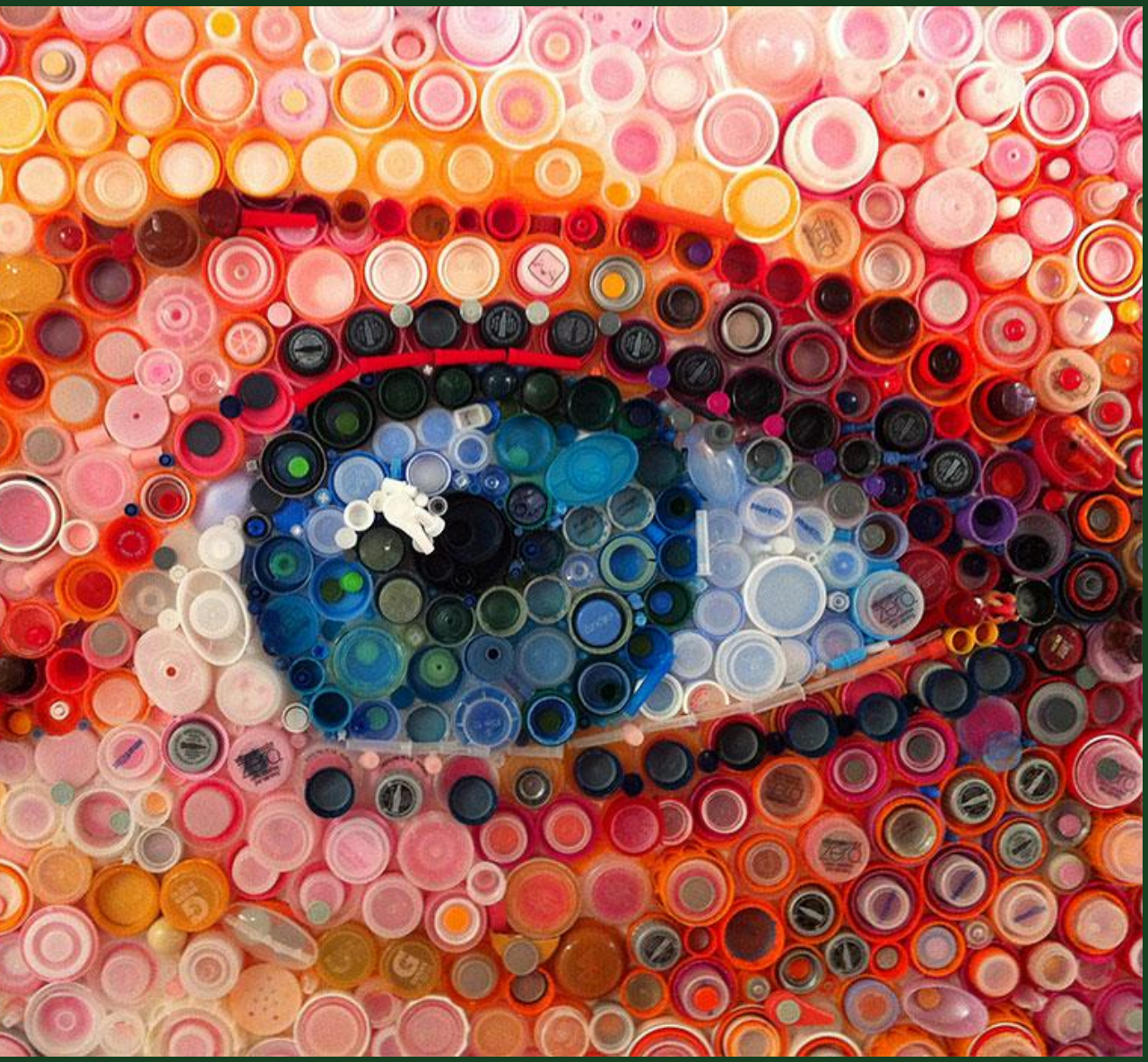

Reducing Waste Through Innovation:

Engaging the Melbourne Community via Plastic Bottle Cap Recycling

Adam Giordani
Melissa Kelly
Oamfah (Faith) Suwannapong

May 3, 2023

Jesuit Social Services
Building a Just Society

WPI

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Submitted By:
Adam Giordani
Melissa Kelly
Oamfah (Faith) Suwannapong

May 3, 2023
Melbourne Project Center

Project Advisors:
Stephen McCauley
Lorraine Higgins

Sponsor:
Jesuit Social Services
Stuart Muir Wilson
Michael McGarvie

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CONTRIBUTIONS

Adam Giordani
Mechanical Engineering

Researched CNC machining process, viability of HDPE for 3D printing, and injection molding process. Wrote the background section on plastic recycling process, CNC fabricated injection molds for eco-friendly use, and producing 3D printing filament and products from recycled high-density polyethylene (HDPE). Wrote the methodology on designing functional, useful, and environmentally friendly plastic products and created instruments used in this method. Designed all of the final products on Solidworks and did several design iterations and technical drawings for each. Recorded and edited the instructional video.

Faith Suwannapong
Chemical Engineering

Researched community partners and their collaborations. Wrote the introduction and the background section on plastic pollution and its impacts, Jesuit Social Services, and community engagement through plastic recycling workshops. Drew the project diagrams. Designed the logos of the package. Wrote the methodology on creating and testing a demonstration mode. Designed and created pre and post surveys and all posters and handouts used in this method.

Melissa Kelly
Aerospace Engineering

Researched existing plastic bottle cap recycling, recycling regulations in Melbourne, and potential marketable products. Wrote the background section on regulations on single-use plastics in Victoria and how to determine marketable products. Planned and designed methods for each objective. Wrote the methodology for creating a functioning recycling assembly line and designing user-friendly instructional materials and created instruments used in this method. Planned the weekly onsite timeline. Organized and improved the recycling assembly line. Created the instruction manual and helped film the instructional video. Wrote the abstract, executive summary, and conclusion.

With Assistance From

Di Abdimash
Aerospace Engineering

Contributed to background research and proposal writing on the challenge in recycling plastic bottle caps. Also helped with initial planning for research methods we eventually adapted for on-site use.

ABSTRACT

The purpose of this project was to assist the Ecological Justice Hub in their efforts to begin their plastics recycling program to recycle bottle caps. We helped set up and create an assembly line, co-designed and prototyped recycled products and story-telling packaging, set up demonstration workshops, and created instructional materials to train future Ecological Justice Hub employees and volunteers on our process. This program aims to promote social change outcomes such as: community awareness, education, and changes in recycling behavior.

EXECUTIVE SUMMARY

The Problem with Plastic

Plastic is inexpensive and has many functional applications; however, the material itself is non-biodegradable. As a result, large quantities of plastic waste end up – and remain – in landfills or are washed into waterways when disposed of improperly or not recycled. This waste eventually breaks down into microplastics, which are known to harm wildlife and humans (Parker, 2019). Moreover, exposure to microplastics and chemicals added in plastic production can disrupt human hormonal balance, damage reproductive systems, and contribute to cancer risk (Lindwall, 2020). The main cause of plastic pollution is single-use plastic, commonly containers such as bottles, which account for 40% of produced plastics every year (Parker, 2019).

Sustainability Victoria (2022) reported that the consumption of bottled water in Australia has increased significantly over the past decade, with the average annual per capita consumption increasing by 34% from 2007 to 2019. Australians buy about 15 billion plastic bottles every year (Sustainability Victoria, 2022). While some can be recycled, many of them cannot. In 2016 alone, about 485 billion PET bottles with caps were produced worldwide, yet only some of these bottles and even fewer of the caps are recycled (Statista, 2023). Bottle caps are especially difficult to recycle because they don't get filtered through the automated recycling machines due to their size, so most end up in landfills (*ibid.*). The Australian state of Victoria implemented a ban on single use plastics and polystyrene (a type of styrofoam) that went into effect on February 1st, 2023 (Victorian Government, 2023), however, single use plastic bottles and bottle caps are not included in this ban. With the large consumption rate, the short length of use, and the long-term life cycle of plastic, recycling plastic bottles and caps is crucial.

The Ecological Justice Hub of the Jesuit Social Services has partnered with two Melbourne groups, Lids4Kids and Precious Plastics, to start a new plastic recycling initiative, Regenerative Plastics. Precious Plastics, an international organization that develops sustainable products from 100% recycled materials, started their own plastic bottle cap recycling initiative in Melbourne. The Ecological Justice Hub aims to create a similar initiative to Precious Plastics, but with an emphasis on community engagement and education. The Ecological Justice Hub believes that community education can lead to broader behavioral changes and an increase in plastic recycling.

Project Goal

Our goal was to assist the Ecological Justice Hub in **developing and launching a plastic bottle cap recycling process that can be used to increase community awareness, education, and engagement in recycling.** In order to accomplish this goal, we completed the following objectives:

1. Created a functional assembly line for recycling plastic bottle caps into useful or meaningful products.
2. Co-designed plastic products that could be created through this process, along with packaging that conveys the importance of plastic recycling.
3. Developed a hands-on education and demonstration workshop to educate the Melbourne community about plastic cap recycling, including assessment materials to measure learning and intended behavior change.
4. Developed user-friendly training materials so that volunteers and employees at the Hub can operate the line and continue to lead workshops.

The results of our project will allow the Ecological Justice Hub to regularly produce a variety of beautiful products from plastic bottle caps that people will enjoy rather than those bottle caps ending up in landfills. The Ecological Justice Hub will be able to continually run demonstration workshops to educate and engage the community to demystify plastic recycling. These results will be able to provide an income stream for the Ecological Justice Hub, which will allow them to continue to grow this initiative.

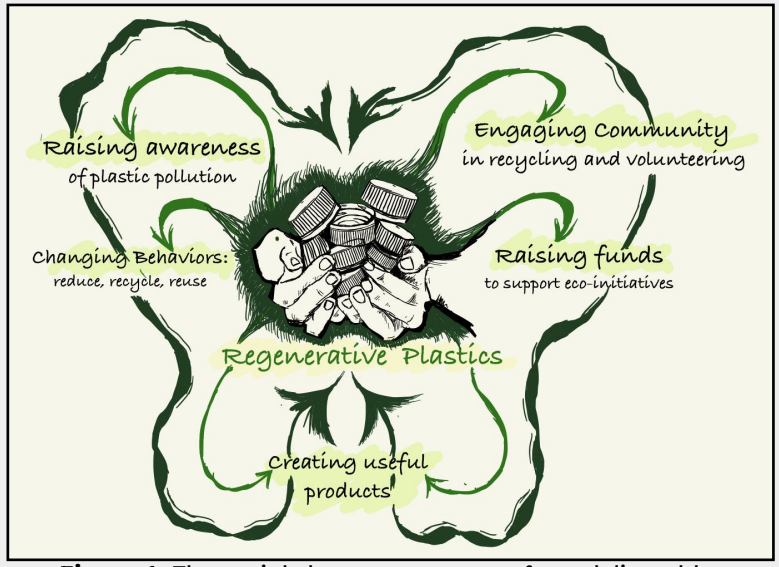

Figure 1: The social change outcomes of our deliverables.

Methods and Results

To fulfill these objectives our team first tested and made improvements to the recycling equipment obtained by the Ecological Justice Hub, to **create a functional assembly line** (see Figure 2).

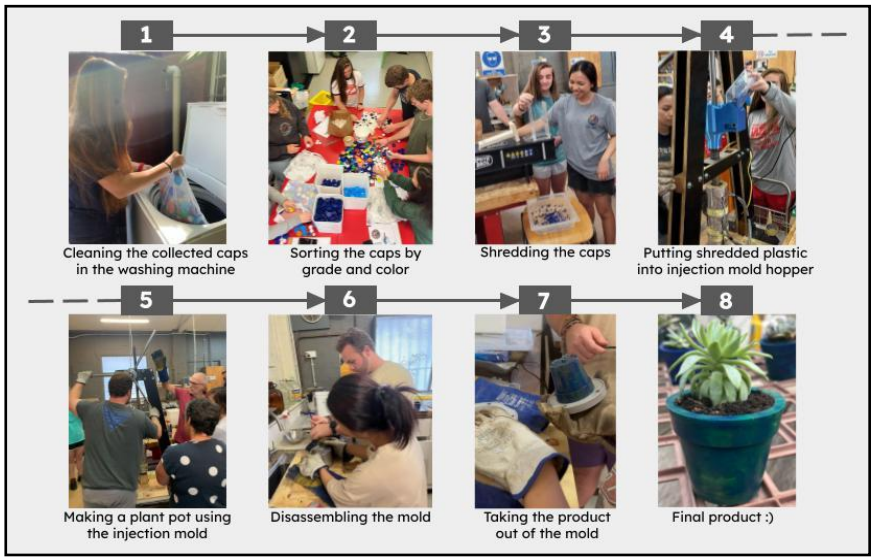

Figure 2: The steps of the recycling assembly line.

The process of turning bottle caps into products starts with collecting the bottle caps from the community and the Lids4Kids program via donation stations, then cleaning the caps. As we were going through the process, we made important innovations to make the assembly line more efficient. We developed a way to use a washing machine and mesh bags to speed up the process of cleaning a large number of lids rather than hand washing them. We cut the lids in half manually and fed them into a hopper on the Precious Plastics benchtop shredder. Cutting the lids in half reduced the chance of the shredder getting jammed. In addition to these steps our team also assembled a 3D printer to prototype and test designs for future products and their molds.

Once our recycling assembly line was set up we **designed products with community input**. First we established a set of criteria for product ideas including: sustainability, functionality, safety, time and resource consumption, and producibility.

We polled visitors at an environmental park (Figure 3) and volunteers at the Hub as to which products they would be interested in buying, yielding five top product ideas: a **self-watering plant pot, garden stake, plant label, garden trowel, and coaster (Figure 4).**

Prototyping then began, starting with creating CAD models of the products using Solidworks. **Initial designs were prototyped using the 3D printer and changes were made and tested again until the products were satisfactory.** Then, we developed technical drawings for future CNC fabrication of injection molds.

Figure 3: Polling at CERES harvest festival.

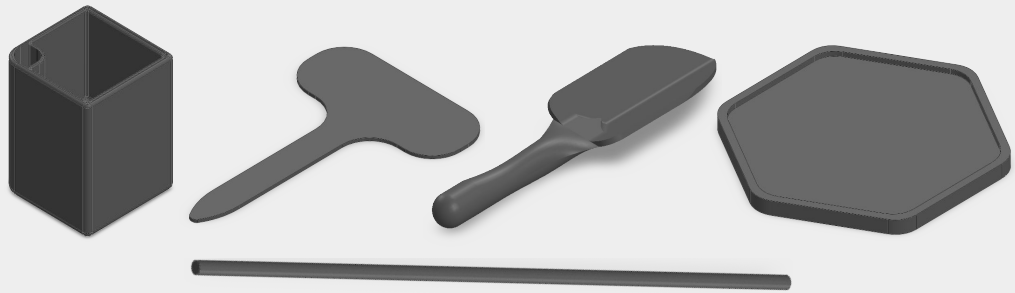

Figure 4: Our top five product ideas.

The last part of our design process was to **create packaging that tells the story of how plastic bottle caps were turned into beautiful new products**. This critical step ensured that buyers would learn about the environmental benefits of purchasing recycled products as well as information on recycling and what they can do to help with our efforts, combining good marketing with education. Figure 5 shows one of 5 packaging designs we created.

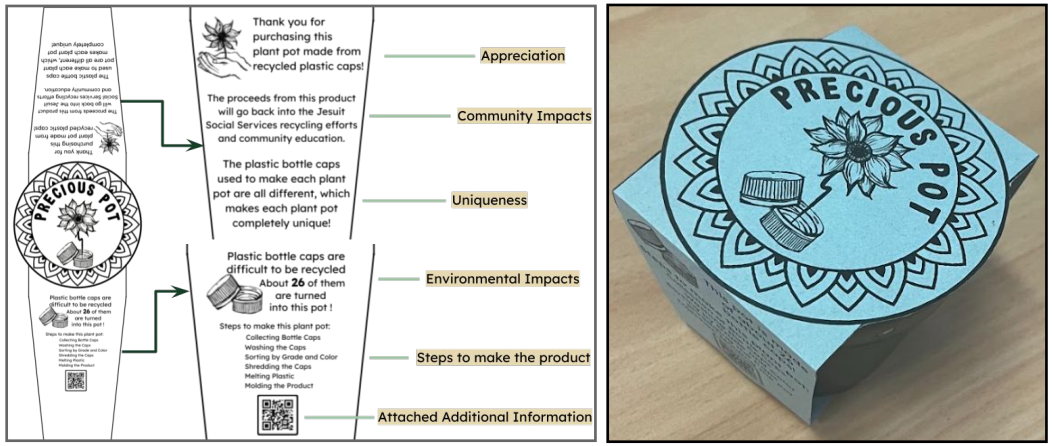

Figure 5: Plant Pot Packaging.

Our next objective was to **create a 2-3 hour hands-on recycling workshop that** teaches participants about the importance and challenges of bottle cap recycling and guides them through a **hands-on activity** where they complete the steps of the recycling assembly line, helping to sort, shred, melt and form a plastic pot, which they would take home. Participants learn the importance of recycling plastic and how they can contribute more to this initiative. We designed **educational handouts** (see Figure 6) for this purpose.

Figure 6: Educational handouts on plastic pollution (left) and plastic bottle cap recycling (right).

We piloted the workshop (Figure 7) with four participants and used our observations to improve the workshop preparation and scheduling.

Figure 7: Testing our workshop with participants. In the picture on the left, participants are shredding the lids and in the picture on the right, participants are using the injection mold to make a plant pot.

To test the effectiveness of the workshops, we developed a **pre and post survey to establish** what they learned through the workshop as to see if they intend to change their recycling behaviors and/or volunteer to work with the Hub. The Hub can collect and use these data in future grant writing to show evidence of workshop impact.

To ensure that future staff and volunteers can lead this workshop, we developed **training materials** on how to use the equipment and lead the workshop effectively. **A training manual** highlights safety precautions regarding the equipment as well as detailed steps for how to use each piece of it. **A supplemental instructional video**[1] was also produced to accommodate different learning styles and make it easier to understand the process.

Conclusion

Our recycling assembly line, product designs, educational and marketing materials, community workshop activities, and assessment instruments will help the Ecological Justice Hub launch the new Regenerative Plastics Initiative. Specifically, with these resources they can manufacture and market several products and continue to run and report outcomes from demonstration workshops. This combination of activities, most importantly, will be used to raise awareness of the plastics problem in Melbourne and to engage community members in taking productive action to address that problem. We hope our materials and process will have a lasting impact on bottle cap recycling efforts and set a good example for other communities to follow.

[1] The Supplemental Instructional Video may be accessed on Youtube via this link: https://youtu.be/rVwzXUIRkU8

INTRODUCTION

01

According to a study by the Plastic Pollution Coalition (2022), only 9% of all plastic produced globally is recycled

02

In Australia specifically, 84% of plastic is sent to landfill while only 13% is recycled (Australian National Plan Summary, 2021)

Sustainability Victoria (2022) reported that bottled water consumption in AUS has increased over the past decade, with an average annual consumption increase of 34%.

03

A majority of plastic pollution is due to discarded plastic bottles.

04

Australians buy about 15 billion plastic bottles every year (Sustainability Victoria, 2022). While some plastic bottles can be recycled, many of them cannot. Bottle caps are especially difficult to recycle because they don't get filtered through the automated recycling machines because of their size leading them to end up in landfills (Sustainability Victoria, 2022).

Regarding the recycling policy in many Australian councils, plastic bottle caps must be separated from bottles before being placed in the recycling bin (Precious Plastic Melbourne, 2023) as the bottles cannot be processed with the lids on. With the large consumption rate, the short length of use, and the long-term life cycle of plastic, recycling of plastic bottles and of caps is crucial.

In response to this challenge, various ecological organizations in Melbourne have taken action to address the issue. Some of these efforts include beach clean-up events, educational campaigns, and public recycling awareness initiatives.

The Ecological Justice Hub, a branch of the Jesuit Social Services which aims to strengthen environment protection and support disadvantaged communities through education and training, has partnered with Lids4Kids to collect plastic caps. They recruit and train volunteers to wash and sort caps. They have acquired some equipment from Precious Plastic to produce recycled plastic products from plastic bottle caps. The Hub aims to develop a small-scale recycling facility, to offer workshops that educate the Melbourne community and de-mystify plastic recycling, and to collect data on plastic recycling to inform the council and foster further grants and activities.

Our goal in this project was to assist the Ecological Justice Hub to create a plastic recycling process that can be used to raise community awareness and increase community engagement in recycling. In order to accomplish this goal, we completed the following objectives:

Objectives

1. To create a functional assembly line for recycling plastic bottle caps through CNC machining and 3D printing
2. To co-design useful and environmentally friendly plastic products that could be produced through this process
3. To educate the Melbourne community about plastic cap recycling through demonstration workshops
4. To develop user-friendly training materials so that others can operate the line in the future

Project Goal

Our goal in this project was to assist the Ecological Justice Hub in developing the plastic recycling process that can be used to increase community awareness, education, and engagement in recycling.

BACKGROUND

In this chapter, we discuss single-use plastics and their environmental impacts, the difficulty in recycling plastic bottle caps, and the regulations on single-use plastics in Victoria, Australia. We introduce the Ecological Justice Hub and its plastic recycling project, reviewing information on the recycling process, product development, and the importance of engaging the community in the process.

Plastic Pollution and its impacts

Global plastic production increased from two million metric tons in 1950 to 380 million metric tons in 2018 (Plastic Soup Foundation, n.d.); in 2021 it was estimated to have reached 390.7 million metric tons (Plastics Europe, 2022). Plastic is inexpensive and has many functional applications; however, the material itself is non-biodegradable. As a result, large quantities of plastic waste clog up landfills, wind up in waterways when disposed of improperly or not recycled, and eventually get broken down into microplastics, which are known to be harmful to wildlife and humans (Parker, 2019). Moreover, exposure to microplastic and chemicals added in plastic production could harm human hormonal balance, damage reproductive systems, and contribute to cancer risk (Lindwall, 2020).

The main cause of plastic pollution is single-use plastic, which accounts for 40% of produced plastics every year (Parker, 2019). Single-use plastics are goods made primarily from fossil fuel-based chemicals and are meant to be discarded right after use or a short period of time after use. Single-use plastics are commonly used as containers such as bottles, styrofoam takeaway boxes and cups, bags, and straws. Courtney Lindwall (2020), a writer for the environmental nonprofit Natural Resource Defense Council, has explained that single-use plastics are endemic to a throwaway culture; instead of investing in quality goods that will last long, the global population prioritizes convenience over durability and the long-term impacts.

During the Covid-19 pandemic, single-use plastics, such as PPE kits, masks, and gloves. were needed to preventing infections and reduce extra steps of washing and sterilization; there has been a significant rise in plastic pollution due to their single use, disposal, and poor waste management (Parashar and Hait, 2020). The leakage of plastic waste into ecosystems is growing concern and the challenging to recycle it is now a problem for researchers, governments, citizens, and other stakeholders must solve.

Challenges in Recycling Plastic Bottle

Plastic bottle caps are a common single-use plastic product in most households. These plastics are lightweight, durable, moisture-and-bacteria resistant synthetic materials made from polymers. These qualities make plastic popular for use in a variety of products, including bottle caps. The three main types of plastic used to produce bottle caps are:

2 High Density Polyethylene (HDPE)

4 Low Density Polyethylene (LDPE)

5 Polypropylene (PP)

Although they can be recycled, they are not widely recycled. However, since these materials can be recycled, this makes them good for purposes such as injection molding and 3D printing.

Only a limited number of recycling facilities have the technology to separate mixed materials and recycle them properly. Caps are small and lightweight and can fall through sorting machines at recycling facilities, making them difficult to capture and recycle. Another reason why bottle caps may not be recycled is that it is not economically profitable. The cost of producing new plastic bottle caps is much cheaper than recycling the caps into new products. It's more efficient to make new plastic bottle caps from raw materials than to sort, clean, and melt down used plastic caps to make new ones. Recycled plastic often lacks the purity and quality of new plastic, leading to lower quality products (Figure 8).

The demand for recycled plastic products is low in comparison to the high demand for new plastic products. The market is more stable for new plastic products and it also allows manufacturers to produce plastic bottle caps quicker and at a lower cost. Low Density Polyethylene and High Density Polyethylene plastics are economically viable and easy to recycle, however, only 29% of these types of plastics were recycled in 2018 (United States Environmental Protection Agency, 2018). While recycling plastic is beneficial for the environment and conserves resources, the costs and time associated with the plastic recycling process make it more expensive than producing new plastic bottle caps.

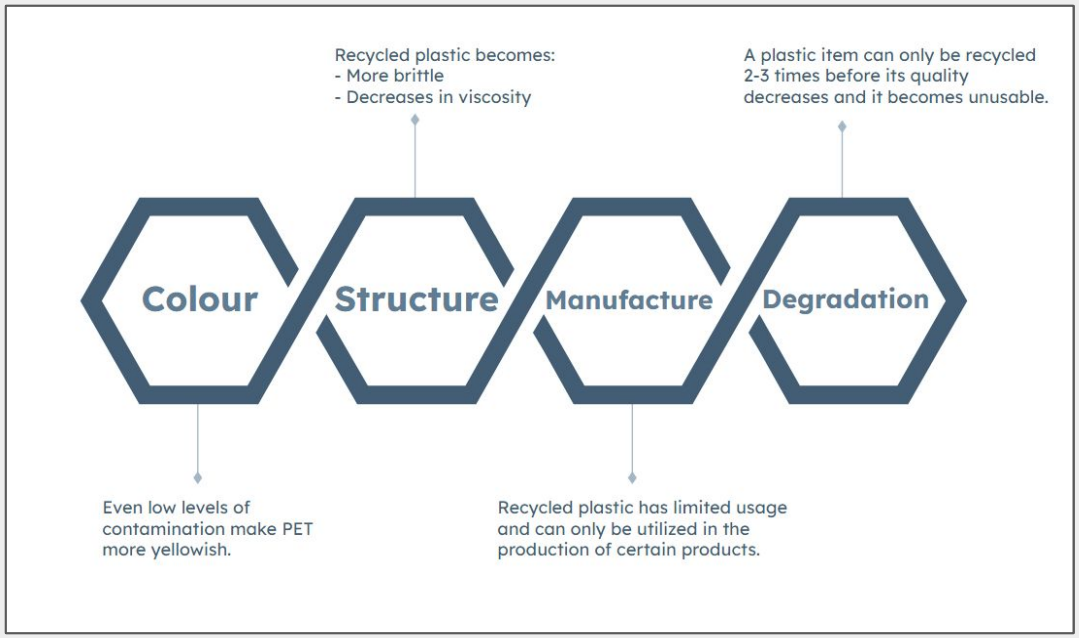

Figure 8: Quality limitations of recycled plastic (adapted from Hahladakis & Iacovidou, 2018)

Regulations and Programs to Reduce Single-Use Plastics

The Australian state of Victoria implemented a ban on single use plastics and polystyrene (a type of styrofoam) that went into effect on February 1st, 2023 (Victorian Government, 2023). Some widely used plastic products that are included in this ban are straws/stirrers, plates, cutlery, and cotton swab sticks. Single-use expanded polystyrene products that have also been banned are food service items and drink containers (Victorian Government, 2023). There are exceptions to the ban for people with disabilities and medicinal needs that may require a single use product for hygienic purposes. Since this ban impacts many businesses, Victoria also implemented a program to help businesses adjust to using more environmentally-friendly and reusable products (Victorian Government, 2023). Although it is too early to assess the impacts of the regulations, similar bans that have been put in place in other parts of the world have proven to be effective in reducing plastic waste.

In addition to the ban, some organizations have been working with Melbourne citizens to get them more involved and aware of plastics recycling in general. Two notable organizations that have been successful in the plastic recycling movement are Precious Plastics and Lids4Kids. Precious Plastics supplies necessary machinery to organizations that are finding ways to recycle plastic. Lids4Kids is an organization that collects bottle caps and turns them into many different useful products. Lids4Kids gives "school certificates" to schools who participate (Lids4Kids Australia, *2021)*. Lids4Kids has their own equipment to make their products, which are for sale on their website. A few examples of the products that they produce are combs, keychains, earrings, and phone holders. These organizations increase community engagement in plastic recycling and they partnered with the Jesuit Social Services as they planned their recycling project.

Jesuit Social Services: Building Potential in the Community Through Plastic Recycling

The Jesuit Social Services is a social change organization working to build a society where all people can live together (Jesuit Social Services Annual Report 2021-2022). The priorities of work within the organization are informed by Catholic Social Teaching and the Jesuit heritage. The organization works to help people with limited access to learning, training, and job opportunities. In 2021-2022, 12,510 people received support from the organization; 5,963 of these individuals participated in education, training, and employment programs. The Jesuit Social Services works in 36 communities across Australia, including Brunswick (north of Melbourne), to create positive impacts in many areas: justice and crime prevention, education, disability, mental health, settlement, gender and culture, and environment.

The Ecological Justice Hub, one of the programs under the Jesuit Social Services' Brunswick branch, is a permaculture garden that helps build knowledge and skills through projects which strengthen environmental protection. Their projects offer disadvantaged people job opportunities, and raise the awareness of environmental challenges within their community. Examples of the projects under the Ecological Justice Hub are shown in Figure 9.

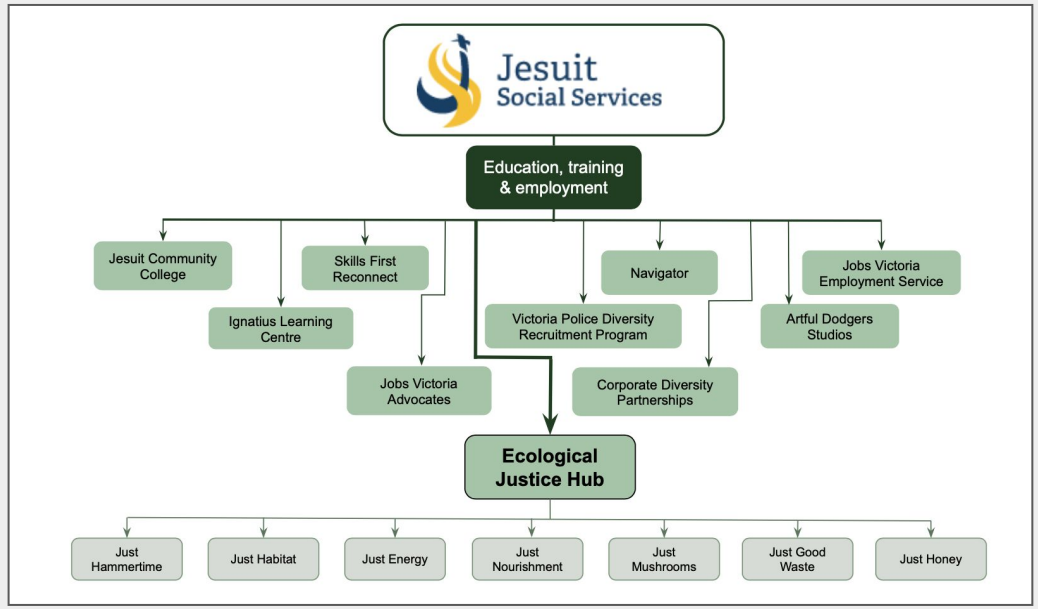

Figure 9: Programs under the Jesuit Social Services (green) and projects under the Ecological Justice Hub (gray)

In the new Regenerative Plastics initiative (shown in Figure 10), the hub aims to produce products from recycled plastic bottle caps that can be sold through social enterprises and educate the Melbourne community about plastic recycling through workshops.

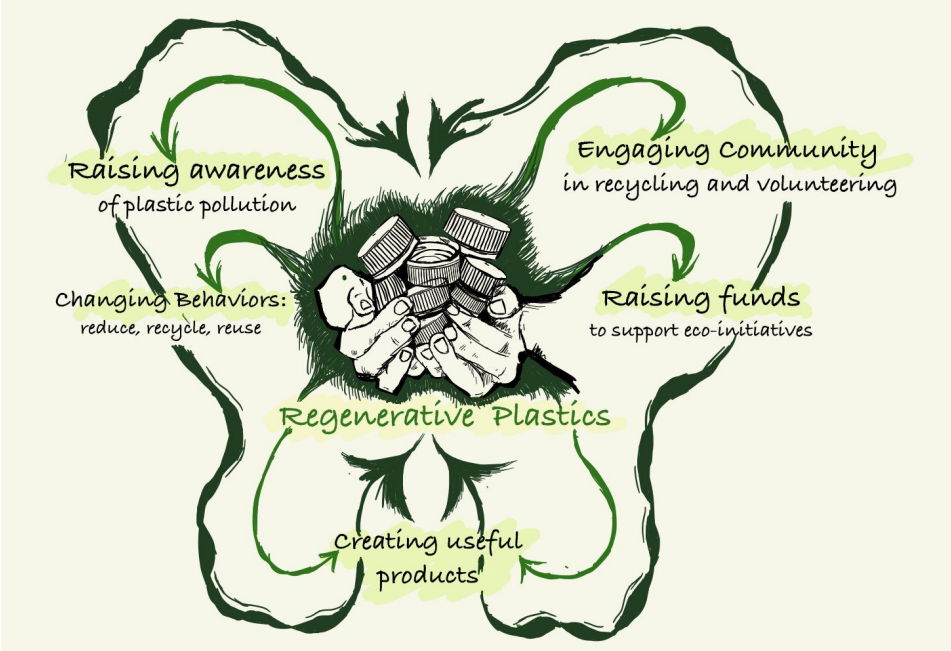

Figure 10: The social change outcomes of our deliverables.

The Hub is partnering with Precious Plastics Melbourne, an international organization that develops sustainable products from 100% recycled materials. The organization provided the Hub with the necessary machinery and training. The Hub will collaborate with them to access industrial equipment and manufacture product molds.

Plastic bottle caps are being supplied from the Lids4Kids Australia and include washed, dried, and color sorted milk/UHT bottle caps, water bottles caps, and soft-drink bottle caps. However, this supply is not sanitized.

In order to set up the recycling process and assembly line, we had to first understand the basics of the recycling process, which we discuss in the next section.

Community Engagement Through A Plastic Recycling Workshop

One of the objectives in this project was to increase public awareness of and engagement in recycling. Sally Hussey (2019), a communication consultant, explained that engaging the community involves collaboratively working with and listening to the community to build long term relationships and develop meaningful solutions to complex issues. In terms of plastic pollution, community engagement can reduce inappropriate waste disposal behavior, and, in turn, contribute to environmental improvement (Phan et al., 2022)

To engage and educate the community on environmental projects, the Ecological Justice Hub offers the workshop to Melbourne residents. Chandra (2022) described how such hands-on workshops allow a group of people to collaboratively develop and share their knowledge or experience. According to Sustainability Pathways (2022), sustainability workshops can help participants bring sustainability in their everyday practice. When participants experientially engage with material, they develop take-home messages and ultimately make better environmental choices (Sustainability Pathways, 2022).

In the past, the hub designed workshops through a brief educational presentation and hands-on activities to demonstrate the goals and processes of the projects to participants.

Planning the workshops involves brainstorming, designing, visualizing solutions can be a way to engage large groups and facilitate collaboration (Li et al., 2020). Throughout the workshop process, community members can participate in activities, be asked about their knowledge and ideas, and asked to give feedback. By having a conversation and interacting with others, community members can learn new information and have experiences which might change in their recycling behaviors.

Plastic Recycling Process: How to Convert Plastic Waste into New Products

There are two methods of plastic recycling: traditional and advanced. Traditional recycling involves melting the plastic and processing it into new plastic products as shown in Figure 11, while advanced recycling breaks down the plastic material through pyrolysis, chemical recycling, or gasification.

In this project we focused on the traditional method, due to its simplicity and because we were implementing this recycling initiative on a small scale. Traditional plastic recycling involves several steps as shown in Figure 11 to produce a final product rather than pellets or filament, however, additional steps are needed.

Figure 11: Typical plastic recycling plant (*Plastics Recycling in Four Simple Steps* (n.d.)).

In this project we focused on the traditional method, due to its simplicity and because we were implementing this recycling initiative on a small scale. Traditional plastic recycling involves several steps as shown in Figure 5 to produce a final product rather than pellets or filament, however, additional steps are needed.

We determined that a feasible plan for micro recycling would be

1. Sourcing the plastic bottle caps from Lids4Kids.
2. Sanitizing them using water and disinfectant during a further quality control check and sorting by plastic type and color.
3. Shredding the caps into flakes using the Precious Plastics shredder.
4. Melting down the flakes using the Precious Plastics extruder.
5. Feeding the material through an extruder machine to make injection molded parts which will then be cooled and removed from molds. Or, if they wish to snake products via 3D printing, the melted material will be fed through a filament making machine. This filament will then be used for 3D printing.

Figure 12 shows the general process; however, the equipment and its specific usage is just as important.

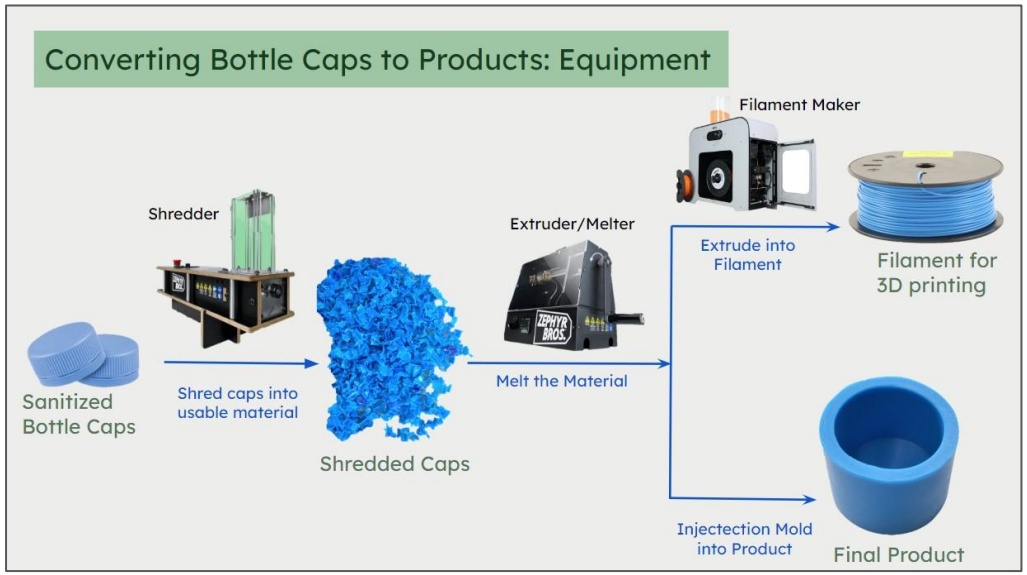

Figure 12: Small scale plastic recycling method. This is what is used at the Ecological Justice Hub.

Figure 13: Benchtop Shredder

The first piece of equipment is the shredding machine (Figure 13). The shredder can turn several different types of plastics, including 3D printer waste, into plastic flakes for further processing. The shredder has low energy consumption, is easy to clean, and the speed and direction of the motors is fully controllable (Precious Plastic Melbourne, 2023).

Figure 14: Benchtop Extruder

Once the flakes from the shredder are produced they can be loaded into the extruding machine. Depicted in Figure 14, the extruder features a hand crank on the side and boasts a simple but effective single screw design that can create 3D printing filament or inject recycled plastic into intricate molds (Precious Plastic Melbourne, 2023).

Figure 15: Pro Series Injector

For larger molds, plastic can be injected using the pro series injector shown in Figure 15. This injector, unlike the benchtop extruder, uses a piston that pushes the plastic flakes through a heated pipe directly into the mold.

Figure 16: Plant Pot Mold

Precious Plastics Melbourne also makes their own molds which are fully compatible with the extruder machine. Designed for use with HDPE, the mold illustrated in Figure 16 is a high end sandblasted alloy that will produce plant pots time and time again (Precious Plastic Melbourne, 2023).

Figure 17: 3devo 3D Printing Filament Maker

The 3devo filament maker (Figure 17) is capable of turning the plastic flakes from the shredder into fully functional 3D printer filament. Because of its temperature versatility (capable of reaching 450 degrees C), this machine can process a wide range of materials. It can also make various different diameter filaments depending on what 3D printer will be used, the filament diameter can vary from 0.5-3 millimeters (3devo, 2022).

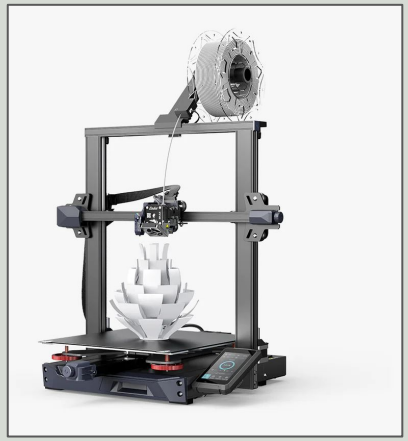

Figure 18: Ender-3 S1 Plus 3D Printer

Many 3D printers can print recycled HDPE material just as normally as they would print another material. Another is shown in Figure 18.

Documenting the equipment and its use will prove beneficial in creating the instructional materials that our group will be making on-site for the community.

Creating the Mold Through CNC Fabrication

Computer Numerical Control (CNC) injection molds are used to shape melted plastic into products. The molds themselves can be produced relatively inexpensively and are commonly made out of aluminum or steel (Patil, 2022). The process of producing the molds is known as CNC machining. CNC machines are a subtractive manufacturing process, meaning the parts are made by programming a cutting and shaping machine to remove material from an original piece of stock. The current quality of CNC machines are very precise and can create a mold with an extremely complex cavity. Cutting and shaping tools can be changed during the machining process to allow for finer machining. Because of their large footprint and maintenance demands, the machines require a skilled workforce and dedicated industrial space (Formlabs, 2023). This means that many companies who need injection molds, not just for recycling purposes but making general items too, will be forced to source the molds from a specialized manufacturer similar to Precious Plastics.

This is just one possible supplier of molds in Melbourne, but it is important that any molds be fully compatible with machines and the material type described above for recycling plastic bottle caps. The Precious Plastic molds are designed with plastic recycling injection molding in mind; however, this does not mean that other CNC companies in the area cannot make suitable molds.

We have reached out to Melfab Engineering, a local shop here in Melbourne and asked them what they would need from us to produce molds that we have designed. We found that our technical drawings are enough for them to go off of. The turnaround time at Melfab Engineering is four weeks to go from our files to the finished aluminum mold so it is important that we get the design exactly how we want it to be before sending it out.

Though the molds are going to be used to inject recycled plastic into, it is not to say that they could not be used for other plastics as well. There is no main difference in the mold design to accommodate recycled plastic, the main concern is just the compatibility with the Precious Plastics machines, which we can design our molds to meet their specifications.

Producing Products From Recycled 3D Printing Filament

High-Density Polyethylene (HDPE) plastics as a material source can be used to 3D print a product in an environmentally friendly way. HDPE is a Type 2 plastic that is fully recyclable and is commonly used as the material for harder bottle caps, such as on a bottle of Coca Cola. The other type of plastic commonly used on bottle lids is low density polyethylene (LDPE), something that would be found on a milk bottle. Chong and colleagues (2017) describe how, “Among recyclable plastics, high-density polyethylene (HDPE) is a popular plastic waste feedstock for filament extrusion because it is commonly found in households and it has good ductility and higher strength as compared to those of low density polyethylene and polyethylene terephthalate”. For these reasons HDPE is a better choice for 3D printing. Before 3D printing with HDPE can occur, a few steps (shown in Figure 19) must happen with the raw materials.

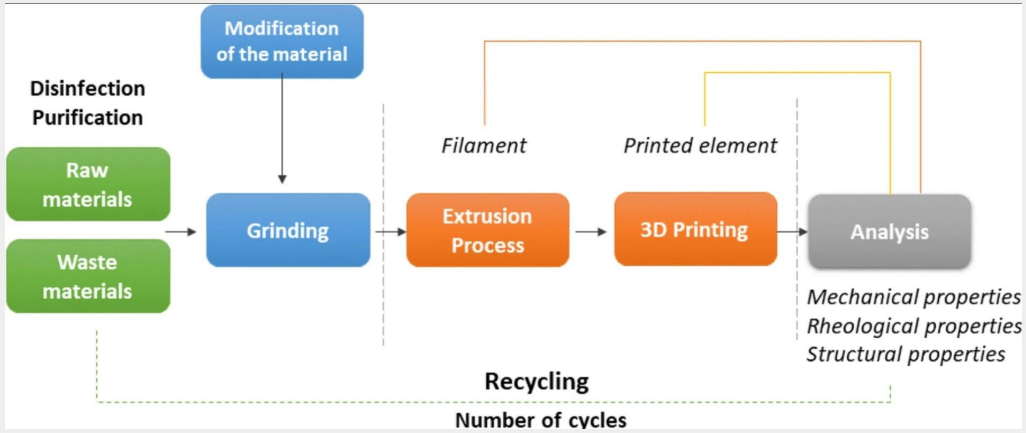

Figure 19: The process of producing 3D printed objects made from recycled HDPE

The material is then cooled and spooled up for later use (Mikula, Skrzypczak et al., 2021). After the filament has been made 3D printing can occur and any waste products or failed 3D prints can be once again recycled and put back at the start of the process again. For this reason 3D printing using recycled materials is environmentally friendly as there are no waste products that are produced. Any injection molding waste from overpours or rejected parts can also be grinded/shredded and put back through this system. This process takes plastic that would otherwise end up in landfills and turns it into something useful.

METHODOLOGY AND RESULTS

This project supported the Ecological Justice Hub's effort to create a plastic recycling process that can be used to raise community awareness and increase community involvement in recycling. Figure 20 shows the main project objectives and the methods we used to accomplish each.

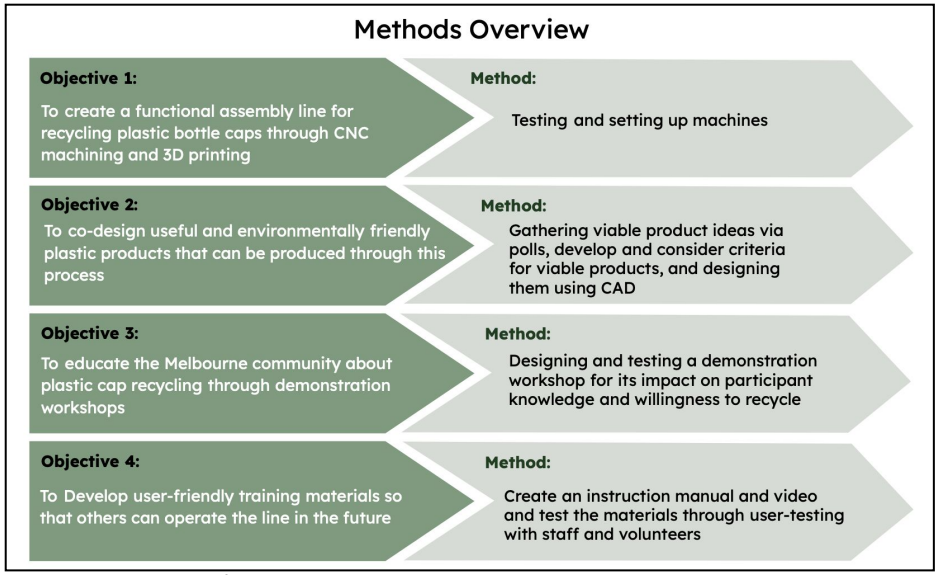

Figure 20: Project Objectives and Methods

Creating A Functional Recycling Assembly Line

The recycling assembly line is more than just the use of the machines to make a product. A functional recycling assembly line includes all steps of the plastic bottle cap recycling process, from the collection of the caps to the production of the final products. To set up the process, we had a representative from Precious Plastics give us a training session and address our questions about the equipment. We then put the machines in the order of the recycling sequence (shredder, extruder, injection molder) and assembled a 3D printer we could use to print products with recycled filament in the future. We then tested the machines' functions and tried the recycling process by working through each step of the process with staff who had operated some of the equipment prior to our arrival.

Our final process is illustrated in Figure 21:

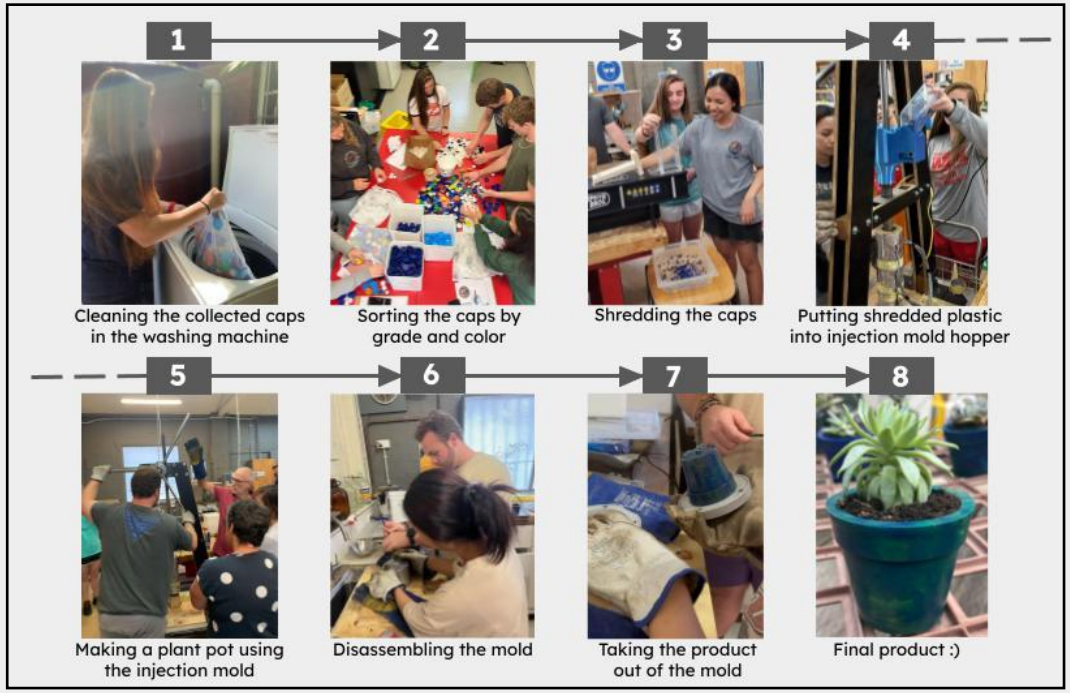

Figure 21: Steps of recycling assembly line

In order to improve the assembly line, we had to rethink some of the steps to make them more efficient. For the first step, we decided to buy a washing machine and laundry bags to wash many caps at once, rather than cleaning each one by hand. In the second step, we found that it was much more efficient to sort the caps by grade and color at the same time. When shredding the lids, the larger bottle caps would sometimes jam the shredder, so we decided to cut the lids in half to avoid any problems. The original hopper that came with the injection mold was fairly small and didn't fit all of the shredded plastic needed to create a plant pot at once. Since having to add more plastic into the hopper while using the injection mold can cause safety issues with hands being very close to the piston, we redesigned the hopper to be a lot bigger and have a shoot. The redesign of the hopper allowed us to have a safer distance from the piston when putting the plastic into the hopper and we would only have to put the shredded plastic into the hopper once.

We also assembled a 3D printer, using standard 1.75mm diameter filament on the Creality Ender 3 Plus S1 printer to prototype our ideas. Eventually, the Ecological Justice Hub would like to obtain a filament maker so they can use the melted bottle lids to make 3D printing filament which can be stored and later made into products. Smaller products would be easier and quicker to produce using a 3D printer rather than going through the entire assembly line process.

Designing Functional, Useful, and Environmentally Friendly Plastic Products

This section covers all the work we completed in determining products through surveying, assessing product viability against our criteria, designing the products themselves as well as their molds for production, and finally packaging to tell the story and sell the product.

Determining Products

Before beginning the design process, we needed to know which products the community would want. We created a list of criteria (Figure 22) that would ensure products are safe, sustainable, and practical to make. Due to health and safety issues surrounding the use of plastics in food and hot drink storage, food related plastic products are not a good idea. As outlined by the United States Food and Drug Administration, “The possibility that chemical contaminants in plastic materials intended for recycling may remain in the recycled material and could migrate into the food the material contacts is one of the major considerations for the safe use of recycled plastics for food-contact applications” (Center for Food Safety and Applied Nutrition, 2021). We then, we brainstormed a list of everyday products that might meet these criteria while being appealing to the average person or useful in the Hub itself. The Hub has programs such as gardening/composting, carpentry, manufacturing, and honey production and gardening is popular in the surrounding areas of Brunswick where the Hub is located. We conducted a survey and polls to evaluate interest in our preliminary list of products (Figure 23).

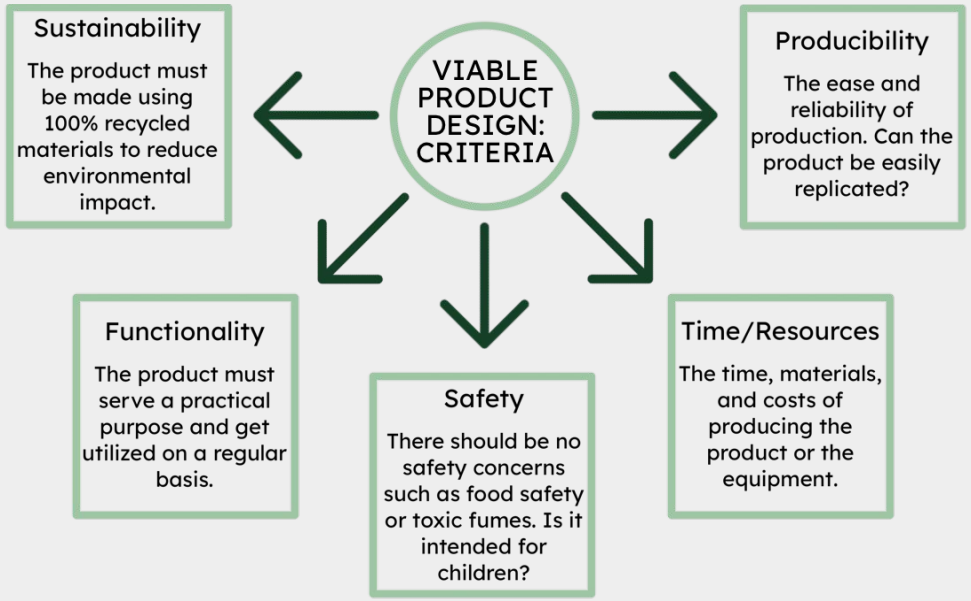

Figure 22: Criteria for determining viable products.

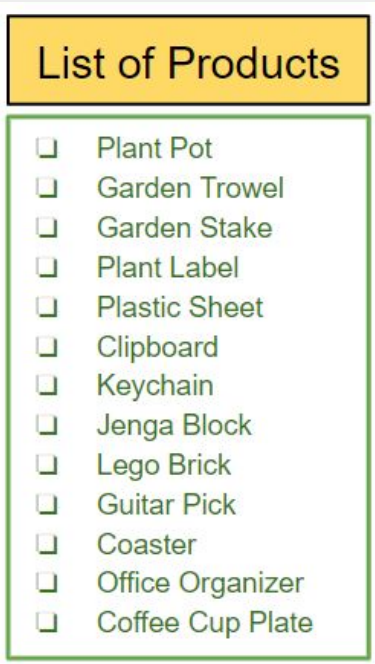

Figure 23: Product ideas list.

We then used a survey to determine which products the community might think would be useful or that they would be the most likely to buy. Our goal was to determine what products are needed in the community, but are also feasible to make with the Precious Plastic equipment. They also have to be sustainable or environmentally friendly and somewhat easy to make. The first poll was an online Google Form shown in Figure 18. We had participants rate their interest in each of the products from 0, not interested at all, to 5, very interested. The Ecological Justice Hub sent the poll out via email to their volunteers, members of the community who toured the Ecological Justice Hub that week, and posted it on their Instagram (see Figure 24).

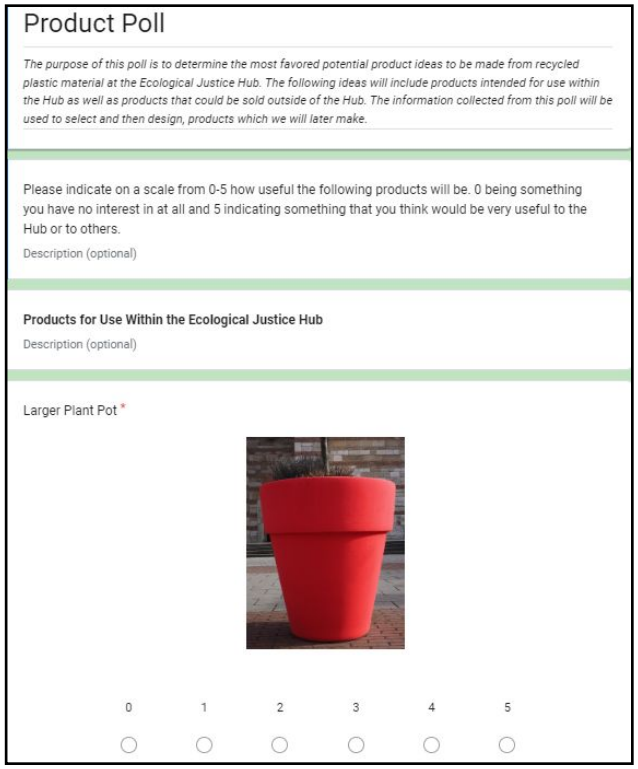

Figure 24: Online poll to determine the favored products

At the Ceres Harvest Festival on March 18th, our team set up a booth to display some of the machinery and product designs, conducting an in person survey of visitors (see Figure 25) asking people to mark products they would be most inclined to buy if they saw it made out of recycled plastic.

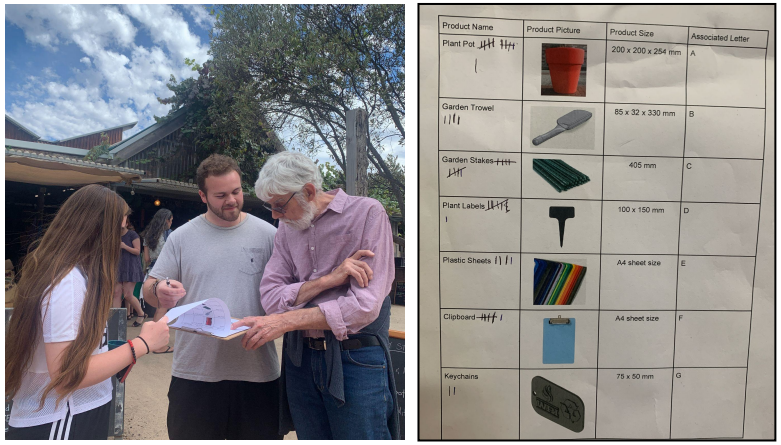

Figure 25: Paper tally survey to gauge participant interest in our list of product ideas.

We received 33 responses across our polls and surveys. We took the products that most often received scores of 4 or 5 to produce our final list. We also collected a list of suggestions for products that we did not have on our initial list but people wanted to see. The top five choices are listed in Figure 26. Other suggested products are shown in Figure 27.

Figure 26: The top five products from the survey.

Figure 27: Suggestions for additional products we could produce at the Hub.

Not all of these products fit all of our criteria. In the end, we chose just the top five products in Figure 26 because they also fit our product criteria.

Designing and Prototyping Products

Each of the products were designed using Solidworks; technical drawings for the final iteration of each one were produced (for an example, see Figure 28; all drawings appear in Supplemental Material B of the Supplemental Materials file[2]). All of the designs were prototyped on the 3D printer to test and make alterations, sometimes multiple times, until the resulting end product was satisfactory. Once the product designs were finalized, the molds were designed accordingly. The first product that was designed was the self-water plant pot (Figure 29).

[2] Supplemental Materials may be found at digital.wpi.edu by searching our project name: Reducing Waste Through Innovation: Engaging the Melbourne Community via Plastic Bottle Cap Recycling.

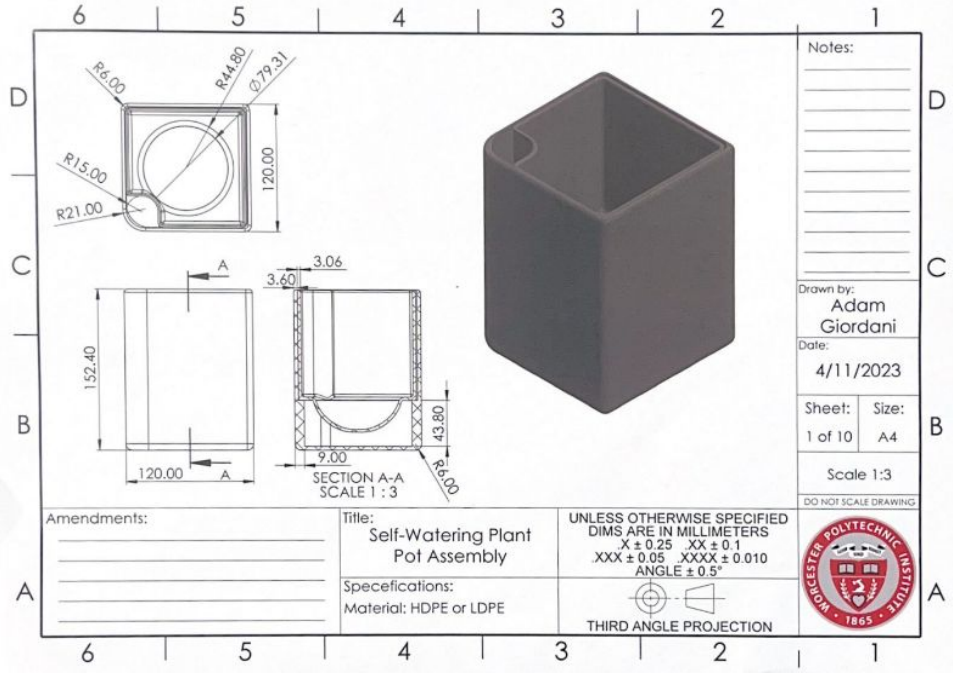

Figure 28: Example of technical drawing (self-watering plant pot).

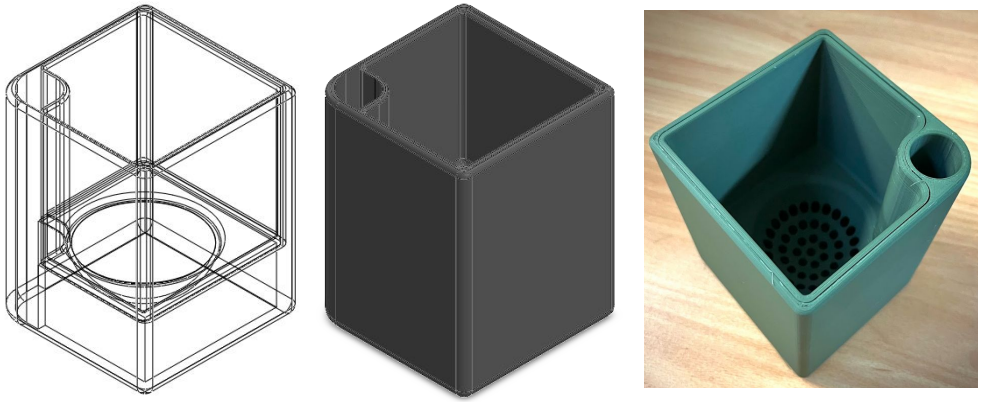

Figure 29: Self-Watering Plant Pot Design

The self-watering plant pot is a two piece product that allows for water to be poured into a reservoir chamber in the pot, while the plant is still in it above. Water is sucked up by the plant as it needs it. The first iteration featured an overhang that would not have been possible to injection mold (see Appendix B). The final iteration is large but should be fine for injection molding because both halves are fairly simple. However, this product requires two different molds, one for each part of the assembly.

It is also important to note that the holes in the 3D printed image of Figure 29, were not included in the mold as these features cannot be injection molded. These holes would need to be drilled out after the injection molding process. The CAD model of the garden stake is shown in Figure 30, and the final CAD model of the plant label is shown in Figure 31.

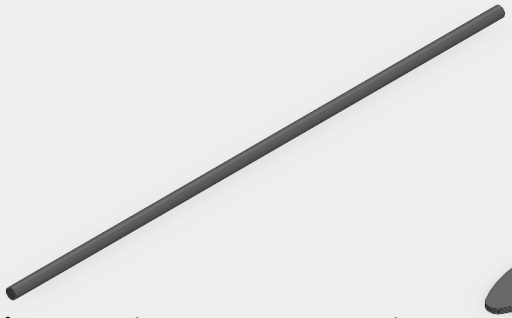

Figure 30: Final Garden Stake Design.

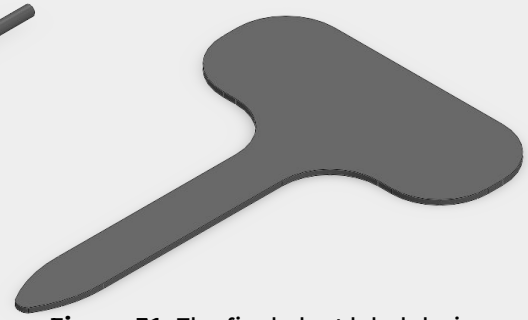

Figure 31: The final plant label design.

The plant label can be injection molded using the Precious Plastics Benchtop extruder using either HDPE or LDPE recycled bottle caps. The original design that we 3D printed was a bit too thick and bulky at 4.00mm of thickness. The first and second design iteration included a pointed edge on the bottom as well as the Jesuit Social Services logo, both of which are not able to be CNC machined after discussing the design with a local manufacturer. This is due to the tool not being able to go into small corners that are below a certain degree. The final iteration is 2.00mm thick and about 25.00mm longer than the original. The prototypes of the garden trowel (Figure 32) and the coaster (Figure 33) can be seen below.

Figure 32: Garden Trowel Design.

Figure 33: Coaster Design.

Creating Molds for Injection

Our team used Solidworks to design all of our products as well as the molds to make them using the equipment available on-site. The process of designing a mold for injection molding use was as follows:

1. Design the completely finished part/product by itself.
2. Create either a rectangular prism or cylindrical prism solid body that is larger than the part.
3. Use the combine cut tool to remove the part/product from the other solid body.
4. Create through holes for the mold to be bolted together and taken apart for injection molding purposes later.
5. Cut the mold into two separate pieces allowing for removal of the final product after injection molding (example shown in Figure 34).

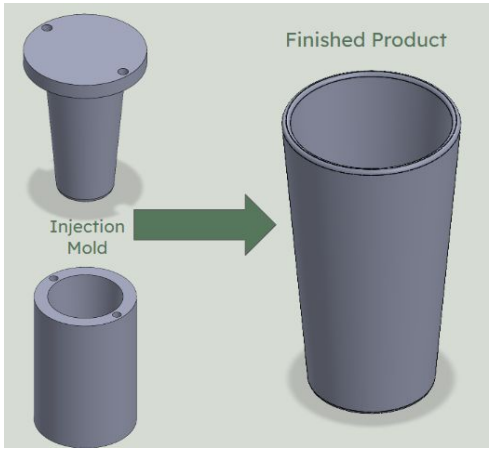

Figure 34: An example of two parts of the mold and the finished product produced.

With these steps our team made a mold for each one of our selected product designs. The first is the self-watering plant pot shown in Figure 35. The general form we decided on for the garden stake is shown in Figure 36

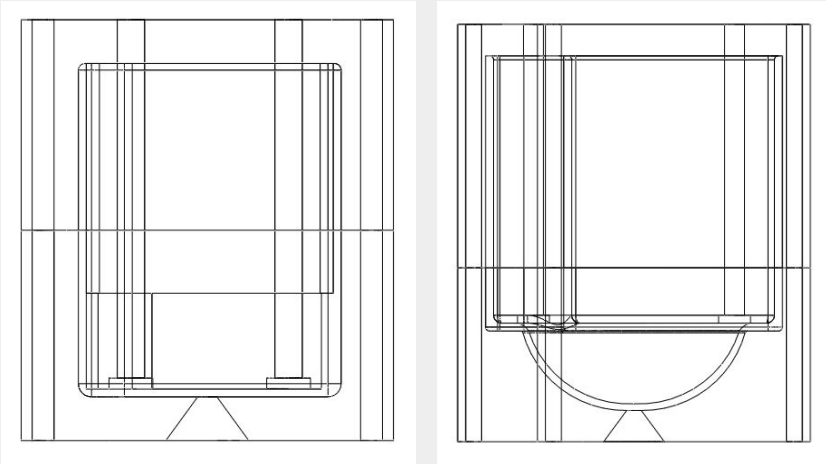

Figure 35: Plant Pot Mold Design.

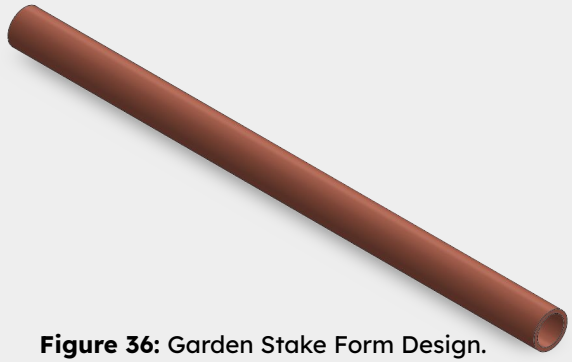

Figure 36: Garden Stake Form Design.

Unlike the rest of the products, the garden stake is produced using a form. Shredded HDPE or LDPE is fed through the benchtop extruder into this copper pipe (dimensions of which can be seen in Supplemental Material B in the Supplemental Materials file). The plastic is then fed through and cooled to harden and then cut off at its desired length. The mold for the plant label is shown in Figure 37.

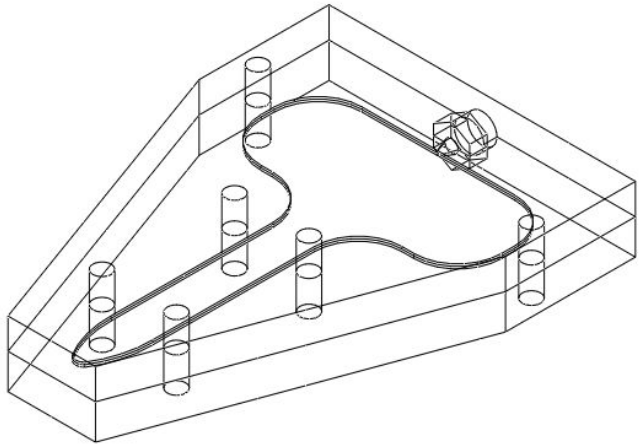

Figure 37: Plant Label Mold Design

The plant label mold is the easiest to manufacture due to its symmetric nature. Both halves of the mold are the same exact part and they are sandwiched together. The plant label was very easy to create a mold from since it is very flat and does not have a complex design.

Unfortunately our team did not have time to complete the molds for the garden trowel and coaster designs that we produced. However, CNC machine shops such as Melfab, mentioned previously, may be able to work with the CAD files we provided the Hub with, to produce some molds for production in the future. A flow chart depicting the overall design and testing process of our products is shown in Figure 38.

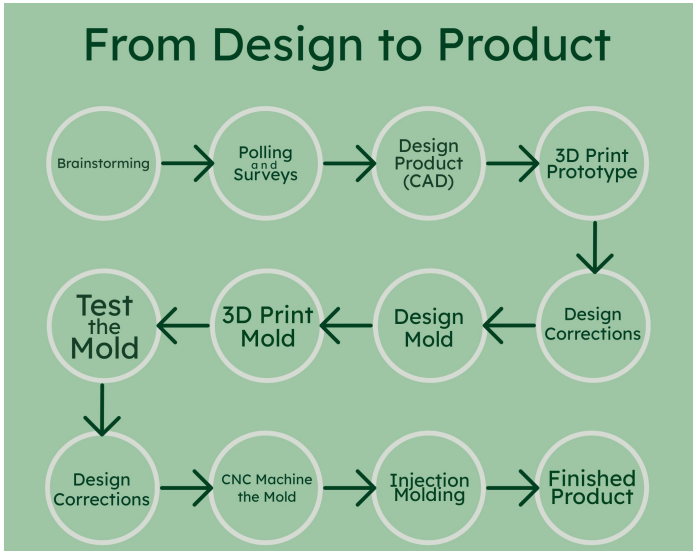

Figure 38: The design and manufacturing process.

The Final Products

This was a tedious process with several design iterations for each product but in the end we completed the designs for our final five products (Figure 39). Though we did not have time to get their molds produced, we have left the Hub with everything they will need to continue this work.

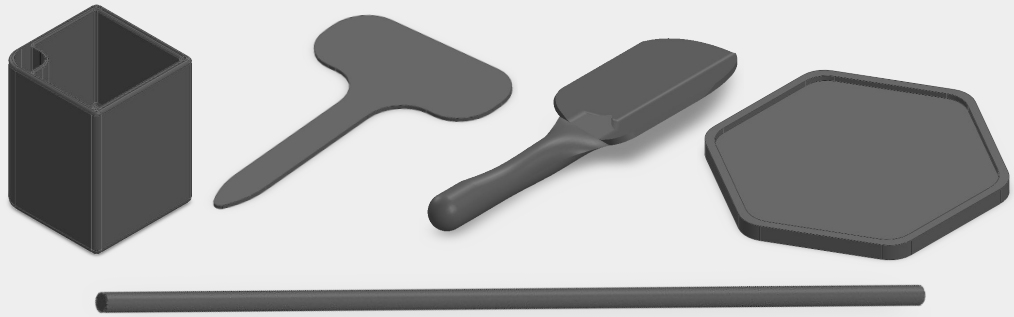

Figure 39: Our final five product designs. From left to right: Self-Watering Plant Pot, Garden Label, Garden Trowel, Coaster, Garden Stake.

Packaging Design: Telling the Story

Making products from plastic bottle caps will only be fruitful if the products are useful and can be sold. What makes these products unique is the story of how they are made and the good that they do. That is why packaging is an important step we used to not only sell the product but to spread the word about plastics recycling and how people can help. We decided to design packaging for the recycled plant pot we call the “Precious Pot,” which can model the type of packaging the Hub can use for other products. The packaging uses as little material as possible to both hold the pot and just as importantly, to tell the story behind it (all packaging materials shown in Supplemental Material C). Minimizing the material will conserve resources and display more of the unique pot itself instead of covering it up. One of the most common questions regarding the pots has been about how many caps it takes to make a pot, and this is included in the packaging design (Figure 40). This reminds consumers just how many caps are being saved from landfills and made into something beautiful. Another important part of the packaging is the process of how the pot is made. Knowing it is recycled material gives it more value and hopefully more incentive for someone to keep it longer. There is also a QR code that brings up more information on plastic bottle cap recycling and how people can recycle caps. Lastly, there is a section that indicates the proceeds of the pots will go back into the program and education of the community. Hopefully, these benefits will encourage more sales as buyers know that they’re supporting future efforts.

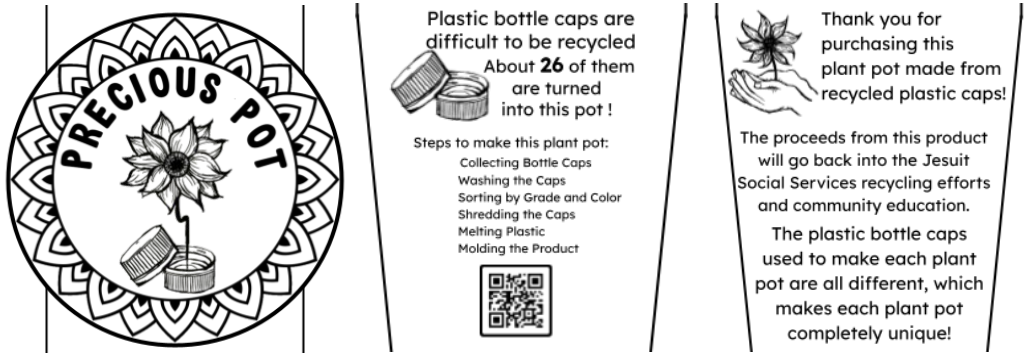

Figure 40: Plant pot packaging content that tells the story of the product.

The packaging material is a heavy paper sleeve wrapped around the top of the pot, and a sticker on the bottom holding the packaging together (Figure 41). The sticker shows the recycling symbol with a plastic bottle cap inside to further reinforce the recycling story. The finished packaged product is shown in Figure 42.

Figure 41: The packaging sticker design.

Figure 42: The finished packaged product

Creating and Testing the Hands-On Workshop

After designing and producing the final products, we created the hands-on demonstration workshop. The workshop intends to raise awareness of plastic bottle cap recycling in the Melbourne community through hands-on activities and educational handouts. We designed the 2-3 hour workshop for 8-12 community participants, led by 2-3 trained workshop leaders. Participants are asked to bring used bottle caps to the workshop. Then we run the workshop in 4 key steps:

1. Ask participants to fill out a pre-workshop survey to determine their knowledge and typical behaviors in regard to recycling plastic caps.
2. Give a pre-workshop demonstration on plastic pollution and proper ways to separate caps and recycle them.
3. After providing safety information, lead a hands-on demonstration and allow each participant to help carry out each step in the assembly line to make the product.
4. Conduct a parallel post-workshop survey, also asking for workshop feedback and interest in volunteering.

In the end, participants leave the workshop with the product they made from plastic bottle caps.

This workshop was designed using the “advocating for change” toolkit (The Community Tool Box at University of Kansas, n.d.), which specifies the importance of gathering background and local information on the problem from participants, providing education and encouragement, and developing an action plan (in this case a plan to recycle and volunteer). We piloted this workshop with 4 number of WPI students from the US, observing the timing of each workshop step, participants’ ability to carry out the steps, and gathering their general feedback on the enjoyability and learning value of the workshop. We designed more detailed pre and post test materials that can be used in the future, but we did not test these on the students, who were not Melbourne residents.

1. Workshop Design

1.1 Pre-Workshop Survey

We created a pre-workshop survey using Google Forms in which we attached its QR code in the middle of the flyer (Figure 43) so that participants can individually scan and complete the survey during the workshop. Example questions on the pre-workshop survey are shown in Figure 44.

Figure 43: Flyer for the pre-workshop survey

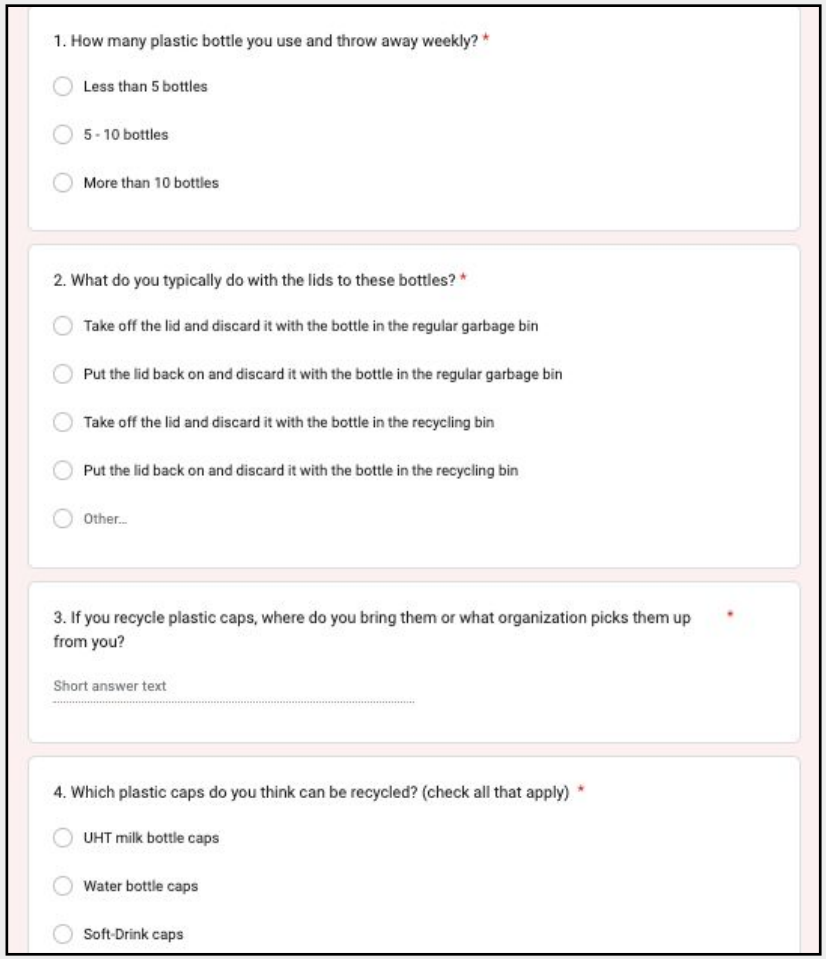

Figure 44: Pre-workshop survey

The result from the pre-workshop survey can be used as a baseline to assess community behaviors and knowledge prior to the workshop.

1.2 The Pre-Workshop Demonstration on Plastic Pollution and Proper Way to Separate Caps and Recycle Them

To educate the Melbourne community about plastic pollution, our team created a poster (Figure 45) explaining the effects of global plastic pollution caused by plastic caps and the pollution in Australia. A small version was laminated and passed around to participants.

Figure 45: Plastic pollution poster.

We then explained the proper way to separate the caps and introduced our project as an alternative solution to recycle plastic bottle caps. A small version of the recycling poster (Figure 46) was passed around to participants during the explanation.

Figure 46: plastic recycling laminated poster

1.3 The Hands-On Demonstration

After the brief overview from the pre-workshop activities, we trained the participants in safety precautions and distributed proper gloves and eye shields. Then, we created a sample plant pot product, showing the participants each stage of the assembly line and inviting them to help. Participants received instruction and close safety guidance at every step from the staff. Throughout the hands-on demonstration, participants had time to ask questions to clarify their understanding. In the end, we produced a plastic plant pot, and participants were then provided with a pre-made pot they made during the workshop.

1.4 The Post-Workshop Evaluation

To motivate participants in recycling plastic bottle caps after the workshop and to test whether they had learned how to properly separate caps in the future, we created another laminated handout (Figure 47) to allow participants to choose between discarding plastic bottle caps and recycling them.

Figure 47: The post-workshop laminated poster

We also created a post-workshop survey in which we attached its QR code in the middle of the post-workshop laminated poster. The post survey repeats the same questions as the pre surveys and asks additional questions to get the feedback on the plastic recycling system in Melbourne and the workshop. Example questions on the post-workshop survey are shown in Figure 48.

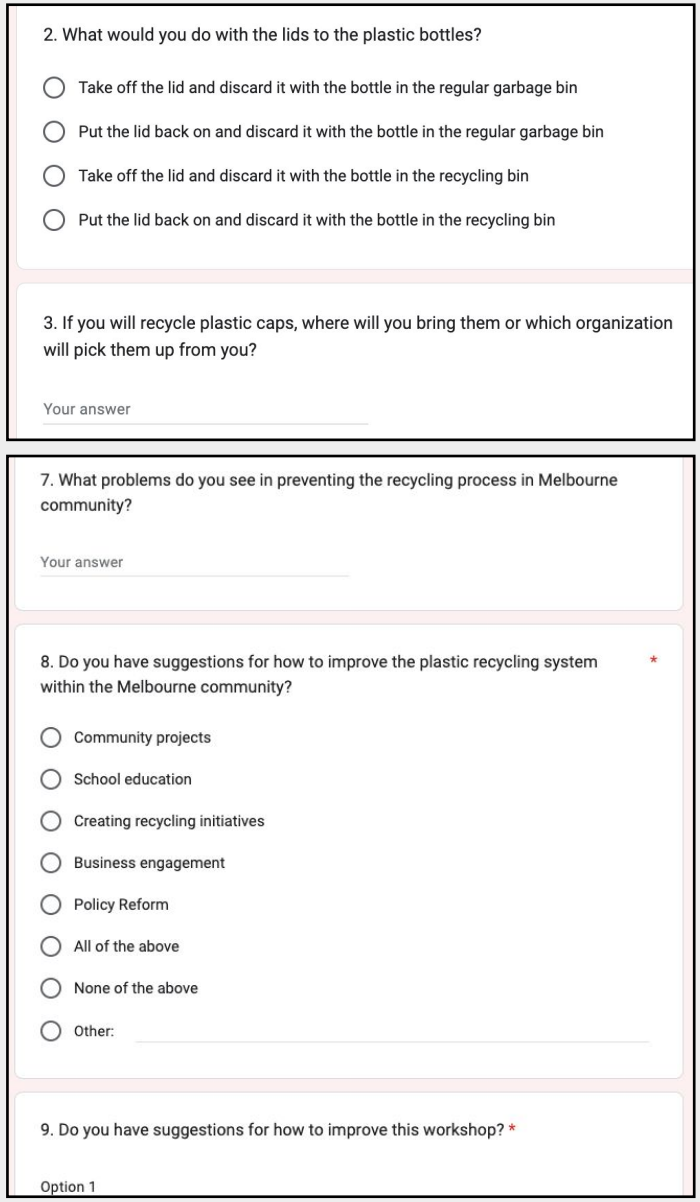

Figure 48: Examples of post-survey questions

The post-survey questions are asked to evaluate the change in participants' behaviors after the workshop and to get reflection on the plastic recycling system in Melbourne and the workshop.

We also designed the interactive poll to measure how many people signed up to get involved in the recycling process throughout the project and to ask if they would like to purchase recycled plastic products from the Hub after the workshop. Figure 49 shows the interactive poll we designed.

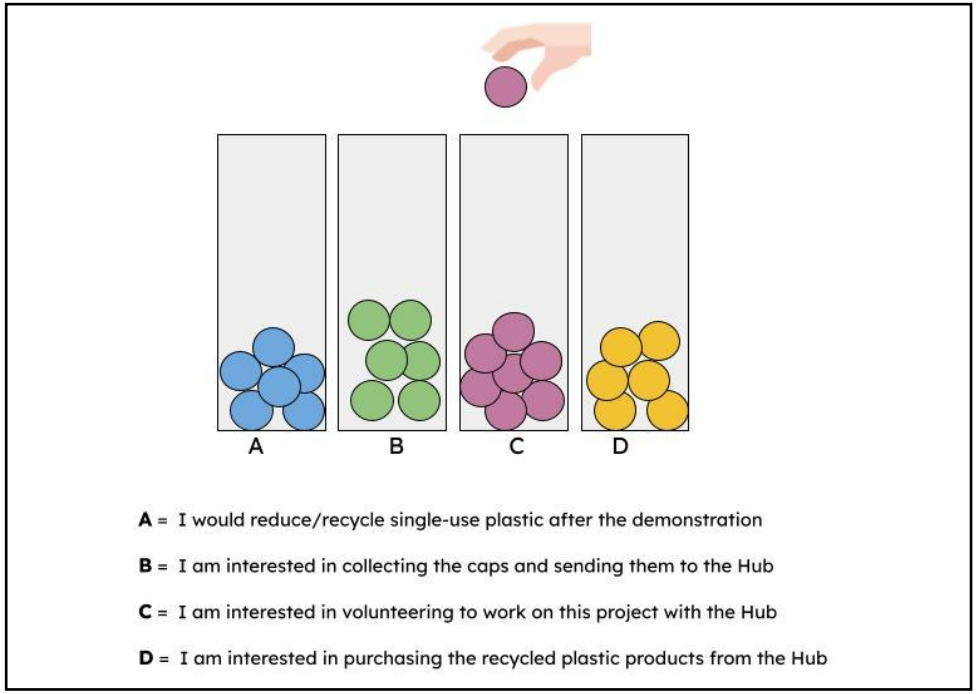

Figure 49: Interactive Poll

plastic bottle caps can be provided for participants to vote if they are interested in participating in any recycling activities at the end of the workshop. Number of bottle caps in each jar can be counted in the end to evaluate their interests in recycling plastic bottle caps.

2 Pilot Test of the Workshop

During the pilot test (Figure 50), our team took notes and timed each of the different activities and steps of the recycling process. We also noted any parts of the workshop that seemed confusing to participants. This allowed us to adjust the timing, instructions, and any verbal clarifications and explanations.

Figure 50: Community Member Engagement during the Pilot Test of the Workshop
Participants are sorting plastic bottle caps (left)
and participants are making the plant pot with the guidance from the staff (right)

The main thing we noticed during the pilot test was that some steps of the process took much longer than anticipated. For example, it took 30 minutes just to sort the caps, and cutting the caps by hand into pieces before shredding also took too long. We decided to prepare some of these steps ahead of time, leaving just enough material that the participants in the future can work with to get a feel for the process. The leader can just talk through the washing and sorting process, giving each person only a few caps to sort. We also decided that we needed scripts to help the workshop leader stay on track. Some of the changes we made were to wash the caps that participants bring but use the pre-washed caps in the sorting process, have them sort the caps by grade and color at the same time, and to preheat the mold and the injection molder. The final workshop timeline is shown in Figure 51.

Plastic Bottle Cap Recycling Workshop

Ecological Justice Hub Date…….. Time 2:30 hours

Time	
00:00 - 00:05	Greet participants, welcome, acknowledgement of country
00:05 - 00:10	Introduce the Ecological Justice Hub and Jesuit Social Services with their goal and example projects to participants
00:10 - 00:15	Hand the pre-survey flyer to participants. Participants scan QR code to complete the pre-survey.
00:15 - 00:30	Hand the plastic pollution poster to participants Brief verbal presentation on plastic pollution - Plastic bottle consumption in global scale and in Australia Hand the plastic recycling poster to participants Brief verbal presentation on plastic recycling - Bottle caps could not be sorted through machine —- > end up in landfill - How to recycle plastic bottle caps — introduce this project - Types of plastic bottle caps and simple examples of them in real life
00:30 - 00:45	Collect plastic caps that participants bring, wash them in the washer
00:45 - 00:50	5 minute break
00:50 - 01:00	Sort the pre-washed bottle caps by color and grade at the same time
01:00 - 01:15	Explain the equipment and the safety instruction **verbally mention safety concern** participants get to ask questions
01:15 - 01:30	Cut and shred the plastic bottle caps // preheat the mold in the oven at the same time
01:30 - 02:00	Example how to inject the mold. ** more details in the instruction manual** then participants try to make the product under supervision from the staff
02:00 - 02:10	10 minute break // participants get to ask questions on the recycling process
02:10 - 02:20	Provide the information on how to collect plastic bottle caps and where to send them
02:20 - 02:30	- Provide the contact information of the Hub. Promote the Hub's instagram account - Hand the post-workshop poster to participants. Participants scan the QR code to complete the post-survey
	Interactive poll is set up. Participants vote their interest after the demonstration and provide their contact information if needed.

Figure 51: Workshop timeline

During the pilot test, all participants enjoyed the hands-on activities throughout the assembly line. They provided the feedback on the survey that they learned more about the plastic pollution and the recycling process which made them want to become more involved in the community. However, as the participants in the pilot test are not Melbourne residents, the data we received from the pre and post surveys could not be used to study the plastic recycling in Melbourne. Still, the pilot test allows us to improve the workshop and this mechanism can be used to measure the results from future workshops with Melbourne residents.

User-Friendly Instructional Materials

In order to ensure that future staff know how to operate the equipment and train other volunteers, we created instructional materials– a manual and a video–based on our own experiences with the machines as well as the instruction provided by Precious Plastics, and a video showing the steps as we created. To properly create an instruction manual, we looked at sample shop manuals for formatting and writing strategies. We took photos and drew images to improve clarity. Our reasoning for creating a video (Figure 52) in addition to the instruction manual is that some people might prefer a visual explanation or are visual learners.

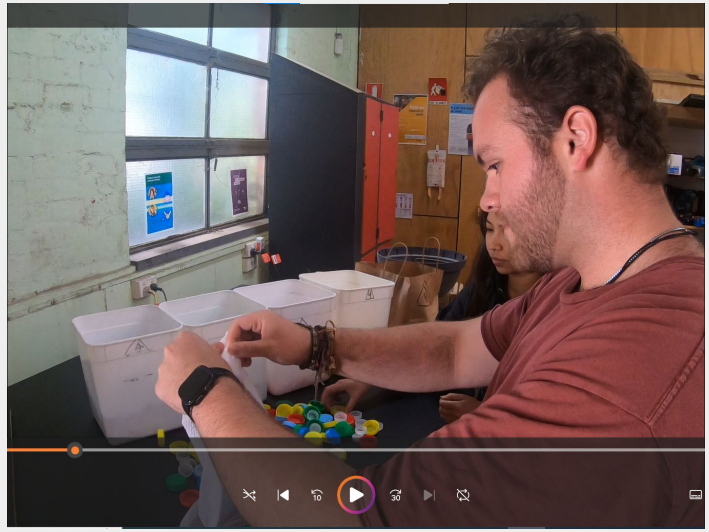

Figure 52: A scene depicting bottle cap sorting from our instructional video.

We then user-tested these materials on four members of our WPI student cohort to make sure that the instructions are easy to follow. We gave the necessary safety instructions to all participants prior to them starting the session. We helped them with the steps of the instructions and with the machines to maximize safety for everyone involved. Direct observation allowed us to intervene when there were questions about the instructions, to see where the participants got stuck, and when a participant attempted something unsafe. We took notes during the user-testing on when and where the participants ran into any problems. After the user-testing session was completed, we made the necessary adjustments to our materials.

We also distributed the feedback form shown in Figure 53, for all users to fill out after participating in the testing and used this to clarify instructions further.

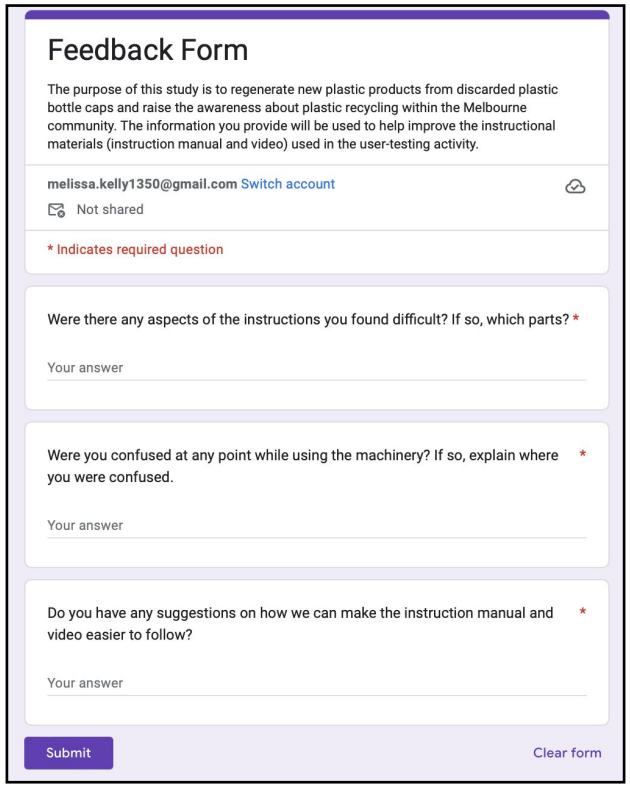

Figure 53: User-Testing Feedback Form

The materials and user-testing are important so that the current and future staff and volunteers at the Ecological Justice Hub can continue to operate our manufacturing process and lead workshops, teaching others.. Involving and training new volunteers within the community will help with our goal of promoting awareness of the problems surrounding plastic bottle caps and how recycling is important. Our final user instructional manual is shown in Supplemental Materials E.

Direct observation allowed us to intervene if there are any questions about the instructions, if the participants get stuck, or if a participant attempts something that is unsafe. We took notes during the user-testing on when and where the participants ran into any problems, so we knew what needed to be revised. After the user-testing session was completed, we made the necessary adjustments to our materials.

We distributed the feedback form shown in Supplemental Material E of the Supplemental Materials file for all users to fill out after participating in the testing. Once we have all of the participant feedback, we will make more modifications and adjustments to the instructional materials.

During the testing of these materials, the participants found that using the injection mold was the hardest part of the process. Even when using the instructions and after watching the demonstration, we found that we still had to help guide them through most of the process using the injection mold. After guiding the participants through the steps and going through the process with them, they were able to successfully go through it on their own. Other than the process of the injection mold, the participants were able to go through all other steps of the assembly line without further instruction or guidance. The participants also believed that the verbal safety instructions paired with the written safety instructions were helpful to make sure they were always following the proper safety procedures for each of the machines. Fortunately, all participants listened carefully to all safety procedures and followed them closely.

CONCLUSION

In working with the Ecological Justice Hub, Precious Plastics Melbourne, and Lids4Kids, our project team was able to turn plastic bottle caps into useful products. We set up and tested an assembly line, from washing the bottle caps to the production of the final product, implementing several improvements to the process and equipment. After polling people in the Melbourne community and using the safety and sustainability criteria we established, we focused on five initial products to design and make. Once we had these designed, we created a hands-on demonstration workshop to educate and engage the community in plastic bottle cap recycling. We created informative handouts and posters about the plastics problem and proper ways to recycle bottle caps, using these materials in the workshop and allowing participants to help make pots from recycled material. We piloted the workshop with four students and used their feedback to improve it.

We also designed instruments to test participants' knowledge gains and behavioral changes. Before and after the workshop, we used these surveys and polls, finding that participants were able to correctly identify ways to separate and recycle caps after the workshop. These materials will also help track the impacts on future participants and will also help measure whether new volunteers are recruited. Lastly, we developed training materials for the Ecological Justice Hub employees and volunteers who will lead these workshops in the future. We delivered a full instruction manual including operations and safety precautions on the benchtop shredder, injection mold, benchtop extruder, and 3D printer. We also filmed a video that shows steps outlined in the instruction manual. In sum, this project contributed to the launch of the new "Regenerative Plastics" initiative at the Ecological Justice Hub. We summarized the inputs and outputs of this project in Figure 54. We hope our materials and process will have a lasting impact on bottle cap recycling efforts and set a good example for other communities to follow.

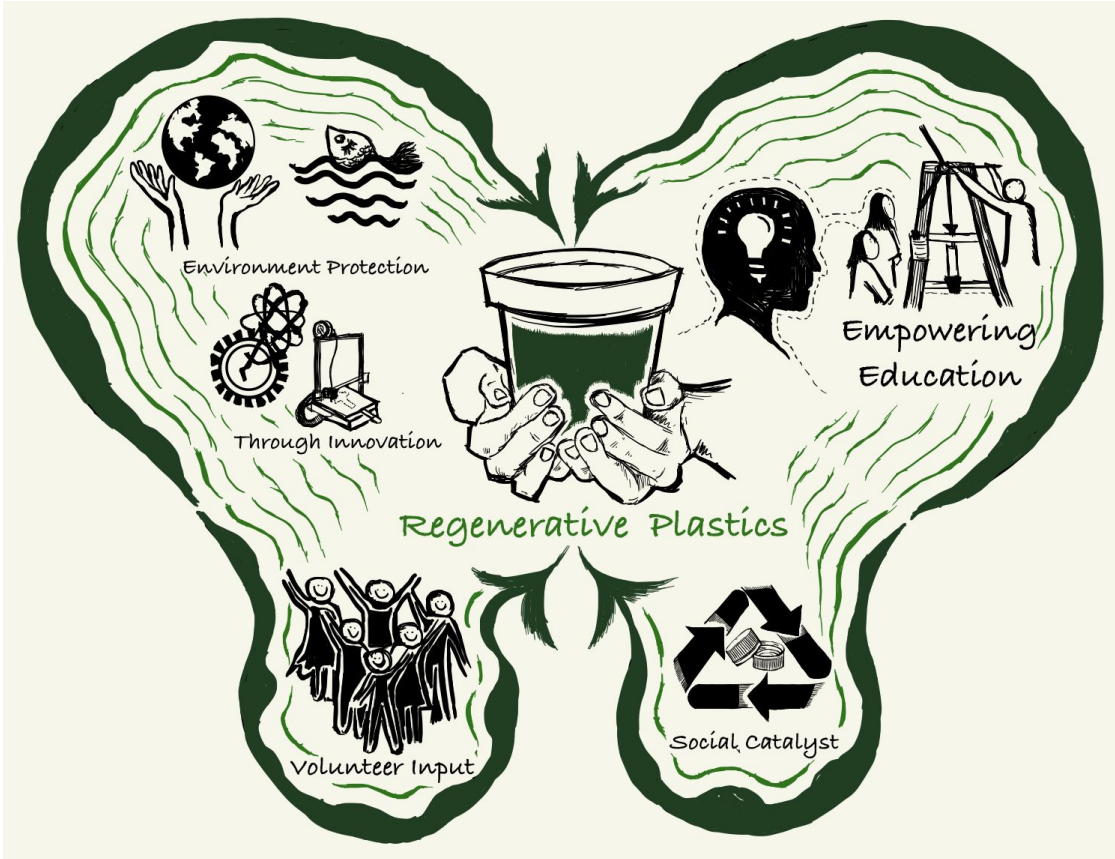

Figure 54: The inputs and outputs of the project

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