Bryant University

HONORS THESIS

Assessing the End-of-Life Environmental Impacts of Glass, Metal, and Plastic: An LCA Approach

BY Gabrielle Ritzer

ADVISOR • Dan McNally
EDITORIAL REVIEWER • Stephanie Mott

Submitted in partial fulfillment of the requirements for graduation
with honors in the Bryant University Honors Program
May 2021

Table of Contents

ABSTRACT

In this study, the environmental impacts of landfilled glass, ferrous metal, and plastic were evaluated and analyzed. This study utilized a life cycle assessment (LCA) approach to determine the environmental impacts of each beverage packaging. The beverage packaging materials glass, ferrous metals, and plastic were analyzed from an end of life of perspective. The significance of this study was to determine the extent and severity of the environmental impacts these materials have once deposited into a landfill. The information gained from this study determined which of the products was more sustainable from an end-of-life perspective. Ferrous metal was found to have the least environmental impact while plastic had the greatest impact.

INTRODUCTION

Plastic waste is one of the major global challenges faced in environmental science today. So many of the objects and products we use in our daily lives are made of plastic. As a result, plastic waste is filling landfills, contaminating oceans e.g., the Great Pacific Garbage Patch, and destroying ecosystems. Plastic bottles contribute greatly to the accumulation of plastic waste. Consumers typically opt for convenience, purchasing single-use products. Consequently, 1 million plastic beverage bottles are bought every minute around the world (Cuthbert et al., 2019). It is estimated that a traditional plastic bottle takes at least 450 years to fully decompose, and no other conventional plastic product will be able to degrade in under 50 years as there is no biodegradation. Biodegradation is the breakdown of organic matter by microorganisms, which is not possible as microbes cannot utilize plastic as a carbon and energy source. Thus, plastic remains in the environment. Even if the plastic product does partially degrade, it will produce many toxins and microplastics that will be absorbed by the surrounding environment. If current trends continue, by the year 2050 there will be roughly 12 billion metric tons of plastic in landfills (Parker, 2019). It is clear there needs to be an alternative to plastic products, but are there materials out there that can suffice? Glass and metal bottles are considered possible alternatives.

Glass bottles were once considered to be a more environmentally friendly alternative to plastic. One major reason glass bottles have not become an alternative to plastic bottles is due to the transportation costs and carbon emissions. Due to the heavier weight of glass, greater amounts of fossil fuels are necessary to transport them. When glass does not get recycled, they end up in the same place as plastic bottles, the ocean, or the landfill. According to the EPA, in 2018, landfills received approximately 7.6 million tons of glass, which was 5.2 percent of all municipal solid waste landfilled that year. Once these products are landfilled, it is important to continue to look at the environmental impacts they are having.

Ferrous metal beverage bottles also contribute greatly to the accumulated waste humans generate. Ferrous metals are used in this study. Ferrous metals include iron in their composition, such as stainless steel for example. Typically, these types of metals are used in reusable bottles. Looking at stainless steel bottles more closely, The New York Times states that producing a 300-gram stainless steel bottle requires 7 times as much fossil fuel and releases 14 times more greenhouse gases than producing an equivalent plastic bottle. Stainless steel also demands the extraction of hundreds of times more metal resources and causes hundreds of times more toxic risk to people and ecosystems than making a 32-gram plastic bottle (Goleman & Norris 2009). If the purpose is to reuse these ferrous metal bottles, then opting for this type of metal appears to be the better option when looking at a cradle-to-gate (raw material extraction to the end of production) analysis. Once this ferrous metal is disposed of in a landfill, if not recycled, it is important to identify its environmental impacts. Glass and ferrous metal-derived products appear to be a better alternative to plastic-based bottles; however, a deeper analysis of their environmental impact is necessary. Most plastic, glass, and metal products end up in landfills, therefore analyzing the environmental impacts these products have once deposited in a landfill is necessary to understand the product's overall sustainable potential. Although recycling has the potential to help mitigate the issue, it is not a sustainable solution. The buildup of end-of-life waste itself is a major issue. Once these products end up in a landfill, they continue to harm their surrounding environment. According to the EPA, the total generation of municipal solid waste (MSW) in 2018 was 292.4 million tons or 4.9 pounds per person per day, shown in Figure 1. The significance of this U.S.-based chart highlights the overall consumption of plastics is much greater, relative to glass and metal.

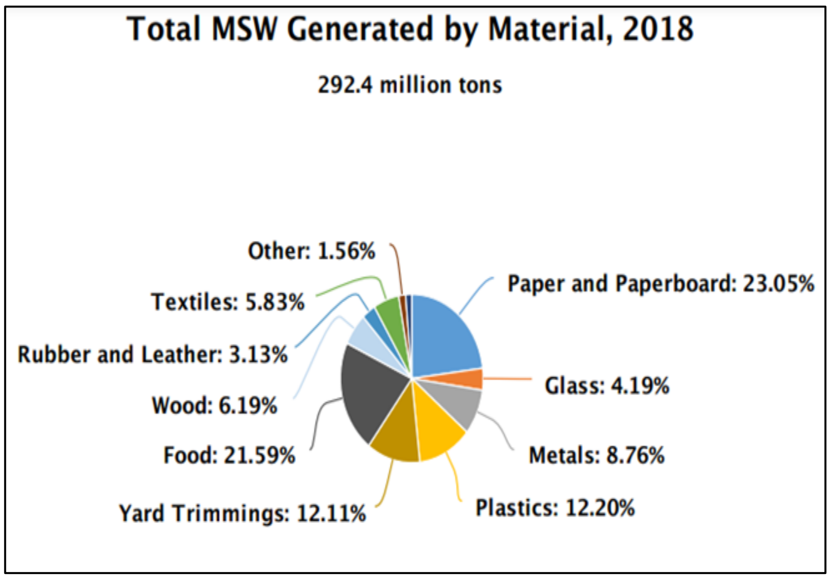


Figure 1
EPA pie chart displaying U.S. total MSW in 2018.

This study uses a data set that represents a typical municipal waste landfill with surface and basic sealing meeting European limits for emissions, as the data comes from a European database. The landfill site includes leachate treatment, landfill gas treatment, sludge treatment, and deposition. Leachate develops when precipitation falls onto open landfills and trickles through garbage and becomes contaminated which can, in turn, contaminate groundwater. The treatment for leachate includes collecting it, then treating it to be evaporated. The gas treatment includes collecting the gas (methane for example) that is released when organic matter decays.

As the negative impacts associated with plastics worsen, alternative solutions are necessary to sustain a healthy earth. A Life Cycle Assessment (LCA) will be conducted to aid in the comparison of glass, ferrous metal, and plastic beverage bottles. This study will provide in-depth analysis to determine each product's environmental impact. Data was collected and utilized from the OpenLCA platform and ELCD 3.2 GreenDelta database. GreenDelta is an independent sustainability consulting and software company. Research and development on this issue has been an ongoing effort for many years now. However, new information and data is released every year, therefore up-to-date analysis is possible.

LCA APPROACH

A Life Cycle Assessment (LCA) is a method by which environmental impacts can be identified, quantified, and evaluated to provide information for guiding decision making about a product, process, or service (Blanco, et al., 2014). The data gathered from the LCA can be utilized for various purposes including, product development and improvement, comparison of design choices, monitoring environmental regulatory compliance, and providing a basis for product environmental claims (Speck 2014). The information gained from an LCA encourages an understanding of the environmental consequences associated with material decisions.

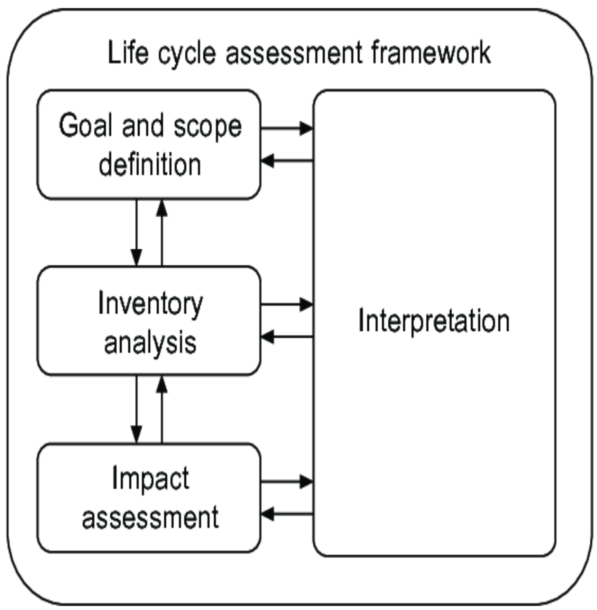


Figure 2
United Nations Environment Program diagram displaying the steps of an LCA.

According to the standardized methodology, there are four main phases of the LCA as, shown in Figure 2, provided by the United Nations Environment Program. Although the steps are arranged sequentially, the arrows point both in directions as the flow through an LCA is dynamic, with review and updates occurring continuously in each step. The framework below, provided by Michigan State University (Speck, 2014) provides the outline of the LCA used in this study:

1. Goal and Scope
2. Inventory analysis
3. Impact assessment
4. Results and Interpretation

The first step in the assessment is goal and scope. Defining the goal and scope of an LCA is essential to having an efficient LCA process. The goals of the LCA determine what information is needed to carry out the purpose of the LCA. The information needed drives the type of assessments that must be made, which in turn defines the type and quality of the data that must be obtained.

The second step in the assessment is the inventory analysis. Performing an inventory analysis includes collecting and quantifying all the inputs and outputs associated with the product, process, or service being studied. During the inventory analysis phase, environmental concerns associated with the product, process, or service will be determined. Moreover, an inventory analysis produces a list of all the elements involved with the production, use, and disposal of a product.

The third step looks at the impact assessment where the inventory data collected is translated into estimations of environmental impact. The environment can be affected in a variety of ways including global warming, acidification, climate change, ozone depletion, eutrophication, etc. Each of these environmental concerns represents an impact category that has been studied, and for which there is a reasonable scientific basis to establish a quantifiable causal relationship between human activities and the severity of the impact on the environment (Speck 2014).

The final step in the LCA is the results and interpretation. During this stage, the results are acquired and assessed. Furthermore, the conclusions formed throughout the previous stages can be evaluated and the results from the assessment can be shared considering assumptions and limitations of the LCA.

Goal & Scope

The goal of this study is to determine and compare the environmental impacts of glass, ferrous metal, and plastic systems to determine their sustainability potential. This study aims to use a life cycle assessment, more specifically focusing on the end-of-life treatment of these materials, to determine if there are less environmentally impactful beverage packaging alternatives than plastic. The packaging types included in the assessment are glass, ferrous metals, and plastic. The significance of this project is to determine the extent and severity of the environmental impacts these materials have at the end of their life. The LCA method quantifies the environmental impact. The objective is to provide data and analysis on the identified impacts these products have once placed in a landfill. The research will analyze and compare the products, thus determining which product is better overall.

Based on the data collected, these products are analyzed to determine if they are a viable and more sustainable alternative to plastic products. This information can help companies who are part of the supply chain make better decisions that can benefit both the company and the environment. This study can educate the public, to bring awareness to the issue of consumption and waste. It can also lead to improved waste management strategies for these specific products.

The data for this study was supplied through preexisting databases available to import into the OpenLCA software. More specifically, the elcd_3_2_greendelta_v2_18 database utilized is provided by the European Reference Life Cycle Database (ELCD). ELCD has updated data from EU-level business associations and other sources regarding energy carriers, waste management, and transport (OpenLCA, 2020). Life Cycle Assessments are not as popular in the United States as they are in Europe, thus, European data was more readily available. Once the products (glass, ferrous metal, and plastic) were selected from the database, each product was converted into a product system to then be analyzed through impact categories provided by the Ecoinvent 3.1 database. Each of these three products have inputs and outputs (flows) that are determined by the database. An example of an input would be the energy used to produce the plastic, and output would be a chemical that is released from that process. These inputs and outputs then become a process that will be used to determine the environmental impact. These impact categories include, but are not limited to, ozone depletion, human toxicology, climate change, and fossil depletion.

To fully understand the processes that happen at the landfill, the ELCD 3.2 database identifies all assumptions and figures regarding the landfill and the treatment involved**.** Landfill data provided that the landfill height is 30 m, the area is 40.000 sqm and has 100 years deposit (OpenLCA, 2020). This deposit time determines the time it will take the landfill material to fully decompose. More specifically, it determines how long the environmental impacts will persist. The background system is addressed as follows, under European conditions: the sealing contains gravel, sand, clay, and polyethylene (PE) film, which are used as filter layers, while the PE film is used as waterproofed sealant and clay as mineral coverage in the surface and basic sealing. The leachate in this study is treated and evaporated. A rate of 60% transpiration/runoff and solubility of fluids is assumed (OpenLCA, 2020). The landfill body is saturated and there is no circulation of leachate and the treatment includes active carbon and flocculation/precipitation processing. Basic sealing utilizes a relatively impermeable barrier designed to keep leachate inside. The liner materials include plastic and dense clay. The distribution of landfill gas is 22 % flare, 28 % used, and 50% emissions, and the use of landfill gas represents the industrial country standard (OpenLCA, 2020).

<u>Inventory Analysis</u>

Appendix A and B show a municipal landfill site flow chart that identifies the inputs and outputs within the system boundary provided by the ELCD database. Appendix A specifically looks at the glass while Appendix B pertains to ferrous metals and plastic. The flow chart provides various inputs that are entered into the landfill body as well as the various treatments that were mentioned previously in the scope of the project. In addition, the OpenLCA software provides a closer look at the inputs and outputs for each product, which can be seen in Appendix C, D, and E. For each product, water is the greatest input, and the radioisotope Krypton-85 is the largest output. The amount of Krypton-85 emitted varies between each product. It is also important to note the Radon-222 as it is within the top 10 outputs for glass, ferrous metal, and plastic. These inputs and outputs are then used to provide deeper analysis for each product. This, therefore, offers quantifiable data that aids in understanding and explaining the specific impact each product has on the environment compared to one another.

Impact Analysis

A Life-Cycle Impact Assessment (LCIA) is a method for transforming the inventory data into consolidated sets of potential impacts. The LCIA method utilized in this study was ReCiPie ReCiPie Endpoint (H, A). It is important to note that each method incorporates factors based on cultural perspectives. The individualist (I) perspective observes products, processes, or services from a short-term viewpoint. This perspective has a positive stance on technology and its ability to avoid issues. The hierarchical (H) perspective is commonly encountered in scientific models and is considered the default model. The egalitarian (E) perspective examines products, processes, or services from a long-term point of view.

The impact analysis category, Endpoint (H, A) is shown in Appendix F. Looking more closely at Appendix F, the single indicators such as climate change and freshwater eutrophication contribute to the damage indicator Ecosystem Quality (total). For this study, Ecosystem quality (total), Human Health (total), and Total (total) damage indicators are discussed.

Results & Interpretation

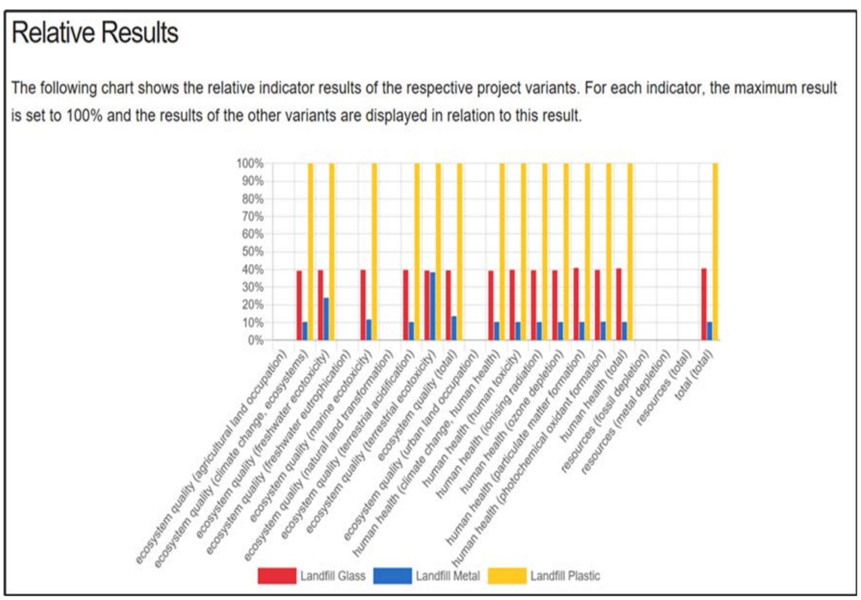


Figure 3
Graph displaying the single indicators and damage indicators.

The LCA software displays the finalized data in a report format. Figure 3 below displays all the given single indicators and damage indicators provided in OpenLCA, corresponding with Appendix G and the points given to each indicator. This graph is significant as it proves that plastic has a greater impact on the environment compared to ferrous metal and glass in all categories. For each category, the maximum result, plastic, was set to 100% and the results of the other variants are displaying in relation to this result. For example, in the climate change category, glass contributes 40% of what plastic contributes. Glass is second to plastic, while ferrous metal scored the lowest points in all the categories.

Glass, ferrous metal, and plastics were compared to one another using two damage indicators from Figure 3. This study focused on two main damage indicator categories: Ecosystem Quality (Total) and Human Health (Total). The single indicators Human Health (Human Toxicity) contribute to the damage indicator Human Health (Total). Appendix H provides further detail of the points given to each indicator. The overall impact of each product uses a point system to normalize the various units. One universal point system was used, to allow comparison between the different materials.

Figure 4 displays the Ecosystem Quality (total) damage indicator of all impact categories. The Landfill ferrous metal scored the lowest points with 8.54e-5, landfill glass 2.48e-4, and plastic 6.27e-4. This data shows that plastics damage to total environmental quality is 86.4% higher than ferrous metal and 60.4% higher than glass. These results indicate that plastic has a greater impact on the environment once disposed of in a landfill when compared to glass and ferrous metal. The differences between the three materials are common among all the results between the different damage indicators. The y-axis scale was adjusted to match the scale of figure 5 for comparison reasons.

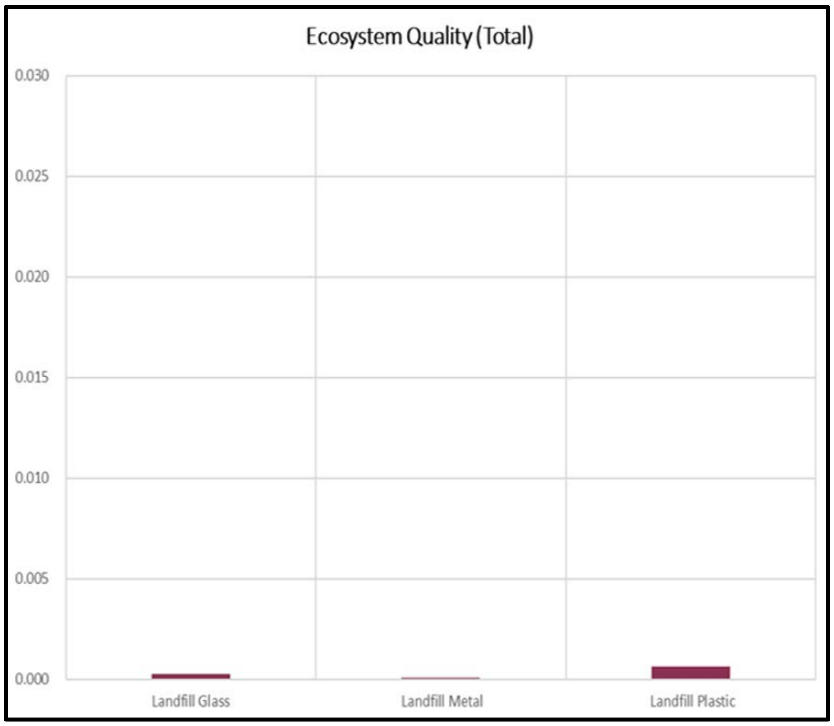


Figure 4
Graph displaying the ecosystem quality (total) damage indicator of all impact categories.

Figure 5 displays the human health (total) damage indicator. The landfilled ferrous metals scored 2.95e-3, the glass scored 1.16e-2, while the plastic scored 2.85e-2. These points mean that plastic impacts human health 89.6% more than ferrous metal and 59.3% more than glass. This damage indicator signifies the greater impact plastic has on human health when compared to glass and ferrous metal. Appendix G provides details on the single impact categories that contribute to the overall human health damage indicator, such as climate change, ozone depletion, and ionizing radiation. This also signifies that ferrous metal has a lesser impact compared to glass when deposited in a landfill.

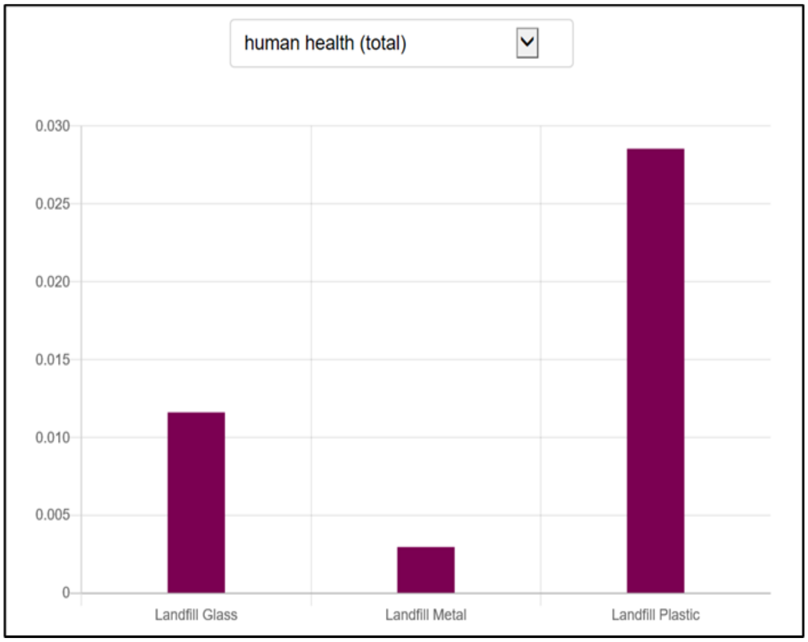


Figure 5
Graph displaying the human health (total) damage indicator of all impact categories.

Figure 6 demonstrates the total damage indicator, which accounts for all the damage indicators Landfill ferrous metal scored 3.03e-3, glass scored 1.18e-2, and plastic scored 2.92e-2. These scores signify that plastic scored the highest points compared to glass and ferrous metal. Plastic has an 89.6% greater total

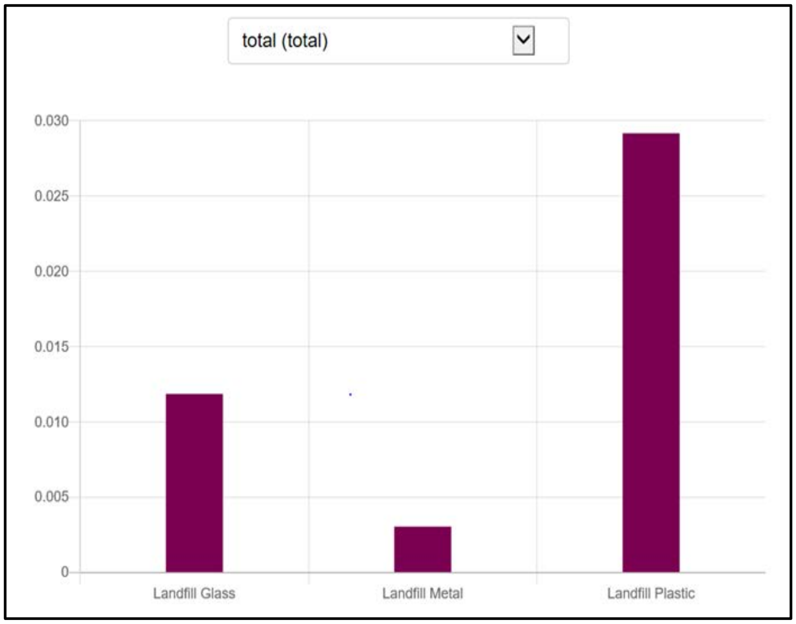


Figure 6
Graph displaying the total (total) damage indicator of all impact categories.

impact compared to metal and a 59.6% greater impact compared to glass. Figure 3, along with Appendix H provides the list of single indicators that factor into the Total (total) damage indicator.

Figure 7 provides a closer analysis of Human Health (Total) by looking at Human Health (Human Toxicity). This figure helps identify why Human Health is so greatly impacted in comparison to Environmental Quality (Total). Looking back at the inputs and outputs for each product, it was noted that Krypton-85 and Radon-222 were major contributors. Both are radioactive gases and can have harmful effects on the body. Krypton reduces or displaces the normal oxygen concentration in breathing air which has narcotic effects on the human body. Krypton-85 impacts breathing and may cause cancers, thyroid disease, skin, liver, or kidney disorders (Environment Pollution Centers, 2021). According to the EPA, Radon can increase the risk of lung cancer. It is also moderately soluble in water, and if ingested, can result in cancers of internal organs. Based on the inputs and outputs of the products, plastic emits roughly 90% more Krypton and Radon than glass and ferrous metal This provides insight into why plastic has a greater impact on human health.

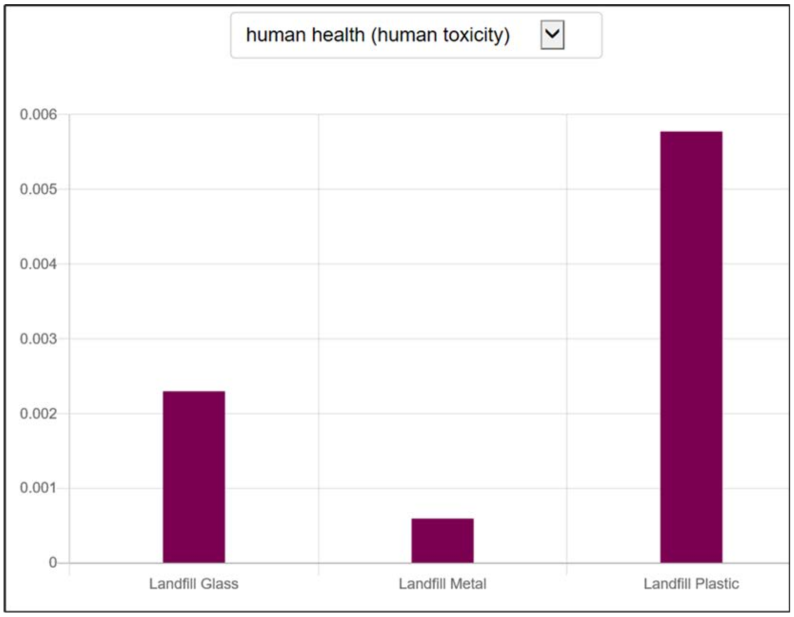


Figure 7
Graph displaying the Human Heath (Human Toxicity) single Indicator.

LIMITATIONS

Although Life Cycle Assessments provide key information in the assessment of a product, process, or service, there are some limitations. The accuracy and dependability of the assessment depend on the availability of the data which can be difficult to find or can be dated. The data that was utilized in this study was last updated in 2016, thus, an updated version is necessary. It is also important to note that this is a European database. Not only are there differing regulations and guidelines across European countries concerning waste production and disposal, but the United States would have varying results. For example, the European Parliament approved a law to ban single-use plastics by 2021, while the US and countries outside of the EU have not. Another limitation is that ferrous metals are typically reusable, thus making it complicated to compare the products. Although plastic has a more harmful end of life, the production of the metal is more impactful than plastic production. This limitation shows how complex this issue regarding the end of life of products is. It is also important to note that the unit used in the software was 1kg. This unit was used to keep the products comparable, but as seen earlier in Figure 1, differing volumes of this waste end up in landfills. In addition to data limitations, an LCA does not consider the cost of the product, process, or service, thus, an LCA should be accompanied with a cost analysis to achieve a clearer understanding of what is under consideration is an economically plausible solution.

CONCLUSION

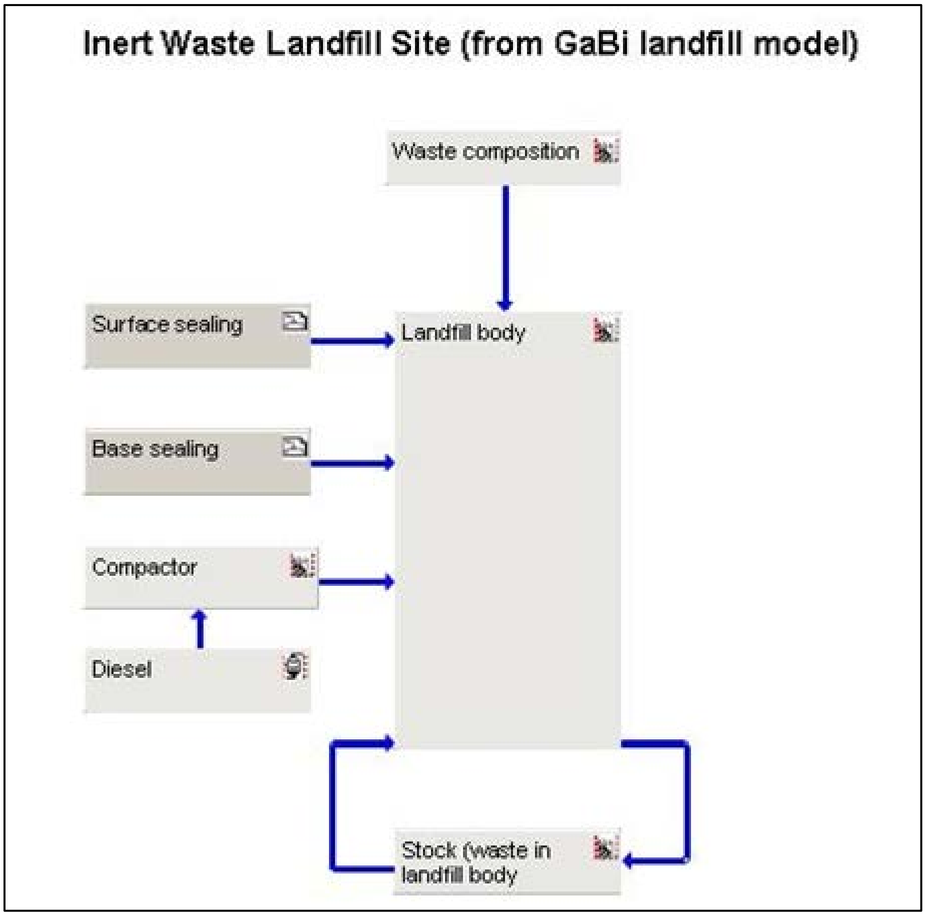
In conclusion, the product with the least environmental impact once in a landfill is made from ferrous metals. In every impact category, ferrous metals scored the lowest points, thus determining that it has the lesser impact on the given products. Plastic scored the most points for each impact category, proving that plastic waste has more severe environmental impacts at its end-of-life. It was apparent that Human Health was impacted more than Ecosystem Quality. Looking at the outputs of the products proved why Human Health (Human Toxicity) was impacted so greatly due to the Krypton and Radon outputs.

Based on these findings, it is clear there must be a change in consumption of these products, more specifically plastics. Plastics are impacting not only the health of the immediate environment but human health as well. To avoid a continuous build-up of plastic in the environment, coordinated global action is urgently needed to reduce plastic consumption. There must be an increase in reuse rates, waste collection, and recycling. Expansion of safe disposal systems and waste management systems will greatly help mitigate the issues of plastic waste. For there to be a long-term change, urgency for innovation in the plastics value chain is necessary. Although this study mainly focused on disposal in landfills, new solutions and alternatives to plastic are emerging and should have a greater value placed on them. To solve an issue, the root cause of the issue must be addressed, thus plastic consumption must be reduced or completely terminated.

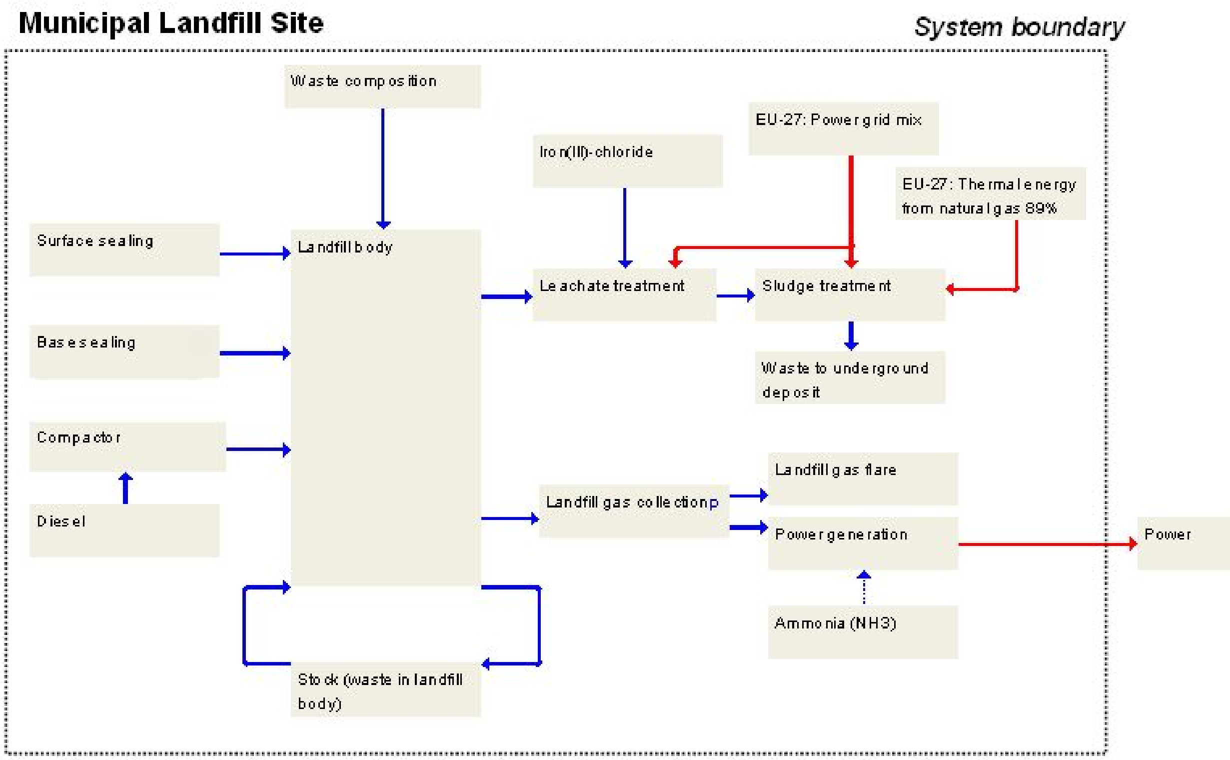
The opportunities for future research include a full life cycle analysis of these products from cradle to grave or cradle to cradle. This research can provide further analysis on the entire lifecycle of plastic, glass, and ferrous metal-based bottles. Further research could potentially include bioplastic-derived bottles as more production of biodegradable and compostable products enter the market. As this new technology emerges it will be valuable to conduct an LCA to determine their impact on the environment and human health.

APPENDICES

Appendix A - (OpenLCA municipal landfill site flow chart: Glass)



Appendix B - (OpenLCA municipal landfill site flow chart: Ferrous Metals and Plastic)



Appendix C – (OpenLCA snapshot examples of inputs and outputs of glass)

Inputs

Flow	Category	Amount	Unit
Water, surface	Resource/in water	0.62878	kg
crude oil; 42.3 MJ/kg	Resource/in ground	0.10564	MJ
natural gas; 44.1 MJ/kg	Resource/in ground	0.03557	MJ
Clay, unspecified, in ground	Resource/in ground	0.03340	kg
Aggregate, natural	Resource/in ground	0.02905	kg
Sand, quartz, in ground	Resource/in ground	0.02322	kg
Air	Resource/in air	0.01809	kg
hard coal; 26.3 MJ/kg	Resource/in ground	0.01562	MJ
Soil	Resource/in ground	0.01334	kg

Outputs

Flow	Category	Amount	Unit
Krypton-85	Emission to air/unspec...	0.88385	kBq
Air, used	Emission to air/unspec...	0.08536	kg
Hydrogen-3, Tritium	Emission to water/fres...	0.03494	kBq
Water vapour	Emission to air/unspec...	0.02121	kg
Heat, waste	Emission to air/unspec...	0.02091	MJ
Overburden (deposited)	Deposited goods/Stoc...	0.01932	kg
Radon-222	Emission to air/unspec...	0.01288	kBq
Carbon dioxide	Emission to air/unspec...	0.01178	kg
spoil (unspecified)	Wastes/Mining waste	0.00524	kg

Appendix D – (OpenLCA snapshot examples of inputs and outputs of ferrous metals)

Inputs

Flow	Category	Amount	Unit
Water, surface	Resource/in water	0.13459	kg
crude oil; 42.3 MJ/kg	Resource/in ground	0.07112	MJ
natural gas; 44.1 MJ/kg	Resource/in ground	0.05970	MJ
Air	Resource/in air	0.03214	kg
Uranium	Resource/in ground	0.01082	MJ
Metamorphous rock, graphite...	Resource/in ground	0.00881	kg
hard coal; 26.3 MJ/kg	Resource/in ground	0.00810	MJ
Clay, unspecified, in ground	Resource/in ground	0.00803	kg
Aggregate, natural	Resource/in ground	0.00746	kg

Outputs

Flow	Category	Amount	Unit
Krypton-85	Emission to air/unspec...	0.85018	kBq
Air, used	Emission to air/unspec...	0.04345	kg
Hydrogen-3, Tritium	Emission to water/fres...	0.03361	kBq
Heat, waste	Emission to air/unspec...	0.02811	MJ
Radon-222	Emission to air/unspec...	0.01239	kBq
Water vapour	Emission to air/unspec...	0.01207	kg
Carbon dioxide	Emission to air/unspec...	0.01084	kg
Overburden (deposited)	Deposited goods/Stoc...	0.01028	kg
Heat, waste	Emission to water/fres...	0.00224	MJ

Appendix E – (OpenLCA snapshot examples of inputs and outputs of plastic)

Inputs

Flow	Category	Amount	Unit
Water, surface	Resource/in water	1.28789	kg
natural gas; 44.1 MJ/kg	Resource/in ground	0.56056	MJ
crude oil; 42.3 MJ/kg	Resource/in ground	0.31671	MJ
Air	Resource/in air	0.27831	kg
Uranium	Resource/in ground	0.10352	MJ
Metamorphous rock, graphite...	Resource/in ground	0.08490	kg
Clay, unspecified, in ground	Resource/in ground	0.07830	kg
hard coal; 26.3 MJ/kg	Resource/in ground	0.07792	MJ
Aggregate, natural	Resource/in ground	0.07273	kg

Outputs

Flow	Category	Amount	Unit
Krypton-85	Emission to air/unspec...	8.13035	kBq
Air, used	Emission to air/unspec...	0.39508	kg
Hydrogen-3, Tritium	Emission to water/fres...	0.32142	kBq
Heat, waste	Emission to air/unspec...	0.21685	MJ
Radon-222	Emission to air/unspec...	0.11851	kBq
Water vapour	Emission to air/unspec...	0.10076	kg
Overburden (deposited)	Deposited goods/Stoc...	0.09927	kg
Carbon dioxide	Emission to air/unspec...	0.06102	kg
Heat, waste	Emission to water/fres...	0.02139	MJ

<u>Appendix F – (OpenLCA Endpoint (H,A) Impact categories)</u>

Appendix G – (Life Cycle Impact Analysis results)

LCIA Results

This table shows the LCIA results of the project variants. Each selected LCIA category is displayed in the rows and the project variants in the columns. The unit is the unit of the LCIA category as defined in the LCIA method.

Indicator	Landfill Glass	Landfill Metal	Landfill Plastic	Unit
ecosystem quality (agricultural land occupation)	0	0	0	points
ecosystem quality (climate change, ecosystems)	1.20646e-4	3.16418e-5	3.06814e-4	points
ecosystem quality (freshwater ecotoxicity)	1.22477e-7	7.42715e-8	3.08890e-7	points
ecosystem quality (freshwater eutrophication)	0	0	0	points
ecosystem quality (marine ecotoxicity)	1.43145e-7	4.21611e-8	3.60011e-7	points
ecosystem quality (natural land transformation)	0	0	0	points
ecosystem quality (terrestrial acidification)	9.79346e-5	2.53291e-5	2.46413e-4	points
ecosystem quality (terrestrial ecotoxicity)	2.89745e-5	2.82897e-5	7.35423e-5	points
ecosystem quality (total)	2.47821e-4	8.53771e-5	6.27438e-4	points
ecosystem quality (urban land occupation)	0	0	0	points
human health (climate change, human health)	1.90877e-4	5.00613e-5	4.85418e-4	points
human health (human toxicity)	2.29688e-3	5.93608e-4	5.77274e-3	points
human health (ionising radiation)	3.58440e-5	9.30364e-6	9.05917e-5	points
human health (ozone depletion)	4.73353e-6	1.22862e-6	1.19633e-5	points
human health (particulate matter formation)	9.07221e-3	2.29403e-3	2.21757e-2	points
human health (photochemical oxidant formation)	6.12483e-7	1.61761e-7	1.54008e-6	points
human health (total)	1.16012e-2	2.94839e-3	2.85380e-2	points
resources (fossil depletion)	0	0	0	points
resources (metal depletion)	0	0	0	points
resources (total)	0	0	0	points
total (total)	1.18490e-2	3.03377e-3	2.91654e-2	points

Works Cited

Blanco, E., Craig T., Bateman A. (2014) *Green Supply Chain Management.* MIT Center for Transportation & Logistics.

Borrelle, S. B., Ringma, J., Law, K. L., Monnahan, C. C., Lebreton, L., McGivern, A., Murphy, E., Jambeck, J., Leonard, G. H., Hilleary, M. A., Eriksen, M., Possingham, H. P., Frond, H. D., Gerber, L. R., Polidoro, B., Tahir, A., Bernard, M., Mallos, N., Barnes, M., & Rochman, C. M. (2020). *Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution.* Science, 369(6510), 1515–1518. https://doi-org.bryant.idm.oclc.org/10.1126/science.aba3656

Cuthbert, L., Root, T., Parker, L., & Borunda, A. (2019). Our Addiction to Plastic. National Geographic, 236(6), 68–77.

Environmental Pollution Centers. (2021, April). *Krypton-85 Poisoning*. Retrieved from Environmental Pollution Centers: https://www.environmentalpollutioncenters.org/krypton-85/

Facts and Figures about Materials, Waste, and Recycling. (2020, September). Retrieved from EPA: https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/glass-material-specific-data

Facts and Figures about Materials, Waste, and Recycling, Glass: Material-Specific Data. (2020, September). Retrieved from EPA: https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials

Goleman, D., & Norris, G. (2009, April). How Green Is My Bottle. Retrieved from The New York Times: https://archive.nytimes.com/www.nytimes.com/interactive/2009/04/19/opinion/20090419bottle.html?_r

Hamilton, L., Feit, S., & Kelso, M. (2019). Plastic & Climate The Hidden Costs of a Plastic Planet. Creative Commons Attribution.

Lau, W. W. Y., Shiran, Y., Bailey, R. M., Cook, E., Stuchtey, M. R., Koskella, J., Velis, C. A., Godfrey, L., Boucher, J., Murphy, M. B., Thompson, R. C., Jankowska, E., Castillo, A. C., Pilditch, T. D., Dixon, B., Koerselman, L., Kosior, E., Favoino, E., Gutberlet, J., & Baulch, S. (2020). *Evaluating scenarios toward zero plastic pollution*. Science, 369(6510), 1455–1461. https://doi-org.bryant.idm.oclc.org/10.1126/science.aba9475

"Life Cycle Assessment: The Basics." Quantifying Sustainability, www.presustainability.com/sustainability-consulting/lca-methodology-basics.

OpenCL. OpenLCA Nexus: The Source for LCA Data Sets, nexus.openlca.org/databases.

OpenLCA. "OpenLCA Software." OpenLCA.org, www.openlca.org/.

Parker, L. (2019, July 5). *A Whopping 91 Percent of Plastic Isn't Recycled*. Retrieved from National Geographic: https://www.nationalgeographic.org/article/whopping-91-percent-plastic-isntr ecycled/#:~:text=You%20can't%20manage%20what%20you%20don't%20measure&text =Of%20the%208.3%20billion%20metric,the%20natural%20environment%20as%20litte

"ReCiPe." PRé Sustainability, 29 Aug. 2016, pre-sustainability.com/articles/recipe/.

Speck, R. L. (2014). *A Comparative Analysis of Commercially Available Life Cycle Assessment Software.* Michigan State University.