CIT Plastic Upcycling Facility

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CIT: Creating A Plastics Assessment and Upcycling Facility

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Abstract

The goal of this project was to write a design proposal for a plastic upcycling facility located on CIT's campus. Through interviewing recycling personnel, hands-on data collection, and working alongside CIT officials, we developed five plastic recycling and reduction posters to be displayed around both schools targeting all age groups, along with a detailed plastic guide, and a complete project proposition, including a site layout and specific machinery information, to give to CIT.

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Authorship

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Executive Summary

Plastic pollution is currently one of the world's most pressing environmental concerns. The Costa Rican population is extremely conscious of the plastics they consume. The country currently holds multiple laws restricting the use of certain types of plastics, specifically styrofoam and single-use bags. Despite having regulations in place and goals to be a carbon-neutral country, Costa Rica struggles with disposing and repurposing plastics, much like the rest of the world. Due to the plastic's harsh chemical composition, they have lifespans of 20 to 500 years before fully decomposing. However, even with this lengthy lifespan, plastics are rarely recycled, with 80% of the global plastic being incinerated or placed in landfills, and 98% of Costa Rican plastic ending up in landfills, oceans, and the ecosystem in 2019 (Zuñiga, 2019).

The Center of Research and Technology (Centro de Investigación y Tecnología or CIT) is a technical school with students ranging from pre-school to high school in Heredia, Costa Rica. The school educates its students in a multitude of ways through science, technology, engineering, art, and mathematics, with the goal of thoroughly preparing them to enter the workforce right after graduation. Not only does the campus house all three levels of schooling, but it also has a veterinary hospital in addition to fields for organic crops, a restaurant, and a small organic grocery store, all working with the company Armonía. Due to its massive 13-acre campus, CIT can rent out the extra space to smaller companies, including a local municipal center that collects waste from the surrounding town. CIT, always looking for ways to reduce waste and its carbon footprint, aimed to create a plastic upcycling facility on its campus that could produce new products to use in-house or sell for profit.

To properly achieve this goal, our team researched upcycling and plastic consumption at CIT and their sister school, New Hope. We compiled research data through our plastic audit, which included interviews with waste personnel at each school and hands-on collection of plastic waste samples. This data gave us a better understanding of the current recycling system and the quantity of plastic we would be dealing with. Beyond the audit, we also got involved with the Green Team at New Hope, a group of students of all ages passionate about solving the plastic pollution problem. With them, we had an interactive presentation during which we showed them the progress of our project and talked about plastic usage in our daily lives. This interaction was valuable to understand their desire to create a clean earth, but also be able to understand their capacity to get involved.

Once our team completed the plastic audit, we then moved on to research and later developed a system. CIT has been processing about 100 metric tons of plastic annually—a quantity that makes industrial-sized machine processes impractical. According to our estimates, industrial shredders would only be running for about six hours per month with this current amount. Instead, we downsized machinery to a shredder that processes 60-80 kilograms of plastic per hour. The smaller shredder would leave room to process more plastic as this machine would run for about 130 hours per month, out of a maximum of 160 hours in the average work month. Once the plastic is shredded, we found it best to heat-press it into sheets. In doing so, CIT can use the sheets like wood, as they can be shaped, cut, and drilled to be used in many ways. The sheet pressing also uses the most plastic out of our three main methods, pressing, injection, and extrusion, making it the most efficient machine to start with. With this currently proposed system, CIT could process about 9000 kilograms of plastic per week, with half pressed into sheets and the other half sold back as shreds. Using our team's proposed machinery, CIT would be able to reduce the amount of plastic being thrown away by an estimated 90 percent.

We came to a few important conclusions and recommendations through the research of equipment and location for this recycling system. The main suggestion is to have the system implemented at CIT. With a simple $10,000 investment, it is economically feasible as this system would pay itself off in less than two months of operation if CIT sold all the sheets. However, the economic side is not the primary focal point, but instead that CIT would be reducing its plastic waste by about 90 percent. Our proposed system brings CIT closer to its waste recycling goal and helps fight the global plastic crisis. We recommend that CIT first purchases a 60-80 kg per hour shredder and a sheet press. These machines are cost-efficient and best suited for the amount of plastic waste CIT collects. We also suggest that CIT buy or build a cleaning station to remove labels and contaminants before shredding. In the future, CIT can upgrade the facility to process more plastic and generate new products. We recommend adding extrusion or injection molding equipment to create benches, building blocks, tiles, flowerpots, and more.

Throughout our project, we wanted to ensure our project was ethical. Thus, we needed to address and consider a few specific aspects. The first concern was that, unfortunately, we are just extending the life of plastic but not eliminating it. While CIT can repurpose and prevent plastic from ending up in landfills and the ecosystem, this is only a temporary solution for a long-term problem. The next concern was that the machinery could be too loud. Originally, when investigating industrial equipment, the decibel levels of the facility would be around 110 dB— 25 dB higher than the legal working limit. To combat this, we researched many ways to reduce noise, including acoustic insulation and quilt panels. However, the solution came when we downsized the machinery into a shredder running on a much quieter five-horsepower electric motor. Lastly, our project was meant to be supplemental to the existing sales of the current municipal center. We did not want to undercut or eliminate their jobs, so instead, we proposed buying their waste from them, ultimately giving them more money in sales and a much more stable income.

Ultimately, our team developed critical recommendations for CIT to create an upcycling facility that will work efficiently and safely. First, we found specific equipment to be employed in CIT's facilities. The machines we suggested can be shipped to Costa Rica and have extensive guides that we also provided to ensure that the staff is knowledgeable in using them. We also offered CIT a proposed layout of the site. Our layout systematically ensures the most is made of the space while also moving the plastic in a "U" shape for efficiency. Lastly, our team researched and recommended possible ways this project could expand. Given the tenacity of the CIT community, we expect them to not only implement our project but to develop it into an even larger tool to combat plastic pollution in Costa Rica.

1.0 Introduction

Plastic pollution is one of the most pressing environmental issues across the world. Finding a way to upcycle plastic would create a solution to reduce plastic waste while developing new products. CIT is a pre-k through 12th-grade school that is one piece of a large multi-use facility that includes a veterinary hospital, pool, and organic farm. This multi-use facility, along with its sister school Nueva Esperanza (New Hope or NH), is looking to expand and add a plastic upcycling center, one that would reduce and reuse some of the plastic waste created by the schools and community. In doing so, CIT aims to set a precedent for businesses and schools that wish to become more environmentally conscious. In this report, we explore the global plastic epidemic, the local plastic problem, and provide a detailed proposal for a plastic upcycling plant for both the CIT and New Hope communities.

2.0 Background

To begin the discussion of plastics and pollution, we introduce the Costa Rican environment and its history. We then present the issue of plastic waste and its abundance locally and globally. Next, we discuss the several types of plastic and how these types influence the plastics' ability to be recycled. Additionally, we examine methods of plastic upcycling, mainly through plastic shredding. We also reviewed the recycling centers and the municipal-owned waste business on-site to see how they dispose of plastics. Finally, we discuss CIT and Nueva Esperanza (New Hope or NH) schools, their values, and the goals that they have in place—acting as models for Costa Ricans in the age of environmentalism.

2.1 Costa Rican Environmental History

Costa Rica has historically had an excellent environmental footprint. In 1949, Costa Rica abolished its military to become a peaceful country after a violent civil war in 1948. The president at the time, Jose Figueres Ferrer, promised to dedicate the budgeted funds for education and culture. Later, in the 1970s, Costa Rica began passing legislation and social programs to promote sustainability. The culture of Costa Rica is so deeply ecological that in 1994 it amended its constitution to read that it is the right of "every person […] to a healthy and ecologically balanced environment." Costa Rica's president from 2018-2022, Carlos Alvarado Quesada, said in his inaugural speech that he would make Costa Rica the first carbon-neutral country by 2021. While this was not the case, the legislation passed during his presidency ensured that Costa Rica would become carbon neutral by 2050 per the Paris Climate Accords. Costa Rica's environmental credentials are impressive: more than 98 percent of its energy is renewable, forest cover now stands at more than 53 percent after painstaking work to reverse decades of deforestation, and the Costa Rican government has protected around a quarter of the country's land by turning it into national parks and reservations. (Unep 2019) Ecologically, Costa Rica has historically focused on three main points:

- Maintain its biodiversity and natural environment.
- Reduce carbon emissions.
- Produce its energy through renewable means.

While these are all great ways to reduce a country's pollution, there is yet to be much motivation to manage plastic pollution throughout Costa Rica.

2.2 Plastic Waste: Abundance Locally and Globally

Plastic waste is one of the most significant contributors to global pollution. Plastics can be recycled and repurposed to reduce waste, yet in 2018, the recycling rate in the United States was only 8.7%. Every year humans produce tons of plastics; however, we only recycle a tiny portion of that. Many of these plastics are found in nondurable products, not intended for prolonged use (US EPA, 2017). If we recycled these products instead of depositing them into landfills after their usage, we could use the plastic in other products.

2.2.1 Global Plastic Waste

The “Plastic Problem” is not a new one—nor is it a local one. The abundance of plastic waste and the question of what to do with it is widespread. Globally, the amount of plastic waste produced annually in 2019 was 460 million tons. The approximate percentage of global plastic waste put into recycling in the year 2015 was only 19.5%. Humans discarded over 50% and incinerated the remainder, releasing harmful fumes into the air (Ritchie & Roser, 2018). According to the UN, “The burning of plastics releases toxic gases like dioxins, furans, mercury and polychlorinated biphenyls (better known as BCPs) into the atmosphere, and poses a threat to vegetation, and human and animal health.” (*Plastic Bag Bans*, 2019) These numbers, along with the emitted toxins, are staggering, causing alarm globally, especially in the country which takes being “green” so seriously—Costa Rica.

2.2.2 Local Plastic Waste

In 2017, the Costa Rican government launched a national initiative to phase out single-use plastic by 2021(Zúñiga, 2019). According to the Costa Rican Ministry of Health, in 2018, Costa Ricans dumped approximately 550 tons of plastic waste into various locations. Following this, they only brought 9% of this renewable waste to a recycling facility; most dumped waste was in the ocean (Smith, 2021). Although this 2017 initiative has reduced some plastic consumption, Costa Rica still produced 564 tons of plastic waste each day in 2019, with 98% ending up in landfills, sewers, rivers, and, again, the ocean (Tico Times, 2019). These numbers are alarming, considering Costa Rica’s many initiatives to help the earth. Suppose the CIT community can expand its recycling percentage, let its newfound plastic upcycling center benefit the area, and teach others how to help. This could lead to a momentous change in the nation’s recycling rate.

2.3 Plastic Waste Types

Not all plastic products are created equal. In many countries, including Costa Rica, plastics are marked with the Plastic Identification code or RIC (Resin Identification Code). This code includes the recycling symbol with a number from one through seven on it. This symbol does not mean that the plastic is recyclable. Instead, it indicates the type of plastic; not all plastics are practical to recycle. For example, Styrofoam is not commonly recycled because it is mostly air, and it is not economical nor environmentally friendly to ship large volumes of air to a recycling facility. Another material infrequently recycled is plastic bags, as they often get tangled in machinery and require a unique recycling process that many plants do not provide. (Miller, 2023) Table 1 lists the 7 RICs or plastics, their scientific and common names, examples, and recyclability.

Code	Name	A.K.A.	Common Examples	Recyclability
1	Polyethylene terephthalate	PET PETE PETG	Soda Bottles, Fruit juice, Mineral Water containers, Cooking Oil containers, Peanut Butter Jars	Commonly and easily Recyclable
2	High-Density Polyethylene	HDPE	Milk Jugs, Cleaning Products, Shampoo Bottles, Detergent Bottles.	Commonly and easily Recyclable
3	Polyvinyl Chloride	PVC Vinyl V	Bubble foils, Sweets and fruit trays, Foam board, Pipes, furniture, toys.	Non-recyclable. Consider Upcycling
4	Low Density Polyethylene	LDPE	Shopping bags, resistant sacks, crushed bottles, fresh produce, bread, newspaper bags	Not Usually recycled, becomes floor tiles and shipping envelopes.
5	Polypropylene	PP	Furniture, luggage, toys, linings and borders for cars, Ketchup, Medicine, yogurt, sour cream, margarine, straws, bottle caps.	Becoming more commonly recycled
6	Polystyrene	Styrene Styrofoam PS	Toys, Hard Packing, Fridge trays, CD cases, Costume jewelry, Styrofoam cups, packing peanuts, coolers	Uncommonly recycled, becomes egg cartons, take out containers.
7	"Other" Acrylic, Polycarbonate, Polylactic, Nylon, Fiberglass Mixtures of 1-6 And or/ Unrecyclable Materials		These plastics typically cannot be recycled. To determine what they are, refer to the labels and manufacturer. Consider upcycling. Acrylic and Polycarbonate Thermoplastics are particularly good for upcycling because they can be reheated without destroying their properties.	

***Table** 1: Resin Identification Code Guide.*

Note. Adapted from *Your guide to plastic recycling symbols,* by Acme Plastics Incorporated, 2023, (*https://www.acmeplastics.com/content/your-guide-to-plastic-recycling-symbols/*) and *1, 2, 3, 4, 5, 6, 7: Plastics recycling by the numbers,* by Miller Recycling Corporation, 2023 (*https://millerrecycling.com/plastics-recycling-numbers/*)

2.4 Methods of Upcycling

Upcycling is reusing and/or repurposing an item to create a new product of higher value or quality. This differs from standard recycling where plastic products are broken down and reformed into the same thing. Most plastic upcycling begins with shredding raw plastic waste. Shredded plastic can be used for injection molding, extrusion, heat pressing, and chemical processes to make new products of higher value. Many companies are pioneering sustainability by incorporating upcycled materials into their products.

2.4.1 Shredding of Plastics

Many options for plastic shredding systems depend on two main factors: types of plastic and amount of plastic. Companies see the interest in granulating plastic waste produced on-site and manufacture machinery to help people complete the process independently. While we did not design the machine itself, we helped CIT determine which machine would best suit them based on the data we collected.

Before any plastic can be processed, it needs to be prepared. Plastic must be cleaned and dried before it can be recycled to ensure that there are no problems as it goes through machinery and that the granules are pure plastic. Additionally, the plastics need to be sorted by type and color. Plastics of different types require different processes to upcycle, so proper separation measures must be taken for the system to continue running smoothly. Additionally, some colors of plastics are less marketable and more challenging to process; if the granules were mixed colors, the product might not be desirable to the consumer, but if the granules are separated by color, they can appeal to more markets.

Once CIT takes in the materials, different parameters need to be considered. Within the shredder there is a series of blades that cut the plastic into small pieces. However, due to different plastic properties, different plastics have different abilities to be shredded. Some of the more rigid ones may need to be shredded twice to become small enough. The placement of these blades matters depending on the rigidity of the plastic. If the intake were primarily soft plastics (plastic films), the blades in the unit would have to be closely mounted at high angles and be very sharp for the most efficient and clean cuts. Suppose the plastic is of the more rigid variety, the opposite is then recommended: knives mounted at low angles with blunt edges. The rotor in the unit also varies depending on the material being processed; firmer plastics typically require a solid, staggered, or segmented rotor system, and plastics that are lighter and more sensitive to heat use usually require an open rotor system for ventilation purposes.

The type and quantity of plastic also affects how the material is loaded into the system. Hopper systems are loading density-dependent and typically are used for more rigid plastics but also accept soft plastics, making this a commonly used and flexible option. Side-feeding machines avoid underloading or overloading with more ease, allowing maximum efficiency. There are also systems designed explicitly for soft plastics that combine the steps of loading and compacting, so the process minimizes time.

One of the most common ways to upcycle plastic is to use a granulator instead of a shredder, however the main limitation of a granulator is the sound pollution that it provides. Most granulators operate at a level of 114 dB, similar to the sound of a gunshot or the operating noise of a chainsaw. Costa Rican labor laws mandate that in working environments over 85 dB, workers wear personal protective equipment (PPE) and partake in routine hearing tests (Arenas & Suter, 2014). Due to these high levels of sound, we then moved into using smaller-scale shredders. The specific machine we are now proposing operates with a five-horsepower electric motor, reducing sound levels to much safer and more sustainable levels. However, we are still proposing and highly suggesting that employees wear PPE, including ear protection.

2.4.2 Trex

With different plastics come different solutions. When speaking to CIT staff, the idea of producing “plywood” from plastic waste arose. Upon doing some research, we discovered that some brands are already doing something similar, and they use some infrequently recycled plastics to do so. The brand Trex, for example, prides itself on being eco-friendly by using recycled plastic film (grocery bags, newspaper sleeves, etc.) and reclaimed wood to produce durable decking material. Because of this system, Trex has become one of the largest plastic recyclers in the United States, saving one billion pounds of plastic film from going into landfills each year. If CIT can employ a process like Trex, they can have a monumental impact on their community and the country.

2.4.3 Sheet Press

After the plastic is shredded, there are many ways to recycle it. One option is to use a sheet press to turn the plastic particles into one cohesive board. All sheet presses are made up of the same components, a mold that will give the plastic its shape as its being pressed and a steel sheet that, before use, must have silicone oil added to its surface. A heating plate will heat the mold, and bottle jacks to compress the mold. When using a sheet press, it is recommended that you have a prep table of the same height as your sheet press so you can load the plastic on the steel sheets in the mold and slide it onto the sheet press to avoid human contact with the hot plate. Similarly, to speed up the production of the plastic sheets, it is recommended that the sheet press station has a cold press that can take the sheets and keep them under pressure while they cool off to maintain the sheets' integrity; please note that the term cold press does not mean that the press will cool the boards off faster with refrigeration but instead press is not heated.

2.4.4 Others

CIT and brands like Trex are not the only companies focused on plastic upcycling. Many other companies are concerned about their ecological footprint and have started upcycling to reduce it. Even big brands like Adidas have started using upcycled plastic to produce shoes. In the clothing industry, Patagonia makes its jackets and other products from materials made of 84% recycled plastic (*What We're Doing*, 2019).

Beyond the realm of fashion, Michelin has begun making tires out of recycled plastic by taking recycled bottles and treating them with an enzyme. The "e-Primacy" tire is the world's first carbon-neutral tire with an extremely high thermal stability and breakage resistance. They use the depolymerization method, which uses an enzyme to break down the polymer and make the plastic more pliable (Taylor, 2021). Other companies like Fab Habitat use PET and polypropylene plastics to create new rugs, Shini USA uses eco-friendly building materials featuring recycled plastics, Suga creates new yoga mats from recycled plastic products like wetsuits, and Green Toys creates children's toys from recycled milk jugs ("10+ Companies Creating Recycled Plastic Products," 2021). Although these are only a few, endless companies create products from recycled plastic.

2.5 School Values, Goals, and Information

CIT (Centro de Investigacion y Technoligica) is a pre-k through 12th-grade school located in Heredia, Costa Rica. It is a technical and scientific school focusing on STEAM (Science, Technology, Engineering, Art, Mathematics) and ecological awareness. Their mission is to prepare their students to competitively enter the workplace while also developing their personal values and professional lifestyles. They do so by using the best academic and technological practices, such as focusing on developing their students' programming, science, robotics, and cyber security abilities. In addition to working with CIT, we are also working with their older sister school, Nueva Esperanza, or New Hope—a more traditional private school. Here we can gather better information from systems already in place compared to the younger CIT school.

2.5.1 Values and Programs

CIT has a set of core values listed as loyalty, creativity, and solidarity. Loyalty creates relationships of honesty and respect between students and teachers. Creativity is the concept of generating innovative ideas and concepts through creative thinking. Solidarity is the sense of unity through a series of common goals or interests, but it also refers to the social ties that bind the members of the school to the surrounding community.

The CIT school has a written mission statement: “prepare students with quality and innovation using the best academic and technological practices. Forming integral beings to competitively enter the work force, personally and professionally.” In a comparable manner to its country, the CIT school values its local environment and how that ecosystem can impact or be impacted by its students or community. (Quienes somos - Complejo Educativo CIT, n.d.)

The vision of CIT is “to be a proactive educational center with academic and technical excellence in order to become a national agent of development.” Traits of independence, professionalism, resourcefulness, and knowledge stem from the school’s mission and vision. In every program established in the school, intensive thought and expertise are put into the design. When outside groups, such as the WPI (Worcester Polytechnic Institute) Interactive Qualifying Project team, Microsoft, Amazon Web Services, or Fujitsu, are to work with this establishment, they must adhere to these exact expectations and carry out the school’s values (Quienes somos - Complejo Educativo CIT, n.d.). A simple photo of each sponsored lab is shown in Figure 1.

***Figure** 1: Microsoft, AWS, and Fujitsu Labs at CIT.*

CIT also has initiatives on bilingualism, scientific exploration, and technological development. Students are aware of how each project can impact the world around them and the lives of its inhabitants (Quienes somos - Complejo Educativo CIT, n.d.). For each section of their learning, the students are instructed on how this knowledge is necessary for the foreseen global problems.

Similarly, Nueva Esperanza, in its more traditional education, has a focus on bilingualism and prepares its students to enter a competitive work environment. With the values of respect, responsibility, and excellence, Nueva Esperanza empowers students to have a positive impact on their surroundings.

2.5.2 Goals

CIT uses technology and ecological awareness methods to prepare its students for the workplace. The school has explored becoming more environmentally friendly and looks to find ways to upcycle its plastic waste into new products. In time, they intend to extend this project to Nueva Esperanza and the communities surrounding both schools. In doing so, they will set an example for other schools and businesses to follow and become more eco-friendly.

Figure 2: The Veterinary Hospital at CIT, Servicing the Surrounding Community.

2.5.3 Campus Information

Between New Hope and CIT, the schools have a total enrollment of 2,200 students. At CIT, students are on campus every day during regular school hours. At New Hope, students must alternate classes due to limited classroom space. CIT has a 13-acre campus that features a restaurant, El Cacaotal, shown in Figure 4, small scale market that sells their produce, a veterinary hospital, shown in Figure 2, a full-sized swimming pool, and a school with classrooms for students from preschool to the 12th grade. CIT also has immense amounts of unused land and buildings that could be perfect for implementing our project. Space is not a limiting factor at CIT, but it may be at New Hope.

***Figure 3**: One of the many crop fields located on the CIT campus. All their produce is grown organically on site.*

Figure 4: *El Cacaotal: A restaurant located on CIT's campus.*

One of the most interesting pieces of CIT is that with all this open space, they rent out warehouses to local companies. A prominent one is the municipal recycling center that collects plastic and trash from the local community of Belen, sorts, and then sells the plastic to buyers, shown in Figures 5 and 6.

***Figure 5**: El Centro de Acopio (Collection Center) Exterior.*

***Figure** 6: El Centro de Acopio (Collection Center) Interior.*

This is important to understand because it is a third-party source that we are now working with on CIT property. However, the third-party recycling source has the same visions and goals as CIT: reduce plastic waste being put in the trash while creating a new product of value that is appealing to consumers.

In contrast, New Hope has a much smaller recycling center that processes more minuscule amounts of plastic, see Figures 7 and 8. Compared to the CIT collection center, the New Hope center processes less waste as they only take trash from the families of their students and the waste from the school campus. Also, unlike CIT, this space is run by New Hope Waste Management personnel. The trash from NH is typically forwarded to the collection center at CIT.

***Figure** 7: New Hope Collection Center Exterior.*

***Figure 8**: New Hope Collection Center Interior.*

2.5.4 The Municipal Collection Center

The municipal collection center on CIT's campus is a third-party recyclable waste collection and sorting center paid for by the municipality of Belen, a town in the Heredia Province of Costa Rica. The municipal collection center employs six people and takes all the recyclable waste from Belen. The waste is collected every Monday, Wednesday, and Thursday from houses, hotels, and businesses in the area. They separate plastic, cardboard, aluminum, and glass from the waste. However, trash is collected with these materials, which must be sent to landfills.

The municipal collection center has no machinery and must sort through all waste manually. They lack machinery for crushing glass and other materials that a machine could easily compact. They sell as much recyclable waste as possible to private companies and have no contractual obligations, allowing them to sell waste to any company willing to buy. They distribute the profits they make from their sales to the workers on a semi-commissioned basis. Currently, the collected plastic waste does not need to be washed, as the purchasing companies do not require it. Of all the plastic waste collected by the municipal collection center, they must throw away about 25% as it is not the desired plastic type of the current buyers. Since they discard potentially recyclable plastic, we saw this plastic as the key to creating a new, sellable product in the form of shreds and sheets. We concluded that focusing on the plastic they throw away was the most environmentally sustainable and profitable option, as we are not taking away from the plastic they sell.

3.0 Methodology

This project aims to contribute to developing a plastic upcycling facility at the CIT school in Heredia, Costa Rica while working with their sister school, Nueva Esperanza (New Hope), to develop their recycling facilities. To achieve this goal, we have broken it down into three key steps:

1) Analyze and compile recycling data from past years at CIT and New Hope.
2) Implement a system solution to upcycle plastic waste.
3) Develop educational programs from our implemented solutions to engage students.

The following sections in this chapter will outline and explicitly define our plan to achieve this goal.

3.1 Assess Current Plastic Waste Management System

In addition to the plastic audit, our team assessed both schools' current systems for plastic waste collection. Our formerly researched waste solutions considered specific types of plastic; therefore, we needed to know all existing collection methods.

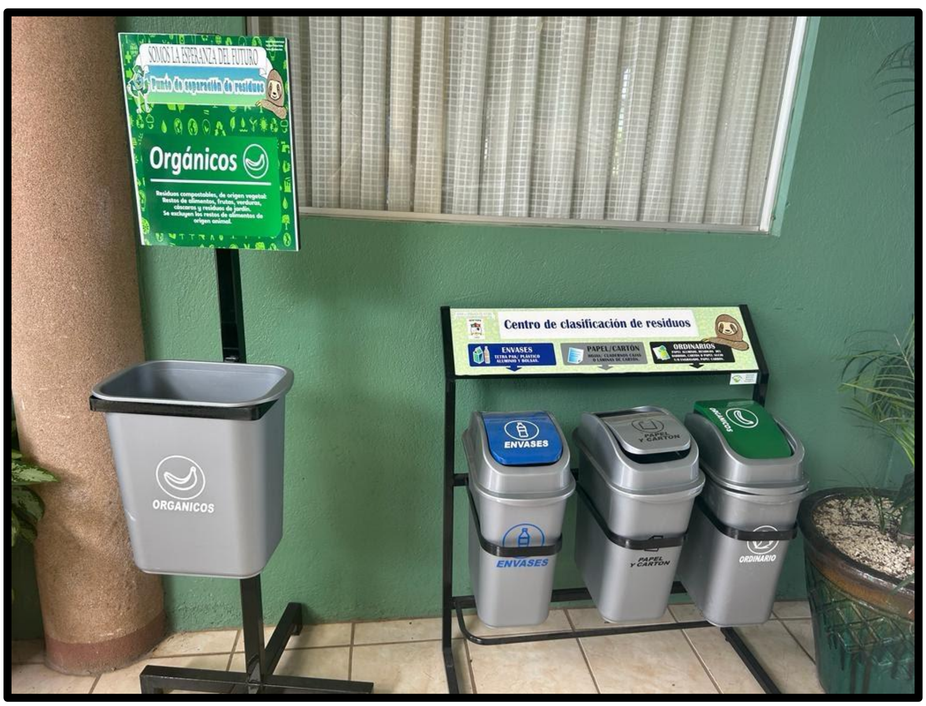


Figure 9*: CIT and New Hope's Waste and Recycling Bins.*

To assess CIT and New Hope's current plastic waste management processes, we examined their systems quantitatively and qualitatively. Quantitatively, if the site did not have certain types or abundance of plastics, we would have performed a manual audit to determine quantities and types of plastics. Luckily, both sites had most plastics accounted for in their records from the previous year. We categorized and statistically analyzed their waste from this data through excel. Qualitatively, our team interviewed waste staff and gathered an understanding of who collects the plastic waste, where they send it, and for how much money they sell each type; in gathering this data we discovered the site's current plastic sales are inconsistent between both prices and buyers. Our team also toured the different facilities, walking through the system in place and observing how they gathered the plastic, sorted it, and then sent it off for recycling.

3.1.1 Interviewing Personnel

Our team gathered qualitative data regarding waste pickup by interviewing CIT waste personnel Susan Astorga Porras, Carlos Mercado, and David Brealey. This allowed our team to analyze the plastic waste issue at CIT further and suggest the best possible solutions. Some questions we asked can be found in Appendix A.

By asking questions like those listed, our team was better equipped to interpret waste data and determine which areas needed attention. In these discussions, we also gathered information on the inflow and outflow of plastic waste and determined where our upcycling project may be located. Through these conversations, our team was able to understand and reinvent the current recycling processes entirely.

As mentioned, both CIT and New Hope have recycling collection centers on their respective campuses. However, our team was challenged to make them more efficient, profitable, and eco-friendly. These were the three main goals we considered when researching and analyzing data for this project. Currently, through our assessment of CIT and New Hope, we have found that both schools are very dependent on a municipal waste collection center for all their recycling needs. The process that CIT and New Hope have in place uses multiple trash bins to collect the various recyclable waste generated by students and staff, shown in Figure 9. At New Hope, waste material was collected not only from the school but also from the families of the students. Any waste the parents would bring in is processed by the New Hope waste management staff in their small recycling center, Figures 7 and 8. They then send this waste to CIT. The recyclable waste is collected at CIT, like at New Hope, with the respective bins. Rather than sending it to another location, recyclables are brought to the municipal collection center on campus.

3.2 Plastic Audit

To understand the scope of our project and the potential solutions to the community's plastic waste issue, we first needed to understand the amount of plastic the community sent into the recycling center, the types of plastics, and the types that other companies are willing to buy. This information was gathered through contact with CIT/NH waste personnel directors Carlos Mercado and Susan Astorga Porras, as they had data from previous years already compiled. We then analyzed these numbers to understand what types of plastic were most abundant, which they currently sold, and what plastic they sent to the landfill. Knowing this gave us a better ability to assess the next possible steps for our project and the solutions we could implement.

3.2.1 The Plastic Being Sold

CIT sends its waste to a third-party center on the school's campus, where they also collect waste for free from the surrounding area. The third party then sells this collected waste to other companies, but do not have a stable buyer. Although we originally intended on using the plastics the municipal site could not sell as our target plastics, we changed our plan upon discovering the state of their current business. Our plastic audit found that the municipal site did not have consistent buyers or prices. CIT can provide stability for the municipal site's business and workers if they buy all the viable plastics it takes in. Our team desired quantitative data to design a practical solution to plastic upcycling with an economic analysis; We obtained qualitative data to help our team understand the dynamics of the CIT workplace and the municipal site. We applied the qualitative data to our project, enabling us to tailor our solution to the school campus and its needs in a way that will continue and thrive after our team's departure.

3.2.2 The Plastic Waste Generated

We collected data on plastic waste generation from the two schools and from select external sources such as the families of attending students and the province of Belen, where the municipal station collects. Quantitative data for most of this project included the measurements of waste the schools are producing and the waste from the students and their families. At the third-party center, they collected waste from Belen, including houses and factories. Our project group obtained this information firsthand through collection, observation, interviews, and inventory reports from previous years.

***Figure 10**: Two-hour sample of plastics not fit for sale.*

To move toward solving the problem, our team needed to know the types of plastic that the third-party facility was collecting and profiting from, along with which were being sent to the landfill. Identifying the quantity of each plastic type and category allowed us to help find the best way to mitigate their waste—maximizing the third party's profits and creating profits for CIT/NH. Product identification was accomplished by analyzing where most of their plastic waste accumulated and determining the source by sorting it out by hand into different types. By gathering this quantitative data, we could better understand the outflow of plastic waste at CIT and supply them with the best options for improving their plastic waste management.

To measure what plastic is being sent to a landfill and in what quantity, we asked the Municipal Waste Manager to collect the plastic that they would usually throw away in their sorting process for a given time. The Municipal Waste Manager, following our request, collected the plastic waste they would have thrown out for two hours; they put that accumulated waste in a bag for us to sort through, shown in Figure 10. To measure the plastics within the bag, we went through the bag by hand, pulling out each piece of waste and finding the number associated with that piece of plastic. As in Figure 11, we then put the identified plastic into a bin, with each container correlated to a different plastic type.

***Figure** 11: Plastic sample separated by type.*

From left to right, each bin represented a plastic numbered one through seven, with the furthest left bin representing plastic number one and the furthest right bin representing plastic number seven. The fifth bin in the sequence representing plastic number five required more than one bin to hold all the plastic waste and is represented by the three containers touching in the number five position. Similarly, plastic number seven require more than one bin. They are represented by the four bins in a rectangular position. After sorting all the plastic waste from the bag into their respective containers, we measured the plastic by weight. We weighed the plastic using a luggage scale connected to a canvas tote bag loaded with the plastic from each bin. We collected data on the weight of each plastic type on paper in a notebook for record keeping. After weighing the plastic, we returned all plastic to the municipality.

3.3 Reduction of Plastics

While finding ways to upcycle/recycle plastic is helpful, the easiest way to reduce plastic waste is to reduce plastic usage. Although plastic is a commonly used material, new products are being engineered to mitigate its need. Conventionally used plastics are made of non-renewable materials that do not break down in the environment. However, new plastics are being developed from renewable resources that are biodegradable and/or compostable. Bioplastics are biodegradable, bio-based, or both. Bio-based plastics are made from the cellulose from plants such as sugarcane and corn. Many products that are being made from typical plastic are now also being made from bioplastics. Many materials used at New Hope and CIT are bioplastics; however, they still take a long time to decompose. One solution to this problem would be to use reusable items whenever possible. The primary example of this would be plates and utensils in the cafeterias. It may increase the work needed and labor costs to wash the dishes, but it will reduce the waste generated significantly.

3.4 Implement a System

Once all plastic data was available, our team analyzed and proposed that creating an upcycling facility was the best solution. With a plastic shredding system, CIT can use a multiple-angle approach to upcycling. In short, to shred plastic, CIT could employ a system of machines that cut the plastic into small, employable pieces. These shreds could be used in an injection mold or extrusion system and turned into new products. If CIT cannot initially create the products from the shreds, they can sell them to other companies. Either way, the shreds provide opportunities to profit. Ultimately, the plastic stays within use through a new purpose and out of the environment.

3.5 Economic Analysis

We conducted a thorough economic analysis before CIT invested in the upcycling facility. The economic analysis compared the net benefits of recycling certain plastic types. The variables that affect the profitability of recycling a particular kind of plastic are:

- Availability
- Cost of materials
- Cost of machinery
- Cost of operation and maintenance (O&M)
- Selling price of the upcycled product

The availability of plastic is essential to profitability because high-capacity upcycling equipment requires large volumes of material to make a return on investment. They throw away large sums of potentially recyclable plastic because there is no demand for it. We determined the availability of each plastic type from data collected by New Hope and CIT waste management staff and manual sorting of rejected plastics at CIT's waste facility. The remaining plastic waste will require a different solution because recycling small quantities of mixed plastic waste is complex.

CIT collects free plastic from students and their families and forwards it to the municipal plastic collection and sorting center on campus. Competitors currently purchase plastic waste and pay for its transport. We based the estimates for the cost of CIT acquiring plastic waste on the current market rates considering the transportation savings and free plastic from students and families. We determined the machinery, operation, and maintenance cost by contacting the recycling machinery vendors.

CIT can sell plastic shreds to manufacturers or use them in-house to make products such as boards, posts, filaments, or injection molded parts. We conducted a make vs. buy analysis to verify if CIT could save money by producing plastic products for their use rather than just purchasing them outright. Estimates for the selling prices of these items were acquired by looking at equivalent products for sale in Costa Rica and online.

The alternatives were compared and ranked by present worth, return on investment, payback period, upfront cost, operating and maintenance cost, and revenue. We also compared them to CIT's current system as a control group. The most feasible alternatives, with the best present value, were then presented to CIT.

The triple bottom line concept includes economics, environmental impact, and social consequences. The latter two are difficult to define monetarily but have a value that must be considered. The environmental impact will be measured by the amount of waste plastic rescued from the dump and the amount of virgin plastic replaced with recycled material. We balance this with the power and water consumption of the machinery and possible fumes released into the atmosphere. The social impact depends on the student's reaction to plastic upcycling happening on campus and the educational materials and presentations given.

3.6 Educational Programs

We created educational learning plans to be adopted by students at the two sister schools. In connection with CIT and Nueva Esperanza's teaching staff, we designed educational programs: programs that could exhibit CIT's new upcycling center and teach both students and community members about recycling with the machinery first-hand. Our team utilized hands-on teaching plans so students could see their recycling efforts put into action on their campus. We completed infographics, guides, and student and staff walkthroughs of our project to ensure the CIT community could continue our project and its planning once our team left the site. These learning plans are not limited to the employed recycling methods; recycling plans for artistic upcycling practices were also designed for the school's usage.

4.0 Results

Through the implementation of our project and the performance of our methods, we found five main results in our project. The first and foremost point would be the overall plastic reduction. Although we are not getting rid of the plastic but repurposing it, we will still decrease the plastic being thrown into landfills and oceans by at least 40%. The second finding was that CIT only sells certain plastics, one, two, and four, and the rest is all thrown away. If we not only buy what they were throwing away, but also buy the previously sold plastic at a consistent price, we will have a wider variety of plastic to work with in addition to stabilizing its business. The third finding was that with our current economic analysis, the machine would pay itself off in half a month, a rapid payback period that appeals to investors. Fourthly, our system may need to implement a sound reduction system. The current decibel level may be high, and unsafe to work in that environment for long periods. We proposed multiple solutions that can be implemented with the machinery to reduce the sound level of the recycling plant. Lastly, we discuss the implementation of Student Educational Guides, ranging in different complexities for different ages, that would educate all students on how to be more eco-friendly and conscious about plastic consumption.

Overall, our project can drastically help reduce the amount of plastic that CIT is putting into the ecosystem while still generating useful products and revenue, with moderate concerns about health that can easily be combatted. This means that our team and the CIT community can implement this project to achieve all of the intended goals.

4.1 Results of the Plastic Assessment and Audit

The results our team found from monitoring the plastic system that CIT and New Hope have in place are exciting and made up of many parts; we have found the flow the plastic traditionally takes between the two schools, see Figure 12.

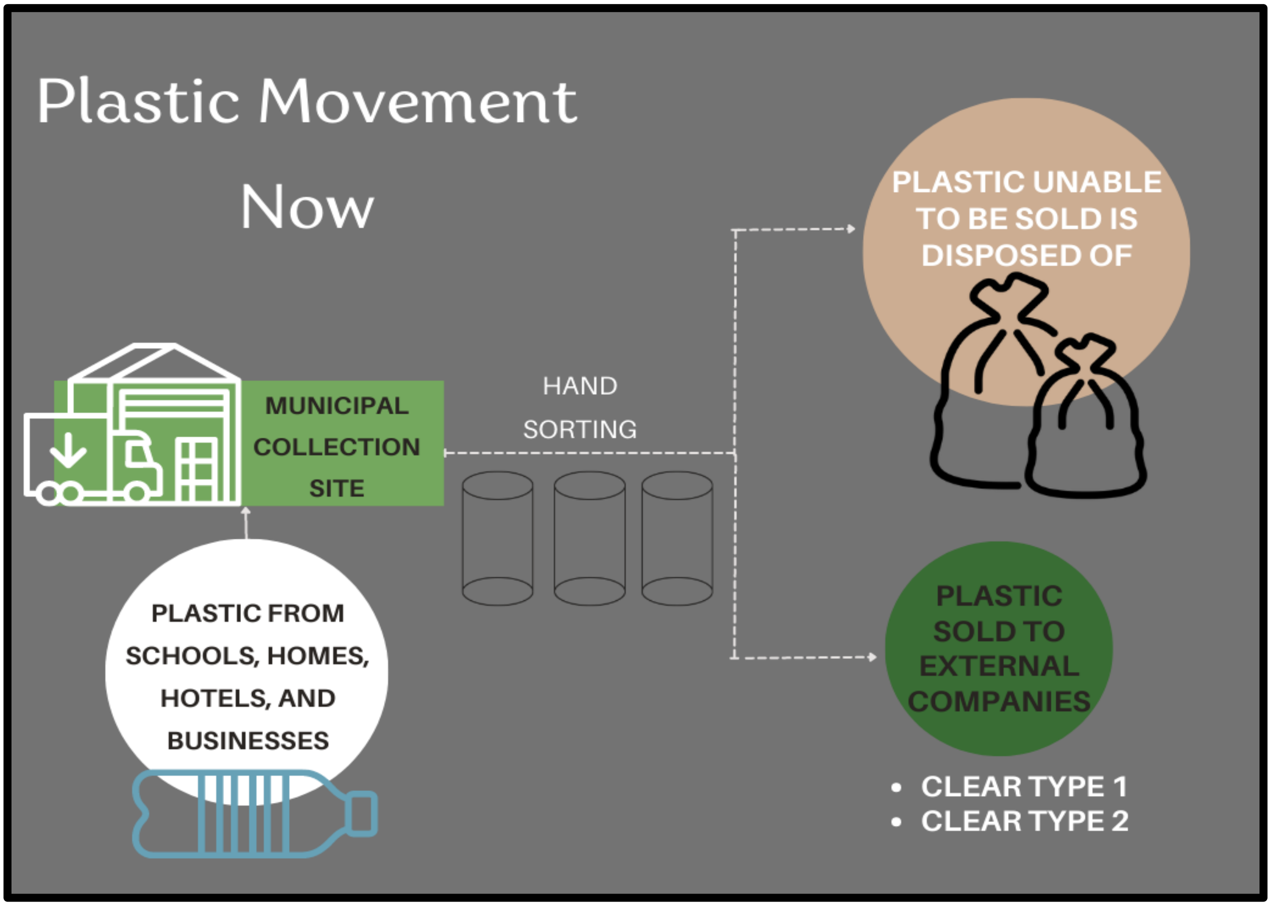


Figure 12*: Current plastic flow.*

We have also found the amount of recyclable waste New Hope has generated in seven months. This data is collected by waste management personnel and then documented. Figure 13 shows how much of each type of waste, cardboard, plastic bottles, aluminum, etc., is collected at the school and then shipped to CIT to be processed through their Municipal Center.

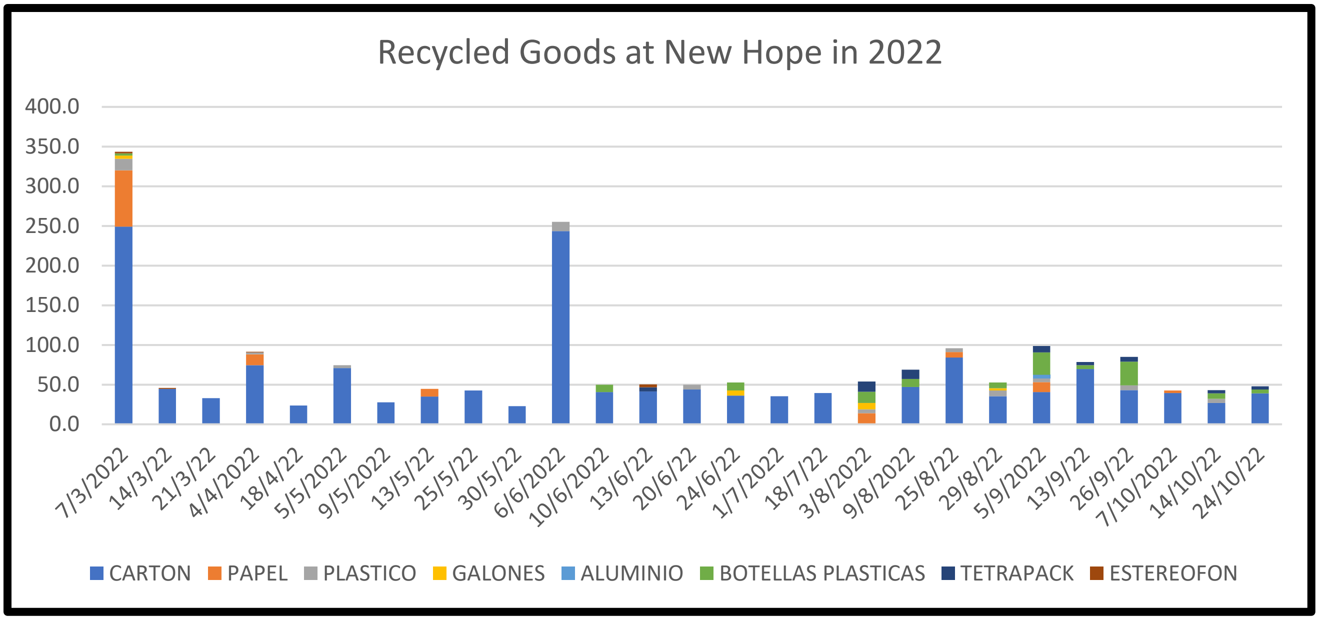


Figure 13*: New Hope's collected recyclables by type.*

Through interviews and discussions with CIT Municipal Center personnel, we also found the amount of plastic sold from the Municipal Collection Center over one year. Table 2 shows this data, separated by month and type of plastic.

2022	PET	HDP
January	1828	1612
February	1837	2184
March	3885	3074
April	1622	2339
May	3346	2993
June	2038	2141
July	2642	2214
August	3045	3415
September	3529	1943
October	1790	2536
November	2968	2350
December	1253	1171
TOTAL ANNUAL	29783	27972
	57755	63.5305
	kg	tons

Table 2: *CIT plastic sales by weight in 2022.*

While we do not have data on the amount of plastic waste generated by CIT, since that plastic is sent directly to the municipal collection center, we found it unnecessary to collect that data as we already included it in the data we collected from the Municipal Collection Center. Since all the recyclable waste from each school is being collected and sorted already at the Collection Center, there is no need to change the system they have in place.

Type of Plastic	quantity found	people working		hours working		days working		total expected
1	1.05	6	x	4	x	5	=	126
2	0.3	6	x	4	x	5	=	36
3	0.2	6	x	4	x	5	=	24
4	0.05	6	x	4	x	5	=	6
5	2.45	6	x	4	x	5	=	294
6	0.6	6	x	4	x	5	=	72
7 & other	4.25	6	x	4	x	5	=	510
								1068

Table 3: *Extrapolation of two-hour plastic sample at CIT*

If we could repurpose the 126 kg of type one and the 294 kg of type five, we could reduce the amount of waste by 420 kilograms, or by 39.32%. However, this solution is only focused on types one and five. If we also use other plastics, we can reduce the amount of plastic wasted drastically. For instance, with a shredder and sheet press from Precious Plastics, we could use all types of plastics, except certain films and bags, to be shredded and heat pressed into sheets. This would then bring our plastic repurposing to 90%, which would be about 961 kg of plastic now being repurposed each week, instead of ending up in the environment of Costa Rica.

4.2 The Chosen System

The method our team ultimately decided to use to upcycle plastic was a shredding and sheet press recycling center where plastic would be sorted, cleaned, shredded, and made into plastic boards that could be either sold or turned into a product. We decided to make plastic sheets because of the finished product's flexibility of use in many different applications. The sheet press also offered the ability to use almost all types of plastics to create these sheets. The sheet press also used the most plastic per hour when compared to injection or extrusion molding. Because of the sheet presses finished products many uses, its ability to take in many different types of plastics and its high usage capacity using it made the most sense.

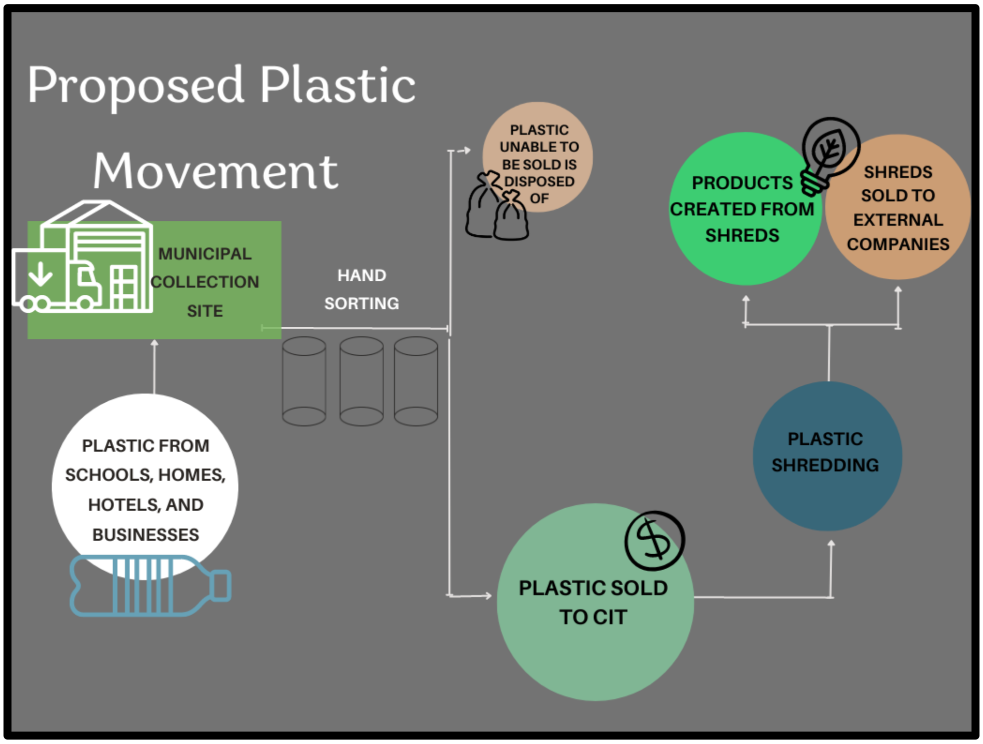


Figure 14: *Proposed Plastic Flow.*

We also found that the plastic flow from the schools, homes, and businesses needed to change to support our project's recycling center. With the shredder and sheet press, the municipal collection center could use more plastics they would otherwise throw away.

4.2.1 Using and Maintaining Machinery

To ensure the proposed system works as we intend, we researched and compiled instructions on properly utilizing the suggested machines. The Precious Plastics website offers an in-depth guide on using each piece of machinery and the maintenance needed to keep the machines in working order. When using the shredder and the heat press, there are some instructions you need to follow to stay safe and produce high-quality products. To use the shredder, the instructions can be found in Appendix B. When changing the type of plastic you are shredding, it is crucial to clean the shredder thoroughly, and not to mix the different types. Not mixing the plastics is essential because have many different properties, such as melting temperature, and can cause excessive fumes if they burn on the sheet press. The steps to clean the shredder can be found in Appendix C.

It is also essential to note that the size of the shreds you produce varies depending on the size of the item you are initially shredding. Small things like bottle caps may only need to be shredded once. In contrast, large items such as gallon jugs or shampoo bottles may need to be shredded multiple times before they make shreds small enough to be used by the heat press. A general rule of thumb is that the plastic shreds must be less than 30 mm in size when using the sheet press.

Regular maintenance on the shredder is essential for keeping the machine running smoothly and efficiently. Proper upkeep will make the pieces and overall machine's operating lifetime much longer. Our team recommends that you follow the maintenance steps in Appendix D.

Like the shredder, we suggest specific instructions for using the heat press. These directions (found in Appendix E) vary slightly depending on the plastic used. The sheet press also requires regular maintenance with the instructions located in Appendix F.

4.3 Current Plastic Sales

The municipal collection center currently only sells plastics one and two. As shown in Table 2, in 2022, they sold 57,755 KG, or 63.5 tons of plastic between polyethylene terephthalate (PET), plastic one, and high-density polyethylene (HDPE), plastic two. However, the sale price for individual plastics is not linear, so prices are constantly changing with the market. Like standard economics, the sale price is based on a supply and demand system. Companies sell material at competitive prices per kilogram. It is also important to note that plastics in different states are sold for different prices; shredded plastic has a different sale price than dirty plastic bottles. Currently, the plastic the municipal center at CIT sells is only separated, not cleaned, compacted, or shredded. This lowers the price and value of the plastic as buyers have more work to do once they receive it. With our project, that material can be bought, shredded, cleaned, and sold for higher prices.

4.4 Payback Period

Finding estimates for equipment and machinery was initially very difficult. However, the website Precious Plastic made our job relatively easy. We recommend buying a shredder and sheet press from the Precious Plastic Bazar to fulfill our project. This investment will be about four million colones, or roughly $7300. Using rough estimates for plastic purchasing prices, 100 colones per kg, employee wages that would be set by CIT, estimated at 3000 colones per hour, average electricity cost of 120 colones per kilowatt/hour, and average sale price for one meter by one meter plastic sheets of just less than 30,000 colones, we estimate that CIT would be able to pay off the machines in about a half of a month. We used the following spreadsheets to calculate the return on investment for both pieces of machinery.

Precious Plastic Shredder						
Plastic Intake	9022	KG per month	Processing Time		128.8857143	Hours Per Month
Price Plastic	CRC 200.00	Colones Per KG	Person-hours		257.7714286	Hours Per Month
Cost Machinery	CRC 1,025,424.06	Colones	Wages	CRC	773,314.29	Colones Per Month
Capacity	70	KG Per Hour	Power Consumption		286.1262857	KWH Per Month
Labor Cost	CRC 3,000.00	Colones Per Hour	Power Cost	CRC	34,335.15	Colones Per Month
Electrictiy Cost	CRC 120.00	Colones per KWH	Plastic Out		8119.8	KG Per Month
Electricity Consumption	3.7	KiloWatts	Revenue from Plastic	CRC	40,599,000.00	Colones Per Month
Operators Required	2	People	Cost of Plastic Waste	CRC	1,804,400.00	Colones Per Month
Yield	90%	Out/In				
Sell Price of Shred	CRC 5,000.00	Per KG				
Profit/Month	CRC 37,986,950.56					
Payback Period	0.026994114	Months				
	0.002249509	Years				

***Table 4**: Payback period calculation of "Precious Plastic" shredder.*

We highlighted essential pieces of information in both spreadsheets. Plastic intake, processing time, and payback period are important for the shredder due to their room for growth. With a larger plastic intake, we can run the shredding machine for longer than 61 hours per month, with the maximum being 160 hours. This would then increase the profit made and plastic output but reduce the payback period. As for the plastic sheet press, the highlighted pieces are the cost of plastic waste and the processing time. It is important to note that the cost of the plastic is zero since we are using the shredded plastic that CIT already purchased to press into sheets. The processing time is the last important piece to note as it is the limiting factor in production. Since sheets take 30-60 minutes to melt into sheets and then cool, the machine will be running 40 hours per week and still won't be able to process all the shredded plastic, so the remaining plastic would then be sold as shredded plastic.

Precious Plastic Sheet Press						
Plastic Intake	8119.8	KG per month	Processing Time		160	Hours Per Month
Price Plastic	CRC -	Colones Per KG	Person-hours		320	Hours Per Month
Cost Machinery	CRC 3,148,730.93	Colones	Wages	CRC	960,000.00	Colones Per Month
Capacity	1.5	Sheets Per Hour	Power Consumption		1440	KWH Per Month
Labor Cost	CRC 3,000.00	Colones Per Hour	Power Cost	CRC	172,800.00	Colones Per Month
Electricity Cost	CRC 120.00	Colones per KWH	Sheets Out		240	Sheets Per Month
Electricity Consumption	15	KiloWatts	Plastic Out		3600	Per Month
Operators Required	2	People	Revenue from Plastic	CRC	6,000,000.00	Colones Per Month
Yield	95%	Out/In	Cost of Plastic Waste	CRC	-	Colones Per Month
Sell Price of Sheets	CRC 25,000.00	Per Sheet				
			Both Machines			
			Plastic Left		4519.8	KG
Profit/Month	CRC 4,867,200.00		Shred Price	CRC	22,599,000.00	Per Month
Payback Period	0.64692861	Months			$38,963.79	Per Month
	0.053910717	Years				

***Table 5:** Payback Period Calculation of Precious Plastics Sheet Press.*

4.5 Implementation of Sound Reduction System

Using the average sound levels for plastic granulators and shredders, the decibel level for granulator machinery would be around 110 decibels (dB). This is a similar sound to a gunshot or a running chainsaw. Due to current Costa Rican labor laws, the maximum permissible level is 115 dB and 85 dB without hearing protection (Arenas & Suter, 2014). We would require all workers to wear proper personal protective equipment (PPE) while working inside the recycling plant. However, more is needed to protect their hearing and hearing longevity. Two central sound reduction systems can be implemented together to reduce the noise level inside the plant and reduce vibrations reflecting off walls and roofing. This, combined with PPE and a hearing conservation program, will protect and monitor the worker's health.

4.5.1 Spray acoustic insulation

SonaKrete, and other ceiling acoustical finishes, are spray-applied products specifically designed to reduce excessive noise without compromising aesthetics. SonaKrete is composed of prepared cellulose fibers, made from 80 percent pre-consumer recycled content, and combined with natural fire retardants, resulting in an eco-friendly and safe product. SonaKrete does not contain silica dust, asbestos, or mineral or glass fibers, as some people may be concerned. The most effective thickness of SonaKrete is the 3/4 inch increment that produces a 0.75 Noise Reduction Coefficient (NRC), which means that the product absorbs 75 percent of the noise. Only 25 percent is reflected in the room (Premium Ceiling Acoustic Finish - Spray Applied Seamless Acoustical System, 2022). This would significantly reduce noise levels that could be amplified without having such a product installed. When working in a large but enclosed space, SonaKrete, or another ceiling acoustic finish, is a must.

4.5.2 Quilt panels

Another product they could implement if necessary is dual-sided absorptive soundproofing quilt panels. These panels enclose machinery and contain the sound before it is emitted into the room. They are highly effective in absorbing sound and can be custom-made to enclose any size machine. A complete enclosure can provide over 20 dB of noise reduction, while partial sections offer 15 dB. The common BBC-13-2LB-2" Sound Seal product produces a Sound Transmission Class (STC) rating of 37, which is approaching industrial soundproofing and noise canceling (a rating of 45) ("Industrial Acoustic Enclosures," n.d.). This product also carries an NRC of 1.05, meaning it absorbs all sound waves. These panels are necessary to reduce the noise within our upcycling plant and protect workers' hearing. A working dB level of 90 is sustainable with PPE and a hearing conservation program, but that is only feasible with complete enclosures.

4.5.3 Safe Work Practices and PPE

When working with large machinery, there is always some danger involved. The Occupational Safety and Health Administration (OSHA) and the Institute of Scrap Recycling Industries or ISRI have outlined recommendations for different ways to minimize risk and keep workers safe. Our number one priority while working on this project was to make sure that the area we design is safe for the workers who would be working inside it and to give a guide on how to keep the workers safe. Workplace safety is made up of 4 parts, engineering controls, safe work practices, administrative controls, and personal protective equipment, or PPE. Engineering controls involve physically changing a machine or work environment. Administrative controls include changing how or when workers do their jobs, such as scheduling work and rotating workers to reduce exposure. Work practices involve training workers to perform tasks that reduce their exposure to workplace hazards. Within our project, we will have limited control over the engineering control of the machinery as we will not design the recycling machines ourselves. Administrative controls within our project should be the same as standard workplace practices. We will not need to worry about rotating employees for excessive exposure to sound, or toxic fumes as the machinery we work with is neither extremely loud nor produces excessive toxic fumes. We believe that the machines can be used in a typical 8-hour workday by employees; however, it may be wise to rotate the employees between stations on a day-to-day basis for three reasons: to prevent repetitive stress injury, train all employees so they may fill in any job as needed, and to help alleviate the tediousness of doing the same position. Maintaining safe work practices is paramount since they will work with hazardous machinery. Some safe work practices to keep in mind are training all employees on how to stop the machines, wearing non-baggy clothes, and keeping long hair up so it may not enter the machinery.

Finally, the last line of protection for a person is PPE. The first step in making sure employees have proper PPE is to identify the hazards within the workplace. The appropriate PPE for the machinery and workplace our team designs consist of ear, eye, face, hand, and fume protection. This PPE is implemented regarding the hazards of working with shredders and the heat press. The list of potential risks is as follows: contact with knives, entanglement, contact or impact from ejecting plastic, fumes, fire and explosion, noise slips, trips, falls, entanglement from unexpected rotor movement (during maintenance, cleaning, and repairs), a collision between moving and fixed knives (*Plastics Granulator*, 2017). With any machinery implemented at the site, its model-specific hazards and requirements will be posted and followed before entering the designated machine space to ensure employees are proactive in their safety. When plastics are melted, Volatile Organic Compounds or VOCs will be released, which can cause immediate irritation to the eyes, nose, and lungs. Prolonged exposure to fumes of any synthetic plastic with no safety precautions can lead to cancer, congenital disabilities, and illnesses. It is recommended that a gas mask is used by the employees working there along with proper ventilation of the working area.

4.5.4 Mandatory hearing checks

Within the code INTE 31-09-16-00, in 2000, Costa Rican legislation established that a hearing conservation program must be implemented at occupational decibel levels above 85 dB (Arenas & Suter, 2014). This program would include hearing tests covering all personnel working in the recycling plant. If permitted, CIT's nurses can conduct this to limit costs and use all the available resources.

4.6 Student Educational Guides

As our team worked on both school campuses, we found that how students divided their trash did not reflect how their waste was disposed of. The current waste sorting systems at both CIT and NH consisted of three bins as seen in figure 9. The recycling centers on the school campus sort these plastics and send them to the municipal site, where they dispose of certain types unknown to the students and most staff members. When hand sorting these plastics at the municipality site, our team realized where the student bin program needed to be improved.

Figure 15: *Green Team Presentation.*

On February 9th, 2023, our team presented to the "Green Team" at Nueva Esperanza, shown in Figure 15. We held this presentation in front of approximately 60 students, spanning grades 3rd-9th. In our presentation, we taught the students about the different types of plastics on the numeric system and how they are currently disposed of on campus and through the municipal site. We then made our presentation interactive with the students, allowing them to identify their daily uses of plastics and their types. We also showed the students our current project of implementing an upcycling facility on the CIT campus to address all plastic waste. Through this presentation, the students were vocal about how they wanted to fix the plastic issue and that guides made for their campus would only go so far. The next step to ensure not only the reduction, reuse, and recycling of plastics, but also the refusal of plastics on campus would be through student motivation—hopefully an effort that this Green Team will further.

We designed multiple plastic guides to be tailored to audiences of different ages (See Figure 16, Appendix G). Simple, visually appealing posters were drawn for lower grades, while detailed infographics were made for the higher grades. The infographics focused on what kids, teenagers, and staff can do to reduce plastic waste.

Figure 16: *Plastic Waste Reduction Poster.*

4.7 Results and Conclusions

After conducting our research and methods, we can conclude that our project is feasible and effective for the main goals that we laid out. The foremost objective of the project is to reduce and upcycle plastic. Our project can reduce the amount of plastic that CIT is throwing out by at least 40% by using only types one and five. However, we can also use other plastics, reducing the overall plastic reduction to 90%. The next goal is to be profitable. Our economic analysis shows that CIT can pay off the shredder and heat press in less than 14 eight hour workdays. The next goal was to involve students. Through the development of educational programs and hands-on learning, the students will gain a much better understanding of recycling and product upcycling. Lastly, the facility must have the ability to grow, which is currently only limited by the amount of plastic taken in. As CIT boosts and increases its intake from the surrounding community, the sky is the limit for plastic it can upcycle and its profit.

5.0 Conclusions and Recommendations

With our project's conclusion, we can make several key takeaways and recommendations to CIT. The first and most important is that CIT should conduct the project with the following recommendations kept in mind. The second is that the project is economically feasible and eco-friendly. Third, our group focused on a few ethical concerns during the conduction of the project that CIT will still need to consider. Fourth, we concluded that furthering the education of the students is a must. Lastly, we offer our recommendations on implementing and expanding upon the project after we depart Costa Rica.

5.1 Economically Feasible and Ecofriendly

Implementing a plastic upcycling facility is economically feasible. The upfront investment of $10,000 is a small price for partial salvation from the plastics industry and its consequences. CIT can use the plastic sheets the facility produces to build desks, shelves, chairs, posts, and other products. This reduces their reliance on suppliers, saving them money and purchasing less virgin plastic. CIT can sell extra sheets on the Precious Plastics Bazar for $60 per sheet. Converting plastic waste into building materials fulfills CIT’s goal of reducing plastic waste and creating a product of higher value.

By producing sheets, CIT personnel can use them in house like plywood or sell them on the Precious Plastic Bazar for a profit of about 30,000 colones. If CIT were to sell every sheet and kilogram of shredded plastic, they would reduce their plastic waste by 90% and pay off their original investment within one month. For a company that is trying to reduce its plastic output, this is a no-brainer to implement as it can reach its goal of reducing plastic while creating a product of much higher value for profit.

5.2 Ethical Concerns

When conducting this project, we kept three main ethical concerns in mind. The first and most important was that this is, unfortunately, just a cycle of plastic. Yes, we are reducing the amount of plastic that CIT is wasting and throwing away, but we are not getting rid of the plastic; just repurposing it. Therefore, this plastic could eventually end up in the trash after repurposing. This is unfortunate for plastics, whose decomposition times range from 20 to 500 years. The second concern was that it would not be ethical to have employees working in a noisy environment. We have done our best through extensive research to find relatively quiet machinery to combat this. The current shredder we suggest runs from a five-horsepower motor and does not emit much noise. However, wearing proper ear protection for safety and comfort is still advised. Lastly, another crucial ethical concern was that there already is a plastic collection center at CIT where they sell plastic. To avoid undercutting them or their jobs, we aimed to find a solution for the plastic that this business still needed to be sold. This way, we are reducing plastic being thrown out and creating more job opportunities, but not stepping on the toes of the business operating there for years. These are the only ethical concerns of the project, and we carefully considered each of them during our research and conduction of this project. However, CIT must remember these concerns now that our work is over. If CIT implements this project on-site, they must consider these concerns as long as the plastic upcycling facility operates.

5.3 Furthering Education

Education and inclusion of students have been focal points of this project from the start. Our team wanted to help the school campuses understand the issues surrounding plastics and feel empowered to do something about it. With the implementation of the shredder, students may be able to see and use the machinery and view the process of plastic upcycling in this method. Our team was fortunate to present what we have learned and what we are planning to the New Hope student Green Team. In discussion with the students, their motivation to help was clear. Our project's follow-through heavily depends on the administration and student support. Since our machinery only repurposes plastics, it is up to the campus communities to decrease plastic usage and reduce the plastic waste brought onto campus in the first place.

If the students of CIT and New Hope are educated on what different plastics are, where they are going, and how they are processed, they can spread this knowledge to their families, friends, neighboring communities, and future careers. Our project is just the start of their plastic journey.

5.4 Recommendations

In the future, there are a few recommendations that our team has for CIT as they go about implementing this project. The first being that CIT should purchase the “Shredder Machine, Industrial, Factory made, CE Certified” Shredder from the *Precious Plastics Bazar* website, shown in Figure 17. This machine has the processing ability perfect for CIT’s plastic intake and will ship in two to three weeks.

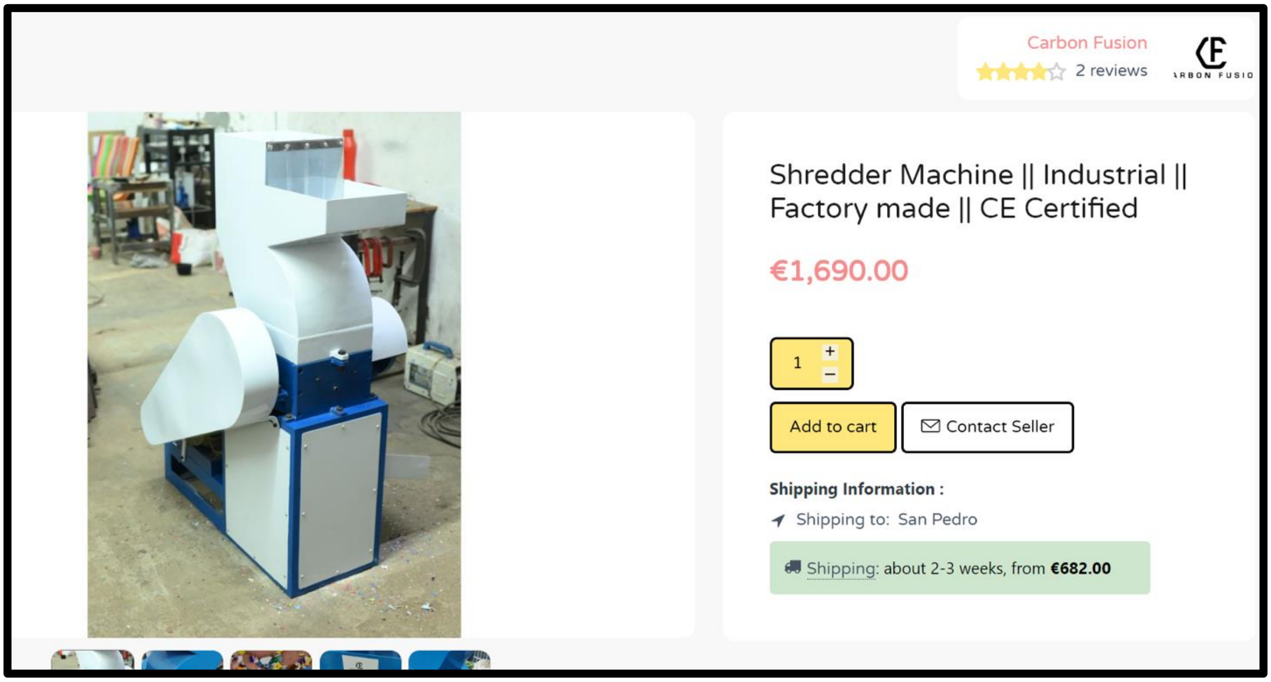


Figure 14*: "Precious Plastics" shredder listing*

Next, CIT should purchase the “Sheet Press System 1 X 1 Meter (Includes Hot Press & Cold Press With Preparations Table)”, on the *Precious Plastic Bazar* website. This machine will compress the shredded plastic into colorful or solid color sheets that can then be treated as wood. People have made poles, tabletops, and many other products from them. If not used in house, the sheets can be sold on the *Bazar*.

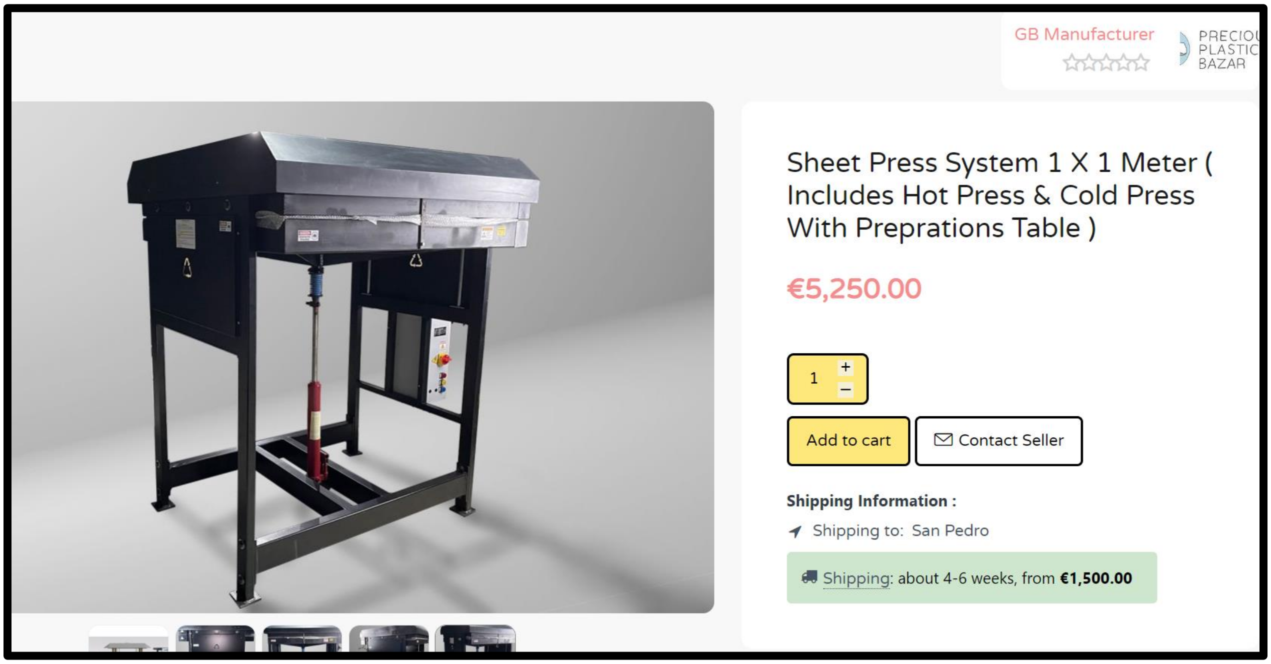


***Figure 15**: "Precious Plastics" sheet press listing*

Our following recommendation is that CIT implements a system to clean the plastics pre or post-shredding. Plastics can go into the machine without deep cleaning but must be stripped of labels. This system can be as simple as a table with soapy water where the plastics are dunked, scrubbed quickly, and separated by color or type of plastic. Before being heat pressed however, the plastic must be more thoroughly cleaned to ensure no residues are being heated in the machinery. The system can be like those already in place at New Hope but needs to be of a more extensive scale. Through this method, CIT can save money by not purchasing actual washing equipment and by reusing water. Although this is a crucial step to maintain longevity in the shredder, it is a simple way to save money and limit overall investment costs.

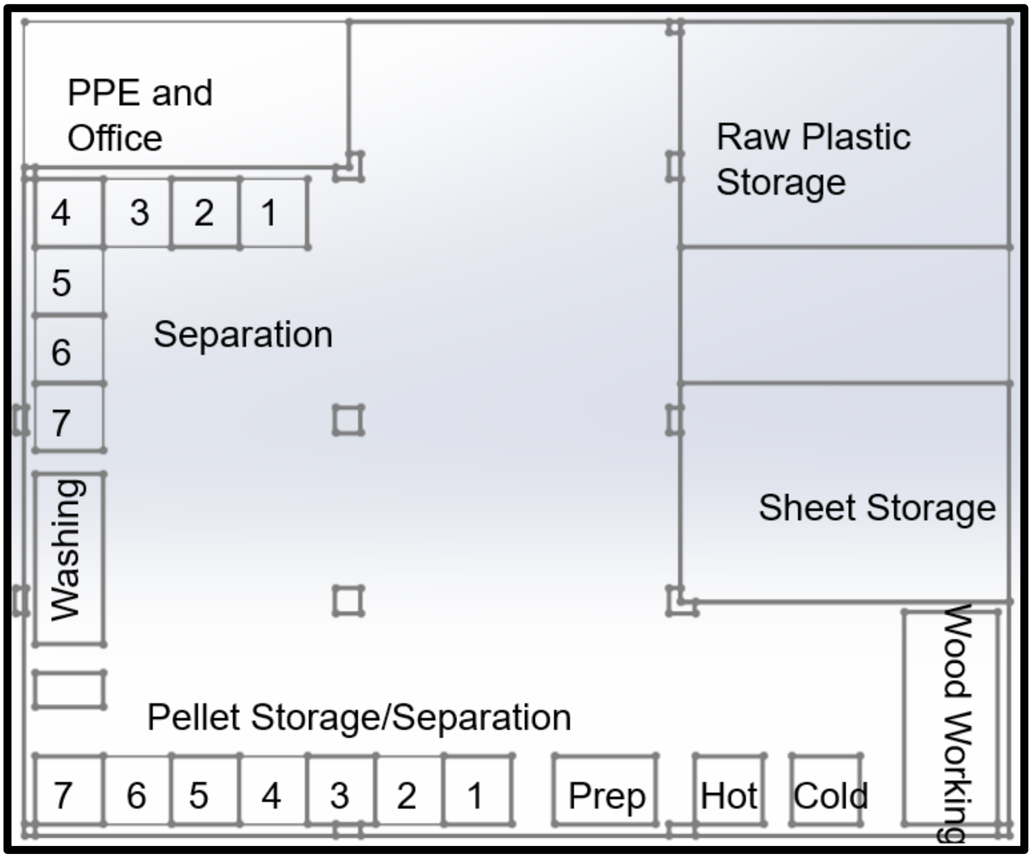


***Figure 16**: Proposed floor plan.*

The third recommendation would be to use the "Bat Cave" location for the plastic upcycling facility. CIT previously used this warehouse for storage next to the municipal collection center. This would limit the transportation of the material and make for an easy workflow of the plastics. Attached in Figure 18, we show our advised floor plan, which features multiple storage sections, a PPE and office space, and a U-shaped workflow for production optimization. This also includes a station where the sheets could be worked like wood with sanders or table saws, however not included in our budget. This leads to our final recommendation to treat the plastic sheets like plywood. This allows for endless uses in construction, agriculture, or simple uses like tabletops or chair legs. By treating the sheets as more than just plastic sheets, there truly are endless uses for them. Our recommendations are simple: buy the specified machinery from the Precious Plastic Bazar, implement a cleaning system within the upcycling center, use the selected location and floor plan as suggested, and get creative with the uses of the plastic sheets. With all of these combined, CIT will successfully reduce the amount of plastic they are throwing away and create an endless number of new products for sale or use on campus.

Appendices

Appendix A – Waste Personnel Interview Questions

"How many students do you have helping or involved with recycling? What is student involvement? Can they help more?"

"Is there plastic sorting? What are the categories? How much of each category?"

"Where does plastic come from? Where is the most generated?"

"Where are plastics being directed after CIT/NH? What are current profits or losses?"

"Are there plastics not being recycled? Where do they go?"

"How much do the current companies pay for plastic?"

"How many hours do your employees work each week?"

"Are there plastic washing stations?"

Appendix B – Plastic Shredder Instructions

1. With the main switch off, the emergency stops off, and the direction switch in the stop position, plug in the shredder (if it was not plugged in) to a 16A three-phase plug.
2. Check that the hopper and the sieve (if it is needed) are mounted properly.
3. Check the hopper is empty of parts that could damage the machine.
4. Turn on the main switch, then the display will turn on.
5. If the display reads "READY", turn on the emergency stop.
6. Run the shredder in reverse mode for a few seconds to check everything works properly. The display should show "REVERSING".
7. Run the shredder in shredding/forward mode. The display should show "SHREDDING".
8. The machine is ready to use.

Appendix C – How to Clean the Shredder

1. Before cleaning the machine, push the emergency stop and turn off the main switch.
2. Remove the sieve (if it is mounted).
3. Remove the hopper.
4. Remove the top plate of the box.
5. Remove the fixed blades.
6. Clean between the blades. The bottom of the machine must be cleaned as well.

7. Clean the hopper, fixed blades, sieve and the interior of the box.
8. Mount the fixed blades, top plate, hopper and sieve (if required).

Appendix D – Shredder Maintenance

Weekly

1. Check the oil of the motor gearbox
2. Deep clean the shredder
3. Once you remove all the blades, inspect both fixed and moving blades: they should not have any scratches. If you see scratches, dismantle the shredder and sand / sharpen damaged blades.
4. Check for plastic stuck in between blades. If this is the case, disassemble the axis, clean blade and reassemble.

Monthly

1. Disassemble gears, clean them and reassemble with new grease.
2. Inspect bearings looking for any cracks and add extra grease if needed.
3. Disassemble the box, sand or sharpen damaged part and oil all plates. If teeth are too damaged, replace them. We recommend ordering extra blades to allow this maintenance to be easy.
4. Depending on the coupling that the machine uses, you may need to replace some rubber components. Check the manufacturer's instructions.
5. Check the paint and repaint damage to prevent long term corrosion issues.

Appendix E – Heat Press Directions

1. Plug in the Sheet press, check the emergency stop is released and switch on the main power switch.
2. Check the required temperature to melt your type of plastic and set the PID controller to this temperature.
3. Close the pressing plates using the bottle jack and wait for them to heat up.
4. Whilst waiting for the heating plates to warm up. Place the bottom sheet of the mold on the prep table and apply a layer of silicone oil. Make sure to remove any remnants of the previous sheet.
5. Place the mold frame in the center of the sheet and apply a layer of silicone oil to the top of the frame.
6. Weigh the plastic and load it into the mold. See the Datasheet (Appendix A) for melting temperatures and times. See the Sheet Color Examples poster (Appendix B).
7. Spread the plastic evenly across the area inside the mold frame with slightly less around a 100mm border offset on the inside of the edges.

8. Oil the top sheet of the mold and place the oiled side face down on the bottom two sections of the mold.
9. When the Sheet press is at the required temperature. Open the pressing plates of the Sheet press by releasing pressure from the bottle jack.
10. Position the prep table next to the open side of the Sheet press.
11. Use the sliding tool, push the mold from the prep table to the Sheet press.
12. Close the pressing plates using the bottle jack until the spring is fully compressed.
13. Whilst waiting for the plastic to melt. Prepare the next mold and sheet on the prep table.

    (Steps 4-8).

Appendix F – Heat Press Maintenance

Weekly

1. Clean the heating plates. Use a trowel to scrape any remnant material from the heating plates. You may need to use a high-volume alcohol if there is heavy corrosion.
2. Grease rails. Use a wooden spatula to apply a liberal amount of grease to all the rails, recommend engine grease.

Monthly

1. Inspect your mold sheets, if any of them are damaged beyond repair then they may need replacing.
2. Grease spring mechanism, detach the spring mechanism and use a wooden spatula to apply a liberal amount of grease to the touching faces. Recommend engine grease.
3. Inspect your plywood sheets, if they are damaged or significantly warped then they may need replacing.

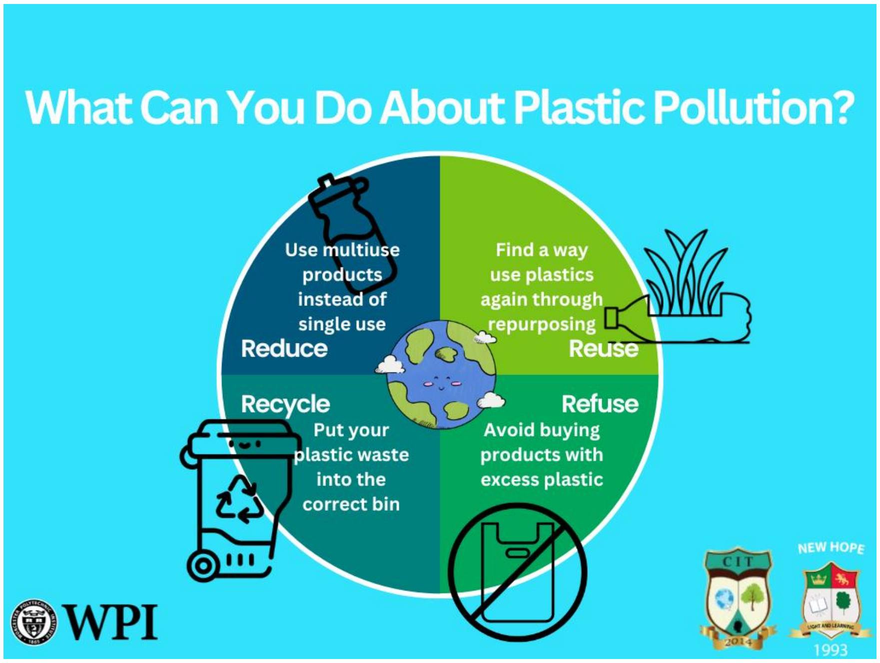
Yearly

1. Deep clean heating plates. Use a trowel to scrape any remnant material from the heating plates. You may need to use a high-volume alcohol if there is heavy corrosion. You may also need to use a rotary sander to remove tough burnt on material but be gentle, use a high grit sandpaper (>220) to preserve the flatness of the sheet.
2. Check oil in jacks. Bleed and replace the oil in the jacks.
3. Check electronics. Check the resistance of your elements on each of the three phases is equal to the number of heating elements attached to each phase. If it does not one of your heating elements may be broken, use a thermal camera to check. Check all the components inside the enclosure for visual signs of melting/burning and replace anything that appears damaged. Re paint worn areas

Check the body panels and frame for signs of ware, repaint any exposed metal to protect it from corrosion.

4. 2 mins before the recommended melting time. See the Datasheet (Appendix A) for melting temperatures and times. close the pressing plates using the bottle jack until the jacks start to give strong resistance.
5. When the mold has been in the sheet press for required melting time. Open the pressing plates of the Cooling Press by releasing pressure from the bottle jack.
6. Open the pressing plates of the Sheet press by releasing pressure from the bottle jack.
7. Use the sliding tool, push the mold from the Sheet press to the Cooling Press.
8. Close the pressing plates of the Cooling Press using the bottle jack.
9. Load and press the next sheet into the Sheet press (Steps 10-13). This time stack it on top of the previous sheet.
10. Repeat steps 13-20 until your work cycle is complete. Finished? Switch off and close the Sheet press.
11. Clean and apply a layer of silicone oil to the mold sheets to protect them for moisture between use.

Appendix G – Posters for the Schools




Seven
Plastic Types &Their
Recyclabilities
1. Polyethylene
Terephthalate (PET)
#1 is commonly found in disposable food and drink containers. This plastic is easily recycled into new bottles and is accepted at most recycling facilities.
2. High Density
Polyethylene (HDPE)
#2 can be found in water, juice, and milk jugs, sturdy containers, and items intended for outdoor use. This plastic is frequently recycled and can be safely reused.
3. Polyvinyl Chloride
(PVC)
#3 is found in pipes, shower curtains, cleaner bottles, and door frames. This plastic contains chemicals that can be harmful and its use should be avoided.
4. Low Density
Polyethylene (LDPE)
#4 is commonly found in plastic wrap, shopping bags, squeezable bottles, and containers. It is recyclable but few facilities process it.
5. Polypropylene (PP)
#5 is the second most commonly produced plastic and is found in disposable plates and cutlery. Less than 3% of all recycled plastics is type 5 because facilities rarely process it.
6. Polystyrene (PS)
#6 is commonly found in in disposable drinking cups, CD/DVD cases, to-go containers, and disposable cutlery. It is possible to recycle, but not practiced everywhere.
7. Other
#7 plastics are comprised of new plastics, bioplastics, and items composed of different types of plastics. These plastics have no standard protocols for recycling.
Know your plastic
to reduce trash.
WPI


NO
TO
PLASTIC
Together we can reduce the plastic that
goes into our environment!
NEW HOPE
WPI

Plastic Guide for CIT and New Hope Schools

Type	Common Examples	Recyclability	Recycling Route at CIT/NH	Health	Notes
Plastic #1 – Polyethylene Terephthalate (PET)					
	Soda bottles, fruit juice, mineral water containers, cooking oil containers, peanut butter jars, detergent bottles	Large quantity commonly and easily recyclable	Mainly bottles being sold from Municipal Center. Can be shredded. Can be heat pressed. Can be molded.	No health issues known	
Plastic #2 — High Density Polyethylene (HDPE)					
	Milk jugs, cleaning products, shampoo bottles, detergent bottles	Clear HDPE containers easily recycled. Colored HDPE converted into plastic lumber, lawn and garden edging, pipes, ropes, toys.	Sold from the Municipal Center. Can be shredded. Can be heat pressed. Can be molded.	No health issues known	

Plastic #3 — Polyvinyl Chloride (PVC or V)					
3 PVC	Bubble foils, sweets and fruit trays, foam board, pipes, furniture, toys	Non-recyclable. Due to additives. See **Health**	Sold from the Municipal Center. Not machined with due to health concerns. See **Health**	Many harmful chemicals are produced in the manufacturing, disposal, or destruction of PVC including: • Lead • DEHA (di(2ethylhexyl)adipate) • Dioxins • Ethylene dichloride • Vinyl chloride Effects of exposure to these chemicals may include: decreased birth weight, learning and behavioral problems in children, suppressed immune function and disruption of hormones in the body, cancer and birth defects, genetic changes.	Harmful chemicals created as a byproduct of PVC can also settle on grassland, where they can be consumed by livestock, and accumulate in meat and dairy products that are directly ingested by us.
Plastic #4 — Low Density Polyethylene (LDPE)					
4 LDPE	Shopping bags, resistant sacks, crushed bottles, fresh produce packaging, bread packaging, newspaper bags	Not typically recycled.	Sold from the Municipal Center. Can be shredded. Can be heat pressed. Can be molded.	No health issues known	While no known health effects associated with the use of this plastic are known, organic pollutants are formed during manufacturing.
Plastic #5 — Polypropylene (PP)					
5 PP	Furniture, luggage, toys, linings and borders for cars, ketchup bottles, medicine containers, yogurt	Not easily recycled. Consistent quality in recycling difficult due to type variations.	Not sold from the Municipal Center. Can be shredded. Can be heat pressed.	No health issues known	

	cups, sour cream tubs, margarine containers, straws, bottle caps		Can be molded.		
Plastic #6 — Polystyrene (PS)					
	Toys, hard packaging, fridge trays, CD cases, costume jewelry, styrofoam cups, packing peanuts, coolers	Not typically recycled. Recycling not normally economically viable.	Sold from the Municipal Center. Can be shredded. Can be heat pressed. Can be molded.	Styrene can leach from polystyrene. Over the long term, this can act as a neurotoxin.	
Plastic #7 — Mixed (Other)					
	Lids, medical storage containers, electronics, most plastic baby bottles, 5-gallon water bottles, “sport” water bottles, metal food can liners, clear plastic “sippy” cups, some clear plastic cutlery	Difficult, if not impossible, to recycle.	Not sold from the Municipal Center. Can be shredded. (dependent on mixture). Can be heat pressed (dependent on mixture). Can be molded (dependent on mixture).	Health effects vary depending on the resin and plasticizers in this plastic that often includes polycarbonates. Polycarbonate plastic leaches bisphenol A (BPA) a known endocrine disruptor. By mimicking the action of the hormone, estrogen, bisphenol A has been found to: effect the development of young animals; play a role in certain types of cancer; create genetic damage and behavioral changes in a variety of species.	

Note: All information adapted from National Geographic https://www-tc.pbs.org/strangedays/pdf/StrangeDaysSmartPlasticsGuide.pdf and from on site research by WPI students

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