# Feasibility Analysis and a plan for Plastic Recycling Center

An Interactive Qualifying Project report submitted to the faculty of

**Worcester Polytechnic Institute**

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## Abstract

The United States currently recycles 10% of its annual plastic garbage. The most common reason for this low recycling rate is a lack of knowledge about what to recycle and how to recycle plastic waste. Plastic recycling at Worcester Polytechnic Institute (WPI) follows a similar trend. The purpose of this research was to examine the viability of establishing a plastic recycling center on the Worcester Polytechnic Institute (WPI) campus by understanding and assessing the plastic waste processing at WPI. Different qualitative and quantitative research techniques including analyzing documents, conducting interviews, visiting various locations, collecting data, and engaging with the community were used to learn and find issues with the current plastic recycling. The results of the research indicate that a lack of awareness about recycling, ineffective efforts to raise awareness, and untracked plastic waste sources are responsible for low recycling rates at WPI. After conducting a feasibility analysis, it was determined that opening a plastic recycling center was viable, and a thorough project plan for doing so was created. This plan provides a starting point necessary to bring a notable change in how the WPI community recycles its plastic waste.

## Acknowledgements

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# Executive Summary

## 1. Purpose

Out of the total of 8.3 billion metric tons of plastic, only 9 percent has been recycled. Plastic waste can be decomposed using one or a combination of three processes: recycling, incinerating, and landfilling. Out of the three processes, recycling is the most effective because of its many advantages that extend beyond the benefits of the other two options. Currently, the United States recycles only 10% of total annual plastic waste. The most prevalent reason for the low recycling rates despite its effectiveness is the lack of awareness about recycling. The trend of lack of awareness and low recycling rates continues in the WPI community. The purpose of this project was to gain a better understanding of the WPI Community's recycling practices and assess feasibility of setting up a plastic recycling center on WPI campus for improving the plastic recycling rates and awareness in the community.

## 2. Background

Plastic has become an inherent component of the day-to-day life of humans. Consequently, global demand and the total waste generated are steadily increasing. There is an urgent need to increase the understanding of plastic to improve the way humans dispose of it on an individual and organizational level. Plastic is a polymer that can be molded and set into a rigid or elastic form. Based on post-manufacturing processing properties, plastics are divided into two major categories: Thermoset and Thermoplastic. Plastics are also classified into seven different types based on their chemical composition. These types of plastic help with categorizing plastic waste into recyclable and non-recyclable plastic waste. This categorized plastic waste can then be handled using three methods: incineration, landfilling, and recycling. Incineration is a process in which plastic waste is burned at hot temperatures to harvest energy. Landfilling involves burying the plastic waste underground and leaving it there to biodegrade naturally. Recycling collects, sorts, and reprocesses the recyclable waste into raw materials that can later be used for creating new products. To accommodate recyclable and non-recyclable plastic waste, a good plastic waste management strategy uses recycling along with incineration or landfilling. This strategy should also incorporate different ways to increase awareness about recycling among people.

## 3. Methods

This study employed qualitative and quantitative research methods for assessing WPI's plastic waste management strategy. These methods included analyzing documents, interviewing people from the community, field visit and data collection, and community engagement. Setting up a plastic recycling center on WPI campus was proposed as a solution for limitations found in the assessment. A feasibility study was conducted to determine if it would be possible to implement the solution.

## 4. Results

The investigation of the WPI's plastic recycling practices found that the total recycling rate at WPI has stayed stagnant at 19% for the last two years and 50% of the waste in recycling bins is not recyclable, and people are putting recyclable waste in the trash. The main limitations of the plastic waste management strategy are lack of awareness about recycling, unsuccessful efforts to raise awareness, and untracked plastic waste sources. The proposed Plastic Recycling Center can help address these issues by creating a community that not only recycles plastic but also educates people about it. The feasibility analysis of setting up a plastic recycling center assessed the solution based on the availability of finances, the technology required for recycling plastic, and human resources for managing the center. The feasibility analysis determined PRC to be feasible as all the resources to start it are readily available from the WPI community.

## 5. Recommendations

As a part of this project, I developed a project management plan with more specific steps for starting a PRC. This project management plan is created for student teams and advisors that can develop the different aspects of the PRC. In addition to increasing the plastic recycling rate, the PRC could be used for technical and art workshops. These workshops will attract students and, in the process, will educate them about plastic waste recycling. PRC will also provide a center for finishing WPI academic projects like Major Qualifying Project (MQP), Interactive Qualifying Project (IQP), or Humanities and Arts Practicum. This will not only help with increasing awareness among students but also improve the effectiveness of the different parts of the center.

## 6. Conclusion

This project has identified the causes of low and stagnant recycling rates at WPI and provided a plan for implementing a PRC. It also created a project management plan that will act as a first step towards starting the Plastic Recycling Center on campus.

# Chapter 1. Introduction

The amount of plastic manufactured in the first ten years of this century eclipses the total produced in the entire last century. - *Jessica Knoblauch, Environmental Health News, 2021 September 29*

Since the beginning of large-scale production of synthetic materials in the early 1950s, humans have generated 8.3 billion metric tons of plastics (University of Georgia, 2017). Since the invention of Plastic, it has become the workhorse material of the modern economy (Trifol Resources Limited., n.d.). Because of its physical properties and low production cost, Plastic is the ideal material for the manufacturing industry, mass consumerism, and the health industry. These businesses have thrived for 50 years, with global production increasing from 15 million metric tons in 1964 to 311 million metric tons in 2014 (McKinsey & Company, 2019). As shown in Figure 1, this number went up to more than 400 million metric tons in 2015. Plastics liberated us from the natural world's limits, as well as the material constraints and restricted supplies that had hitherto limited human activities (Freinkel, S., 2011). The introduction of these malleable and versatile materials allowed manufacturers to build a plethora of novel items while also broadening consumer choices for persons of modest means (Freinkel, S., 2011). While Plastic is an unrivaled solution to many problems, the widespread production, use, and disposal of plastics have become a fatal hazard to the environment (Shershneva, E.G., 2021).

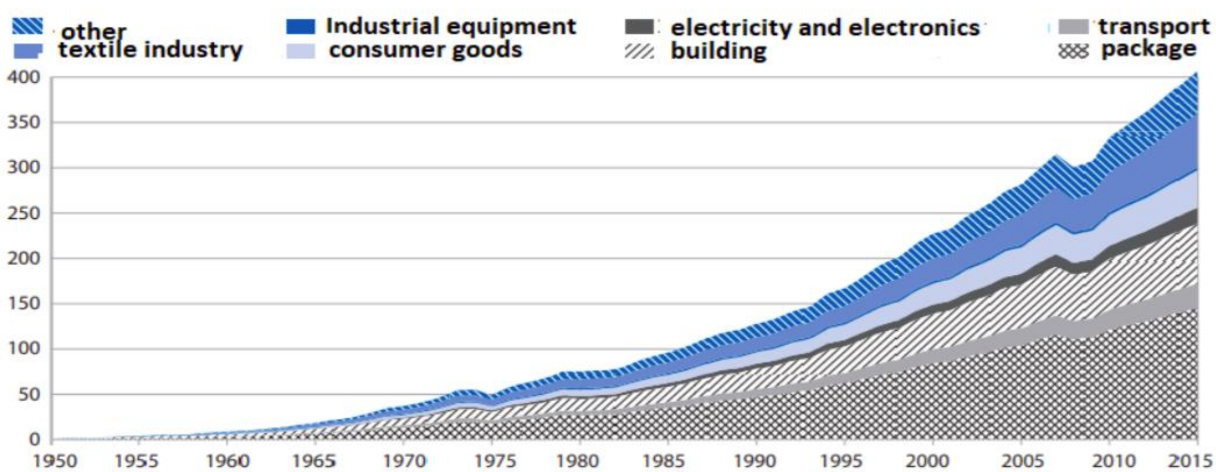


*Figure 1: World Production of Plastic by Economic Sectors (in millions of tons) (Shershneva, E.G., 2021) ["Plastic Waste: Global Impact and Ways to Reduce Environmental Harm"] by Shershneva, E G is licensed under CC BY 4.0*

As Mark Twain is often quoted as saying, “Too much of anything is bad '', overuse of plastic has led to plastic pollution and is affecting not only the environment and wildlife but also humans all over the world. Out of total plastic production, measured in global research conducted by researchers from the University of Georgia, 6.3 billion metric tons has become waste and from this waste, 9 percent was reclaimed through recycling, 12 percent was incinerated, and 79 percent accrued in the landfills and the nature (University of Georgia, 2017). The physical properties of Plastic make it the heart of manufacturing but after it is discarded these properties make plastic the worst enemy of humans and the environment. Because of its complex chemical structure, it takes 450-1000 years to decompose and until then it stays in the environment affecting its surroundings in many ways. Plastics are also a major contributor to climate change. Throughout the lifecycle of plastics, from fossil fuel extraction to daily use products to managing plastic waste, millions of metric tons of greenhouse gases are released into the environment. The growing global demand for plastics does not help efforts to halt climate change.

Many communities around the globe have become aware of these problems and are collaborating to bring about change. Hundreds of thousands of organizations are implementing various methods for effectively managing plastic waste and reducing its impact on the environment, and countries all over the world have started various programs to address these issues.

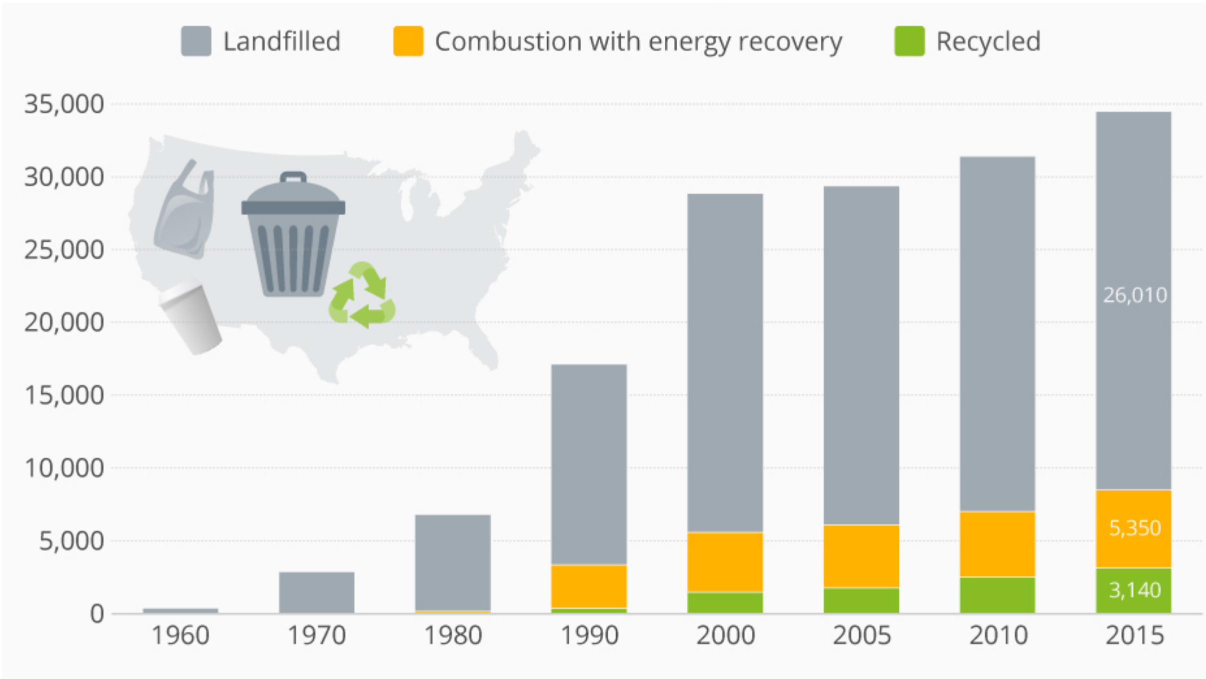


*Figure 2: Plastic Waste Handling in the United States (in thousands of tons) (Richter, F., 2019) "Plastic Recycling Still Has A Long Way To Go" by StatistaCharts is licensed under CC BY-SA 4.0*

Effectively managing plastic waste is one of the best ways the public can help with the negative environmental impacts of plastic. In the United States, there are three main ways used to manage plastic waste: recycling, incinerating, and landfilling. Recycling is the most successful of the three methods for disposing of plastic since it has many advantages that outweigh the advantages of the other two. Recycling plastic packaging or material into new plastic items saves a substantial amount of energy, ranging from 42,000 to 111000 kJ/kg, which is significantly more than the energy created by incineration and then utilized to manufacture virgin plastic products (Morris, J., 1996). Currently, the United States recycles only 10% of total annual plastic waste (Richter, F., 2019). This number is so low because of the lack of awareness about what to recycle and what not to recycle (Shershneva, E.G., 2021). The lack of awareness renders all tools and facilities for recycling useless.

The Worcester Polytechnic Institute (WPI) community also follows these trends, producing a lot of plastic waste, and recycling very little. Though there are recycling bins around the campus, one can easily find recyclable plastic waste in the trash bins. The 8th Annual Waste Audit found that 50% of the recycling bin contents were trash. Similarly, there are many 3D printing labs on campus, and they use plastic for creating 3D prints. WPI 3D printing labs predominantly use Polylactic Acid (PLA) as the primary 3D printing filament. PLA is recyclable, but there are no ways on WPI campus to recycle this plastic waste. As the campus expands, it is gaining new 3D printing labs. This would result in a stream of recyclable plastic waste that would be discarded rather than recycled. There is a clear need to expand the number of ways to recycle plastic garbage on campus and raise recycling awareness.

The purpose of this project is to dive deeper into WPI's recycling practices and waste streams using research techniques like interviewing, collecting data, and engaging with the community. The results of this research phase are then used to create a plan for a Plastic Recycling Center (PRC) on the WPI campus to fill the gaps in the recycling of plastic waste and increase the awareness of recycling in the student body. The overarching goal of the PRC will be to become an integral part of the plastic life cycle on the campus, engage and raise awareness of the WPI community, and increase the WPI’s total recycling rate.

# Chapter 2. Background

Plastic has become ubiquitous, and with increasing global demand, its production is also steadily increasing. As its usage has risen, the total plastic waste generated is also piling up. There is an immediate need to raise awareness of how to handle plastic waste on an individual and organizational level. Understanding the fundamental properties of plastics can aid in the development of more effective plastic waste handling strategies. This knowledge can be obtained by responding to a few questions about Plastics. What exactly is plastic? What are the various kinds of plastic? What are the best practices for dealing with different types of plastic waste?

## 2.1. Plastics

Plastic has become an inherent component of the day-to-day life of humans. Its low production cost, versatility, and wide range of applications have made it the first choice for manufacturers around the world. Oxford University press defines plastic as “a synthetic material made from a wide range of organic polymers, that can be molded into shape while soft, and then set into a rigid or slightly elastic form.” A polymer is a chain of many small repeating components called monomers. Plastics are split into two broad types based on post-manufacturing processing properties: Thermoset and Thermoplastic. Plastics are also classified into seven different types based on their chemical composition.

### 2.1.1. Types of Plastic (Based on Post Manufacturing Properties)

#### *2.1.1.1. Thermoset*

Thermosets are defined as materials that will undergo or have undergone a chemical reaction by the action of heat, catalyst, ultraviolet light, etc., resulting in a relatively infusible state. The process of hardening or toughening a polymer into a Thermoset polymer is called curing. Curing a thermosetting polymer transforms it into plastic by cross-linking polymer chains. Cross-linking in polymers is linking two polymers to change the physical properties, in this case toughening the polymer. Cross-linking can be visualized as two long chains placed parallelly connected at many places with short links. Plastic made from thermosetting materials is known as Thermoset Plastic. Thermoset Plastic is a prized material in the manufacturing industry because of its strength and durability and is extensively used in automobiles and construction including applications such as adhesives, inks, and coatings (Romeo RIM Incorporated, n.d.). The infusible state of thermosetting plastic makes it very difficult to recycle, and if heated to melt it, it starts to degrade. This degradation worsens the quality of the plastic and leaves it unworkable. Some examples of Thermoset plastics and their applications are as follows:

| **Thermosets** | **Applications** |
| --- | --- |
| Polyurethanes | Mattresses, Cushions, Insulation |
| Epoxies | Adhesive Glues, Coating for electronic devices, Helicopter and jet engine blades |
| Unsaturated Polyesters | Bathtubs, Furniture |
| Phenol-Formaldehyde | Plywood, Electronics circuit boards, and switches, electrical appliances |

*Table 1:Different Thermoset Plastics and their common applications*

##### *2.1.1.2. Thermoplastic*

Thermoplastics are defined as polymers that can be melted and recast indefinitely. The molecules in thermoplastics are held together with secondary weak bonds that make it easy to reform by heating and cooling, provided that the temperature is not high enough to cause decomposition and degrade the polymer. This reformation can be accomplished by the manufacturing processes like extrusion, injection molding, or pressing. This property of thermoplastics gives them the name "reversible material" because they can be reversed to their original form and recycled into new products. Some common examples of thermoplastic are as follows:

| **Thermoplastics** | **Applications** |
| --- | --- |
| Polyethylene | Packaging, Shampoo Bottles, Bullet-proof Vests |
| Polypropylene | Microwave containers, Carpet fibers, Automotive bumpers |
| Polyvinyl Chlorides | Floor and wall covering, Sheathing for electric cables, Water Pipes |

*Table 2: Different Thermoplastic Plastics and their common applications*

### 2.1.2. Types of Plastic (Based on Chemical Composition)

The Society of Plastic Industry (SPI), now Plastic Industry Association, established a classification system in 1988 that allowed consumers and recyclers to identify different types of plastic based on their chemical composition. This classification system categorized plastic into seven types, numbered from 1 to 7, based on their chemical composition. This classification system is known as ASTM International Resin Identification Coding System (RIC) (2EA Consulting Limited., 2018). Each type has its symbol, and plastic manufacturers punch these symbols on all the plastic articles with their respective types. Table 3 shows the different types and symbols in the RIC system.

| Types | Chemical Composition | Symbol | Recyclable/Non-Recyclable |
|---|---|---|---|
| Type 1 | Polyethylene Terephthalate (PET) | 1 PETE | Recyclable |
| Type 2 | High-Density Polyethylene (HDPE) | 2 HDPE | Recyclable |
| Type 3 | Polyvinyl Chloride (PVC) | 3 PVC | Recyclable |
| Type 4 | Low-Density Polyethylene (LDPE) | 4 LDPE | Recyclable |
| Type 5 | Polypropylene (PP) | 5 PP | Recyclable |
| Type 6 | Polystyrene | 6 PS | Recyclable |
| Type 7 | All other plastic | 7 OTHER | Varies based on different materials |

*Table 3: Types of plastic based on the chemical composition*

The seven types of plastic can be categorized in the types of plastic based on the processes. The plastic types 1 through 6 are thermoplastics because they can be melted and reformed into new items. Type 7 plastics include all other varieties of plastic that do not fall into types 1 through 6. As a result, Type 7 plastics include both thermoplastics and thermosets.

## 2.2. Plastic Waste Handling

Plastic is adaptable, lightweight, flexible, moisture-resistant, durable, and reasonably priced (Coastal Care, 2018). These are the alluring attributes that contribute to such excessive use of plastic goods all over the world (Coastal Care, 2018). According to the United Nations, one million plastic bottles are bought every minute, while up to 5 trillion single-use plastic bags are used worldwide every year (United Nations Environment Programme, n.d.). Plastic is durable and takes centuries to degrade. Plastics used by manufacturers for making products ultimately become waste. Nowadays, plastic waste has become ubiquitous in the natural environment, and its presence is ever-growing. Every year, humans generate 300 million tons of plastic waste, which is nearly equal to the weight of the entire human population (United Nations Environment Programme, n.d.). This plastic waste stays on the surface for centuries and adversely affects human health, oceans, food chain, wildlife, and groundwater sources. These are a few noticeable effects of plastic, but numerous others go unnoticed and are still being researched by scientists.

To take care of all the plastic waste, governments across the globe employ plastic waste management strategies like landfilling, incineration, and recycling.

### 2.2.1. Landfilling

Landfills are usually municipal solid waste facilities that collect and bury anything that is not sent to municipal recovery facilities (otherwise known as MRFs) (Plastic Industry Association, 2021). This solid waste includes food waste, paper, glass, plastic, and other products (Plastic Industry Association, 2021).

The garbage is left to decay or biodegrade over time in these landfills. Both processes are typically slow, and the length of time it takes for objects to biodegrade or decompose varies substantially depending on the material. In landfills, plastic bags can take anywhere from 10 to

100 years to disintegrate (Plastics Industry Association, 2021). In such an environment, other plastic items can take as long as or longer to disintegrate (Plastics Industry Association, 2021).

Landfilling plastics is a considerably cheaper, easier, and faster solution for disposing of plastic trash than recycling and incineration (Better Meets Reality, 2021). Plastic waste management varies between different municipal corporations based on the waste management budget, personnel, and technology available. Landfilling is the go-to option if the technology available for recycling and incineration is ineffective to produce benefits over the cost operation.

Though landfilling is a readily available option, it comes with two major drawbacks: waste takes very long to decompose in landfills and, if not engineered carefully, the landfills can contaminate the underground water with chemicals and other impurities. Landfills also become places where waste will stay for decades, centuries, or even millennia. Plastic garbage is an underutilized resource, and burying it inhibits humanity from putting it to good use for the environment and the economy (Plastics Industry Association, 2021).

### 2.2.2. Incineration

Incineration is a process in which plastic waste is burned at high temperatures to harvest energy. Due to landfill space constraints, it is commonly employed in wealthy countries (Fisher, M. R., n.d.). Around 130 million tons of trash are estimated to be combusted each year in more than 600 plants across 35 nations (Fisher, M. R., n.d.).

Incineration can generate enough electricity for local grids and can provide supply energy to cement manufacturing plants (Harrabin, R., 2018). Plastic is also more energy-dense than coal because it is formed of hydrocarbons, exactly as oil (Royte, E., 2021). Incinerating plastic addresses the problem of land availability for landfilling plastic waste. With the continuous increase in plastic production, more land will be required for landfilling, and incineration provides an ideal method to manage space for plastic waste.

Even though incineration can provide energy, it cannot hide the fact that plastic products still cause pollution in various ways before they are incinerated (Better Meets Reality, 2021). According to many authorities, incineration in its current form does not contribute to a circular or sustainable society (Royte, E., 2021). Incineration technology can be costly and difficult to scale (Better Meets Reality, 2021). For example, one plant in Scandinavia spent a billion kroner, approximately 156 million US Dollars, to try to meet European standards for dioxin, a pollutant found in emissions (Better Meets Reality, 2021). Emission and air pollutants from incinerators also need to be managed, which adds extra cost to the incineration plant (Better Meets Reality, 2021). If managed poorly, toxic pollutants like dioxins, acid gases, and heavy metals can degrade air quality and impact human health. According to some sources, US incineration plants do not satisfy the same environmental criteria as European plants, nor do they have the most up-to-date pollution controls (Alter, L., 2019). Incinerators also contribute significantly to climate change through greenhouse gas emissions. In 2016, waste incinerators in the United States released the equivalent of 12 million tons of carbon dioxide, with plastics accounting for more than half of that (Royte, E., 2021). Every positive result of incineration is accompanied by a negative environmental impact.

### 2.2.3. Recycling

Plastic recycling is the process of recovering garbage and solid plastic waste by collecting it, separating it, and reprocessing it into raw materials that can be used to make new products. Recycling is a preferred way of managing plastic waste and plays a vital role in waste management strategies. Big companies like Waste Management Inc. utilize and recommend sustainable strategies that encourage recycling and enlist ways to use recycling for generating revenue.

In general, the Plastic Recycling Process is similar across the globe. Recyclable plastics are first sorted at the recycling facilities. Once sorted, it is shredded and washed to get rid of any impurities like paper (Cho, R.,2019). Shredding plastic is a process of converting the big chunks of plastics into small evenly sized pieces called plastic pellets. Converting plastic into small pieces helps to clean it more efficiently. These plastic pellets are then melted and made into other commercial products.

When compared to landfills and incineration, recycling plastic has the lowest potential for global warming and uses the least amount of energy (Ritchie, H., 2018). Recycling plastic garbage saves more energy than burning it, along with other household waste, because it reduces the need to extract fossil fuel and turn it into new plastic, according to studies (Royte, E., 2021). Recycling can also create up to 20 more jobs than landfilling in some economies (Better Meets Reality, 2021).

Though recycling is a more ecological and economical option than incineration and landfilling, it comes with limitations. Only the recyclable plastic can be reclaimed, but the non-recyclable plastic still needs to be landfilled or incinerated. Another problem with recycling is that households and businesses are not aware of proper disposal procedures for their plastic waste, consequently, a lot of recyclable plastic waste ends up in the trash (Better Meets Reality, 2021). YouGov, an international research and data analytics group, surveyed 5,509 adults from Mexico, Spain, the United Kingdom, and the United States, and found out that 60% of adults could not recycle some types of plastic packaging (Hi-Cone Group, n.d.).

Any effective plastic waste management strategy involves the use of recycling along with incineration or landfilling. Though both incineration and landfill have potential environmental risks, the best choice may depend on the local context (Ritchie, H., 2018). This strategy also needs to take steps to increase people's awareness about the diverse ways to dispose of plastic waste.

China's "National Sword" policy, which took effect in January 2018, prohibited the import of most plastics and other materials destined for China's recycling processors, which had previously handled half of the world's recyclable garbage (Katz, C.,2019). This ban created recycling backlogs worldwide, and high-income countries started sending recyclable material to incinerators and annulling landfill bans (Vermont Law School, n.d.). Some municipalities across the US and Europe have halted the recycling programs altogether, to evade the significant rise in recycling cost (Vermont Law School, n.d.). This policy change has acted as a catalyst for the world to rethink how waste is dealt with. This recycling crisis, according to experts, should serve as a wake-up call to the world about the need to drastically reduce single-use plastic and expand waste recycling facilities (Katz, C., 2019). The United Nations Environment Program also predicted that this ban would improve domestic recycling facilities and motivate product designers to include more recyclable content in their designs (Vermont Law School, n.d.). China’s waste ban exposed many gaps in the global recycling system, and to fill in these gaps countries and private organizations all around the world must collaboratively find solutions (Vermont Law School, n.d.).

Governments throughout the world have recognized the problem of single-use plastics and the need for more recycling facilities, and they are taking action. For example, Canada has pledged to ban single-use plastic by 2021, and the UK government has set an ambitious goal of phasing out all the avoidable plastic waste by the end of 2042 (Hi-Cone Group, n.d.). Similarly, the EU is aiming to make all the plastic packaging recyclable by the end of 2030 (Hi-Cone Group, n.d.). In 2019, Mexico's senators signed a bill into law that encourages public-private partnerships in waste recycling, a $3 billion industry, according to ANIPAC, Mexico's national association of plastic industries (Hi-Cone Group, n.d.).

## 2.3. WPI Sustainability and Plastic Waste Recycling

WPI is a medium-sized university with a total of 7,230 enrollments in the 2021 Fall Semester (Worcester Polytechnic Institute, 2021). WPI has 15 academic departments spread over the 96 acres campus (O'Neil, S., 2019). WPI is known for its project-based curriculum that incorporates science, engineering, and humanities to solve problems on both local and global scales (Worcester Polytechnic Institute, 1970). Learning has always been about theory and practice at WPI, and long-term solutions must include both (Sun, M.,2018). On the one hand, theoretical advances provide new insights into how to best address current sustainability issues; on the other hand, these ideas must be implemented to have any impact (Sun, M., 2018).

Sustainability has been an inherent part of WPI's mission since 1865, and it has been reaffirmed expressly in the last decade (Sun, M., 2018). Sustainability is often the ability to meet the requirements of the current generation without affecting future generations' ability to meet their own needs (Caton, O., 2020). Over the last 20 years, it has become a higher priority at WPI, especially with the formulation of WPI's Sustainability Plan and the formation of the Sustainability Advisory Committee (Caton, O., 2020). In 2014, WPI created the first Sustainability Plan, and it served as a valuable guide for sustainability programs and initiatives for five years (Sustainability Plan, n.d.). In the fall of 2020, WPI reviewed the old plan and created a new one, and it will guide sustainability for another five years (Sustainability Plan, n.d.). This Sustainability Plan focuses on how WPI can contribute to the movement of solving global challenges in sustainability. Continuous increase in Plastic Waste is a growing global problem, and WPI Facilities and Office of Sustainability are constantly finding ways to improve recycling. Currently, a single-stream recycling program collects recyclable plastic garbage on campus. The recyclables are sorted at the recycling facilities in the single-stream recycling program. Every trash bin on campus has a blue recycling bin next to it, and there are "How to recycle?" instructions near each bin. Even though there are these instructions, a lack of awareness about recyclables and non-recyclables is evident if anyone peeks in one of these bins. A clear water bottle, marked as recyclable on the instructions, could easily be found in the trash bins instead of the recycling bins. There is a need for better ways to spread awareness about ways to recycle plastic.

# Chapter 3. Methods

## 3.1. Project Statement and Objectives

The goal of this project was to determine the feasibility of implementing a PRC that will recycle clean and label-free plastic, especially 3D printing filaments and plastic water bottles, on the WPI campus. If found feasible and beneficial for the WPI community, create a detailed project plan for opening a plastic recycling center on campus. This Plastic Recycling Center will also focus on spreading awareness about plastic waste and recycling in the community with the overarching goal of reducing campus-generated plastic waste and increasing the recycling rates. Five major objectives were created to structure the process of achieving those goals, and they are as follows:

1. Investigate the current state of recycling at WPI and determine if the Plastic Recycling is needed on the campus
2. Develop a project plan for the Plastic Recycling Center that will fill in some of the gaps found in WPI's Plastic Recycling processes
3. Perform feasibility analysis for implementing a Plastic Recycling Center
4. Identify small scale technologies that can be used in the Plastic Recycling Center
5. Craft recommendations on using the plastic recycling center for raising awareness about recycling plastic

To achieve the listed objectives, qualitative field research and data collection techniques were used to collect and analyze data. These techniques included interviews, historical document analysis, field visits, waste audits, conversing with the WPI campus community, and active participation in community events.

## 3.2. Investigate the Current Recycling Processes at WPI

### 3.2.1. Analyze Historical Documents and Reports

I examined historical documents like annual reports with facts to acquire knowledge about the fundamental workings of an existing system or process. During this step, I reviewed documents related to the WPI Recycling program. They informed me about the system and raised important questions that helped to determine the challenges or limits of current recycling practices at Worcester Polytechnic Institute (WPI).

I used two criteria to select the documents for analysis: published within the last 5 years and published by the WPI Office of Sustainability. I used the document analysis method, in which I read the document and noted key facts, figures, or quotes. This method gave a structured approach to document analysis and got to the core idea and most relevant findings of the documents.

The most relevant historical documents that fit the criteria were Annual Sustainability Reports and Annual Waste Audits

- Annual Sustainability Reports, 2016-17, 2017-18, 2018-19, and 2019-20

WPI Sustainability Plan is a bold and comprehensive strategy to advance the three broad goals of Sustainability. This Annual Sustainability report evaluates WPI's progress in implementing the WPI Sustainability Plan in four areas: Operations, Academics, Research & Scholarship, and Community Engagement. WPI's Annual Sustainability Report provided an overall understanding of the sustainability goals of WPI and the current status of WPI sustainability by listing various facts and sustainability activities happening on campus. Some relevant key facts and quotes from these documents can be found in Appendix 2.1, 2.2, 2.3, 2.4.

- Annual Waste Audit Reports, 2018 and 2019

WPI Green Team and Office of Sustainability conducted the 8th Annual Waste Audit on April 13, 2019. The audit recorded the current and potential recycling rate at WPI and gave a rough idea of the state of recycling at WPI. Some key facts and quotes from these documents can be found in Appendix 2.5, 2.6.

### 3.2.2. Interviews

Interviews help understand aspects of the topic that require lengthy explanation or need a dialogue between two people to thoroughly investigate. Additionally, interviews are the best method to utilize if the study involves describing and examining any kind of process, which in this case is the process of plastic recycling on the WPI campus.

There are two types of interviews: structured and unstructured (Mcleod, S., 2014). In the structured interview, the interviewer asks a set of predetermined questions, while in unstructured interviews the questions are open-ended about the research topic. In this project, I conducted structured interviews because specific information was required to understand the state of plastic recycling at WPI, and the time for conducting interviews was limited to a maximum of one hour.

In this project, structured interviews had three phases: Pre-Interview, Interview, and Post-Interview. Each phase used methods that aimed to maximize the amount of information gathered from the interview. The Pre-Interview phase involved formulating interview questions using the interview methods from the Human-Centered Design approach (IDEO.ORG, n.d.). The human-Centered Design approach is a way of solving problems that involve humans. It laid out interviewing principles to get the best information from an interview. The questions prepared were asked in the Interview Phase. During this phase, the interview was conducted and recorded on a laptop. Along with recording, key points during the interview were noted down on a notepad. After the interview was over, the detailed notes were taken from the recordings during the post-Interview phase. This phase also involved analyzing and consolidating the information collected during the interview.

### 3.2.3. Field Visits and Data Collection

I conducted Field Visits to various locations on the WPI campus at different times of the day for taking field notes that guided the further study and decisions (Bailey, C.A., 2018). Field visits play a key role in this project since they help to get a better understanding of sources of plastic waste at WPI and observe the effectiveness of recycling methods employed on the campus.

During Field visits, I used a method of field research known as direct observation. Direct observation is a method of research where the researcher watches and records the activities of the research object, individual, or location (The United States Department of Health and Human Services, n.d.). A researcher's role in this method might range from passive observer to full, active participant (Genkova, A., 2020). A passive spectator is distanced from the study environment and interferes very slightly, whereas an active participant is absorbed and contributes to it (Genkova, A., 2020). In contrast to a passive spectator, a participant-observer, or moderate participant, is not integrated with the scene as a general participant but participates in it (Genkova, A., 2020).

To study the state of WPI's plastic recycling without any interference, the role of a passive observer was assumed during the field visits. To record the observations during the field visit, field notes and images were taken.

Eliminating and choosing the best locations for the field visit was necessary to effectively get information about the state of recycling. The locations for field visit were chosen based on two criteria and they are as follows:

1. Has high daily traffic of students
2. Has a potential source of plastic waste nearby

These criteria helped identify locations that not only gave an understanding of the limitations of plastic recycling but also provided an insight into the level of awareness about recycling in the student body.

In addition to conducting Field Visits, I used Field Data Collection to gather data that was not already recorded. A field data collection project is carried out in person, in a specific physical area or environment (Summa Linguae Technologies, 2021). The location for conducting Field Data Collection was chosen based on the notes recorded during the field visits.

#### 3.2.4. Community Engagement

Community engagement is the practice of collaborating with and through groups of people who are linked by geography, shared interests, or comparable circumstances to address issues that affect their well-being (Pennsylvania State University, College of Agricultural Sciences, n.d.). Community engagement allows making connections with the communities and identifying meaningful issues (DeFino, M., 2020). I connected with student organizations and volunteered at sustainability-related events to engage with the community and get a general understanding of the impact of these events on the community.

### 3.3. Conduct Feasibility Analysis

I conducted a Feasibility study that considers all project's relevant factors—including economic, technical, legal, and scheduling considerations—to ascertain the likelihood of completing the project successfully (Team, T. I., 2021). Many projects are unfinished because of the lack of workforce, finances, or technology required to execute the project. Feasibility analysis ensures that the plan is not missing any crucial detail required to finish the project.

Feasibility analysis involves many different steps to finalize an assessment of the project. There are many online resources that describe steps for conducting a feasibility study, but most of them present similar information. One resource for the feasibility study was selected using the C.R.A.P. test that evaluates resources in four main categories: Currency, Reliability, Authority, Purpose/Point of View (Colorado Community Colleges, n.d.). Once the feasibility study was finalized, it was conducted based on the data collected about the resources available for successfully setting up the Plastic Recycling Center.

## 3.4. Create Plastic Recycling Center Plan

I created a Plastic Recycling Center Plan as a deliverable for the project. A project plan, also known as a project management plan, is a document that outlines how a project will be implemented, managed, and closed (Kissflow Inc., 2021). Proper project planning breaks down the entire project into steps and ensures that resources are available on time (Kissflow Inc., 2021).

Creating a project plan involves many steps like creating a budget, scheduling different tasks, managing available and required resources. Creating a plan for this project from nothing would have taken a significant amount of time. I used previous templates of a project management plan as a reference to save time while maintaining the quality of the final project plan developed.

# Chapter 4. Results

## 4.1. Resources Found for Research

### 4.1.1. Experts Interviewed and Their Contributions

To identify the problem with current recycling practices on the WPI campus, one of the best sources was the people from the Office of Sustainability (OOS) and the Facilities Department. These people include the Ex-Associate Director of OOS, Elizabeth “Liz” Tomaszewski, and the Director of OOS, Paul Mathisen. Liz summarized the current state of the system, potential improvements, and directed me to the other resources for my project research. Liz also described the plastic life cycle, described in section 4.2., at WPI. Paul helped with finding untracked plastic waste sources like Environmental and Chemical Engineering labs. Liz’s interview and Paul’s interview key findings can be found in Appendix 4.1 and 4.2 respectively.

To gain an understanding of managing 3D printing plastic waste, I interviewed Makerspace Advanced Technology and Prototyping Specialist, Mitra Varun Anand. Mitra gave more information about 3D printing at WPI and how to handle PLA waste. The directions from Mitra are made into “PLA Waste Handling Guide”, which can be found in Appendix 5. This guide went through multiple revisions and a final review by Mitra.

### 4.1.2. Selecting Locations and Conducting Field Visits

Based on the criteria for selecting the location for a field visit, I shortlisted multiple locations all over the campus. The highlighted locations in the table below show the locations selected for the field visit research. During the document analysis, I gathered statistics on plastic waste, but some plastic waste sources did not have any historical data about the plastic waste generated, and Fitzgerald Prototyping Lab in the Innovation Studio was one of them. A seven-week survey was conducted in the prototyping lab to get concrete data on the plastic waste generated. Since Plastic water bottles were a common source of plastic waste and made good raw material for the recycling center, data collection for plastic bottles was conducted at the 8th Annual Waste Audit (See Appendix 1 for more information).

| Locations | High Student Traffic | Nearby a Plastic Waste Source |
|---|---|---|
| McDonough Makerspace, Innovation studio | Yes | No |
| Fitzgerald Prototyping Lab, Innovation Studio | Yes | Yes |
| Sports and Recreation Center | Yes | No |
| Environmental Labs, Kaven Hall | No | Yes |
| Dunkin Donuts, Rubin Campus Center | Yes | Yes |
| Food Court, Rubin Campus Center | Yes | Yes |
| Gordon Library | Yes | No |

*Table 4: Evolution of WPI locations shortlisted for field visits*

### 4.1.3. Engaging with Community

Community engagement activities conducted by the WPI Green Team and Office of Sustainability were attended to gain a better understanding of the current situation of the community. These events included Annual Waste Audit, E-Waste Drive, and Bike Smoothies during Earth Day week.

- 8$^{th}$ Annual Waste Audit

During the 8th Annual Waste Audit, I discovered that various parties, including the Green Team, the Office of Sustainability, and Facilities, may work together to sort waste. With the support of organizers, I was able to collect statistics on plastic water bottles disposed of in recycling and garbage bins.

- E-Waste Drive

The Office of Sustainability, in cooperation with the Green Team, hosted E-Waste Drive to assist the WPI community in safely disposing of their electronic waste. This event demonstrated that a considerable amount of electronic garbage is typically discarded.

- Bike Smoothies with Soccomm and Green Team

Bike blenders were used to prepare smoothies, and students were also requested to participate in a sustainability quiz game with rewards for the winners. Due to a large number of participants, this event was quite entertaining. This event demonstrated that gamifying sustainability can greatly increase participation.

## 4.2. Plastic Waste Life Cycle at WPI

Currently, WPI contracts Waste Management Inc. (WM), a waste handling and recycling company, to handle the management of on-campus waste. Custodians from WPI's Facilities department collect the trash from all over the campus in big trash compressors present at different locations throughout the campus. WM collects all the trash and recyclables from these compressors every three weeks. Trash is sent to the waste to energy program, where the trash is incinerated to produce energy. Recyclables are sent to the recycling facility for further processing.

The recyclables sent to the recycling facilities are not readily available for further use. There are multiple steps the recyclables must go through to be useful again. For the recyclables from WPI, the steps are as follows:

1. WPI custodians pick up the waste, trash in white bags, and recyclable in green plastic trash bags.
2. The waste from recycling bins is then taken to recycling compactors at:
   - Founders Hall
   - Morgan Hall
   - Sports and Recreation Center
3. WM trucks empty the above-mentioned compactors every three weeks.
4. This waste is sent to the recycling facilities, where the recyclables from the compactor are dumped on conveyors and are then sorted with the help of manual labor.
5. The waste is sorted into distinct categories like plastic, glass, metals, etc.
6. Sorted plastic waste is recycled and processed to be sold as commodities to manufacturing companies.

## 4.3. Identified Problems

This study found that the total recycling rate at WPI has stayed stagnant at 19% for the last two years, 50% of the waste in recycling bins is not recyclable, and people are putting recyclable waste in the trash. The main limitations of plastic waste management at WPI are as follows:

### 4.3.1. Lack of Awareness

The biggest flaw of plastic waste management on the WPI campus is that its effectiveness relies on the WPI community's awareness about recycling. Currently, many community members are not aware of recycling and how it should be properly sorted.

Innovation Studio and Rubin campus center are popular student study and food spots. Observations at Dunkin Donuts found that the trash bin contained recyclable trash, and a recycling bin contained non-recyclable trash (See Appendix 3.1., 3.2.). For example, even though the paper bags of Dunkin Donuts were marked as recyclable, they were thrown in the trash. This trend was continued in the trash and recycling bins near the Food Court, but at this location, the trash bins also contained plastic water bottles. These observations suggested a lack of student awareness about recycling. The confusion in what is recyclable is also evident from the results of the 2019 Waste Audit conducted by the Office of Sustainability. According to the data collected, 20 pounds of plastic bottles were found in one day's trash, which is approximately 900 half-liter water bottles, and 66% of the plastic bottles were found in the trash instead of recycling bins.

### 4.3.2. Untracked Plastic Waste Sources

In addition to the lack of awareness, many plastic waste sources go unmonitored. According to Elizabeth Tomaszewski and Paul Mathisen, plastic waste from the Environmental Engineering and Chemical Engineering labs is never recycled (See Appendix 4.1, 4.2). Similarly, the Fitzgerald Prototyping labs, which is a prime location for students to print 3D parts for academic and personal projects, do not have specialized plastic waste handling. The seven-week data collection, shown in Figure 4, on PLA waste generation found that, on average, 2.6 pounds of recyclable plastic waste is thrown into the trash every week. Based on the weekly average, the projected yearly plastic waste comes out to be approximately 140 pounds. This amount of waste can be diverted from trash bins to recycle bins. This number does not include the recyclable waste that was not collected in the bins. According to Mitra Anand, the Prototyping lab in its lifetime of 3 years has used 1.38 tons of 3D printing filament, and all the plastic waste created while using this material went to the trash bins (See Appendix 4.3). The 3D printing lab is only two years old, and the WPI community is not aware of how to use this resource. As time passes, more people from the community will start using this lab and the amount of recyclable waste will increase significantly. This unmonitored recyclable waste is only going to increase with the opening of a new 3D printing lab in the WPI Unity Hall.

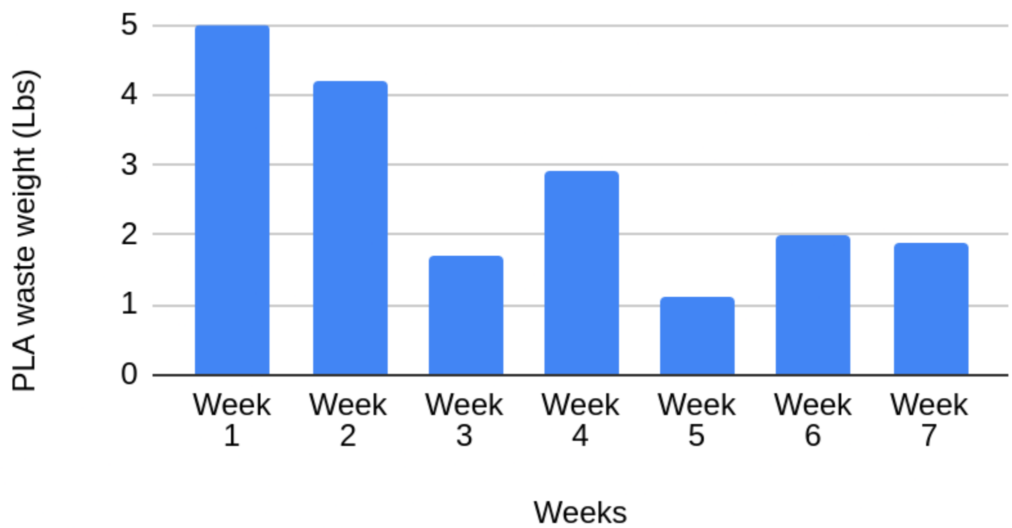


*Figure 3: PLA Plastic Waste Collected over Seven Weeks*

### 4.3.3. Unsuccessful Efforts to Raise Awareness

The student organizations and Office of Sustainability host many events throughout the year to increase awareness about sustainability and recycling. The waste audit conducted in 2017 and 2019 by the Green Team and Office of Sustainability found that the recycling rate was stagnant at approximately 19%. This suggests that sustainability events are not successful in inculcating the behavior of recycling waste. While attending these events for research, the same group of people attended all the events and there was a lack of emphasis on getting new participants to join the events.

## 4.4. Plastic Recycling Center Feasibility Analysis

The Feasibility Analysis method found during the research evaluated the Plastic Recycling Center in three categories: Finances, Technology, and Management.

### 4.4.1. Finances

PRC was found financially feasible with the availability of $9200, breakdown shown in Table 5, through different grants and programs at WPI. Finances are usually a bottleneck for finishing any project. Based on the Bill of Materials acquired from the Precious Plastic Project and revising it with the prices of the same materials to reflect the current prices, the proposed plastic recycling center will cost approximately $4550. The cost breakdown can be seen in Table 5.

| PRC Budget | Amount |
|---|---|
| Collection Station | $1150 |
| Shredder Station | $2500 |
| Injection Molding Station | $400 |
| Miscellaneous Cost | $500 |
| Total | $4550 |

*Table 5: Budget breakdown for setting up the Plastic Recycling Center*

To identify potential funding sources, a survey of student grants was conducted. The following table shows the breakdown of available funding sources.

| Fund Name | Amount |
|---|---|
| Green Revolving Fund | Upto $5000 |
| Tinkerbox | $500 to $2000 |
| Makerbucks | $200 |
| MQP Project (4 Student team) | $2000 |
| Total (max. available) | $9200 |

*Table 6: Funds available from WPI Grants and Programs (in US Dollars)*

### 4.4.2. Technology

I concluded establishing PRC on the WPI campus is technically viable because the technology required for PRC can be built or acquired easily with the help of the WPI community.

To be able to recycle plastic waste at the Plastic Recycling Center, the project will require two big machines, a plastic shredder and injection machine, and a desktop computer for collecting data and communicating within the team in case there are any issues with the machines.

Precious Plastic project's website has all the technical documents required to replicate the machines for shredding and injection molding plastic. A large portion of the WPI community includes engineers whose expertise lies in designing, building, and modifying technology. A team of students and a faculty or staff advisor could build these machines. In addition to the plans, the Precious Plastic project has a global community of Plastic Recycling Centers that have machines built based on Precious Plastic plans. This community provides continuous support in case there are any issues with the machine.

The desktop setup with a screen, a keyboard, a mouse, and a modern processor (manufactured within the last 3 years) can be requested from the WPI IT department. This desktop should have a Windows Operating System and should be connected to the WPI network to be able to access the internet and run any web-based data collection software. The request would have to go through a student organization or an advisor of the project.

### 4.4.3. Plastic Recycling Center Management

Like the Technology feasibility assessment, having an enthusiastic and technically inclined WPI community makes setting up PRC feasible in the availability of manpower that can carry out the operations of the PRC.

For the success of the project, there is a need for a team with management and technical sub-teams. The management sub-team will be responsible for acquiring funds and resources, creating project proposals, and managing both sub-teams. The technical sub-team will be responsible for building and testing the machines required for the shredding and injection molding plastic. Other than these two teams, there would be a need for faculty advisors who will guide the students throughout the project.

These human resources are also available through the WPI community. Many academic projects like IQP and MQP have a sustainability theme. In the past few years, WPI's Mechanical Engineering department has had projects where students developed the technology for shredding plastic waste. Getting the Plastic Recycling center up and running can be pitched as a potential MQP or IQP to different WPI departments. Other than academic projects, this project can also be handed to a student organization that is willing to work on it and take it to the end. For example, WPI's Gompei's Gears is a student organization-run project and is very popular in the student body. This can be done with the Plastic Recycling Center too.

# Chapter 5. Discussion and Recommendations

## 5.1. Plastic Recycling Center

To raise awareness about recycling and keep track of untracked sources of recyclable plastic waste, establishing a Plastic Recycling Center (PRC) was assessed as the potential solution. The plan for setting up a PRC on the WPI campus is based on a Precious Plastic project by an environmental group named One Army (One Army, n.d.). The Precious Plastic project's goal is to increase the amount of plastic being recycled all around the world. This project does this by creating an open-source website that provides free plans and procedures for Do-It-Yourself projects for creating machines that will help recycle the plastic waste generated daily. Additionally, it also provides resources and plans for setting up a PRC. After referring to Precious Plastic Project's resources, the following plan for setting up a PRC on the WPI campus was prepared.

### 5.1.1. Plastic Recycling Center Overview

The goal of the PRC will be to recycle plastic by sorting, cleaning, shredding, and melting it to use in a new product/article. Multiple stations must be set up in the PRC to perform the above-mentioned steps. These stations include Plastic Waste Collection station, cleaning station, Shredding Station, and Injection Molding Station.

### 5.1.2. Plastic Waste Collection Station

The plastic Waste Collection station is responsible for collecting clean and label-free plastic waste from the WPI community. The waste collection station should have large bags and small containers. These bags and containers should be labeled with the plastic-type, in Table 3, that will be stored in them. This station will also have a weighing hook to weigh the incoming plastic waste. This station will act as a filter for acceptable and non-acceptable plastic for recycling. Additionally, this station educates people about the different types of plastic and how they can use the PRC along with the curbside recycling program to maximize the household recycling rate. Since the primary focus of the PRC will be to recycle 3D printing filaments, especially PLA, proper guidelines should be established to handle the waste. With help from Mitra Anand from the Fitzgerald Prototyping Lab, a PLA Waste Handling Guide was created during the project. This guide can be found in Appendix 5.

### 5.1.3. Cleaning Station

Collecting clean and label-free plastic is necessary to create end products impurities-free. Many times, people bringing in the plastic to the collection point might not have clean plastic. The cleaning station will provide the location to clean the dirty plastic instead of rejecting the plastic waste at the collection station.

### 5.1.4. Plastic Shredding Station

The shredding station, as the name implies, will feature a plastic shredder machine, as illustrated in Figure 5, that will shred the collected plastic waste. This system will shred the collected plastic into little pellets that can be utilized to make plastic products at a later date.

*Figure 4: Shredder Pro(Precious Plastic, 2020) "Shredder Pro" by Precious Plastic is licensed under CC BY 4.0*

### 5.1.5. Injection Molding Station

Injection Molding is the process of melting the plastic pellets and giving them desired shape using a mold. This station will have an injection machine, shown in Figure 6, that will perform the injection molding process and create different recycled plastic articles.

*Figure 5: Injection Machine (Precious Plastic, 2020) ["Injection"]() by [Precious Plastic ]()is licensed under [CC BY 4.0]()*

## 5.2. Project Management Plan for setting up Plastic Recycling Center

This project is a multifaceted project that requires technical expertise and community integration to be able to fulfill its objectives. Consequently, it needs to have an organized approach to executing the plan. To provide a starting point, I created a Project Management Plan that lays out different steps required to start a Plastic Recycling Center on the WPI campus. This project management plan is intended for student-teams and advisors that would develop several aspects of the center. This plan can be found in Appendix 6.

## 5.3. Limitations of the Plastic Recycling Center

There are challenges that will need to be addressed in order to implement the recommended project management plan. Below are some preliminary research topics that will need more attention before executing the plan.

### 5.3.1. Funds and Location

Executing the Plastic Recycling Center (PRC) with the proposed plan will have many obstacles related to budget and location. The plan suggests acquiring funding from different grants available from WPI but may require additional sources. As a contingency, more sources of funds from WPI and outside sponsors should be Identified. In addition, finding a location for the PRC is another challenge. Currently, many student organizations are already struggling with finding spaces on campus; and there have been many student-led petitions sent to WPI administration to increase the number of study spaces on campus.

### 5.3.2. Lack of Proper Measurement of Recycling Rate

WPI plastic recycling rates would need to be more accurately established and monitored to effectively measure the impact of the PRC. As mentioned in the results, the lack of accurate measurements of the recycling rates makes it difficult to measure the impact of the project. Not being able to measure the impact will slow down the improvement of the PRC. Lack of documentation of its impact will also make gathering funds and human resources extremely difficult.

### 5.3.3. Lack of Resources

Even though there are skilled people in the WPI community to carry out the project, there may be a staffing deficit to oversee the daily responsibilities. The PRC would consist of three mechanical machines and would require a student attendant to oversee the operations of the PRC all the time. Student volunteers to run the PRC would be a good starting point but it is not a sustainable way of managing the PRC. The sustained functioning of the PRC may be accomplished by recruiting WPI departments or the office of sustainability to sponsor the PRC and hire student workers or find a student organization that would be willing to take over the management of the PRC.

## 5.4. Recommendations on using the PRC

Once the PRC is set up, it can be used in many ways to help raise awareness about not only plastic recycling but also about other environmentally sustainable practices. The following are some recommended ways to utilize the PRC other than its primary purpose of recycling plastic:

### 5.4.1. Technical and Art Workshops

The PRC will have machines to perform some standard manufacturing processes like shredding the plastic waste and injection molding. There are no courses at WPI that offer hands-on experience with these manufacturing processes. This gap can be filled by creating technical workshops that will teach students about these manufacturing processes, maintenance of the machines, and creating furniture or art pieces shown in Figures 7, 8, and 9. Other than technical workshops, art-making workshops can also be an option for students who do not want to learn about details of the recycling processes.

*Figure 6: Recycled Plastic Table (Precious Plastic Products, n.d.) "Products", Precious Plastic is licensed under CC BY 4.0*

*Figure 7: Recycled Plastic Flowerpots (Plastichunches-Beautiful Flower Pot, n.d.) "Beautiful Flower Pot", Precious Plastic is licensed under CC BY 4.0*

*Figure 8:Recycled Plastic Mini Planters (Recycled Plastic mini Planters, n.d.) "Recycled Plastic mini Planters", Precious Plastic is licensed under CC BY 4.0*

### 5.4.2. Incentives

Incentives are a popular way of encouraging the use of public centers like PRC. The recycling center should have a waste collection point that will collect plastic waste from the community and use it as a raw material for making plastic parts shown in Figures 7, 8, and 9. In exchange for raw materials, students can earn 3D printing credit or GoatBucks as an incentive. Students will be able to use this credit at any location on campus that will accept It. For example, this credit can be used at the Innovation Studio makerspace to buy materials for any project or pay for the 3d prints. This incentive will not only encourage the students to learn and sort recyclable waste but also help create a sustainable stream of raw materials for the PRC.

### 5.4.3. Integration with WPI Academic Projects

In the academic year 2019–20, WPI offered 119 and 30 sustainability-related undergraduate and graduate courses respectively; and 87 percent of departments on campus had at least one course focused on sustainability (Caton, O., 2020). In addition, this year, 80 Interactive Qualifying Projects (IQP) with the theme of sustainability were completed (Caton, O., 2020). These facts suggest the faculties' openness to work on Sustainability problems by creating projects that can be counted towards degree requirements. The same can be done with the PRC development.

Various projects can be created out of the process of setting up and running a Plastic Recycling Center on the WPI campus.

## 5.5. Recommendations beyond the PRC

Plastic waste is a major problem on the campus, and there are many other ways to tackle the issues found. These other potential solutions can be standalone or complement the proposed solution.

### 5.5.1. Research on Changing the behavior of Students

Lack of awareness about recycling has been a consistent theme in the plastic waste problem. To tackle the problem at its root there is a fundamental change necessary in the personal waste handling behavior of the students. This project did not incorporate research on changing student behaviors while proposing solutions to the problems. Finding different ways to change the behavior of the college students, specifically WPI students, will help with organizing different actions/activities to increase awareness about recycling in WPI students.

### 5.5.2. Increase emphasis on outreach

Following my attendance at the sustainability events, I saw that there was a lack of focus on encouraging students to participate in sustainability initiatives. The WPI Student Activities Fair, held twice a year, is the only occasion when most clubs/organizations try to recruit as many new members as possible. To maximize the effect of sustainability initiatives, the Office of Sustainability should collaborate with student clubs/organizations to host events specifically aimed at encouraging students to learn about and participate in various sustainability activities taking place on campus.

### 5.5.3. Evaluate current method for calculating recycling rate and propose one standard method

During the review of the Sustainability and annual waste audit reports, three sources of the recycling rate at WPI were found. These three sources included the one published in the Sustainability report, second reported to the Recyclemania competition, and third calculated during the annual waste audit. Having three sources made it difficult to draw conclusions about the state of recycling at WPI. Research should be conducted to evaluate the different methods used to calculate these recycling rates and recommend one standard way of calculating recycling rate at WPI.

# Chapter 6. Conclusion

This project focused on investigating WPI's plastic recycling practices and conducting a feasibility study for setting up a Plastic Recycling Center. Findings for this study included: A lack of awareness about recycling, ineffective efforts to raise awareness, and untracked plastic waste sources are responsible for low plastic recycling rates. The study also determined that setting up a Plastic Recycling Center on campus is a feasible solution for increasing awareness about recycling, tracking untracked recyclable plastic waste, and increasing community participation in sustainability practices. The methods used in the study provided many insights into the study of recycling practices at WPI. Though these methods were effective, there is still much work to be done. The results of this study provided evidence that the WPI community does not recycle all of its plastic waste while raising the question of how the WPI Office of Sustainability and student organizations related to sustainability can organize events that have more impact on the community's recycling behaviors. Future research should be conducted to develop ways to change the behavior of the community, especially a college community like WPI. The findings of this study also have the potential to impact college communities globally. I recommend setting up a Plastic Recycling Center to address the limitations of current recycling practices. As a deliverable, I created a project management plan for setting up the Plastic Recycling Center based on the findings of this project. This plan provides an essential starting point to a larger effort that can help the WPI community to attain its sustainability goal of creating graduates with a sustainability-oriented mindset who will be able to use their skills to generate sustainable solutions to global problems (WPI's Sustainability Plan 2020-2025 Overview, 2020).

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# Appendices

## Appendix 1. Field Data Collection 1 – $8^{th}$ WPI Annual Waste Audit

**1. Data Collection Method**

The waste audit consisted of two parts: sorting the contents of the trash bags and sorting the contents of the recycling bags. The waste was further sorted into different categories. For this project specifically, the waste was also sorted in Plastic Bottles since they can be recycled at a Plastic Recycling Center.

**2. Data Collected**

- Approximately 20 lbs. of plastic bottles were found in one day's trash
- 66% of the plastic bottles were found in the trash
- 34% of the plastic bottles were found in the recycling bin
- Approximately 50% of the recycling bin content was not recyclable

**3. Analysis**

- The recycling bins contained a lot of trash (50% of the recycling bin content was not recyclable), but the trash bins did not contain many recyclable items. This indicates that there is still confusion over what is recyclable, and it has increased since the last waste audit (previously was about 39%).
- The recycling rate has not improved between this year and last year, although the amount of waste was more than halved. This finding may not be a good thing though because the contents of the food waste bins were not considered in this calculation, meaning compared to last year, the recycling rate has decreased. Unfortunately, we are unable to calculate how much it has decreased since last year as we do not have the weight of this year's food waste.

## Appendix 2.1. Document Analysis 1 – Sustainability Report 2016 - 2017

# Document Analysis 1: Sustainability Report 2016 - 2017

**Document Name:** Sustainability Report 2016 - 2017

**Author:** Ashley Choi, Chemical Engineering, WPI Class of 2019

**Key Facts, Figures, and Quotes:**

- Operations
    - The 43 water bottle filling stations that are in our academic and residential buildings accounted for the consumption of nearly 140,000 gallons of water, while avoiding the use of nearly 1.1 million disposable water bottles.
    - The overall campus waste and recycling totaled 718.83 metric tons. This year's recycling rate is 22.9%, not including food diversion. The overall total has decreased by 3.4%.
    - This fiscal year, 58 metric tons of food waste was diverted from the waste stream. The recycle rate including all the donated food waste is 28%.
    - In August, a pilot test was conducted in Daniels Hall to improve recycling performance. Waste and recycle bins were placed in every residential room along with larger collection bins in the common areas. The student response was in favor of expanding the bin program in other residential halls.
- Academics
    - Majors:
        1. Environment and Sustainability Studies (ESS)
        2. Environmental Engineering (EVE)
    - Minor: Sustainability Engineering
    - 131 sustainability related courses offered
- Research & Scholarship
    - This year, WPI was awarded over $2.5M in new research grants across several areas of sustainability. Sponsors include the National Science Foundation, U.S. Department of Agriculture, Department of Energy, NASA, The Commonwealth of Massachusetts, and more.
- Community Engagement
    - Reusable Container Program - This program is a simple way to reduce waste and be sustainable by allowing the use of reusable takeout containers rather than non-recyclable plastic containers
- Miscellaneous

- The Princeton Review’s Green Schools 2016: The Princeton Review’s recognition was given to WPI for demonstrating a strong commitment to sustainability in academic offerings, campus operations, and student activities

## Appendix 2.2. Document Analysis 2 – Sustainability Report 2017-18

# Document Analysis 2: Sustainability Report 2017- 2018

**Document Name:** Sustainability Report 2017 - 2018

**Author:** Maya Sun, Computer Science, WPI Class of 2021

**Key Facts and Quotes:**

- Academics
  - At WPI, learning has always been about theory and practice, and sustainable solutions must incorporate both. On the one hand, advances in theory provide new insights into how to best address current sustainability issues; on the other hand, these ideas must be put into practice to have any effect.
  - 103 Undergraduate Courses related to the sustainability
  - 28 graduate courses related to sustainability
  - 8 Great Problem Seminars addressing sustainability, including topics such as Feed the World and The World's Water
  - More than 45 Global Project Centers and dozens of IQPs and MQPs focused on sustainability topics
  - Over 40 Lectures and seminars related to sustainability hosted both campus-wide and by departments from Fire Protection Engineering to Computer Science
  - WPI offers degree programs in Environmental Engineering (BS and MS), Environmental and Sustainability Studies (BA and minor), and a recently approved minor in Sustainability Engineering. In addition, sustainability is integrated into the curricula for many of the degree programs at WPI. Students can complete concentrations in sustainability in a wide range of fields, including Architectural Engineering, Civil Engineering, and Mechanical Engineering. At the graduate level, WPI offers certificates in Renewable and Distributed Power Systems, Water Quality Systems, and Water Resources.
- Research & Scholarship
  - Approximately $2.9 million in grants for sustainability-related research projects
- Campus Operations
  - Established in 2017, the WPI Green Revolving Fund finances projects that enhance WPI's sustainability through increased efficiency or reduced consumption. Each project is designed to produce savings which are reinvested in the Fund each year.

    - This year our audit revealed that 23% of the total waste was recycled, but there was a potential of 28% if all materials had been disposed of properly.
    - In February 2014, WPI set the goal to achieve a recycling rate of 44.5%, 10% above the national average of 34.5% reported by the EPA. This year, total waste including recycling was 735 metric tons, an increase of 2% from last year. The recycling rate was 29.3%, an increase of 7% from last year, but a decrease of 1% from the benchmark year of FY14.
- Community Engagement
    - To reduce the waste from items residents no longer want, WPI student Maria Daigle started Trash 2 Treasure (modeled on the program begun at UNH by Alex Fried) this past year. For a week at the end of the year, boxes were placed in each dorm - Morgan, East, and Faraday, among others - where students moving out could place their unwanted items such as appliances, clothing, fans, and calculators. Hundreds of items, including 744 pounds of clothing, were collected, and donated to the Hartsprings Foundation, where they will go to help local children in the Big Brother Big Sisters mentoring program.
- Miscellaneous
    - WPI's project-based curriculum provides WPI graduates the foundation for developing technological solutions to sustainability problems, and understanding the social and environmental impacts of their solutions
    - Sustainability - it's an idea that has been implicit in WPI's mission since 1865 and has been reiterated explicitly within the past decade.

## Appendix 2.3. Document Analysis 3 – Sustainability Report 2018 – 2019

# Document Analysis 3: Sustainability Report 2018 - 2019

**Document Name:** Sustainability Report 2018 - 2019

**Author:** Sarah O'Neil, Mechanical Engineering, WPI Class of 2020

**Key Facts, Figures, and Quotes:**

- Campus Operations
  - 1,156,522 water bottles saved from disposal through the use of water-bottle filling stations
  - This year, WPI reached an all-time high recycling rate of 32.7%, an increase of 3.3% in the past year. As WPI works toward reaching its goal of a 45% recycling rate, the implementation of new food waste and recycling containers has helped in the move toward more sustainable waste disposal practices.
  - On the Go reusable containers are available for students, faculty, and staff. Additionally, Plastic straws have been replaced with paper straws. On-the-Go reusable containers available at dining locations.
  - The Green Revolving Fund (GRF) provides funding for projects that increase WPI's sustainability by reducing resource consumption and increasing efficiency. The GRF, which initially was funded with a $1.5 million dollar seed by WPI, focuses on investing money into sustainable projects that will not only make WPI a greener campus, but will generate cost savings over time.
- Academics
  - Since the publication of the Sustainability Plan in 2012, the campus has seen a decrease in resource consumption as well as more popularity in sustainability-related course offerings and project opportunities.
  - 80% of academic departments offer sustainability-related coursework
  - 101 sustainability-related undergraduate courses
  - 50 sustainability-related graduate courses
  - 30% of Interactive Qualifying Projects with sustainability-related topics
  - 9+ Great Problems Seminar courses focusing on sustainability
- Research
  - 7,000,000 dollars, the estimated amount of funding and grants received for sustainability-related research projects this year
  - 7+ research centers and laboratories on campus focused on sustainability
  - Research lab for recycling: Center for Resource Recovery and Recycling (CR3)
- Community Engagement

- Over the course of the year, the WPI campus has seen an increase in the promotion of reusable straws. Resident advisors across campus, sororities (such as Chi Omega), and organizations (such as the Green Team) held events promoting the transition to metal or silicone straws. This transition is important as plastic straws are not recyclable because of the difficulty with their small size and the additives in the formulation to provide color. Because they cannot be recycled, they often end up in oceans where marine animals can mistake them for food, harming or even killing them.
- On Monday, April 8, the 8th Annual Electronics Recycling Drive (e-waste drive) was held on the Quad. The Green Team and the Office of Sustainability partner to run this event that allows students and staff to dispose of unwanted or broken electronics in an environmentally friendly manner. This drive allows for the collection of any electronics (except for large appliances). This year's e-waste drive collected 7,388 pounds of material. Data from the past three years of the e-waste drive is shown in the figure to the right.
- Over the course of the year, multiple clothing drives were held on campus, encouraging students to donate their clothes rather than throw them away. This practice of donating old clothes is important to sustainability as it reduces the quantity of clothing placed in landfills and cuts down the demand for clothing production as items are reused. With the incorporation of plastic fibers into many fabrics, the reuse of clothing is especially helpful for the environment as plastics take a long time to break down in landfills and are a major cause of pollution in oceans.
- For these reasons, students began a petition to eliminate the use of Styrofoam cups at Planet Smoothie. The petition, signed by hundreds of members of the WPI community, helped spur the switch from Styrofoam to recyclable plastic cups. While the corporate office of Planet Smoothie was already planning a transition from Styrofoam cups, the concern of the WPI community allowed our location to switch to locally sourced plastic cups ahead of the corporation-wide transition.
- Recylemania Recycling Rate - 41.493 %
- This year's e-waste drive collected 7,388 pounds of material.

- Miscellaneous
  - WPI Statistics:
    1. 15 Academic Department
    2. 2.7 million Square Feet of building space
    3. 96 Acres of campus

- The Sustainability Plan, created in 2012, has helped guide efforts to reduce natural resource consumption and take actions to reduce our impact on the planet and its inhabitants.
- Laurie Leshin - Concepts of sustainability are embedded in the fabric of our academic programs through coursework, projects, and research so our students can see the impact of their work and learn the intangible aspects of how their efforts affect humanity and the environment.

## Appendix 2.4. Document Analysis 4 – Sustainability Report 2019 – 2020

# Document Analysis 4: Sustainability Report 2019 - 2020

**Document Name:** Sustainability Report 2019 - 2020

**Author:** Olivia Caton, Environmental Engineering, WPI Class of 2021

**Key Facts and Figures:**

- Academics
  - 119 sustainability-related undergraduate courses
  - 30 sustainability-related graduate courses
  - 87% of departments with at least one course with related topics
- Projects and Research
  - Over 80 sustainability related IQPs were completed this year.
  - Computer Science and Robotic Engineer Assistant Professor Berk Calli focuses on robotic manipulation research. Recently, the National Science Foundation awarded funding for a multidisciplinary collaboration between WPI, Yale University, University of Washington, and Boston University. The focus is using robots to sort waste and recycling in facilities, which complements human workers by increasing workplace safety and process efficiency. WPI has multiple students and an MQP working on this project and includes installing a mock recycling line on the WPI campus. Calli and Sarah Wodin-Schwartz co-advised the Reusable Cup Machine MQP centering on making reusable cups more convenient and widespread. The MQP group designed a reusable cup dispensary that receives dirty cups from a consumer and returns clean cups ready-for-use.
- Campus Operations
  - 53 Water Bottle Filling Stations and 729,776 Single Use Water Bottles Saved
  - Recyclemania Recycling Rate = 43.29%
- Miscellaneous
  - The focus was elevated when former President Dennis Berkey created the President's Task Force on Sustainability, an organization to focus on incorporating a Sustainability Plan into the everyday function and decisions of WPI. This group has since been renamed the Sustainability Advisory Committee whose purpose is to evaluate the performance against the Sustainability Plan.
  - Sustainability is commonly defined as the ability to meet the needs of the current generation without jeopardizing the ability for future generations to meet their own needs. It has become a primary focus at WPI over the past 20

years, particularly with the development of WPI's Sustainability Plan and formation of the Sustainability Advisory Committee.

## Appendix 2.5. Document Analysis 5 – 8th Annual Waste Audit Report

# Document Analysis 5: 8th Annual Waste Audit Report

**Document Name:** 8th Annual Waste Audit Report

**Date Published:** April 11th, 2019

**Published by:** WPI Green Team and Office of Sustainability

**Document Description:**
This document describes how the 8th WPI Annual Waste Audit was conducted. It also analyses the data collected during the waste audit and creates a list of recommendations that can be used to improve WPI waste streams.

**Key Facts, Figures, and Quotes**:

- The goal of a waste audit is to separate the recyclables and the trash, determine recycling rates and identify areas in which WPI could improve its waste stream
- The total recycling rate found during this audit was approximately 19.23%. Potential recycling rate was found to be 19.27%.
- The recycling rate has not improved between this year and last year.
- The recycling rate has not improved between this year and last year, although the amount of waste was more than halved. This finding may not be a good thing though because the contents of the food waste bins were not considered in this calculation, meaning compared to last year, the recycling rate has decreased. Unfortunately, we are unable to calculate how much it has decreased since last year as we do not have the weight of this year's food waste.
- The recycling bins contained a lot of trash (50% of the recycling bin content was not recyclable), but the trash bins did not contain many recyclable items. This indicates that there is still confusion over what is recyclable, and it has increased since the last waste audit (previously was about 39%).

## Appendix 2.6. Document Analysis 6 – 7$^{th}$ Annual Waste Audit Report

# Document Analysis 6: 7$^{th}$ Annual Waste Audit Report

**Document Name:** 7th Annual Waste Audit Report

**Date Published:** November 15$^{th}$, 2017

**Published by:** WPI Green Team and Office of Sustainability

**Document Description:**
This document describes how the 7th WPI Annual Waste Audit was conducted. It also analyses the data collected during the waste audit and creates a list of recommendations that can be used to improve WPI waste streams.

**Key Facts, Figures, and Quotes**:

- The Campus Center had a recycling rate of 19%.
- The Potential Recycling Rate was 29%. This is also an improvement over the potential rate from previous years, however, it will not change unless students learn which waste goes into which bin.

## Appendix 3.1. Field Visit Notes – Innovation Studio

# Field Visit 1- Innovation Studio

**Date:** September 14th, 2020

**Time:** 11am - 12pm, 4pm - 5pm

**Key Observations:**

- This location is a combination of classrooms, study spaces, makerspace, labs, and food cafe.
- Majority of students in the building used this location as a study space and food space.
- Sources of waste include a 3D printing lab, makerspace, events, Auntie Anne's Pretzels and Planet Smoothies, and student consuming food.
- Sometimes the recycling and trash cans were filled, and students were not considering where to throw the trash.
- Makerspace has a location for leaving scrap/unused material, which is available to use for free. This diverted some waste from the trash bins to the scrap material bins.
- Some of the common trash in the bins around the building included printing paper, Dunkin Donuts paper bags, soda plastic water bottles, plastic food containers, paper food containers, and plastic cups.
- Most common recyclables found in the trash bins were Dunkin Donuts paper bags, plastic cups, plastic food containers.
- Recycle bins had very few items that were non-recyclable.
- Some recyclables in the recycle bins were not recycled properly. For example, plastic cups had drinks in them, and plastic food containers still had food in them.
- Fitzgerald Prototyping Lab was the key source of plastic waste in the building,
- The filament waste created during the 3D printing process was being thrown in both recycling and trash bins. There was an apparent confusion among students about how to handle 3D printing waste.
- The above observation was also true for the student workers in the building.
- Students received their finished 3D prints in a zip lock plastic bag.
- Makerspace has a box for recycling abovementioned plastic bags. These bags are then reused by the prototyping lab staff for handing out future 3D prints.

**Inferences:**

- The state of the trash and recycling bins suggested that there is a need for educating students on not only what to recycle but how to recycle the recyclable waste.
- There is a confusion on how to handle the plastic waste from the 3D prints. There is a need for directions on how to dispose of this plastic waste.

- Availability of the scrap bins and recycling box for plastic bags suggests that the building operations staff is also trying ways to increase the recycling rate in the building. In addition, they also suggest the building staff might be open to recommendations on how to improve the recycling in the building.

## Appendix 3.2. Field Visit Notes – Dunkin Donuts, Rubin Campus Center

# Field Visit 2 - Dunkin Donuts, Rubin Campus Center

**Date:** September 15th, 2020

**Time:** 9am - 10am, 4pm - 5pm

**Key Observations:**

- Dunkin Donuts is a students' and staffs' highly preferred location for early morning breakfast and afternoon snacks.
- This location was most crowded during the morning field visit. There was a constant line of 25-30 students waiting to place their order.
- In the evening, the crowd significantly reduces. There are approximately 15 - 20 customers every 30 minutes.
- Trash generated from Dunkin Donuts include paper bags, paper pouches (for holding the food item), plastic cups (in small, medium, and large sizes), plastic bottles, receipts, paper napkins, and small cardboard boxes.
- Except receipts and paper pouches, all other trash is recyclable even after use.
- Even though the paper bags have a note asking customers to recycle, the students ignored the note and still threw them in the trash bins.
- Abovementioned observation was true for the plastic cups too. Some recycled plastic cups still had liquids which it harder to recycle.
- There was no clear distinction between the trash found in the trash and recycling bin. It was clearly visible that the recyclable waste was not recycled properly.
- Dunkin Donuts also promoted the Reusable Mug program, which allowed students to bring their own reusable mugs/cups for getting any kind of drink.
- On the day of the field visit, Dunkin Donuts sold more than 700 orders.

**Inferences:**

- Considering the volume of the trash generated every day, this location should be of high importance for any reform related to recycling on campus.
- The state of the trash and recycling bins suggested that there is a need for educating students on not only what to recycle but how to recycle the recyclable waste.

## Appendix 3.3. Field Visit Notes –Food Court, Rubin Campus Center

# Field Visit 3 - Food Court, Rubin Campus Center

**Date:** September 21st, 2020

**Time:** 11am - 12pm, 4pm - 5pm

**Key Observations:**

- Food court is a prime location for students and staff to get lunch, dinner, and snacks.
- This location got very crowded during lunch and dinner time. Students had to line outside the food court because the space inside the Food Court was filled with three long lines for three different food stations.
- The waste generated from the Food Court includes plastic containers (different sizes), plastic bottles, cardboard boxes, paper wrappers, plastic wrappers, single-used plastic bags, plastic cutlery, paper napkins, and food.
- The bins surrounding the food court are different from the ones found across campus. The bin is a 3-In-1 bin, which includes separate spaces for recyclables, trash, and food waste.
- These bins also have graphics that direct students on how to use the bins effectively.
- Even though there is designated space for throwing food, students were still throwing the food in the regular trash space.
- Plastic bottles were the most common recyclable found in the trash bins.
- Food court has a reusable container program which allows customers to take out their food and return the container whenever they are done with their food.
- There was a lot more trash in the recycle bin because the commonly known recyclables like clear plastic containers and cardboard boxes were rendered non-recyclable because of food leftovers on them.

**Inferences:**

- Like Dunkin Donuts, this location should be of high importance for implementing and measuring the impact of any reform related to recycling.
- The state of the trash and recycling bins again suggested that there is a need for not only what to recycle but how to recycle the recyclable waste.

## Appendix 4.1. Interview Analysis 1 – Elizabeth Tomaszewski

| | |
|---|---|
| **Interviewee Name** | Elizabeth Tomaszewski (Liz) |
| **Position** | Associate Director of Office of Sustainability |
| **Day, Date** | Tuesday, April 2nd, 2019 |

**Interview's Objectives**

- Understand Plastic Recycling Process on campus
- Get any available data on plastic waste generated and recycled on campus
- Find sources of plastic waste on campus
- Understand Liz's expectations from the project like this

**Interview Questions, Responses, and Inference**

1. What happens to plastic waste generated on campus?
    - Liz's Answer - Waste Management Inc. collects all the trash and recyclables from WPI campus. Trash is sent to the waste to energy program where the trash is incinerated to generate energy. Recyclables are sent to the recycling facility for further processing.

2. What happens to the plastic waste that is thrown in the recycling bin?
    - Liz's Answer -
        a. Custodians pick up the waste, trash in white and recyclables in green trash bags.
        b. The waste from recycling bins is then taken to recycling compactors at:
            - Founders Hall
            - Morgan Hall
            - Rec Center
        c. Waste Management Inc. collects this waste every three weeks.
        d. Then this waste is sent to the recycling facilities, where the recyclables from the compactor are dumped on conveyors and are then sorted with the help of manual labor. The process of sorting is very labor intensive.
        e. Sorting process sorts of waste in different categories like plastic, glass, metals, etc.

f. After the plastic waste is sorted, it is recycled and processed to be sold as commodities to manufacturing companies.

- My impression - This is a combined impression for question 1 and 2.

Waste Management Inc. handles all the waste generated on campus. Recyclable waste that goes in the trash bins is never recycled. The amount of recyclable waste in trash bins can be minimized by increasing awareness about recycling in the community. As a result, there will be more recycling and an increase in the magnitude of benefits from recycling. The process of recycling is very long and includes manual labor and many third parties to convert the waste into a marketable product.

- How it helps my project - The presence of recyclable waste in trash confirms the community's limited knowledge on recycling and justifies the need to increase awareness about recycling in the community.

The fact that the recycling process takes a long time will support the argument that this project cuts out all the third parties and significantly reduces the time it takes from waste to a final product. This argument will become part of the feasibility analysis of this project.

3. Can sorting be done on campus?
   - Liz's Answer -Yes, the sorting can be done on campus if needed for any student research purpose.
   - My impression - The sorting is a labor-intensive process when done for the large amount of waste that is why it is not done on campus. But it can be done for waste generated at a specific location for a limited period.
   - How it helps my project - The sorting done by facilities will reduce the time it will take to audit, which will be carried out later in the project to find the sources of suitable plastic waste for the plastic recycling center.

4. Is there any data available on the plastic waste generated on campus?
   - Liz's Answer - Yes, there is data available on overall waste generated on campus (she sent me files with all the data).
   - My impression- After WPI switched to the single stream, the data is not segregated into categories, but it does specify the total recycled waste on campus. This data can be used to find the total recycling rate.

- How it helps my project - This data can be used to calculate the recycling rate that will be later utilized in the feasibility analysis.

5. Is there data available on plastic waste recycled?
   - Liz's answer - Yes, there is old data till 2014, before WPI went single stream recycling (she sent me all the files with data).
   - My Impression - The waste data before a single stream was recorded in different sections. Again, the data doesn't specify the plastic waste generated but can be used to predict its recycling rate.
   - How it helps my project - The predicted data can be compared with the improved recycling rate after implementation of the project.

6. What do you think are the drawbacks of the system? Is there any plastic waste stream that is not redirected to recycling?
   - Liz's Answer -

   This is a guess. Plastic waste generated in labs is not fully recycled because of handling issues, contamination, and inconvenience. You can work on finding ways to recycle plastic waste in these labs?

   - My impression - Since this is a guess, I need to have solid information on this section by talking to other people in charge (I addressed this question in the interview with Paul Mathisen and Terrence Pellerin)
   - How it will help my project - This could be a place where improvements can be made to the current system with the help of a plastic recycling center

7. I am planning to run an audit to identify sources of suitable plastic for the plastic recycling center. Which building is the best representation of plastic waste generated on campus?
   - Liz's answer -

   East hall - Since it is a building with upperclassmen and most of them don't have a meal plan, they buy their groceries. This will be a good place to do the audit.

   Rec Center - Majority of athletes and gym users use plastic water bottles and recycle them. The Auditing Rec Center might be able to give data suitable for your project.

- My impression - I agree with Liz's reasoning for both the buildings. I will be giving high priority to these buildings while deciding on the building to audit.
- How it will help my project - The data from these buildings will work as proof of existing suitable plastic waste on campus and has a potential to be a source of raw materials when scaling up the recycling center.

8. Can we separate the plastic water bottles for Waste Audit?
    - Liz's answer - Yes, they can be separated. We can set up different bins for plastic water bottles and separate data can also be taken from this plastic waste.
    - My impression - According to my knowledge, Liz had talked to the facilities about this, and plastic water bottles are going to be separated from the waste. This will provide data on plastic waste from the Library and Campus Center.
    - How it will help my project - This data will help us determine if the Library and Campus Center will provide good sources of suitable plastic waste.

9. What are some criteria to receive sponsorship through the Green Revolving Fund?
    - Liz's Answer - The criteria for a project to be considered and stand a good chance of receiving Green-Revolving funds are:
        - Economic Benefit to the institution because of the project
        - The project creates academic and research opportunities for students.
        - The project helps WPI to reduce its carbon footprint.

      This project covers all three requirements and will be a good contender for the funds.
    - My Impression - Based on Liz's understanding of the project, it qualifies for the Green Revolving Fund. I can address these criteria in my feasibility analysis.
    - How it will help the project - These criteria provide a robust framework for justifying the project's implementation.

10. What do you think of the Project? As a part of the community what do you expect out of this project?
    - Liz's answer - In the next 10 years, I want to be able to bring my plastic waste to this plastic recycling center and make a plastic chair out of it by myself.
    - My impression - Based on Liz's expression, she was very excited about the part where she could recycle and build a chair out of it by herself.

- How it will help the project - Gave an idea on how the community would like to use this plastic recycling center.

## Appendix 4.2. Interview Analysis 2 – Paul Mathisen

| | |
|---|---|
| **Interviewee Name** | Paul Mathisen |
| **Position** | Director of Office of Sustainability |
| **Day, Date** | Thursday, April 4$^{th}$, 2019 |

Key Findings:

1. The plastic bottles used in the Environmental Engineering labs are not recycled.
2. Daniel Sarachick, WPI EHS Coordinator, is the best contact for understanding the ways to recycle plastic waste from the Environmental and Chemical Engineering labs on WPI Campus.

## Appendix 4.3. Interview Analysis 2 – Mitra Varun Anand

| | |
|---|---|
| **Interviewee Name** | Mitra Varun Anand |
| **Position** | Makerspace Advanced Technology & Prototyping Specialist |
| **Day, Date** | Wednesday, September 25th, 2019 |

Key Findings:

- Mitra helped with creating and revising PLA waste handling guide that will be useful while setting up the Plastic Recycling Center.
- He helped with setting up 3D Printing waste data collection at the Fitzgerald Prototyping lab.
- He also provided some facts about 3D printing at WPI
    - Fitzgerald Prototyping Lab has total 17 3D printers, and they run for 13 hours on weekdays and 15 hours on weekends.
    - The Prototyping lab, in 3 years, has consumed 1.38 tons of 3D printing filaments.

## Appendix 5. PLA Waste Handling Guide

PLA waste generated in our case is predominantly in the form of 3d printing filament. If this waste is going to be stored for later use, it is very important to write a waste handling guide, since PLA is sensitive to its surrounding conditions. If not stored properly, PLA starts to absorb water in the air, and this can lead to problems during the 3D printing process. This humidity absorption can also lead to increased brittleness, diameter augmentation, filament bubbling, filament degradation, or easily breakable filament. To prevent this and to keep the PLA waste in best condition for recycling, following steps should be followed.

**Step 1:** Find an airtight container, heated dry box, or airtight plastic bag, which will keep the humidity away, that can hold the amount of waste generated.

**Step 2:** Make sure that the inside of the container is clean and no moisture inside, so that there are no other impurities that might affect the PLA waste.

**Step 3:** Put some silica gel packets in the container and then pour your waste in it.

**Step 4:** Make sure the container's lid is closed tightly.

**Step 5:** Label the container with the name of the plastic in it and waste collection start date. In this case, the name on the container will be 'PLA Plastic'.

Future upgrades for plastic waste containers:

- Install humidity sensor on the storage box. Make sure the humidity of the plastic is constant, below 15%. PLA plastic degrades eventually, and to use it we must keep the humidity levels constant.
- Microwaveable silica gel to remove humidity from the waste container. - Cheaper option. Facilities might be able to provide some silica gel packets.
- Find how long silica gel takes to bring the humidity of all the PLA waste to constant level. Usually, it takes two hours from 60% to 5%.
- Find how long one silica gel packets last

## Appendix 6. Plastic Recycling Center – Project Management Plan

### 1. Project Management Approach and Governance

Agile Project Management will be used for the project. Agile project management promotes iterative development. Since the project involves WPI community members as users, getting their feedback and making improvements through multiple iterations of the project will help achieve the high-quality results by the end of the project.

The project will have a team of 6 students: two mechanical engineers, two electrical engineers, and two systems engineers. Mechanical engineers will be responsible for designing, building, testing, and assembling the mechanical parts required for recycling machines. Electrical engineers will connect and test electrical circuits of the machines. System engineer will act as a project manager and make sure that the finalized version of this project plan is being followed throughout the period of the project. The number of team members are not fixed since this will be an ongoing project. This project is also open for volunteers to join.

Worcester Polytechnic Institute (WPI) will be the key sponsor of the project. The funding for the project will be acquired from the different departments of WPI.

### 2. Project Scope

This project will focus on starting the Plastic Recycling Center on WPI's campus and finish the instructions manual and safety guide required to effectively use the Plastic Recycling Center. This Plastic Recycling Center will provide a location to recycle plastic waste through injection molding. The goal of the center is to increase the plastic recycling rate at WPI through increasing the amount of plastic recycled and by educating the WPI community about plastic recycling. Though this is an ongoing project, the first period of the project will last for three academic terms of WPI. Three terms is usually the duration of a WPI capstone project. This project can be used for both Major Qualifying Project and Interactive Qualifying Project. Getting academic credit by working on the project will motivate students to produce higher quality work within the assigned deadlines.

### 3. Project Deliverables

There are three key deliverables:

1. Start a Plastic Recycling Center
2. Machine Instructions Manual
3. Safety Guidelines Document

### 4. Work Breakdown Structure (WBS)

WBS will be used to make sure that the team does not creep out of the scope of the project. I will also be used to create a schedule outline and assign deadlines for different tasks. Breaking down tasks into smaller tasks will help the agile project management by allowing the team to prioritize and assess the time required to finish the task more accurately.

| Major Tasks | Tasks | Subtasks |
|---|---|---|
| 1. Project Planning | 1.1. Project Plan Revision | 1.1.1. Scope |
| | | 1.1.2. Milestones |
| | | 1.1.3. Deliverables |
| | | 1.1.4. Stakeholder Analysis |
| | 1.2. Project Plan Additions | 1.2.1. Communication Plan |
| | | 1.2.2. Budget |
| 2. Find Location | | |
| 3. Gather Funding | 3.1. Project Proposal | 3.1.1. Project Pitch |
| | | 3.1.2. Presentation Slides Deck |
| | 3.2. Submit Funding Requests | 3.2.1. Green Revolving Fund |
| | | 3.2.2. Makerbucks |
| | | 3.2.3. Tinkerbox |
| | 3.3. Find More Sponsors | 3.3.1. Email Academic Department |
| | | 3.3.2. Email On-campus Clubs |
| | | 3.3.3. Student Government Organization |
| 4. Plastic Waste Collection Point | 4.1. Clean the location found | |
| | 4.2. Set up the space | 4.2.1. Large and small bags/containers |
| | | 4.2.2. Mark bags/containers with Plastic types |
| | | 4.2.3. Add Washing Station |

| | | |
|---|---|---|
| | | 4.2.4. Get Weighing Hook |
| | | 4.2.5. Add plants for decoration (optional) |
| 5. Recycling Machines | 5.1. Plastic Shredder | |
| | 5.2. Injection Molder | |
| 6. Safety Guidelines | 6.1. Find Potential Risks | 6.1.1. Handling Plastic Waste |
| | | 6.1.2. Using Plastic Shredder |
| | | 6.1.3. Using Injection Molder |
| | 6.2. Create Guidelines | 6.2.1. Write Guidelines |
| | | 6.2.2. Get them reviewed from WPI Environment Health and Safety (EHS) |

## 5. Milestone List

| MILESTONE | DESCRIPTION | DATE |
|---|---|---|
| Finalized Location | Got a specific room on campus to start the center | TBD |
| Gathered required funding | Received approvals from the sponsors | TBD |
| EHS Approval | WPI EHS has approved the machine designs | TBD |
| Setup Plastic Waste Collection Point | Plastic Collection Point where WPI community members can drop off plastic waste has opened | TBD |
| Built Plastic Waste Shredder | Finished building and testing plastic shredding machine | TBD |
| Built Injection Molding Machine | Finished plastic injection molding machine | TBD |
| Instructions Manual | Instruction manuals about how to use the machines of the center are written and reviewed | TBD |
| Safety Guidelines | Safety Guidelines documents are written and reviewed by EHS | TBD |

## 6. Communication Within Team

Different communication methods should be discussed and set up between the parties involved in the project. For effective communication, the following questions should be discussed.

- Which mode of communication to use (Email, Slack, Microsoft Teams, etc.)?
- How frequent should communication be?
- What is the latest time by which the project team or sponsor should expect the reply by?
- Who will be the contact person for each party involved in the project?
- When and where should the team meetings be organized?