Final Project

ENGS 171: Industrial Ecology

MINI Cooper S Ride-on Toy

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Project Team 1

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Executive Summary

Our term project consisted of conducting a full eco-audit and sustainable redesign of the Rollplay Mini Cooper S toy car. We began our analysis by performing a full disassembly of the car into its individual components. We then weighed each component, identified the materials used, and utilized this data to perform a baseline eco-audit. This analysis allowed us to determine the amount of embodied energy, carbon emissions, and water used to source the materials, manufacture the car, transport it to a consumer, and be used over the course of its lifetime.

The goals of our system redesign were to reduce the lifetime eco-impact of the Mini Cooper S without compromising the strength, stiffness, and durability of the materials used to manufacture the toy cars. Specifically, we sought to reduce the lifetime embodied energy, carbon emissions, and water usage per service unit by at least 50% without reducing material stiffness and strength by more than 10%. After conducting our full material trade-off analysis, we determined that the polypropylene plastic used for a majority of the components already provides an optimal solution for a strong, stiff, lightweight, and inexpensive material. As a result, we looked for innovative ways to reduce the eco-impact while still utilizing polypropylene throughout the vehicle. We were able to surpass our eco-impact goals by replacing a number of plastic components with stickers to reduce the weight of the material and by introducing an innovative subscription sales model. Under this business model, we believe that we can meet the product demand of 5,000 units annually by instead selling 5,000 two-month subscriptions and manufacturing only 1,000 toy cars. Through a combination of both lightweighting and this novel subscription model we can meet consumer demand, maintain profitability, and use less than 20% of the embodied energy, carbon, and water it currently takes to manufacture and sell 5,000 toy cars directly to the consumer.

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Introduction

The Product

The MINI Cooper S Ride-On car is an electrically powered toy car designed for use by children from ages 3 to 7 years old and up to 77 pounds in weight. The current retail price of this car is approximately $180. Our goals for redesigning this product include reducing the total number of parts, reducing the weight of polymers used in the chassis, body and wheels, designing a solar charging station, and developing a buy-back program to allow for the toy cars to be reused and/or recycled at the end of their lifespan.

Problem Statement

The MINI Cooper S Ride-On car, like many toys of its nature, has a significant environmental impact. By our estimate, there are 5,000 toys of this particular model sold annually in the US. As children outgrow the toy quickly, we estimate that a typical family uses the car for 5 years, approximately 100 days per year (twice per week) for 90 minutes (one full battery life) each use. The car likely ends up in a landfill at the end of this 5 year period. It is made primarily of virgin polypropylene plastic, and uses a lead acid battery. The car is manufactured in China using non-renewable energy sources, and travels a long distance to consumers' homes in the United States. In addition to the impacts of material and manufacturing, use phase of the product presents an environmental risk. Given the short battery life, the toy requires frequent charge. Furthermore, children may lose interest quickly in the toy and will likely grow out of it in just a few years. Our goal is to minimize the water usage, use energy and embodied energy of this product, while maintaining its performance, value, and appeal to young children. Our hope is that our solution will be applicable to other toys as well, and will thus have an impact on the entire $25.5 billion American toy industry.

Disassembly

Time

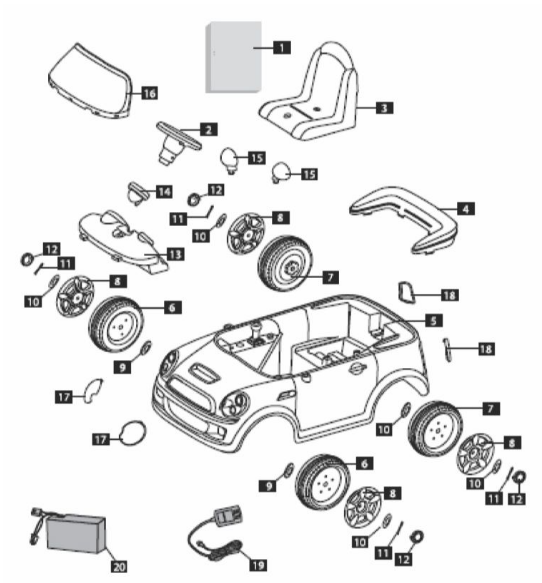
It took 45 minutes total to completely disassemble the MINI Cooper S Ride-on Toy.

Figure 1: Disassembled view of the components of the Mini-Cooper S ride on toy. A majority of the components consist of polypropylene polymers.

Tools

The tools we used to disassemble and reassemble the car were screwdrivers (flat & phillips), pliers, and brute force to separate some fused parts.

Exploded Diagram



1. Manual
2. Steering wheel assembly
3. Seat
4. Rear Spoiler
5. Chassis
6. Front wheels (2)
7. Rear wheels (2)
8. Rim
9. Large Washer
10. Small Washer
11. Snap pins (4)
12. Hub cap
13. Dashboard
14. Speedometer
15. Wing mirror
16. Windshield
17. Front light cover
18. Rear light cover
19. Charger
20. Battery

Figure 2: An exploded, assembly diagram of the components used in the toy car.

List of Components

Our car had 60 different parts, which we grouped into 10 subassemblies. A full breakdown of the parts with subassemblies, part names, number of parts, material composition, and mass can be found in the Appendix.

Body: chassis / body, door handles (2), front bumper, front fender, front grill, front logo, gas pedal, mirror (2), pedal mount, pedal trigger, rear bumper, rear panel, rear spoiler, seat, side bumper (2), side logo (2), windshield

Lights: headlight (2), headlight cover (2), light bulbs, tail light cover (2), tail light frame (2)

Dashboard: compass, compass base, dashboard, dashboard sub-layer, directional switch, fuel gauge, fuel gauge base, key, key switch, power switch, shifter, speedometer, steering wheel mount

Steering Wheel: AAA battery (2), horn cover, sound tab (2)

Drive Train: battery brace, front axle, rear axle

Tires: front tire (2), rear tire (2), tire hubcap (4), tire rim (4)

Gearbox: gearbox top, gear box bottom, large gear, medium gear, small gear

Moter: motor, motor case

Battery: battery, charger

Miscellaneous: assorted hardware, manual

Materials Identification

Initial Eco-Audit analysis indicated that 93% of the MINI Cooper's weight consisted of three primary materials: Polypropylene (PP 68% of total weight), High Carbon Steel (15% of total weight), and the lead-acid battery (10% of total weight). See Appendix for list of materials broken down by individual component.

Table 1: Total weight of materials used in the Mini-Cooper S toy car. Note that polypropylene, the high carbon steel, and the lead-acid battery are the top three materials used in the car by weight.

Material	Total Mass (kg)	Material Production (l/kg)	Manufacturing (l/kg)
Alkaline AA cell battery	0.024	1.8	0.867
High carbon steel	1.853	48.1	56.0
Lead-acid battery (for cars)	1.240	2421.0	0.0
Copper	0.216	324.0	367.2
Paper and cardboard	0.063	1790.0	303.0
Acrylonitrile butadiene styrene (ABS)	0.298	185.0	206.9
Diodes and LEDs	0.024	568.4	0.0
Polypropylene (PP)	8.135	41.2	87.6
Plugs, inlet and outlet	0.096	580.0	0.0
Polyamides (Nylons, PA)	0.095	194.0	921.0
TOTALS	**12.044**	**3751.5**	**1063.5**

Eco Audits with CES Pack

Energy & CO_2: Materials, Manufacture, Transport, Use, and End of Life

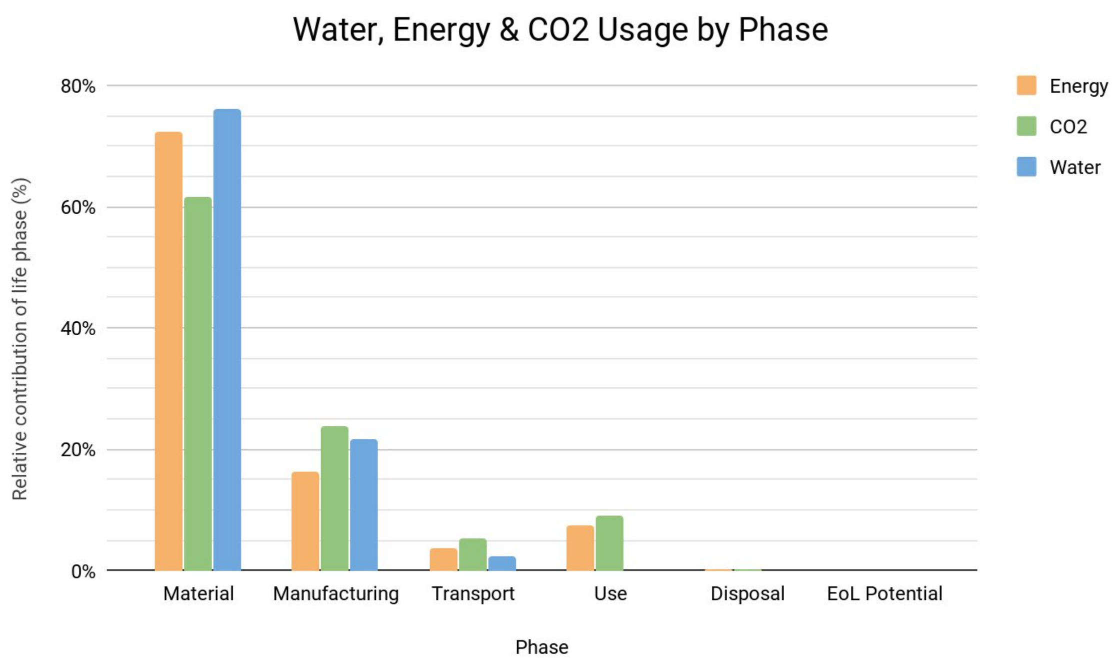


Figure 3: Results of initial eco-audit showing the percentage of embodied energy, carbon emissions, and water use during the materials sourcing, manufacturing, transport, use, disposal, and end of life for the Mini-Cooper S toy car. Note that the material sourcing and manufacturing dominate the total amount of all three parameters.

Assumptions and methods

In setting up our eco-audit, we made a number of assumptions. First, we assumed that the product lifetime is 5 years. This was a reasonable guess because an average family with two children might use the car for about two years for each child, as the toy has a narrow age range. We also assumed that the car is deposited in a landfill at the end of life, since the manufacturer will not take it back and few families care to take it apart for individual part recycling. Since we know the car is originally manufactured in China, we assumed that it is shipped via container ship to Los Angeles and then transported to retailers throughout the country by a 32-ton truck. Finally, we assumed that the car is used about 100 days per year (twice per week), for 90 minutes each time (the car's battery life on one full charge). We assumed that it is charged using electricity from a conventional grid, rather than from renewable energy sources.

Results

According to CES Edupack, our MINI Cooper S uses a total of 1250 MJ of energy and emits 64 kg of CO_2 over its lifetime. As shown in table 2 the material used in the product seems to be the biggest contributor to both impacts, making up 72% of energy use and 62% of the CO_2 footprint. The manufacturing phase is the next biggest contributor, comprising 16% and 24% of the energy use and CO_2 footprint, respectively. To our surprise, in spite of the car's long journey, transportation only makes up 4% of the energy use and 5% of the carbon footprint. Similarly, the car's use phase has a small impact, with only 7% of the energy use and 9% of the CO_2 footprint, likely because of the product's assumed short lifespan. Since we assumed that the car winds up in a landfill, its disposal and end of life potential have a negligible impact, comprising 0.3% and 0.2% of the energy use and CO_2 footprint, respectively.

Table 2: The percentages of total lifetime embodied energy, carbon emissions, and water use in the material sourcing, manufacturing, transport, use, disposal, and end of life of our product.

	Material	Manufacturing	Transport	Use	Disposal	EoL Potential
Energy	72%	16%	4%	7%	0.2%	0%
CO2	62%	24%	5%	9%	0.3%	0%
Water	76%	22%	2%	0%	0%	0%

Water Audit: (Materials, Manufacture, Transport, Use, and End of Life)

Assumptions and Methods

For the water usage analysis in CES Edupack, we made all of the same assumptions as for the energy usage and CO_2 footprint analysis. We assumed no additional water was used in the use phase of the toy, as it typically doesn't require regular washing.

Results

In total, the car uses 4930 liters of water over its lifetime. Similarly to the energy and CO_2 footprint analysis, material and manufacturing proved to be the biggest sources of water usage, at 76% and 22% respectively. Transport uses only a small amount of water, at 2% of the total, and use and disposal use no water at all.

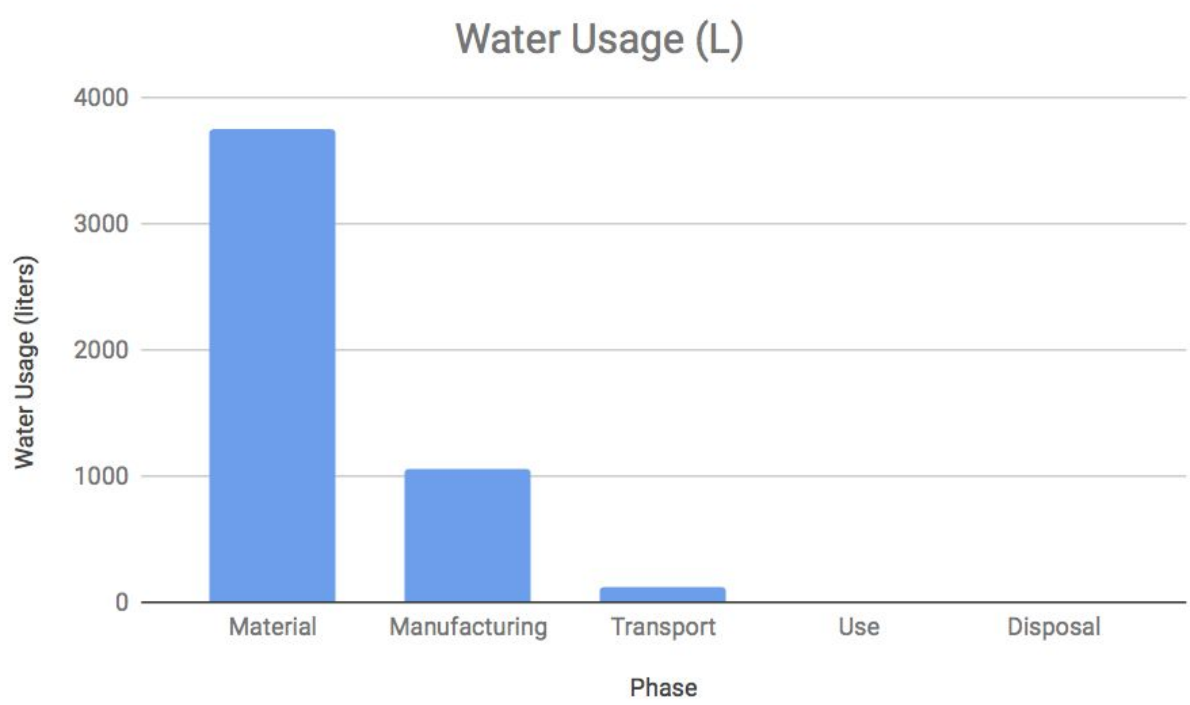


Figure 4: Total water usage in liters used in the materials, manufacturing, transport, use and disposal of our product.

Discussion & Conclusion (Energy, CO_2, Water, etc.)

Materials

The results of the eco audit showed the largest contribution of water, CO_2, and energy usage to be from the the material phase. Upon further examination of the car's materials, we found that 93% of the MINI Cooper's weight came from just three materials / components: Polypropylene (PP 68% of total weight), High Carbon Steel (15% of total weight), and the lead-acid battery (10% of total weight). With this in mind, it is clear that in order to reduce the car's energy consumption, CO_2 footprint and water usage, we must either select more environmentally benign materials or use less material in general. To accomplish the latter, we can integrate a more effective lifestyle design that demands a lower number of total products and we can reduce the number of extraneous parts to use less total material per car.

Manufacture

As it is produced now, the MINI Cooper S ride-on toy's manufacture contributes to 16%, 24% and 22% of its energy use, CO_2 emissions, and water usage, respectively. Our product is currently manufactured in China. This is not optimally sustainable. China's primary energy sources are coal and oil, so we assume that these are the energy sources involved in the production of the ride-on car. Unfortunately, these are the two sources of energy that produce the highest quantity of CO_2 emissions per kWh. Thus, our product could be made more efficient by manufacturing it in a region where alternative energy sources are more viable. If the car were manufactured using exclusively solar energy, it would reduce the CO_2 emissions by approximately 95%. If we simply supplemented fossil fuels with renewable energy sources, we estimate that we could reduce emissions by at least 50%.

Transport

The full journey that our product took from China to Dartmouth is broken down as follows: (1) trucked from manufacturing plants to the Port of Hong Kong, (2) shipped across the Pacific Ocean to the Port of Long Beach (given on shipping label), (3) trucked from the Port of Long Beach to an Amazon Facility in Long Beach, (4) trucked to the Anaheim, California Regional Transportation Intermodal Center, (5) transported by rail to another Intermodal Center in Watterson Park, Kentucky, (6) trucked to an Amazon Facility in Lexington, Kentucky, (7) trucked to an Amazon facility in Stoughton, Massachusetts via USPS, (8) trucked to Hanover, NH, and finally (9) trucked to Dartmouth College. If we calculated the fuel consumption, CO_2 emissions, and water usage for each leg, it follows that the entire journey of our product requires 1726 gallons of fuel and 234 gallons of water, and emits 13.5 kg of CO_2.

Based on these figures, there is clearly room for improved when it comes to the transport portion of our MINI's lifespan. Since our MINI traveled across the Pacific Ocean and the United States in order to get to Dartmouth, simply changing the material suppliers to a domestic company will reduce carbon emissions by 5.7 kg, fuel consumption by 1620 gallons, and water usage by 234 gallons since we no longer would need to ship our materials on a large cargo vessel. On a similar note, our subscription program that we propose later on will need to be operated at a facility close to a large intermodal station. This will reduce our usage of trucks, which are the most inefficient method of transportation. By simply domesticating our manufacturing process and picking a strategic location to house our subscription program, we will greatly reduce the current impact that transporting the MINI has on our environment.

Use & End of Life

As it stands, our MINI is run by a lead-acid battery that is charged by a standard wall outlet. One goal of our redesign is to replace this wall plug to a clean energy source that does not demand burning fossil fuels in order to give the battery a full charge. To do this, we would place our 120V wall plug with a solar-powered charging station, and redesign the battery so that it has a shorter charging time and longer timespan between charges. Even though our car runs on electricity and doesn't actively emit greenhouse gasses, these improvements will allow our car to have (1) a much lower energy usage over its lifespan, (2) a larger amount of time spent using the car compared to charging it, and (3) passively introducing children to electric-powered vehicles.

Another improvement to our design is making it easier to disassemble and reassemble the car with modular parts. By doing this, we will allow for all the primary components (ex. the body frame, steering/wheel rods, wheels, etc.) to be easily separated if one fails during use. This will also make it easier to separate during the recycling process, particularly for our parts made out of Polypropylene. The positive impact from this is twofold: it'll (1) increase the rate of polypropylene recycling and (2) eliminate the dangerous impact caused by the improper disposal of polypropylene, which are the two primary challenges related to recycling PP.

Conclusions

Another important find from our Eco-Audit was the degree of difficulty it took to disassemble the primarily PP plastic components. Even though it only took two of us 45 minutes to take apart the MINI Cooper S, using only screwdrivers (flat & phillips) and pliers, a large portion of our time was dedicate to separating our PP components. As we will discuss later on, it is important that we greatly improve the material efficiency of the PP in the MINI Cooper's redesign. By doing this, we in turn will reduce both the overall weight of the vehicle and the energy and water used to produce the ride-on toy. On the other hand, we will evaluate other materials that have similar mechanical properties to PP in the hopes of finding a material that will not compromise the functionality of our design but will be much more environmentally sustainable as well.

Eco Redesign

Redesign Requirements

We began conducting our product redesign with the following requirements in mind. We wanted to significantly reduce the embodied energy, carbon emissions, and water use by at least 50% per service unit. However, the car cannot lose more than 10% of its current strength, stiffness, or toughness. In addition, the battery life of the car cannot be decreased and user safety cannot be compromised in any way. We conducted a material comparison with the free variable of panel thickness in an attempt to find a material substitute for the polypropylene components of the car.

Component Function

The primary function of the MINI Cooper S Ride-on toy is to provide entertainment for children ages 3 or older, who weigh less than 77 lbs.

Objectives

The objectives of our redesign are to minimize product cost, minimize eco-impact, and maximize product lifespan. We also hope to minimize overall product mass, as this will help to minimize cost and energy usage.

Constraints

The toy car must be stiff and strong enough to hold a 77lb child without breaking or deforming. A key value driver of the car is its appearance, so the material must be moldable into the shape of a real mini cooper. As it will be used by children, likely outside, the car must have a durable and tough. Finally, it must be non-toxic so that it presents no health risks to children.

Free Variables

The free variables in our redesign are shell thickness, material, decorative features, and extra features such as sound effects.

Additional Required Criteria

The car must not present any dangers to children. Additionally, the aesthetic of the car is a key value driver.

Trade-offs and Analysis

Material Indices and Material Selection

When selecting a material to potentially replace Polypropylene, we wanted to make sure that we chose something that met our product constraints (ex. Is moldable, has an elongation percentage greater than 50%, etc.), was not extremely expensive, and had a low embodied energy from primary production. We started off by defining an expression that describes the cost of our body frame material of a given size and geometry. Since the cost C of a material is its price (denoted as C_m) multiplied by its mass m, we can say that

$$C = mC_m \quad \text{eq. 1}$$

where $m = volume * density = lwh \times \rho$, with ρ denoting the material density. Based on this, we find our function that minimizes cost with our thickness set as our free variable. This equation is given as

$$M_1 = \frac{\rho C_m}{E^{1/3}} \quad \text{eq. 2}$$

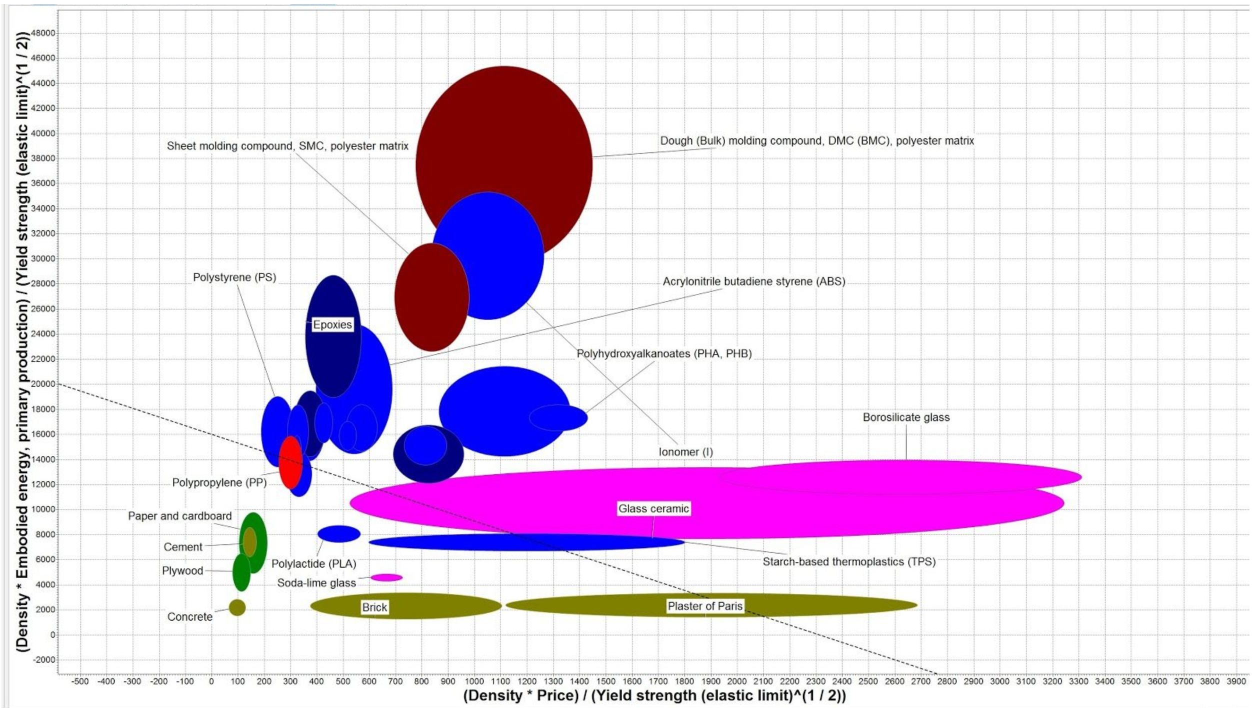
If we take a similar approach for finding a function that minimizes embodied energy from primary production, we see that the expression that describes the embodied energy from primary production of our PP components is

$$H = mH_m \quad \text{Eq. 3}$$

Where H is the amount of embodied energy for a material with mass m. Since our equation has the exact same setup as our cost expression, then we find that our function which minimizes embodied energy with the thickness set as our free variable is

$$M_2 = \frac{\rho H_m}{E^{1/3}} \quad \text{eq. 4}$$

Now that we have found our two expressions, we wanted to see which material had the a low value for both M_1 and M_2. To do this, we graphed the M_1 and M_2 values for all our potential materials using CES EduPack. Before we created this plot, we applied the following limits to our CES plot to eliminate any impractical materials. These limits were: (1) Moldability rated at least 4, (2) Durability rated Excellent in a Rural Environment, (3) Price less than 15 USD/kg, (4) Vicker's Hardness of at least 1 MPa, and (6) Elongation of at least 50%. Below is our resulting CES plot of M_1 and M_2 values after applying these six limits.



<u>Figure 5:</u> Embodied energy per unit strength vs. price per unit strength. With an alpha value of -22.40, we find that polypropylene is one of the most practical materials to optimize both embodied energy and cost per material strength.

When we made this plot shown in Figure 5, we calculated our alpha value based on the current energy cost for Hanover, NH. Since it costs 0.1607$/kWh, which converts to 0.0446 $/MJ, then the slope of the line in our plot (i.e. our alpha value) is -(1/0.0446) = -22.40. Based on this plot, it appears that one material substitution we could make for Polypropylene is Polylactide since they have the same Z-value. However, upon further analysis, Polylactide ends up being too brittle and wouldn't have the same desired longevity that our MINI would need to have when in use.

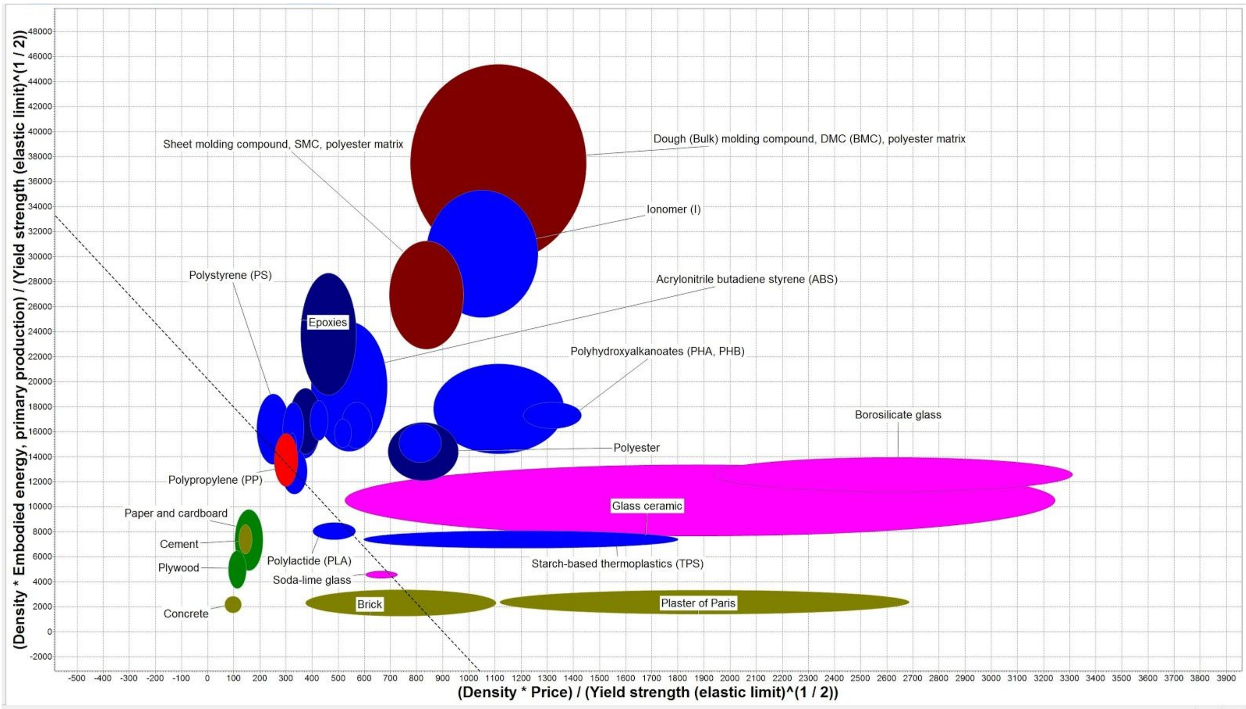


Figure 6: Embodied energy per unit strength vs. price per unit strength under a scenario in which electricity costs 10 times as much as in figure 5. With an alpha value of -6.92, we find that polypropylene is one of the most practical materials to optimize both embodied energy and cost per material strength even at higher electricity costs.

If we bump up our cost for electricity by a factor of 10, then we find a new alpha value of -6.92. Based on this modified plot, it appears that one material substitution we could make for Polypropylene is TPS since they have the same Z-value. However, upon further analysis, TPS is not a very durable material and begins to dissolve when exposed to water, making it unsuitable for our design.

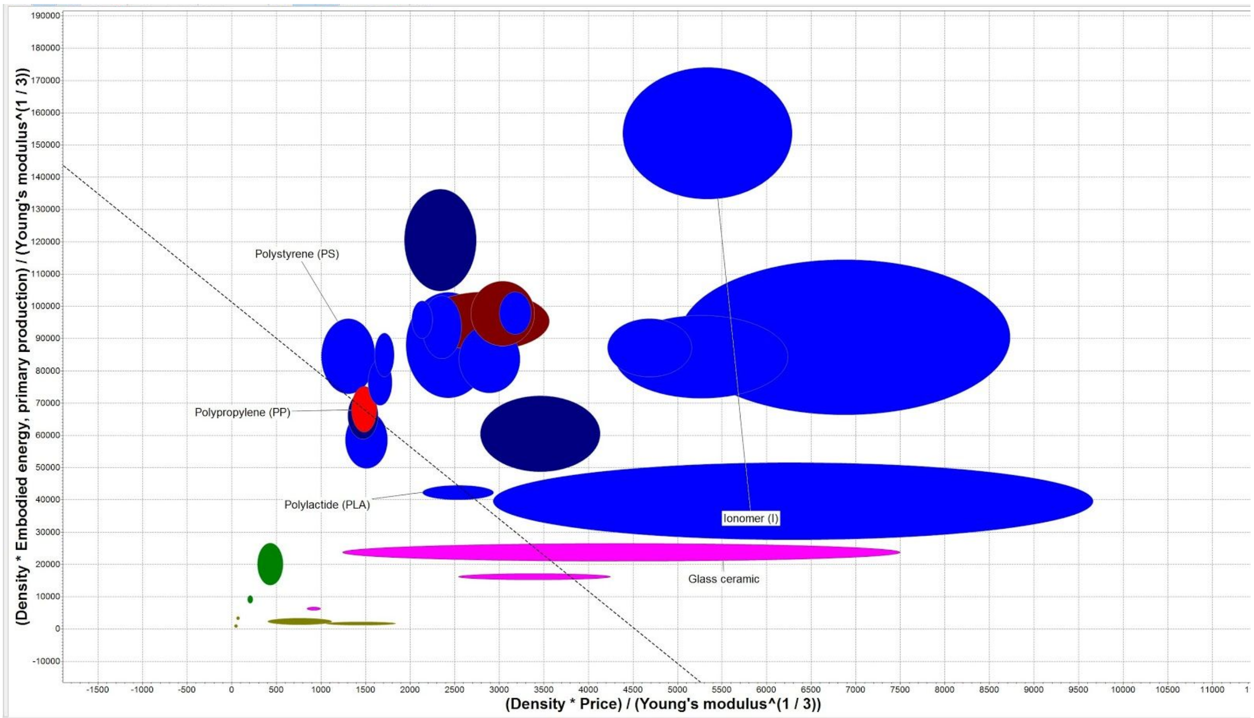


Figure 7: Embodied energy per unit stiffness vs. price per unit stiffness. With an alpha value of -22.40, we find that polypropylene is one of the most practical materials to optimize both embodied energy and cost per material stiffness.

Based on this plot shown in Figure 7, it again appears that Polylactide would be a suitable alternative, which we previously discussed would in practice is not a logical substitution to make.

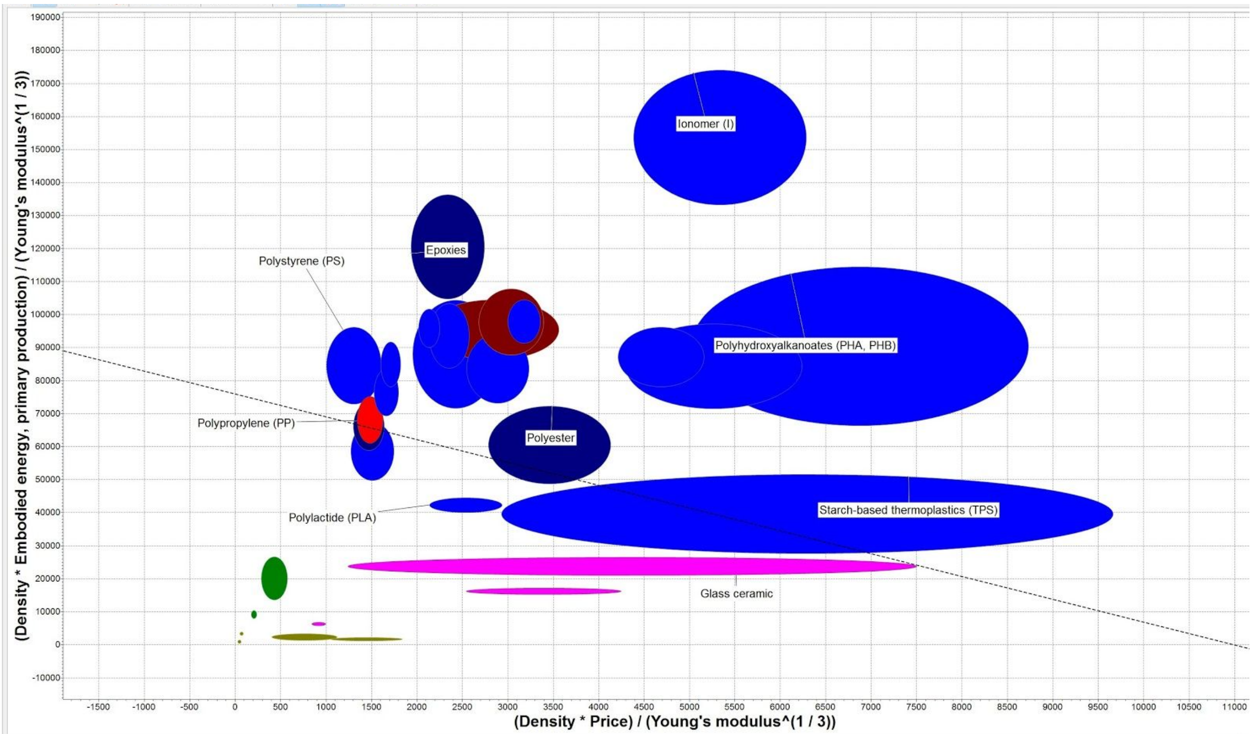


Figure 8: Embodied energy per unit stiffness vs. price per unit stiffness under a scenario in which electricity costs 10 times as much as in Figure 7. With an alpha value of -6.92, we find that polypropylene is one of the most practical materials to optimize both embodied energy and cost per material stiffness.

If we bump up our cost for electricity by a factor of 10, then we find a new alpha value of -6.92. Based on this modified plot, it again appears that one material substitution we could make for Polypropylene is TPS, even though it would in practice is not a suitable substitution to make.

Product Manufacture

For our manufacture versus usage trade-off strategies, we used the same basic equations given in Problem 7 of our third homework assignment. Our component mass value was 8.135 kg, since that was the weight of the PP in our MINI. Since our base material was PP, then we see that $\rho_o = 890\ kg/m^3$, $\sigma_y = 20.7\ MPa$, $H_m = 75.7\ MJ/kg$, and $C_o = 1.7\ \$/kg$. We also used the value of $H_{km} = 0.17\ MJ/kg$ for the efficiency of our

Lead-acid battery. Based on these values taken from CES, we got the following two comparison charts for product manufacture versus use phase, with PP emphasized in red.

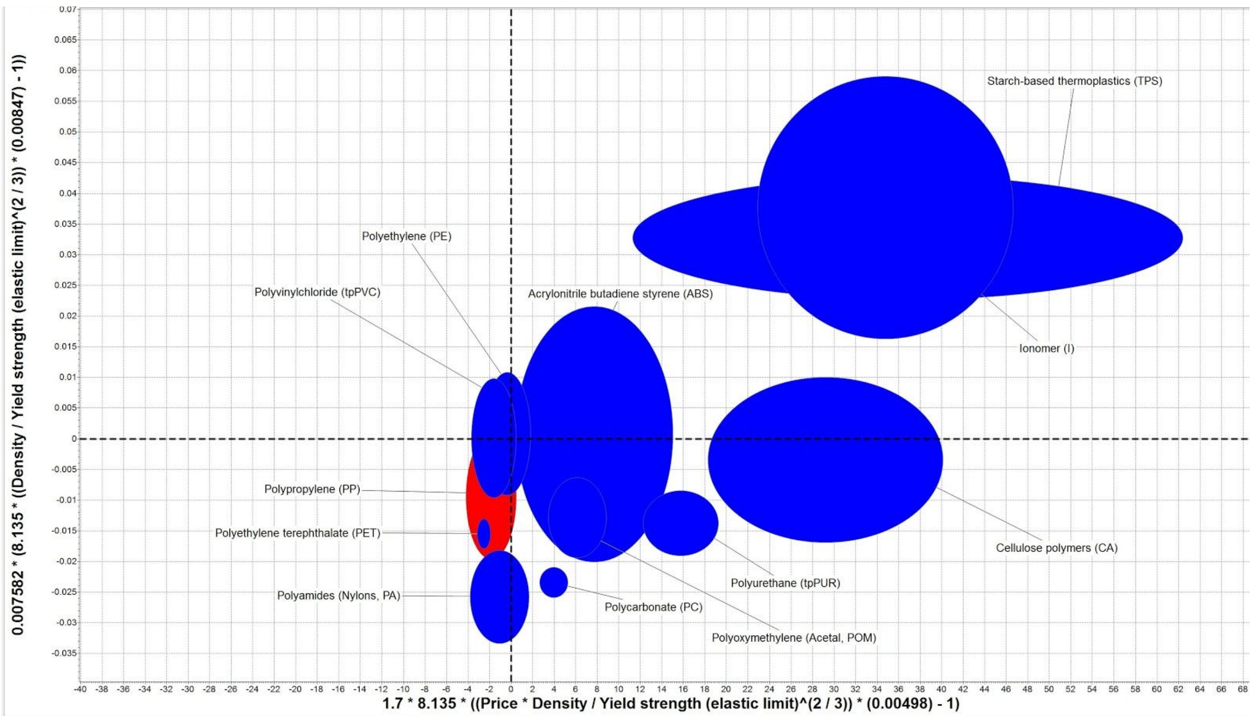


Figure 9: Cost tradeoff in Use vs. Manufacture of material (centered at PP)

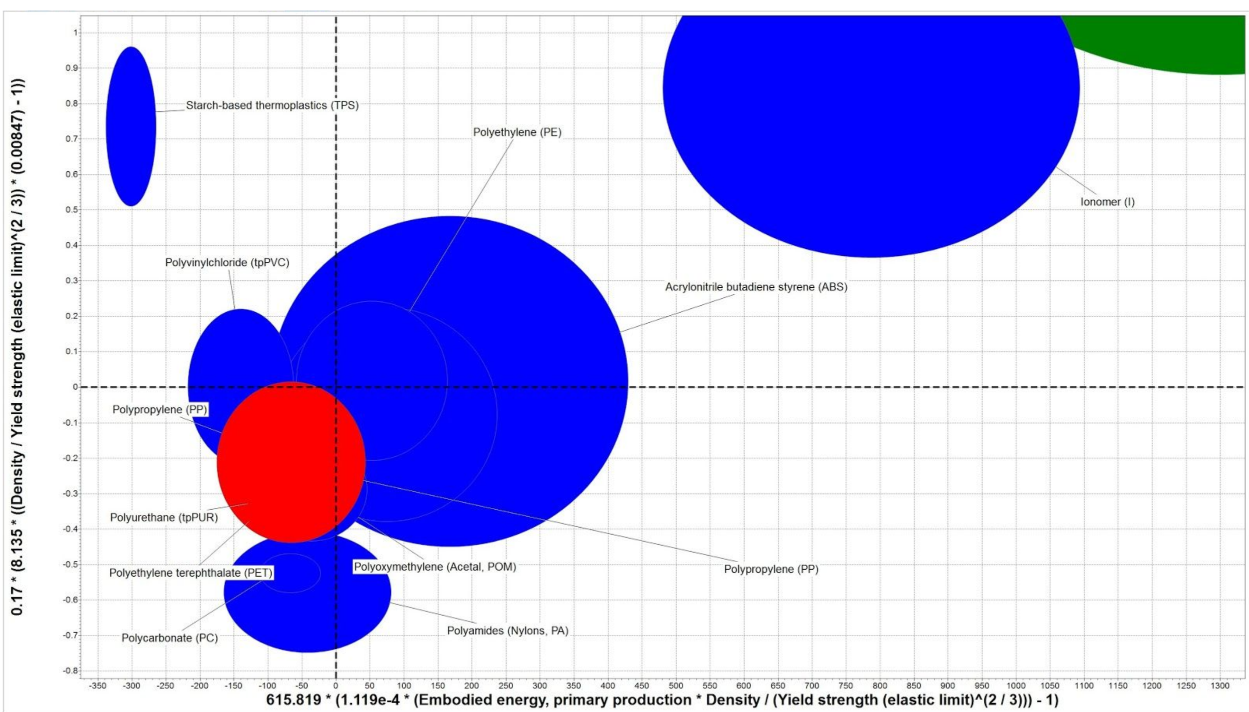


Figure 10: Energy tradeoff in Use vs. Manufacture of material (centered at PP)

Discussion of Results (Tradeoffs)

We see that in the cost trade off shown in Figure 9 , the price for all our materials is a much larger factor in determining the overall cost than the energy cost is over the lifespan of the MINI. Thus, there is not a huge benefit in replacing our PP with another material that is slightly less dense since the price difference will completely negate that. Similarly, we see that in Figure 10 that the embodied energy in primary production of each material has a much larger impact in the total energy demand for that material than the energy consumed in the use phase. This huge difference in both Figure 9 and Figure 10 is due to the relatively small difference in the energy drawn from the lead-acid battery when we increase its weight by 1 kg.

Conclusions (Tradeoffs)

Since the manufacturing of a material has a much larger impact on its overall energy consumption and cost, and because the savings are minimal during the MINI's limited use phase, we decided to continue using PP as our material but reduce the amount it is used since this is the best way to reduce the bottom line and total energy demand.

Analysis of the Product's Use Phase

Currently, the toy car derives its power from a 6-volt battery with a total energy density of 42 W-hr per battery charge. If we assume that a single charge equals a service unit and children use the car for 100 service units per year, then the Mini Cooper requires 4.2 kWh of energy annually. By comparison, a single photovoltaic solar panel can produce between 400-600 kWh annually depending upon location. As such, the carbon emissions from the use phase of this product can easily be offset by either buying solar credits or installing a small solar array which would likely become a net energy producer.

Cost Barrier

Since we plan to use the same materials, with less total polypropylene, we will actually reduce the cost of materials and manufacture for our car. Additionally, we will need fewer total cars, which will save money on the manufacturing end. The subscription model will also reduce costs for purchasers, as they will only pay $90 for a two-month subscription, as opposed to $180 for ownership of the car. Though they will only borrow the car instead of owning it, this may be of equivalent value to families who have limited storage space or who know their child will tire quickly of the toy.

Conclusions and Recommendations

Lightweighting

Reducing polypropylene remains our primary goal as it attributes to 68% of the car's weight while the closest other material only contributes 15% of the weight. That being said, there are numerous smaller polypropylene components on the current model which can be replaced as they are purely decorative, not functional. For example, some of the trim and polymer light covers could be replaced by stickers of the items (or gecko tape for easy removal). One option is that children could even decorate the car themselves, for added value and fun. If some components got replaced by stickers (front and rear bumpers, side trim panels, headlight covers, and dashboard), the weight contribution of polypropylene would garner a 9.3% reduction (approximately 760 grams per car).

Educational Opportunity

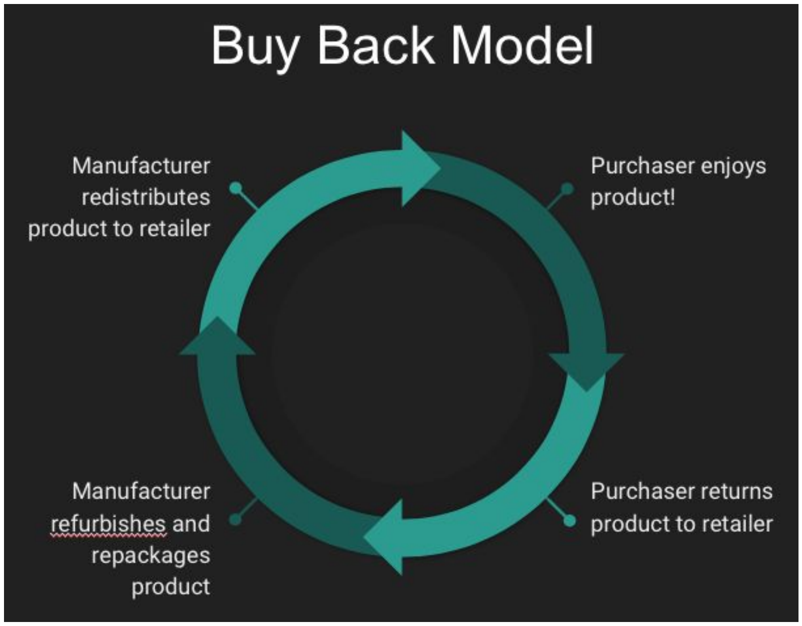
In the marketing of our revamped MINI Cooper S toy, we will emphasize the environmental and fiscal benefits of a subscription model. We will advertise the car as an eco-friendly option, thereby getting kids excited about sustainability from a young age. The potential introduction of a solar powered battery charger will help children to become comfortable with solar energy, hopefully impacting their decisions to utilize renewable energy sources later in life.

Subscription System

One key strategy to reducing resource consumption is a shift in values towards a shared economy based on the philosophy of “use rather than own”. This concept could be applied by a forward-thinking toy manufacturer to both decrease material consumption and increase profits by reducing the number of toy cars which need to be manufactured in order to meet the demand of consumers. Under this model, a toy car could be bought on a monthly subscription basis for a fee less than the current market price of the car. At the end of the subscription process, the car is returned, refurbished, and then sent to the next subscriber. Consumers would also have the option of renewing their subscription with a new model to avoid the age-old problem of children becoming disinterested in their toys.

We know that approximately 5,000 Mini-Coopers are normally sold per year. We know that the current retail price of the car is $180 and we’ll assume that the cost of manufacture is about 60% of the sale price or $114. We can perform a quick back of the envelope calculation to determine the material savings that could be achieved by meeting the same demand with a two-month subscription, assuming that sales are distributed equally throughout the course of the year for a cost of $90 per subscription or half of the current market value. Under these assumptions, the company could, in theory, manufacture as few as ⅙ as many cars to meet the demand, but we'll assume a factor of ⅕ to have standing, excess stock. Under this scenario, the company would generate $450,000 of revenue for their subscription service by selling 5,000 two month subscriptions. This allows 2 months of "buffer time" for car shipment and refurbishing. While this is only half of the gross revenue that would be made by selling the toy cars outright ($900,000), the net profit will still increase because the total cost of manufacturing and the amount of resources used is drastically reduced by producing fewer cars. Producing 1,000 cars at $114 costs $114,000 and requires 8,135 kg of polypropylene polymer components. Meanwhile, producing 5,000 cars at $114 costs $570,000 and requires 40,675 kg of polypropylene. Hence, the net profit of the subscription service ($336,000) would be higher than the selling the cars outright to the consumer ($330,000), while using ⅕ the amount of material, energy, and water resources in the material and manufacturing stages of the toy's lifecycle. This would be an incredibly significant step to reducing material consumption while increasing the profitability for the toy manufacturer.

In the event that a child falls in love with the toy, there will be an option to renew the subscription and to potentially purchase the car for permanent ownership at a reduced price.



<u>Figure 11</u>: Our recommended manufacturing, marketing, and refurbishment cycle to be used for our proposed subscription program rather than a linear strategy of direct sales to a single consumer.

Eventual End of Life

Eventually, the toy car will become sufficiently worn, damaged, or out of style that it is unrealistic to refurbish. This will vary with the type of use (i.e. how roughly children play with the car) that the car experiences, but we estimate that it will be at the end of approximately 2 years, or 10 subscriptions. At this point, some parts can be repurposed to use for a future model of ride-on toy. These include the steel rear and front axle and the motor. The polypropylene parts, which comprise the majority of the product, can be recycled. Unfortunately, our research indicates that currently only 1% of PP is recycled in the United States. However, ongoing efforts are in place to make polypropylene recycling more efficient and popular. We are optimistic that these processes will allow us to retain a recycle fraction of 20% at the beginning, and 75% in the next decade. The frame of the lead-acid battery can also be recycled. According to recyclenation.com, up to 80% of most lead-acid batteries that are properly disposed of can be recycled.

Donate Car to Howe Library

When we performed our Eco Audit, it was assumed that our MINI Cooper was completely thrown out due to the difficulty and amount of time required to fully separate different materials. This in turn meant that our own MINI Cooper has zero end-of-life potential.

We felt that, given the content of this course, it would be disappointing have the next step in our MINI Cooper's life be in a landfill. In the spirit of the shared economy we propose, we plan on donating our MINI Cooper to Hanover's downtown Howe Library upon the completion of this project. We chose to donate to the Howe Library because they already have a toy-loaning model in place. The library has themed backpacks that children can check out for a one-week period with related toys and books. According to a family in Hanover with two young children, this program is a great way to preserve the novelty of toys, as children tend to tire of new things very quickly. Furthermore, it helps to teach children at a young age about communal use and the value of sharing. The aforementioned family has been very pleased to see that their two and four year old children treat the library's toys with even more care and respect than their own, because they know that they will later be used by another child and must be returned in good condition. We hope that local children will enjoy the car. We certainly did when we test-drove it around Thayer!

Even though photographing each individual part and reassembling the car required significant time and effort, we are happy to avoid wasting 4930 liters of water, 1250 MJ of Energy, and 64 kg of CO_2.

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Appendices

Table A1: Comprehensive list of all components, their material makeup, and total mass for the Mini-Cooper toy car.

Part Number	Subassembly	Part Name	Quantity	Material	Mass (g)
1	steering wheel	AA battery	2	alkaline battery	24.0
2	misc.	assorted hardware	1	Painted Steel	202.0
3	battery	battery	1	Lead-Acid	1240.0
4	drive train	battery brace	1	Painted Steel	22.0
5	battery	battery plug	1	75% Copper 25% PP	72.0
6	battery	charger	1	Plug	96.0
7	body	chassis / body	1	PP	3480.0
8	dashboard	compass	1	PP	8.0
9	dashboard	compass base	1	PP	10.2
10	dashboard	dashboard	1	PP	274.0
11	dashboard	dashboard sub-layer	1	PP	104.0
12	dashboard	directional switch	1	50% Al 50% PP	14.0
13	body	door handles	2	PP	6.0
14	drive train	Front Axle	1	Painted Steel	1045.0
15	body	front bumper	1	PP	60.0
16	body	front fender	1	PP	210.0
17	body	front grill	1	PP	44.0
18	body	front logo	1	PP	2.0
19	tires	front tire	2	PP	350.0
20	dashboard	fuel gauge	1	PP	18.0
21	dashboard	fuel gauge base	1	PP	22.0
22	body	gas pedal	1	PP	10.0
23	gear box	gear box bottom	1	PP	116.0
24	gear box	gear box top	1	PP	64.0
25	lights	headlight	2	Treated PP	36.0
26	lights	headlight covers	2	ABS	18.0
27	steering wheel	horn cover	1	PP	12.0
28	dashboard	key	1	PP	6.0
29	dashboard	key switch	1	PP	10.0
30	gear box	large gear	1	Polyamide	66.0
31	lights	light bulbs	1	LED, Cu wiring	24.1
32	misc.	Manual	1	Paper	62.6
33	gear box	medium gear	1	Polyamide	21.0
34	body	mirror	2	PP	30.0
35	motor	motor	1	60% cu, 40% steel	244.0
36	motor	motor case	1	PP	74.0
37	body	pedal mount	1	PP	12.0
38	body	pedal trigger	1	50% Al 50% PP	12.0

39	dashboard	power switch	1	50% Al 50% PP	12.0
40	drive train	Rear Axle	1	Painted Steel	486.0
41	body	rear bumper	1	PP	62.0
42	body	rear panel	1	PP	396.0
43	body	rear spoiler	1	PP	248.0
44	tires	rear tire	2	PP	460.0
45	body	seat	1	PP	554.0
46	dashboard	shifter	1	PP	50.0
47	body	side bumper	2	PP	82.0
48	body	side logo	2	PP	4.0
49	gear box	small gear	1	Polyamide	8.0
50	steering wheel	sound Tabs	2	PP	1.0
51	dashboard	speedometer	1	PP	34.0
52	dashboard	steering rod mount	1	PP	10.0
53	steering wheel	steering wheel top	1	PP	106.0
54	steering wheel	steering wheel bottom	1	PP	50.0
55	steering wheel	steering wheel electrical	1	copper	16.0
56	lights	tail light cover	2	ABS	14.0
57	lights	tail light frame	2	Treated PP	26.0
58	tires	tire hubcaps	4	PP	6.0
59	tires	tire rims	4	PP	50.0
60	body	windshield	1	ABS	234.0