement specification document will end with discussing the acceptance test plan. The deliverable for the proof of concept will be demonstrated in August 2021.

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Glossary

Term	Definition
Artificial Intelligence	Artificial Intelligence (AI) refers to the simulation of human intelligence in machines that are programmed to think like humans and imitate their behavior.
CSA	Standards organization; Canadian Standard Association.
Microcontroller	Microcontroller is a small computer that used for automatically controlling in a device.
OpenCV	OpenCV (Open-Source Computer Vision Library) is a library of programming functions mainly aimed at real-time image and video.
Raspberry Pi 4	Raspberry Pi 4 a specific model of microcontroller.

1 Introduction

The Sort-e machine uses artificial intelligence technology to identify and transfer waste material to their designated waste bins. Sort-e is an add-on accessory that may be adjusted to fit over current existing waste bins to encourage and promote sustainable practices. This system allows users to sort waste materials effectively and efficiently, pursuing a zero-waste future.

The Sort-e machine is composed of three subsystems: the controller and the input/output (I/O), used for image processing; the camera, to capture images as input; and the mechanical component, to dispose of waste which includes a frame for waste bin attachment. Details regarding design specifications and design requirements for each subsystem will be discussed in this document.

1.1 Background

Waste management reduces the detrimental impact of waste on both our health and our environment. Zero Waste is a waste management strategy that addresses waste prevention through innovation and sustainable practices. One of the greatest challenges waste experts have yet to resolve is the high contamination of recyclable materials [1]. When a non-recyclable item is placed in a recycling bin, it is deemed contaminated and cannot be processed. One contaminated bin may lead to multiple bins to end up in the landfill. Canada's Zero Waste initiative aims to reduce and eliminate waste by reducing, reusing, recycling, recovering, and managing waste [2]. In 2018, British Columbians disposed of an average of 505kg of municipal solid waste per person, excluding reused and recycled waste [2].

Our company's goal is to advocate a sustainable future by addressing contamination of recyclable materials and increasing waste literacy. Taiwan is recognized for its higher recycling rate than many developing nations around the world. This is a result of their waste management and recycling education implemented in schools since the 1980s [3]. Sort-e aims to educate users, emphasizing newcomers and students on waste classification and promoting recycling education. Assisting users to classify their waste allows users to increase their waste literacy and to build their confidence. Sort-e fosters sustainable and positive behavior changes towards building a zero-waste future.

1.2 Scope

This document outlines the functional requirements of Sort-e to be met by our team at BGreen Inc. The general functional requirements of the product will be discussed. These requirements will be categorized by their phase of development: proof of concept, prototype, and finished product. Engineering standards and efforts regarding sustainability and safety will be outlined.

1.3 Requirement Classification

The following convention will be used to label the requirement in this document:

Req {Section}.{Subsection}.{Requirement Number} {Stage of Development}

The different phases of development are shown in the table below:

Table 1.3 - Development Phase Encoding

Encoding	Phase of Development	Deadline
C	Proof of Concept	End of ENSC 405W
P	Prototype	End of ENSC 440
F	Final Product	In production

2 System Overview

Waste classification is the process of dividing waste into different types of material. Waste sorting can be done manually at home then collected through roadside collection plans, automatically separated in material recycling facilities, or mechanical biological treatment systems. Annually, Canadians dispose 3 million tonnes of plastic waste, but only 9% is recycled, which allows approximately 29,000 tonnes to end up in our natural environment [4]. The Sort-e aims to promote waste literacy among society especially in schools for future generations to promote sustainability. Therefore, the main purpose of designing the overall system of Sort-e is to sort waste materials while increasing waste literacy efficiently and effectively. The specific classification method will be determined in accordance with waste management in Canada [5]. Our purpose is to provide an accessible, sustainable, and educational product that benefits both the environment and society.

Figure 2.1 and figure 2.2 show the 3D concept model of the Sort-e. The product shall be able to sort up to 3 different kinds of waste. The external structure of Sort-e should be divided into three parts: The upper structure integrated with the camera, the strobe lights, and a motion sensor which determines when the waste is approaching; The middle structure is the mechanical part for directing waste to their designated bin; The bottom structure is the attachment site that may be adjusted over commercial bins or over the bins that are paired with the product.

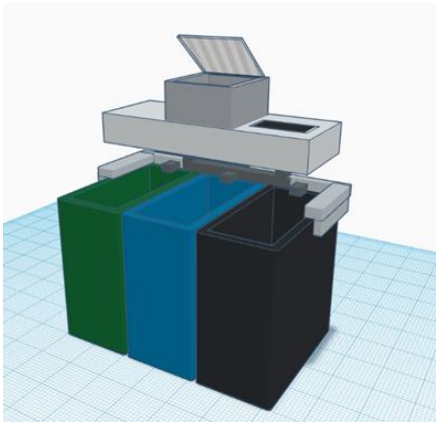

Figure 2.1 Sort-e Concept 3D Model

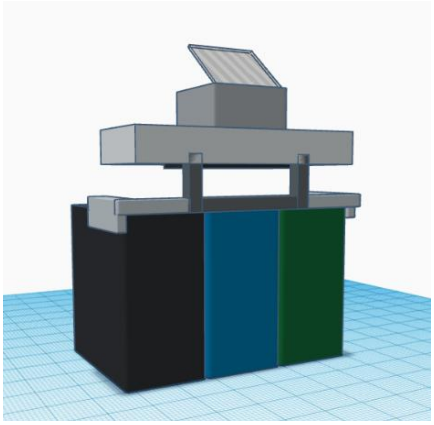

Figure 2.2 Sort-e Concept 3D Model (Back view)

Figure 2.3 explains the system structure of Sort-e, where the green blocks in the flowchart indicate the external components and the yellow blocks indicate the internal units. Sort-e uses a camera to perform image processing to determine the type of waste product. Prior to capturing the image, the motion sensor must detect the waste approaching. Once waste material is detected, the lid of the scanning area will open. The light sensing system is installed within the scanning area which turns on when the light source is insufficient. After the photo is taken, the internal system will determine whether it can be classified. If it can be classified, the waste will be directed to its designated bin. After the operation is completed, the system will notify the user, and all external devices will reset. The system will be on standby mode for the next waste identification.

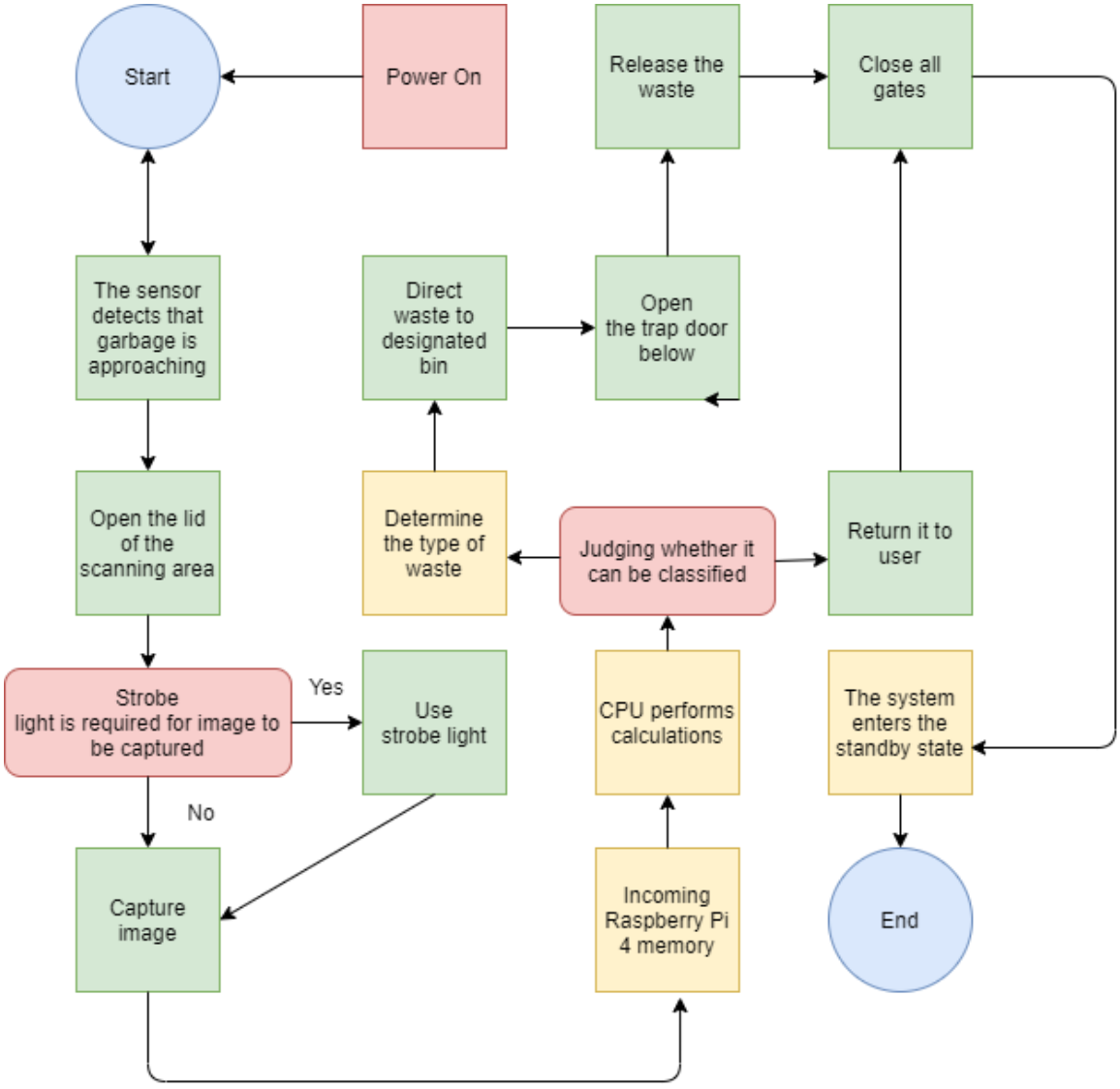

Figure 2.3 - Flowchart of Sort-e

Raspberry Pi 4 will be used as a control unit, integrate and control other components required for the waste specification process [6]. As a control unit, Raspberry Pi 4's main function is to analyze the image and decide whether it can be classified. After the conclusion is reached through calculation, it will issue the corresponding instructions to the other external facilities of the machine. All related data will be stored in Raspberry Pi 4's memory, and all algorithms will be operated by its CPU. As the figure 2.4 shows below.

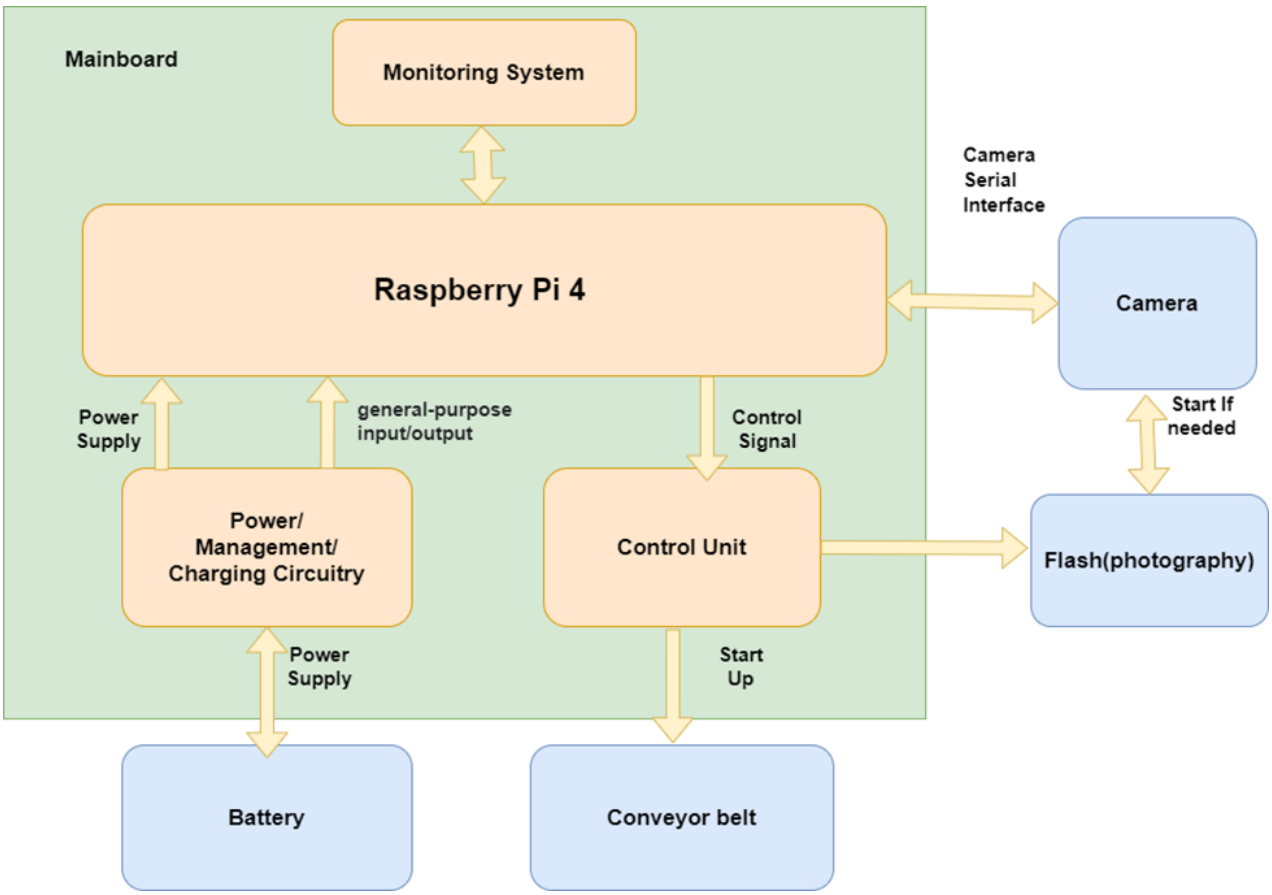

Figure 2.4 - Sort-e System Block Diagram

3 General requirements

This section specifics the general requirements for the product. The general requirement will be shown in two different categories: system requirement and functional requirement as shown below.

3.1 System Requirements

The following table shows the general requirements for the product.

Table 3.1 - System Requirements and Progress

Requirement ID	Requirement Description
Req 3.1.1 C	The system must have a designed scanning area for holding waste.
Req 3.1.2 C	LED light must be installed in the system as an operational indicator.
Req 3.1.3 P	The system must be able to distinguish the type of waste.
Req 3.1.4 P	The system must have a power button to turn the product on/off.
Req 3.1.5 P	The system shall consist of a microcontroller, camera, power supply, sensor, and mechanical part.
Req 3.1.6 P	The system must transport waste into their designated bin according to the signal.
Req 3.1.7 P	The product must be able to attach to a set of bins.
Req 3.1.8 P	The system must detect whether the bin is full or not.
Req 3.1.9 F	The system must be able to withstand different temperatures.
Req 3.1.10 F	The waste much be less than 10 lbs.
Req 3.1.11 F	The product capable of operating for a minimum of 24 hours.
Req 3.1.12 F	The product must be suitable for both outdoor and indoor environments.
Req 3.1.13 P	The total weight of the product must be less than 10 kgs.
Req 3.1.14 P	The total length of the product must be less than 1.5 m.
Req 3.1.15 P	The product must not cover the entire garbage bin for manual disposal of waste.

3.2 Functional Requirements

The following table shows the requirement for the product's functionality.

Table 3.2 - Functional Requirements and Progress

Requirement ID	Requirement Description
Req 3.2.1 C	The system must be able to capture image of the waste and determine its category.
Req 3.2.2 C	The image processing time must be less than 1 second.
Req 3.2.3 P	The lid of the scanning area must open automatically when the system detects that waste is approaching.
Req 3.2.4 P	The screen must be able to display the status/progress of the operation.
Req 3.2.5 P	The device should display/notify the user when the waste bin is full.
Req 3.2.6 F	The whole operation needs to be completed in equal or less than 5 seconds.

4 Software Requirements

Image processing requires a trained model for development of the product. The training for the image processing will use the existing open-source library; it can train and create a model according to the image that we will import and export with the python code. In addition, the OpenCV will be used to improve the performance as the python in OpenCV is a wrapper around the original C++. This means that the python-OpenCV is slightly slower than C++, but easier to implement. The software will attempt to handle exceptions at any given time. If exceptions cannot be handled, then the software will notify the user by displaying the error message.

4.1 General Requirements

The following table shows the general requirements for the system software.

Table 4.1 - General Software Requirements and Progress

Requirement ID	Requirement Description
Req 4.1.1 C	The software must be able to run on a Windows/ Linux OS desktop computer.
Req 4.1.2 C	The software must be able to find the object in the image.
Req 4.1.3 C	The software must be able to label the waste in the image.
Req 4.1.4 P	Software must send the desired signal to the mechanical part according to the waste label.
Req 4.1.5 P	Software must send a reset signal to the mechanical part after waste sorting is completed.
Req 4.1.6 P	Software must restart when processing error.
Req 4.1.7 F	The system must allow software update.

4.2 Performance

The following table shows the performance requirements for the system software.

Table 4.2 - Performance Requirements and Progress

Requirement ID	Requirement Description
Req 4.2.1 P	The success rate of identifying the waste must be higher than 80%.
Req 4.2.2 F	The software must be able to handle any major exceptions and reset to the initial state.
Req 4.2.3 F	The system must recover from error in less than 5 seconds.

5 Hardware Requirements

The main purpose of this product is to sort waste using the image processing method. The reason we use Raspberry pi is because it possesses a powerful processing unit that improves image processing performance [6]. As a product that functions to dispose waste materials, the hardware must be able to withstand the force of moving around the waste. During the proof-of-concept, we do not expect to have a full scale of product, we only intend to show the software capabilities for that stage: to determine the type of the waste based on the captured image.

5.1 General Requirements

The following table shows the performance requirements for the system hardware.

Table 5.1- General Hardware Requirements and Progress

Requirement ID	Requirement Description
Req 5.1.1 C	All data and system of Raspberry Pi 4 shall be stored in the memory card.
Req 5.1.2 P	The sensor must work when the system is powered on.
Req 5.1.3 P	Sensor must send signal when waste bin is full.
Req 5.1.4 P	The product must have circuit protection for all hardware components, including camera, raspberry pi, and power supply.
Req 5.1.5 P	The bottom bracket must be able to support the weight of the remaining components.
Req 5.1.6 F	The product design must be suitable for both outdoor and indoor environment.

5.2 Electronic Requirements

The following table shows the electronic requirements for the system hardware.

Table 5.2- Electronic Requirements and Progress

Requirement ID	Requirement Description
Req 5.2.1 C	The camera must be able to capture a high-quality image for image processing.
Req 5.2.2 C	The product must be connected to the power source for operation.
Req 5.2.3 C	Raspberry pi require a minimum 5V to operate [7].
Req 5.2.4 P	All the circuit must not be exposed.
Req 5.2.5 P	The flash shall resolve the negative effects of taking pictures in dim conditions.
Req 5.2.7 P	The motor must be able to rotate with the weight of the waste.
Req 5.2.4 F	The service life of the camera unit shall be greater than five years.

5.3 Mechanical Requirements

The following table shows the mechanical requirements for the system hardware.

Table 5.3 - Mechanical Requirements and Progress

Requirement ID	Requirement Description
Req 5.3.1 C	The product must be able to direct and dispose the waste to the corresponding bin.
Req 5.3.2 P	The product must have a security lock for preventing from being damaged or stollen.
Req 5.3.3 P	The lid of the scanning area must be able to open.
Req 5.3.4 P	All gates must automatically reset after disposing the waste.
Req 5.3.5 P	The attachment piece of the product much be adjustable for attaching waste bin.
Req 5.3.6 P	Users must be able to attach/detach the product to/from the bins easily.

6 Engineering Standards

The guidelines that Sort-e will comply with and implement, are from world glorious standards organization CSA and ASTM for related waste classification standards. Compliance with industry standards is critical to the design and integration process in the development of the Sort-e. To create compliance with international and Canadian standards, the Sort-e will follow specific relevant laws are as below.

6.1 AI system in Machine Learning

The following table shows the AI system in Machine Learning Standard for the project.

Table 6.1 - Artificial Intelligence in Machine learning Standards

Standard	Description
CAN/CSA-ISO/IEC 2382-31-01 (R2009)	Information Technology - Vocabulary - Part 31: Artificial Intelligence - Machine Learning [8].

6.2 Electrical

The following table shows the Electrical Standards for the project.

Table 6.2 - Electrical Standards

Standard	Description
CAN/CSA-C22.2 No. 61508-1:17	Functional safety of electrical/electronic/programmable electronic safety related systems — Part 1: General requirements [9].
CSA C22.2 No. 0:20	General requirements — Canadian Electrical Code, Part II [10].
CAN/CSA E60335-2-14-05	Household and Similar Electrical Appliances - Safety - Part 2.14: Particular Requirements for Kitchen Machines [11].

6.3 Robot System

The following table shows the Robot System Standards for the project.

Table 6.3 - Robot System Standards

Standard	Description
CAN/CSA-Z434-14 (R2019)	Industrial robots and robot systems (Adopted ISO 10218-1:2011, second edition, 2011-07-01, with Canadian deviations and ISO 10218-2:2011, first edition, 2011-07-01, with Canadian deviations) [12].

6.4 Maintenance

The following table shows the Maintenance Standards for the project.

Table 6.4 - Maintenance Standards

Standard	Description
CSA Z463	Maintenance of electrical systems [13].

6.5 Sterilization Standards

The following table shows the Sterilization Standards for the project.

Table 6.5 - Sterilization Standards

Standard	Description
CAN/CSA-Z314.14	Selection and use of Rigid Sterilization Containers [14].

6.6 Waste Management standard

The following table shows the Sterilization Standards for the project.

Table 6.6 - Waste Management Standards

Standard	Description
ASTM D4843 - 88(2016)	Standard Test Method for Wetting and Drying Test of Solid Wastes [15]
ASTM D5232 - 19	Standard Practice for Determining the Stability and Miscibility of a Solid, Semi-Solid, or Liquid Waste Material [16].

6.7 Environmental Standard

The following table shows the Environmental Standards for the project.

Table 6.7 - Environmental Standards

Standard	Description
CAN/CSA-ISO/TR 14047-04 (R2008)	Environmental Management - Life Cycle Impact Assessment - Examples of Application of ISO 14042 (Adopted ISO/TR 14047:2003, first edition, 2003-10-01) [17].
CSA ISO 14016:21	Environmental management — Guidelines on the assurance of environmental reports [18].

7 Sustainability and Safety

BGreen is committed to sustainability and safety for the production. We plan to use smaller sensors and mechanicals to ensure the product can be fit in various of locations for future implementation. The sustainability and safety terms will be shown in the following table. Our sustainability and safety considerations are based on the cradle-to-cradle sustainability cycle. Specific requirements are listed in Table 7.1.

The following table shows the sustainability requirements for the product.

Table 7.1 - Sustainability Requirements and Progress

Requirement ID	Requirement Description
Req 7.1.1 P	The designated scanning area must be cleanable.
Req 7.1.2 P	Each bin must have the same dimensions for optimal operation.
Req 7.1.3 P	The bins must be replaceable for sanitary purposes.
Req 7.1.4 F	Metal used for this product shall be made of stainless steel.
Req 7.1.5 F	The plastic used for the bins shall be waterproof.
Req 7.1.6 F	The camera must be detachable for cleaning purposes.
Req 7.1.7 F	The motors must be replaceable for maintenance.
Req 7.1.8 P	The waste sorting system shall be built with recyclable plastic and wood material.
Req 7.1.9 P	The internal system shall be built with recyclable electronic components.
Req 7.1.10 P	The Sort-e shall be capable of being refurbished.

The following table shows the safety requirements for the product.

Table 7.2 - Safety Requirements and Progress

Requirement ID	Requirement Description
Req 7.2.1 C	The circuit and the bins must be separated in different components.
Req 7.2.2 P	The strobe light must be isolated from the waste materials.
Req 7.2.3 P	There must be an emergency shut off button for the machine.
Req 7.2.4 F	The circuitry and the power plug shall not trigger an electrical hazard, fire, or explosion under normal operation conditions.
Req 7.2.5 F	The bins shall only be removed when the system is not in operation.
Req 7.2.6 F	The product must not contain harmful materials that negatively impacts human health.
Req 7.2.7 F	The edges of the product must not be sharp to minimize injury.

8 Conclusion

The Sort-e guide users to sort waste materials effectively and efficiently to pursue a zero-waste future. The user-friendly system allows users to build their waste literacy as well as their self-confidence. The Sort-e is designed as add-on accessory that may be adjusted to fit over current existing waste bins. Users have the option to dispose of waste manually, or through the system. This creates an inclusive environment to meet the needs of all users while encouraging and promoting sustainable practices.

BGreen advocates for a sustainable future by addressing contamination of recyclable materials, and by increasing waste literacy. As a company, we strongly believe in accessibility, sustainability, and educating the future generation.

As a company, we are committed to seek solutions towards a zero-waste future. The Sort-e is a cost-effective, multipurpose, sustainable suitable for the public sector. This waste management system will benefit both the society and the environment. The product is suitable for daily use and can be easily integrated to promote sustainable practices towards a zero-waste future. Our passionate team will build valuable product that will meet all requirements listed in this document.

References

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[14] *Selection and use of rigid sterilization containers*, Z314.14-10, 2015.

[15] *Standard Test Method for Wetting and Drying Test of Solid Wastes*, ASTM D4843-88, 2016.

[16] *Standard Practice for Determining the Stability and Miscibility of a Solid, Semi-Solid, or Liquid Waste Material,* ASTM D5232-19, 2019.

[17] *Environmental Management - Life Cycle Impact Assessment - Examples of Application of ISO 14042,* CAN/CSA-ISO/TR 14047-04, 2008.

[18] *Environmental management — Guidelines on the assurance of environmental reports,* CSA ISO 14016:21, 2020.

Appendix A: Acceptance Test Plan

By the term of this term, the system will be tested for two major parts: image processing and waste disposal. For image processing, the goal is to identify and label waste material in the image that will be captured by the camera. The expected successful rate is estimated to be 80%. In terms of waste disposal, the main goal is to ensure the waste will be directed and disposed of to the corresponding bin based on the type of waste material. This acceptance test plan will be used to evaluate our product during the proof of concept.

The following table indicates the test plans of a Sort-e in practice.

Test #1: Waste scanning process		
Pre-condition N/A		
Procedure	**Accepted Requirement**	**Accepted If**
1	When the user approaches near the scanning area, the protective cover above the scanning box will automatically open.	The protective cover open and close after three seconds.
2	Once the lid closes, Sort-e will automatically capture an image with or without flash based on the intensity of the light.	The flash is operating normally.

Test #2: Dispose waste		
Pre-condition: Scan completed		
Procedure	**Accepted Requirement**	**Accepted If**
1	Places a single waste item into the machine for scanning.	1. The Sort-e correctly identifies the type of waste, with the success rate of 80% or higher. 2. The duration of each waste sorting process shall be less than three seconds.
2	The user places five waste material separately into the machine.	1. The total process time shall be less than 30 seconds. 2. The average waste classification time for each item is less than 5 seconds.