December 8, 2021

Professor Melissa Montalbo-Lomboy

Rowan University, College of Engineering

201 Mullica Hill Road

Glassboro, NJ

Dear Professor Lomboy,

This document contains the report of FEC 1 section 12 team 3's low density polyethylene (LDPE) bag. The purpose of this project was to conduct a life cycle assessment on LDPE bags to understand the impacts on sustainability of the environment while also testing for tensile strength after inducing conditions a bag would experience in real life after improper disposal. Included in this report is the research the team performed to understand the physical properties and characteristics of the LDPE material. Using the knowledge gained, the team was able to assess the product with respect to the triple bottom line and.

Sincerely,

Team 3,

Emma Padros, Aidan Sharpe, Krisha Darji, and John Leahy

Conducting an LCA and Tensile Strength Test on Low Density Polyethylene Bags

Team 3: Krisha Darji, Emma Padros, John Leahy, Aidan Sharpe

Honors First-Year Engineering Clinic

Professor Lomboy

December 8, 2021

ABSTRACT

The purpose of this experiment was to determine the impacts a low density polyethylene (LDPE) grocery bag had on the environment through a cradle to grave life cycle assessment. While researching the LDPE bag, the process in which it was manufactured and processed was noted, while also understanding its physical properties and characteristics. Two tests were performed on the LDPE bag to determine its tensile strength. The first test conducted only changed the load rate at which a dog-bone piece of the LDPE bag was stretched. The second test was conducted on two separate days (Day 3 and Day 7) after the LDPE bag was exposed to a constant UV light that replicated the natural light from the Sun that a plastic bag discarded outside would receive. The team then conducted the same tensile strength test for the exposed LDPE bags. The data showed that after exposure to UV light, the amount of stress and strain the LDPE material could withstand actually increased. This supports why LDPE bags are not degradable.

INTRODUCTION

Low density polyethylene bags are recyclable, however, the thin material often gets caught in machinery, therefore it is not always recycled in facilities. The team found that the bags are sometimes taken to specific retailers that will recycle them. LDPE bags, when recycled properly, can be made into a variety of products such as plastic condiment containers, manufactured lumber, or even trash cans.

In order to create low density polyethylene, the first step in this process is to modify natural gasses to form a catalytic of crude oil and into gasoline. The gasses that are typically used for this process are methane and propane mix, and the most commonly used gas in order to make low density polyethylene is ethane. In this case the ethane is then pumped through a piping system that goes through a refinery process in a polymerization plant. In this refinery process, the ethane is heated to extreme temperatures and raised to high pressures. In doing so, this creates a double bond between the ethylene monomers. These double bonded monomers then create long chains where each compound is linked up with each other. What differentiates LDPE from HDPE is the linked chains that are created. In LDPE the chain contains short branches of the monomer compounds, as pictured in Figure 1. This occurs when the high pressure acting upon the gas is quickly released in the autoclave. As seen in Figure 2, once this polyethylene liquid is produced, the process to create it into a packable form is done by placing it as an extruder. As the material moves through the barrel due to gravity, it then gets heated. The heated material gets filtered and moved to the hopper where it is blown and forced to keep its new shape as it cools to conform to the shape of the bag.

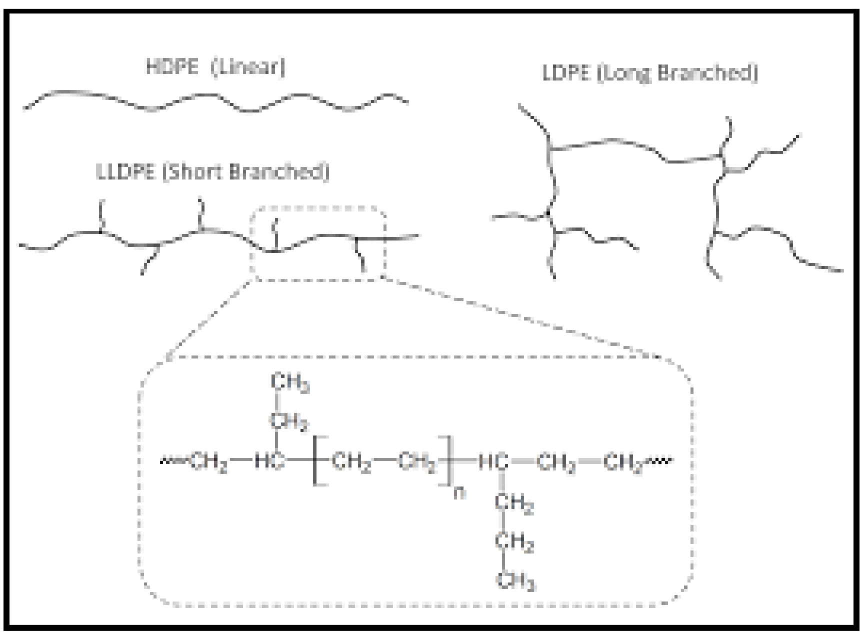

Figure 1: Microscopic Chain Structure of LDPE Plastic

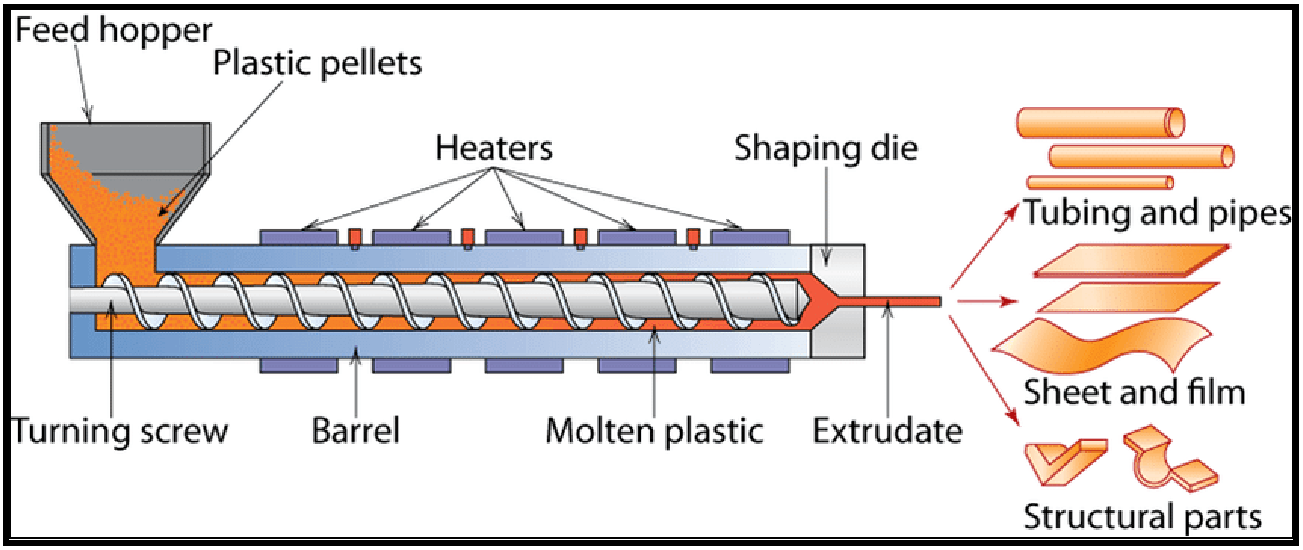

Figure 2: Extrusion Machine Profile

At the end of the LDPE grocery bag's life cycle, it most often is discarded and gone straight to landfills. The LDPE, however, cannot decompose, and instead will break down into smaller pieces, known as microplastics. There are billions of microplastics that are on our planet, and some are barely visible to the human eye, posing a threat to society. A very small 6.2% of LDPE ends up being recycled. Since LDPE cannot be broken down it instead will commonly be melted down and reformed into a new plastic such as ketchup bottles or trash bags.

A cradle-to-grave life cycle assessment of LDPE bags was conducted through the Gabi software. The goal was to produce data regarding the impact the extraction and manufacturing process of LDPE bags has on the environment through a cradle to grave study for the team's client. In all instances, the actual making of the low density polyethylene granulate had the highest effect on each of the categories reported on: global warming potential, eutrophication potential, acidification potential, and smog air potential.

The triple bottom line of the LDPE plastic bag is that all three P's, people, planet and prosperity are affected negatively long term by the lifecycle of the bag. positive short term effects.

These include lower cost in production of the bag itself which allows for people to pay less for products containing LDPE plastics. These plastics also have the ability to be melted down and reformed into new types of plastics products. Even with these positive short-term effects, the long term effects of LDPE have much more catastrophic effects on the three P's, since the plastic is unable to decompose. Its end of life cycle is in a landfill. This negatively affects the planet and people for it creates a large amount of pollution. This plastic is also created from a nonrenewable source, ethane. Therefore, the plastics production takes away from limited resources in the planet adding to the already prominent problem. Since these sources are becoming limited in the long term, it will also affect the economy for when the resources run out. There will be inflation in prices for the cost to manufacture other plastics that don't include the nonrenewable source which will be more expensive. In turn, this economic effect will result in a negative impact on the prosperity aspect in the triple bottom line.

The goal of this project was to produce data regarding the impact the extraction and the manufacturing process of LDPE bags has on the environment through a cradle to grave LCA. Another goal of this project was to assess the tensile strength of the LDPE material after exposure to UV light. The final goal of this project was to learn to integrate multiple softwares to assess the data the team had to extract through experiments.

METHODS (TENSILE STRENGTH EXPERIMENT)

The materials used in the tensile testing experiment were an exacto knife and cutting board to cut out the sample strips of the LDPE plastic. A metal dog bone was used to trace out 9 strips needed to place into the tensile testing machine. A heat lamp was used to simulate UV effects on the plastic after certain time periods. In order to carry out the tensile test itself, a tensile test machine was used.

When performing the tensile test, only one element was changed for the first test: the load rate. The team used three different speeds: 40 mm/min, 50 mm/min, and 60 mm/min. At first, the team did have difficulty getting accurate results because the dog bone shaped LDPE material was not properly positioned within the holder, so it would stretch until the max position was reached. Other times, the material would snap at one of the ends of the cutout instead. After trial and error, the team was able to properly place the dog bone LDPE material into the tensile strength machine. This allowed the team to obtain accurate readings of what the stress and strain were as the loading rate increased in increments

For the second test, the team opted to use a UV light to imitate the effects that an LDPE bag exposed to the Sun would experience. A sheet of LDPE was left under a constant UV light. The team did this to note any differences the bag's physical properties would undergo. The team measured the tensile strength after 3 days of UV exposure and 7 days of exposure. This was done to see if longer periods of exposure had more of an effect on the stress and strain of the LDPE bag.

METHODS (LIFE CYCLE ASSESSMENT)

The scope of the LCA was a system boundary of a stand-alone cradle to grave LCA of LDPE bags. It was assumed that the user was not contributing to any of the impacts because they were only to use it and dispose of it. So this means that they aren't burning it or deforming it in any way that could potentially harm the environment directly through its use. Therefore, this LCA conducted followed the extraction of LDPE, the LDPE bag manufacturing plant, and then to the landfill.

It was assumed in the LCA model that the plastic was going straight from the distribution to the landfill. The packaging waste factors were excluded, instead the model was only focused on the waste of the LDPE plastic itself and the improper discarding into landfills.

The functional unit was the bags used by U.S. consumers to transport items for a family of 4 for 14.6 shopping trips from the grocery store to the consumer's home in 2012. The actual LCA model is shown below in Figure 3.

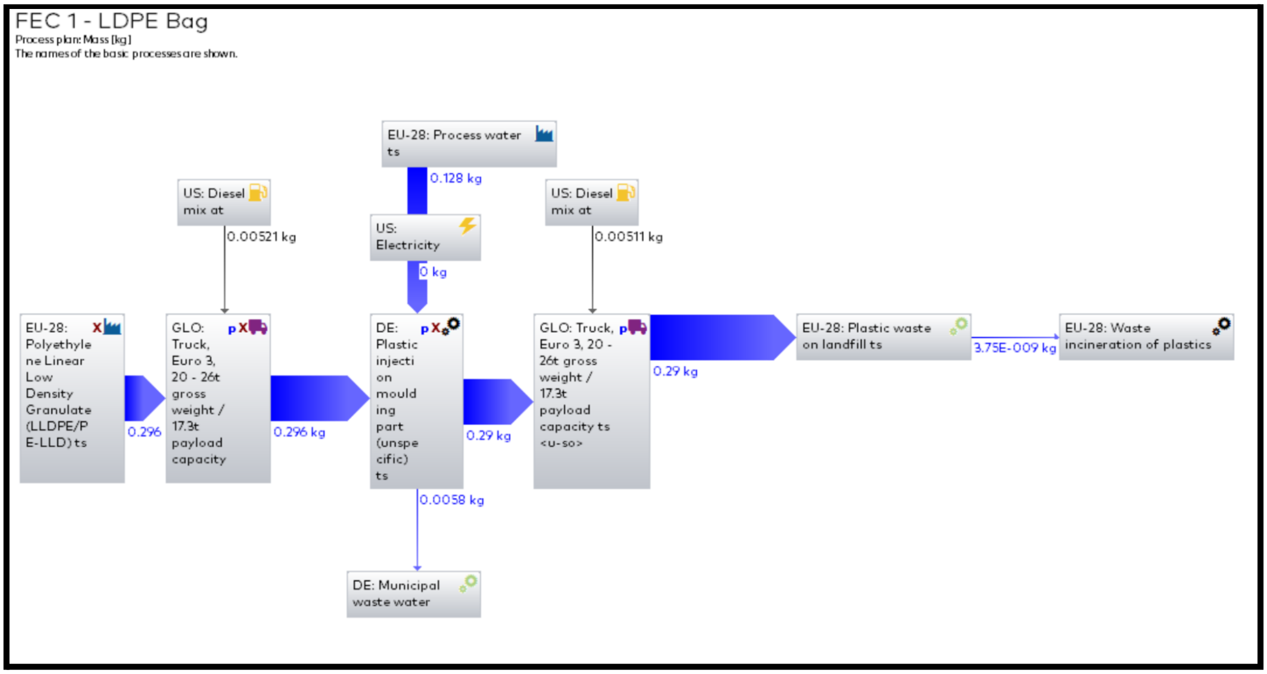

Figure 3: Life Cycle Gabi Model Flowchart

The boundaries that the LCA system contained were finite resources in order to produce the LDPE plastic. In order to obtain the materials needed to carrot out the LCA model it is necessary to obtain raw materials. Due to this, there is a raw materials extraction boundary in this model as seen in Figure 4. There is also a mass restraint on the plastic being produced; this was 0.296 kg. There was a restraint on the amount of electricity applied to the system. The trucks used to transport the plastic from place to place also have restraints due to weight and size. The fuel used to power these trucks is bound by the diesel, which is a nonrenewable material. The next boundary is the waste disposal of the plastic, and finally the incineration process of this plastic waste is the last boundary in this LCA. This LCA was bound from cradle to grave.

Table 3 Summary of Processes used from the GaBi database

Product/Process	Title in GaBi Database	System Boundary
HDPE	DE: Polyethylene High Density Granulate (HDPE/PE-HD) Mix ts	Raw Material Extraction
PLA	US:Ingeo Polylactide (PLA) biopolymer production NatureWorks	Raw Material Extraction
LDPE	EU-28: Polyethylene Linear Low Density Granulate (LLDPE/PE-LLD) ts	Raw Material Extraction
PP	DE:Polypropylene granulate (PP) mix ts	Raw Material Extraction
Diesel	US: Diesel mix at refinery ts	Transportation Fuel
Truck	GLO: Truck, Euro 3, 20-26t gross weight/17.3t payload capacity ts <u-so>	Transport
Electricity	US: Electricity grid mix ts	Electricity
Landfill	EU-28: Plastic waste on landfill ts	Manufacturing Waste, Grocery Bag Disposal
Incineration	EU-28: Waste incineration of plastics (PE, PP, PS, PB)	Grocery Bag Disposal

Figure 4: System Boundaries of the LDPE plastic

RESULTS AND DISCUSSION (EXPERIMENT)

Before treating the LDPE strips with UV light, Figures 5, 7, and 9 had a concave up shape at the top. However, after the treatment, Figures 6, 8, and 10 maintained a consistent concave down appearance. Furthermore, before treatment, stress peaked between 80,000 and 90,000, whereas after treatment with UV exposure, maximum stress was close to 1,400,000 for all three speeds. This means that the LDPE material is able to withstand higher stress after more exposure under the UV light, and therefore, when under the sun. This could be a contributing factor for why LDPE bags are unable to be broken down when discarded into landfills. Although their physical and chemical properties are taken into account, chemical reactions that occur when exposed to UV light should also be considered when researchers and engineers are developing new materials. If engineers were able to find a way to reduce this reaction where the LDPE bag was able to withstand more stress and strain, there could be a possibility for the LDPE to be able to be broken down easier, if not completely.

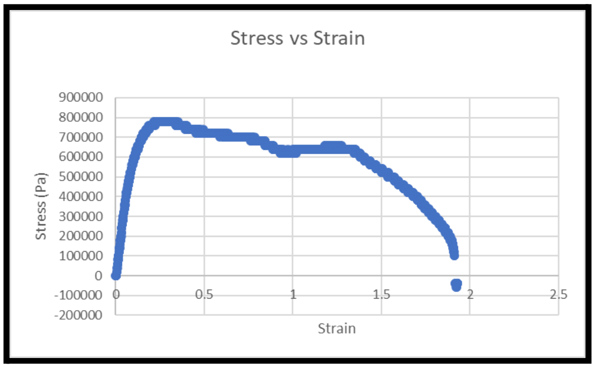

Figure 5: 60 mm/min no UV

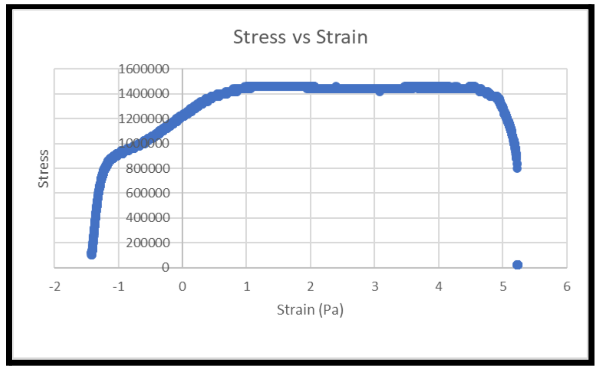

Figure 6: 60 mm/min one week UV exposure

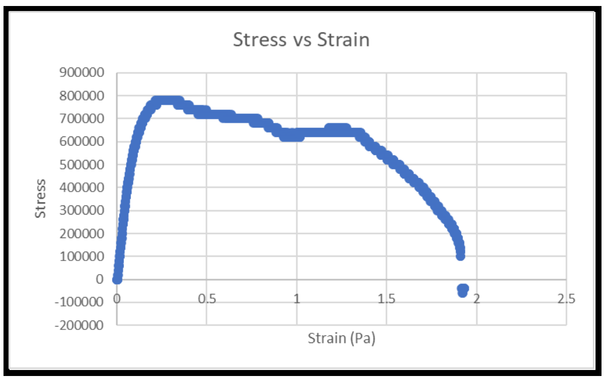

Figure 7: 50 mm/min no UV

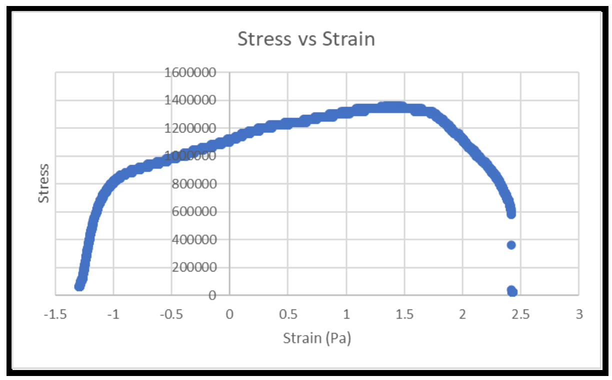

Figure 8: 50 mm/min one week UV exposure

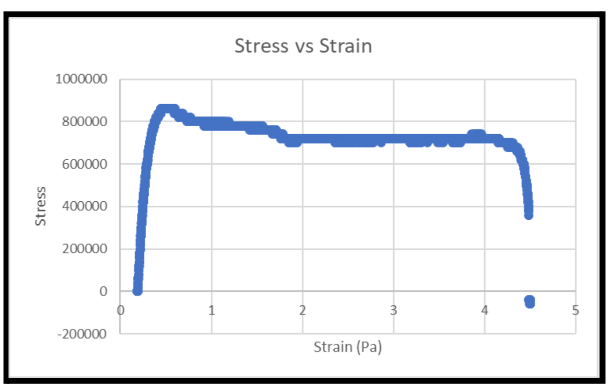

Figure 9: 40 mm/min no UV

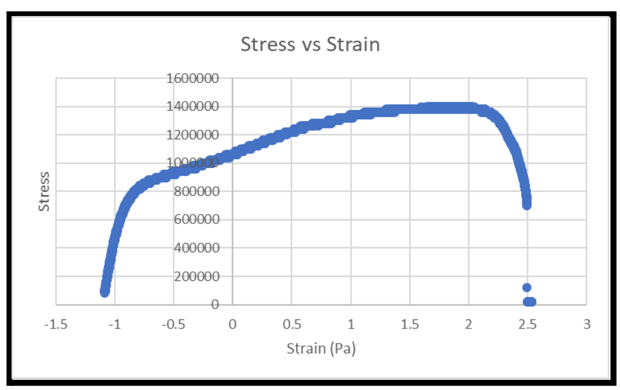

Figure 10: 40 mm/min one week UV exposure

RESULTS AND DISCUSSION (LCA)

The four main categories of the LCA results are Global Warming Potential (GWP), Eutrophication Potential (EP), Acidification Potential (AP), and Smog Air Potential (SP). Figures 11, 12, 13, and 14 show how the different stages of our LCA contributed to the results. The total amount of GWP is 0.853 kg CO_2 eq, the total amount of EP is 0.000147 kg N eq, the total amount of AP is 0.00176 kg SO2 eq, and the total amount of SP is 0.0324 kg O_3 eq.

For GWP the main contributing factor is the making of the LDPE plastic, because the factories that the plastic is made in releases CO_2 into the atmosphere. CO_2 is a greenhouse gas which means that it traps UV radiation in the atmosphere which then heats up the planet. The lowest contributing factor for the GWP is the space the plastic takes up on the landfill, because the plastic is just sitting on the landfill. This means that it has little to no effect on the GWP.

For the EP, the main contributing factor is the making of the LDPE plastic, because the factories where the plastic is made uses water in the injection molding process. This means that after the process, the wastewater has to go somewhere and it goes back where they got it. When the wastewater is deposited into the water source, it has some nutrients left over from the injection molding which causes eutrophication. The space on the truck is the lowest contributing factor to the EP because it has no effect on water so there is little eutrophication happening.

For the AP, the making of the LDPE plastic has the highest effect because the factories that make the plastic release SO_2 into the air which reacts with the clouds to create acid rain. The space on the landfill has the lowest effect on the AP because it doesn't have any effect on the air so there is no chance for acid rain to be created.

For the SP, the biggest contributing factor is the making of the LDPE plastic because the factories release Ozone into the atmosphere which reacts with the oxygen and creates smog near the surface. The space on the landfill is the least contributing factor because it doesn't have any effect on the air so there is no smog created. These results highlight how the making and using of LDPE bags affect some of the different aspects of the environment.

Making LDPE has the highest effect (0.5 kg CO2 eq), and the waste on landfill has the lowest effect (0.02 kg CO2 eq).

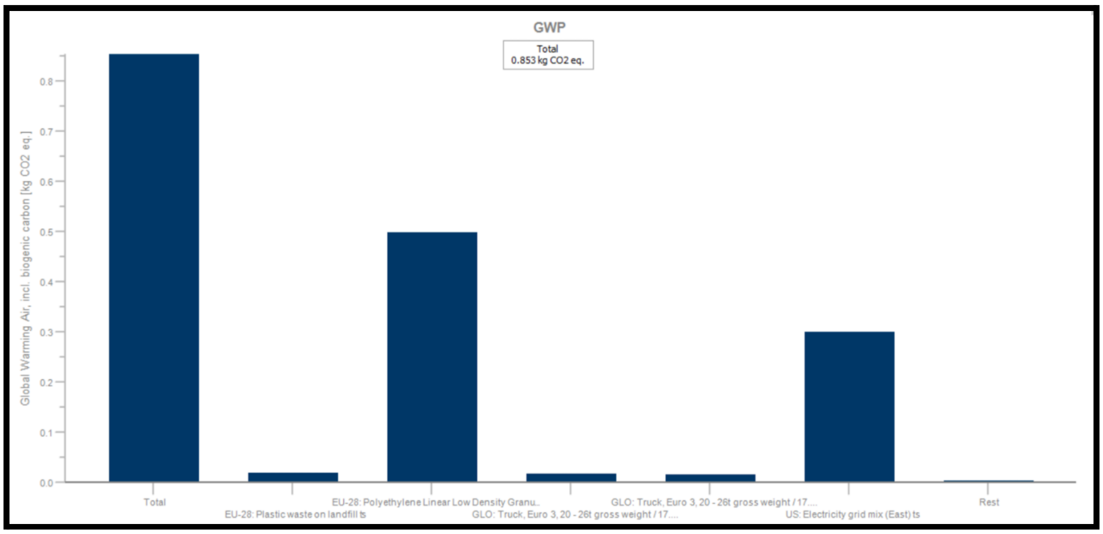

Figure 11: Global Warming Potential

Making the LDPE has the highest effect (0.00006 kg N eq), and the space taken up on the truck has the lowest effect (0.00002 N eq).

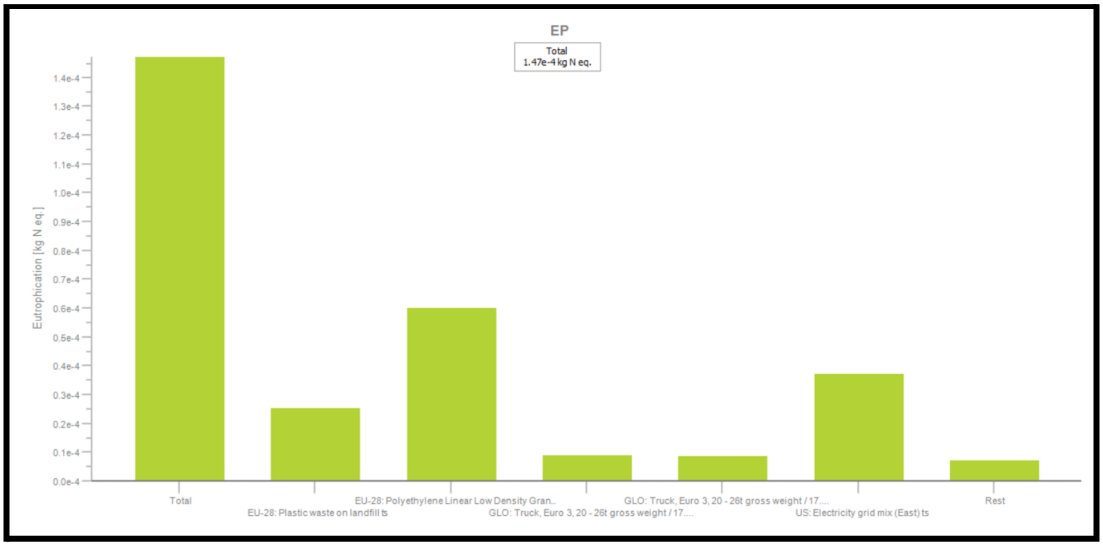

Figure 12: Eutrophication Potential

Making the LDPE has the highest effect (0.001 kg SO2 eq), and the waste on the landfill has the lowest effect (0.00005 kg SO2 eq).

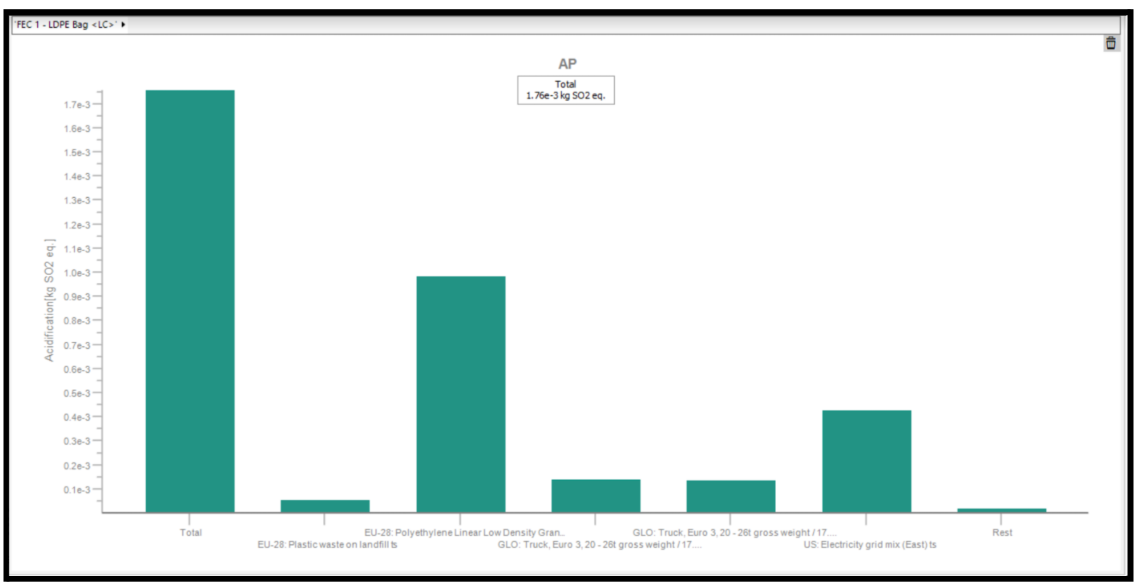

Figure 13: Acidification Potential

Making the LDPE has the highest effect (0.01944 kg O3 eq), and waste on the landfill has the lowest effect (0.00162 kg O3 eq).

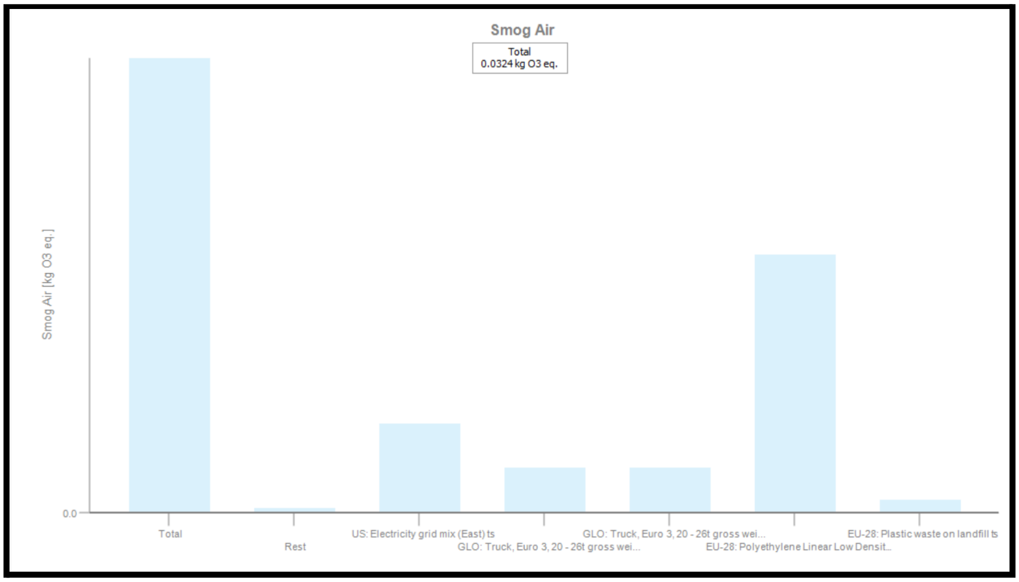

Figure 14: Smog Air Potential

CONCLUSION

AFter conducting the life cycle assessment on LDPE bags through Gabi software, the team found that the production of the polyethylene granulate in the LCA model is what produces the most amount of over all of the pollution factors. For a future experiment, an aspect of the LCA Gabi model that can be altered is the initial conditions of the waste factors from packaging and transportation to stores. That was not factored in this model because of the team's assumption that the user would not alter the bag in any way. If these were to be included the data on pollution of the LDPE that would have resulted from the software will have an outcome of a greater total pollution value on each of the pollution factor graphs.

Three experiments of tensile strength were performed. The initial test was used as a controlled experiment to then compare future alterations of the bag to. After 7 days of constant UV exposure, the tensile strength of the LDPE bag actually increased, which could contribute to why the bag doesn't break down easily. The data obtained from these trials can help scientists engineer the properties of LDPE so that it could be broken down. Some aspects of the tensile test that we could have changed are the time that the plastic spent under the UV. If the plastic had more time to sit under the exposure of the UV then the effects from the light could be more evident in the tensile tests as well as the data that would result would be more accurate if more tests were performed as well.

APPENDIX

Reflections

Phase 1 - Research and Experimental Plan

How does your research affect your plans for experimentation?

After researching LDPE bags, it was found that they are not biodegradable, therefore, the team would not be able to perform a biodegradability test on the bag. Instead, the team performed tensile strength tests. Moreover, LDPE plastic is water-proof, so the team had to come up with a plan that would evaluate the bag without the use of water.

In your research, what design opportunities exist based on your analysis of the product's life cycle assessment?

Since this is a cradle to grave life cycle assessment, the scope of the experiment for the team will be significantly altered. Instead, the team will assess degradation in tensile strength based on exposure to UV light, each a week apart. From this, a prediction could be made for how UV light exposure affects the life cycle assessment of LDPE bags.

Phase 2 - Conduct Experiment

Is it possible for one environmental aspect (air, water, solid waste, energy) to be treated as more important than another? If so, how? And why? Who makes these decisions in our society?

It is possible for one environmental aspect to be more important than others. Currently, it seems as if everyone is in a race to produce energy, ignoring the consequences human greed poses. People in the rich upper class, such as chief executive officers, are often promoting their technological advances. The harm, however, that was poured into the environment, such as air pollution in CO_2 emissions, accidental oil spills into the ocean, and irresponsible discardment of waste, are important environmental aspects that are overlooked. These decisions are not in the hands of regular, working-class citizens because they do not have the power or resources to promote or create an alternative to production of items that are slowly becoming necessities.

How can we decrease the impact of consumerism on the environment? How does your work on the project so far inform your thoughts on consumerism?

The impact of consumerism on the environment can be reduced if consumers stopped purchasing directly from department stores or malls. In the case of the textile industry, fast fashion is increasing rapidly, and finite resources are being wasted. If consumers instead bought their clothes from the thrift store or second-hand shop, this would be recycling and repurposing garments that can decrease the impact of consumerism on the environment. Working on the project so far, the team has been involved with researching the impacts humans have on the global environment. Pollution and waste is an unfortunate byproduct of consumerism. It is important to note, however, that consumerism is unnecessary and can be easily avoided if the citizens of the world worked together to save the environment.

Which experiment do you think will be the most useful and why?

After much consideration, the team opted to complete a test measuring the effects on tensile strength after exposure to constant UV light for a week. This was chosen as the third test because the UV light was to replicate the sun and a scenario where a plastic LDPE bag could be left outside or improperly discarded.

Phase 3 - Conduct Experiment

Comment on your hypothesis from all of your experiments - were any proven incorrect? If so, how?

The hypothesis for the initial tensile strength experiment was that the piece being tested would not break at a low load rate (speed). This was proven incorrect because the LDPE piece snapped at each speed tested: 40 mm, 50 mm, and 60mm. The hypothesis for the second experiment was that the LDPE piece being tested for tensile strength would break easily. This was true.

What other hypothesis could be further tested that arose from your results?

With more UV light exposure time, the team could have tested how the physical properties of the LDPE plastic bag had altered. The hypothesis would be: With longer exposure to UV light, the LDPE plastic bag could degrade physically and break quicker.

How can you determine whether your product is adding value to your customer?

The team could determine whether the product is adding value to the customer by presenting solutions that could help degrade the LDPE plastic bag.

Phase 4 - Conduct LCA

How did your results compare to the LCA found in your literature or research?

The results of our LCA compared to our research very similarly. The team was able to compare the results of the LCA to other LCAs performed on different plastic bags. This allowed the team to understand the different effects of the process and manufacturing the LDPE bag had on the environment in general.

Which process has the greatest impact on global warming? Why do you think that is?

The greatest impact on global warming was making the Polyethylene Low Density Granulate. This is because the granulate has to be extracted and a lot of processing and materials go into the making of the granulate.

How did the end-of-life of the grocery bag impact your LCA?

The end-of-life of the grocery bag impacted the LCA because instead of being recycled, it was thrown away improperly, infiltrating landfills. This means that the thrown-out grocery bag will negatively impact the environment. In the actual LCA model, the team had to add elements that resembled a cradle-to-grave LCA. Transportation was required twice to accurately account for the entire life cycle and the grocery bag's impacts on the environment.

Raw Data

Link to Gabi Excel File:

https://studentsrowan-my.sharepoint.com/:x:/g/personal/darjik87_rowan_edu/ESmPWlnmZPNDjRfRlmLGRb8BlIFZSbxrt3TAcRGacvMpSQ

Link to Tensile Strength File:

https://studentsrowan-my.sharepoint.com/:x:/g/personal/darjik87_rowan_edu/EYwYnWusE3hLqsBIciFQ-1IB65XE0lF4WZyZB7dp7hA_5Q

References

Encyclopædia Britannica, inc. (n.d.). *Polyethylene*. Encyclopædia Britannica. Retrieved November 29, 2021, from https://www.britannica.com/science/polyethylene.

Hinsley, N. (n.d.). *The history of polyethylene*. The History of Polyethylene. Retrieved November 29, 2021, from https://www.globalplasticsheeting.com/our-blog-resource-library/bid/23095/The-History-of-Polyethylene.

Johnson, S. C. (n.d.). *: SC Johnson*. SC Johnson - What's Inside. Retrieved November 29, 2021, from https://www.whatsinsidescjohnson.com/us/en/brands/ziploc/ziploc-brand-freezer-bags.

The manufacture of polyethylene - NZ Institute of Chemistry. (n.d.). Retrieved December 9, 2021, from https://nzic.org.nz/app/uploads/2017/10/10J.pdf.

Miller, B. R. (2020, December 28). *Keeping LDPE from your business out of landfills*. Miller Recycling. Retrieved December 9, 2021, from https://millerrecycling.com/ldpe-out-of-landfills/#:~:text=In%202015%20%E2%80%93%20the%20most%20recent,landfills%20can%20have%20devastating%20consequences.

Plastic number 4 LDPE - low-density polyethylene. Everyday Recycler. (2021, October 17). Retrieved November 29, 2021, from https://everydayrecycler.com/plastic-numbers-no-4-ldpe/.