

Project 3

ME 270: Design for Manufacturability

University of Illinois Urbana-Champaign



Repurposed Fan And Mocktail Dispenser

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ANALYSIS

1.1 Manufacturing Processes and Additional Operations for Repurposing

a. Steel Paper Clips VS Plastic Paper Clips

The process of manufacturing these steel begins with galvanized steel wire fed from a spool into a machine that straightens it. The wire then passes through another machine with a series of tiny wheels with microscopic dimples on their perimeters, which catch and bend the wire into the familiar "gem" shape. These machines typically make three 180-degree bends to create the standard paper clip design. Once shaped, the wire is cut to the appropriate length, forming individual clips (Frohman, 1998.). Modern paper clip machines can produce up to 150 clips per minute, with some advanced equipment capable of even higher output. Quality control measures may include polishing to remove rough edges and additional coatings for enhanced durability. The entire process is extremely efficient, with one operator often managing multiple machines (Scientific American, 2009). Plastic paper clips are typically manufactured using injection molding techniques. This process involves melting plastic pellets and injecting the molten material into a mold cavity shaped like a paper clip. Once the plastic cools and solidifies, the mold is opened, and the finished clip is ejected from the mold. While plastic clips offer advantages such as being non-conductive and resistant to rust, they are generally less durable than their steel counterparts and may not hold papers as securely (Made How, n.d.).

Between the two products in the pair, if a steel paper clip were to be chosen for repurposing into jewelry (as an example), additional operations would involve plating to have a nice decorative finish like rose gold or gold (this would also prevent rusting), polishing to smooth out rough surfaces for safety and comfort, and maybe even heat treatment to strengthen the steel and make the repurposed product more durable.

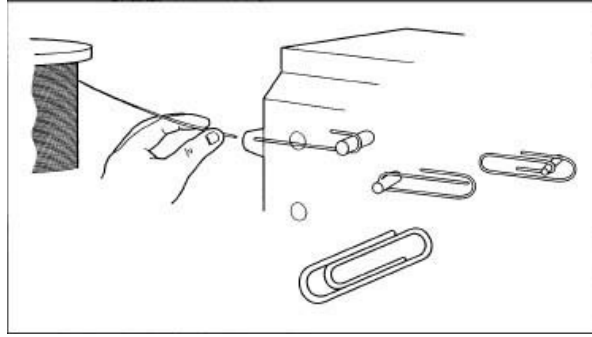


Figure 1 - Threading of a paper clip machine (Made How, n.d.)

b. Forged VS Cast Crankshafts

Forged crankshafts are manufactured through a complex process that begins with heating a steel ingot to approximately 2,200°F, making it highly malleable. The heated ingot is then placed into a forging die and subjected to either a hammering or pressing process, which shapes it into the desired crank profile. This compression not only fills the die precisely but also strengthens the alloy by compacting molecules and aligning the grain structure (Mavrigian, n.d.). The typical forging process includes several steps: cutting, peeling, heating, roll forging blocking, flattening, pre-forging, finish forging, trimming, twisting, hot finishing, suspension control temperature, normalizing and tempering, alignment, stress relief, shot peening, flaw detection, anti-rust treatment, and final inspection (Drop Forging, n.d.). This method results in a stronger, more durable crankshaft with a refined grain structure, making it suitable for high-performance applications (Engine Builder Magazine, 2018).



Figure 2 - Forged crankshaft (Mavrigian, n.d.)

The process for cast crankshafts involves pouring molten metal into a mold shaped like the final crankshaft. Once the metal cools and solidifies, the casting is removed from the mold. Cast crankshafts are typically made from nodular iron (carbon added to iron for greater tensile strength), which provides a good balance of strength and wear resistance. While cast crankshafts are generally less expensive to produce than forged ones, they may not be as strong or durable for high-performance applications. However, advancements in casting technology and materials have improved the quality of cast crankshafts, making them suitable for many automotive applications (Engine Builder Magazine, 2018).

Between the two products in the pair, I would pick the forged crankshaft because they tend to be stronger and more durable than cast crankshafts. It can easily be repurposed into something like an aesthetically pleasing table stand for a car enthusiast. For additional operations, I would recommend a heat treatment process followed by cutting, polishing and a clear coating finish. Annealing (a heat treatment process) would relieve internal stresses and improve machinability so it can then be cut to the desired height (The Federal Group USA, 2024). A high-gloss polish and clear coat would protect it from corrosion and increase its aesthetic appeal.

c. Plastic VS Glass Pitchers

The manufacturing process for forged plastic pitchers typically involves injection blow molding. In this method, plastic resin is first injected into a preform mold to create a parison (a tube-like piece of plastic with a threaded neck). This preform is then transferred to a blow molding cavity where it is stretched and blown into the final pitcher shape. The process allows for precise control over the neck finish and overall shape of the pitcher. After cooling, the pitcher is ejected from the mold and may undergo additional finishing processes such as trimming or labeling (O'Berk Company, n.d.).

Glass pitchers, on the other hand, are manufactured through a multi-stage process. The production begins in the batch house, where raw materials like silica, soda, and lime are mixed with cullet

(recycled glass). This mixture is then melted in a furnace at temperatures around 1748°C. The molten glass is formed into the pitcher shape using either the Blow and Blow (B&B) or Narrow Neck Press and Blow (NNPB) process. After forming, the glass pitchers undergo annealing in a lehr to relieve internal stresses. Finally, they receive protective coatings and undergo rigorous quality inspections (Ajanta Bottle, n.d.).



Figure 3 - Annealing in glass pitcher/bottle manufacturing (Ajanta Bottle, n.d.)

Between the two products, the glass pitcher can be converted into a durable flower holder.

Applying a hydrophobic coating through chemical vapor deposition would help create water resistance and allow the soil to absorb water better. The exterior surface could also be sandblasted to create an aesthetically pleasing frosted appearance.

d. Paper VS. Ceramic Cups/Mugs

Paper cups are produced through a multi-step process that begins with sourcing food-grade paperboard from sustainable forests. The paperboard undergoes cleaning and pulping, followed by bleaching to achieve a desired color. A cup-forming machine then cuts the prepared paperboard into circular blanks, which are shaped into cups using heat and pressure. To ensure

leak-proof properties, a thin layer of polyethylene (PE) coating is applied to the cup's interior. The cups can then be customized with printed designs using flexographic or offset printing techniques. Finally, the cups are trimmed, have their rims rolled for comfort, and undergo quality control checks before packaging (GreenFeel, 2023).



Figure 4 - Shaping Paper Cups (GreenFeel, 2023)

Ceramic mugs, on the other hand, are crafted through a process that combines artistry with industrial techniques. The production begins with the preparation of clay, which is then shaped using various methods such as slip casting, jiggering, or ram pressing. Once formed, the mugs undergo a drying process to remove excess moisture. The dried mugs are then fired in a kiln at high temperatures, typically around 1000°C, to achieve the desired hardness and durability. After the initial firing, the mugs can be glazed to add color, designs, or a smooth finish. A second firing is then performed to set the glaze. Throughout the process, quality control measures are implemented to ensure consistency and structural integrity. The final products are inspected, packaged, and prepared for distribution (S'more Science, n.d.).

For repurposing a ceramic mug into a more durable and aesthetically pleasing than paper cups in general. One can easily make a similar flower holder like in the previous section. The mug could undergo another firing at temperatures around 1000°C to 1200°C (S'more Science, n.d.) with a

new glaze application to increase water resistance. Additionally to improve drainage for plants to be put in it, a small hole can be created at the base of the mug using precision drilling before applying the final glaze coating.

e. Sheet-Metal VS Cast Hubcaps

The manufacturing of sheet metal hubcaps involves a metal stamping process which utilizes specialized stamping dies to shape and cut the workpiece into the desired form and size, producing components with extremely tight tolerances (American Industrial Co., 2023). The process begins with feeding sheet metal into stamping machines, where it undergoes a series of operations including blanking, piercing, and forming. (American Industrial Co., 2023).

For cast hub caps, the manufacturing process primarily relies on aluminum die casting. This method begins with preparing an aluminum alloy, typically containing elements like silicon, copper, and magnesium to enhance strength and casting ability. The molten alloy is then injected into a high-quality steel mold under high pressure, ensuring that it fills all parts of the mold and captures intricate design details (Easiahome, 2023). After injection, the aluminum is allowed to cool and solidify, taking the shape of the hub cap. Once solidified, the hub caps are removed from the mold, and any excess material is trimmed off. The process may include additional finishing steps such as polishing or painting to enhance aesthetics and corrosion resistance (Easiahome, 2023).

For repurposing sheet metal hubcaps into anything like furniture or other sheet metal parts, powder coating would be a good additional operation choice due to its durability. The process involves applying a free-flowing dry powder electrostatically and curing it under heat, resulting in a tough, even finish that is more resistant to chipping, scratching, and fading compared to conventional liquid paints (American Industrial Co., 2023). This coating method would be particularly beneficial for outdoor applications or high-wear scenarios, as it provides enhanced protection against corrosion and UV damage.

f. Steel VS Copper Nails

Steel nails production begins with steel wire being fed into a nail-making machine, where it is straightened and cut to the desired length. The machine then forms the nail's head by compressing one end of the wire, while the other end is sharpened to create the point. This process can produce up to 700 nails per minute. Heat treatment may be applied to increase the nail's strength, followed by cleaning and coating processes to enhance durability and corrosion resistance (Advameg, Inc., 2024).

Copper nails are crafted using a more manual approach. The process starts with a long, flattened strip of copper being cut into individual nail blanks using a press. Each blank is then placed into a small mold or former with the point facing down. The exposed top is hammered by hand to flatten it out, forming the nail head. This method results in thin flattened strips on opposite sides of the nail, just below the head, due to the copper being forced into the gap between the two halves of the adjustable former (Glossop Curiosities, 2017).

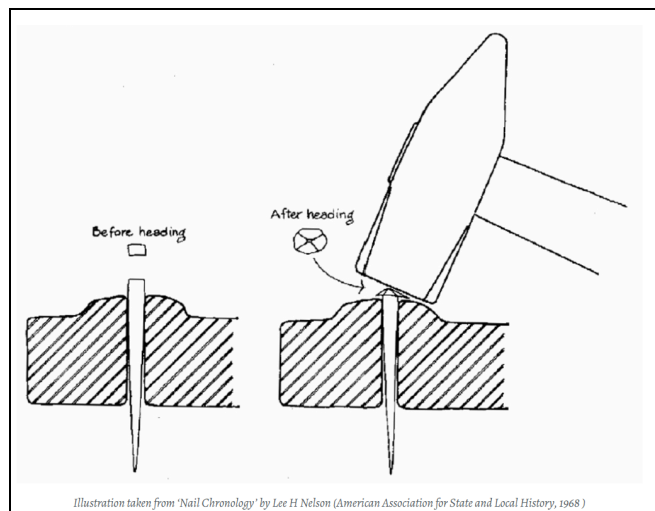


Figure 5 - Copper Nail Heading (Glossop Curiosities, 2017)

For repurposing steel nails, additional operations like galvanizing or zinc plating could be used to increase corrosion resistance, making them suitable for outdoor applications such as marine

hardware or even in simpler applications like arts and crafts. Heat treatment could be applied to increase the nails' strength and hardness, potentially allowing them to be repurposed as precision pins or alignment tools in manufacturing processes too.

1.2 Circular Economy

A circular economy is a model of production and consumption that tries to extend the life cycle of products and materials to minimize waste and maximise resource efficiency. It involves sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products for as long as possible (European Parliament, 2023). The circular economy stands in contrast to the traditional linear economic model of "take-make-consume-throw away" by keeping resources within the economic system through a number of means so they do not go to waste. For example, aluminum cans can be used by consumers, put into recycling bins and recycled into new cans or other aluminum products and never truly gets thrown away.

The U.S. Environmental Protection Agency (EPA) defines a circular economy as one that "keeps materials and products in circulation for as long as possible" (EPA, 2024). This system-focused approach involves industrial processes and economic activities that are restorative by design, enabling resources to maintain their highest value for extended periods.

Both definitions emphasize the importance of reuse, repurposing, and recycling in the circular economy. Reuse involves using products or components multiple times for their original purpose, while repurposing adapts items for new uses. Recycling processes materials into new products, closing the loop and reducing the need for virgin resources. These practices help to reduce waste, conserve natural resources, and minimize environmental impacts, including greenhouse gas emissions (European Parliament, 2023; EPA, 2024). All this is reflected in the diagram below - it shows two interconnected circles: the biological circle (green) which focuses on renewable materials and emphasises regeneration through farming, biochemical feedstock extraction, etc and the technical cycle (blue) that involves activities like refurbishment or

remanufacturing to extend product lifespans. By staying in the circular economy, resources are constantly being reused or repurposed and do not go to waste.

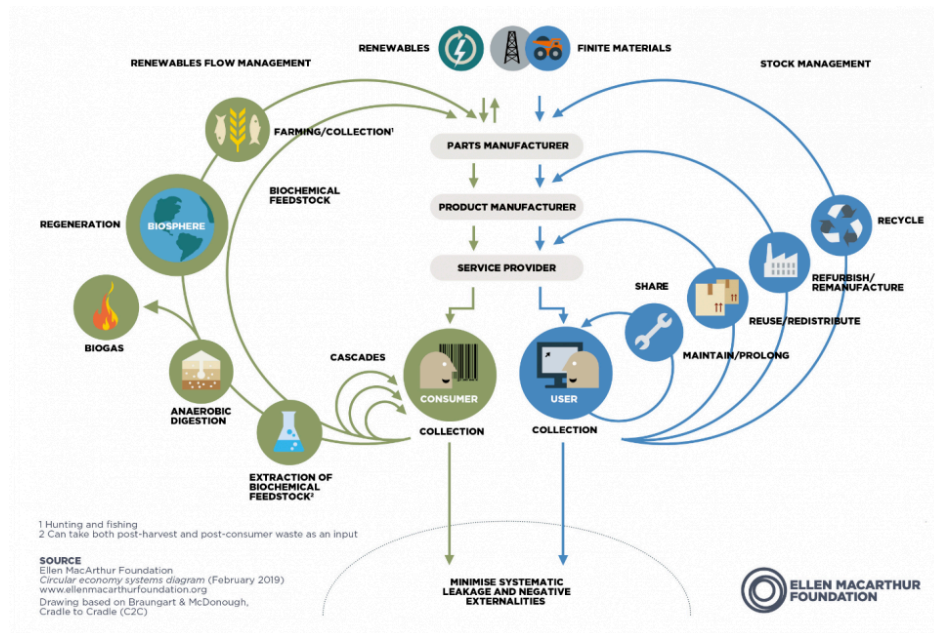


Figure 6 - Circular Economy - Biological and Technical Cycles (EPA, 2024)

1.3 Cradle-To-Cradle Design Approach

The cradle-to-cradle design approach refers to a circular regenerative system developed by architect William McDonough and chemist Michael Braungart. It aims to create products that can be fully disassembled, repurposed, or biodegraded at the end of their useful life, leading to a closed-loop, regenerative cycle (ugreen.io, n.d.). The cradle-to-cradle philosophy is built upon three key principles: everything is a resource for something else, use clean and renewable energy, and celebrate diversity (McDonough, n.d.). It eliminates waste by designing products that can be either biologically or technically (see diagram in 1.2) cycled back into new production processes so even waste becomes a valuable input (ugreen.io, n.d.).

In contrast, the cradle-to-grave approach, also known as lifecycle thinking, considers the impact of products throughout their entire lives, from raw material extraction to ultimate disposal (Ashkin, n.d.). It typically results in products being "downcycled" after use, leading to lower-value materials or waste accumulation in landfills (Ashkin, n.d.). The cradle-to-cradle design offers a number of benefits over the

cradle-to-grave approach, including reduced waste and pollution, preservation of natural resources, cost savings through efficient material use, new business opportunities in recycling and remanufacturing, and improved health and well-being through the use of non-toxic materials (ugreen.io, n.d.).

1.4 Disposable and Reusable Products

Table 1 - Disposable and Reusable Products, Materials and Manufacturing

Disposable Products					
Sr. No.	Product	Material	Material Selection	Manufacturing Process	Process Selection
1.	Plastic Water Bottle	Polyethylene terephthalate (PET)	It is lightweight, transparent, strong and resistant to moisture - making it convenient and safe to use.	Injection molding for preforms followed by blow molding to actually shape to bottles.	The two-step process allows for extremely efficient mass production - machines handling such processes produce high volumes at very fast rates with little waste.
2.	Paper Coffee Cup	Paperboard (with polyethylene or PE coating)	Paperboard provides structure and PE is water resistant, both materials are inexpensive.	Paperboard is shaped, a PE coating is applied to the shaped PE and the cup is formed and sealed.	These methods use existing infrastructure that can mass produce efficiently inexpensively and creates a liquid resistant disposable cup.
3.	Plastic Utensils	Polypropylene or polyethylene	These plastics are inexpensive, food-safe, and can be molded fairly easily.	Injection Molding	This method allows for rapid, high volume production of identical items.
4.	Paper Towels	Wood pulp (sometimes with synthetic fibers)	This material is absorbent and biodegradable.	Wood pulp is processed into sheets, cut and perforated.	These methods can use existing infrastructure that can mass produce efficiently inexpensively and create absorbent disposable sheets efficiently in bulk.
Reusable Products					
1.	Stainless Steel Water Bottle	Food-grade stainless steel (18/8 or 304 grade)	It is durable, non reactive, non-corrosive, retains temperature well, and is dishwasher safe.	Cutting, deep drawing, welding and polishing.	These processes create durable bottles that can withstand repeated use.
2.	Ceramic Coffee Mug	Clay (often kaolin), silica, etc.	Ceramics are heat-resistant, durable and can be glazed for	Clay is shaped, dried, glazed and fired in a kiln.	These process create strong, heat resistant vessels that are suitable for drinks of all temperatures.

			aesthetics.		
3.	Stainless Steel Utensils	Food-grade stainless steel (18/8 or 304 grade)	It is durable, non reactive, non-corrosive, and is dishwasher safe.	Stamping or forging, followed by polishing.	Stamping mass produces these utensils and together, these processes create durable, safe utensils that can withstand repeated use.
4.	Fabric Napkins	Cotton or cotton blend fabrics	These are absorbent, soft and washable.	Cotton is spun into a thread, woven into fabric, cut and sewn.	These processes are suitable to the material, well known and allow for customisation. They create absorbent towels that can be washed and reused.

(Note: All stated 'estimates' are based off of readings of Protolabs, n.d.; Bernard Lab, n.d.; Tempelman et al., 2014 and Kalpakjian & Schmid, 2014)

The manufacturing processes for reusable and disposable products seem to differ quite a bit, reflecting their intended lifespan and usage. Reusable products like stainless steel water bottles and utensils are made using methods such as deep drawing, stamping, or forging that create durable, long-lasting items that can withstand repeated use and cleaning. For instance, the deep drawing process used for stainless steel water bottles creates a seamless product that resists leaks and corrosion.

In contrast, disposable products like plastic water bottles and utensils are manufactured using high-speed, automated processes like injection molding. These methods prioritize speed and cost-effectiveness over durability because the products are intended for single use. The paper-based disposable items, such as coffee cups and paper towels, use continuous production methods that can quickly produce large quantities of uniform products.

Reusable products involve more complex manufacturing steps and higher-quality materials. Ceramic coffee mugs, for example, go through multiple stages including forming, glazing, and firing, resulting in a product that can last for years. Fabric towels and napkins require weaving or knitting processes that create durable textiles that can withstand multiple wash cycles.

The choice of materials also reflects the different priorities in manufacturing reusable versus disposable products. Reusable items use materials like stainless steel, ceramics, and durable fabrics that can maintain

their properties over time. Disposable products, on the other hand, use materials like PET plastic, thin paperboard, and wood pulp that are inexpensive and easily processed but not designed for longevity. Therefore, the manufacturing of reusable products emphasizes durability and quality, often resulting in more complex and time-consuming production processes. Disposable product manufacturing, however, focuses on efficiency and cost-effectiveness, using high-speed processes and less durable materials. These differences in manufacturing approach directly relate to the intended use and lifespan of the products, balancing factors such as cost, environmental impact, and consumer needs.

1.5 Numeric Questions

a. Total Potential Recoverable Value Calculation

Table 2 - Material-Wise and Total Recoverable Value Calculations

Material	Mass (kg)	Price Secondary (\$/kg)	Minimum Recoverable Value (\$)	Maximum Recoverable Value (\$)
Steel	0.20	0.40 - 0.50	0.08	0.1
Wrought Aluminium	0.10	1.60 - 1.70	0.16	0.17
Copper	0.12	4.80 - 5.30	0.576	0.636
Polypropylene (PP)	0.70	0.80 - 1.00	0.56	0.7
Glass	0.28	1.00 - 1.20	0.28	0.336
Total	1.40		1.656	1.942

(Note: Secondary Price values were taken from the Project 3 document (Tempelman et al., 2014))

As seen in Table 2, the total recoverable value lies in the range of **\$1.66 to \$1.94 (~\$1.656 to \$1.942)**. To arrive at this range, the lower and upper bounds of the secondary price per kilogram were multiplied by the mass of each material to get the minimum and maximum recoverable values respectively.

b. Profit VS Disassembly Time

Labour costs approximately \$15/hour or \$0.0042/second (= 15/3600).

Therefore profit can be calculated using the following formula :

$$\text{Profit} = \text{Recoverable Value} - (\text{Labour Cost per Second} * \text{Disassembly Time (in Seconds)})$$

. The profit was plotted using the lower and upper bounds of the range for recoverable value, i.e.,

\$1.66 and \$1.94, giving a range for disassembly times where the process is no longer profitable.

The chart can be seen in figure 7 below.

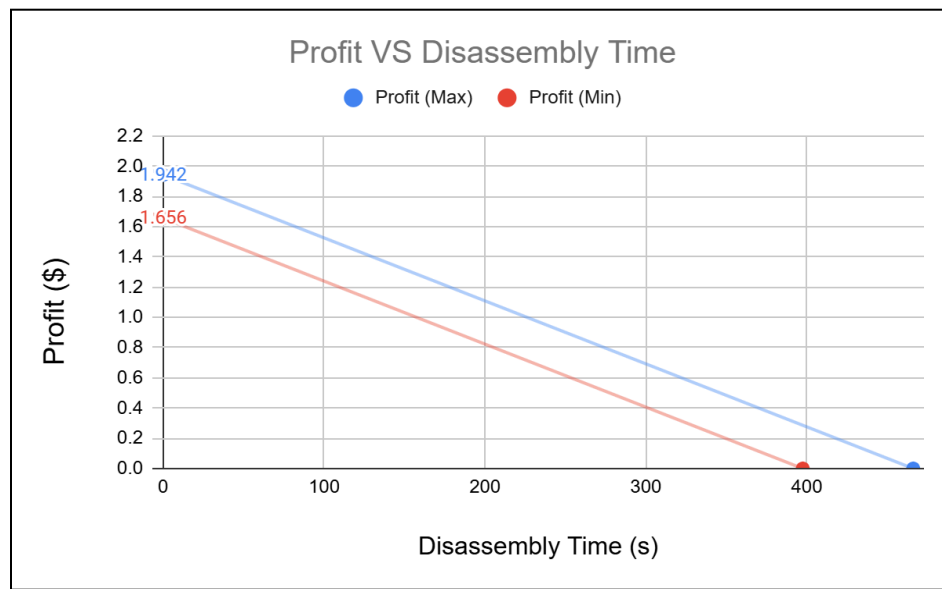


Figure 7 - Profit Vs Disassembly Time

As seen in the figure 7, the range of disassembly times where the process is no longer profitable is between **397.5s and 466.2s**. These are the values for disassembly time when the profit touches 0.

c. Reduction In Energy

Energy reduction was calculated using the following formula:

$$\text{Energy Reduction (\%)} = \frac{GER_{primary} - GER_{secondary}}{GER_{primary}} * 100$$

Since GER primary and secondary values were also provided in a range, the median values of each were used to calculate the energy reduction percentage for simplicity.

Table 3 - Material-Wise Energy Reduction Calculations

Material	GER _{primary} (MJ/kg)	GER _{secondary} (MJ/kg)	Energy Reduction Percentage
Steel	32.00	9.00	71.88
Wrought Aluminium	207.50	18.50	91.08
Copper	71.00	18.00	74.65
Polypropylene (PP)	95.00	40.00	57.89
Glass	25.00	11.50	54.00

(Note: GER values were taken from the Project 3 document (Tempelman et al., 2014))

On average, this is about 69.90% across materials.

d. Adding Energy Cost Savings To Profit

To calculate the profit after adding the energy cost savings, the following formula was used:

$$\text{Profit} = \text{Recoverable Material Value} + \text{Energy Saved (kWh)} \times \text{Energy Cost (\$/kWh)} - \text{Labor Cost}$$

where energy saved is calculated using the following formula:

$$\text{Energy Saved (kWh)} = \text{Mass (kg)} \times \text{GER Reduction (MJ/kg)} \div 3.6$$

and labor cost refers to the labor cost for 120s. Energy saved was divided by 3.6 to cover it to kWh.

Since the recoverable material value was in a range, the median of this range (\$1.80) was used for simplicity. Similarly, the average value for GER reduction (absolute, = GER_{primary} - GER_{secondary}) was taken for simplicity.

The calculation for this is provided in Table 4.

Table 4 - GER Reduction Calculations

Material	GER _{primary} (MJ/kg)	GER _{secondary} (MJ/kg)	Reduction (MJ/kg)
Steel	32.00	9.00	23.00
Wrought Aluminium	207.50	18.50	189.00
Copper	71.00	18.00	53.00
Polypropylene (PP)	95.00	40.00	55.00
Glass	25.00	11.50	13.50
		Average	66.70

Therefore, with values plugged in the Profit formula is the following.

$$Profit = 1.8 + \frac{1.4 \times 66.70}{3.6} \times Energy\ Cost\ (\$/kWh) - 120 \times 0.0042$$

$$\therefore Profit = 1.296 + 25.9 \times Energy\ Cost\ (\$/kWh)$$

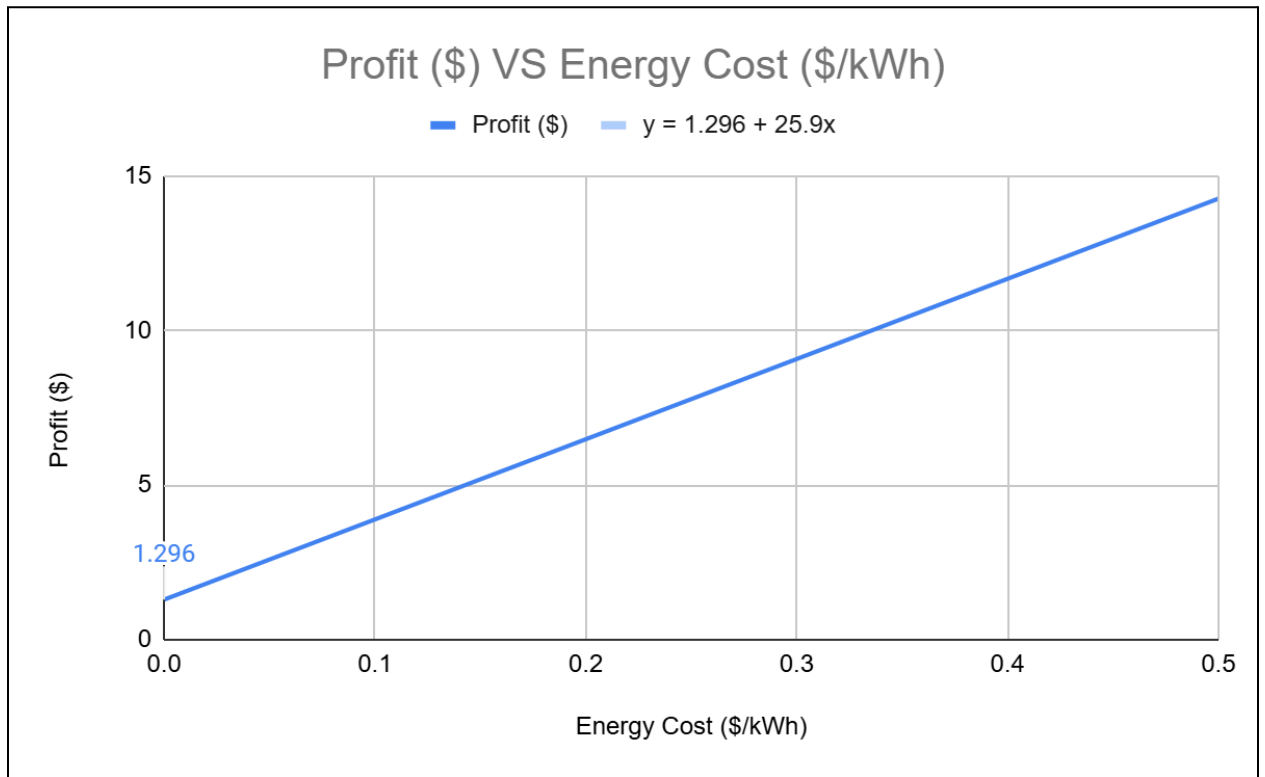


Figure 8 - Profit Vs Energy Cost

As seen in figure 8, the profit (y) increases with energy cost (x). With every \$/kWh increase in energy cost, profit increases by approximately \$25.90.

DESIGN CHALLENGE

2.1 Chosen Product

The product chosen for repurposing is a handheld fan (Figure 9) with four-blades powered by an AA battery. It is a compact personal cooling solution commonly found at amusement parks and outdoor venues. While the exact product spec was not made public by the company that sells the product, research on similar fans indicates that it likely uses a DC motor, specifically a 130-size brush motor (ProtoSupplies, n.d.), which typically operates between 8,000-12,000 RPM (ProtoSupplies, n.d.) at 1.5V (Farnell, n.d). This motor type is ideal for this application due to its high torque-to-size ratio and reliable performance.



Figure 9 - Repurposed Product : Handheld Fan

My design objective is to repurpose this handheld fan into a mocktail mixing system by integrating it into a beverage dispenser. This would prevent particles from settling down in the dispenser ensuring a homogenous taste and texture throughout the drink. The transformation involves removing the original plastic housing and fan blades, then designing and injection molding new food-safe Polyethylene

Terephthalate (PET) blades that retain the optimized fluid movement of the original blades. The 130-size DC motor is perfect for the dispenser because it's small enough to fit easily and powerful enough to mix mocktail ingredients smoothly. Powered by a single AA battery, it delivers just the right amount of speed to avoid spills or over-aerating the drinks. This repurposed design creates an efficient, cost-effective solution for mocktail mixing while maintaining food safety standards through better material selection.

2.2 Research, Empathizing

The original product is a handheld battery-operated fan commonly found at outdoor venues like amusement parks or parks especially during warm weather. They are a portable, quick and convenient way to stay cool and create a small but powerful airflow to do so (Reuters, 2015). Such fans are particularly helpful in places such as my hometown, Mumbai where it is perpetually warm and humid. However, I no longer feel the need for it during the cold winters of Illinois - making it an ideal product to repurpose. The main components include a DC motor (likely a 130-size brush motor operating at 1.5V) , a four-blade propeller design, an AA battery compartment, and a plastic housing unit (Instructables, 2021). The motor typically operates between 8,000-12,000 RPM (Instructables, 2021) at no load. The manufacturing processes for the original components involve injection molding for the plastic housing and fan blades, with the motor, battery compartment, and electrical components being off-the-shelf parts. The housing appears to be made from ABS plastic, while the fan blades are likely polypropylene for durability and safety (The Rodon Group, 2022).

For repurposing this fan into a mocktail mixer, several modifications are required. There are a number of features of the original product that make it helpful for repurposing into a mocktail mixer. The 130-size DC motor provides sufficient power for mixing mocktail ingredients because of its high RPM capabilities. Its compact size (diameter of approximately 60mm) allows for easy mounting within the liquid dispenser. The motor's standard operating voltage from a single AA battery provides enough power for mixing without being too aggressive, which could lead to overflow or excessive aeration of the drinks. However, there are also a number of challenges - the blades need to be food safe, and there isn't necessarily

water-tight sealing enclosing the motor axle connecting the 4-blade propeller. To finalise the changes I'd have to make, I went through a couple of design iterations. Since each design would require food safe blades - I could either add a protective food safe coating like PTFE (polytetrafluoroethylene, more commonly known as Teflon), or 3D print on injection mold entirely new blades. Research into spraying PTFE onto the blades suggested that it could eventually peel off and be ingested by the consumer making it extremely unsafe and redundant after multiple uses (Dowren new material co.,ltd, 2024). Therefore, I looked into designing entirely new blades. I initially defaulted to 3D printing them with a food safe plastic like PET or PP. However, research indicates that 3D printing with food-safe plastics is not inherently food-safe due to the layered structure creating microscopic gaps that can harbor bacteria and resist thorough cleaning (Smith3D Malaysia, 2023). The printing process itself may introduce contaminants, while additives and colorants in the materials can potentially leach into food, compromising safety. Therefore, I finally decided to injection mold the propeller and blades with PET (Formlabs, 2023). I also decided to add an O-ring as a water tight sealing connecting the new propeller to the motor housing for an added layer of safety. PET is the idea candidate to be injection molded such a food safe products due to its PET (Polyethylene Terephthalate) is an excellent candidate for injection molding food-safe products due its FDA approval, chemical resistance, and excellent barrier properties (Wankai Global, 2024). Its durability, strength, and ability to withstand a wide range of temperatures make it ideal mocktail mixing, while its low gas permeability helps maintain drink freshness. Additionally, PET's suitability for injection molding processes, combined with its recyclability, makes it a sustainable choice for producing food-safe containers with consistent quality (SyBridge Technologies, 2021).

Having finalised the materials and manufacturing processes, I moved on to ideating designs for the finished mocktail mixer. Every iteration now had the remanufactured blades and O-ring. The very first design involved simply holding the original fan with the food-safe modifications over the drink with the propeller and blades dipped into the drink to be mixed (somewhat like a whisk, see Figure 10).

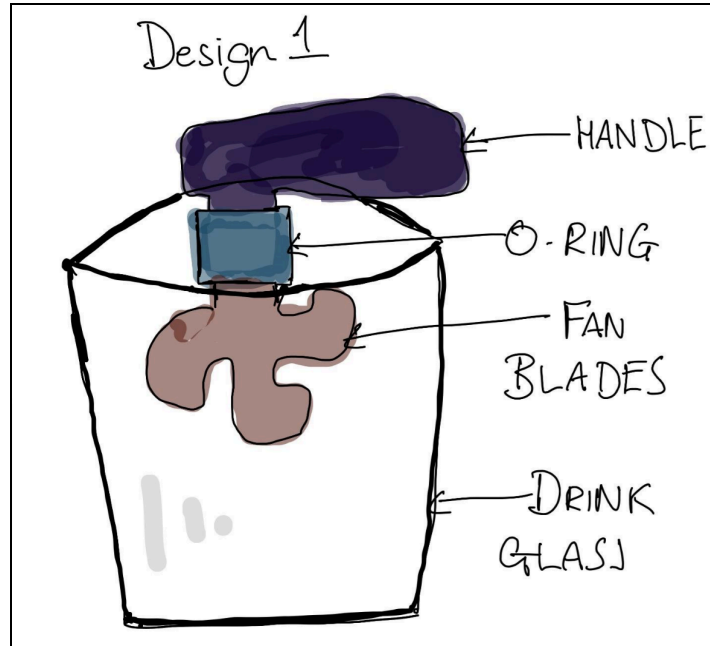


Figure 10 - Design 1 : Handheld mixer with food-safe modifications

However, this is inconvenient because the fan would have to be held throughout the mixing process and the drink particulates would begin settling as soon as the mixer is removed and the drink is left alone. A longer lasting solution needed to be found.

I then decided to incorporate it into an existing drink dispenser. Design 2 in Figure 11 involved attaching the blades to a revolving cooling ice chamber cylinder that would extend laterally from the lid of the container. However, I realised that once the drink was consumed enough to drop below the level of the cylinder, it would no longer be mixed, defeating the purpose after a certain amount of consumption.

Therefore for Design 3 (Figure 12), I decided to extend the propeller and its motor and housing from the bottom of the cylinder so it would access the drink at an even lower level. For this design, the cylinder would not rotate - only the propellers would. While this did solve the problem of keeping the drink mixed after longer consumption, I realised that having a motor even with a housing submerged in the drink would be risky and can be avoided.

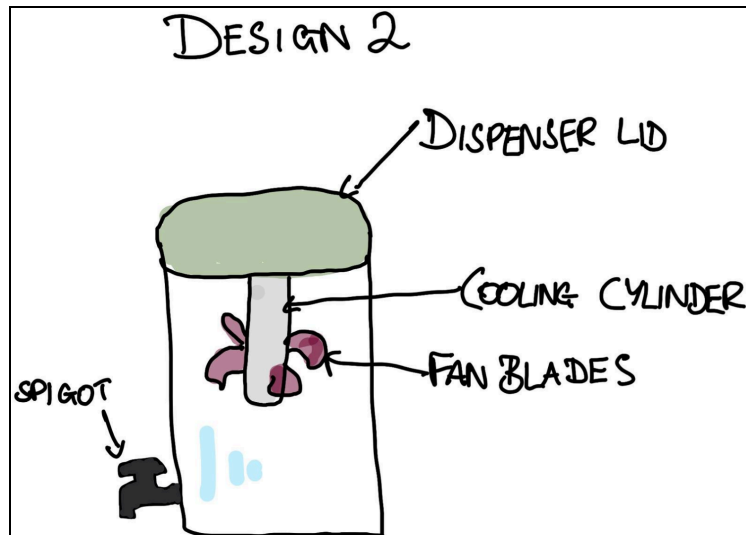


Figure 11 - Design 2 : Mixer-dispenser with blades extending laterally from cooling cylinder

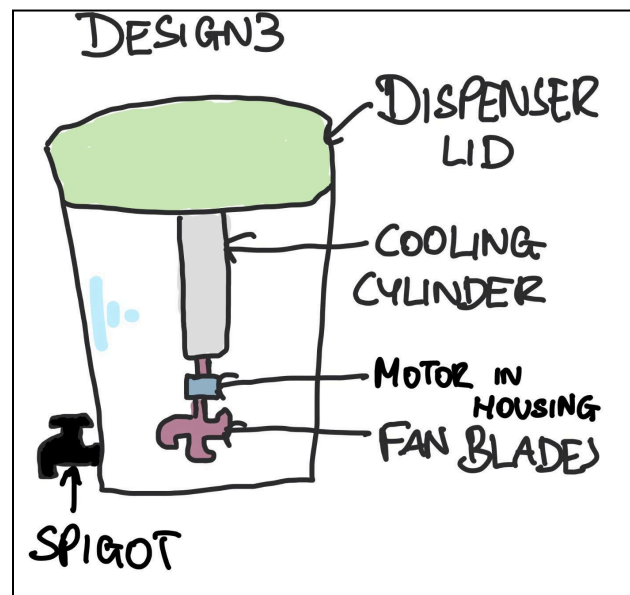


Figure 12 - Design 3 : Mixer-dispenser with blades, motor and housing hanging from the cooling cylinder

My next couple of designs involved having the motor and housing outside the container and a precision-cut hole in the dispenser container with the same diameter as the O-ring. The O-ring would be fitted into the hole after the hole is carefully finished with food-grade sealant and the propeller would be attached to it from the inside of the dispenser container, and the motor and housing would be attached from the outside. The hole would however have to be cut lower in the dispenser to avoid the issue with Design 2. Cutting it through the dispenser floor would be completely infeasible and inconvenient because

the motor would extend from the floor making a non uniform base for the container to stand on (Figure 13).

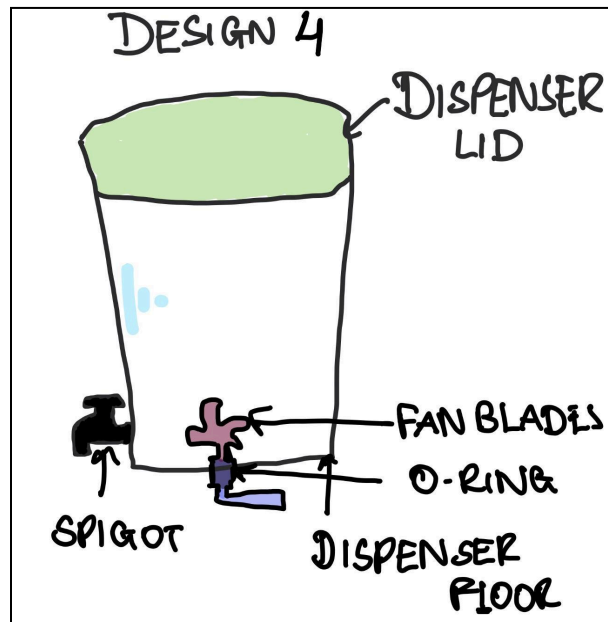


Figure 13 - Design 4 : Mixer-dispenser fan attached to the floor

Thus, I decided to cut a hole through the side wall towards the bottom, about 70mm from the bottom as seen in figure 14. This was the design I decided on.

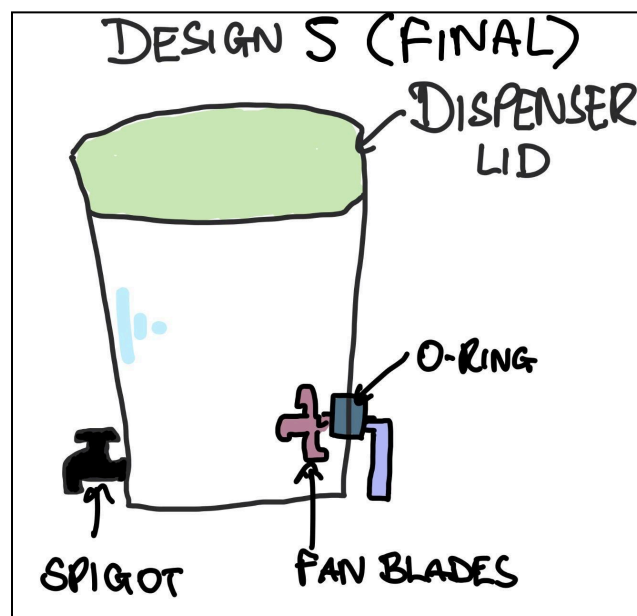


Figure 14 - Design 5 (Final) : Mixer-dispenser fan attached to the side wall

Throughout this design process, a variety of contextual factors were considered including environmental, economic, social and cultural. The repurposing approach extends the original product life and reduces waste and using readily available affordable materials while maintaining safety standards make it economical and environmentally friendly (Srivastava & Srivastava, 2020). Furthermore, PET, which was used for the redesign of the blades, is a recyclable and safe plastic. Social and cultural factors include the growing trend towards sustainable design and the repurposing approach is in line with this trend (Boston Consulting Group, 2023).

This repurposing project exemplifies the principles of sustainable design while creating a practical solution for beverage service needs. It uses existing components while upgrading critical elements to meet food safety requirements, resulting in an efficient and cost-effective product transformation since very few modifications are made.

2.3 Redesign For Disassembly and Assembly

a. Product Description

The "MixMaster Pro" is an innovative mocktail dispenser featuring an integrated motorized mixing system repurposed from a handheld fan. The design incorporates a clear glass beverage container with a capacity of approximately 4 litres, equipped with a spigot for controlled dispensing. The distinguishing feature is the converted mixing mechanism, which consists of a modified DC motor mounted through a precision-cut, sealed port in the container's side wall. The motor drives a custom-designed four-blade propeller made from food-grade PET plastic, ensuring thorough mixing of beverages while maintaining food safety standards.

This product is specifically designed for bartenders, catering professionals, and restaurant staff who need to maintain consistent mixed beverages throughout service periods. The battery-operated mixing system provides reliable performance for up to 5 hours on a single AA battery (WebstaurantStore, 2024), making it ideal for both mobile catering events and fixed bar installations. The transparent container allows for easy monitoring of liquid levels and mixing

action, while the sealed motor mount and food-safe materials ensure compliance with commercial food service requirements.

b. Original Product

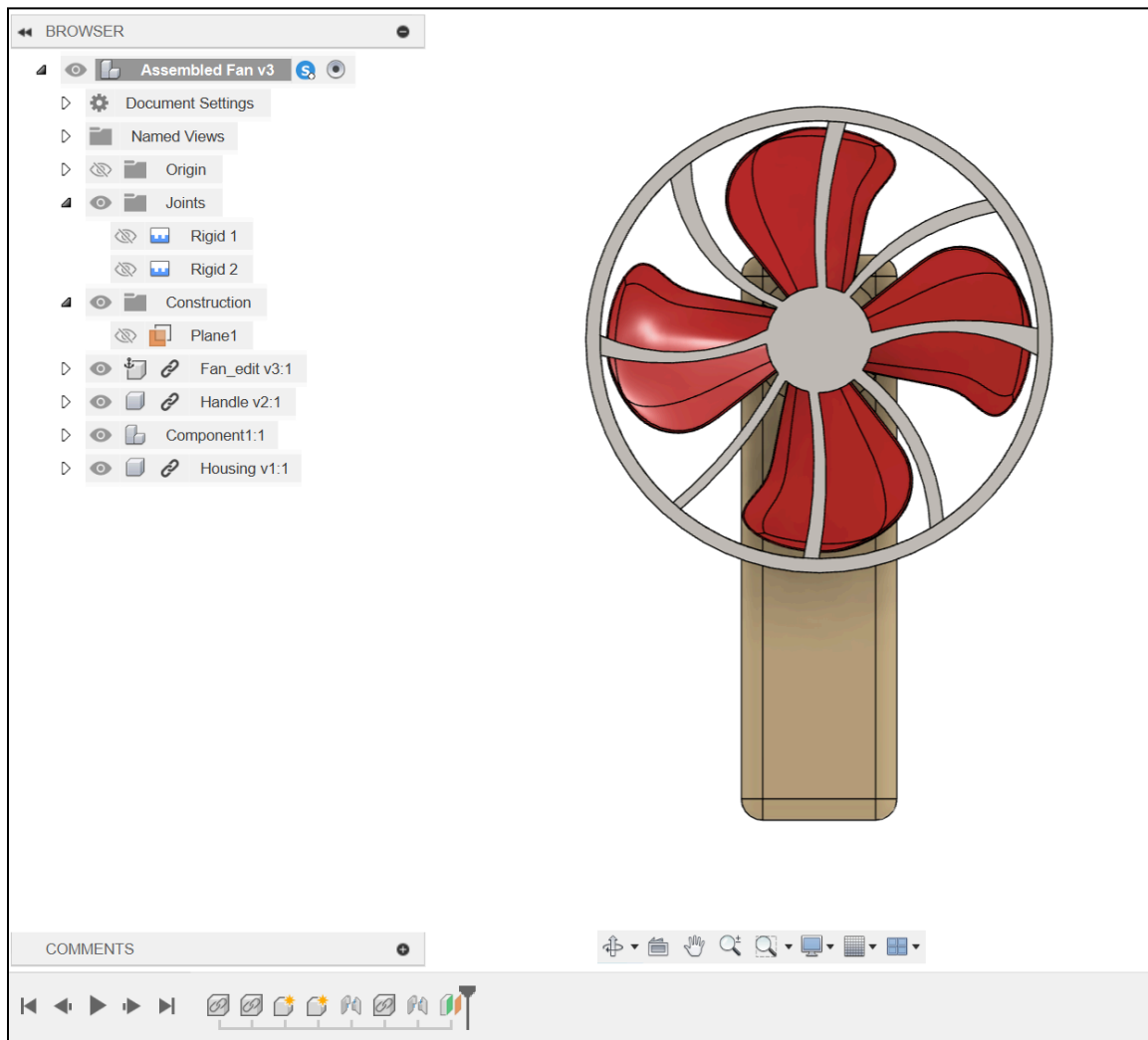


Figure 15 - CAD Model of Original Hand-Held Fan

Table 5 - BOM For Existing Parts (Refer to Figure 16)

Number	Name of Part	Material	Quantity	Manufacturing Process	Repurposed/Recycled?
1.	Propeller Housing	ABS Plastic	1	Injection Molding	Not Repurposed : This likely will not be reused but ABS plastic is a recyclable material. Thus the part can be recycled into something else. (Protolabs, n.d.)
2.	Handle (Serves as Battery and Motor Housing)	ABS Plastic	1	Injection Molding	Repurposed
3.	Propeller (With 4 Blades)	Polypropylene	1	Injection Molding	Not Repurposed : This likely will not be reused but polypropylene is a recyclable material. Thus the part can be recycled into something else. (Protolabs, n.d.)
4.	DC Motor (130-size)	Carbon, copper, silicon steel laminations (Monolithic Power Systems, 2023)	1	(Off-the-shelf) Wire Drawing, Powder Metallurgy	Repurposed
5.	AA Battery (WebstaurantStore, 2024)	Zinc-Carbon or Alkaline	1	Cell Assembly	Repurposed
6.	Power Switch	ABS Plastic	1	Injection Molding, Stamping	Repurposed
7.	Motor Shaft	Stainless Steel	1	Turning, Grinding	Repurposed
8.	Wiring	Copper Core (AWG 24) with PVC Insulation	1 set	Wire Drawing, Extrusion	Repurposed

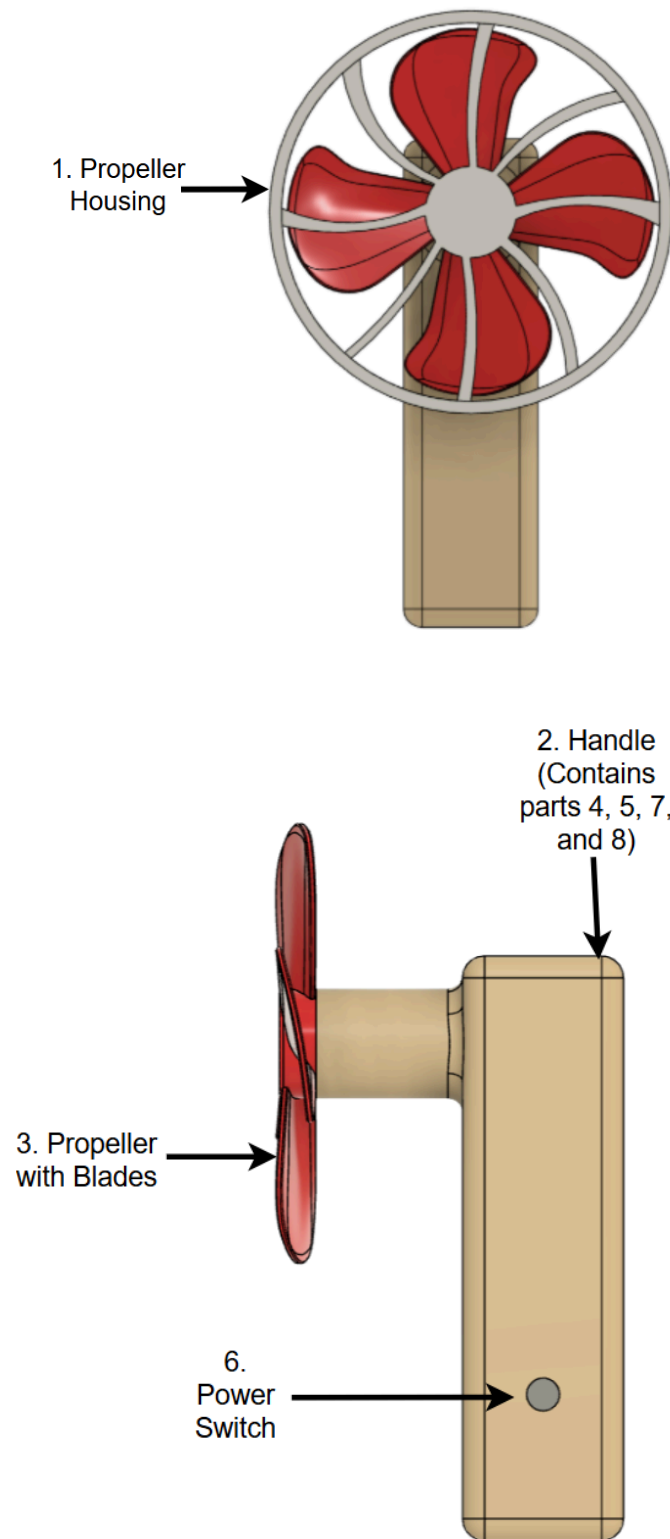


Figure 16 - Front View and Side View of Components for BOM

c. Repurposed Product

As previously described in section 2.2, a new 4-blade propeller with an attached O-ring will be manufactured to make the repurposed product food-safe. For ease of manufacturing and assembly, the O-ring will be manufactured as an extension of the propeller and not as a separate component. The new cumulative part will be *injection molded* using *PET or Polyethylene terephthalate*. A hole will be precision cut and finished to be food-safe into the wall of the mocktail dispenser. The hole will be the same diameter as the O-ring. The O-ring will then be slid into the hole from the inside of the dispenser such that the propeller is on the inside. The handle (which also serves as a housing for the motor shaft and motor) will be slid into a circular cut in the O-ring and press fitted to stay on. Finally, the dispenser lid will be put - making it a complete MixMaster Pro as seen in Figures 17, 18 and 19.

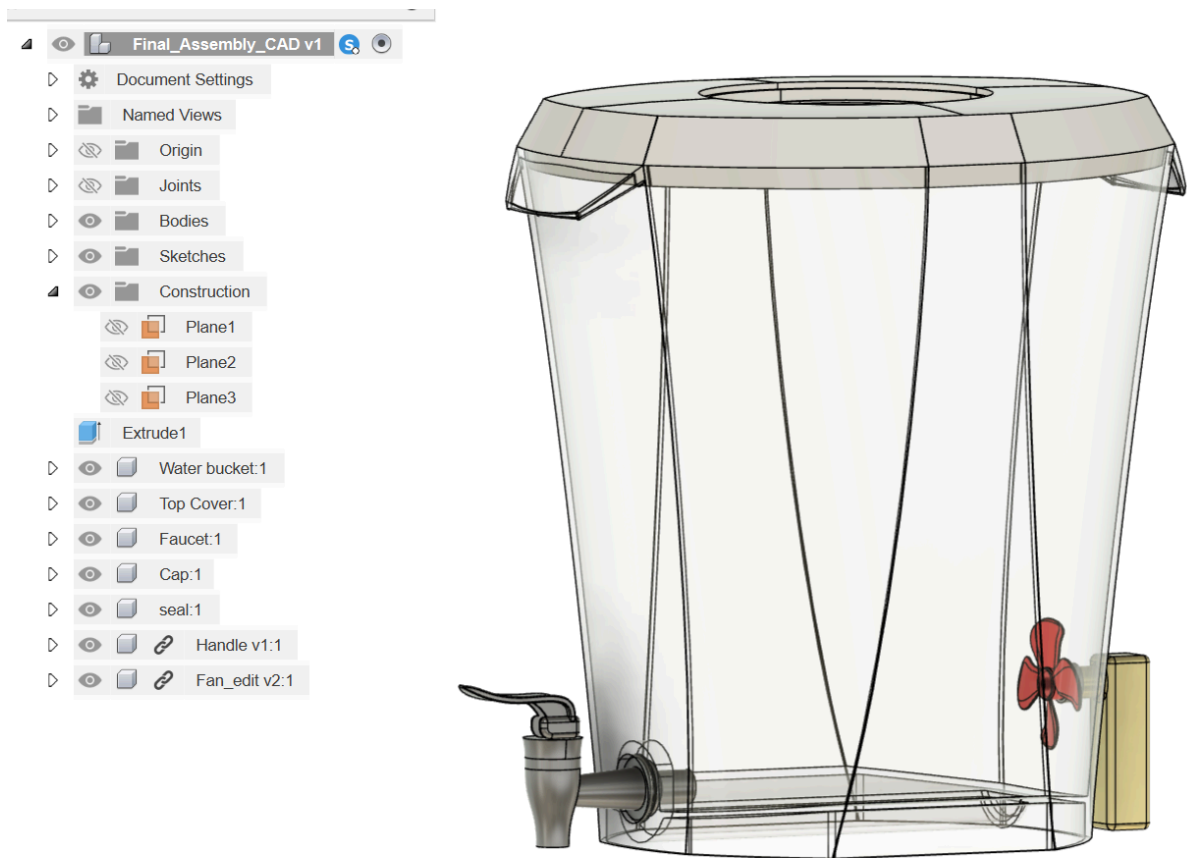


Figure 17 - Complete CAD Model of MixMaster Pro

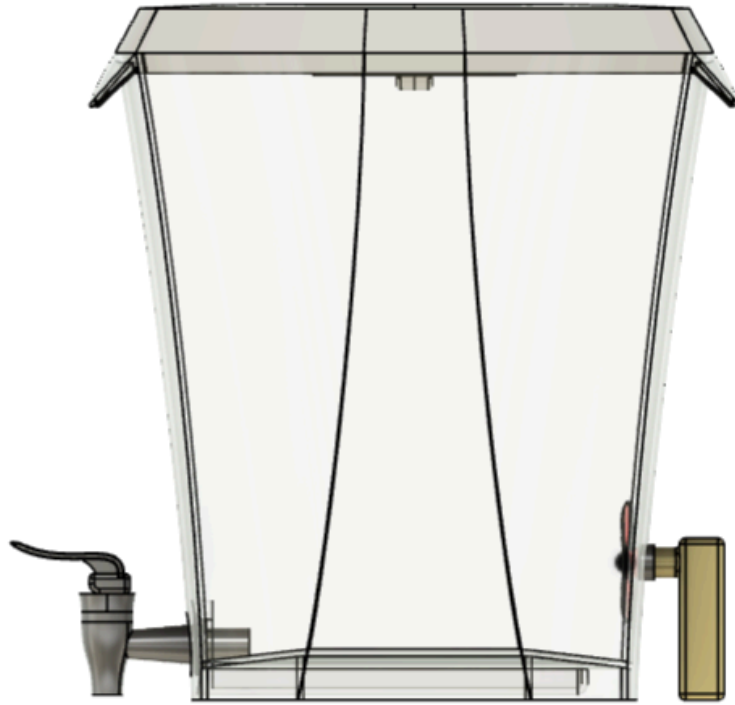


Figure 18 - MixMaster Pro Side-View



Figure 19 - MixMaster Pro Back-View

The dimensions of the blade were kept the same. New dimensions include those for the O-ring, and the circular cut slit for the handle to slide into. Tolerancing for holes was based on typical injection molded hole tolerances from Fictiv, 2023 (.0508mm for tight tolerances). The CAD and Drawings for the new injection molded part can be found in Figures 20 and 21 respectively.

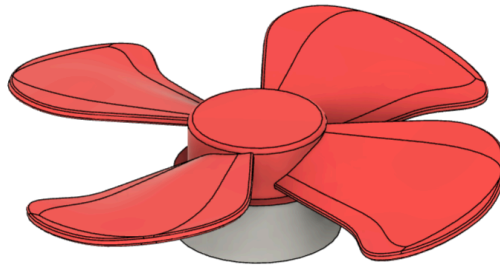


Figure 20 - New Propeller and O-Ring Part

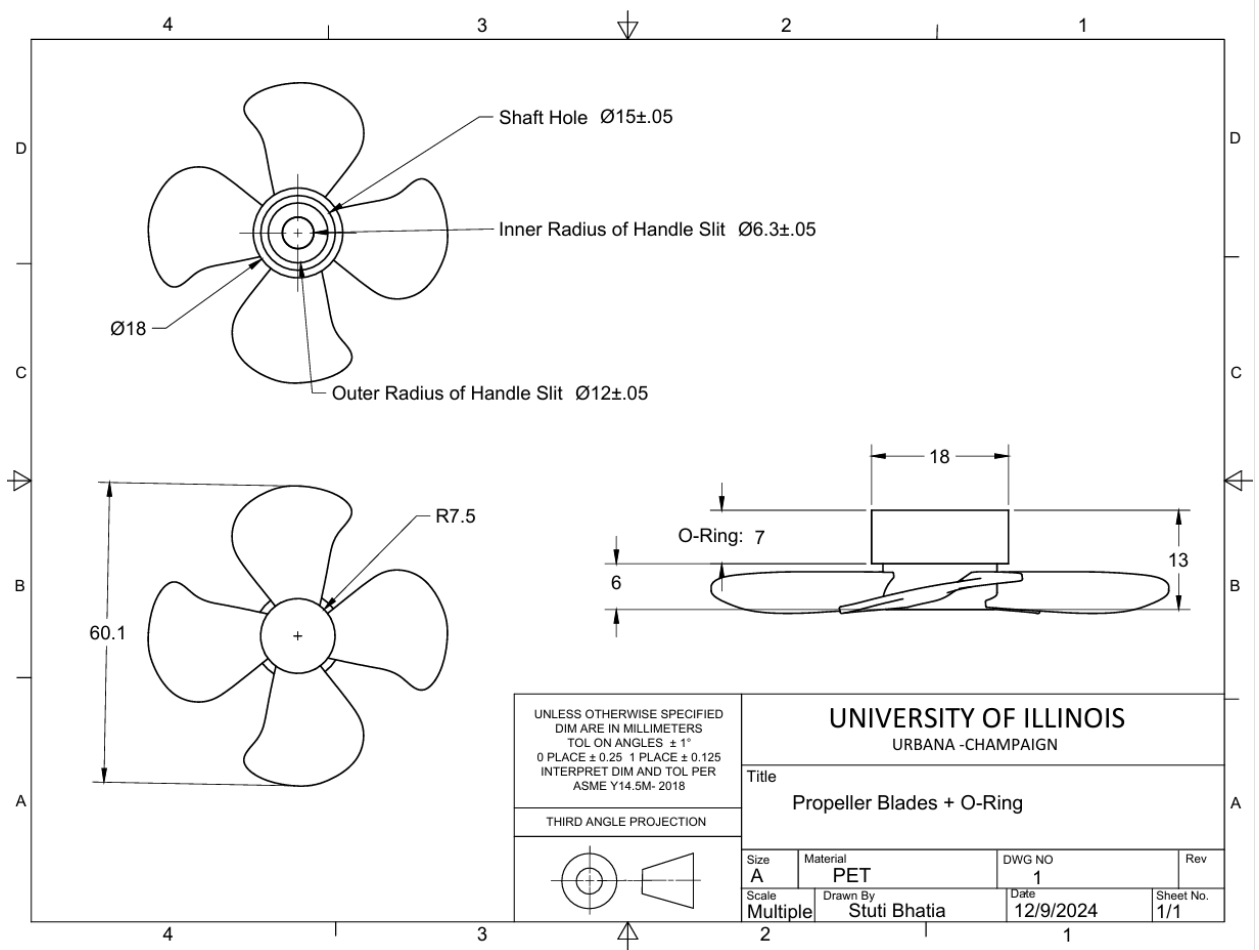


Figure 21 - Engineering Drawings for New Part

A drawing for the hole cut in the dispenser's wall has also been included in Figure 22. The corresponding CAD is in Figure 23.

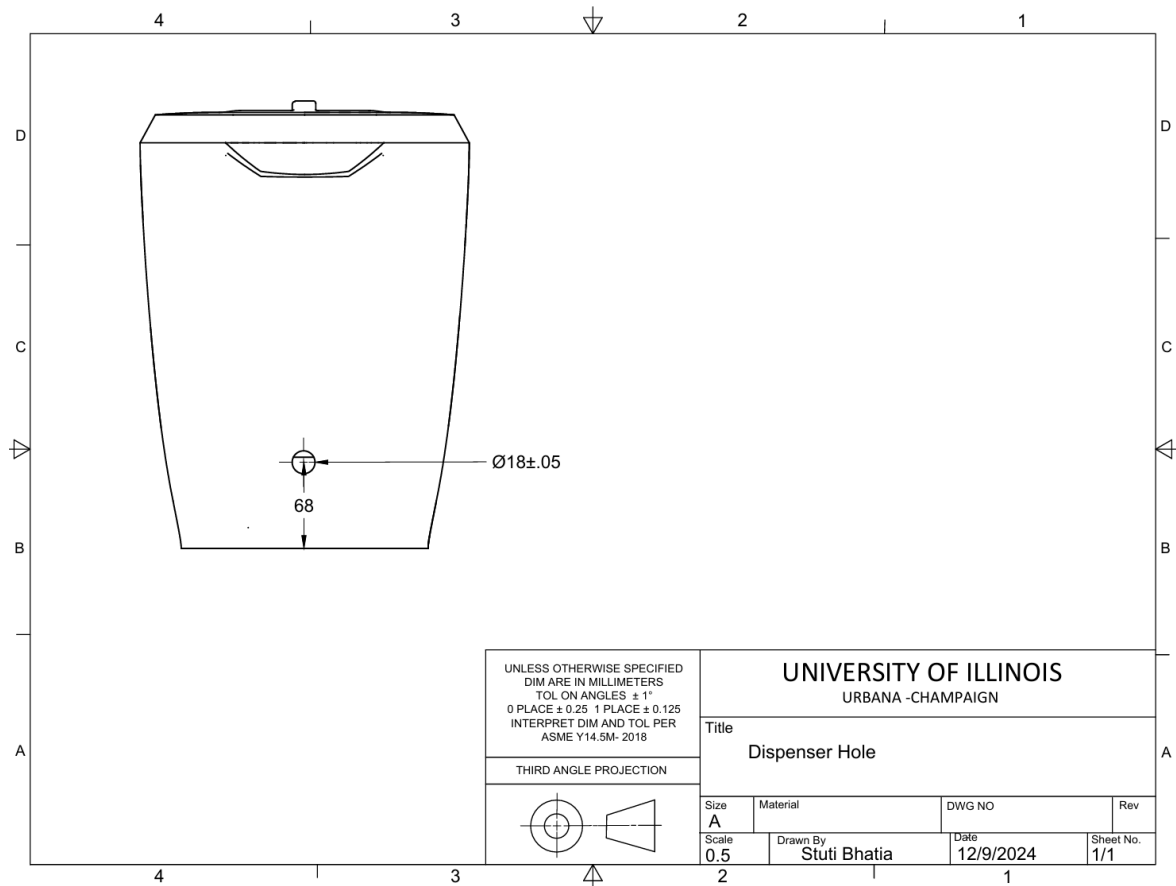


Figure 22 - Engineering Drawings Hole Cut

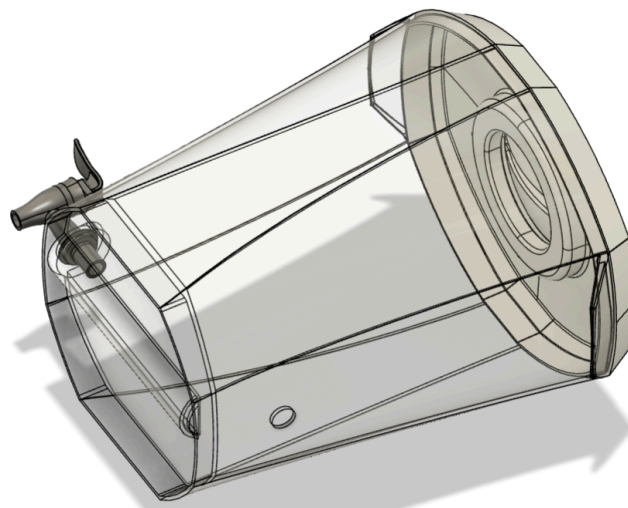


Figure 23 - Dispenser CAD with Hole

Throughout the design process, I asked myself Design for Assembly (DFA) questions to identify opportunities for reducing the number of parts and simplifying assembly. This is the thought process that led to eliminating the cooling cylinder (section 2.2), and combining the propeller and the O-ring into one part. The original assembly contains 8 parts as listed in the Bill of Materials: propeller housing, handle (battery/motor housing), propeller, DC motor, AA battery, power switch, motor shaft, and wiring. In the repurposed design, while we eliminate the original propeller housing and propeller, we add a new integrated propeller-O-ring component.

The original handled fan's primary functions included the following:

- Power storage and supply (battery and housing)
- Power control (switch)
- Mechanical power generation (motor)
- Air movement (propeller)
- User interface (handle/housing)

The repurposed MixMaster Pro's functions include the following:

- Power storage and supply (battery and housing)
- Power control (switch)
- Mechanical power generation (motor)
- Liquid mixing (new propeller-O-ring)
- Liquid containment (dispenser)
- Liquid dispensing (spigot)

With these functions and components listed out, DFA questions can be explored to identify if there are more opportunities for simplification.

Starting with *Material Combination Potential*, some components have been successfully integrated. For example, the new propeller and O-ring are combined into a single PET component, and the handle already doubles as the housing for the battery. There's also potential to incorporate the power switch housing (not the switch itself) into the main handle, which could further streamline the design.

In terms of *Motion Analysis*, some parts need to stay separate to ensure proper operation. The motor shaft and propeller can't be combined because they have to move relative to each other. The battery also needs to stay accessible for replacement, and the switch has to move independently to work properly.

For *Assembly Requirements*, the handle is designed to serve dual purposes as both the grip and the housing, which makes it more efficient. Additionally, the integrated propeller-O-ring design removes the need for extra sealing parts, simplifying the assembly process even more.

When looking at *Alternative Fabrication*, the propeller-O-ring component is made using injection molding, allowing it to be produced as a single piece. There's also the possibility of using more advanced molding techniques to combine the switch housing with the handle, which could further reduce the number of parts.

Based on this analysis, the design could be reduced to six parts: the integrated handle/housing, motor, motor shaft, battery (since it needs to be replaceable), integrated propeller-O-ring, and essential wiring. This is a reduction from the original eight parts, mainly due to the integration of the propeller and O-ring and the potential to combine the switch housing with the handle. However, further reduction isn't feasible because some components need to remain separate for motion and maintenance purposes.

2.4 Design for Repurposing

The handheld fan's components offer several durable materials suitable for repurposing into a cocktail mixer. The DC motor, constructed with silicon steel laminations and copper windings, provides reliable mechanical power that can withstand continuous operation in a new role. These core components maintain their functionality while transitioning from air movement to liquid mixing because of the appropriate torque and RPM (see section 2.2).

The immediate functionality of the original fan design translates well to its new purpose. The motor's rotary motion, initially designed for moving air, naturally adapts to creating liquid circulation patterns necessary for mixing cocktails. The original blade mounting mechanism provides a ready-made attachment point for the new food-safe PET propeller and O-ring part. The battery housing's (in the

handle) sealed design already offers protection against moisture, making it suitable for use near liquids with minimal modification, i.e, only the O-ring.

The repurposed design invites use through its integration with a familiar beverage dispenser format. The transparent container allows consumers to visually monitor the mixing process, while the standard spigot provides a familiar dispensing method. The simple single-button operation inherited from the original fan design maintains user-friendly operation. The visible mixing action through the clear container provides immediate feedback on the device's function, making it obvious how to achieve desired results. The design's inherent simplicity - mounting the mixing unit to the side of the container - creates an approachable and easily understood modification that maintains the original product's straightforward operation while adapting it to its new purpose.

The value of this repurposing project lies in its demonstration of sustainable design principles through the creative reuse of existing components. The design successfully transforms a personal cooling device into a practical food service tool while preserving the core mechanical elements that made the original product effective.

REFLECTION

This design challenge of repurposing a handheld fan into a mocktail mixer provided taught me a fair amount about sustainable design and manufacturing principles. I now understand the complexity of material selection when transitioning from consumer electronics to food-safe applications. Looking back at the design process, the initial assumption that 3D printing with food-safe materials would be an adequate solution proved incorrect. Research revealed that even food-safe plastics, when 3D printed, could harbor bacteria in layer lines, leading to the decision to use injection molding for the new PET propeller design. This highlighted how manufacturing processes impact material properties and product safety beyond just material selection.

Looking forward, this experience has emphasized several key principles for future design work:

- Manufacturing processes must be considered alongside material selection, as they significantly impact product performance and safety.
- Design decisions should account for both immediate functionality and potential future repurposing or recycling.
- The transition between different use contexts (like personal electronics to food service) requires careful consideration of material properties and safety standards.

The challenge of maintaining food safety while repurposing existing components taught me valuable lessons about the balance between sustainability goals and practical safety requirements. Overall, it was a very thorough, informative and enriching experience that will inform my future design approaches by emphasizing the importance of considering a product's entire lifecycle, including potential secondary uses, during the initial design phase.

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