Re:Plastic

Mechanical Engineering 589: Sustainable Design of Technology Systems
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Final Design Review
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EXECUTIVE SUMMARY

We conducted an extensive research study to understand the supply chain and end of life for plastic films, including manufacturing, use, and recycling. We discovered that plastic is the least recovered material by percentage weight of municipal solid waste (MSW) generated. In particular, plastic films are not recycled as efficiently as high density plastics because films cannot be easily remanufactured into new products, and films are often contaminated by the goods being packaged (e.g., foods). Forty-five percent of LDPE plastic is used as packaging (GreenBlue, 2009). These films are used in food packaging, newspaper bags, diapers, packaging for consumer goods, industrial shipping packaging, heat seal packaging applications, and so on.

LDPE can be recycled into a handful of second-life materials, one of the most common being composite lumber. Plastic film is shredded, ground up and mixed with additives, such as rubber substitute, to create the composite lumber. Unfortunately, composite lumber is very energy intensive to produce and requires 4,200 ton-miles of transportation for the life cycle of 1 Mbf.

Re:Plastic is a community-based plastic film recycling business. Rather than shipping plastic film to composite lumber manufacturing facilities, Re:Plastic has developed a machine that heats and moulds plastic film into an unpcycled stock material for manufacturing consumer products. Our goal is to inspire people to view plastic film as a valuable resource, rather than waste.

Re:Plastic will design and sell affordable furniture and home goods to environmentally conscientious consumers. Specifically, we would target our products to millennials, individuals born between 1981 and 2000, who exhibit a strong propensity to buy products based on their social and environmental impact.

Re:Plastic is a significant environmental and social improvement compared to landfilling or recycling into composite lumber. Landfilling results in chemicals leaching into groundwater, while composite lumber generates significant CO_2 emissions through transportation and manufacturing. Re:Plastic would avoid all of these environmental and social damages. Re:Plastic may release some emissions during the plastic melting process, yet we will limit these emissions by heating the plastic to only 200^{o}C.

To finalize our project, we will need to further explore the technical specifications of the Re:Plastic stock material to ensure a quality product can be repeatedly created in the machine. Similarly, we will need to perform additional market research to determine the financial viability of the Re:Plastic business idea.

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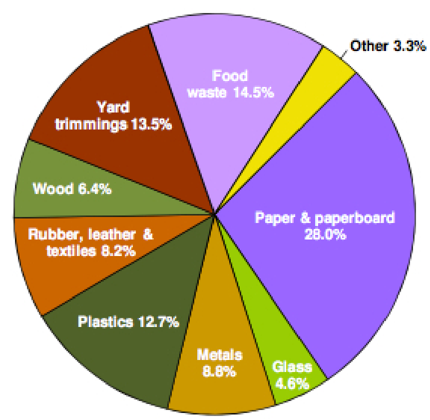
Introduction

Re:Plastic stemmed from the desire to reduce environmental damages from plastic films. Plastic films pose significant environmental costs, including littering land and waterways, occupying landfill space, and emitting greenhouse gases through incineration. By weight, LDPE plastic packaging represents 61% of plastic bags, sacks, wraps and other films generated in municipal solid waste, yet only 15.7% of LDPE plastic film packaging is currently recovered (EPA, 2011). This year, plastic recycling has been further compromised as a result of China's Operation Green Fence, whereby China will no longer accept "poorly sorted or dirty shipments of recyclable waste from foreign exporters" (Earley, 2013). Because plastic recycling infrastructure is limited in the US, more plastics may end up in landfills and waterways. Our goal for this project is to transform LDPE plastic film from waste to a valuable product for society.

Description of Baseline Product

Plastic Waste Overview

Municipal solid waste (MSW) is defined by the EPA as the waste that ends up in landfills from consumer use. This waste excludes, but is not limited in exclusion of, construction waste, wastewater treatment sludge, and non-hazardous industrial waste from manufacturing. Plastic composes 12.7% of MSW generated, yet only 8.3% was recovered for recycling. As such, plastics are the least recovered materials by weight of all of the MSW in the pie chart to the right, provided by the EPA MSW 2011 Facts and Figures (EPA, 2011).



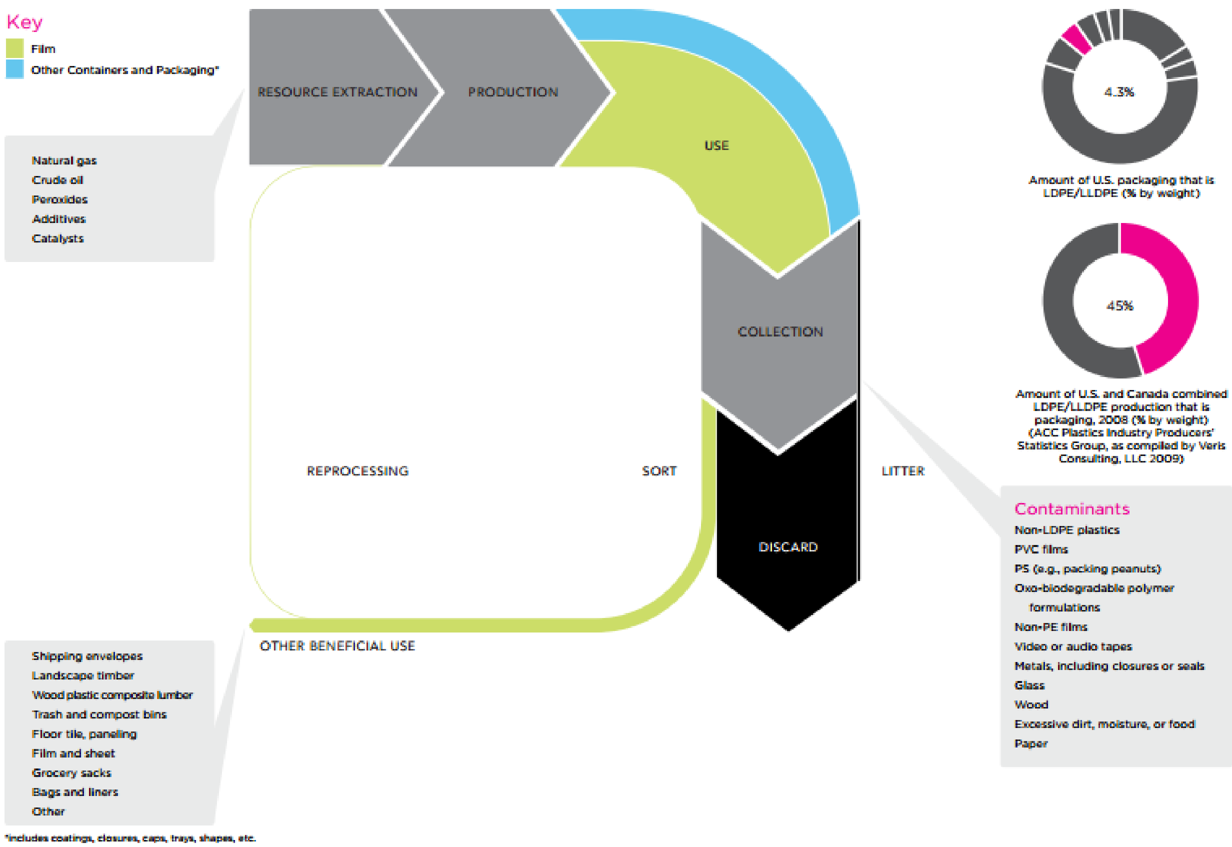
According to a study conducted in the School of Process Engineering at UCL in London, packaging generates 35% of all plastic solid waste worldwide (Al-Salem, 2009). In the US, LDPE composes 4.3% of packaging by weight (GreenBlue, 2009).

Recycling high density plastics is becoming more common and varied. Sorting waste is the biggest challenge in recycling plastics. Current plastic separation techniques include: mechanical sorting, triboelectric separation, and speed acceleration techniques. These methods utilize size and density, static charge, and infrared wavelength to classify and sort PSW. While these methods are not widespread yet, high density plastic recycling is growing because of the high manufacturing cost of these plastics.

LDPE plastics, on the other hand, are cheaper and easier to manufacture, but have a much lower recyclability. LDPE films can be collected and mixed (<50% LDPE) with virgin additives and rubbers, and then extruded for use as a recycled plastic (Kowalska, 2002). While this is a viable option to recycle thin LDPE films and thin plastics, it requires virgin chemicals and rubbers and generates carbon emissions during manufacturing and transportation processes.

Below is a material flow diagram for LDPE plastics from the Sustainable Packaging Coalition. As illustrated, approximately two-thirds of LDPE plastic is transformed into films. Additionally, there is a long list of contaminants that would impede recyclability. Finally, the diagram effectively illustrates the minimal LDPE end-of-life reprocessing options.

LDPE Material Flow (GreenBlue, 2009)



Uses of LDPE Plastic Packaging

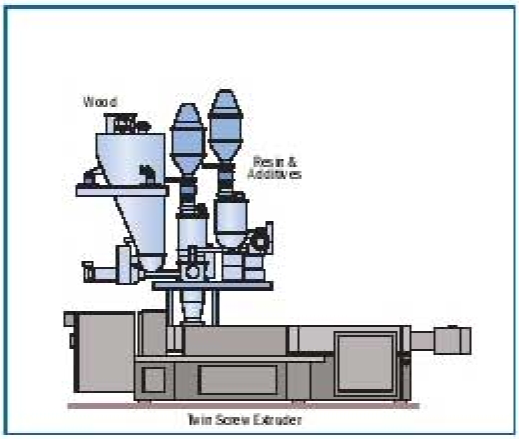
LDPE is a preferred form of packaging because of its strength compared to its small mass and its lost cost. An LDPE grocery bag can hold up to 2000 times its own weight. When purchased in bulk, LDPE packaging film costs between $2.00 and $8.00 per kilogram, depending on the grade and the supplier. With an average LDPE package weight of 4g, that is 250 packages per kg and 0.8 to 3.2 cents per package (Alibaba, 2013). Companies that package their goods in LDPE film purchase it from separate manufacturers, then package the products at their own company.

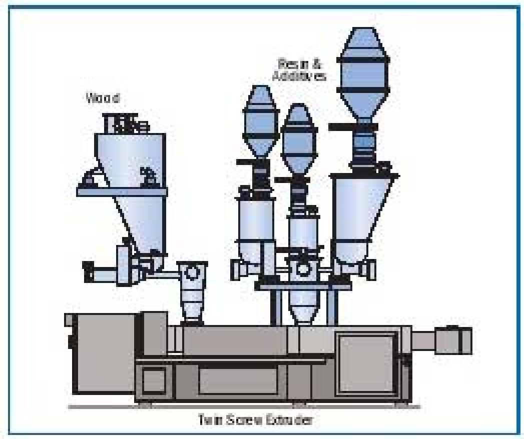
Recyclability of LDPE Plastic Packaging

Some regions have infrastructure to collect plastic films for recycling. For example, California has mandated all supermarkets to have an 'at-store recycle program' for plastic bags (CalRecycle, 2013). The state also mandates the stores to track and follow up on the collection and transportation. California has also required plastic manufacturers to provide educational materials for consumers on plastic bag recycling.

Most plastic bags are sent to recycling companies to create composite lumber. Composite lumber is a mixture of plastic resin and wood fiber with some additives such as wax fiberglass and preservatives (Chenu, 2006). Fossil fuels are involved in the transportation of these LDPE products to the recycling centers where they get turned into lumber.

The production of plastic-wood composite is among the most dynamic industries in the recycling sector (K-Tron, 2013). Shown below are two diagrams obtained from K-Tron that shows the basic steps involved in the processing.





In the above diagrams, wood is used to represent any material that could be used. For our case, wood could be replaced with LDPE plastics. Plastic/wood gets fed on the left, and additives are added in the barrel. Continuous mixing of dried plastic/wood with additives with high-speed compounding feeds a gear pump to produce the profile. Composite wood can then be used to create decks, park benches, playgrounds, etc. In particular, composite wood is a nice replacement for traditional lumber because it does not rot or degrade when exposed to most weather conditions.

While recycling for LDPE plastic packaging is available, consumers are not fully utilizing these options. Moore Recycling Associates found that 72% to 74% Americans have access to plastic film recycling via curbside collection or a drop-off facility within 10 miles of their home (Moore Recycling Associates, 2012). However, these recycling options appear to be minimally utilized. According to the EPA, only 15.7% of consumer generated LDPE and LLDPE plastic film packaging waste is recovered (EPA, 2011), even though it appears that a greater portion of the population has access to recycling. There are two hurdles for recovery of LDPE plastic packaging:

1. Consumers need to drop-off LDPE plastic packaging to a material recovery facility (usually a local grocery store). In 2008, only 4% of recovered plastic bags and films were generated through curbside recycling programs (Moore Recycling Associates, 2010)
2. Grocery store managers may not be aware of the store's material recovery program, thereby providing misinformation to consumers (Moore Recycling Associates, 2012).

Replacements for LDPE Plastic Packaging

Because LDPE plastic packaging cannot degrade in a landfill, some companies are replacing LDPE plastic packaging with a recyclable, biodegradable and/or compostable alternatives. For example, Nestlé Prepared Foods Co.'s Stouffer's brand adopted paperboard trays for its family and large-family sizes of multi-serve frozen meals, replacing plastic trays (Mininni, 2010). However, paper packaging may not be a solution for all products. Paper products, such as paper towels, toilet paper and/or diapers, cannot get wet before they reach the consumer, in which case, paper packaging may not provide the appropriate level of protection for the product.

Much research has been dedicated towards the development of biodegradable plastics. PLAs, PHAs and cellophane are the most likely alternatives for LDPE plastic packaging. Below is a table comparing the alternative bioplastics.

Criteria	**PLAs**	**PHAs**	**Cellophane**
Global production capacity (European Bioplastics)	62%	4%	6%
Key ingredients	Renewable starch sources, such as corn or sugarcane (Rahmat, 2012)	Synthetic product produced by different types of bacteria (Flint, 2013)	Typically made from cotton pulp (Wikipedia)
Manufacturing considerations?	Emits few greenhouse gases (Rahmat, 2012)	TBD	TBD
Can be turned into film?	Yes (Rahmat, 2012)	Yes	Yes
Biodegradability on land	Only in a controlled compost facility (Royte, 2006)	Degrade in aerobic and anaerobic conditions (Flint, 2013)	80% biodegradable in landfill conditions (Shin, 1997)
Biodegradability in oceans	Submerged in seawater for 26 weeks, lost only 1% of its mass (Winter, 2012)	Completely degraded within 5 weeks (Winter, 2012)	Submerged in seawater for 26 weeks, lost 20% of its mass (Winter, 2012)
Heat resistance	Up to 180°C (Plastics News, 2013)	Up to 150°C (Winter, 2012)	Up to 190°C (Wikipedia)

Price	$1.90/kg (Rahmat, 2012)	$1.00 - $1.25/kg (Winter, 2012)	$5.00/kg (Rahmat, 2012)

Though some companies are transitioning towards bioplastic alternatives, LDPE plastics remain the the market standard for packaging, suggesting that in the short term, recycling options for LDPE plastic will reduce packaging from landfills and waterways.

Design Ethnography

Prior to conducting interviews and research, we developed a design ethnography plan. First, we outlined the guiding questions, to ensure that the interviews lead to new and useful information about plastic films. Following this, we defined who to interview for this project, including the users or clients of the Re:Plastic product and service, stakeholders for plastic films, and experts about plastic. Next, we compiled a literature review of preexisting knowledge about plastic films. After these steps were completed, we formed data collection methods. We considered what type of information could be obtained from each "who" via interviews and observations. Then we determined the best information gathering technique for each individual "who" in our plan. Finally, we developed our the data collection structures. For observations, we decided where and when the observations would happen. To prepare for interviews, we created semi-structured interview outlines. Once all of the aforementioned steps were complete, we commenced our design ethnography.

When we started our project, we did not have a preconceived idea for how to reduce plastic packaging from landfills and waterways. In our initial design ethnography, we wanted to understand the following areas:

- In households, how are decisions about waste management made and maintained? What do consumers find easy/difficult about waste management? How do individuals learn about waste management options in their community?
- How do businesses decide to package their products -- specifically ones that use LDPE plastic film? Who in the organization makes these decisions? How do they source their suppliers?
- How do recycling facilities manage/recover LDPE plastics? How do they interface with drop-off stations? How do recycling facilities find buyers for recycled materials?

First, we conducted an observation to determine how prevalent plastic film was in grocery store products. We found that over 30 different product categories used plastic films. We also observed the contents of recycling bins to gain insight into the recycling habits of Ann Arbor community members. We found that recycling bins predominantly contained paper/cardboard products and generally no LDPE, which cannot be handled by the recycling stream in Michigan. Next, we considered whether we could eliminate LDPE at the source by developing a sustainable packaging alternative for food products. We interviewed the packaging purchaser at Eden Foods. We learned that Eden Foods is already considering transitioning to a biodegradable packaging option (e.g., wood fiber based material or PLA). We also learned that manufacturing lines could easily adopt biodegradable packaging materials, but a major hurdle is testing whether product would contaminate/interact with foods inside packaging. Based on this ethnographic research, we determined that developing an alternative to LDPE packaging was outside of the realm of our abilities within this semester, so we decided to focus on a second life use for plastic films.

We performed a secondary literature review for current reuse and recycling options for plastic films. We learned that composite plastic lumber is currently the most common second life for plastic films. Concurrently, we started to test whether LDPE could be melted and pressed into a reusable product. We discovered that we could create a stock material comparable to composite plastic lumber or wood by melting and pressing plastic films. At this point, we conducted further design ethnography to understand:

- Who would be interested in using stock re:Plastic? What potential uses most interest consumers?
- What steps would be necessary in order to secure an abundant supply of the raw material used in manufacturing re:Plastic, LDPE films?
- How do recycling facilities manage/recover LDPE plastics? How do they interface with drop-off stations? How do recycling facilities find buyers for recycled materials?
- How would we obtain a specialized machine for making re:Plastic and what would the cost be?

Below is a list of the interviews/surveys that we conducted.

Users

- Homeowners/Renters, college age through age 80 interested in upcycled products
    - Key findings
        - The majority of people, regardless of age, were interested in Re:Plastic furniture.
        - Most adults who had lived in the same spot for several years or more did not need any more furniture for their home.
        - College students frequently stated having an immediate need for furniture.
        - Most students reported that their dorm or rental was missing at least one useful piece of furniture, such as a bookshelf or dining table.
        - Students reported that their ideal furniture would be durable, but also lightweight for ease of transportation.
        - Most students would be willing to pay no more than lower end of what is currently on the market.
- Student engineering design teams
    - Key findings
        - All teams were drawn to the idea of using a recycled, environmentally friendly material.
        - Most teams said that stock Re:Plastic would be especially useful if it could be loaded into a 3D printer. Re:Plastic is not suitable for this use, however.
        - Some teams hoped that they could machine Re:Plastic (using the mill or lathe), but Re:Plastic is not suitable for this use either.
- Chris Gordon, Director of Wilson Student Project Center
    - Key findings

        - The University is currently interested in using material such as (current material) wax to reduce tool wear
        - Pressed plastic could eliminate waste in the lab and be repressed into a material for use again on site
        - The center would benefit greatly from plastic modeling

Stakeholders

- Store Managers with Bag Collection Programs
    - Key finding- Kohls Department Store (Haggerty Road, Northville, MI)
        - Store manager was interviewed regarding the Kohls Cares sustainability program
        - Discovered that the financial return for collecting plastic bags is not great and does not support the recycling program, finances come from other areas of company.
        - Willing to donate bags to community based projects for Re:Plastic or sell bulk material to Re:Plastic.
        - Interested in the community educational value of Re: Plastic and willing to work to promote the recycling of films.
- Plastic Film Recycling Facilities
    - Key findings- Bryan Plastics (Bryan, Ohio)
        - Films are not always collected, only a few times a year because the demand for the collected films is so low that they keep a very low inventory and only begin to collect again as orders are placed.
        - Films sold for composite lumbers to Trex indirect suppliers.
    - Key Findings- NPR Recycling (Romulus, MI)
        - #4 LDPE films collected but only 'processed' at their facility. (Films are balied into large blocks and tied off)
        - Sold to next level recycler to be shredded and turned into LDPE pellets.
        - Films often sorted out of the recycling with other debris such as organic material that will be landfilled. Material is rarely ordered by next level recycling companies.

Experts:

- Machine tool companies
    - Key findings
        - Eight Michigan based specialty machine tool companies were contacted to get a rough estimate for the cost of building the Re:Plastic machine.
        - Seven of the eight companies were not willing to take the time to give us an estimate, since we were not ready to immediately purchase the machine and have it made.
        - Bernal, the one company that was willing to work with us, put us in contact with their Senior Applications Engineer, Dave Radlick.
        - Radlick was not able to give us a cost estimate, because the machine design is currently a very broad description.

Description of Persona

Marie Turner is starting her sophomore year at University of Michigan, where she is majoring in the Program in the Environment (PitE). She and her three friends are moving into an apartment on Arch Street in August, but none of them have much money to buy furniture for their apartment. Marie and her roommates were able to find a couch, dining table and chairs at the Ann Arbor PTO Thrift Shop, but they're still looking for a coffee table. Marie had recently heard about a company started by University of Michigan students called Re:Plastic, which transforms plastic films, such as bags and wraps, into affordable furniture. She visited the Re:Plastic website, where she found not only a coffee table for $15 -- more affordable than the flimsy coffee tables at IKEA -- but also a cutting board, stool, a desk and other useful items for their apartment. Better yet, Marie had an array of color options because the furniture could be coated with acrylic, then painted her desired color. Marie was so excited to tell her friends that she found really great and affordable furniture for their apartment that was also great for the environment because it would reduce plastic waste from landfills and waterways.

Project Requirements and Engineering Specifications

Re:Plastic aims to inspire people to no longer view plastic bags and films as waste, but rather view it as a valuable stock material. Re:Plastic has developed a machine that can melt plastic films into plastic boards and blocks, which can be used as a stock material substitute for wood or composite lumber. Re:Plastic will build coffee tables, desks, bookshelves from the reformed plastic, which thus provides value both to the community and the environment. All in all, we hope that Re:Plastic will raise awareness about plastic films and reframe how plastics can be used in our society.

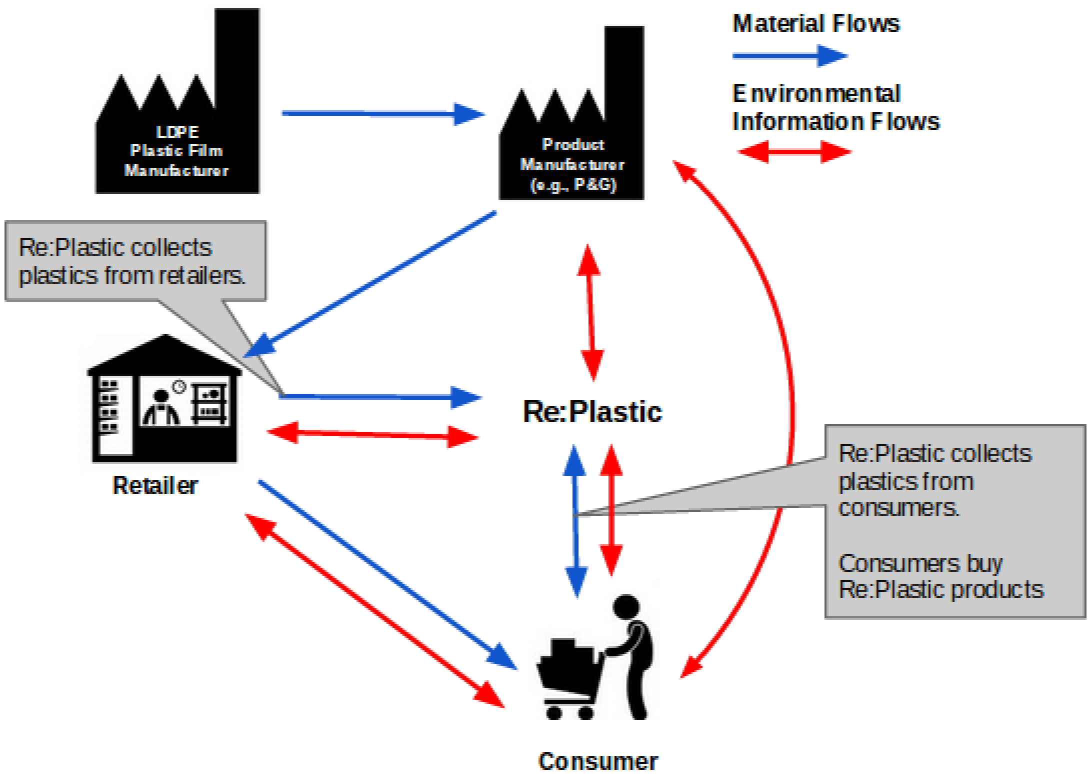
We have divided our project specifications into two areas: (1) the engineering specifications for the machine and (2) the stakeholder requirements. We developed our engineering specifications by comparing the Re:Plastic machine to the composite plastic lumber manufacturing process, which we consider our baseline. We have used a functional unit for recycling 2000 lbs (1 ton) of plastic film. We chose this functional unit because it is the common denomination by which plastic films are collected, processed and sold. For comparison, it is worth noting that the 2000lbs of collected films (1 ton) is equivalent to 26.5 Mbf. Mbf is the functional unit used in the comparative LCA by Bolin discussed later in this paper. The Mbf is a unit of measure of 1,000 board foots with dimension 12"x12"x1" (Bolin and Smith, 2010). We have identified the following specifications for the Re:Plastic machine:

1. *Material Strength/Density.* The material should have a density within that of 15% of virgin stock LDPE (0.91-0.93g/cubic cm)
2. *Minimize energy used in creating plastic stock material.* The material should use less than 11,050kWh/ton with an absolute maximum of 45,527 kW/h/ton to manufacture. Fossil fuels account for over 95% of total environmental impact in the LCA for wood composite plastic.
3. *Minimum dimensions*. The stock material will need to be consistently made with a minimum *thickness of 1", width of 6" and be reconfigurable* to allow scaling of the procedure or manufacturing process to accommodate any length.
4. *Reduce the end use waste that ends up in landfills* from comparable processes, mainly composite decking and treated lumber manufacturing. A target of 2,385 lb of waste per 1 ton should be set. This would compete with

the waste stream from treated lumber and be much lower than that of composite decking, at 118,269 lb/ton. (Bolin and Smith, 2010). Re:Plastic should create zero municipal solid waste since any scrap material can be used again within the press to make another piece of stock material.

5. *Safety should be a priority* when manufacturing the material, including but not limited to use of PPE, ventilation, emission awareness, etc.

Next, we will outline our stakeholder requirements. Below is an image of our stakeholder network:



In the short term, we plan to procure plastic packaging from retailers with existing plastic collection programs. Currently, stores earn minimal returns for used LDPE plastic films because the supply greatly outweighs demand. As such, we can acquire these plastics for a low price. In the long term, we hope to develop a direct to consumer plastic collection program in order to maximize the amount of plastic collected, thus diverted from landfills. We developed our plastic procurement specifications using insights from other plastic recycling programs in the US, listed in the table below.

Plastic Recycling Initiative	**Partners**	**Description**
Iowa Build with Bags	Iowa Grocery Industry Association, Keep Iowa Beautiful, the Iowa Department of Natural Resources, Metro Waste Authority, City Carton	Grant program aimed at providing funding for schools and parks to purchase equipment made of

	Recycling and *The Des Moines Register*	recycled plastic
Wisconsin W.R.A.P (Wrap Recycling Action Project)—Recycling Plastic Film Beyond Bags	Wisconsin Department of Natural Resources (DNR), American Chemistry Council's Flexible Film Recycling Group (FFRG) and GreenBlue's Sustainable Packaging Coalition (SPC)	Retailers, schools, and commercial facilities host plastic bag collection sites, who can recycle bags through recommended partners (http://plasticfilmrecycling.org/pdf/FilmMarkets.xlsx.pdf)
Santa Cruz Recycling Alliance Program (SCRAP)	California Grey Bears	SCRAP offers a pick up service for businesses to recycle their plastic films
Peninsula Sanitary Service, Inc.	Stanford University	3,000 bins around campus and in 600 buildings, curbside service for 700 single family homes (located on campus and owned by the University) and a cart available for film collection at the on-campus drop-off site

For the plastic film procurement, we have the following specification:

1. *Reduce the transportation required for collecting and manufacturing the plastic material.* A significant part of the energy required for building a structure with composite lumbers is shipping the material. Just over 117 ton-miles of transportation is required in the life cycle of 1 ton of composite lumber. (Bolin and Smith, 2010). We aim to reduce the ton-miles for 1 ton of the Re:Plastic stock material life cycle to less than 15% of the transportation required for composite lumber. This value has been set in order to reduce the transportation not only below that of wood plastic composite, but the pure wood lumber as well. We assume that 10 plastic film collection points in Ann Arbor each generate 100lbs of plastic a week, which Re:Plastic would collect once a week traveling a total of 20 miles to collect this plastic. In turn, Re:Plastic would also deliver products to customers along this route, adding another 5 miles per weekly trip. Re:Plastic products require 0.4 ton miles of transportation during their life cycle -- significantly less than for composite lumber.

Along these lines, we will need to educate consumers and retailers on where and how to return plastic bags and wraps for recycling.

We will need to perform user testing for the Re:Plastic machine to make it as user friendly as possible. We expect our primary user to be a member of a maker co-op such as Maker Works. Specifically, the persona of Eddie Fox described above encapsulates who might be using the Re:Plastic machine. Below are some requirements we will need to test:

1. How will users know when they've input enough plastic to generate stock material

for their desired dimensions?
2. How clean does the plastic need to be upon entering the machine to ensure isotropy?
3. How do different types of plastics meld together to ensure isotropy of stock material?

User testing will also help inform safety precautions and durability of the machine to ensure integrative design considerations.

Sustainability Evaluation

Use Context

Re:Plastic press would mould plastic films into affordable furniture for millennials, such as university students. Furniture products that could be made from Re:Plastic include large items, such as tables, desks, or chairs, and smaller items, such as picture frames, cutting boards, etc.

Re:Plastic would provide two unique services to its customers

- Customers can customize furniture to fit space and size requirements for their homes
- Customers could sell back their Re:Plastic product at a lower price. The company would then remould the plastic into another product. This attribute would attract students and faculty members who are planning to leave Ann Arbor after graduation.

The two traits above, together with a lower price for products, would appeal to students and people affiliated with the University of Michigan.

Overview of Environmental Impacts

We assessed the life cycle of Re:Plastic products from material acquisition to the end of life use of Re:Plastic products. Below are the five main stages for Re:Plastic furniture:

- *Raw materials:* Re:Plastic would collect plastic films from collection point, such as stores, as well as shipping and receiving facilities where plastic film packaging is often generated
- *Manufacture:* Re:Plastic would purchase plastic films from collection points for $100/ton. A Re:Plastic employee would clean the film if necessary, put it in the Re:Plastic machine press, where it will melt and mould into plastic stock material. The Re:Plastic stock material would then be assembled into furniture and home goods products.
- *Transport:* Plastic films would be picked up from collection points within 10 miles of Ann Arbor. After manufacturing the products, Re:Plastic would deliver finished products along the same route as the plastic film pick-up in order to minimize emissions.
- *Use:* Re:Plastic uses a customized press machine that melts the plastic films at temperatures below 200^{o}C. The machine press would have few parts to reduce maintenance activities and frequent services. Typically the machine would be

powered by standard socket outlet. In the future, the company hopes to have the press solar powered. Solar panels would require additional installation. There are no additional use specifications for the Re:Plastic consumer products.

- *Disposal:* Re:Plastic products could be purchased back by the company in two ways:
    - If the customer needs a different look of his/her furniture. The company could use its press to remould the film into a different product at a cheaper price.
    - If the customer no longer needs her furniture. The company could offer some cash for those products and use the materials to make another piece of furniture for a different customer.

Environmental Profile and Root Causes

This step covers environmental impacts according to each life cycle stage. A clearer picture for each environmental focus is covered using the following categories:

- *Materials:* Plastic films are products of crude oil and take years to degrade, yet Re:Plastic aims to create a zero waste cycle for plastic films (e.g., a customer who no longer wants his Re:Plastic furniture could return it to Re:Plastic to be remoulded)
- Energy: Re:Plastic uses significantly less energy in both manufacturing and transportation compared to composite plastic lumber, as will be described in the next section (Quantified sustainability evaluation of baseline)
- *Chemicals:* In the making of Re:Plastic furniture, the press would be heated to less than 200ºC to limit volatile organic compound emissions.
- *Other:* At the moment, Re:Plastic would not recommend making Re:Plastic toys until the products are fully tested for safety. Similarly, Re:Plastic would need to receive FDA material approval to create products that interact with food.

Stakeholder Network (please reference diagram on page 12)

Retailers and consumers are the most important stakeholders for the Re:Plastic business model. We would need to develop strong relationships with retailers in order to best understand our material supply. Specifically, we would help retailers develop marketing materials for their customers to bring in plastic bags and wraps to be collected. Additionally, we will want to recognize retailers for successful collection campaigns.. For consumers, we would also need to educate consumers directly on the proper methods for recycling plastic films and wraps. Our suppliers and customers will expect transparent business practices -- particularly related to our social and environmental impact. As such, we will develop metrics to track the sustainability of our business.

Quantified sustainability evaluation of baseline

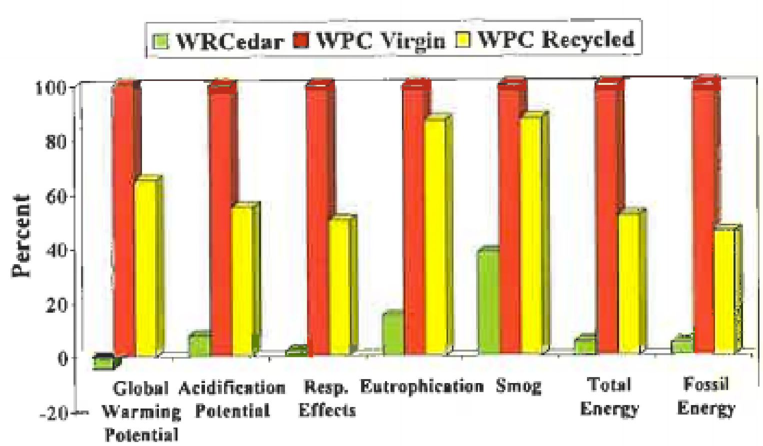
To assess the environmental and social impacts of Re:Plastic, we leveraged existing LCAs to compare our business model and product to the baseline. For the baseline of the business model, we compared the Re:Plastic model to recycling plastic into composite lumber. We also highlight how the Re:Plastic stock material compares to wood lumber (specifically cedar) and wood plastic composite.

Both Re:Plastic and composite plastic lumber aim to reduce plastic films that escape into land- or waterways. Sixty to eighty percent of marine debris is comprised of plastic materials (ESI, 2011). According to Greenpeace International, of the 100 million tons of plastic is produced each year, 10% of this ends up in the sea (Greenpeace International, 2013). Plastic debris in oceans has become so severe that there are five large plastic gyres, the largest of which is greater than the size of Texas. Plastic bags are made of toxic chemicals that are harmful to health and the environment. The toxic chemicals (ethylene oxide, xylene and benzene) are known to cause diseases and create negative effects to animals (Go Green Blog, 2013). For example, over 100 species of seabirds are known to ingest plastic artefacts and/or become entangled with them (Gregory, 2009). All in all, transforming plastic into a reusable form would prevent plastic from escaping into waterways.

We compared recycling plastic into composite lumber to recycling plastic into Re:Plastic stock material. Recycling plastic reduces the amount of waste and toxic chemicals generated. We analyzed two LCAs comparing the environmental impacts of hardwood lumber versus wood plastic composite (WPC). Hardwood lumber generally comes from naturally durable wood, such as cedar. WPC is generally a mixture of one part sawdust to one part shredded plastic.

The first LCA was performed by Dovetail Partners, a think tank on environmental issues, where the functional unit was 100 sqft installed decks (one of each material) that were defined for a service life of twenty five years. The LCA assumed that all environmental flows were attributed 100% to the decking products, both the lumber and the WPC deck were disposed of in a landfill at the end of life, and transportation was considered to be the same all products. Environmental impacts associated with deforestation were not considered in this LCA (Bowyer, 2010). Across the board (no pun intended), WPC was considered to have higher environmental impact than hardwood lumber, due to the energy intensive process required to produce WPC, as shown in the graph below (Bowyer, 2010). Hardwood lumber production generated 567kg carbon emissions per cubic meter of lumber, while WPC generated 1129kg carbon emissions per cubic meter.

Figure 3
Life Cycle Impact Assessment of Decking Products



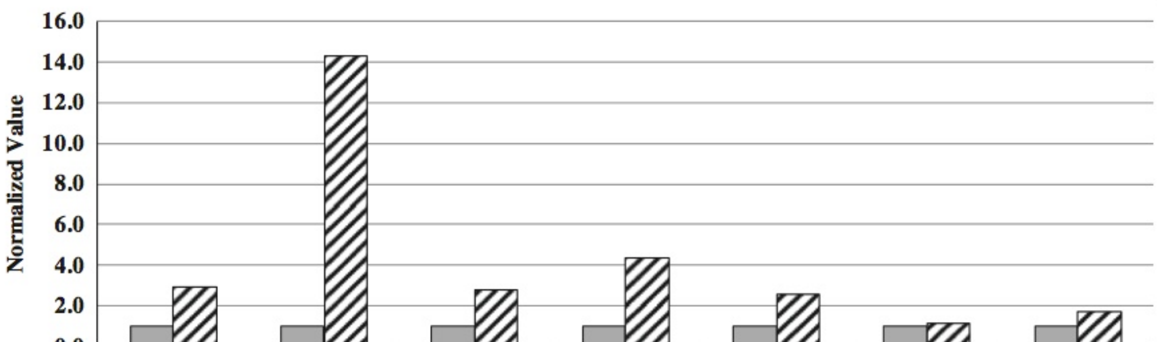
Graph: A comparison of environmental impacts of hardwood lumber to WPCL. The material with highest impact was given the baseline of 100% and impacts of the other materials are shown in proportion to this.

Source: Bowyer, 2008

The second LCA we analyzed was performed by AquAeTer, an environmental engineering firm, where the functional unit was 1000 board feet for both alkaline copper quaternary (ACQ)-treated lumber and WPC. The AquAeTer LCA also found that WPC had more significant environmental impact -- particularly related to fossil fuel use -- than the wood lumber, as illustrated in the graph below.

We also referenced a life cycle inventory for hardwood lumber production, where we learned that hardwood lumber requires 608MJ/m^3 of electrical energy and 5.8GJ/m^3 of thermal energy (Bergman, 2008), while WPC consumes 1.52GJ/m^3 of energy inputs from cradle to grave (Bolin and Smith, 2010).

All in all, Re:Plastic stock material would have less environmental impact than either wood or WPC because transportation costs would be significantly lower and energy use would be minimal -- especially if we can build the Re:Plastic machine to use solar energy feeding a socket outlet. The solar source would have to be connected to a battery that would provide the same output when needed. This would reduce the amount of carbon in the atmosphere if we were to use the same electrical output from a fossil fuel energy source. This adds to the sustainability of our product.

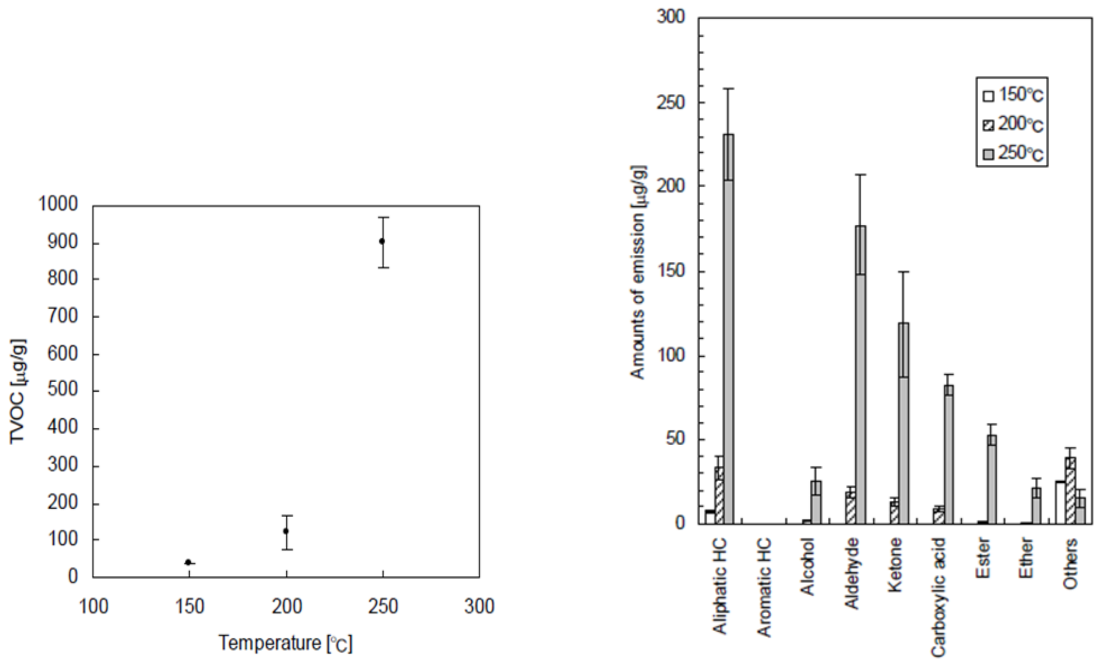


	Greenhouse Gases	Fossil Fuel Use	Water Use	Acid Rain	Smog	Eutrophication	Ecological Impact
ACQ Lumber	1.0	1.0	1.0	1.0	1.0	1.0	1.0
WPC Decking	2.9	14	2.8	4.3	2.6	1.1	1.7

Graph: Cradle-to-grave impact indicator comparison of a representative U.S. family deck of 320 square feet (29.7 square meters) (normalized to ACQ-treated lumber = 1.0) ***Source: Bolin and Smith, 2010***

In addition to using LCAs to evaluate the environmental and social impact of Re:Plastic stock material, we researched whether melting plastic would release any toxic emissions. Yamashita, et al. (2007) performed a comprehensive study on melting LDPE, Polypropylene (PP), and Polystyrene plastics and the resulting Toluene equivalent of the Volatile Organic Compound (TVOC) emissions. In this study, we learned that plastic polymer chains degrade more rapidly at higher temperatures, which in turn releases a higher TVOC. Below is a graph showing that TVOCs are emitted at an exponential rate between 200^{o} - 250^{o}C. In addition to emissions due to polymer degradation, additives and print ink are the likely sources of emissions when plastics are subjected to melting. Organic Compound (TVOC) emitted at the temperature less or equal 200°C are inconsequential. That accounts for our decision to melt the plastic films at that temperature. In the

Re:Plastic tests, we heated the LDPE plastic bags only to 200ºC suggesting that we would have limited emissions in creating Re:Plastic stock material. Below is a graph showing the specific chemicals emitted when heating LDPE to 150ºC, 200ºC and 250ºC based on the Yamashita study.



Graph: ***(on left)*** **Total Volatile Organic Compounds released for 150ºC, 200ºC and 250ºC.** ***(on right)*** **Amount of emissions for key organic compounds at 150ºC, 200ºC and 250ºC. Source: Yamashita, et al.. 2007.**

In tests with waste plastics, there were more emissions of chlorinated hydrocarbons, phthalates and nitrogen compounds that were probably generated from food residue attached to waste plastics.

In summary, increase in temperature leads to increase in the TVOC emission. Food residues are likely sources of VOCs. These could contribute to an increase in VOC emissions in waste plastics and unseparated plastics. As such, we will explore expedient ways to wash plastic before used in the Re:Plastic machine to avoid these emissions.

Concept Generation

Our team has been guided by the key question: How can we reduce plastic film packaging in landfills and waterways? We have tackled this question from a number of different dimensions, through which we have generated a number of concepts to eliminate plastic film packaging from landfills and waterways. In our process, we followed three main approaches to solve our problem, within which we developed a number of individual concepts/solutions. These three approaches included:

1. Eliminate plastic packaging from the source by replacing LDPE plastic films with a bioplastic alternative
2. Collect LDPE plastic film packaging in a community and ship it to a composite lumber company to transform the plastic into composite lumber

3. Create a machine that a community could use to transform LDPE plastic film packaging into construction material for community members to build benches, tables and other objects for the public good.

When we started researching our project, we hypothesized that the most effective way to eliminate plastic film packaging would be to influence companies to transition from LDPE plastic to bioplastics. Within this idea, we had first considered that the LDPE plastic packaging could be replaced by (1) paper packaging, (2) polylactic acid (PLA) plastic, (3) polyhydroxyalkanoate (PHA) plastic or (4) cellophane. However, in our design ethnography and literature review, we discovered that many companies were already transitioning from LDPE plastic packaging to recyclable/biodegradable alternatives. In particular, we learned that Eden Foods was well on their way to transition their packaging to bioplastics. From this perspective, we felt that our initial solution would not make a meaningful impact given that companies were already engaged in this activity.

Next, we explored the idea of working with one company to develop a framework for how they could test bioplastic packaging interactions with the items they were packaging. However, we realized that our team experience and expertise did not align well with this concept because it would require chemical or material science background. Moreover, we were concerned that working with a company on their packaging strategy may not align with the timeframe allotted for our class. As such, it seemed prudent to work on a project that did not depend on the requirements and expectations of an external client.

After exploring options to eliminate LDPE plastic packaging at the source, we were inspired by integrative design principles to identify solutions to transform the end-of-life for LDPE plastic film packaging into something productive. LDPE plastic film packaging is currently viewed as inconsequential trash -- particularly in developed countries where its impact is not as visible as in developing countries. We decided to leverage some 10XE Design Principles, such as 'design nonlinearly' and 'start downstream,' to consider LDPE plastic film packaging as a resource, rather than waste. From this perspective, we realized that LDPE plastic film packaging could be reused by transforming it into composite lumber and using it as construction material for public goods.

Once we realized LDPE plastic film had reuse potential, we realized we needed to develop a supply source for LDPE plastic film as well as a customer for the composite lumber output. For our supply source, we decided we could collect LDPE plastic film from community members and retailers. Moreover, we realized that by engaging directly with community members, we could also educate community members about LDPE plastic packaging and its environmental effects.

In turn, we initially decided that city waste managers would be the ideal customer for our composite lumber products because they have an incentive to reduce waste in the community. Yet as we considered our idea further, we realized that university sustainability groups, such as University of Michigan's Planet Blue, or even corporate sustainability groups, such as Google Green, could be compelling customers as well.

However, we realized there were two major flaws in our design strategy for creating composite lumber from LDPE plastic packaging -- particularly from a Life Cycle Assessment point of view. First, we did not account for the environmental impact from the production of plastic composite lumber. Producing composite lumber from LDPE plastic is an energy intensive process, thereby negating many environmental benefits. Second, we did not account for the environmental impact from the distribution system in this model. We would have had to transport the collected LDPE plastic film from the community to the composite lumber facility and then return it to the community. Again, we would have emitted excessive CO_2 in our effort to eliminate plastic from landfills and waterways.

At this point, we turned to our third solution where we decided to create a machine to transform LDPE plastic film packaging within the community. Even in this option, we explored a myriad of concepts. For the machine itself, we've considered:

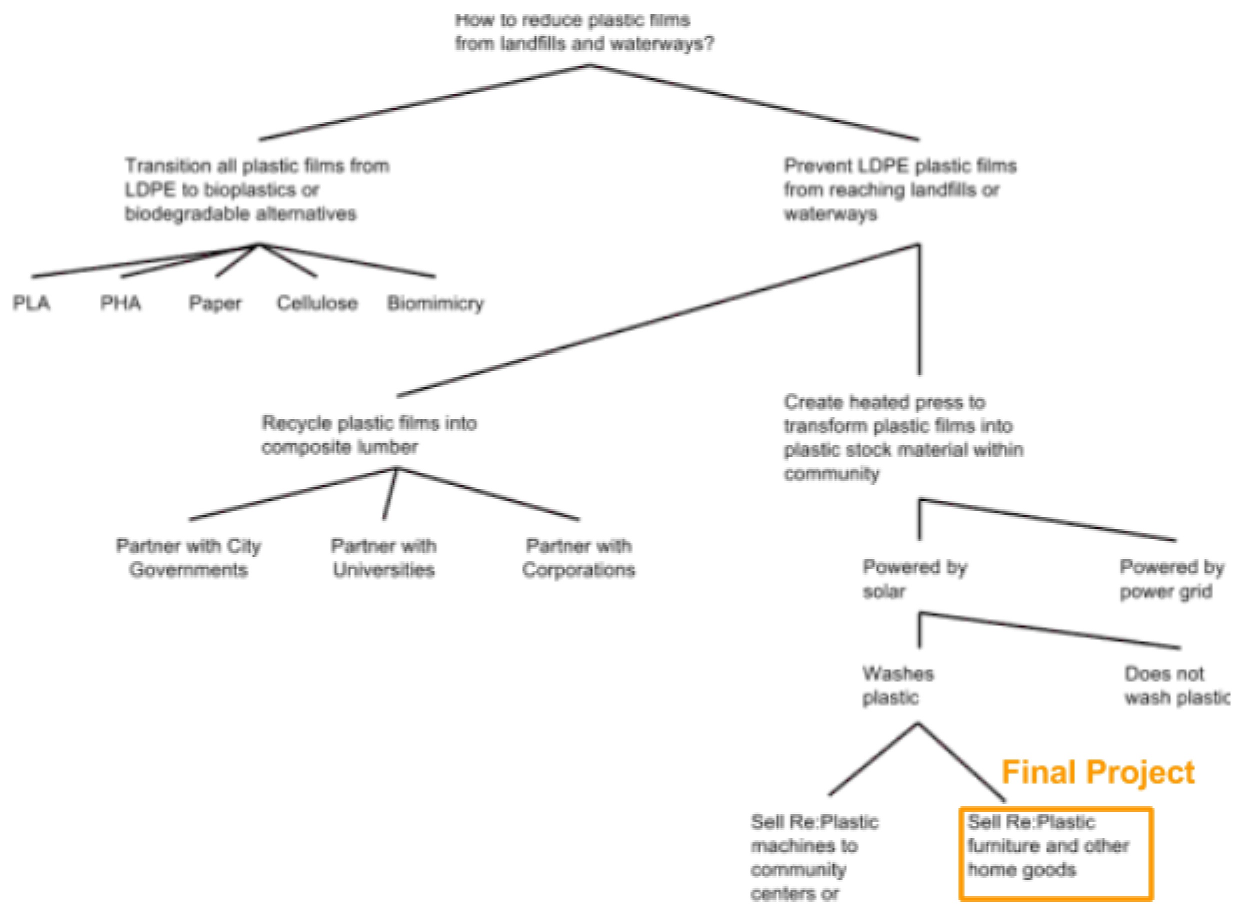
- using renewable energy, such as solar
- incorporating a centrifuge to clean the plastic before it is added to the machine
- using easily replaceable parts to accommodate for design for reuse and durability

Similarly, we have explored multiple business models for the Re:Plastic machine. We have considered selling the machine to workshop co-ops, such as Maker Works, to have accessible for community members. We have also considered creating a retail business, where Re:Plastic would create furniture and home goods to sell directly to consumers.

Throughout our concept generation process, we have prioritized integrated design, where we have not only considered the environmental impact of the Re:Plastic machine, but also the Re:Plastic stock material. We have similarly examined our stakeholder network to ensure that these stakeholders would benefit from Re:Plastic products.

Concept Selection

We followed a fairly organic process for our concept selection, where at each phase we questioned whether we could find an option that would not only be more impactful from an environmental and social sustainability perspective, but also an economic perspective. Below is a decision tree for our concept for Re:Plastic.



Alpha Design

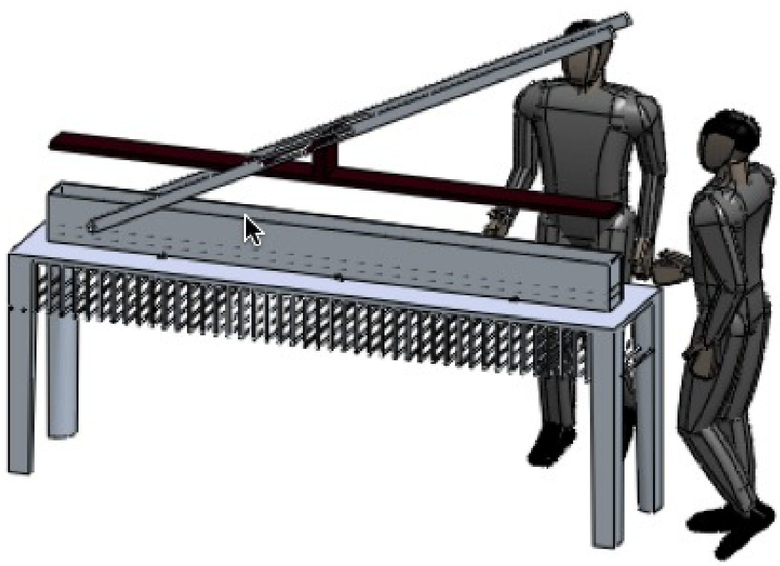
Re:Plastic is a community based program which recycles plastic films in a more direct and less energy intensive manner than converting them into composite lumber. Plastic films will be collected within a community, aggregated to a central location, and made into solid plastic stock of a specified dimension. The Re:Plastic stock material will then be used for:

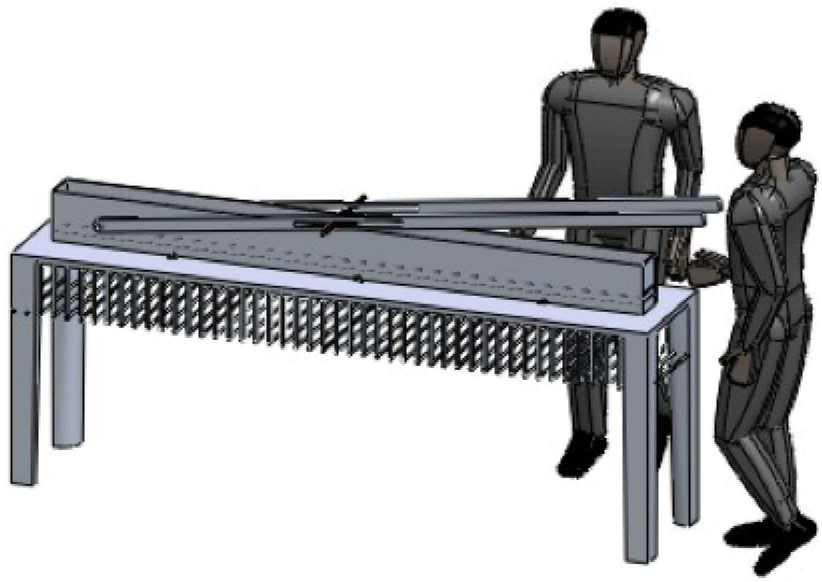
1. Beautification projects within the community such as park benches or playground equipment
2. Raw material for design prototypes in engineering, architecture and other construction based disciplines
3. Furniture and home goods to be sold commercially.

Re:Plastic will educate the community about the environmental impact of plastic by presenting these recycled products to the public.

Initially, community stores will be used as the local plastic collection sites. Retailers such as Home Depot, Kohls, and many others already offer plastic bag collection bins, where the plastic is baled and sold to be made into pellets and then new materials. We learned through interviews with stores in the Ann Arbor and Detroit Metro that they would be willing to donate the bags collected to a community program, free of charge. We could arrange to have the plastic film collected by a community organization such as the Eagle Scouts or National Honor Society.

We would acquire a prototype for the Re:Plastic machine through a grant or community funding. The Re:Plastic machine is designed to heat and press plastic bags firmly into a stock material. The Re:Plastic stock material will harden upon removal from the heat and can be used as a building material. The Re:Plastic machine will be electrically powered utilizing a common 120VAC outlet. Heaters will heat the chamber, which is manually loaded. As the plastic is heating, the screw press can be tightened to add pressure to the heating plastic films inside. The bags will be pressed until the screw is hand tight and the temperature has reached its desired value (~200°C). After the Re:Plastic stock material cools, it can be used to build be used to build benches, playground equipment, furniture or other beautification projects within the community. Below are renderings of the Re:Plastic machine.





The Re:Plastic machine design would be simple to construct and cheap to maintain. This means that once the model is perfected, the design could be used in developing countries that do not have recycling infrastructure. In developing countries, plastics often end up being blown by wind to a nearby water body (Environmental Literacy Council, 2008). With few machine parts at low cost, Re:Plastic machines could help reduce water pollution and diseases generated by plastic waste. Moreover, Re:Plastic stock material could be used to build schools, garden and other community projects.

Our product will be better than the baseline both environmentally and socially. As our product is made from 100% recycled LDPE, its production will not contribute to the depletion of natural resources and will decrease the amount of LPDE that ends up in landfills. The emissions due to transportation will be considerably lower than that of the baseline products, lumber and wood plastic composites, for which the raw materials and the final products are transported throughout the country. Our product is meant to be made within a community to create items that will remain in the community, virtually eliminating transportation and the negative environmental impacts that go along with it. The implementation of our product will include educating the community on recycling, giving community members tangible results for their donations of plastic bags. Ideally, this will motivate people to become more environmentally friendly in other aspects of their lives.

Re:Plastic stock material will have a much less energy intensive production that either wood or wood plastic composites, as the entire production only involves heating an oven for several minutes. Another benefit of Re:Plastic stock material is its isotropic construction. Wood can be easily split if force is applied in a certain direction, and this is not the case for our product. Plastic does not swell or crack due to weather changes and is not susceptible to mildew. All of these are issues associated with both hardwood lumber and wood plastic composites. We are still in the process of determining the technical specifications of our product, but overall it seems that Re:Plastic stock material will be an improvement both environmentally and functionally on the baseline.

From a social perspective, Re:Plastic will reduce health hazards from chemicals leaching from landfills and preventing plastics from destroying marine ecosystems.

Feedback on Alpha Design

As of Design Review 2, our alpha design revolved around having a community based program that recycled plastic film into re:Plastic, a useful stock material. The idea was to use Re:Plastic for community beautification projects such as benches and playground equipment. Other outcomes we had considered were marketing re:Plastic as a stock material to student engineering project teams to use for making prototypes or using Re:Plastic to build furniture to sell commercially. We had hoped that the machine could be run on solar power in order to further decrease negative environmental impacts.

From the feedback we received on Design Review 2, we determined that powering our machine with solar power is an impractical specification, as this would greatly limit the locations that our machine could be housed, make integrating our machine difficult, and would increase the startup cost for our project. Since funding the project is an integral part of bringing this idea to life, we looked into applying for grants. At this point we discovered the difficulty of getting full funding for a project, thus realizing that our project would realistically need to start out as a for profit business. To gauge the consumer interest level in using Re:Plastic as a prototyping material we polled the U of M student engineering design teams (Human Powered Submarine, Supermileage, etc.). The feedback we received was not entirely positive. All of the teams were interested in our material, but since it cannot be used in 3D printers nor can it be machined on mills and lathes, the teams did not see a lot of potential uses for re:Plastic. The reasonability of making and selling re:Plastic furniture was also tested. To do this we surveyed a variety of people, from college students to grandparents, and almost everyone stated that they would be interested in purchasing Re:Plastic Furniture. College students showed the most interest, as many of those interviewed had had to purchase furniture for their apartments or dorms within the last few years. A drawback, however, was that many people were less than keen on having furniture with the extremely eccentric color patterns of stock re:Plastic. Based on this feedback, we decided to nix the idea of harnessing solar power for this project and focus on a for profit furniture business.

Final Concept Description

Our final design still involves recycling LDPE plastic films into a usable stock material. These films will be gathered from locations that already have plastic bag collection bins, such as Meijer and Kohls, and then be brought to a central location where the Re:Plastic machine will be housed. The machine will be used to heat the plastic films until they reach a gum-like consistency then press the plastic into boards. Upon removal from the heat, the plastic will harden, resulting in a durable, lightweight material. This material will be used to make furniture, such as bookshelves, tables, and even sofa frames. These would be sold at a very low cost, as the raw material - plastic films - is incredibly inexpensive and the production is not energy intensive as compared to that of hardwood lumber or wood plastic composites. The natural appearance of Re:Plastic is a kaleidoscope of colors from the variety of plastic bags, so the furniture can either have that look or be coated in acrylic and painted for customers wanting more conventional appearance.

The marketing for this product would be directed toward millennials who are looking to purchase furniture for their apartment. Even apartments that are supposed to be fully furnished are generally missing something like a desk chair or coffee table. Based on surveys following Design Review 2, students will be looking for furniture that is inexpensive and able to put up with the wear and tear of college life. Re:Plastic fits this criteria perfectly, as its hydrophobic properties make it more durable than wood and Re:Plastic furniture can be sold for less than comparable products at IKEA. Additionally, students noted that their ideal furniture could be easily transported, as college students frequently live in a different apartment each year and/or move to a different city over the summers for internships. Since Re:Plastic is very lightweight, moving would be a breeze.

Business Plan

Company Description

Re:Plastic upcycles plastic films into furniture and home goods to sell to environmentally conscientious, yet frugal millennials. Currently, plastic films litter land- and waterways because there is no perceived value to these products. Re:Plastic has developed a business model that reuses plastics, and as a result, transforms the perception of plastic from waste to a valuable stock material. As a basis for comparison, aluminum cans rarely litter the streets of Michigan because individuals earn $0.10 for returning their cans. By creating a similar incentive structure, people and businesses would opt to collect and return their plastic bags, rather than throw them in the trash, where they easily escape into the environment.

We will operate Re:Plastic within a community, which will allow us to build strong relationships with our suppliers and educate community members on plastic recycling. Moreover, Re:Plastic will minimize its emissions from transportation by optimizing travel within a community, rather than shipping plastics long distances for reprocessing.

Market Analysis

As mentioned above, we will sell Re:Plastic furniture and home goods to environmentally conscientious, yet frugal millennials in the US. The millennial generation is composed of approximately 75 million individuals. We are targeting this generation because they are cost conscious and attuned to the social and environmental impact of the products they purchase. According to the Pew Research Center, Millennials who have attended college are particularly environmentally conscious. Specifically, over three-quarters (78%) of Millennials who have completed at least some college recycle compared to only three-fifths of Millennials who have not gone to college. According to the US Census Bureau Surveys, over half of Millennials (54%) have completed some college or have graduated. Combining these statistics, we can confidently say that there are at least 31.6 million Millennials who express environmentally conscientious behaviors (Pew Research Center, 2010).

Many studies have shown that Millennials express their environmentally conscientious preferences through their purchases. According to the Pew Research Center, over half of Millennials (53%) buy green products (Pew Research Center, 2010). Another study by Cone Communications concluded that 84% of Millennials consider the corporate social responsibility of a product before making a purchase (Cone Communications, 2013).

Millennials often struggle to follow through on their green purchase intent because green products are often more expensive than traditional products. Because millennials have limited income, they are price-conscious when making purchases (Pew Research Center, 2010). While there some upcycled furniture available online, these options are price prohibitive to millennials. For example, DesignbyThem, an Australian furniture design brand, sells a 1005 recycled plastic chair for $621. Re:Plastic allows millennials to follow through on his or her environmental values, at a price point comparable to traditional furniture options.

In addition to being environmentally sustainable and affordable,, Re:Plastic furniture and home goods would appeal to millennials because they are durable, lightweight, and customizable. Millennials prefer durable and light-weight furniture because they are still in the process of establishing their homes and careers, meaning that they relocate often. Finally, millennials pride themselves on self-expression (Pew Research Center, 2010) suggesting that they would be interested in customizable furniture.

Re:Plastic furniture and home goods would compete with other affordable furniture millennials might buy. In Ann Arbor, students typically buy affordable furniture from IKEA, Target, Meijer, and other big box stores. Particularly thrifty and environmentally friendly millennials buy furniture and home goods from Craigslist, Ann Arbor PTO Thrift Shop, Salvation Army, and the ReUse Center.

Re:Plastic furniture and home goods would be more appealing to millennials than those available at big box stores because our products allow them to merge their purchases with their values. According to Craig Bida, executive vice president of Social Impact at Cone Communications, a pre-eminent cause marketing research firm, "When it comes to getting involved with social impact, millennials can perceive their job to be sharing information about issues and initiatives with their network. They're less likely to feel their job is to donate or pursue more traditional cause activation elements" (Cone Communications, 2010). As a result, millennials would be excited about the affordability and the environmental impact of Re:Plastic products. Moreover, they would be willing to share this impact with their network. In turn, Re:Plastic products may not appeal to shoppers who prefer a more traditional coffee table made from hardwood.

We will price our products to be competitive with other affordable furniture products on the market. Because our material costs are so low, we have quite a bit of flexibility to price our products for the market. We performed market analysis for coffee tables available for purchase in Ann Arbor. We found that the most affordable coffee tables were available for purchase from Amazon for $32 and IKEA for $39.99. We would price our coffee table for $35. Because Re:Plastic operates within the Ann Arbor community, Re:Plastic could deliver the coffee table directly to the buyer for a small charge or the buyer could pick up the furniture for free..

Our primary barrier to entering the market will be sourcing a machine to mould the plastic. In the short term, we can create some small products in a conventional oven. Additionally, for products that interact with food, such as cutting boards, we would have to acquire FDA material certification since our material is a new product.

Currently, we have designed the Re:Plastic business model to operate in US communities. However, it is possible to replicate the Re:Plastic model in other countries -- especially developing countries. In fact, there is a company in Guinea, called DIA Plastique, which creates a financial incentive for individuals to collect plastic waste and transforms the waste into usable products. The company purchases plastic for $0.29 per kilogram. DIA cleans, boils and moulds the plastic to create buckets, washboards, flower pots and a number of other items. Currently, they have approximately 35 moulds and process 9 tons of plastic per day. DIA Plastique have been incredibly successful and continue to expand their capacity.

Product Description

Re:Plastic products are affordable, environmentally friendly, durable, light-weight and customizable. As described in the Market Analysis section, millennials seek out these characteristics in products that they buy.

Customers will be able to select their preferred shape, size and color of Re:Plastic products. Because apartments on college campuses or in big cities are often confined on space, customers can specify the exact dimensions for each piece of furniture. Additionally, the Re:Plastic material can be painted with acrylic, which allows the customer even greater customization opportunity.

Currently, Re:Plastic products are in the design verification stage, where we are:

1. Identifying products that could be created without a press or machine, but rather in a conventional oven.
2. Determining the detailed design specifications required to build a machine
3. Evaluating financing options to build the machine and launch the business.

Marketing and Sales Strategy

We will launch Re:Plastic in Ann Arbor, where we already have an intimate understanding of our target customers (i.e., our classmates) and have an opportunity to develop strong relationships with plastic collection points, such as stores and manufacturing facilities. We will test customer interest using a crowdfunding platform, where customers can in a sense "pre-pay" for Re:Plastic products by contributing to the start-up costs of the machine. Similarly, we can test customer interest by creating small upcycled plastic products in a conventional oven and sell these products on Etsy. If we can prove there is interest and purchase intent from consumers, we can proceed to expanding our producing by sourcing a machine to mould the plastic.

Our start-up costs include the costs related to the plastic press and initial marketing costs. We estimate that it would cost us $15,000 to design and build the Re:Plastic press. Assuming we generated this money through a loan, it would take us approximately 15 months to pay this off (SBA loans under $150,000 have a 0% fee). Additionally, we would spend $1,500 on marketing in our first three months.

Below we've illustrated the financial proforma for the first three years for Re:Plastic:

	Year 1	**Year 2**	**Year 3**
Revenues			
Coffee tables	$19,589	$28,328	$40,389
Cutting boards	$76,757	$107,917	$153,864
Total Revenues	$96,346	$136,245	$194,253
Expenses			
Plastic press loan payments	$12,000	$3,000	$0
Monthly wages - press operator(s)	$30,000	$50,000	$60,000
Monthly wages - manager	$48,000	$48,000	$48,000
Monthly transportation costs	$10,080	$10,080	$10,080
Monthly marketing costs	$13,500	$12,000	$12,000
Other incidental costs	$12,000	$12,000	$12,000
Plastic film supply	$710	$1,012	$1,442
Total Expenses	$126,290	$136,092	$143,522
Net income	-$29,943	$154	$50,731

Full financial model can be viewed at:
https://docs.google.com/a/umich.edu/spreadsheet/ccc?key=0Al4edJ58ErfWdDVEcDJzcG85VDExOFBCNGRTYzhQY0E#gid=0

Key assumptions for this model include:

- Coffee tables require 20,000 plastic bags and represent any larger product, including tables, desk, chairs etc.
- Cutting boards require 300 plastic bags and represent any smaller product, including picture frames, floating shelves, etc.
- 40% of plastic bags will be used for larger products and 60% for smaller products

- We will start by sourcing half a ton of plastic material a month, which we project to grow by 3% per month.
- We will pay suppliers $100 per ton of plastic bags/films
- We will add a new press operator for every 2.5M (0.78 tons) plastic bags processed
- We estimate that Ann Arbor produces 50M plastic bags per year. In year 1, we will process 22.7M, in year 2, 32.4M and in year 3, 58.3M plastic bags. By years 2 and 3 we will need to expand our material sourcing from plastic bags in stores to commercial shipping and receiving docks, where lots of plastic films are used for packaging.

We will promote our products through video advertising, social media and word of mouth. Video advertising is a cost efficient mechanism to raise awareness for new products. We would spend $0.30 if a viewer watches up to 30 seconds of our marketing videos on YouTube. Further, we would be able to track data on who watches our videos and completes a purchase to better target our advertising over time. We estimate spending $1,000 per month on digital marketing, we can reach 3,000 interested customers per month. Because millennials are very media savvy, we plan to leverage social media as a platform to both educate our customers about plastic litter and recycling and promote our products. Of all generations, millennials have the largest percentage (75%), who have a social media profile. Finally, we hope to engage with groups such as the Graham Institute for Sustainability, the Erb Institute for Global Social Enterprise, School of Natural Resources and Environment and other campus organizations involved with sustainability to spread awareness to students via word of mouth.

We will sell our products online, and as mentioned above, allow customers to design their own product (given certain dimension/shape/color constraints). We will distribute our products within the community on the same pick-up routes as for the plastic materials, which will minimize shipping costs.

Re:Plastic will begin by selling its products direct to consumer collecting primarily plastic bags from existing collection facilities, such as stores, in Ann Arbor. To expand production, Re:Plastic can collect plastic films from businesses that generate plastic films in their shipping and receiving departments.

Re:Plastic can grow its footprint by replicating this same model to other communities -- particularly other college campuses. Re:Plastic can also expand horizontally by transitioning to a business to business model, where Re:Plastic would transform plastic films to shipping crates or other packaging materials, which would be very low cost. Alternatively, Re:Plastic could create construction material to sell to construction companies. Many of these alternative customer segments would require a stronger material than LDPE, in which case we would need to research how strengthening materials could be added to the Re:Plastic material.

Financial Projections

We will need a loan of $30K to offset costs during the first 15 months of operation. We expect to reach cash flow positive in 20 months. Please reference financial proforma in 'Marketing and Sales Strategy' above. We would source our start-up costs from grants through start-up competitions, such as Planet Blue Student Innovation Fund or the Walmart Better Living Business Plan Challenge, loans, or investments.

In the worst case, we would only sell 16 large products per month and 1,600 small products, which would require us to raise prices to $75 for large products and $6 for the smaller products in order to break even. In this scenario, we would process only 0.25 tons of plastic bags per month for the duration of the three years. In the best case, we assume our plastic processing rate would grow 5% per month, rather than 3%. Halfway through year three, we would be processing over four tons of plastic bags, which would translate to >250 large item sales per month and >25,000 small item sales per month. It would take us 12 months to break even in this scenario.

Additional Reflections on Project Outcome

Justifications for Sustainable Design

From an environmental perspective, Re:Plastic products will certainly reduce some plastic from landfills and waterways. However, it will take Re:Plastic at least five years to meaningfully ramp up and refine its supply chain to create significant reductions of plastic film waste. Even in our best case scenario, we project it to take 3 years to process over 4 tons of plastic per month. Each year, the US creates 3,880 thousand tons of waste from plastic bags, sacks and wraps. As such, we would need to process 3,233 tons of plastic per month in order to reduce even 1% of the plastic film waste created today. That said, we could optimistically imagine a Re:Plastic operation in 1,000 cities across the country, which might collectively process 4,000 tons of plastic per month.

From a social perspective, we have illustrated that we could be financially sustainable with one manager and one machine operator for every 0.75 tons of plastic processed. This is an optimistic sign because machine operators would be low-skill employees, thereby creating green jobs for unemployed citizens.

From an economics perspective, we received feedback from a number of venture capital and commercialization professionals who encouraged us to consider a B2B model, where we might be able to achieve scale more quickly because we would have more consistent and predictable buyers of our products, compared to fickle millennial consumers. In particular, in the Michigan Business Competition, we received feedback that the judges questioned whether there is a significant demand for upcycled furniture an home goods. This is a point we would need to validate further through crowdfunding and/or selling small amounts of products through an online marketplace, such as Etsy. As discussed many time in class, a product that does not fit a need is by nature unsustainable.

Design Critique

Retrospectively, we should have evaluated the key inputs and outputs of plastic involved with the business model to determine not only the environmental impact, but also the commercial viability. Our team became very focused on the fact that plastic films could be acquired for such an affordable cost, yet did not comprehensively assess the associated financial costs of building the press and the supply chain for the business model to succeed. Towards the end, we realized that the capital and overhead costs were still very high and difficult to offset, despite the affordability of the source material.

The Re:Plastic design is intentionally focused on lengthening the use phase for plastic films, helping make the plastic film life-cycle more eco-efficient. A truly sustainable design would have eliminated LDPE at the source.

From a positive point of view, Re:Plastic is a successful design in that it was a creative approach to creating value to something that has no perceived value. We iterated on a number of potential customers and business models illustrating our ability to be informed, rather than beginner designers.

Recommendations

To continue developing the Re:Plastic business model, we would need to assess the input-output flow of the supply chain to determine the most cost effective supply chain. On the supply side, we should gather more data for how much plastic film could be collected in Ann Arbor from existing collection point per month. Next, we should determine where else plastic films could be sourced. As mentioned in the report, shipping and receiving docks at commercial and university facilities would presumably generate large stocks of plastic film that we could buy. Finally, we should explore options to collect plastic directly from consumers. All of this data would help us better understand how much material we would have available each year. In turn, we would be able to optimize our business model for the supply of plastic. Specifically, we would be able to determine the size, quantity and price of the the products we could create. For example, we discovered in our current financial model that larger products, such as coffee tables, would require more manual labor than smaller products that could be created using a designated mould. Further, a B2C model would be appropriate for a small inflow of plastic film material. Yet a B2B morel might be more appropriate for a larger inflow of plastic material. All in all, Re:Plastic is a strong start to evaluating the possibility for using plastic film as a valuable stock material, yet additional research could optimize the quality of the stock material itself as well as the associated business model.

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