SustainableSolutions
CORPORATION

Hefty® EnergyBag® Program Life Cycle Assessment

Prepared For:

Reynolds Consumer Products

7/27/2022

155 Railroad Plaza, Suite 203
Royersford, PA 19468 USA
T: 610 569 1047
F: 610 569 1040
www.SustainableSolutionsCorporation.com

Life Cycle Assessment

Reynolds Consumer Products

Hefty® EnergyBag® Program

7/27/2022

Commissioned by Reynolds Consumer Products

LCA Practitioner: Sustainable Solutions Corporation

Prepared for: Hefty® (Reynolds Consumer Products)

Conducted to Conform with ISO 14040, 14044, 14071 LCA Standards

Life Cycle Assessment

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Hefty® EnergyBag® Program

Executive Summary

Life cycle assessment (LCA) is a rigorous study of the inputs and outputs of a particular product or product system which provides a scientific basis for evaluating the impacts through the life cycle. LCA is a tool which helps facilitate a better understanding of environmental impact throughout the Hefty® EnergyBag® product system's life cycle to enable decision makers to make more informed decisions on impact drivers.

This report documents the details, data, and results of the 2022 LCA of the Hefty® EnergyBag® program as compared to a baseline of a Hefty® Flex Trash Bag ("Flex Bag") disposed at end-of-life (EOL) in a landfill. The cradle-to-grave analysis includes filling the two bags with identical contents. The Hefty® EnergyBag® program enables a pathway for a more circular economy for hard-to-recycle plastics that would otherwise be sent to landfill. The program aims to create a more sustainable future by diverting this waste and utilizing the material as a valued resource. At the time of the study, the Hefty® EnergyBag® program was active in four geographic regions in the US: Cobb County, GA; Omaha, NE; Lincoln, NE; and Boise/Ada County, ID. This LCA study quantifies the cradle-to-grave environmental impacts of the Hefty® EnergyBag® program and includes a life cycle analysis of six landfill alternatives including use in roofing cover boards, construction blocks, concrete aggregate, drainage material, unique pyrolysis technology, and cement kiln fuel. The study utilized a Hefty® Flex (drawstring with flex) trash bag sent to a landfill as a baseline. The LCA results were characterized into impact assessment indicator categories using the US Environmental Protection Agency's (EPA) Tools for the Reduction and Assessment of Chemicals and Other Environmental Impacts v2.1 (TRACI v2.1) factors[1].

The objective of Reynolds Consumer Products commissioning this study was to better understand the cradle-to-grave impacts of the Hefty® EnergyBag® program and determine the environmental impacts of various end-of-life technologies. This analysis serves as a snapshot of the Hefty® EnergyBag® program in mid-2021 as an update to the study conducted on the program in late 2019. The results section includes TRACI impacts across the life cycle stages as well as a calculation for how far the alternative end-of-life

[1] Environmental Protection Agency. Tools for Reduction and Assessment of Chemicals and Other Environmental Impacts. Version 2.1.2014. https://nepis.epa.gov/Adobe/PDF/P100HN53.pdf

technologies can be sited to maintain environmental advantages (in global warming potential) over sending to a landfill.

A review of the full text LCA report was conducted in January 2022 to identify improvements and demonstrate conformance with the ISO 14040:2016; ISO 14044:2006; and ISO/TS 14071:2006 Life Cycle Assessment standards. Per ISO standards, the external third-party independent expert review was conducted by a three-person independent review panel including:

1. **Tom P. Gloria, Ph.D.: Managing Director**
   Industrial Ecology Consultants
2. **Mike Levy, CLE: Senior Associate**
   First Environment
3. **James Salazar: Senior Research Specialist**
   ATHENA Sustainable Materials Institute

Key Findings

This LCA study identified life cycle impacts and opportunities for improvement of the Hefty® Energy Bag® program compared to the baseline of the Hefty® Flex Trash Bag program (i.e., landfill baseline). The study determined that the raw materials of the contents filling the bag are the main driver across most impact categories followed by the end-of-life processes. The end-of-life analysis revealed using the materials as an alternate fuel in cement production (-7.69E-01 kg CO_2 eq) and processing the materials into construction blocks (1.52E-02 kg CO_2 eq), roofing board (-3.46E-01 kg CO_2 eq), and drainage material (-9.16E-01 kg CO_2 eq) fare better than landfilling the materials (1.53E-01 kg CO_2 eq) when focusing on global warming potential (i.e. greenhouse gas emissions). Using a unique pyrolysis technology (6.39E-02 kg CO_2 eq for one dataset, 3.87E-01 kg CO_2 eq for another dataset) to process the materials into petroleum products had varying results, concluding that operating conditions and other parameters are significant considerations when comparing this technology to landfilling the materials. The recycling into concrete aggregate end-of-life option (2.94E-01 kg CO_2 eq), is more impactful than landfill due to electricity inputs required in the process and low impact offset credit of gravel. The end-of-life global warming potential (GWP) impacts are summarized in Table ES.1 below and further analyzed in Section 6.1.

Table ES.1 – End-of-Life GWP Summary Table

End-of-Life Option	Global Warming (kg CO_2 eq)	Percent of Landfill Baseline
Drainage Material	-9.16E-01	-598%
Cement Kiln Fuel	-7.69E-01	-502%
Roofing Cover Board	-3.46E-01	-226%
Construction Block	1.52E-02	10%
Unique Pyrolysis Technology Dataset 2	6.39E-02	42%
Landfill (baseline)	1.53E-01	100%
Concrete Aggregate	2.94E-01	192%
Unique Pyrolysis Technology Dataset 1	3.87E-01	266%

Table ES.2 below provides a summary of the environmental impacts of the different end-of-life options in each geographic region. The end-of-life scenarios which are environmentally preferential from a GWP perspective include using plastics as an alternate fuel in cement production (Cement Kiln Fuel) in all regions, and converting the plastics using unique pyrolysis technology using dataset 2's operating conditions in Cobb County. In Boise, converting plastics into a construction block is slightly more impactful in cradle-to-grave GWP impact than landfilling due to the additional transport distance required for the initial block creation during the pilot project. Section 6.2.4 discusses the GWP benefit if a processing facility were co-located with a material recovery facility (MRF) in the future.

Table ES.2 – LCA Summary Table

Location	End-of-Life Option	Global Warming (kg CO_2 eq)	Ozone Depletion (kg CFC-11 eq)	Smog (kg O_3 eq)	Acidification (kg SO_2 eq)	Eutrophication (kg N eq)	Fossil Fuel Depletion (MJ Surplus)
Cobb County, GA	Unique Pyrolysis Technology Dataset 1	3.76+00	2.97E-06	1.95-01	1.79-02	5.74-03	5.39+00
	Unique Pyrolysis Technology Dataset 2	3.44E+00	2.97E-06	1.78E-01	1.51E-02	5.74E-03	4.98E+00
	Cement Kiln Fuel	2.65E+00	2.97E-06	1.19E-01	-1.32E-04	5.81E-03	9.45E+00
	Landfill	3.49E+00	2.98E-06	1.67E-01	1.36E-02	1.79E-02	9.67E+00
Omaha, NE	Cement Kiln Fuel	2.64E+00	2.97E-06	1.14E-01	-3.38E-04	5.79E-03	9.42E+00
	Landfill	3.50E+00	2.98E-06	1.68E-01	1.37E-02	1.79E-02	9.68E+00
Lincoln, NE	Cement Kiln Fuel	2.64E+00	2.97E-06	1.16E-01	-2.38E-04	5.80E-03	9.43E+00
	Landfill	3.50E+00	2.98E-06	1.70E-01	1.38E-02	1.79E-02	9.69E+00
Boise, ID	Construction Block	3.60E+00	2.96E-06	2.07E-01	1.76E-02	5.96E-03	1.07E+01
	Cement Kiln Fuel	2.66E+00	2.97E-06	1.23E-01	1.39E-05	5.82E-03	9.48E+00
	Landfill	3.50E+00	2.98E-06	1.68E-01	1.37E-02	1.79E-02	9.68E+00

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1.0 Introduction

Life cycle assessment (LCA) is a powerful tool used to quantify the environmental impacts associated with the various stages of a product's life. This section will provide a background and overview of LCA methodology, including the benefits of quantifying the environmental impacts of a product's life cycle, such as identifying opportunities for improvement in environmental impact reductions of the product system.

1.1 Background

The use of LCA is growing rapidly in the consumer products market. Reynolds Consumer Products is a leader in developing sustainable and innovative products. The company is evolving its product stewardship program to evaluate and reduce the impacts of products and processes throughout the corporation and business groups. The Hefty® EnergyBag® program was developed as part of Reynolds Consumer Products' commitment to helping create end-of-life solutions for plastic waste. The Hefty® EnergyBag® program provides consumers in participating markets the ability to collect hard-to-recycle plastics such as candy wrappers, packing peanuts, straws, and foam carry-out containers and see them converted into valuable resources rather than placing these items in a traditional trash bag destined for landfill. This report details the comparative analysis of the Hefty® EnergyBag® orange bag to the Hefty® lavender vanilla scented traditional flex trash bag. This report provides an update from the baseline study published in 2020 and will assist with measuring and understanding the environmental impacts of the Hefty® EnergyBag® program across the life cycle. Reynolds will use the results of this critically reviewed LCA to communicate the environmental impacts and benefits of the Hefty® EnergyBag® program to internal and external stakeholders.

1.2 Overview of Life Cycle Assessment

LCA[2] is an analytical tool used to comprehensively quantify and interpret the environmental flows to and from the environment (including emissions to air, water and land, as well as the consumption of energy and other material resources) over the entire life cycle of a product (or process or service). By including the impacts throughout the product system life cycle, LCA provides a comprehensive view of the environmental aspects of the product and an accurate picture of the true environmental tradeoffs in product selection.

The standards in the ISO 14040-series set out a four-phase methodology framework for completing an LCA, as shown in Figure 1.1 (1) goal and scope definition, (2) life cycle inventory (LCI), (3) life cycle impact assessment, and (4) interpretation. An LCA starts with

[2] This introduction is based on international standards in the ISO-14040 series, *Environmental Management – Life Cycle Assessment. https://www.iso.org/standard/76121.html . Accessed June 28, 2022.*

an explicit statement of the goal and scope of the study; the functional unit; the system boundaries; the assumptions, limitations and allocation methods used; and the impact categories chosen. In the inventory analysis, a flow model of the technical system is constructed using data on inputs and outputs. The input and output data needed for the construction of the model are collected (including resources, energy requirements, emissions to air and water, and waste generation for all activities within the system boundaries). Then, the environmental loads of the system are calculated and related to the functional unit, to finalize the flow model. Inventory analysis is followed by impact assessment, where the LCI data are characterized in terms of their potential environmental impact (e.g., acidification, eutrophication and global warming potential effects). The impact assessment phase of LCA is used to evaluate the significance of potential environmental impacts based on the LCI results. The impact assessment data is interpreted and validated by sensitivity analysis by the LCA practitioner to provide useful data to the company that commissioned the LCA.

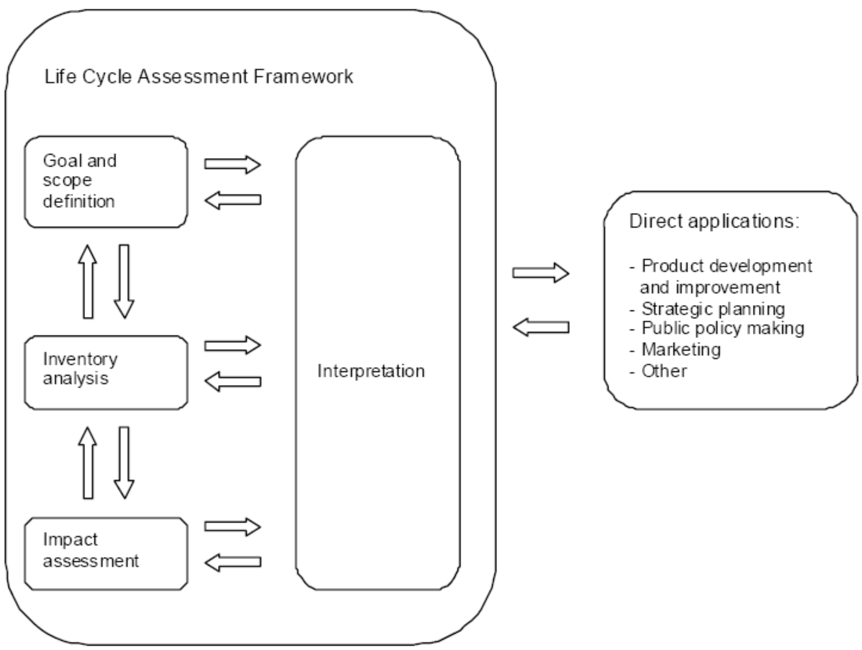

Figure 1.1 – The Four Stages of Life Cycle Assessment

The working procedure of LCA is iterative, as illustrated with the back-and-forth arrows in Figure 1.1. The iteration means that information gathered in a later stage can cause effects in a former stage. When this occurs, the former stage and the following stages must be reworked, taking into account the new information. Therefore, it is common for an LCA practitioner to work at several stages at the same time.

This LCA study is characterized as a "cradle-to-grave" study, examining the Hefty® EnergyBag® program from raw material extraction through final disposal. For this life cycle assessment, Sustainable Solutions Corporation (SSC) collected specific data on energy and material inputs, wastes, water use, emissions, and transportation impacts for the Hefty® EnergyBag® system. This LCA compares the cradle-to-grave impacts of the Hefty® EnergyBag® product system utilizing landfill alternatives as compared to the cradle-to-grave impacts of the Hefty® Flex Trash Bag being landfilled. This LCA was conducted using SimaPro v9.2 software with the National Renewable Energy Lab (NREL) US LCI and the ecoinvent LCI databases serving as the primary source of life cycle inventory data for raw materials and processes not directly collected from the Temple, TX manufacturing plant or end-of-life option partners. Where primary data were not available or missing from these databases, published reports were used. The TRACI 2.1 (TRACI) impact assessment methodology was used to calculate the environmental impacts in this LCA. TRACI was developed by the US Environmental Protection Agency (EPA) as a tool to assist in impact analysis in life cycle assessments, process design, and pollution prevention. Impact categories include:

1. Global Warming Potential
2. Acidification
3. Carcinogens
4. Non Carcinogens
5. Respiratory Effects
6. Eutrophication
7. Ozone Depletion
8. Ecotoxicity
9. Smog

Potential benefits of a life cycle assessment include: the opportunity to identify and implement better materials sourcing, manufacturing process environmental impact reductions, education, evaluation of raw materials, impacts to product standards, decreased air emissions, waste reduction, increased recycling, reduced water use, and cost savings, among many others.

2.0 Goal and Scope Definition

Life cycle assessment is a tool used to quantify the environmental impacts associated with the various stages of a product's life. The nature of life cycle assessment is to include a wide range of inputs associated with the product being analyzed. The following section defines the goal, scope, and boundaries of this LCA study.

2.1 Goal of the Study

The goal of this study is to identify and quantify the environmental impacts associated with each stage in the life cycle of the Hefty® EnergyBag® program including raw material extraction, transport, manufacturing, distribution, collection transport, end-of-life bag processing and avoided burden. The intended use of this study is to determine the environmental benefits of alternative end-of-life options currently utilized in the Hefty® EnergyBag® program compared to a traditional trash bag (Flex Bag) sent to landfill.

2.2 Functional Unit

The functional unit of an LCA is the quantification of a product's performance characteristics which ensures equal functionality of the alternative products that are compared. All flows to and from the environment within the system boundary are normalized to a unit summarizing the function of the system. The function of the Hefty® EnergyBag® orange bag is to serve as an alternative household waste bag to collect and divert difficult-to-recycle plastics from landfill.

Once the primary functions of the systems are defined, a functional unit is selected to provide a similar basis, consistent with the above-mentioned goals, for summarizing the LCA. The functional unit utilized for this study is the equivalent volume (13-gallons) of trash for each bag system. This functional unit is consistent with the goal and scope of the study. Table 2.1 lists specific product details of the Hefty® EnergyBag® orange bag and Flex Bag.

Table 2.1 – Hefty® EnergyBag® and Flex Bag Product Details

Item	EnergyBag®	Flex Bag
Manufacturing Location	Temple, TX	Temple, TX
Functional Unit	One (1) 13-gallon EnergyBag® orange bag	One (1) 13-gallon Flex Bag
Weight (empty)	0.0273 kg	0.0225 kg

The functional unit determines the environmental impacts and is the basis for comparison in an LCA. It provides a unit of analysis and comparison for all environmental impacts. This study focuses on the functional equivalences of avoided materials based on the specific end-of-life process. The functional equivalences in this study are described in Table 2.2 below.

Table 2.2 – End-of-Life Functional Equivalencies

End-of-Life Option	Functional Equivalence
Unique Pyrolysis Technology	Petroleum products and petroleum products in refineries
Cement Kiln Fuel	Plastics as an energy source and coal
Concrete Aggregate	Resin aggregate and stone aggregate
Construction Block	Plastics as a construction building material and ready mixed concrete
Roofing Board	Plastics as a roofing board material and gypsum roofing board
Drainage Material	Plastics as a water conveyance material and a French drain

2.3 System Boundary

Figure 2.1 defines the system boundary for the Hefty® EnergyBag® and Flex Bag product systems.

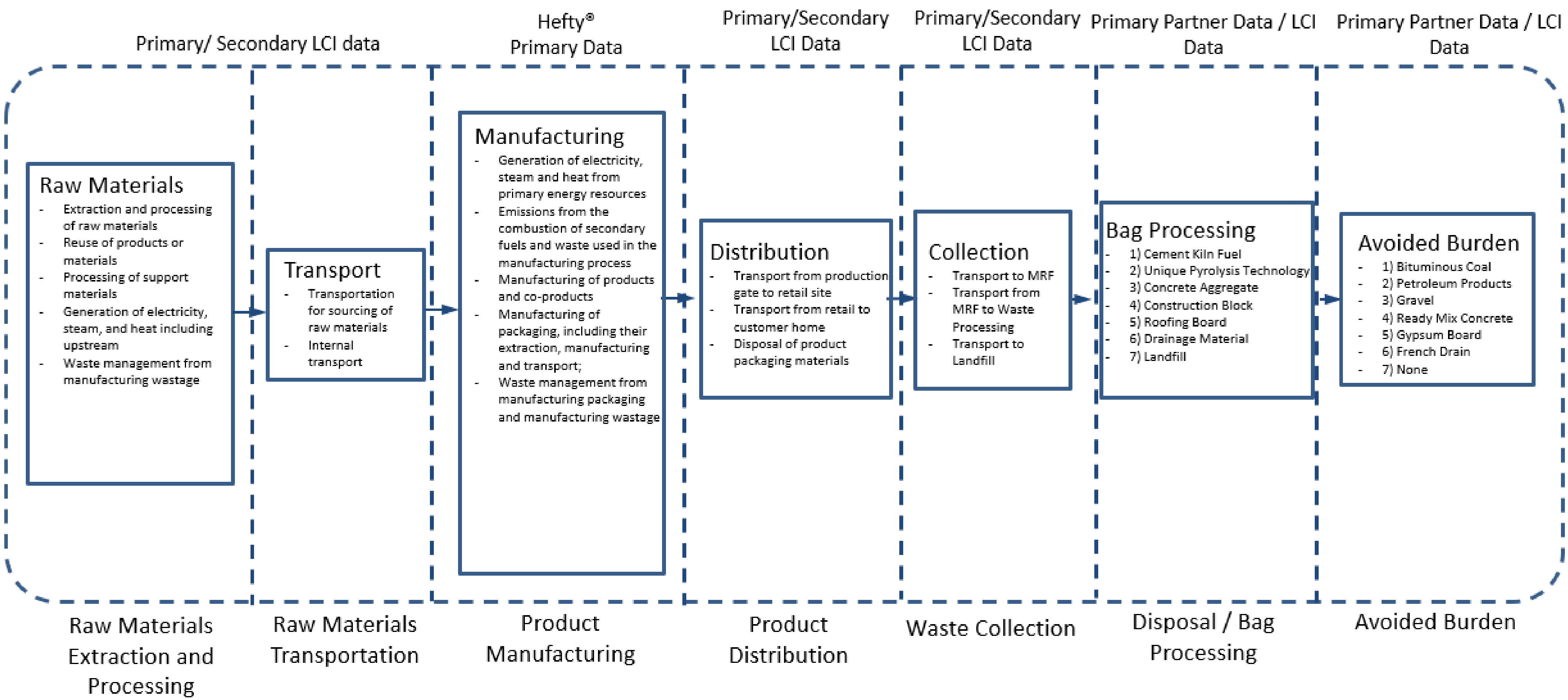

Figure 2.1 – Hefty® EnergyBag® and Flex Bag System Boundary

The study's system boundary includes the transportation of major inputs to (and within) each activity based on logistics data provided by Reynolds, as well as transportation to a landfill, or landfill alternative, at the end of the service life. Any site-generated energy and purchased electricity is included in the system boundary. The extraction, processing, and delivery of purchased primary fuels, e.g., natural gas and primary fuels used to generate purchased electricity, are also included within the boundaries of the system. Purchased electricity consumed at the various site locations is modeled based on regional grid mixes, using the models published in the NREL US LCI database.

Both human activity and capital equipment were excluded from the system boundary. The environmental effects of manufacturing and installing capital equipment and buildings have generally been shown to be minor relative to the throughput of materials and components over the useful lives of the buildings and equipment. The waste resulting from the packaging of the trash bags is considered. Paper and paperboard are assumed to be conventionally recycled, which is a cut-off process, or disposed of within the Hefty® EnergyBag® orange bag as part of the small amount of paper contamination. Human activity involved in the manufacturing of the Hefty® Flex Bag and Hefty® EnergyBag® orange bag, material recovery facility operations, end-of-life processing, and the processing component materials no doubt have a burden on the environment; however, the data collection required to properly quantify human involvement is particularly complicated and allocating such flows to the production of the Hefty® EnergyBag® orange bag as opposed to other societal activities, was not feasible for a study of this nature. Typically, human activity is only considered within the system boundary when value-added judgments or substituting capital for labor decisions are within the scope of the study; however, these types of decisions are outside this study's goal and scope. The details of the data excluded from the system boundary can be found in the subsequent inventory sections. Table 2.3 describes processes that are excluded from the study. All known processes not listed as excluded were considered.

Table 2.3 – System Boundary Description

Included	Excluded
Raw material acquisition	Construction of capital equipment
Processing of materials	Maintenance of operation and support equipment
Transport of raw materials	Human labor and employee commute
Energy used in production at manufacturing facility	General corporate overhead, including executive travel
Final product shipping	Personal vehicle travel
Packaging	Use phase
Manufacturing waste and emissions	
Product disposal	

Table 2.4 details the data sources used for this study. Primary data were collected from Reynolds Consumer Products and the alternative end-of-life processors. The landfill baseline was modeled for the Hefty® Flex Bag system. The Hefty® EnergyBag® system was modeled for the six landfill alternatives.

Table 2.4 – System Boundary and Data Source Comparison of Flex Bag and EnergyBag®

Life Cycle Stage	Flex Bag	EnergyBag®
Raw Material Extraction and Upstream Processes	Integrated via SimaPro v9.2 datasets (ecoinvent 3.7.1 and US LCI)	Integrated via SimaPro v9 datasets (ecoinvent 3.7.1 and US LCI)
Raw Material Transport	Primary data on supplier locations	Primary data on supplier locations
Manufacturing	Primary data on Temple, TX facility	Primary data on Temple, TX facility
Packaging	Primary data on all packaging material compositions and weights	Primary data on all packaging material compositions and weights
Product Distribution	Primary data on Hefty® distribution channels	Primary data on Hefty® distribution channels
End-of-Life – Landfill	Integrated via SimaPro v9.2 datasets (ecoinvent 3.7.1)	-
End-of-Life – Unique Pyrolysis Technology	-	Primary data from an operational pyrolysis facility
End-of-Life – Concrete Aggregate	-	Primary data from an operational concrete aggregate material manufacturer
End-of-Life – Cement Kiln Fuel	-	Combination of primary and secondary data collected from an operational cement kiln.[3,4]
End-of-Life – Construction Block	-	Primary data from an operational construction block manufacturer
End-of-Life – Roofing Cover Board	-	Primary data from an operational roofing cover board manufacturer
End-of-Life – Drainage Material	-	Primary data from an operational drainage material manufacturer

End-of-life landfill alternative data represents predominantly primary data collection. Cement kiln fuel data were collected from a combination of primary and secondary sources. Primary data were used for the energy requirements of pre-processing the EnergyBag® materials versus coal. Secondary data were collected in collaboration with personnel from the operational cement manufacturer for validation. The secondary data collected consisted of non-carbon air emission profiles of plastics and bituminous coal, as well as heating values of the fuels.

2.3.1 Cut-off Criteria

Processes whose total contribution to the final result, with respect to their mass and in relation to all considered impact categories, is less than 1% can be neglected. The sum of

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[3] Georgiopoulou, Martha & Gerasimos Lyberatos, (2017). Life Cycle Assessment of the Use of Alternative Fuels in Cement Kilns: A Case Study. *Journal of Environmental Management* 216.

[4] Simge, Cankaya and Beyhan Pekey, (2018). Comparative Life Cycle Assessment of Clinker Production with Conventional and Alternative Fuels Usage in Turkey. *International Journal of Environmental Science and Development*.

the neglected processes may not exceed 5% by mass and by 5% of the considered impact categories. For that, a documented assumption is admissible.

For Hazardous Substances, as defined by the U.S. Occupational Health and Safety Act,[5] the following requirements apply:

- The Life Cycle Inventory (LCI) of hazardous substances will be included if the inventory is available.
- If the LCI for a hazardous substance is not available, the substance will appear as an input in the LCI of the product, if its mass represents more than 0.1% of the product composition.
- If the LCI of a hazardous substance is approximated by modeling another substance, documentation will be provided.

This LCA is in compliance with the cut-off criteria since no known primary data included in the system boundary were cut-off including any known effluents and emissions. Based on the development of secondary datasets, some secondary data may have been excluded by the developer of the databases based on lack of information, access to primary data, etc. This information can be found in the documentation associated with each database.

The study modelled six end-of-life landfill alternative scenarios for the EnergyBag® materials: (1) converting plastics using unique pyrolysis technology to make fuels and waxes, (2) using plastics as an alternative fuel in cement production, (3) recycling plastics into concrete aggregate for use in durable products, (4) pressing plastics into a block as an alternative construction material to ready mix concrete, (5) using plastics as a raw material with additional paper for roofing board, and (6) processing into a drainage board as an alternative water conveyance and drainage technology to a French drain application. Processes such as recycling for materials that are rejected by these processes, but are recycled, such as corrugate cardboard in pyrolysis, are cut-off after transportation.

3.0 Data Sources and Modeling Software

The quality of results of an LCA study are directly dependent on the quality of input data used in the model. This section describes the data quality guidelines used in this study, the sources from which the data were selected, the software used to model the environmental impacts, and any data excluded from the scope of the study.

3.1 Data Quality

Wherever secondary data were used, the study adopts critically reviewed data for consistency, precision, and reproducibility to limit uncertainty. Regarding geographic and technological coverage, the data sources used are complete and representative of North

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[5] U.S. Department of Labor, Occupational Safety and Health Administration. *Occupational Safety and Health Act of 1970*. https://www.osha.gov/laws-regs/oshact/completeoshact

America, where available. Where unavailable, global data from European databases were used. All datasets are of recent vintage (i.e., less than ten years old). Any deviations from these initial data quality requirements for secondary data are documented in the report.

The results of an LCA are only as good as the quality of input data used. Important data quality factors include precision (measured, calculated or estimated), completeness (e.g., unreported emissions or excluded flows), consistency (uniformity of the applied methodology throughout the study), and reproducibility (ability for another researcher reproduce the results based on the methodological information provided). The primary data from the manufacturer was from the latest data available. Each dataset used was taken from SimaPro v9 databases, either US LCI or ecoinvent. These databases are widely distributed and referenced within the LCA community and are either partially or fully critically reviewed.

Precision

The data used for primary data are based on direct information sources of the manufacturer and end-of-life partners. The energy and water usage data were collected directly from the utility meters and the allocation was based on an automated machine run-time and energy use tracking system at the plant. The precision for primary data is considered high; the uncertainty of the primary data is considered low since actual production and utility data were utilized and are considered reliable sources.

Secondary datasets were used for raw materials extraction and processing, cement kiln emission profiles for coal and plastics, transportation, and energy production flows. The ecoinvent database was used for most of the raw material datasets, unless US LCI data was available. Since the inventory flows for ecoinvent processes are very often accompanied by a series of data quality ratings, a general indication of precision can be inferred. Using these ratings, the datasets generally have medium-to-high precision. Precision for the datasets used from the US LCI database was not formally quantified. Many datasets from the US LCI were developed based on well-documented industry averages utilizing primary data. Furthermore, the datasets provided data quality indicators for each flow; considering them to have medium-to-high precision.

Completeness

The processes modeled represent the specific situations in the Hefty® EnergyBag® system life cycle. System boundaries and exclusions are clearly defined in the sections above, and no other data gaps were identified.

Consistency

Primary data were collected from Reynolds Consumer Products personnel. For the end-of-life options, data were collected and provided by the respective plants. Data validation was conducted with the end-of-life partners. Since most of the data is annually reported, the consistency is considered high. Secondary data were consistently modeled using either US LCI or ecoinvent databases as available. Proxies were only identified and used if secondary data were not available in these or other databases. This methodology provides consistency throughout the model. For the life cycle analysis of the Hefty® EnergyBag® and Flex Bag product systems, the primary data is consistent as both products are manufactured in the same facility, thereby making production and operational data consistent and highly reliable for each product. Both products have very similar bills of materials, therefore the US LCI and ecoinvent datasets utilized are consistent for materials in each product. Manufacturing allocation was determined with plant operations members for consistent allocation practices. For this study, the content of each bag was identical as well as the databases utilized to model the materials between the Flex Bag and EnergyBag® product systems.

Reproducibility

Most datasets are from nationally accepted and publicly available databases, ensuring reproducibility by an average practitioner. Confidential data from the plant and end-of-life options would inhibit reproducing these results without access to the data.

Representativeness

The representativeness of the datasets is chosen to be representative of North America or European average technologies of the major producers and distributors and are of recent and modern vintage.

Uncertainty

Most of the secondary datasets in the US LCI and ecoinvent databases have some uncertainty information documented and vary per model. Uncertainty for primary data is low since reliable measured and metered data was utilized. The collected data and allocation methodologies were judged by the operations personnel to be accurate, so the uncertainty is considered low.

The primary data from the manufacturer were from the latest data available (2019), incorporating the most recent updates to the process into the model. Each dataset used was taken from SimaPro databases, either US LCI or ecoinvent. These databases are widely distributed and referenced within the LCA community. The datasets use relevant yearly averages of primary industry data or primary information sources of the manufacturer and technologies. The uncertainty of each dataset is not formally quantitatively known. Each dataset is from publicly available databases, ensuring reproducibility. The representativeness of the datasets is chosen to be representative of North America, where available, and European datasets, where North American is not available. Section 3.2 and 3.3 below contain a more detailed description of the datasets and sources used in the model of the life cycle stages of the Hefty® EnergyBag® and Flex Bag systems.

3.2 Data Sources – Reynolds Consumer Products

North America was considered the geographic boundary of this study; specifically, the Hefty® EnergyBag® program is active in four geographic regions: Cobb County, GA; Omaha, NE; Lincoln, NE; and Boise, ID. The reference year of the study is 2021 based upon the data reflecting the EnergyBag® program in 2021. Both primary and secondary LCI and metadata were used throughout the study. All secondary data were taken from published literature, previous LCA studies, and life cycle databases. Primary data include Hefty® EnergyBag® orange bag and Flex Bag raw materials, raw material supplier locations, bag contents raw materials, manufacturing inputs, distribution channels, and packaging materials. The manufacturing energy data were collected utilizing the power draw of the production lines for the Hefty® EnergyBag® orange bag and Flex Bag. The US LCI and ecoinvent databases were frequently used in this analysis. Much of the LCI data residing in the US LCI database pertain to common fuels – their combustion in utility, stationary, and mobile equipment inclusive of upstream or pre-combustion effects. Generally, these modular data are of recent vintage (less than ten years old). This study draws on the US LCI database and ecoinvent database for combustion processes, electricity generation, and transportation.

3.3 Data Sources – End-of-Life

The breakdown of the materials within the full bags was determined via multiple waste characterizations conducted by a third-party consultant. Waste characterizations were conducted by the same third-party consultant across each geographic region. The waste characterizations were conducted following the Hefty® EnergyBag® program's standard operating procedure across all locations. The procedure includes details to ensure reported data comes from a statistically representative sample considering the weight and sourcing location. Following this procedure, sub-samples from each community and for each day of collection are captured to have a community-wide analysis of a given Hefty® EnergyBag® program location. The LCA used bag audit data from all program locations to determine the composition of materials. The average material composition was calculated utilizing a weighted average based on each respective region's January through June 2021 total collection weights.

Data for converting plastics using unique pyrolysis technology were collected from an operational pyrolysis company. Data were collected for two sample campaigns, designated separately as Dataset 1 and Dataset 2 in the analysis. Contaminants to the pyrolysis process are either landfilled, recycled, or stockpiled. Stockpiled contaminants were omitted from this study.

Data for recycling plastics into concrete aggregate were collected from an operational aggregate plant. Data were provided for a projected 12 months at full production. While this process is currently operational, the international location of the plant is prohibitive to receiving Hefty® EnergyBag® materials. The study modeled the processing inputs and outflows of the plastic aggregate manufacturing process, adapting the data to US grid averages for electricity usages. The processing conversion factor and aggregate product yield were validated with a trial using Hefty® EnergyBag® materials at a pilot-scale system in the US that reproduces performance from the operational aggregate plant. From discussions with plant personnel, contaminants of the process would be recycled.

Data for using the plastics as an alternate fuel in cement production were collected from a combination of primary and secondary sources. Primary data were used for the energy requirements of pre-processing the Hefty® EnergyBag® materials versus coal. Secondary data were collected in collaboration with personnel from the cement manufacturer currently processing Hefty® EnergyBag® materials for validation. The secondary data collected were used for the purposes of modeling the emission profiles of incineration of plastics and bituminous coal in a cement kiln. SimaPro v9.2 databases were utilized for higher heating values (calorific values) of the bag constituents to quantify the energy contained within an equivalent mass of cement kiln fuel. Where higher heating values were not available in SimaPro v9.2 databases, secondary data were collected. Table 3.1 below lists the heating values assumed in the model and the data source. The higher heating values were validated by personnel at the plant for consistency.

Table 3.1 – Higher Heating Values and Data Sources of Bag Contents and Bituminous Coal

Material	Higher Heating Value [MJ/kg]	Source
Polyethylene	42.8	ecoinvent 3.7.1
Mixed Plastics (Unidentifiable)	34.1	ecoinvent 3.7.1
Polyethylene Terephthalate	24.7	Secondary Data[6]
High Density Polyethylene	40.2	Secondary Data[6]
Polyvinyl Chloride	19.1	ecoinvent 3.7.1
Low Density Polyethylene	45.7	Secondary Data[6]
Polypropylene	44.1	Secondary Data[6]
Polystyrene	38.9	ecoinvent 3.7.1
Glass	0.14	ecoinvent 3.7.1
Paper	16.61	ecoinvent 3.7.1
Bituminous Coal	26.4	ecoinvent 3.7.1

Data for using the plastics in construction block were collected by block manufacturing personnel at their current site. The construction block's technology is designed to be co-located with a material recovery facility (MRF), although at the time of this study this deployment has not occurred.

Data for using the plastics as a raw material with additional paper for roofing cover board were collected by roofing cover board manufacturing personnel at their current manufacturing site.

Data for processing the plastics into a drainage board were collected by drainage material manufacturing personnel from their operational facility. The specific equipment and operations were kept proprietary but primary data were collected for material, energy, and water inputs and outputs.

Landfills were assumed to be located 10km away from the material recovery facility in each Hefty® EnergyBag® program region. Sanitary or inert landfill ecoinvent processes were utilized for each material constituent of the Hefty® EnergyBag® orange bag based upon the waste characterizations.

3.4 Raw Material Assumptions

Life cycle analysis requires that assumptions be made to constrain the project boundary or model processes when little to no data are available. When data limitations existed for particular raw materials, proxy data from SimaPro v9.2 databases were used.

[6] Tsiamis, A. Demetra and Marco J. Castaldi (2016). Determining Accurate Heating Values of Non-Recycled Plastics (NRP)

3.5 Manufacturing Assumptions

Primary data were collected monthly for production of Hefty® EnergyBag® orange bags and Flex Bags at the Temple, TX facility for the 2019 calendar year during the original study. The data were confirmed with plant personnel to have remained the same. The power draw and run time hours were measured by onsite personnel for the extrusion line.

3.6 Distribution and Packaging Allocation and Assumptions

The distribution data were collected through primary Hefty® data and is further detailed in Section 4.0 below. The following assumptions were made for the Hefty® EnergyBag® orange bag distribution and packaging:

- All distribution occurred via truck within the United States and originated from Temple, TX.
- Where multiple distribution paths were available for one Hefty® EnergyBag® program region, a weighted average was used.

3.7 Modeling Software

SimaPro v9.2 software was utilized for modeling the complete cradle-to-grave LCI for the Hefty® EnergyBag® and Flex Bag product systems. All process data including inputs (raw materials, energy and water) and outputs (emissions, wastewater, solid waste, and final products) were evaluated and modeled to represent each process that contributes to the life cycle of the Hefty® EnergyBag® system. The study's geographical and technological coverage has been limited to North America, focusing on the regions applicable to the Hefty® EnergyBag® program. SimaPro v9.2 was used to generate life cycle impact assessment (LCIA) results utilizing the TRACI impact assessment methodology.

4.0 Life Cycle Inventory Analysis

This section describes the cradle-to-grave life cycle inventory of the Hefty® EnergyBag® product system. Primary manufacturing data were collected from surveys completed by personnel from the Hefty® manufacturing plant located in Temple, TX. The participating manufacturing plant provided resource transportation mode and distance data to support the calculation of raw material transportation flows. The transportation LCI data from the US LCI database (kg-km basis) were used to develop the resource transportation LCI profile.

4.1 Raw Material Transport and Product Recipe Overview

Raw material transport included the distance traveled from the raw material processing location (ingredient supplier) to the Temple, TX manufacturing facility. Ingredient supplier locations were provided by Reynolds Consumer Products. All raw materials were transported domestically via truck. A thorough analysis of the material inputs and the product recipes were completed for the inventory of this study.

4.2 Manufacturing Process Overview

The Temple, TX facility was used to compare the manufacturing of the Flex Bag and Hefty® EnergyBag® orange bag. To produce the Hefty® EnergyBag® and Flex Bag, electricity is the main input to the manufacturing process.

4.3 Packaging Options

The Hefty® EnergyBag® program currently has one packaging option. This packaging option was compared to the primary packaging format of the Flex Bag. Both items are similarly packaged in a corrugate carton, placed in a corrugate case, and shipped on a pallet.

4.4 Bag Contents Raw Materials

Understanding the contents of materials that fill the bag is an essential piece to quantifying the environmental impacts of the Hefty® EnergyBag® program as end-of-life technologies may reject certain incoming materials. Additionally, the contents of the bag determine the materials that are being landfilled as the baseline. To better understand the materials contained within the Hefty® EnergyBag® orange bag during consumer use, Reynolds Consumer Products commissioned waste audits in 2021 at locations in which the program is currently active. As noted in Section 3.3, waste characterizations were conducted following the Hefty® EnergyBag® program's standard operating procedure by the same third-party consultant across all locations. The study used the weighted average composition of materials from these waste audits based on the January through June 2021 collection weights in each program area. Based on discussions about the audits with the Hefty® team, an inventory of materials was created. These materials play a key role in both raw material impacts as well as the efficacy of the different end-of-life options.

4.5 Transportation

The study models the distribution impacts of transporting the Hefty® EnergyBag® orange bags and Flex Bags from the manufacturing plant to the specified warehouse and then to retail stores. Personal vehicle travel is omitted. Distances from warehouses to retail stores were estimated based on the distance from the specified warehouse to the geographic center of each county.

Collection and transportation distances were determined based on the geographic center of the Hefty® EnergyBag® program regions to the material recovery facility (MRF) then from the MRF to the end-of-life partner.

4.6 End-of-Life Options

The main goal of this study is to evaluate the end-of-life options for the Hefty® EnergyBag® orange bag and material contents using landfilling of the Flex Bag and material contents as the baseline end-of-life scenario for these materials. The alternative options explored in this study for end-of-life include converting plastics using unique pyrolysis technology, using plastics as an alternative fuel in cement production, processing plastics into concrete aggregate, roofing board, construction blocks, and drainage materials.

4.6.1 Unique Pyrolysis Technology

Pyrolysis is a decomposition technology utilized to convert plastic waste in the absence of oxygen to produce gaseous and liquid hydrocarbons that could be used as either transportation fuel or a source of chemical products. A US-based pyrolysis plant with experience processing Hefty® EnergyBag® materials was selected to collect primary data. The processing protocol at this plant included sorting out PET and PVC plastics as well as any other non-plastic contaminant. Contaminants to the pyrolysis process are either landfilled, recycled, or stockpiled. Stockpiled contaminants were omitted from this study. The product that is being offset as the avoided burden of this process is transportation fuels.

Data were collected for two separate campaigns; the first campaign is delegated as "Dataset 1", and second campaign as "Dataset 2". While the two campaigns do not necessarily represent a minimum and maximum range, they do represent a general range of impacts and avoided burdens from this specific pyrolysis process. Variation between the datasets are generally caused by the variation of the types of materials in the bag contents, seasonal variation, weather differences, and general operational efficiencies and production outputs.

4.6.2 Concrete Aggregate

The second end-of-life option assessed in this study was the recycling of the Hefty® EnergyBag® contents into an aggregate material for use in concrete masonry units (CMUs). This partner has had experience qualifying the Hefty® EnergyBag® orange bag and material. Due to the current location of the plant, this end-of-life option is not currently receiving Hefty® EnergyBag® material, but provided data based on hard-to-recycle waste plastics received locally. The Hefty® team completed a trial with Hefty® EnergyBag® materials to confirm parameters used in this study. The study adapted the facility's grid mix to the US average grid mix to model the electricity inputs of the facility in North America. The product that is being offset as the avoided burden of this process is gravel, which is currently the standard coarse aggregate material in concrete.

4.6.3 Cement Kiln Fuel

The third end-of-life option assessed in this study is the utilization of the Hefty® EnergyBag® contents as fuel in a cement kiln. The study measured the impacts of substituting a coal-fired cement kiln with a Hefty® EnergyBag® material-fueled cement kiln. Refuse-derived fuels have been used in cement kilns as a replacement for coal and to divert waste from landfill. Some options for refuse-derived fuels include rubber tires, municipal solid waste, bio-sludge, and plastics.

Plastics have a benefit compared to coal due to two properties of the plastics. The first advantage is the weighted-average heating value of the Hefty® EnergyBag® contents. The mixed plastics heating value was determined from a weighted average of the material composition of Hefty® EnergyBag® collected materials from waste characterization results.

The second advantage is emissions. In addition to this energy density advantage, data were collected from the partnering cement kiln's carbon emission calculation tool for using plastics versus coal. In terms of carbon dioxide stack emissions, the plastics showed a lower emission factor (ton CO_2 eq per ton fuel) than coal. To complement primary data available from the cement kiln, a literature review was completed to assess the emission profiles of coal fired cement kilns and substitution with refuse-derived fuels (Hefty® EnergyBag® contents). It was determined through discussion with personnel from the cement kiln that the end-of-life option remained the same from the 2020 study.

4.6.4 Roofing Cover Board

The fourth end-of-life option considered for the Hefty® EnergyBag® system is as an input for roofing cover boards. This partner has had experience qualifying the Hefty® EnergyBag® orange bag and material but is not currently processing Hefty® EnergyBag® material on an ongoing basis. However, a trial was completed with EnergyBag® materials to confirm the parameters used in this study.

This material would share properties with and highly resemble gypsum board. Gypsum is one of the most prevalent building materials in residential and commercial buildings for walls and ceilings as a roof cover board. The contents of the Hefty® EnergyBag® orange bag are all acceptable for this application; however, paper is also required for the process, which does increase the environmental impact of this option somewhat. The benefit of this option is the avoidance of using gypsum board and the avoidance of the trash bag sent to a landfill.

4.6.5 Construction Block

The fifth end-of-life option evaluated replaces pre-cast concrete blocks as a construction material with a material made from compressed Hefty® EnergyBag® contents. However, the applications of this product are limited to relatively low compressive strength applications, such as retaining walls, sheds, landscaping, sound walls, and other similar applications. The avoided burden of this option is the avoidance of the production of low compressive strength ready mix concrete. These blocks are produced by shredding the bag contents and fusing the material into a block. Contaminants are separated from the stream and include items like paper, expanded polystyrene foam, and cardboard.

Primary data were collected utilizing Hefty® EnergyBag® material shipped from Boise to the company's main facility. However, the technology is designed to be deployed in a shipping container and co-located with a material recovery facility to minimize transportation cost and environmental impacts.

4.6.6 Drainage Material

The final landfill alternative option utilizes Hefty® EnergyBag® material to produce a water drainage and conveyance board. Personnel at the company confirmed that none of the contents of an average Hefty® EnergyBag® filled bag would be rejected. The traditional method of water drainage and conveyance is the French drain application. The French drain application consists of aggregate (gravel), non-woven polypropylene geotextile cloth, and PVC pipe.

Primary data were collected from drainage material operations personnel; however, the manufacturing process was deemed proprietary. The only inputs to the system are electricity and water with the only outputs being the avoided burden products. The avoided products for this end-of-life option are the components of a French drain.

4.6.7 Landfill

The baseline landfill scenario was developed using secondary data from the ecoinvent 3 database. The full bag bill of materials as well as the bag itself were considered for the landfill baseline. All materials, excluding glass, were modeled as treatment in sanitary landfills with landfill gas and leachate capture technology. Waste glass is modeled as treatment in an inert material landfill with renaturation after closure.

5.0 Life Cycle Impact Assessment (LCIA)

The environmental impacts of a system can be categorized and presented in many ways. This section briefly describes the methodology used to develop the impact assessment and defines the selected impact categories used to present the results. This section also lists assumptions of the study and describes the inherent limitations and uncertainty of the LCA results. LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

5.1 Impact Categories/Impact Assessment

As defined in ISO 14040:2006, "the impact assessment phase of an LCA is aimed at evaluating the significance of potential impacts using the results of the LCI analysis". In the LCIA phase, SSC modeled a set of selected environmental issues referred to as impact categories and used category indicators to aggregate similar resource usage and emissions to explain and summarize LCI results. These category indicators are intended to "characterize" the relevant environmental flows for each environmental issue category to represent the potential or possible environmental impacts of a product system.

ISO 14044 does not specify any specific methodology or support the underlying value choices used to group the impact categories. The value-choices and judgments within the grouping procedures are the sole responsibilities of the commissioner of the study.

The framework surrounding LCIA includes three steps that convert LCI results to category indicator results. These include the following:

1. Selection of impact categories, category indicators, and models.
2. Assignment of the LCI results to the impact categories (classification) – the identification of individual inventory flow results contributing to each selected impact indictor.
3. Calculation of category indicator results (characterization) – the actual calculation of the potential or possible impact of a set of inventory flows identified in the previous classification step.

To maximize the reliability and flexibility of the results, SSC used an established impact methodology for assigning and calculating impacts. The Tools for Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) methodology was used for all calculations of environmental impact. TRACI was developed by the US EPA to assist in impact analysis in life cycle assessments, process design, and pollution prevention. The Reynolds team was interested in understanding the typical potential environmental impacts associated with this study, therefore TRACI v2.1 was utilized since the analysis of the Hefty® EnergyBag® program was limited to North America as the geographic region. The Reynolds team was particularly interested in the GWP impacts of the Hefty® EnergyBag® program. This study assessed the GWP transportation cut-off distances for the end-of-life options. Although GWP was the main area of focus, all TRACI impact categories listed in Section 5.2 below are analyzed and discussed. The impact categories discussed in Section 5.2 are traditionally utilized for LCA studies and are the basis for understanding and communicating the potential impacts and benefits of the Hefty® EnergyBag® program.

5.2 Selected Impact Categories

While LCI practice holds to a consistent methodology under ISO 14040, the LCIA phase is less prescriptive with several assumptions that can be made by each practitioner. Following the ISO 14040 and 14044 standards for LCA provides guidance on how to conduct LCIAs. Once completed, the LCI flows are sifted through various possible LCIA indicator methods and categories to determine possible impacts. Due to the North American focus of this LCA study, the TRACI LCIA methodology was used to characterize the study's LCI flows. Impact categories include:

1. *Ozone depletion* (kg CFC-11 eq) – Certain chemicals, when released into the atmosphere, can cause depletion of the stratospheric ozone layer, which protects the Earth and its inhabitants from ultraviolet radiation. This radiation can have a negative impact on crops, materials, and marine life, as well as contributing to cancer and cataracts. This impact measures the releases of those chemicals.
2. *Global warming potential* (kg CO_2 eq) – The methodology and science behind the Global Warming Potential calculation can be considered one of the most accepted LCIA categories. Carbon dioxide and other greenhouse gasses are emitted at every stage in the manufacturing process. These gasses can trap heat close to the Earth, contributing to global warming.
3. *Smog* (kg O_3 eq) - Under certain climatic conditions, air emissions from industry and transportation can be trapped at ground level where, in the presence of sunlight, they produce photochemical smog, a symptom of photochemical ozone creation potential (POCP). While ozone is not emitted directly, it is a product of interactions of volatile organic compounds (VOCs) and nitrogen oxides (NO_x). The Smog indicator is expressed as a mass of equivalent ozone (O_3).
4. *Acidification* (kg SO_2 eq) – Acidification is a more regional rather than global impact affecting fresh water and forests as well as human health when high concentrations of SO_2 are attained. Acidification is a result of processes that contribute to increased acidity of water and soil systems, frequently through air emission that contribute to acid rain. The largest contributors to acid rain are sulfur dioxide and nitrogen oxide. The acidification potential of an air emission is calculated on the basis of the number of SO_2 molecules that can be produced and therefore is expressed as potential SO_2 equivalents on a mass basis.

5. *Eutrophication* (kg N eq) – Eutrophication is the fertilization of surface waters by nutrients that were previously scarce. When a previously scarce or limiting nutrient is added to a water body, it leads to the proliferation of aquatic photosynthetic plant life. This may lead to the water body becoming hypoxic, eventually causing the death of fish and other aquatic life. This impact is expressed on an equivalent mass of nitrogen (N) basis.
6. *Human Health: Carcinogens & Non-carcinogens* (CTU_h) – This impact assesses the potential health impacts of more than 200 chemicals. These health impacts are general, based on emissions from the various life cycle stages, and do not consider increased exposure that may take place in manufacturing facilities. These impacts are expressed in terms of Comparative Toxic Units (CTU_h). For human health this represents the estimated increase in morbidity in the total human population per kg of chemical emitted.
7. *Respiratory effects* (kg $PM_{2.5}$ eq) – This impact methodology assess the impact of increasing concentrations of particulates on human health. Most industrial and transportation processes create emissions of very small particles which can damage lungs and lead to disease and shortened lifespans. This impact is expressed in terms of $PM_{2.5}$ (particulates that are 2.5 microns or less in diameter).
8. *Ecotoxicity* (CTU_e) – Many chemicals, when released into the environment, can cause damage to individual species and to the overall health of an ecosystem. Ecotoxicity measures the potential damage to the ecosystem that would result from releasing that chemical into the environment. This impact is measured in terms of Comparative Toxic Units (CTUe) and provides an estimate of the potentially affected fraction of species (PAF) integrated over time and volume per unit mass of chemical emitted.
9. *Fossil fuel depletion* (MJ surplus) - Maintaining fossil fuel resources for future generations is an essential part of sustainable development. This impact category measures the depletion of those resources in terms of megajoules (MJ). Fossil fuels are used as energy sources as well as raw materials for chemical productions.

6.0 Hefty® EnergyBag® Program LCA Results

This section presents the results of the LCA study. This section illustrates the quantified impacts for each of the TRACI impact categories, including energy consumption and global warming potential. The focus of this study is a comparison of end-of-life alternatives for the Hefty® EnergyBag® program as compared to a baseline of a Hefty® Flex Bag filled with the same materials disposed at end of life in a landfill. Therefore, Section 6.1 focuses on the end-of-life phases of the life cycle (bag processing and avoided burden) only. Section 6.2 analyzes the full life cycle impacts.

6.1 End-of-Life Analyses

The primary focus of this study is a comparison of end-of-life options. The results in this section focus on the Hefty® EnergyBag® materials processing and avoided burden, which include the input requirements of each end-of-life option and the environmental benefit of avoiding the virgin raw materials that can be mitigated by the output from these processes. The avoided burden for each process represents the extent to which the output from each end-of-life option displaces production and processes required to traditionally produce the outputs. These avoided burdens for each process can be found in Section 4.6. As this section focuses only on the end-of-life alternatives compared to the baseline landfill scenario, these results do not include any upstream differences in the Hefty® EnergyBag® orange bag versus the Flex Bag including raw materials, manufacturing, and transport.

6.1.1 Unique Pyrolysis Technology End-of-Life Analysis

Figure 6.1 below shows the relative impact of the Hefty® EnergyBag® material processing and avoided burden for pyrolysis Dataset 1.

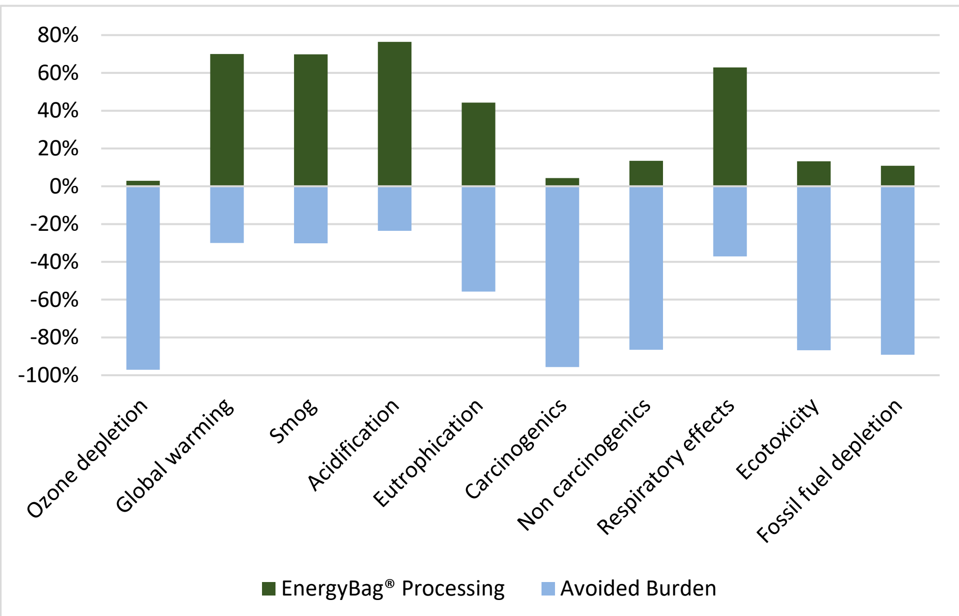


Figure 6.1 – Unique Pyrolysis Technology Hefty® EnergyBag® Material Processing Dataset 1 and Avoided Burden Relative Impacts

How To Read:

- *The green "EnergyBag® Processing" bars are the amount of resources and environmental impact required to take the Hefty® EnergyBag® and its contents to produce a new product.*
- *The blue "Avoided Burden" bars are the benefit of not using additional resources to produce standard wax and oils that the bag contents are offsetting by being recovered materials.*
- *If the blue bars are bigger than the green bars, then this technology has a net benefit.*
- *If the green bars are larger than the blue bars, then this technology has net impact.*

The main impacts of the Hefty® EnergyBag® processing for pyrolysis are in global warming, smog, acidification, and respiratory effects. Figure 6.2 below shows the relative impact of the Hefty® EnergyBag® material processing and avoided burden for the unique pyrolysis technology Dataset 2.

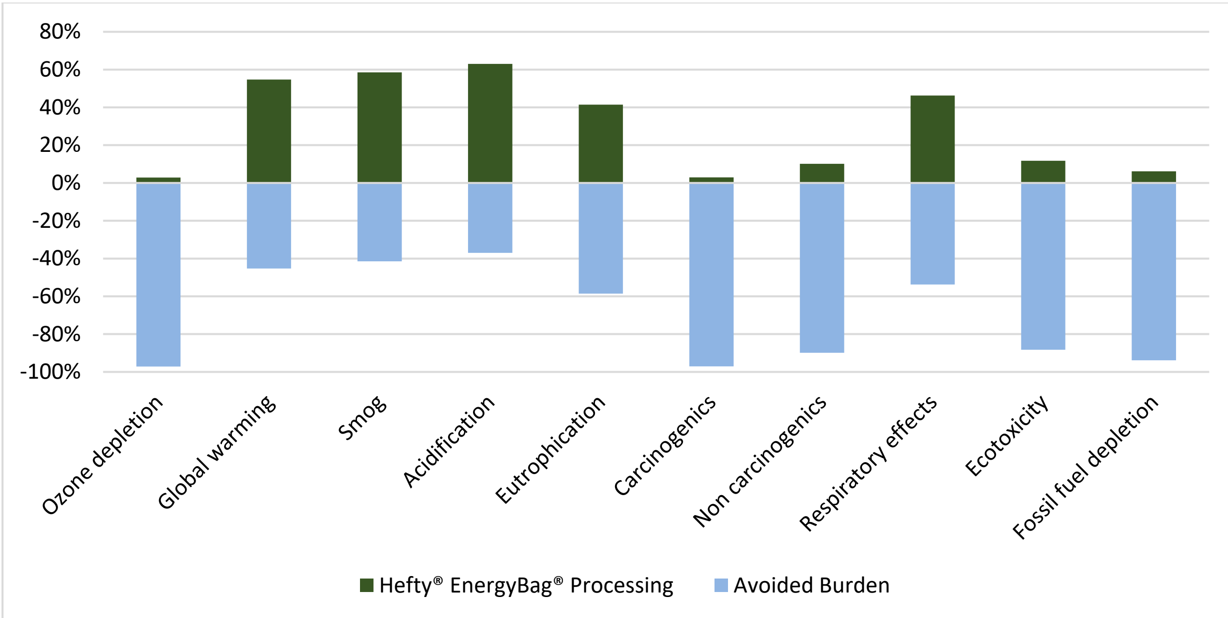
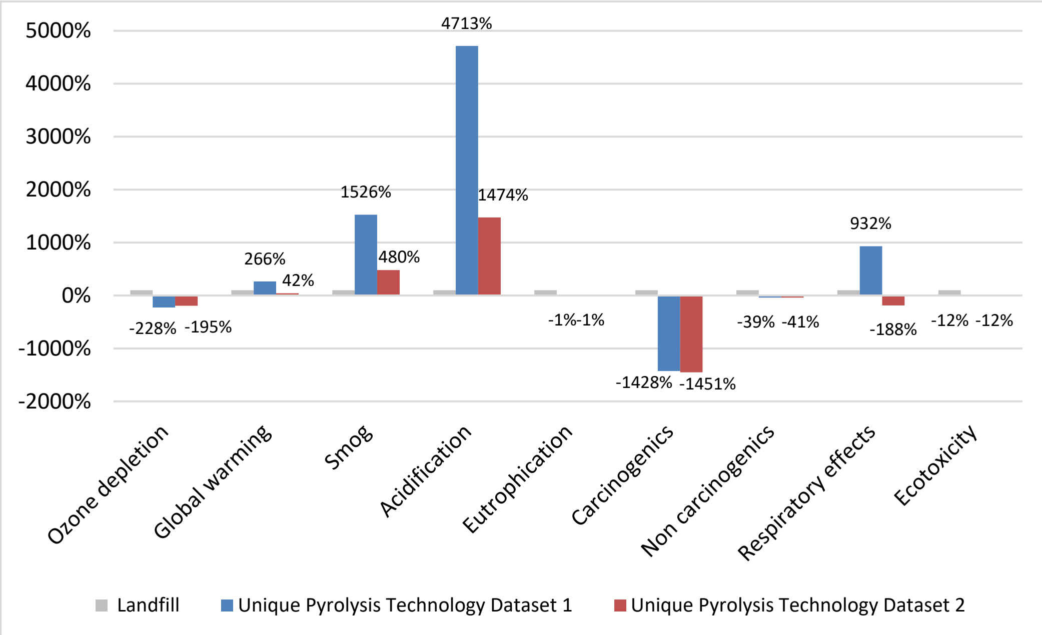


Figure 6.2 –Unique Pyrolysis Technology Hefty® EnergyBag® Material Processing Dataset 2 and Avoided Burden Relative Impacts

Figures 6.3 and 6.4 show the impacts of landfill versus pyrolysis. Landfill is set to 100% impact to show the relative impact of pyrolysis to landfill in each impact category. Fossil fuel depletion is shown separately in Figure 6.4 due to the large offset impact of direct fossil fuel production. The fossil fuel depletion percent is calculated as follows:

$$Percent\ of\ Landfill\ Baseline = \left(\frac{MJ\ Surplus_{pyrolysis}}{MJ\ Surplus_{landfill}}\right) * 100$$



How To Read:

- *The gray "Landfill" bar is the baseline impact from sending the Hefty® EnergyBag® contents to landfill.*
- *The blue and red bars "Unique Pyrolysis Technology Dataset 1 and 2" are the net impacts/benefits of using this technology and offsetting petroleum products based on one production campaign.*
- *If the blue or red bars are smaller than 100% or negative, then this technology has less environmental impact than landfilling.*

Figure 6.3 –Unique Pyrolysis Technology Datasets and Landfill Relative End-of-Life Impacts

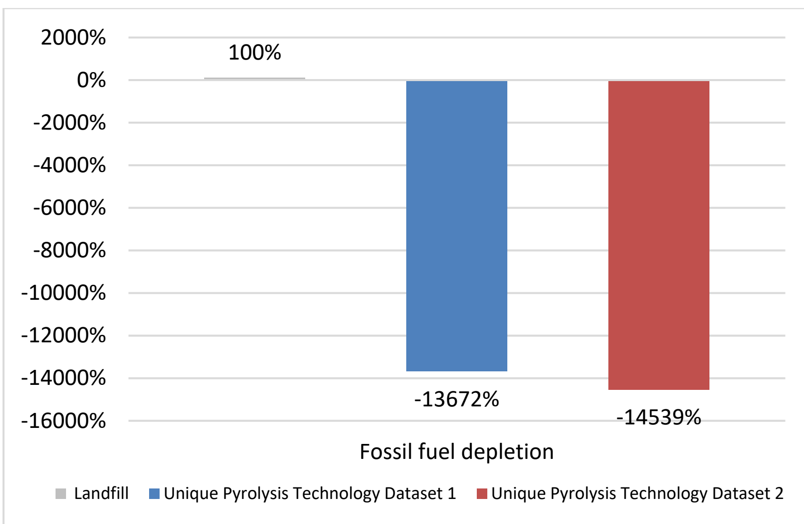


Figure 6.4 –Unique Pyrolysis Technology Datasets and Landfill Relative Fossil Fuel Depletion End-of-Life Impacts

Table 6.1 – Unique Pyrolysis Technology and Landfill TRACI Impacts

Impact Category	Unit	Landfill	Unique Pyrolysis Technology Dataset 1	Unique Pyrolysis Technology Dataset 2
Ozone Depletion	kg CFC-11 eq	3.31E-09	-7.53E-09	-6.45E-09
Global Warming	kg CO_2 eq	1.53E-01	3.87E-01	6.39E-02
Smog	kg O_3 eq	1.90E-03	2.60E-02	9.12E-03
Acidification	kg SO_2 eq	9.21E-05	4.16E-03	1.36E-03
Eutrophication	kg N eq	1.20E-02	-1.50E-04	-1.34E-04
Carcinogenics	CTU_h	2.57E-09	-3.66E-08	-3.74E-08
Non-Carcinogenics	CTU_h	5.29E-07	-1.78E-07	-2.16E-07
Respiratory Effects	kg $PM_{2.5}$ eq	1.37E-05	1.05E-04	-2.57E-05
Ecotoxicity	CTU_e	5.58E+01	-6.40E+00	-6.59E+00
Fossil Fuel Depletion	MJ surplus	3.27E-02	-4.33E+00	-4.75E+00

When compared to the baseline of landfilling the Flex Bag, across both pyrolysis datasets the Hefty® EnergyBag® product system is favorable in several categories except smog and acidification, where both datasets show a greater contribution to those two categories. Additionally, the Unique Pyrolysis Technology Dataset 1, due to its increased benchmarked electricity input, has a greater contribution to global warming and respiratory effects than landfilling, but Dataset 2 has slightly lower impacts in those categories. The main driver of impacts in the pyrolysis process is the electric energy input. This is, in part, due to the specific pyrolysis system scale. Variability in electric efficiency in the pyrolysis process occurs from outside factors such as ambient temperature and feed stock quality. Increases in energy efficiency of the pyrolysis process are anticipated to show a reduction in life cycle impacts. This is particularly true in GWP impacts where the electricity accounts for 95% of the impact.

The Unique Pyrolysis Technology Dataset 1 contributes more to GWP than landfill and therefore does not have a calculated GWP cut-off collection distance. The GWP cut-off collection distance for the Unique Pyrolysis Technology Dataset 2 versus landfill is 770 km (479 mi).

The study compared the results of the pyrolysis vs. landfill model against publicly available peer-reviewed literature. The results of the study are directionally in alignment with the Argonne National Laboratory life cycle analysis of fuels from non-recycled plastics, seen in Figure 6.5 below. This study analyzed the life cycle of utilizing non-recycled plastics (NRP) and conventionally produced diesel fuels. This study included the feedstock, fuel conversion, and vehicle operation of the fuels produced as the life cycle boundary for pyrolysis. The main life cycle GHG emission differences come from the feedstock stage (using plastics as a feedstock rather than traditional petroleum extraction methods). The conversion to fuel was slightly more efficient for plastic-derived fuels than for petroleum-derived fuels.[7]

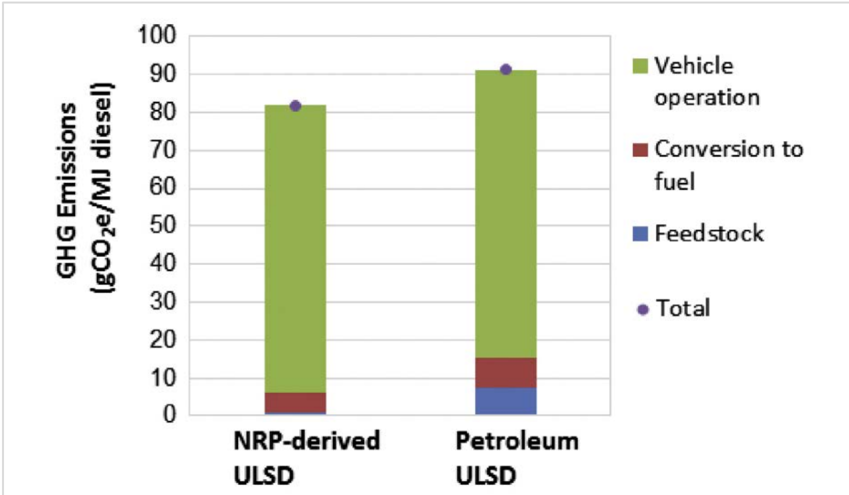


Figure 6.5 – Breakdown of Life Cycle GHG Emissions of Base Case (gCO_2e/MJ Diesel)[5]

The pyrolysis process modeled in the Argonne study required a smaller amount of electricity per mass of product manufactured when compared to the unique pyrolysis technology. This referenced study utilized process yield and material and energy consumption data sourced and aggregated from five different pyrolysis companies. Therefore, most of these companies had better economies of scale than what the unique pyrolysis technology currently offers, as seen in the smaller electricity input requirements.

6.1.2 Concrete Aggregate End-of-Life Analysis

The second end-of-life option assessed in this study was the recycling of the Hefty® EnergyBag® collected materials into an aggregate material for use in concrete masonry units (CMUs). This option utilizes the Hefty® EnergyBag® contents to make a coarse pre-conditioned resin aggregate material used as an alternative to traditional aggregates in concrete manufacturing. Based on discussions with the EOL partner, gravel is the traditional material used as a coarse aggregate in concrete production. Sand is often blended as a finer aggregate with the coarse gravel. Through discussions with the partner, there are benefits to the plastic resin aggregate block versus the gravel block in that it is lighter and has additional thermal benefits. This study analyzed the equivalence of resin aggregate and stone aggregates; therefore, the benefits of utilizing the pre-conditioned aggregate in CMUs during a building's lifetime was not included in this study. Figure 6.6

[7] Benavides, Pahola Thathiana, et. al. (2017). *Life-cycle analysis of fuels from post-use non-recycled plastics*. Fuel. 203:11-22.

below shows the Hefty® EnergyBag® processing and avoided burden associated with this process.

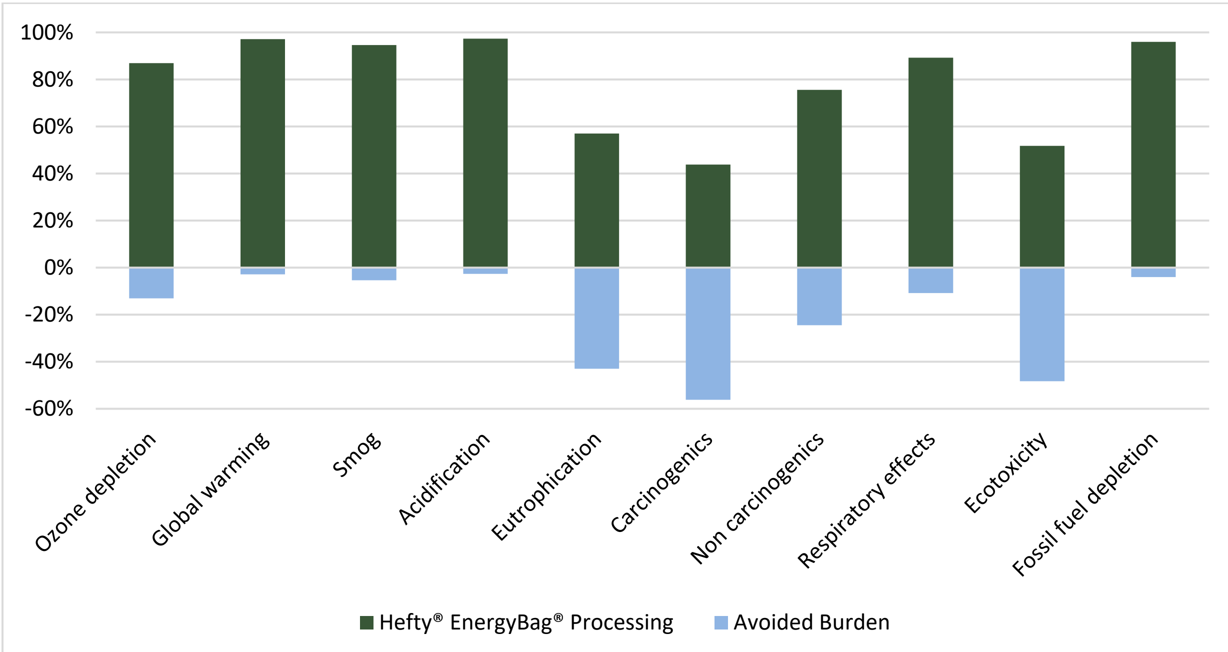


Figure 6.6 – Concrete Aggregate Hefty® EnergyBag® Processing and Avoided Burden Relative Impacts

Gravel has a minimal contribution to the life cycle impacts of the product as it requires minimal processing, is abundant, and locally available. Therefore, the avoided burden across the impact categories is relatively insignificant to the Hefty® EnergyBag® content processing. Figure 6.7 below shows the relative impacts compared to the Flex Bag being sent to landfill baseline.

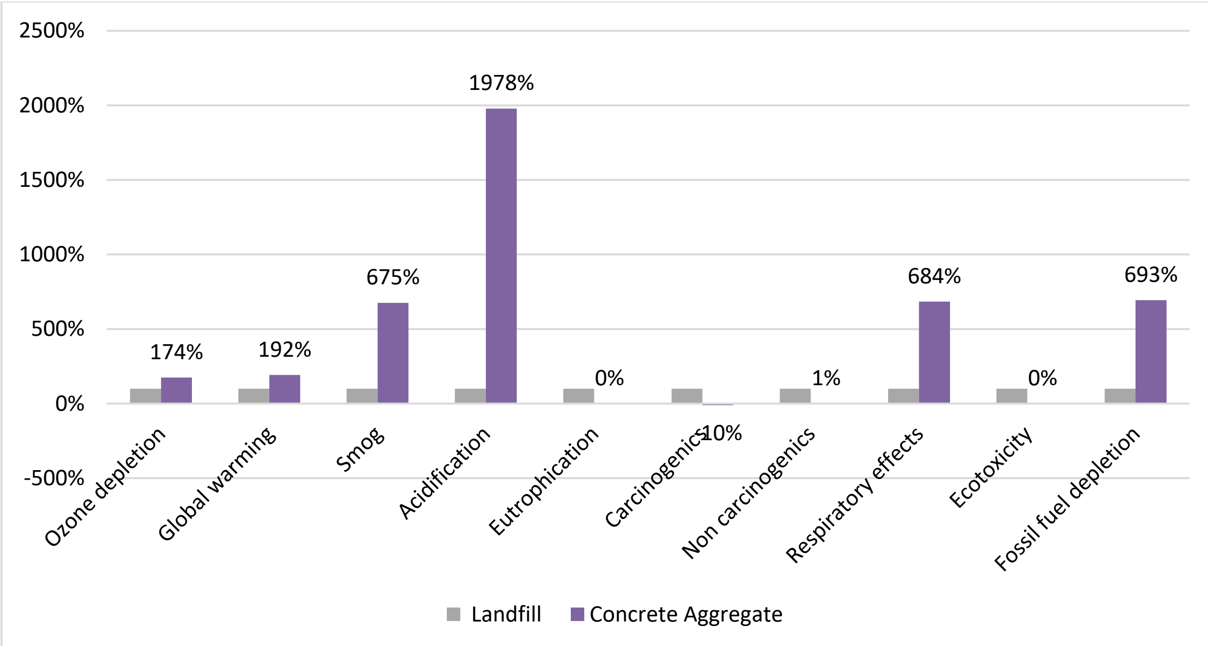


Figure 6.7 – Concrete Aggregate and Landfill Relative End-of-Life Impacts

Table 6.2 – Concrete Aggregate and Landfill TRACI Impacts

Impact Category	Unit	Landfill	Concrete Aggregate
Ozone Depletion	kg CFC-11 eq	3.31E-09	5.77E-09
Global Warming	kg CO_2 eq	1.53E-01	2.94E-01
Smog	kg O_3 eq	1.90E-03	1.28E-02
Acidification	kg SO_2 eq	9.21E-05	1.82E-03
Eutrophication	kg N eq	1.20E-02	1.47E-05
Carcinogenics	CTU_h	2.57E-09	-2.66E-10
Non-Carcinogenics	CTU_h	5.29E-07	6.72E-09
Respiratory Effects	kg $PM_{2.5}$ eq	1.37E-05	9.36E-05
Ecotoxicity	CTU_e	5.58E+01	1.31E-02
Fossil Fuel Depletion	MJ surplus	3.27E-02	2.26E-01

The results shown in Figure 6.7 above show a spike in the smog, acidification, respiratory effects, and fossil fuel depletion impact categories for the aggregate material. These impacts are driven mainly by the electricity requirements for the process, with a smaller percentage from inorganic compound additives.

6.1.3 Cement Kiln Fuel End-of-Life Analysis

The third end-of-life option analyzed in this study is the processing and combusting of the Hefty® EnergyBag® collected materials in a cement kiln as fuel in lieu of coal. Since the higher heating value (HHV) of plastic is larger than coal's, less mass of plastic is required than coal to make equivalent amounts of heat, thus resulting in a lower environmental impact as compared to using coal in cement kilns. The cement kiln requires electricity inputs for the conditioning and feeding of the Hefty® EnergyBag® material as an alternative fuel displacing coal. The avoided burden in this process is the production of coal, processing electricity, and the emissions reduction from burning less material in the kiln. Figure 6.8 below shows the Hefty® EnergyBag® material processing and avoided burden associated with this process.

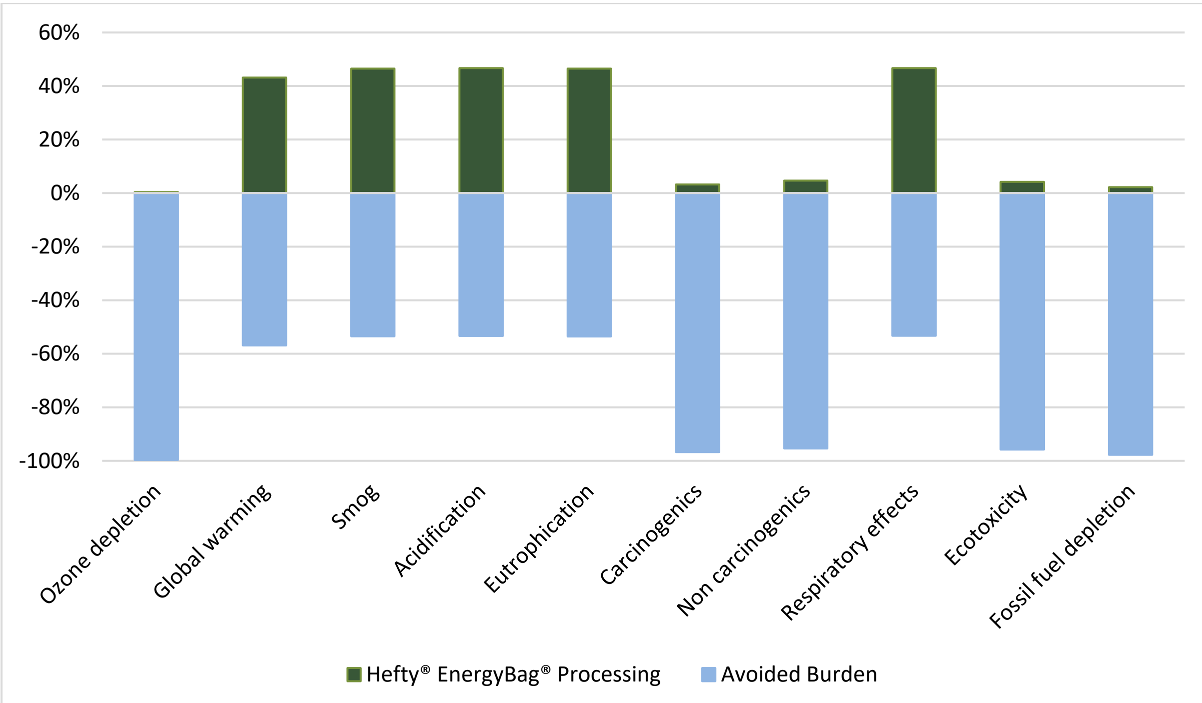


Figure 6.8 – Cement Kiln Fuel Hefty® EnergyBag® Material Processing and Avoided Burden Relative Impacts

Figure 6.8, above, illustrates the processing of the Hefty® EnergyBag® materials as fuel in a cement kiln has a reduced environmental impact across air emission related categories; the offset, resulting from the avoided burden of coal production, is greater than the overall impact of the Hefty® EnergyBag® material processing. Figure 6.9 below shows the relative impacts of the cement kiln EOL option compared to the landfill baseline.

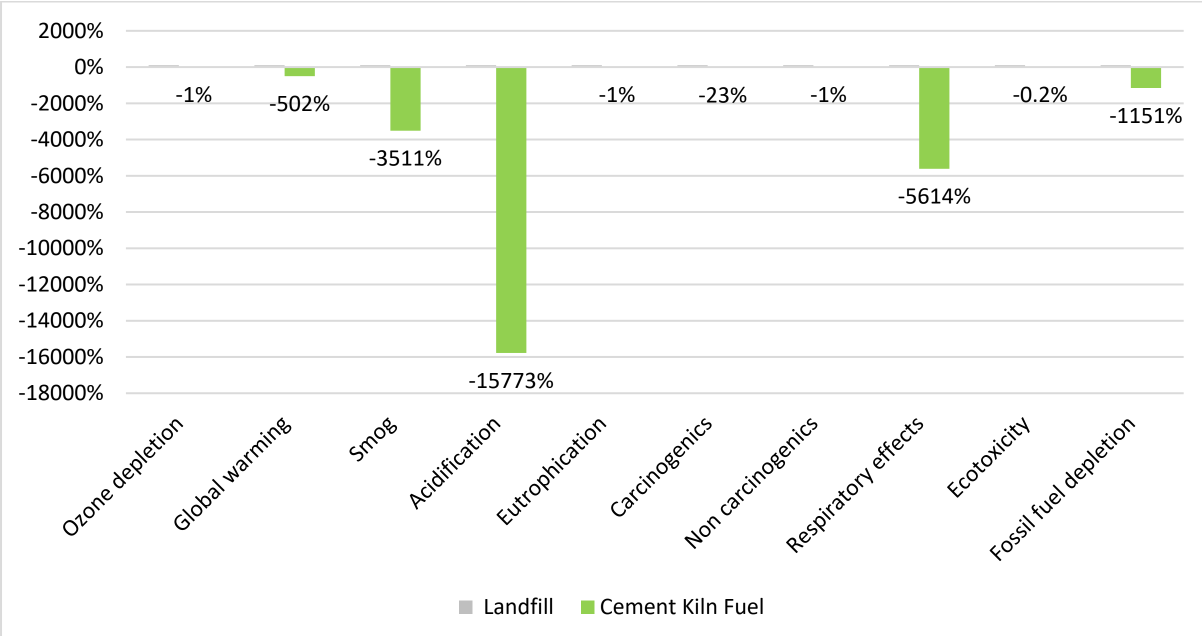


Figure 6.9 – Cement Kiln Fuel and Landfill Relative End-of-Life Impacts

Table 6.3 – Cement Kiln Fuel and Landfill TRACI Impacts

Impact Category	Unit	Landfill	Cement Kiln Fuel
Ozone Depletion	kg CFC-11 eq	3.31E-09	-4.65E-11
Global Warming	kg CO_2 eq	1.53E-01	-7.69E-01
Smog	kg O_3 eq	1.90E-03	-6.67E-02
Acidification	kg SO_2 eq	9.21E-05	-1.45E-02
Eutrophication	kg N eq	1.20E-02	-1.20E-04
Carcinogenics	CTU_h	2.57E-09	-5.89E-10
Non-Carcinogenics	CTU_h	5.29E-07	-6.70E-09
Respiratory Effects	kg $PM_{2.5}$ eq	1.37E-05	-7.68E-04
Ecotoxicity	CTU_e	5.58E+01	-1.09E-01
Fossil Fuel Depletion	MJ surplus	3.27E-02	-3.76E-01

Air emission and energy-related impact categories such as GWP, smog, acidification, and fossil fuel depletion show a significant amount of reduction ranging from -602% to -15,873% for the cement kiln end-of-life scenario as compared to landfill due to coal having a greater emission factor and lower heating value than the Hefty® EnergyBag® plastics. The GWP cut-off distance for the cement kiln process alone as compared to landfill is 7,952 km (4,940 mi).

6.1.4 Construction Block End-of-Life Analysis

Another option for Hefty® EnergyBag® plastic materials is as a raw material for a multi-purpose, high-performing construction block that offers water-resistant properties and avoids the production of ready-mix concrete. The avoided burden impacts associated with ready mix concrete are taken from the National Ready Mix Concrete Associate (NRMCA) 2019 industry average LCA.[8] The impact assessment results of this referenced LCA study are limited to environmental impacts and therefore, the impact categories for this option do not include human health impact categories. Figure 6.10 below shows the EnergyBag® material processing and avoided burden associated with this process.

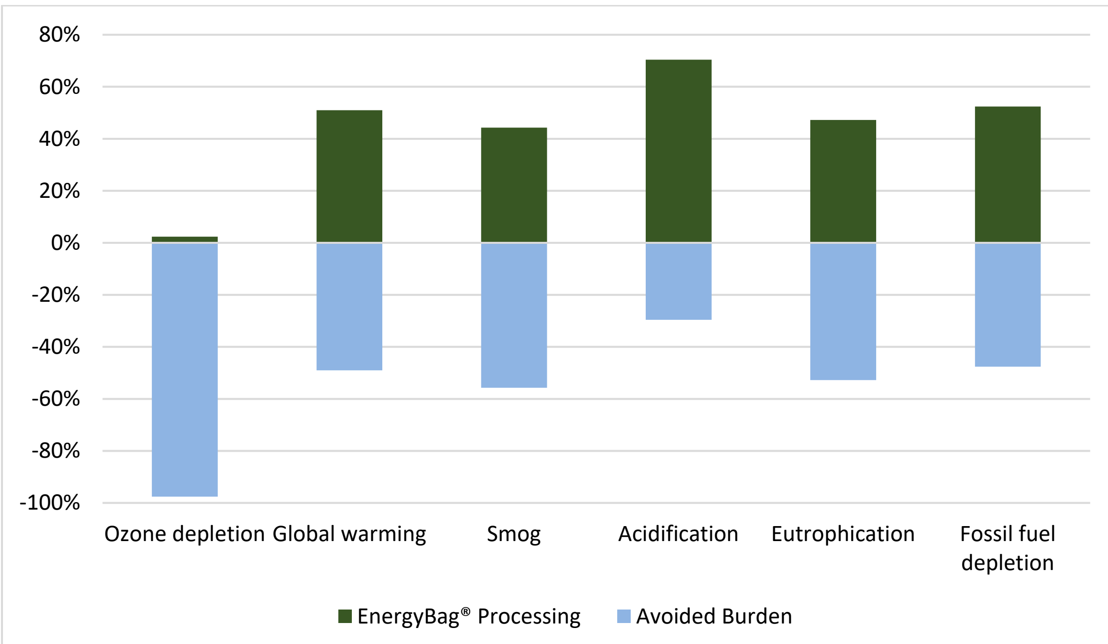


Figure 6.10 – Construction Block Hefty® EnergyBag® Material Processing and Avoided Burden Relative Impacts

Figure 6.10 shows a high avoided burden in ozone depletion. Global warming, smog, eutrophication, and fossil fuel depletion waste processing and avoided burdens are similar in magnitude, while acidification has a larger impact than the avoided burden. Figure 6.11 below shows the relative impacts of the construction block EOL option compared to the landfill baseline.

[8] NRMCA member industry average EPD for ready mixed concrete https://www.nrmca.org/wp-content/uploads/2020/02/EPD10080.pdf

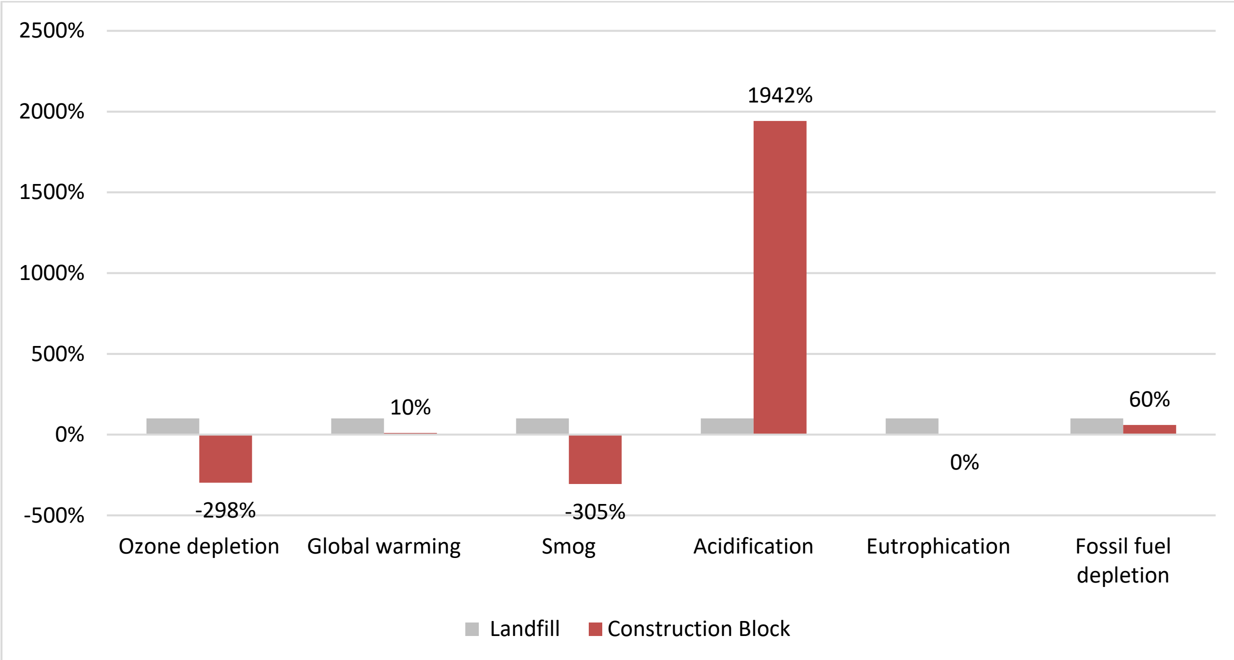


Figure 6.11 – Construction Block and Landfill Relative End-of-Life Impacts

Table 6.4 – Construction Block and Landfill TRACI Impacts

Impact Category	Unit	Landfill	Construction Block
Ozone Depletion	kg CFC-11 eq	3.31E-09	-9.85E-09
Global Warming	kg CO_2 eq	1.53E-01	1.52E-02
Smog	kg O_3 eq	1.90E-03	-5.80E-03
Acidification	kg SO_2 eq	9.21E-05	1.79E-03
Eutrophication	kg N eq	1.20E-02	-5.42E-05
Fossil Fuel Depletion	MJ surplus	3.27E-02	1.95E-02

Figure 6.11 demonstrates that processing the materials into a construction block as an end-of-life option is favorable to landfill in all impact categories shown besides acidification. Acidification is considerably higher for this option compared to landfill due to the required electricity input and the upstream use of coal incineration to produce the electricity. The GWP cut-off distance for the construction block process ranges between 711 to 1,190 km (442 to 739 mi) based on the variation between the current facility and a potential new production location.

6.1.5 Roofing Cover Board End-of-Life Analysis

This end-of-life option for Hefty® EnergyBag® materials utilizes all the materials within the bag with the addition of recycled paper from other sources to produce a roof cover board. The avoided burden associated with this product is a standard gypsum board, which is the traditional material used for roof cover boards. Figure 6.12 below shows the Hefty® EnergyBag® material processing and avoided burden associated with this process.

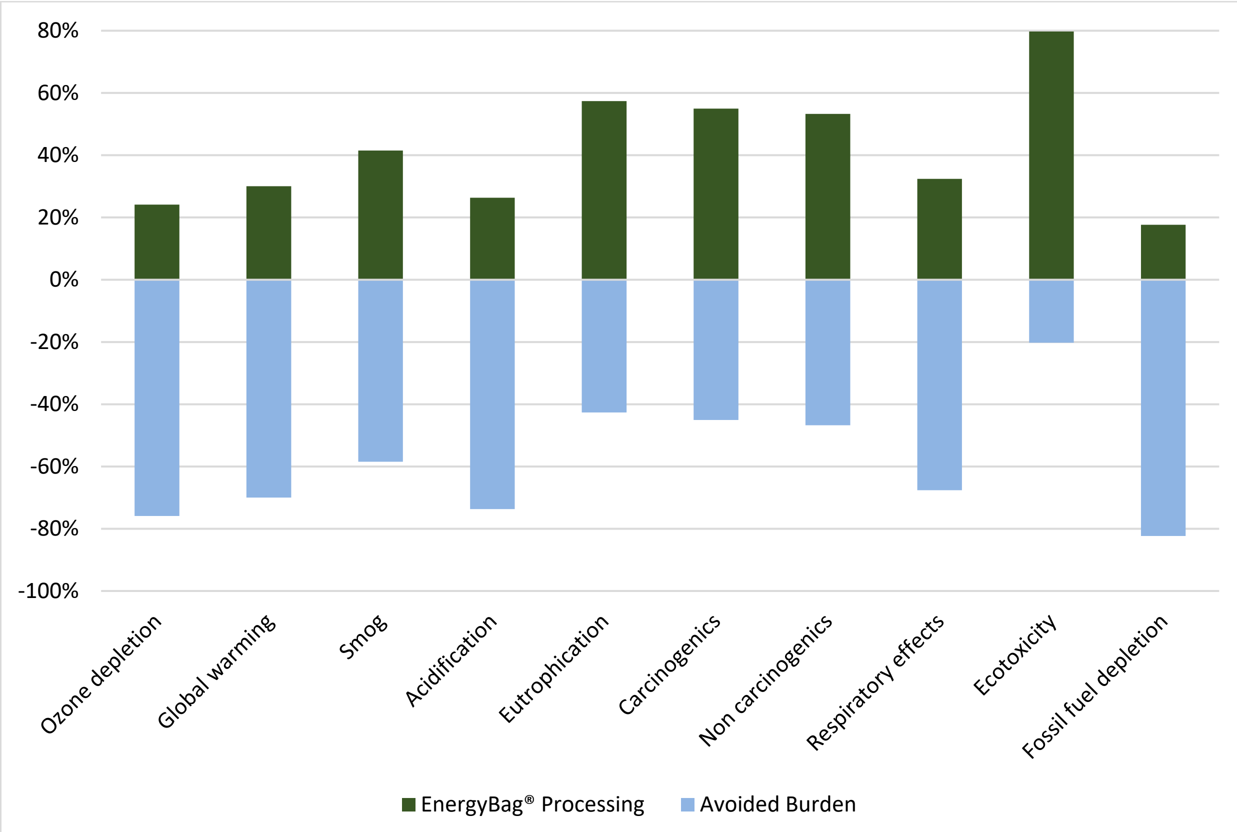


Figure 6.12 – Roofing Cover Board Hefty® EnergyBag® Material Processing and Avoided Burden Relative Impacts

Figure 6.12 shows a comparatively greater magnitude of avoided burden than processing impacts for all impact categories besides ecotoxicity. The ecotoxicity impact is a result of the non-hazardous waste generated from the process that is landfilled. Figure 6.13 below shows the relative impacts of the roofing cover board EOL option compared to the landfill baseline.

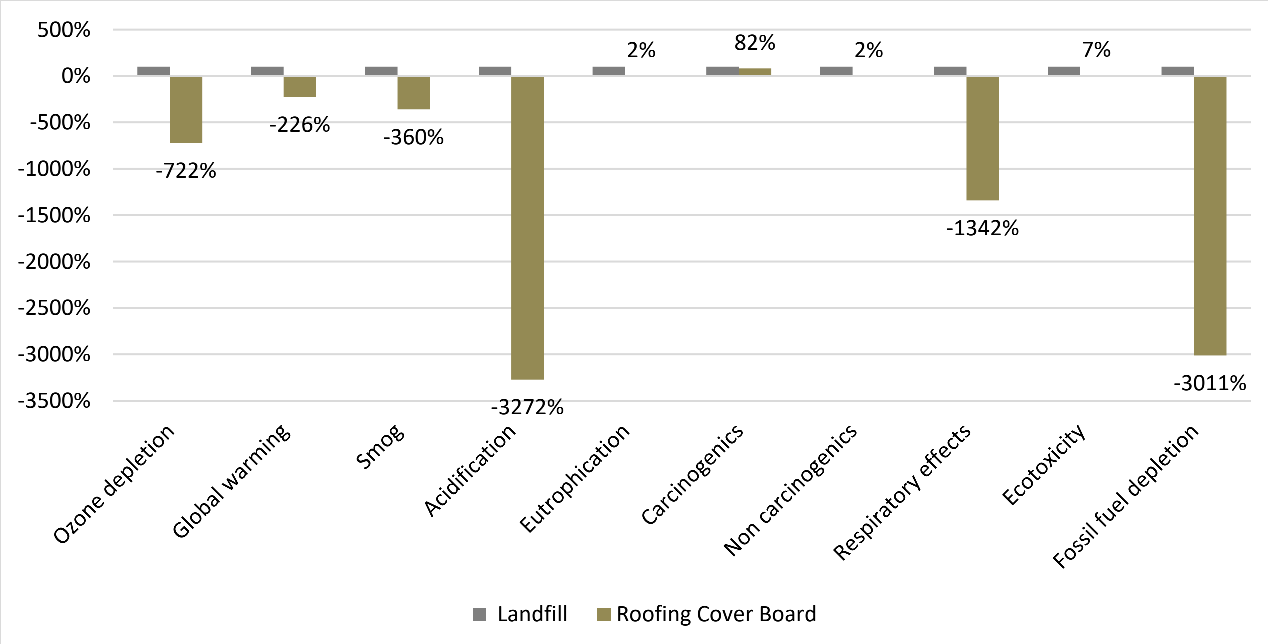


Figure 6.13 – Roofing Cover Board and Landfill Relative End-of-Life Impacts

Table 6.5 – Roofing Cover Board and Landfill TRACI Impacts

Impact Category	Unit	Landfill	Roofing Board
Ozone Depletion	kg CFC-11 eq	3.31E-09	-2.39E-08
Global Warming	kg CO_2 eq	1.53E-01	-3.46E-01
Smog	kg O_3 eq	1.90E-03	-6.83E-03
Acidification	kg SO_2 eq	9.21E-05	-3.01E-03
Eutrophication	kg N eq	1.20E-02	2.73E-04
Carcinogenics	CTU_h	2.57E-09	2.11E-09
Non-Carcinogenics	CTU_h	5.29E-07	9.78E-09
Respiratory Effects	kg $PM_{2.5}$ eq	1.37E-05	-1.83E-04
Ecotoxicity	CTU_e	5.58E+01	3.86E+00
Fossil Fuel Depletion	MJ surplus	3.27E-02	-9.83E-01

Figure 6.13 shows the avoided burden compared to the inputs and outputs of the roofing board manufacturing process. The manufacturing process of gypsum board is energy intensive compared to this specific alternative product, thus when compared to landfill this roofing board has less impact in every impact category. The GWP cut-off distance for use in roofing cover board vs. landfill is 4,300 km (2,672 mi).

6.1.6 Drainage Material End-of-Life Analysis

The final end-of-life landfill alternative option in this study is utilization of Hefty® EnergyBag® collected plastics as a drainage material. Figure 6.14 below shows the Hefty® EnergyBag® material processing and avoided burden associated with this proprietary process.

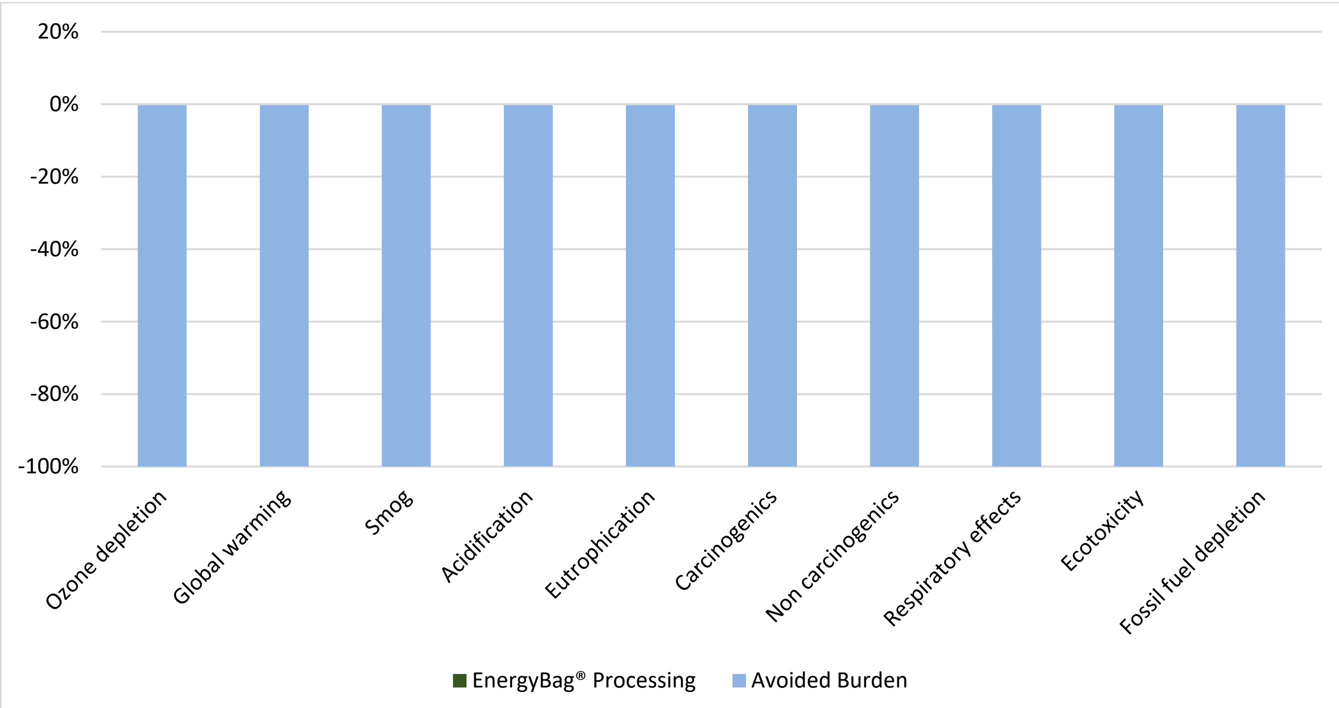


Figure 6.14 – Drainage Material EnergyBag® Material Processing and Avoided Burden Relative Impacts

Figure 6.14 shows the minimal comparative magnitude of inputs to the drainage material process compared to the avoided burden. This process utilizes less energy than the other end-of-life options while also having avoided burdens of high impact products and a large amount of relatively low impact products. Figure 6.15 below shows the relative impacts of the drainage material EOL option compared to the landfill baseline.

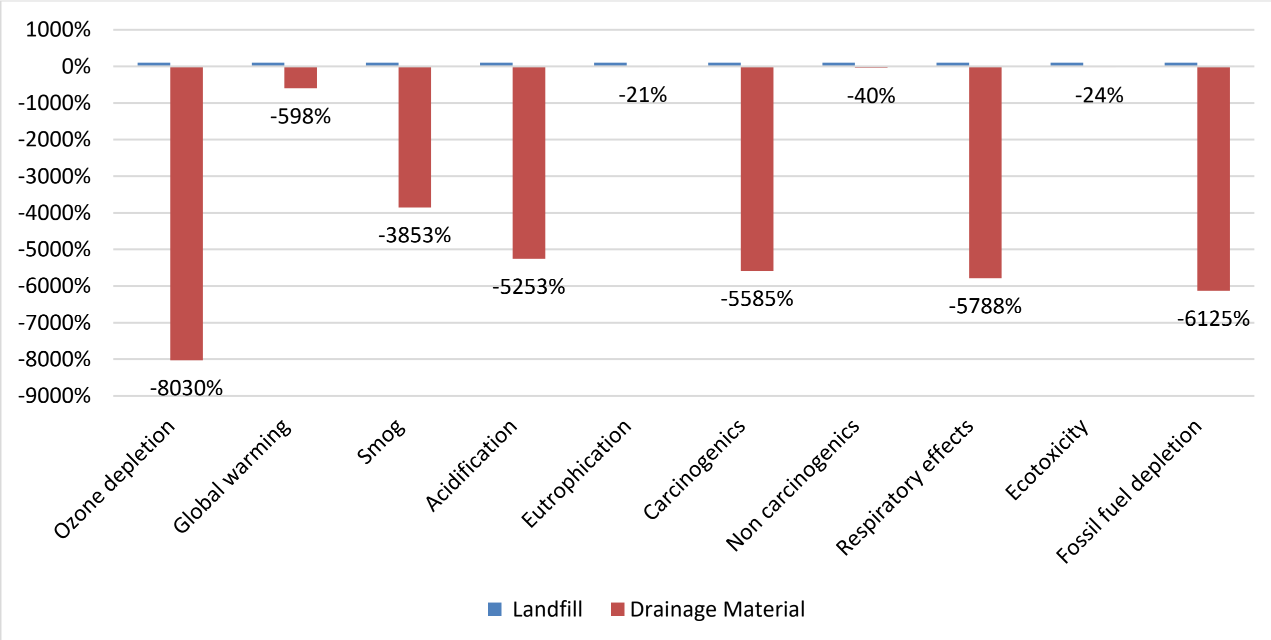


Figure 6.15 – Drainage Material and Landfill Relative End-of-Life Impacts

Table 6.6 – Drainage Material and Landfill TRACI Impacts

Impact Category	Unit	Landfill	Drainage Material
Ozone Depletion	kg CFC-11 eq	3.31E-09	-2.65E-07
Global Warming	kg CO_2 eq	1.53E-01	-9.16E-01
Smog	kg O_3 eq	1.90E-03	-7.32E-02
Acidification	kg SO_2 eq	9.21E-05	-4.84E-03
Eutrophication	kg N eq	1.20E-02	-2.47E-03
Carcinogenics	CTU_h	2.57E-09	-1.44E-07
Non-Carcinogenics	CTU_h	5.29E-07	-2.11E-07
Respiratory Effects	kg $PM_{2.5}$ eq	1.37E-05	-7.92E-04
Ecotoxicity	CTU_e	5.58E+01	-1.35E+01
Fossil Fuel Depletion	MJ surplus	3.27E-02	-2.00E+00

Figure 6.15 shows that when compared to the impacts of landfill, the drainage material end-of-life option is favorable in every impact category with comparatively high advantages in air emission categories such as ozone depletion, smog, and acidification. The GWP cut-off collection distance for drainage material versus landfill is 9,216 km (5,727 mi).

6.2 Current Hefty® EnergyBag® Program Status

This section of the report focuses on the LCA impacts associated with the full life cycle in the current scenarios available in each participating region. The focus of this analysis is

GWP impacts and for use as a decision-making tool in locating new partners within the end-of-life sectors analyzed in this study. GWP cut-off distances were calculated based on modeling the Hefty® EnergyBag® orange bag being transported one kilometer. The difference between the life cycle GWP impacts of landfill alternatives and landfill baseline is divided by the one-kilometer transport distance impact to determine the cut-off distance.

6.2.1 Cobb County, GA

End-of-life options include converting the plastics using unique pyrolysis technology and using the plastics as an alternate fuel in cement production.

Figure 6.16 shows the overall GWP impact for each EOL option. The cement kiln fuel EOL option has the lowest impact due to the high avoided burden. The unique pyrolysis technology Dataset 1 is 8% higher in GWP impacts than landfill while the unique pyrolysis technology Dataset 2 is 2% lower than the impact of landfill. Therefore, pyrolysis is considered comparable to landfill in GWP impacts due to its variability, particularly on electricity input variability.

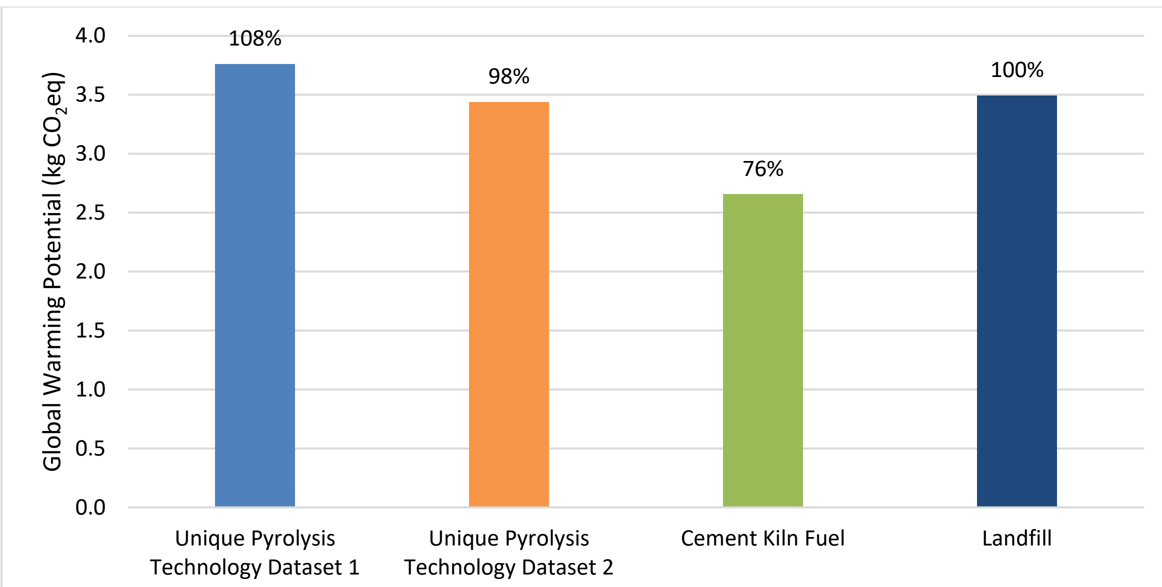


Figure 6.16 – GWP Impacts for Different EOL Options at Cobb County

Table 6.7 below shows the TRACI methodology LCA environmental impacts and the percent comparison to the landfill baseline. Pyrolysis fares similarly to landfill in the air emission related categories but is slightly higher in impact for Dataset 1 and slightly lower in impact for Dataset 2. Both pyrolysis and cement kiln fuel results are lower than landfill for eutrophication, as the ecoinvent3 landfill databases include short-term leachate treatment in wastewater treatment and long-term emissions from landfill to groundwater after base lining failure.

Table 6.7 – TRACI Methodology Impacts and Relative Impacts to Landfill Baseline at Cobb County

Impact Category	Unit	Landfill	Pyrolysis Technology Dataset 1	Pyrolysis Technology Dataset 2	Cement Kiln Fuel	Landfill	Pyrolysis Technology Dataset 1	Pyrolysis Technology Dataset 2	Cement Kiln Fuel
Ozone Depletion	kg CFC-11 eq	2.98E-06	2.97E-06	2.97E-06	2.97E-06	100%	100%	100%	100%
Global Warming	kg CO_2 eq	3.49E+00	3.76E+00	3.44E+00	2.65E+00	100%	108%	98%	76%
Smog	kg O_3 eq	1.67E-01	1.95E-01	1.78E-01	1.19E-01	100%	116%	106%	71%
Acidification	kg SO_2 eq	1.36E-02	1.79E-02	1.51E-02	-1.32E-04	100%	131%	111%	-1%
Eutrophication	kg N eq	1.79E-02	5.74E-03	5.75E-03	5.81E-03	100%	32%	32%	32%
Carcinogenics	CTU_h	2.07E-07	1.67E-07	1.66E-07	2.04E-07	100%	81%	80%	98%
Non-Carcinogenics	CTU_h	9.72E-07	2.68E-07	2.30E-07	4.46E-07	100%	27%	24%	46%
Respiratory Effects	kg $PM_{2.5}$ eq	2.10E-03	2.20E-03	2.07E-03	1.35E-03	100%	105%	99%	65%
Ecotoxicity	CTU_e	7.93E+01	1.72E+01	1.70E+01	2.36E+01	100%	22%	21%	30%
Fossil Fuel Depletion	MJ surplus	9.67E+00	5.39E+00	4.98E+00	9.45E+00	100%	56%	51%	98%

6.2.2 Omaha, NE

Hefty® EnergyBag® orange bags in this location were evaluated for using the plastics as an alternate fuel in cement production only.

Figure 6.17 shows the overall GWP impact for the EOL option available in Omaha. Utilizing Hefty® EnergyBag® material as a cement kiln fuel replacement reduces the cradle-to-grave GWP impact to 75% of the impact of landfilling the material.

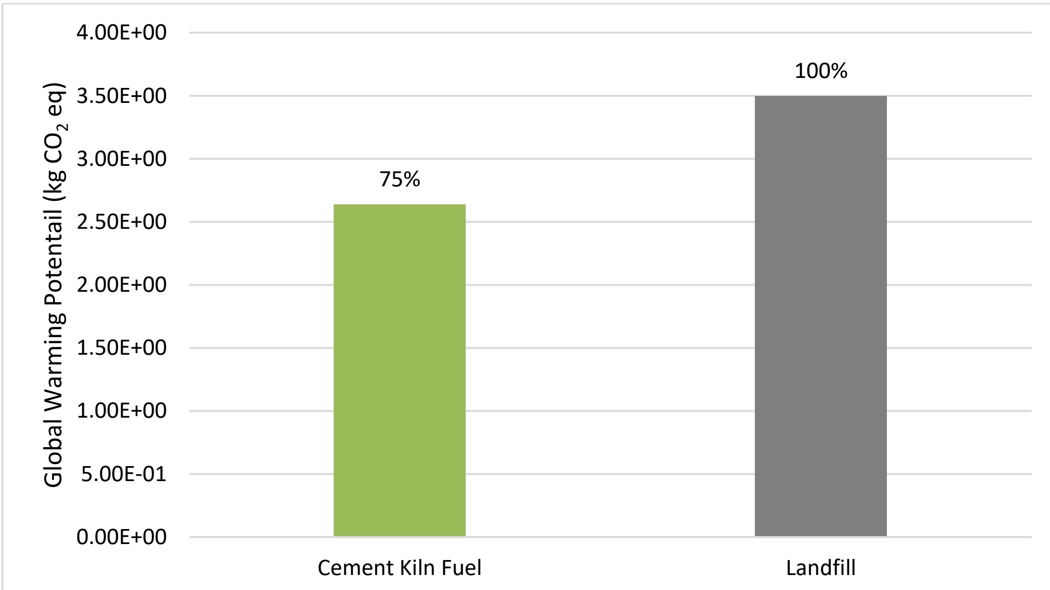


Figure 6.17 – GWP Impacts for Different EOL Options at Omaha

Table 6.8 below shows the impact per bag and the relative impact to the baseline landfill scenario across all the LCA impact categories.

Table 6.8 – TRACI Methodology Impacts and Relative Impacts to Landfill Baseline at Omaha

Impact Category	Unit	Landfill	Cement Kiln Fuel	Landfill	Cement Kiln Fuel
Ozone Depletion	kg CFC-11 eq	2.98E-06	2.97E-06	100%	100%
Global Warming	kg CO_2 eq	3.50E+00	2.64E+00	100%	75%
Smog	kg O_3 eq	1.68E-01	1.14E-01	100%	68%
Acidification	kg SO_2 eq	1.37E-02	-3.38E-04	100%	-2%
Eutrophication	kg N eq	1.79E-02	5.79E-03	100%	32%
Carcinogenics	CTU_h	2.07E-07	2.04E-07	100%	98%
Non-Carcinogenics	CTU_h	9.72E-07	4.44E-07	100%	46%
Respiratory Effects	kg $PM_{2.5}$ eq	2.10E-03	1.35E-03	100%	64%
Ecotoxicity	CTU_e	7.93E+01	2.35E+01	100%	30%
Fossil Fuel Depletion	MJ surplus	9.68E+00	9.42E+00	100%	97%

6.2.3 Lincoln, NE

Hefty® EnergyBag® orange bags in this location were evaluated for using the plastics as an alternate fuel in cement production only.

Figure 6.18 below shows the overall GWP impact for the EOL option. Utilizing Hefty® EnergyBag® material as a cement kiln fuel replacement reduces the cradle-to-grave GWP impact to 75% of the impact of landfilling the material.

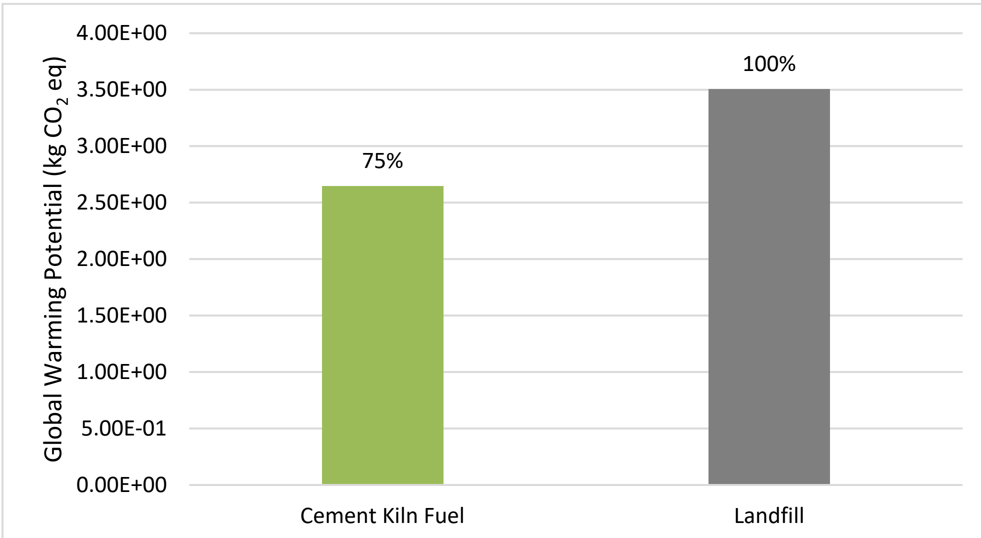


Figure 6.18 – GWP Impacts for Different EOL Options at Lincoln

Table 6.9 below shows the impact per bag and the relative impact to the baseline landfill scenario across all the LCA impact categories.

Table 6.9 – TRACI Methodology Impacts and Relative Impacts to Landfill Baseline at Lincoln

Impact Category	Unit	Landfill	Cement Kiln Fuel	Landfill	Cement Kiln Fuel
Ozone Depletion	kg CFC-11 eq	2.98E-06	2.97E-06	100%	100%
Global Warming	kg CO_2 eq	3.50E+00	2.64E+00	100%	75%
Smog	kg O_3 eq	1.70E-01	1.16E-01	100%	68%
Acidification	kg SO_2 eq	1.38E-02	-2.38E-04	100%	-2%
Eutrophication	kg N eq	1.79E-02	5.80E-03	100%	32%
Carcinogenics	CTU_h	2.08E-07	2.04E-07	100%	98%
Non-Carcinogenics	CTU_h	9.73E-07	4.45E-07	100%	46%
Respiratory Effects	kg $PM_{2.5}$ eq	2.10E-03	1.35E-03	100%	64%
Ecotoxicity	CTU_e	7.94E+01	2.36E+01	100%	30%
Fossil Fuel Depletion	MJ surplus	9.69E+00	9.43E+00	100%	97%

6.2.4 Boise, ID

End-of-life options evaluated in Boise, ID include using the plastics as an alternate fuel in cement production or processing the plastics into a construction block.

Figure 6.19 below shows the overall GWP impact for each EOL option. The cement kiln fuel option has the lowest impact due to the avoided burden of coal as the energy source. Due to the additional transport distance required for the initial block creation, the GWP impact for the construction block is higher than the landfill baseline. However, the GWP impact would decrease to 97% of landfill baseline if a facility were co-located with a MRF in the future.

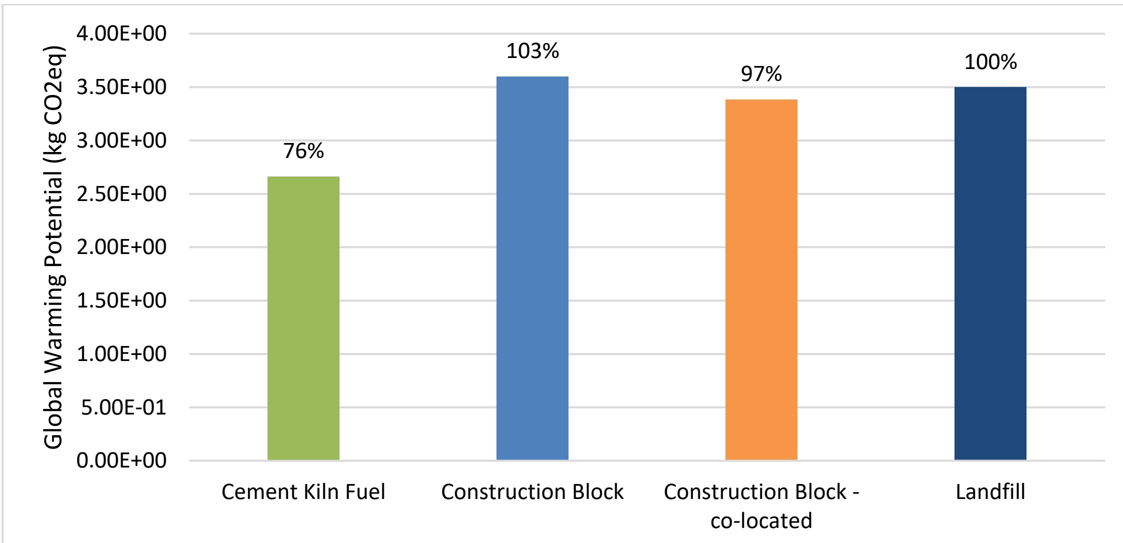


Figure 6.19 – GWP Impacts for Different EOL Options at Boise

Table 6.10 below shows the absolute and relative TRACI methodology LCA impacts for both alternative end-of-life options and landfill baseline. Similar to the other locations, the cement kiln fuel option fares better in each environmental impact category than landfill, besides ozone depletion, which is equal due to the impacts being derived from the bag content raw materials. The construction block end-of-life option fares similar to, but slightly worse than, landfill on the air emission categories. Both end-of-life options show a reduction in impacts compared to landfill in eutrophication.

Table 6.10 – TRACI Methodology Impacts and Relative Impacts to Landfill Baseline at Boise

Impact Category	Unit	Landfill	Construction Block	Construction Block Co-Located	Cement Kiln Fuel	Landfill	Construction Block	Construction Block Co-Located	Cement Kiln Fuel
Ozone Depletion	kg CFC-11 eq	2.98E-06	2.96E-06	2.96E-06	2.97E-06	100%	100%	100%	100%
Global Warming	kg CO_2 eq	3.50E+00	3.60E+00	3.39E+00	2.66E+00	100%	103%	97%	76%
Smog	kg O_3 eq	1.68E-01	2.07E-01	1.62E-01	1.23E-01	100%	123%	97%	73%
Acidification	kg SO_2 eq	1.37E-02	1.76E-02	1.55E-02	1.39E-05	100%	129%	113%	0%
Eutrophication	kg N eq	1.79E-02	5.96E-03	5.83E-03	5.82E-03	100%	33%	33%	32%
Carcinogenics	CTU_h	2.08E-07	2.10E-07	2.06E-07	2.04E-07	100%	101%	99%	98%
Non-Carcinogenics	CTU_h	9.72E-07	5.90E-07	5.49E-07	4.48E-07	100%	61%	56%	46%
Respiratory Effects	kg $PM_{2.5}$ eq	2.10E-03	2.33E-03	2.25E-03	1.36E-03	100%	111%	108%	65%
Ecotoxicity	CTU_e	7.94E+01	3.16E+01	3.06E+01	2.36E+01	100%	40%	39%	30%
Fossil Fuel Depletion	MJ surplus	9.68E+00	1.07E+01	9.74E+00	9.48E+00	100%	111%	101%	98%

6.3 Cut-off Distance Conclusions

The following table is a summary of the cut-off distances from the collection location to the end-of-life management system that would be the break-even point for global warming potential savings. Beyond the cut-off distance, landfilling would be preferable from a carbon equivalencies standpoint but below the distance, the alternative end-of-life option is more favorable. Table 6.11 below shows the cut off distances for each current technology in each Hefty® EnergyBag® program location.

Table 6.11 – Global Warming Potential Cut-Off Distances

Location	End-of-Life Option	Cut Off (km)	Cut Off (miles)
Cobb County, GA	Unique Pyrolysis Technology Dataset 1	N/A	N/A
	Unique Pyrolysis Technology Dataset 2	502	311
	Cement Kiln Fuel	7,701	4,785
Omaha, NE	Cement Kiln Fuel	7,479	4,647
Lincoln, NE	Cement Kiln Fuel	7,482	4,649
Boise, ID	Construction Block	492	306
	Cement Kiln Fuel	7,752	4,817

Transporting the Hefty® EnergyBag® materials to a cement kiln regardless of location is favorable if transported less than 7,479 – 7,752 km (4,647 – 4,817 mi), depending on location. Converting the plastics using unique pyrolysis technology is only favorable compared to landfill in Cobb County for the unique pyrolysis technology Dataset 2 dataset. The cutoff distance for pyrolysis in Cobb County is 502 km (311 mi). Overall, the construction block option is feasible but co-location of the site to both the MRF and Hefty® EnergyBag® program location is important.

7.0 Conclusions

This study analyzed the life cycle impacts of the Hefty® EnergyBag® product system (that is an EnergyBag® orange bag filled with hard-to-recycle plastics) as compared to landfilling hard-to-recycle plastics using a Flex Bag from a cradle-to-grave system boundary. The Hefty® EnergyBag® program targets plastics for which there is limited recycling or landfill alternative infrastructure. The study included the cradle-to-grave life cycle assessment of both product systems including an end-of-life analysis of six landfill alternative scenarios.

From the LCA conducted on the Hefty® Flex Bag and the Hefty® EnergyBag® orange bag with different end-of-life alternatives, the study revealed that the raw material content in the bags dominates the overall environmental impacts across all categories, followed by end-of-life processing. This is due to mass of the contents of the bag being significantly greater than the bag itself, thus requiring higher amounts of raw material inputs to the materials filling the Hefty® EnergyBag® orange bag than for the bag.

This study concluded that substituting coal with plastics as fuel in a cement kiln is beneficial even when traveling longer distances. All end-of-life options besides cement kiln fuel were concluded to be sensitive to the electricity grid mix, as the majority of the GWP impact is driven by the electricity input. As the concrete aggregate EOL option offsets a naturally abundant and low impact material, gravel, there is no GWP cut off distance in this study.

Table 7.1 lists the GWP impacts of each scenario in the four Hefty® EnergyBag® program locations including different end-of-life options.

Table 7.1 – Life Cycle Impacts Summary Table

Location	End-of-Life Option	Global Warming (kg CO_2 eq)	Ozone Depletion (kg CFC-11 eq)	Smog (kg O_3 eq)	Acidification (kg SO_2 eq)	Eutrophication (kg N eq)	Fossil Fuel Depletion (MJ Surplus)
Cobb County, GA	Unique Pyrolysis Technology Dataset 1	3.76E+00	2.97E-06	1.95E-01	1.76E-02	5.74E-03	4.97E+00
	Unique Pyrolysis Technology Dataset 2	3.44E+00	2.97E-06	1.78E-01	1.51E-02	5.75E-03	4.98E+00
	Cement Kiln Fuel	2.65E+00	2.97E-06	1.19E-01	-1.32E-04	5.81E-03	9.45E+00
	Landfill	3.49E+00	2.98E-06	1.67E-01	1.36E-02	1.79E-02	9.67E+00
Omaha, NE	Cement Kiln Fuel	2.64E+00	2.97E-06	1.14E-01	-3.38E-04	5.79E-03	9.42E+00
	Landfill	3.50E+00	2.98E-06	1.68E-01	1.37E-02	1.79E-02	9.68E+00
Lincoln, NE	Cement Kiln Fuel	2.64E+00	2.97E-06	1.16E-01	-2.38E-04	5.80E-03	9.43E+00
	Landfill	3.50E+00	2.98E-06	1.70E-01	1.38E-02	1.79E-02	9.69E+00
Boise, ID	Construction Block	3.60E+00	2.96E-06	2.07E-01	1.76E-02	5.96E-03	1.07E+01
	Cement Kiln Fuel	2.66E+00	2.97E-06	1.23E-01	1.39E-05	5.82E-03	9.48E+00
	Landfill	3.50E+00	2.98E-06	1.68E-01	1.37E-02	1.79E-02	9.68E+00

8.0 Limitations

This study is intended to be used by Reynolds Consumer Products as a tool and benchmark of the Hefty® EnergyBag® product system at the time of analysis. The study was conducted following appropriate ISO standards and best practices. This LCA has benefited from the independent critical review panel conformance assessment to the ISO 14040 and ISO 14044 standards and has identified the following limitations.

8.1 End-of-Life Limitations

The data for the end-of-life alternatives utilized primary and projected data, including assumptions associated with calculations. The unique pyrolysis technology data were generated from two shorter duration batch campaigns, rather than a continuous flow production campaign. Continuous flow production campaigns over longer time periods would make future studies of the Hefty® EnergyBag® program more robust. The concrete aggregate data were calculated based on the current operations at the international plant. The next-generation facility is expected to scale up and increase energy efficiencies. Cement kiln fuel data were collected as a mix of primary collected data and data from publicly available cement kiln literature. The data sourced from the published literature was determined by plant personnel to be accurate and representative of the specific cement kiln. Roofing cover board data were collected for current plant operations, but plant personnel expressed planned efficiency of scale upgrades to the process in the future. Construction block data were collected from one load of Hefty® EnergyBag® material, which is subject to discrepancies between quality of the feedstock (Hefty® EnergyBag® materials) between loads. Drainage material data were collected for 12 months of data, however, the manufacturing process was left proprietary and therefore, assessing quality of data and allocation of impacts is limited. Data quality improvements could be made as follows:

- *Cement Kiln Fuel Data* – would be more robust with primary, complete emission data collected from a cement kiln. Particularly, air emission data for combustion of EnergyBag® plastics specifically versus coal and other refuse-derived fuels would add to the data quality of the study.
- *Concrete Aggregate Data* – if the concrete aggregate manufacturing plant were sited in North America, data from the plant receiving Hefty® EnergyBag® materials from EnergyBag® program locations would reduce the assumptions within the concrete aggregate process.
- *Landfill* – incorporating primary landfill data would also create a more robust analysis. Landfills in the US are of varying age, with varying technologies to minimize environmental impacts, and are under different levels of regulation from local and state laws. The regional differences of landfills are not captured in this study.
- *Life Cycle Inventory* – while quality control was undertaken at each step in building the LCI and conducting the LCIA, uncertainty is still present in the results since the data for manufacturing the bags and the end-of-life processes were collected from varying time lengths from shorter duration campaigns to a full year. Future iterations of this study may benefit from increasing the data collection time length to reduce the uncertainty. Some level of uncertainty is inherent in conducting LCA and decision-making must reflect this fact.

9.0 Recommendations

For better or enhanced data quality and opportunities for refinement of this study, the following are recommendations for future updates:

- As grid mixes change both regionally and throughout time, reassessment of end-of-life technologies, specifically for technologies for which electricity drives the impacts, should be reassessed as well as for shifts in geographic location.
- It is recommended that future studies incorporate updated plastics data as they become available, as the bag content raw materials are the main driver for each impact category. Updates to this database likely will include lower ethane crackers to produce ethylene, which may reduce the environmental impacts.
- While cement kiln fuel primary data were collected for preprocessing of Hefty® EnergyBag® materials and carbon emissions from a participating cement kiln, it is recommended that future studies obtain complete primary data from a participating cement kiln including non-carbon emissions.

- Collecting unique pyrolysis technology data for longer temporal periods, such as 12 months, would limit the possibility of outlier data or seasonal variability, as evidenced with the variability in data collected from the two datasets in this study.
- Collecting construction block data for multiple loads or for a longer time period would also reduce uncertainty in the data quality.
- As the Hefty® EnergyBag® program matures in the current regions and expands to new regions, future studies should consider differences in the content placed within the Hefty® EnergyBag® orange bags.

Continuing to assess the overall environmental impacts as new outlets and technologies are identified for the Hefty® EnergyBag® materials will help the program in supporting a more circular plastics economy.