Hefty® EnergyBag® Program Life Cycle Assessment

Prepared For:

Reynolds Consumer Products

8/27/2020

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Life Cycle Assessment

Reynolds Consumer Products

Hefty® EnergyBag® Program

8/27/2020

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

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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. This tool helps facilitate a better understanding of the 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 LCA of the Hefty® EnergyBag® (EB) program as compared to a baseline of a Hefty® Flex Bag (FB) disposed at end of life (EOL) in a landfill. The cradle-to-grave analysis includes the contents filling the two waste bags with the composition of the contents being identical. 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 from taking previously landfilled waste and utilizing the material as a valued resource. Currently, the EnergyBag® program is active in four geographic regions in the US: Cobb County, GA; Omaha, NE; Lincoln, NE; and Boise, ID. This LCA study quantifies the cradle-to-grave environmental impacts of the Hefty® EnergyBag® program and includes a life cycle analysis of three landfill alternatives – converting plastics using a unique pyrolysis technology, using plastics as an alternate fuel in cement production, and recycling plastics into a concrete aggregate. 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 in commissioning this study was to better understand the cradle-to-grave impacts of the EnergyBag® program and determine the environmental impacts of three specific varying end of life technologies. This analysis serves as a snapshot of the EnergyBag® program in late 2019 and was designed as a tool for guiding expansion of the program. The results sections include TRACI impacts across the life cycle stages as well as calculations for how far the alternative end of life

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[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 July 2020 to identify improvements and demonstrate conformance with the ISO 14040:2016; ISO 14044:2006; and ISO/TS 14071:2006 Life Cycle Assessment standard. The external third-party independent expert panel per ISO 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 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 converting materials using unique pyrolysis technology (9.05E-02 kg CO_2 eq) and using the materials as an alternate fuel in cement production (-6.11E-01 kg CO_2 eq) fare better than landfilling the materials (1.31E-01 kg CO_2 eq) when focusing on greenhouse gas emissions. The end of life only global warming potential (GWP) impacts are summarized in Table ES.1 below and further analyzed in Section 6.1. Recycling plastics into concrete aggregate is more impactful than landfill due to electricity inputs required in the process and low impact offset credit of gravel. The global warming potential impact in the four geographic regions across the different packaging and alternative end of life options range from 2.09E+00 - 2.81E+00 kg CO_2 eq per bag. The GWP impact for the landfill baseline ranges from 2.77E+00 – 2.78E+00 kg CO_2 eq per bag. The overall impacts in each geographic region are summarized in Table ES.2 below. Therefore, there are cases in which the landfill option, from a GWP perspective, is preferable to the current alternative scenario. The end of life scenarios which are environmentally preferential from a GWP perspective include using plastics as an alternate fuel in cement production in all regions. Converting plastics using unique pyrolysis technology in Boise and Cobb County is slightly more impactful in cradle-to-grave GWP impact than landfilling.

Table ES.1 – End of Life GWP Summary Table

EOL Option	Global Warming (kg CO_2 eq)	Percent of Landfill Baseline
Unique Pyrolysis Technology	9.05E-02	69%
Cement Kiln Fuel	-6.11E-01	-466%
Concrete Aggregate	2.32E-01	177%
Landfill (Baseline)	1.31E-01	100%

Table ES.2 – LCA Impact Summary Table

Location	Packaging	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	Starter Kit	Unique Pyrolysis Technology	2.79E+00	7.60E-08	1.49E-01	1.39E-02	4.08E-03	4.92E+00
	Starter Kit	Cement Kiln Fuel	2.13E+00	7.94E-08	1.02E-01	1.67E-03	4.21E-03	7.93E+00
	Flex Bag Open Stock	Landfill (Baseline)	2.78E+00	7.78E-08	1.40E-01	1.25E-02	1.40E-02	8.03E+00
Omaha, NE	Open Stock	Cement Kiln Fuel	2.09E+00	7.43E-08	9.64E-02	1.38E-03	4.12E-03	7.84E+00
	Retail Display	Cement Kiln Fuel	2.10E+00	7.64E-08	9.70E-02	1.42E-03	4.15E-03	7.86E+00
	Flex Bag Open Stock	Landfill (Baseline)	2.77E+00	7.65E-08	1.40E-01	1.25E-02	1.40E-02	8.02E+00
Lincoln, NE	Open Stock	Cement Kiln Fuel	2.09E+00	7.43E-08	9.84E-02	1.46E-03	4.13E-03	7.85E+00
	Retail Display	Cement Kiln Fuel	2.10E+00	7.65E-08	9.90E-02	1.50E-03	4.15E-03	7.88E+00
	Flex Bag Open Stock	Landfill (Baseline)	2.78E+00	7.65E-08	1.42E-01	1.25E-02	1.40E-02	8.03E+00
Boise, ID	Open Stock	Unique Pyrolysis Technology	2.81E+00	7.28E-08	1.63E-01	1.44E-02	4.05E-03	4.98E+00
	Open Stock	Cement Kiln Fuel	2.11E+00	7.62E-08	1.03E-01	1.66E-03	4.14E-03	7.90E+00
	Flex Bag Open Stock	Landfill (Baseline)	2.78E+00	7.83E-08	1.40E-01	1.25E-02	1.40E-02	8.04E+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. Section 1 provides a background and overview of LCA methodology. This section will discuss 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 developing its product stewardship program to evaluate and reduce the impacts of products and processes throughout the corporation and business groups. The EnergyBag® program was developed as part of Reynolds Consumer Products' commitment to helping create end of life solutions for plastic waste. The 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 will baseline and benchmark the EnergyBag® program to assist with measuring and understanding the environmental impacts of the EnergyBag® program across the life cycle.

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) goal and scope definition, (2) life cycle

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[2] International Organization for Standardization, ISO 14040:2006 *Environmental Management – Life Cycle Assessment – Principles and Framework https://www.iso.org/standard/37456.html.*

inventory (LCI), (3) life cycle impact assessment, and (4) interpretation. An LCA starts with 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). The environmental loads of the system are then 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.

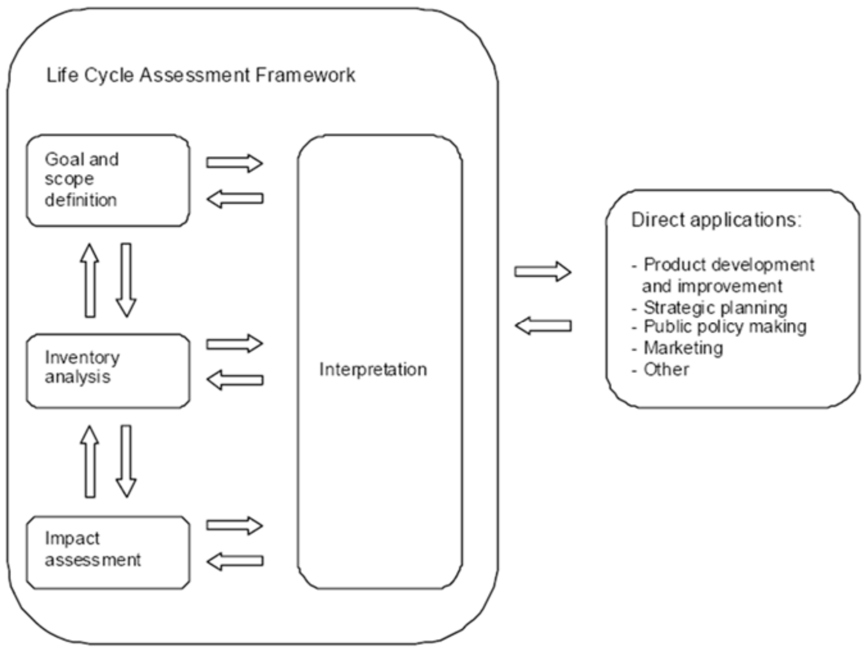

Figure 1.1 – The Four Stages of Life Cycle Assessment

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 have to 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 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 EnergyBag® program. This LCA compares the cradle-to-grave impacts of the EnergyBag® product system utilizing landfill alternatives to the cradle-to-grave impacts of the Hefty® Flex

Trash Bag being landfilled. This LCA was conducted using SimaPro v9 software with the National Renewable Energy Lab (NREL) US LCI database 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 data were not available in the US LCI database, data from the ecoinvent LCI database, and 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 reduction, 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 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 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

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 EnergyBag® orange bag and Flex Bag.

Table 2.1 – Hefty® 13-Gallon 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)	0.0272 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:

- Equivalence of pyrolysis petroleum products and petroleum products in refineries
- Equivalence of resin aggregate and stone aggregate
- Equivalence of plastics as an energy source and coal

2.3 System Boundary

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

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 were modeled based on US grid averages, using the models published in the NREL US LCI database.

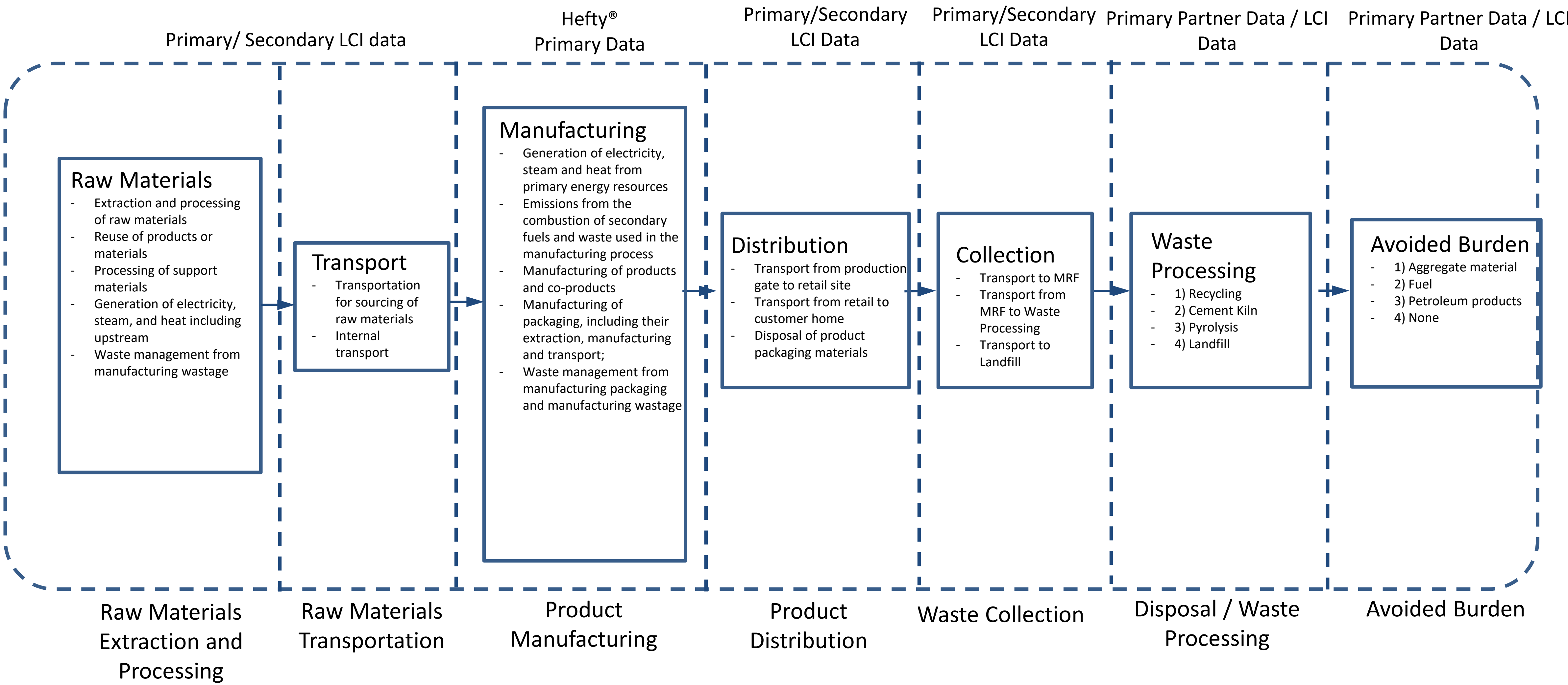

Figure 2.1 - Hefty® EnergyBag® and Flex Bag System Boundary

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. Film plastic from packaging is assumed to be disposed of within the EnergyBag® orange bag. Paper and paperboard are assumed to be conventionally recycled, which is a cut-off process, or disposed of within the EnergyBag® orange bag as part of the small amount of paper contamination. Human activity involved in the manufacturing of the Flex Bag and EnergyBag® orange bag, material recovery facility (MRF) operations, end of life processing, and their component materials no doubt has 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 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 considered to be 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 2.2 describes processes that are excluded from the study. All known processes not listed as "Excluded" in the table below were considered.

Table 2.2 – 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 2.3 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 case was modeled for the Flex Bag system. The EnergyBag® system was modeled for the three landfill alternatives.

Table 2.3 – 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 datasets (ecoinvent 3 and US LCI)	Integrated via SimaPro v9 datasets (ecoinvent 3 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

Life Cycle Stage	Flex Bag	EnergyBag®
Product Distribution	Primary data on Hefty® distribution channels	Primary data on Hefty® distribution channels
End of Life – Landfill	Integrated via SimaPro v9 datasets (ecoinvent 3 and US LCI)	-
End of Life – Unique Pyrolysis Technology	-	Primary data from an operational pyrolysis facility
End of Life – Concrete Aggregate	-	Primary data from an aggregate material manufacturer
End of Life – Cement Kiln Fuel	-	Combination of primary and secondary data collected from an operational cement kiln

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 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[3], 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 complies 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

[3] 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.*

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 three 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 alternate fuel in cement production, and (3) recycling plastics into concrete aggregate for use in durable products. 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 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 were 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 were 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 data sets 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. These datasets are typically developed from reliable sources.

Completeness

The processes modeled represent the specific situations in the 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 the 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 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. Each product is manufactured from very similar ingredients and 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. 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 of recent and modern vintage.

Uncertainty

Most of the secondary data sets in 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, 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 global 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 EnergyBag® system. SSC understands there are updated plastics material datasets being developed which will be available in the US LCI database in the next 6 months. SSC will recommend to Reynolds that these LCA models be updated in a future study to utilize this US LCI dataset. Sensitivity analysis and more detailed certainty ranking can then be conducted at that time for the materials datasets. More information on this limitation may be found in Section 8, below.

3.2 Data Sources – Reynolds Consumer Products

North America was considered the geographic boundary of this study; specifically, the EnergyBag® program is active in four geographic regions in the US: Cobb County, GA; Omaha, NE; Lincoln, NE; and Boise, ID. The reference year of the study is 2019 based upon the data reflecting the EnergyBag® program in 2019. 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 the 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 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 trash bags was created 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 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 within a full period are captured to have a community-wide analysis of a given EnergyBag® program location. The LCA study used the composition of materials from an established EnergyBag® program region, which was considered to be a good representation of 13-gallon bag contents from the program.

Data for converting plastics using unique pyrolysis technology were collected from an operational pyrolysis company. 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 projected 12 months at full production. While this process is currently operational, the international location of the plant is prohibitive to receiving 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 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 EnergyBag® materials versus coal. Secondary data were collected in collaboration with personnel from the cement manufacturer currently processing 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 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 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
Mixed Plastics (Unidentifiable)	34.1	ecoinvent 3
Polyethylene Terephthalate	24.7	Secondary Data[4]
High Density Polyethylene	40.2	Secondary Data[4]
Polyvinyl Chloride	19.1	ecoinvent 3
Low Density Polyethylene	45.7	Secondary Data[4]
Polypropylene	44.1	Secondary Data[4]
Polystyrene	38.9	ecoinvent 3
Glass	0.14	ecoinvent 3
Paper	16.61	ecoinvent 3

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

Landfills were assumed to be located 10km away from the material recovery facility in each EnergyBag® program region. Sanitary or inert landfill ecoinvent processes were utilized for each material constituent of the 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 databases were used.

3.5 Manufacturing Assumptions

Primary data were collected monthly for production of EnergyBag® orange bags and Flex Bags at the Temple, TX facility for the 2019 calendar year. Extruder line power draw and run time hours were measured by onsite personnel.

3.6 Distribution and Packaging Allocation and Assumptions

The distribution data were collected through primary Hefty® data and is further detailed in Section 4 below. The following assumptions were made for 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 packaging option in one EnergyBag® program region an average was used

3.7 Modeling Software

SimaPro v9.0 software was utilized for modeling the complete cradle-to-grave LCI for the 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 EnergyBag® system. The study's geographical and technological coverage has been limited to North America, focusing on the regions that are applicable to the EnergyBag® program. SimaPro v9 was used to generate life cycle impact assessment (LCIA) results utilizing the TRACI impact assessment methodologies.

4.0 Life Cycle Inventory Analysis

This section describes the cradle-to-grave life cycle inventory of the EnergyBag® product system. Primary manufacturing data were collected from surveys completed by personnel at 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. All raw materials were transported domestically via truck.

A thorough analysis of the material inputs and the product recipe was 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 EnergyBag® and Flex Bag, electricity is the input to the manufacturing process.

4.3 Packaging Options

The EnergyBag® program currently has three packaging options. The packaging options were compared to the primary packaging format of the Flex Trash Bag. The three EnergyBag® orange bag packaging options include the starter kit, retail display, and open stock. The open stock option has a roll of EnergyBag® orange bags inside of a plastic film bag, which are placed in corrugated boxes to be shipped on a pallet. The open stock option is placed directly on retail shelves. The retail display packaging option utilizes cardboard to shelve the EnergyBag® orange bags, which are placed inside of a plastic film cover bag. This option requires an additional transportation stop for assembly and is similarly shipped on a pallet. The starter kit contains a smaller number of bags per individual package, which are packaged inside of a plastic film bag. Starter kits are shipped in cardboard boxes on a wooden pallet. Flex Bag packaging uses a cardboard container in lieu of plastic film as the primary packaging but is similarly packaged in a corrugated box 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 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 EnergyBag® orange bag during consumer use, Reynolds Consumer Products commissioned waste audits throughout 2019 at locations in which the program is currently active. As noted in Section 3.3, waste characterizations were conducted following the EnergyBag® program's standard operating procedure by the same third-party consultants across all locations. The study used the composition of materials from a representative EnergyBag® program region, which was considered to be a good representation of 13-gallon bag contents from an established program. 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 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 warehouse to retail stores was estimated based on the distance from the specified warehouse to the geographic center of each county.

Averages of the different routes per packaging option were calculated. After discussions with the Hefty® team it was determined that the Flex Bag takes the same transportation route as the EnergyBag® orange bag. Transportation distances were determined based on the geographic center of the 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 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 options explored in this study for end of life are converting plastics using unique pyrolysis technology, recycling plastics into concrete aggregate, and using plastics as an alternate fuel in cement production.

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 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.

4.6.2 Concrete Aggregate

The second end of life option assessed in this study was the recycling of the EnergyBag® contents into an aggregate material for use in concrete masonry units (CMUs). This partner has had experience qualifying the EnergyBag® orange bag and material. Due to the current location of the plant, this end of life option is not currently receiving EnergyBag® material, but provided data based on hard to recycle waste plastics received locally. The Hefty® team completed a trial with 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 EnergyBag® as fuel in a cement kiln. The study measured the impacts of substituting coal-fired cement kiln with EnergyBag® material fueled cement kilns. 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 EnergyBag® contents. The mixed plastics heating value was determined from a weighted average of the material composition of EnergyBag® collected materials from waste characterization results. In addition to this energy density advantage, data were collected from the partnering cement kiln company's carbon emission calculation tool for using plastics versus coal. In terms of CO_2 stack emissions, the plastics showed a lower emission factor (ton CO_2 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 (EnergyBag® contents).

4.6.4 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, besides glass, were modeled as treatment in sanitary landfills with landfill gas and leachate capture technology. Waste glass was 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 to understand the typical potential environmental impacts associated with this study, therefore TRACI v2.1 was utilized since the analysis of the EnergyBag® program was limited to the North America as the geographic region. The Reynolds team was particularly interested in the GWP impacts of the 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 commented on. 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 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 a number of 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 take into account 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 assesses 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 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 Analysis

The primary focus of this study is a comparison of end of life options. The results in this section focus on the EnergyBag® materials processing and avoided burden, which include the input requirements of each end of life option and the environmental benefit of avoiding having to create the products output from these processes. The avoided burden for each process represents the extent to which the output from each EOL 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 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 EnergyBag® material processing and avoided burden. The EnergyBag® processing for pyrolysis main impacts are in global warming, smog, acidification.

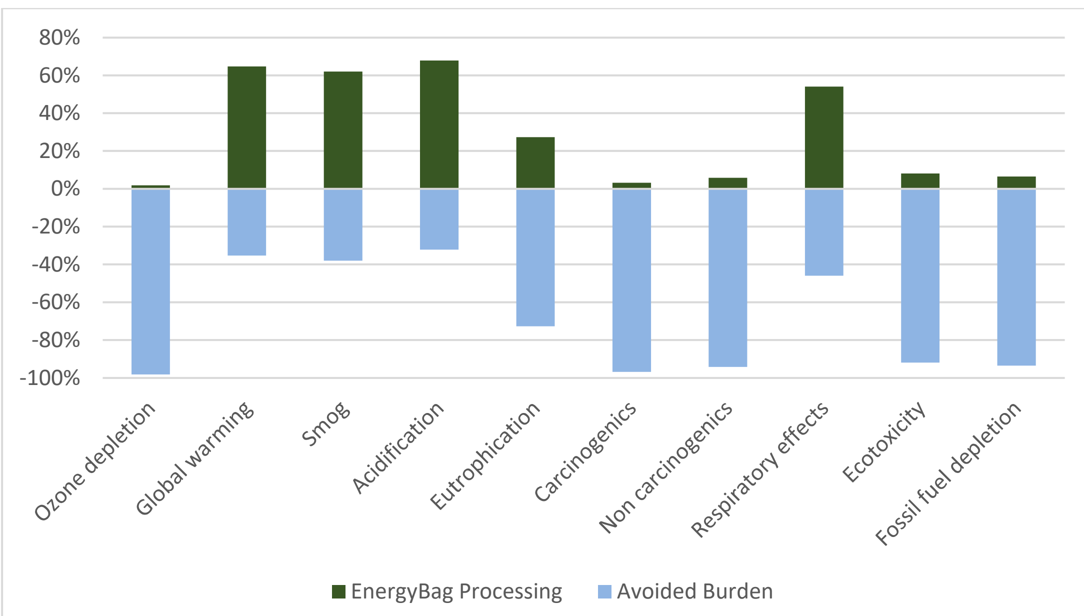

Figure 6.1 – Unique Pyrolysis Technology EnergyBag® Material Processing and Avoided Burden Relative Impacts

When compared to the baseline of landfilling the Flex Bag, pyrolysis of the EnergyBag® materials is favorable in all categories besides smog, acidification, and respiratory effects impacts. This study shows that in the EOL life cycle stage, pyrolysis has a 31% reduction in

GWP compared to landfill. Figure 6.2 shows 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 omitted from the figure due to the large offset impact of direct fossil fuel production. The percent value as compared to landfill for pyrolysis is -11,248%. This fossil fuel depletion percent is calculated as follows:

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

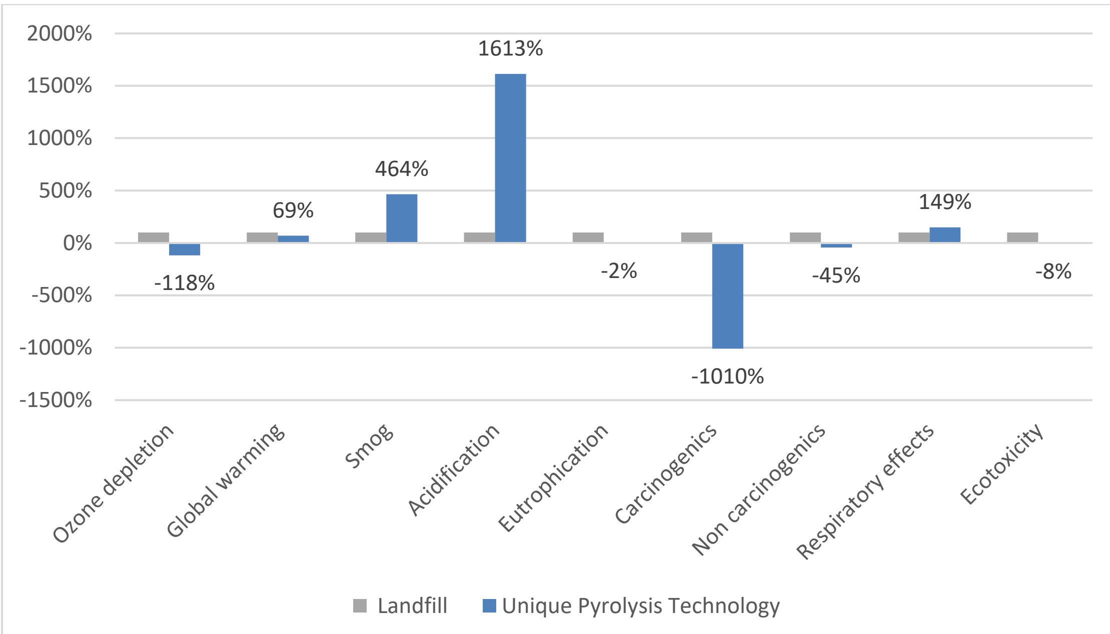

Figure 6.2 – Unique Pyrolysis Technology and Landfill Relative End-of-Life Impacts

Table 6.1 – Unique Pyrolysis Technology and Landfill TRACI Impacts

Impact Category	Unit	Landfill	Unique Pyrolysis Technology
Ozone depletion	kg CFC-11 eq	2.91E-09	-3.44E-09
Global warming	kg CO2 eq	1.31E-01	9.05E-02
Smog	kg O3 eq	1.52E-03	7.08E-03
Acidification	kg SO2 eq	7.61E-05	1.23E-03
Eutrophication	kg N eq	9.83E-03	-1.88E-04
Carcinogenics	CTUh	1.95E-09	-1.97E-08
Non carcinogenics	CTUh	4.18E-07	-1.86E-07
Respiratory effects	kg PM2.5 eq	1.15E-05	1.72E-05
Ecotoxicity	CTUe	4.79E+01	-3.64E+00
Fossil fuel depletion	MJ surplus	2.86E-02	-3.22E+00

When compared to the landfill baseline, pyrolysis shows greater contribution to the smog, acidification, and respiratory effects impact 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. This is particularly true in GWP impacts where the electricity accounts for over 95% of the impact. The GWP cut-off collection distance for pyrolysis versus landfill is 441 km (274 mi).

This study compared the results of the pyrolysis vs. landfill model against publicly available peer-reviewed literature. The results of the study are directionally similar to the Argonne National Laboratory life cycle analysis of fuels from non-recycled plastics, seen in Figure 6.3 below. This study analyzed the life cycle of utilizing non-recycled plastics (NRP) as a pyrolysis fuel source 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 primary source of differences in the life cycle GHG emissions is 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 fuel.[5]

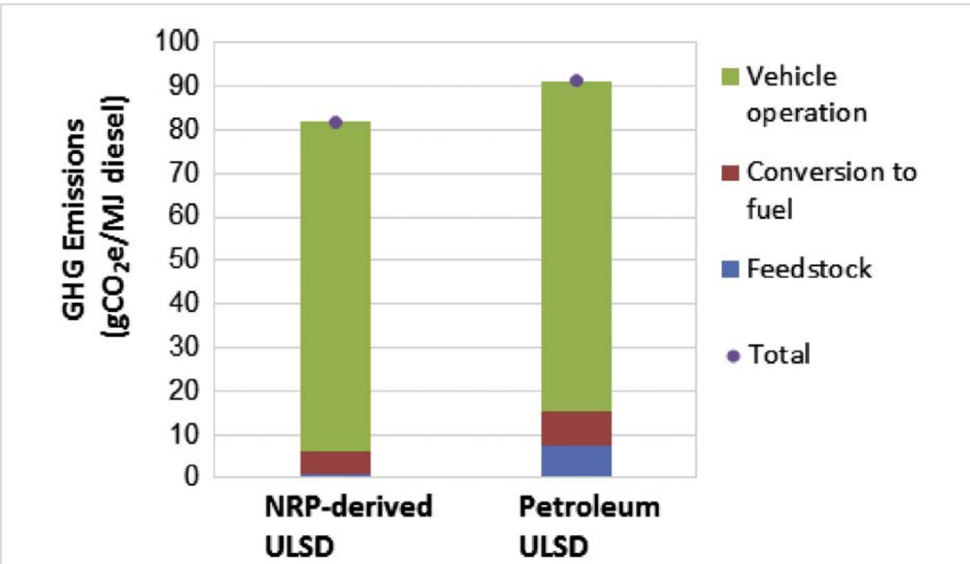

Figure 6.3 – Breakdown of Life Cycle GHG Emissions of Base Case (gCO_2e/MJ Diesel)[5]

The pyrolysis process modeled in the study required a larger amount of electricity per mass of product manufactured as compared to the referenced study. This referenced study utilized process yield and material and energy consumption data sourced and aggregated from five different pyrolysis companies.

6.1.2 Concrete Aggregate End-of-Life Analysis

The second end of life option assessed in this study was the recycling of the EnergyBag® collected materials into an aggregate material for use in concrete masonry units (CMUs). This option utilizes the EnergyBag® contents to make a coarse pre-conditioned resin

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

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

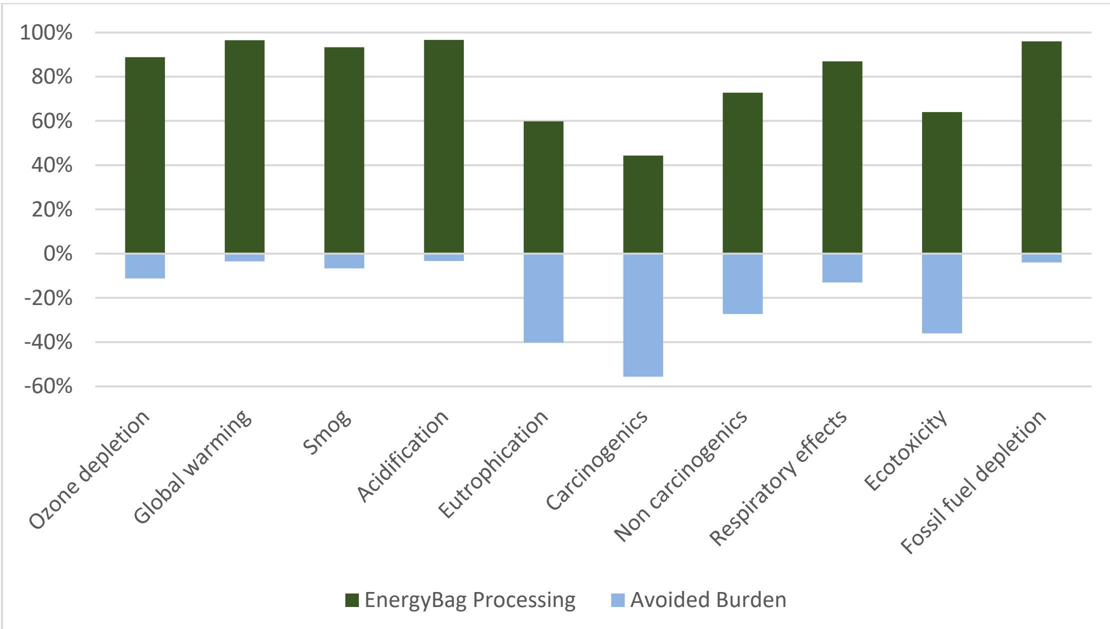

Figure 6.4 – Concrete Aggregate EnergyBag® Processing and Avoided Burden Relative Impacts

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 EnergyBag® content processing. Figure 6.5 below shows the relative impacts compared to the Flex Bag being sent to landfill baseline.

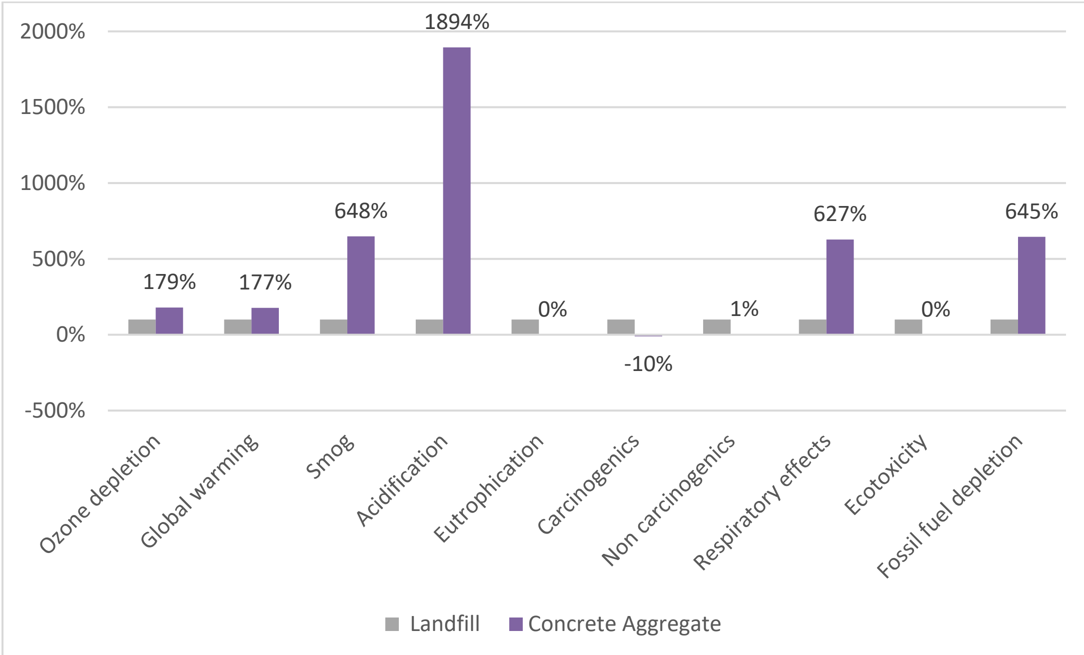

Figure 6.5 – Concrete Aggregate and Landfill Relative End-of-Life Impacts

Table 6.2 – Concrete Aggregate and Landfill TRACI Impacts

Impact Category	Unit	Landfill	Concrete Aggregate
Ozone depletion	kg CFC-11 eq	2.91E-09	5.21E-09
Global warming	kg CO2 eq	1.31E-01	2.32E-01
Smog	kg O3 eq	1.52E-03	9.88E-03
Acidification	kg SO2 eq	7.61E-05	1.44E-03
Eutrophication	kg N eq	9.83E-03	1.67E-05
Carcinogenics	CTUh	1.95E-09	-2.01E-10
Non carcinogenics	CTUh	4.18E-07	5.03E-09
Respiratory effects	kg PM2.5 eq	1.15E-05	7.24E-05
Ecotoxicity	CTUe	4.79E+01	6.12E-02
Fossil fuel depletion	MJ surplus	2.86E-02	1.85E-01

The results in Figure 6.5 illustrate a spike in the smog, acidification, and respiratory effects impact categories for concrete aggregate. 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 EnergyBag® collected materials in a cement kiln as fuel in lieu of coal. Since the higher heating value (HHV) of plastic is greater 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 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 6.6 below shows the EnergyBag® material processing and avoided burden associated with this process.

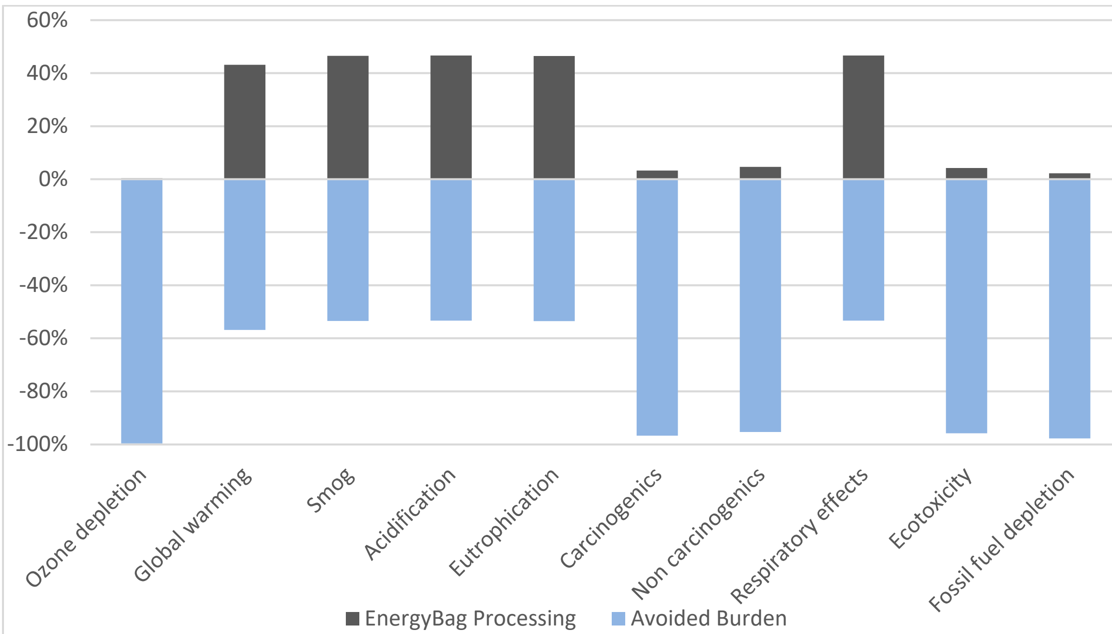

Figure 6.6 - Cement Kiln Fuel EnergyBag® Material Processing and Avoided Burden Relative Impacts

Figure 6.6, above, illustrates the processing of the 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 EnergyBag® material processing. Figure 6.7 below shows the relative impacts of the cement kiln EOL option compared to the landfill baseline.

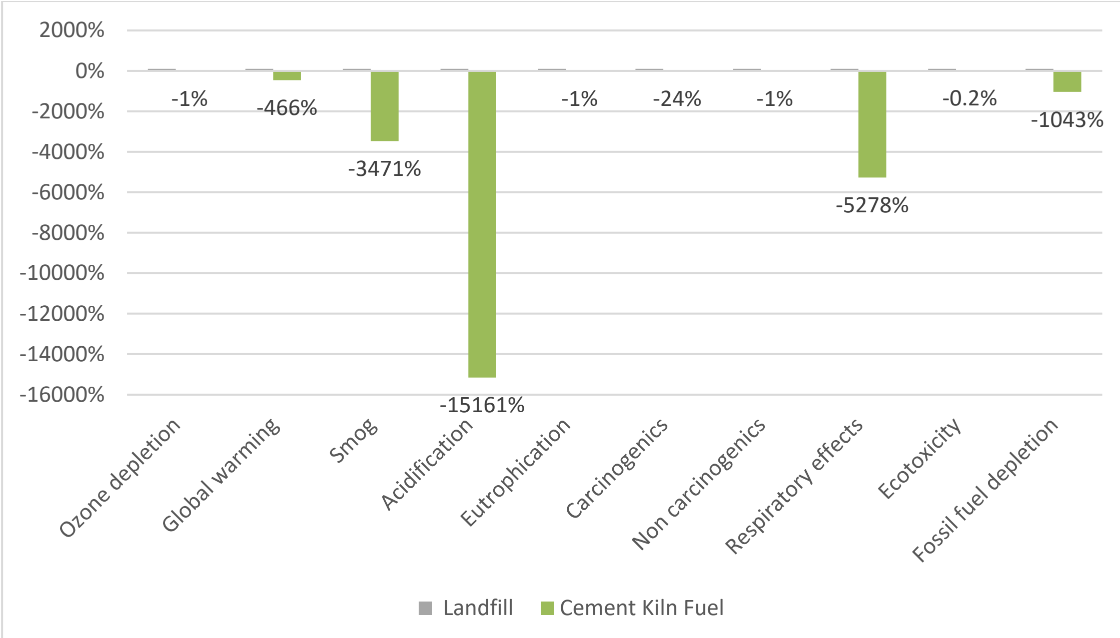

Figure 6.7 - Cement Kiln Fuel and Landfill Relative End-of-Life Impacts

Table 6.3 – Cement Kiln Fuel and Landfill TRACI Impacts

Impact Category	Unit	Landfill	Cement Kiln Fuel
Ozone depletion	kg CFC-11 eq	2.91E-09	-3.69E-11
Global warming	kg CO2 eq	1.31E-01	-6.11E-01
Smog	kg O3 eq	1.52E-03	-5.29E-02
Acidification	kg SO2 eq	7.61E-05	-1.15E-02
Eutrophication	kg N eq	9.83E-03	-9.56E-05
Carcinogenics	CTUh	1.95E-09	-4.67E-10
Non carcinogenics	CTUh	4.18E-07	-5.32E-09
Respiratory effects	kg PM2.5 eq	1.15E-05	-6.09E-04
Ecotoxicity	CTUe	4.79E+01	-8.64E-02
Fossil fuel depletion	MJ surplus	2.86E-02	-2.98E-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 -466% to -15,161% 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 EnergyBag® plastics. The GWP cut-off distance for the cement kiln process alone as compared to landfill GWP impacts is over 5000 mi.

6.2 Current 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 on GWP impacts and for use as a decision-making tool in locating of new partners within the end of life sectors analyzed in this study. GWP cut-off distances were calculated based on modeling the EnergyBag® orange bag being transported 1 km. The difference between the life cycle GWP impacts of landfill alternatives and landfill baseline is divided by the 1 km transport distance impact to determine the cut-off distance.

6.2.1 Cobb County, GA

The packaging type evaluated for this location was the starter kit, scaled to a 13-gallon size. End-of-life options include converting the plastics using unique pyrolysis technology and using the plastics as an alternate fuel in cement production.

Figure 6.8 shows the overall GWP impact for each EOL option at this location. The Cement kiln EOL option has the lowest impact due to the high avoided burden.

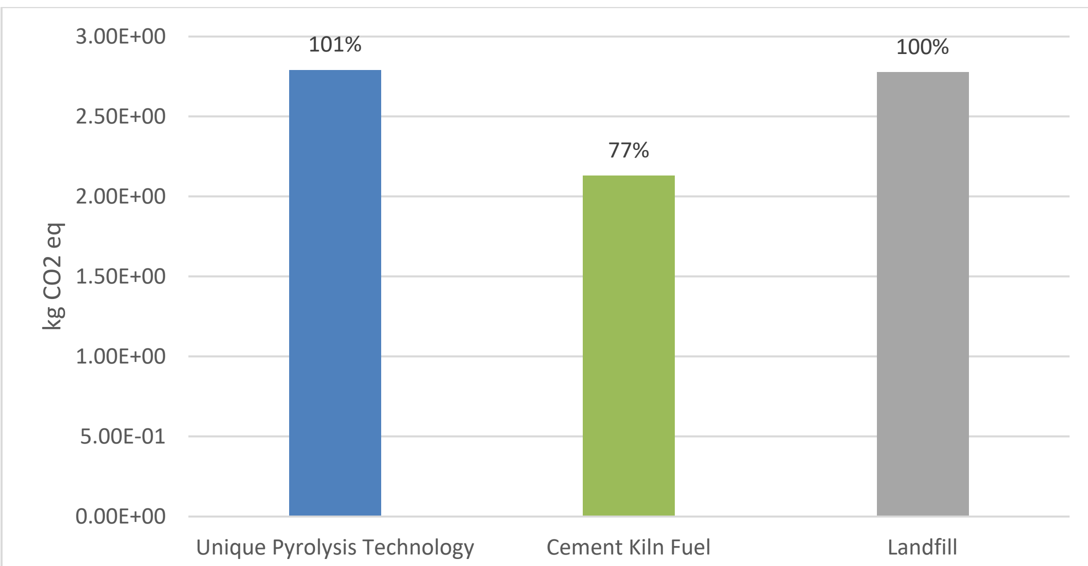

Figure 6.8 - Overall GWP Impacts for Different EOL Options at Cobb County

Table 6.4 below shows the TRACI methodology LCA environmental impacts and the percent comparison to the landfill baseline. Pyrolysis fares similar to landfill in the air emission related categories but is slightly higher. Both pyrolysis and cement kiln results are lower than landfill for eutrophication, as the ecoinvent 3 landfill databases include short-term leachate treatment in wastewater treatment and long-term emissions from landfill to groundwater after base lining failure.

Table 6.4 – TRACI Methodology Impacts and Relative Impacts to Landfill Baseline at Cobb County

Impact Category	Unit	Landfill	Unique Pyrolysis Technology	Cement Kiln Fuel	Landfill	Unique Pyrolysis Technology	Cement Kiln Fuel
Ozone depletion	kg CFC-11 eq	7.78E-08	7.60E-08	7.94E-08	100%	98%	102%
Global warming	kg CO2 eq	2.78E+00	2.79E+00	2.13E+00	100%	101%	77%
Smog	kg O3 eq	1.40E-01	1.49E-01	1.02E-01	100%	106%	73%
Acidification	kg SO2 eq	1.25E-02	1.39E-02	1.67E-03	100%	111%	13%
Eutrophication	kg N eq	1.40E-02	4.08E-03	4.21E-03	100%	29%	30%
Carcinogenics	CTUh	1.84E-07	1.64E-07	1.84E-07	100%	89%	100%
Non carcinogenics	CTUh	8.08E-07	2.19E-07	4.06E-07	100%	27%	50%
Respiratory effects	kg PM2.5 eq	1.92E-03	1.96E-03	1.35E-03	100%	102%	70%
Ecotoxicity	CTUe	6.14E+01	1.03E+01	1.40E+01	100%	17%	23%
Fossil fuel depletion	MJ surplus	8.03E+00	4.92E+00	7.93E+00	100%	61%	99%

6.2.2 Omaha, NE

EnergyBag® orange bags in this location were evaluated for using the plastics as an alternate fuel in cement production only. Figure 6.9 shows the overall GWP impact for each packaging option. Cement kiln EOL scenarios, for both open stock and retail display packaging, have similar environmental impacts, which are lower than the impact of landfilling at the EOL.

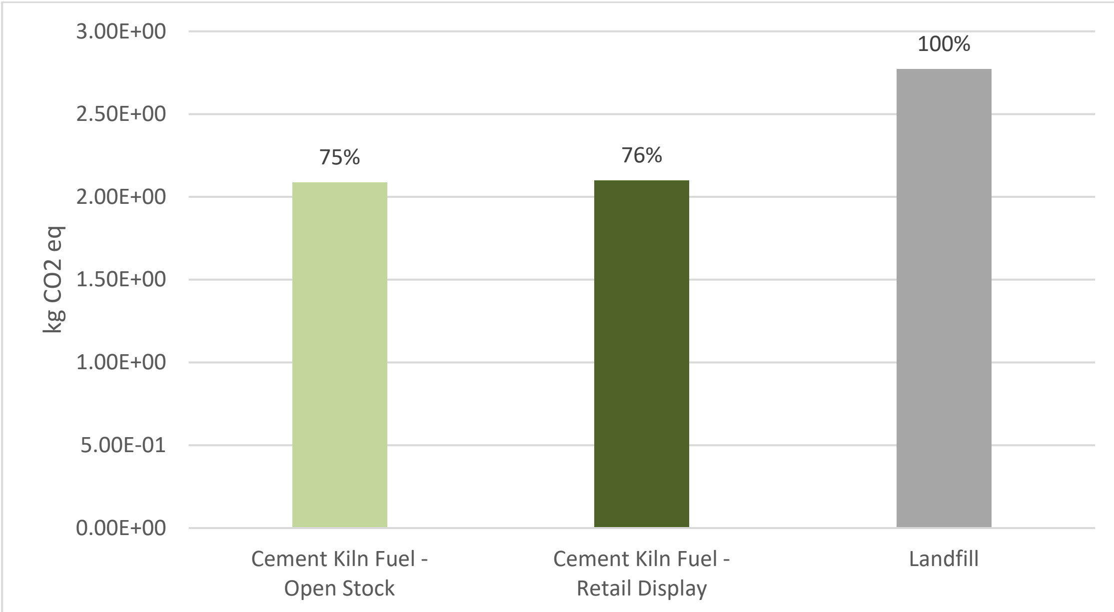

Figure 6.9 - GWP Impacts for Different EOL Options at Omaha

Table 6.5 below shows the impact per bag and the relative impact to the baseline landfill scenario across all the LCA impact categories. The minimal difference in environmental impact for the two cement kiln EOL scenarios can be attributed to the difference in the packaging options, which does not drive the LCA impacts.

Table 6.5 - TRACI Methodology Impacts and Relative Impacts to Landfill Baseline at Omaha

Impact Category	Unit	Landfill	Cement Kiln Fuel (Open Stock)	Cement Kiln Fuel (Retail Display)	Landfill	Cement Kiln Fuel (Open Stock)	Cement Kiln Fuel (Retail Display)
Ozone depletion	kg CFC-11 eq	7.65E-08	7.43E-08	7.64E-08	100%	97%	100%
Global warming	kg CO_2 eq	2.77E+00	2.09E+00	2.10E+00	100%	75%	76%
Smog	kg O3 eq	1.40E-01	9.64E-02	9.70E-02	100%	69%	69%
Acidification	kg SO2 eq	1.25E-02	1.38E-03	1.42E-03	100%	11%	11%
Eutrophication	kg N eq	1.40E-02	4.12E-03	4.15E-03	100%	29%	30%
Carcinogenics	CTUh	1.84E-07	1.82E-07	1.83E-07	100%	99%	99%
Non carcinogenics	CTUh	8.07E-07	3.88E-07	3.92E-07	100%	48%	49%
Respiratory effects	kg PM2.5 eq	1.92E-03	1.32E-03	1.33E-03	100%	69%	69%
Ecotoxicity	CTUe	6.13E+01	1.37E+01	1.38E+01	100%	22%	23%
Fossil fuel depletion	MJ surplus	8.02E+00	7.84E+00	7.86E+00	100%	98%	98%

6.2.3 Lincoln, NE

EnergyBag® orange bags in this location were evaluated for using the plastics as an alternate fuel in cement production only. Figure 6.10 shows the overall GWP impact for each packaging option at this location.

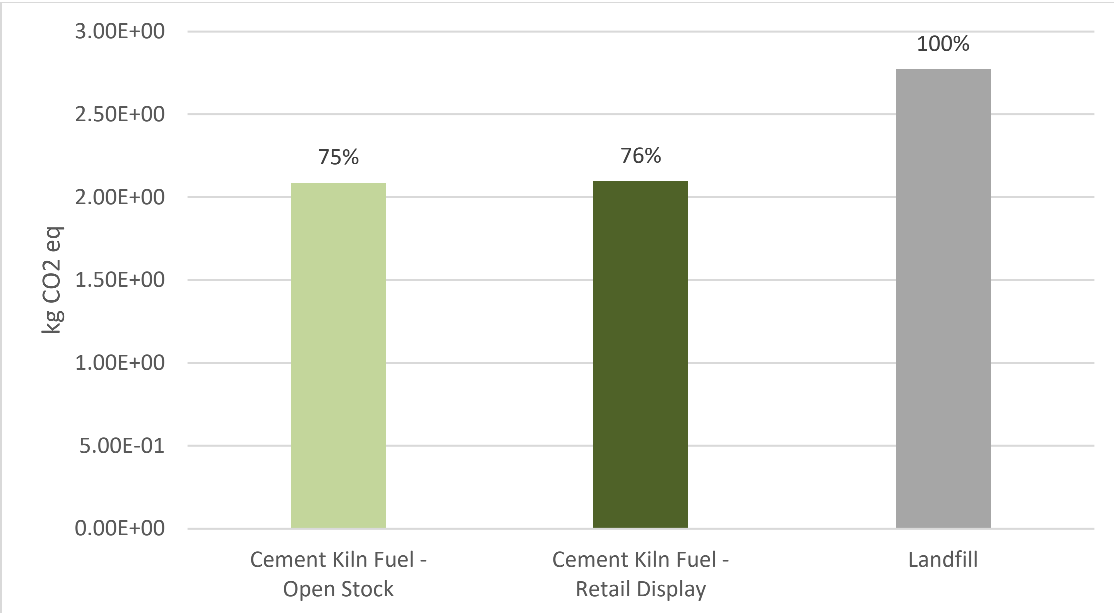

Figure 6.10 - GWP Impacts for Different EOL Options at Lincoln

Table 6.6 below shows the impact per bag and the relative impact to the baseline landfill scenario across all the LCA impact categories. Similar to the results in Omaha, the small relative significance of the packaging option compared to the cement kiln impacts is seen by the similarities in results from the two cement kiln scenarios in Lincoln.

Table 6.6 - TRACI Methodology Impacts and Relative Impacts to Landfill Baseline at Lincoln

Impact Category	Unit	Landfill	Cement Kiln Fuel (Open Stock)	Cement Kiln Fuel (Retail Display)	Landfill	Cement Kiln Fuel (Open Stock)	Cement Kiln Fuel (Retail Display)
Ozone depletion	kg CFC-11 eq	7.65E-08	7.43E-08	7.65E-08	100%	97%	100%
Global warming	kg CO2 eq	2.78E+00	2.09E+00	2.10E+00	100%	75%	76%
Smog	kg O3 eq	1.42E-01	9.84E-02	9.90E-02	100%	69%	70%
Acidification	kg SO2 eq	1.25E-02	1.46E-03	1.50E-03	100%	12%	12%
Eutrophication	kg N eq	1.40E-02	4.13E-03	4.15E-03	100%	29%	30%
Carcinogenics	CTUh	1.84E-07	1.82E-07	1.83E-07	100%	99%	99%
Non carcinogenics	CTUh	8.08E-07	3.89E-07	3.92E-07	100%	48%	49%
Respiratory effects	kg PM2.5 eq	1.92E-03	1.32E-03	1.33E-03	100%	69%	69%
Ecotoxicity	CTUe	6.13E+01	1.37E+01	1.38E+01	100%	22%	23%

Impact Category	Unit	Landfill	Cement Kiln Fuel (Open Stock)	Cement Kiln Fuel (Retail Display)	Landfill	Cement Kiln Fuel (Open Stock)	Cement Kiln Fuel (Retail Display)
Fossil fuel depletion	MJ surplus	8.03E+00	7.85E+00	7.88E+00	100%	98%	98%

6.2.4 Boise, ID

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

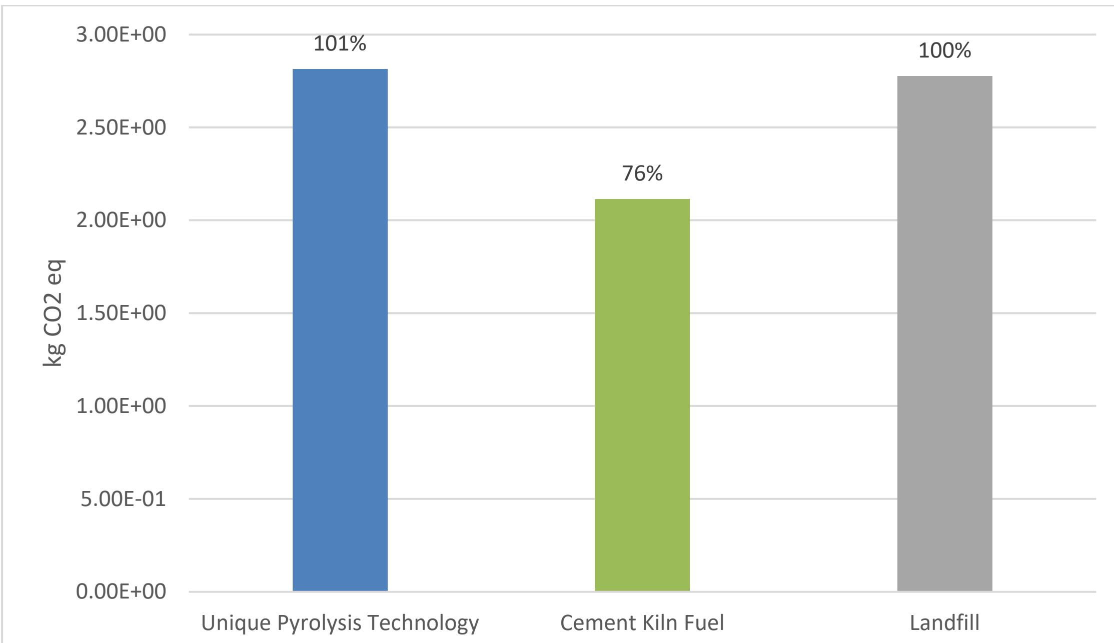

Figure 6.11 - GWP Impacts for Different EOL Options at Boise

Table 6.7 below shows the absolute and relative TRACI methodology LCA impacts for both alternative end of life options and landfill baseline. Similar to Cobb County, the pyrolysis option is slightly more impactful in GWP, smog, and acidification due to the high input of electricity into the pyrolysis process. The cement kiln option, similar to all other regions, has lower LCA impacts than pyrolysis and landfill.

Table 6.7 - TRACI Methodology Impacts and Relative Impacts to Landfill Baseline at Boise

Impact Category	Unit	Landfill	Unique Pyrolysis Technology	Cement Kiln Fuel	Landfill	Unique Pyrolysis Technology	Cement Kiln Fuel
Ozone depletion	kg CFC-11 eq	7.83E-08	7.28E-08	7.62E-08	100%	93%	97%
Global warming	kg CO_2 eq	2.78E+00	2.81E+00	2.11E+00	100%	101%	76%
Smog	kg O3 eq	1.40E-01	1.63E-01	1.03E-01	100%	117%	74%
Acidification	kg SO2 eq	1.25E-02	1.44E-02	1.66E-03	100%	116%	13%

Impact Category	Unit	Landfill	Unique Pyrolysis Technology	Cement Kiln Fuel	Landfill	Unique Pyrolysis Technology	Cement Kiln Fuel
Eutrophication	kg N eq	1.40E-02	4.05E-03	4.14E-03	100%	29%	30%
Carcinogenics	CTUh	1.84E-07	1.63E-07	1.83E-07	100%	89%	99%
Non carcinogenics	CTUh	8.09E-07	2.12E-07	3.93E-07	100%	26%	49%
Respiratory effects	kg PM2.5 eq	1.92E-03	1.96E-03	1.33E-03	100%	102%	69%
Ecotoxicity	CTUe	6.14E+01	1.03E+01	1.38E+01	100%	17%	23%
Fossil fuel depletion	MJ surplus	8.04E+00	4.98E+00	7.90E+00	100%	62%	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 standpoint but under the distance, the alternative end of life option is more favorable. Table 6.8 below shows the cut off distances for each current technology in each EnergyBag® program location.

Table 6.8 – Global Warming Potential Cut-Off Distances

Global Warming Potential Cut-Off Collection Distances				
Location	**Packaging**	**End of Life Option**	**Cut Off (km)**	**Cut Off (miles)**
Cobb County, GA	Starter Kit	Unique Pyrolysis Technology	N/A	N/A
	Starter Kit	Cement Kiln Fuel	7,508	4,665
Omaha, NE	Open Stock	Cement Kiln Fuel	7,790	4,840
	Retail Display	Cement Kiln Fuel	7,674	4,769
Lincoln, NE	Open Stock	Cement Kiln Fuel	7,854	4,880
	Retail Display	Cement Kiln Fuel	7,733	4,805
Boise, ID	Open Stock	Unique Pyrolysis Technology	153	95
	Open Stock	Cement Kiln Fuel	7,781	4,835

Using the EnergyBag® plastics as a cement kiln fuel alternative, regardless of location or packaging type, is favorable if transported less than of 4,665 – 4,880 miles (7,508 – 7,854) kilometers), depending on location. Converting the plastics using unique pyrolysis technology is only favorable compared to landfill in Boise, ID if the pyrolysis site is less than 95 miles (153 km). While recycling plastics into concrete aggregate was not an available end of life option at any EnergyBag® program location at the time of this study, the GWP impacts are higher than the landfill baseline scenario for all locations and packaging options.

7.0 Conclusions

This LCA study analyzed the cradle to grave life cycle impacts of the Hefty® EnergyBag® program compared to the baseline case of landfilling the Flex Trash Bag. The study included the cradle-to-grave life cycle assessment of both product systems including an end of life analysis of three landfill alternative scenarios: converting plastics using unique pyrolysis technology, using plastics as an alternate fuel in cement production, and recycling plastics into concrete aggregate.

The LCA conducted on the Flex Bag and the EnergyBag® orange bag with different end of life and packaging options revealed 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 EnergyBag® orange bag than for the bag.

The GWP impacts from the end of life processes of converting plastics using unique pyrolysis technology and recycling plastics into concrete aggregate are driven by electricity consumption.

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

Table 7.1 – Life Cycle Impacts Summary Table

Location	Packaging	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	Starter Kit	Unique Pyrolysis Technology	2.79E+00	7.60E-08	1.49E-01	1.39E-02	4.08E-03	4.92E+00
	Starter Kit	Cement Kiln Fuel	2.13E+00	7.94E-08	1.02E-01	1.67E-03	4.21E-03	7.93E+00
	Flex Bag Open Stock	Landfill	2.78E+00	7.78E-08	1.40E-01	1.25E-02	1.40E-02	8.03E+00
Omaha, NE	Open Stock	Cement Kiln Fuel	2.09E+00	7.43E-08	9.64E-02	1.38E-03	4.12E-03	7.84E+00
	Retail Display	Cement Kiln Fuel	2.10E+00	7.64E-08	9.70E-02	1.42E-03	4.15E-03	7.86E+00
	Flex Bag Open Stock	Landfill	2.77E+00	7.65E-08	1.40E-01	1.25E-02	1.40E-02	8.02E+00
Lincoln, NE	Open Stock	Cement Kiln Fuel	2.09E+00	7.43E-08	9.84E-02	1.46E-03	4.13E-03	7.85E+00
	Retail Display	Cement Kiln Fuel	2.10E+00	7.65E-08	9.90E-02	1.50E-03	4.15E-03	7.88E+00
	Flex Bag Open Stock	Landfill	2.78E+00	7.65E-08	1.42E-01	1.25E-02	1.40E-02	8.03E+00
Boise, ID	Open Stock	Unique Pyrolysis Technology	2.81E+00	7.28E-08	1.63E-01	1.44E-02	4.05E-03	4.98E+00
	Open Stock	Cement Kiln Fuel	2.11E+00	7.62E-08	1.03E-01	1.66E-03	4.14E-03	7.90E+00
	Flex Bag Open Stock	Landfill	2.78E+00	7.83E-08	1.40E-01	1.25E-02	1.40E-02	8.04E+00

8.0 Limitations

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

8.1 End of Life Limitations

The data for the unique pyrolysis technology, concrete aggregate production, and cement kiln fuel utilized primary and projected data, including assumptions associated with calculations. The unique pyrolysis technology data were generated from a shorter duration batch campaign, rather than a continuous flow production campaign. Continuous flow production campaigns over longer time periods would make future studies of the 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.

8.1.1 Cement Kiln Fuel Data Limitations

This study 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.

8.1.2 Concrete Aggregate Data Limitations

When the concrete aggregate manufacturing plant is sited in North America, data from the plant receiving EnergyBag® materials from EnergyBag® program locations would reduce the assumptions within the concrete aggregate process.

8.1.3 Landfill Limitations

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 regionality differences of landfills are not captured in this study.

8.1.4 Life Cycle Inventory Limitations

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 short duration campaigns to 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.

At the time of this study, it is understood that new plastics LCI data is being developed for US LCI by the American Chemistry Council's (ACC) Plastics Division and National Renewable Energy Laboratory. At the time of this study, the LCI data had not been reviewed or published. Therefore, this data was not available in the LCA software for utilization. Future iterations of the EnergyBag® program LCA should consider integrating the updated plastics data as the use of low ethane crackers may have an impact on energy consumption.

9.0 Recommendations

This study analyzed the life cycle impacts of the Hefty® EnergyBag® product system as compared to landfilling the Flex Bag. The Hefty® EnergyBag® program targets plastics for which there is limited recycling or landfill alternative infrastructure. This study concluded that substituting coal with plastic fuel in a cement kiln is beneficial even with a large range of transport. Unique pyrolysis technology was concluded to be sensitive to electricity grid mix as a significant amount of the GWP impact is driven by the electricity input. As this study used the US average grid mix, it is recommended that future siting of pyrolysis plants in any EnergyBag® program expansion investigate the regional grid mix as compared to the average grid mix utilized in this study. As the concrete aggregate EOL option uses the plastics to offset a naturally abundant and low impact material, gravel, there is no GWP cut off distance in this study. It is recommended that future studies incorporate updated US LCI plastics data that was not published or available at the time of this study. Updates to this database likely will include low ethane crackers to produce ethylene, which may reduce the environmental impacts. While cement kiln fuel primary data were collected for pre-processing of 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. In addition, collecting unique pyrolysis technology data for longer temporal periods, such as 12-months, would limit the possibility of outlier data or seasonal variability. As the EnergyBag® program matures in the current regions and expands to new regions, future studies should consider differences in the material content being placed within the EnergyBag® orange bags.