LIFE CYCLE IMPACTS OF PLASTIC PACKAGING COMPARED TO SUBSTITUTES IN THE UNITED STATES AND CANADA

Theoretical Substitution Analysis

PREPARED FOR

The Plastics Division of the American Chemistry Council (ACC)

BY

Franklin Associates, A Division of
Eastern Research Group (ERG)

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Preface

This work is an expansion and update of an energy and greenhouse gas analysis conducted in 2014 for The Plastics Division of the American Chemistry Council (ACC) and the Canadian Plastics Industry Association (CPIA) under the direction of Mike Levy for ACC, Cathy Cirko and Fred Edgecombe for CPIA, and Ashley Carlson of Ashley Carlson Consulting. Emily Tipaldo of ACC provided leadership for the expanded version of the analysis. We gratefully acknowledge their assistance in the development of this report.

At Franklin Associates, the project to expand the scope of the analysis to include additional environmental impacts was led by Beverly Sauer, Senior Chemical Engineer and Project Manager, who served as reviewer of the original substitution model and report, as well as assisting with modeling and writeup of results in both the original study and the expanded study. For the original substitution analysis, Rebe Feraldi was the lead in developing the substitution model and writeup and conducted the majority of the modeling with assistance from Janet Mosley. Shelly Schneider and Anne Marie Molen assisted with research tasks and development of the report. Lori Snook contributed to report preparation tasks.

Franklin Associates gratefully acknowledges significant contributions to the original substitution analysis project by external reviewers Harald Pilz of Denkstatt GmbH and Roland Hischier of the Empa Research Institute. Revisions made in response to their review comments improved the quality and transparency of the report.

The work was performed by Franklin Associates, A Division of ERG as an independent contractor. The findings and conclusions are strictly those of Franklin Associates acting in this role. Franklin Associates makes no statements nor supports any conclusions other than those presented in this report.

April 2018

List of Acronyms (Alphabetical)

ACC	American Chemistry Council
CPIA	Canadian Plastics Industry Association
CED	Cumulative Energy Demand
DC	Distribution Center
EGRID	Emissions & Generation Resource Integrated Database
EMR	Energy of Material Resource
EOL	End of Life
ERG	Eastern Research Group, Inc.
EQ	Equivalents
EPS	Expanded Polystyrene
GHG	Greenhouse Gas
GWP	Global Warming Potential
HDPE	High Density Polyethylene
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ISBM	Injection Stretch Blow Molding
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LDPE	Low Density Polyethylene
LF	Landfill
LMOP	Landfill Methane Outreach Program
NREL	National Renewable Energy Laboratory

ODP	Ozone Depletion Potential
PC	Postconsumer
PET	Polyethylene Terephthalate
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl Chloride
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
WTE	Waste-to-Energy Incineration

Terms and Definitions
(Alphabetical)

Acidification Potential— potential of emissions such as sulfur dioxide and nitrogen oxides to result in acid rain, with damaging effects on ecosystems and buildings.

Allocation—partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems.

Biomass—the total dry organic matter or stored energy content of living organisms that is present at a specific time in a defined unit of the Earth's surface. As an energy source, the Energy Information Administration defines biomass as organic non-fossil material of biological origin constituting a renewable energy source.

Carbon Sequestration—removal of carbon from the atmosphere.[1]

Carbon Storage—retaining carbon of biogenic or atmospheric origin in a form other than as an atmospheric gas.[2] In this analysis, carbon storage occurs when packaging materials containing biogenic carbon are disposed in a landfill and do not decompose.

Characterization Factor—factor derived from a characterization model which is applied to convert an assigned life cycle inventory analysis result to the common unit of the category indicator.

Closed-Loop Recycling—transformation of a recovered material into an equivalent form (e.g. recycled product is equivalent to product in previous life, no loss in inherent material properties), and/or use of postconsumer recycled material as an input to the same type of product system from which the material was recovered.

Combustion Energy—the higher heat value directly released when coal, fuel oil, natural gas, or biomass is burned for energy consumption.

Co-product—any of two or more products coming from the same unit process or product system.

Cradle-to-Material—refers to an LCA or LCI covering life cycle stages from raw material extraction through raw material production (i.e. does not cover entire life cycle of a product system).

Cradle-to-Grave—an LCA or LCI covering all life cycle stages of a product system from raw material extraction through end-of-life and recycling when applicable.

End-of-Life—refers to the life cycle stage of a product following disposal.

Energy Demand—energy requirements of a process/product, including energy from renewable and non-renewable resources). In this study, energy demand is measured by the higher heating value of the fuel at point of extraction.

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[1] Definition from PAS 2050: 2008, Specifications for the assessment of the life cycle greenhouse gas (GHG) emissions of goods and services.

[2] Definition from PAS 2050: 2008, Specifications for the assessment of the life cycle greenhouse gas (GHG) emissions of goods and services.

Energy of Material Resource—the energy value of fuel resources withdrawn from the planet's finite fossil reserves and used as material inputs. Some of this energy remains embodied in the material and can potentially be recovered. Alternative terms used by other LCA practitioners include "Feedstock Energy" and "Inherent Energy."

Eutrophication Potential—assesses the potential of nutrient releases to the environment to decrease oxygen content in bodies of water, which can lead to detrimental effects such as algal blooms and fish kills.

Expended Energy—energy that has been consumed (e.g., through combustion) and is no longer recoverable

Fossil Fuel—fuels with high carbon content from natural processes (e.g. decomposition of buried dead organisms) that are created over a geological time frame (e.g. millions of years). Natural gas, petroleum and coal are examples of fossil fuels.

Fugitive Emissions—unintended leaks of substances that escape to the environment without treatment. These are typically from the processing, transmission, and/or transportation of fossil fuels, but may also include leaks and spills from reaction vessels, other chemical processes, methane emissions escaping untreated from landfills, etc.

Functional Unit—quantified performance of a product system for use as a reference unit.

Global Warming Potential—an index, describing the radiative characteristics of well-mixed greenhouse gases, that represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing infrared radiation. This index approximates the time-integrated warming effect of a unit mass of a given greenhouse gas in today's atmosphere, relative to that of carbon dioxide.[3]

Greenhouse Gas—gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds. This property causes the greenhouse effect. Water vapor, carbon dioxide, nitrous oxide, methane, and ozone are the primary greenhouse gases in the Earth's atmosphere.

Impact Category—class representing environmental issues of concern to which life cycle inventory analysis results may be assigned.

Life Cycle—consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal.

Life Cycle Assessment—compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.

Life Cycle Inventory—phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle.

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[3] Definition from the glossary of the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report - Climate Change 2001.

Life Cycle Impact Assessment—phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product.

Life Cycle Interpretation—phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations.

Non-Renewable Energy—energy from resources that cannot be created on scale to sustain consumption (i.e. cannot re-generate on human time-scale). Fossil fuels (e.g. coal, petroleum, natural gas) and nuclear power (uranium) are considered non-renewable energy resources.

Open-Loop Recycling—recycling in which the inherent properties of the recycled material changes with recycling and/or when the recycled material is used as an input to a different product than its previous use.

Ozone Depletion Potential—potential of emissions to result in depletion of stratospheric ozone, which increases exposure to radiation. This can lead to increased frequency of human health issues such as skin cancers and cataracts as well as detrimental effects on crops, other plants, and marine life.

Postconsumer Content—the quantity of material input to a product that is derived from recycled materials.

Postconsumer Waste—waste resulting directly from consumer disposal of the product system of the analysis.

Process Waste—wastes from processes along the entire life cycle of the product system. Does not include postconsumer waste.

Precombustion Energy—the energy required for the production and processing of energy fuels, such as coal, fuel oil, natural gas, or uranium, starting with their extraction from the ground, up to the point of delivery to the customer.

Raw Material—primary or shipping (i.e., recycled) material that is used to produce a product.

Renewable Energy—energy from natural resources that can be replenished (e.g. biomass) or are not depleted by use (e.g., hydropower, sunlight, wind).

Smog Formation Potential— potential of emissions to form ground-level ozone which can affect human health and ecosystems.

Solid Waste—any wastes resulting from fuel extraction and combustion, processing, or postconsumer disposal. Solid waste in this study is measured as waste to a specific fate (e.g. landfill, incinerator).

System Boundary—set of criteria specifying which unit processes are part of a product system.

System Expansion—a methodology to expand the system boundaries, thus avoiding the need for allocation. In this study, system expansion is used, for instance, to model recycling. If the end-of-life recycling rate is higher than the recycled content of the product, the system is a net producer of recycled material, so the system is credited with avoiding production of the equivalent amount of virgin material. If the end-of-life recycling rate is less than the recycled content, the system is a net user of recycled material, so the system is applied a burden for the equivalent amount of virgin material.

Transportation Energy—energy used to move materials or goods from one location to another throughout the various stages of a product's life cycle

Unit Process—smallest element considered in the life cycle inventory analysis for which input and output data are quantified.

Waste-to-Energy Combustion—creating energy (electricity or heat) from combustion of waste materials.

Water Consumption—consumptive use of water includes freshwater that is withdrawn from a water source or watershed and not returned to that source. Consumptive water use includes water consumed in chemical reactions, water that is incorporated into a product or waste stream, water that becomes evaporative loss, and water that is discharged to a different watershed or water body than the one from which it was withdrawn.

EXECUTIVE SUMMARY

ES.1. INTRODUCTION & BACKGROUND

Packaging is an important focus today as businesses and other organizations strive to create the most efficient environmental "footprint" for their products. Figure ES–1 shows thermoplastic resin demand in North American packaging versus non-packaging markets from 2007 to 2011. Packaging uses account for over a third of sales and captive use of thermoplastic resins.[4] The packaging categories analyzed in this study are estimated to capture 95-99 percent of plastic use in North American packaging.[5] Relative to other packaging materials such as steel, aluminum, glass, paper, etc., plastic-based packaging is 39 to 100 percent of total North American market demand for packaging categories analyzed in this study.

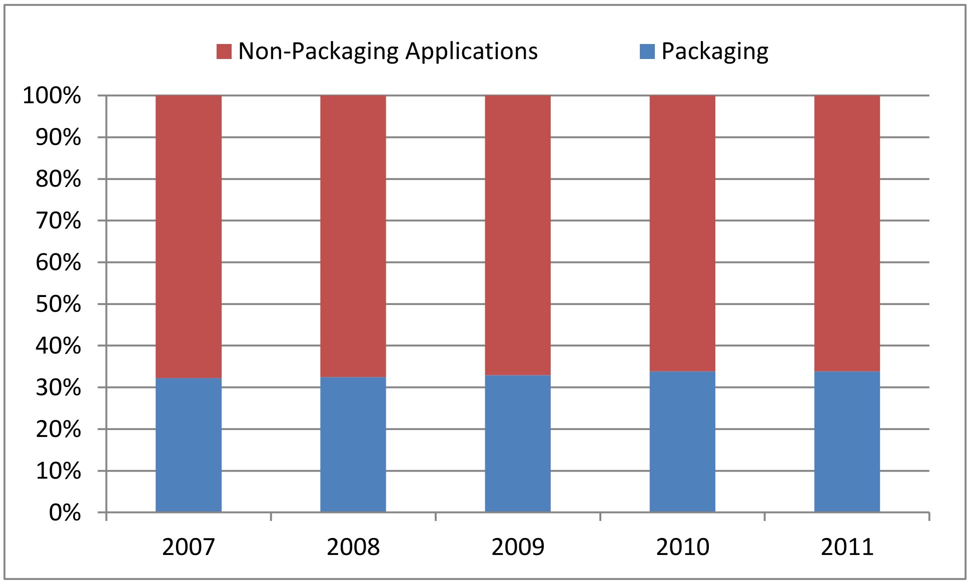

Figure ES–1. Thermoplastic Resins Demand in Packaging vs. Non-Packaging Markets – 2007-2011 (per data from the ACC 2012 Resin Review)

The goal of the substitution analysis presented in this report is to use LCA methodology to assess the environmental impacts of plastics packaging relative to alternative packaging in North America and answer the question: "If plastic packaging were replaced with alternative types of packaging, how would environmental impacts be affected?" Impact

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[4] ACC (2012). The Resin Review: The Annual Statistical Report of the North American Plastics Industry, American Chemistry Council, 2012 Edition.

[5] Per cross-checking total weights of plastic packaging in North America as calculated based on data provided by Freedonia market reports with total weights of plastic reported by the American Chemistry Council and US and Canadian national statistics on annual waste generation.

categories addressed in the analysis include energy demand, water consumption, solid waste, global warming potential, acidification potential, eutrophication potential, smog formation potential, and ozone depletion potential.

In the theoretical substitution analysis, the impacts of current amounts of plastic packaging products are compared to a scenario in which plastic packaging is substituted by alternative materials (e.g., paper and paperboard, glass, steel, aluminum, textiles, rubber, and cork). All of the plastic resins investigated in this study are modeled to be sourced from fossil fuels (i.e., natural gas and petroleum). Though there have been recent developments in the production of biomass-based plastic resin, the market shares of these materials is not yet sufficient to warrant analyzing their substitution with other materials.

The geographic scope of this study is for packaging materials of the selected applications produced and sold in the US and Canada. The boundaries for this study incorporate raw material extraction through production of the packaging materials, their distribution, and their end-of-life management. This study examines greenhouse gas (GHG) emissions and energy demand.

This analysis was conducted to provide ACC and CPIA with transparent, detailed Life Cycle Assessment (LCA) results serving several purposes:

1. To provide stakeholders with valuable information about the relative life cycle impacts of plastic packaging and alternative packaging materials that might be used to substitute for plastic packaging in applications in the US and Canada,
2. To communicate plastics packaging sustainability information, important for customer purchasing and procurement, to ACC and CPIA, their member companies, and the plastics value chain, and
3. To provide the North American market with key regional data for plastic packaging to show plastics’ contribution to sustainable development.

The results of the substitution analysis in this report are not intended to be used as the basis for comparative environmental claims or purchasing decisions for specific packaging products, but rather are intended to provide a snapshot of the environmental impacts of the current overall mix of plastic packaging in several categories, and the environmental impacts of the overall mix of alternative types of packaging that might be used as substitutes. Because the study addresses packaging products in broad categories rather than comparing specific packages that compete in specific end use applications, the analysis presented in this report is not considered to fall under the ISO 14040 requirements for “comparative assertions,” defined in ISO 14040 as environmental claims regarding the superiority or equivalence of one product versus a competing product that performs the same function. However, the substitution analysis used as the basis of the report was reviewed by two external LCA experts, Harald Pilz of Denkstatt GmbH and Roland Hischier of the Empa Research Institute.

ES.2. METHODOLOGY

The LCA method as defined in ISO standards has four distinct phases:

1. ***Goal and Scope Definition:*** defines the boundaries of the product system to be examined.
2. ***Life Cycle Inventory (LCI):*** examines the sequence of steps in the life cycle boundaries of the product system, beginning with raw material extraction and continuing on through material production, product fabrication, use, and reuse or recycling where applicable, and final disposition. For each life cycle step, the inventory identifies and quantifies the material inputs, energy consumption, and environmental emissions (atmospheric emissions, waterborne wastes, and solid wastes). In other words, the LCI is the quantitative environmental profile of a product system. Substances from the LCI are organized into air, soil, and water emissions or solid waste.
3. ***Life Cycle Impact Assessment (LCIA):*** characterizes the results of the LCI into categories of environmental problems or damages based on the substance's relative strength of impact. Characterization models are applied to convert masses of substances from the LCI results into common equivalents of one category indicator.
4. ***Interpretation:*** uses the information from the LCI and LCIA to compare product systems, rank processes, and/or pinpoint areas (e.g., material components or processes) where changes would be most beneficial in terms of reduced environmental impacts. The information from this type of assessment is increasingly used as a decision-support tool.

This study has been conducted with an LCA approach as defined in ISO standards 14040 and 14044. As stated previously, two LCA experts familiar with packaging analyses reviewed the details of the substitution analysis to ensure that the approach was reasonable and that the data sources and assumptions used were robust. The results presented in this report are specific to the US and Canadian geographic context and should not be interpreted as representing current or future plastic packaging substitution in other geographic areas. The following sections discuss the specifics of this methodology as applied in this study.

ES.2.1. Functional Unit

In any life cycle study, products are compared on the basis of providing the same defined function or unit of service (called the functional unit). This study uses a modeling approach to account for the standard LCI basis of product functionality for packaging materials. The general functional unit of the overall study is the substitution of total consumption of plastic used in each packaging category for the data year in which the most recent market data is available. Because the function of plastic packaging products differs amongst the investigated packaging categories, the functional unit is unique for each packaging category. Table ES-1 summarizes the functional unit considered for each packaging category.

Table ES–1. Functional Unit of Comparison for Investigated Packaging Categories

Category:	Functional Unit of Comparison for Alternative Material Weight Required:
Other Rigid	Volume Capacity for Non-Bulk & Bulk Rigid Packaging
	Protective Performance for Protective Packaging
Other Flexible	Volume Capacity for Converted & Bulk Packaging (except strapping)
	Protective Performance for Protective Packaging
	Unitizing Performance for Flexible Bulk Strapping
Beverage Containers	Volume Capacity
Carrier Bags	Number of Units (adjusted for difference in capacity)
Stretch & Shrink	Square Footage adjusted for performance
Caps & Closures	Number of Units

ES.2.2. Product Systems Studied

In 2010, packaging accounted for over a third of the major markets sales and captive use of thermoplastic resins in North America.[6] The types of plastic packaging evaluated in the analysis are limited to the predominant packaging resins:

- Low-Density Polyethylene (LDPE)
- High-Density Polyethylene (HDPE)
- Polypropylene (PP)
- Polyvinyl Chloride (PVC)
- Polystyrene (PS)
- Expanded Polystyrene (EPS)
- Polyethylene Terephthalate (PET)

Other resins, including specialty copolymers, biopolymers, etc. are not included. This scope keeps the analysis focused on resins that represent the largest share of plastic packaging and for which data are readily available.

Alternative materials that substitute the plastic packaging include: steel; aluminum; glass; paper-based packaging including corrugated board, packaging paper, cardboard (both coated and uncoated), molded fiber, paper-based composites and laminates; fiber-based textiles; and wood. Substitutes for plastic packaging vary depending on the market sector and packaging application. Cork and rubber are included as substitutes only in the caps and closures category.

This LCA focuses on plastic packaging applications and the plastic materials which are substitutable by alternative materials. The packaging sector is divided into the following

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[6] ACC (2012). The Resin Review: The Annual Statistical Report of the North American Plastics Industry, American Chemistry Council, 2012 Edition.

categories of case studies presented in descending order of plastic packaging weight, e.g., from highest to lowest percent share of the total weight of current plastic packaging:

- Other rigid packaging (includes the subcategories non-bulk rigid packaging, rigid protective packaging, and rigid bulk packaging)
- Other flexible packaging (includes the subcategories converted flexible packaging, flexible protective packaging, and flexible bulk packaging)
- Beverage packaging
- Carrier bags
- Shrink and stretch film
- Caps and closures

The following life cycle stages are included for each packaging material application:

1. **Raw material production** of the packaging materials, which consists of all steps from resource extraction through raw material production, including all transportation,
2. **Fabrication of the packaging** from their raw materials and the subsequent transportation of empty packaging from the fabrication site to the commodity filling site,
3. **Distribution transport** of commodity and packaging from the commodity filling site to the use site (focusing on differences in impacts due to packaging itself),
4. **Postconsumer disposal** of packaging in a landfill or waste-to-energy incineration, and/or
5. **Recycling** of packaging, including transport from the use site to recycling facilities, where applicable.

If the plastic packaging for a specific packaging application is made of more than one polymer, the market shares of the relevant polymers are considered. Likewise, if more than one alternative packaging material could substitute the analyzed plastic packaging, the national market shares of these materials is included in the calculations. The analysis focuses on the primary material components of each package and does not include small amounts of substances such as adhesives, labels, and inks.

The boundaries account for transportation requirements between all life cycle stages. Because of the very broad scope of packaging products covered by the project, some broad simplifying assumptions have been made regarding transportation distances and modes for shipping packaging from converters to fillers in both the US and Canada. For the production of electricity used in US packaging production and converting operations, the US average electricity grid mix is used.[7] For production of electricity used in Canadian

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[7] The exception is for the primary aluminum supply chain, which is modeled with the electricity grids of its corresponding geographies (including Australia and Jamaica).

packaging production and converting operations, the average Canadian electricity grid mix is used.[8]

Filling requirements for the products contained in the investigated packaging applications are excluded from the boundaries of this study as they are beyond the scope of this study. Storage, refrigeration, and/or freezing requirements as well as the burdens associated with the product use phase are considered equivalent between directly substituted packaging materials and so are excluded from the analysis. This analysis is based on the amounts and types of substitutes that would provide equivalent functionality to plastic packaging and therefore does not attempt to evaluate differences in product damage associated with use of different packaging materials.

For the average US or Canadian geographic context, average recycling rates and pathways for packaging used in the analyzed applications have been developed from research, recent publications, and previous work conducted by Franklin Associates. For the US geographic scope, postconsumer disposal of the percentage of packaging not recycled is modeled with current US EPA statistics for waste management.[9] For the Canadian geographic scope, average recycling rates and pathways for packaging used in Canada are modeled with current Canadian national waste management statistics.[10] Franklin Associates uses the system expansion end-of-life (EOL) recycling methodology to account for changes in life cycle burdens due to the recycling of packaging materials and the use of recycled material in packaging products.

A summary flow diagram of the boundaries for the packaging applications is shown in Figure ES–2. These boundaries are identical for either the US or Canadian geographic scope.

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[8] IEA 2014 electricity generation data for Canada accessed at http://www.iea.org/statistics/statisticssearch/report/?country=CANADA=&product=electricityandheat in November 2017.

[9] US Environmental Protection Agency. Municipal Solid Waste Generation, Recycling, and Disposal in the United States, see: http://www.epa.gov/wastes/nonhaz/municipal/msw99.htm.

[10] Statistics Canada (2012). Human Activity and the Environment: Waste Management in Canada, 2012 – Updated, Statistique Canada, Catalogue no. 16-201-X, Ministry of Industry, September 2012.

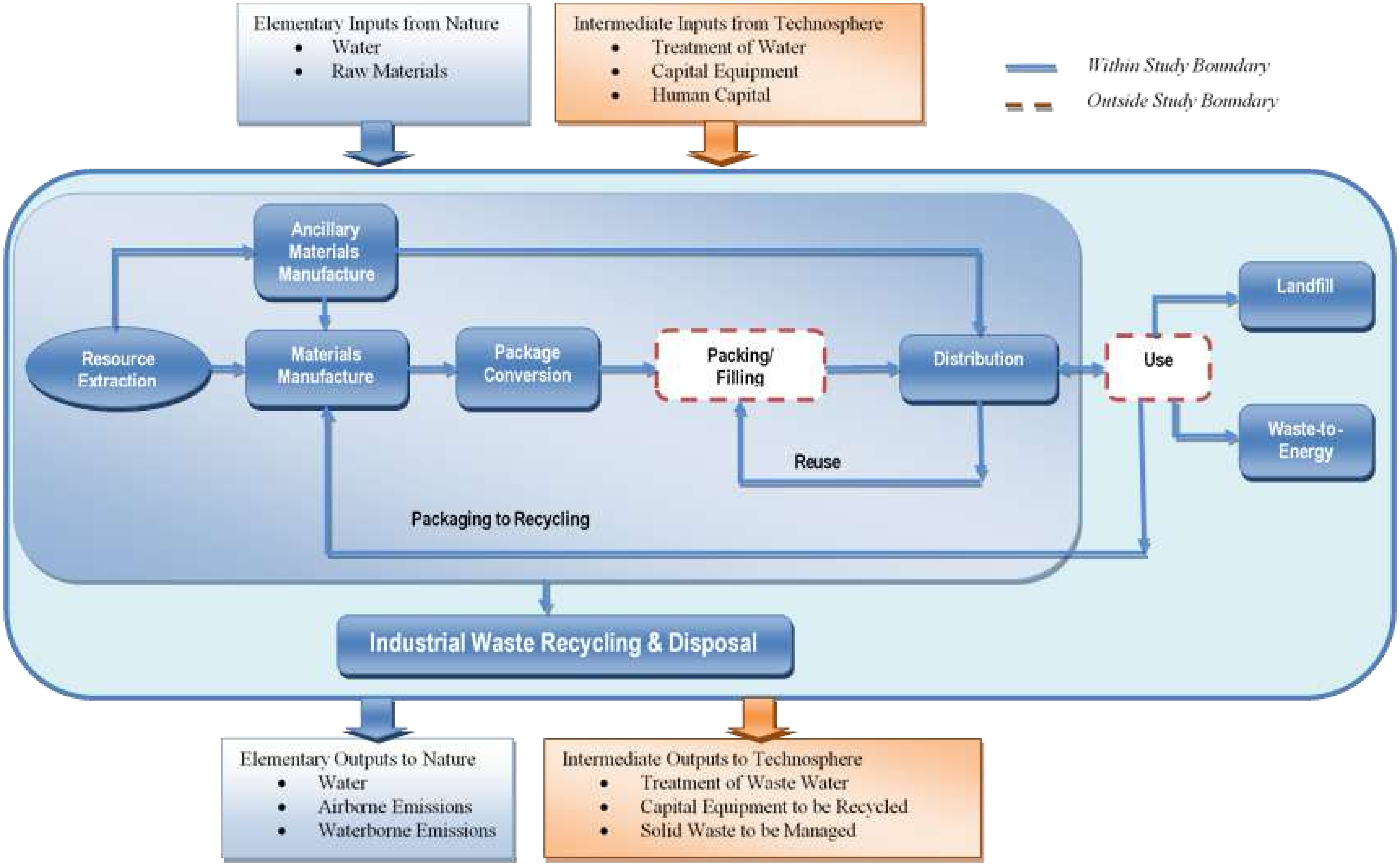

Figure ES–2. Packaging Products System Boundaries

ES.2.3. Data Sources

The primary source of market data (i.e., market shares of packaging product applications by type and by material) for packaging materials in the US and Canada were from Freedonia Market Reports for data years 2007-2011 and from the ACC 2012 Resins Review.[11] These data along with public and private LCA and packaging case studies and assumptions made by Franklin Associates were used to compile the weight factors for non-plastic materials to substitute for plastic packaging resins. To model the life cycle impacts of plastic versus non-plastic packaging materials, Franklin Associates uses the most current North American life cycle data on materials and fuels used in each system. Data transparency is important, so wherever possible we have used data from publicly available sources, such as the US LCI Database.[12] For unit processes for which public data were not available, Franklin Associates has clearly cited the private data sources and disclosed as much information as possible without compromising the confidentiality of the data source. For example, where data from the ecoinvent database are used, Franklin Associates has adapted the data so it is consistent with other North American data modules used in the study and representative of the energy production and transportation.[13]

ES.2.4. Reuse & Recycling Modeling Approach

In this study, national reuse and recycling rates for the packaging product type and/or material are applied for the US and Canadian geographic scopes. When material is used in one system and subsequently recovered, reprocessed, and used in another application, there are different methods that can be used to allocate environmental burdens among different useful lives of the material.

In this study, burdens associated with recycled content of products include collection, transport, and reprocessing of the postconsumer material. None of the virgin production burdens for the material are allocated to its secondary use(s).

For packaging material that is recycled at end of life, the recycling of packaging materials is modeled as a mix of closed- and open-loop recycling, as appropriate for each packaging application and/or material. System expansion is the approach used to avoid allocation in this analysis. Under the system expansion approach, the types and quantities of materials

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[11] ACC (2012). The Resin Review: The Annual Statistical Report of the North American Plastics Industry, American Chemistry Council, 2012 Edition.

[12] National Renewable Energy Lab (NREL). US LCI Database. See: http://www.nrel.gov/lci/database/default.asp.

[13] In addition to data developed specifically for North American processes and materials, Franklin Associates has an LCI database of materials and processes adapted from the ecoinvent LCI Database for the North American context. The database generally contains materials and processes specific to commodities sold in North America for which U.S. LCI data are not currently available. To adapt the LCI processes to the North American geographic context, most of the following (foreground and background) material and fuel unit processes within the European module were substituted with those inventoried in North America: 1) transport processes, 2) fossil fuels extraction, processing, and combustion, 3) mineral and metals extraction and fabrication processes, 4) plastic resin production and plastics fabrication processes, 5) paper and paperboard products production , 6) organic chemicals production, and 7) inorganic chemicals production.

that are displaced by the recovered post-consumer material determine the types and quantities of avoided environmental material production credits. If the end-of-life recycling rate is higher than the recycled content of the product, the system is a net producer of material, so the system receives open-loop credit for avoiding production of virgin material equivalent to the amount of end-of-life recycling that exceeds the system's recycled content. Conversely, if the end-of-life recycling rate is lower than the recycled content of the product, then the system is a net consumer of material and is charged with burdens for the production of material needed to make up the deficit.

ES.2.5. Key Assumptions

Although the foreground processes in this analysis were populated with reliable market data and the background processes come from reliable LCI databases, most analyses still have limitations. Further, it is necessary to make a number of assumptions when modeling, which could influence the final results of a study. Key limitations and assumptions of this analysis are:

- Because of the large scope of this study, this analysis uses the LCA approach to identify overall trends in the GWP and energy demand of packaging categories rather than performing a detailed LCA on hundreds of packaging products for individual applications;
- For each plastic packaging category, the current market share of plastic resins determines the weight of replaced resin. The weight of replaced resin is multiplied by the substitute material-to-plastic weight ratio calculated for each packaging application (based on functional equivalency to the representative plastic packaging product) to provide the weight of alternative material projected to substitute for the plastic package.
- For the substitutions, it is assumed that the product contained/unitized by the packaging would not be changed or altered in any way (e.g., a rigid plastic container for liquid soap must be substituted by another rigid container designed for liquids rather than projecting that the weight of a paperboard box designed for powdered soap may substitute for the plastic container)
- For each geographic scope, all foreground processes are assumed to utilize the national average electricity grid fuel mix; the exception is for the primary aluminum supply chain. The electricity grids for each aluminum production step from bauxite mining through alumina production are modeled based on the mix of geographies (including Australia and Jamaica) where each production step takes place.
- LCI requirements for filling, storage, freezing, refrigeration, product manufacturing, capital equipment, and support personnel as well as differences in product damage in various packaging materials are excluded from the analysis
- Transportation requirements inventoried for specific transportation modes are based on industry averages for that mode for each country;
- Transportation requirements do not include environmental burdens for transporting the weight of the products contained by the packaging as this weight is equivalent between the packaging materials/types and the life cycle burdens of the contained products are outside the scope of this study;

- For each geographic scope, estimates of the end results of landfilling and waste-to-energy (WTE) combustion are limited to global warming potential (GWP) effects, electricity credits, and requirements for transporting waste to a landfill and operating landfill equipment. Recycling energy requirements are also taken into account, and include transportation and reprocessing of the material as well as credit for virgin material displaced by the recycled material.

ES.3. KEY FINDINGS

The LCI results are characterized to give an overview of environmental impacts for plastic and alternative material packaging systems. The categories included the study and the methods used to evaluate each category are shown in Table ES-2.

Two scenarios are analyzed for substitute packaging. The “no decomposition” scenario includes biogenic CO_2 sequestration credit for all the biogenic carbon in landfilled packaging (i.e., no decomposition over time of any landfilled biomass-derived packaging), while the “maximum decomposition” scenario is based on maximum decomposition of uncoated paper and paperboard packaging that is disposed in landfills. For coated/laminated paper and paperboard products, the barrier layers are assumed to minimize any decomposition of the fiber content; therefore, to use a conservative approach, no decomposition of the fiber content of coated/laminated paper-based packaging is modeled in either decomposition scenario.

An overview of comparative results for all packaging categories for all impacts is shown in Figure ES-3 for US packaging and Figure ES-4 for Canadian packaging. Results for each impact category are normalized to the highest value for that category among the packaging system scenarios evaluated. The figures show that plastic packaging has lower impacts than substitute packaging for all impacts evaluated for both the US and Canadian scenarios for both decomposition scenarios.

The main factors influencing differences in results for plastics and alternative packaging types include the following:

- Less weight of plastic packaging required to perform same packaging function
- Higher embodied energy for plastics compared to substitute materials
- Lower water consumption per kg for plastic materials compared to alternatives
- No decomposition (and therefore, no associated methane releases) for landfilled plastics
- Carbon sequestration credits for landfilled material is only assigned to biomass-based carbon content (e.g., in paper, paperboard, wood) and not to fossil fuel-derived carbon content in plastic packaging
- Higher embodied energy/kg for plastics, so higher energy credits for plastics disposed via waste-to-energy combustion.

Table ES–2. Environmental Indicators Evaluated

	Impact/Inventory Category	Description	Unit	LCIA/LCI Methodology
LCI Categories	**Total energy demand**	Measures the total energy from point of extraction; results include both renewable and non-renewable energy sources	MJ	Cumulative energy inventory
	Expended energy	Energy irretrievably consumed; calculated as total energy minus the potentially recoverable energy embodied in the material.	MJ	Cumulative energy inventory minus energy embodied in material
	Water consumption	Freshwater withdrawals which are evaporated, incorporated into products and waste, transferred to different watersheds, or disposed into the sea after usage	liters H_2O	Cumulative water consumption inventory
	Solid waste by weight	Measures quantity of fuel, process and postconsumer waste to a specific fate (e.g., landfill, WTE) for final disposal on a mass basis	kg	Cumulative solid waste inventory
	Solid waste by volume	Measures quantity of fuel, process and postconsumer waste to a specific fate (e.g., landfill, WTE) for final disposal on a volume basis	m^3	Cumulative solid waste inventory
LCIA Categories	**Global warming potential (GWP)**	Represents the heat trapping capacity of the greenhouse gases. Important emissions: CO_2 fossil, CH_4, N_2O	kg CO_2 equivalents (eq)	IPCC (2013) GWP 100a
	Acidification potential	Quantifies the acidifying effect of substances on their environment. Important emissions: SO_2, NO_x, NH_3, HCl, HF, H_2S	kg SO_2 eq	TRACI v2.1
	Eutrophication potential	Assesses impacts from excessive load of macro-nutrients to the environment. Important emissions: NH_3, NO_x, COD and BOD, N and P compounds	kg N eq	TRACI v2.1
	Smog formation potential	Determines the formation of reactive substances (e.g. tropospheric ozone) that cause harm to human health and vegetation. Important emissions: NO_x, BTEX, NMVOC, CH_4, C_2H_6, C_4H_{10}, C_3H_8, C_6H_{14}, acetylene, Et-OH, formaldehyde	kg O_3 eq	TRACI v2.1
	Ozone depletion potential	Measures stratospheric ozone depletion. Important emissions: CFC compounds and halons	kg CFC-11 eq	TRACI v2.1

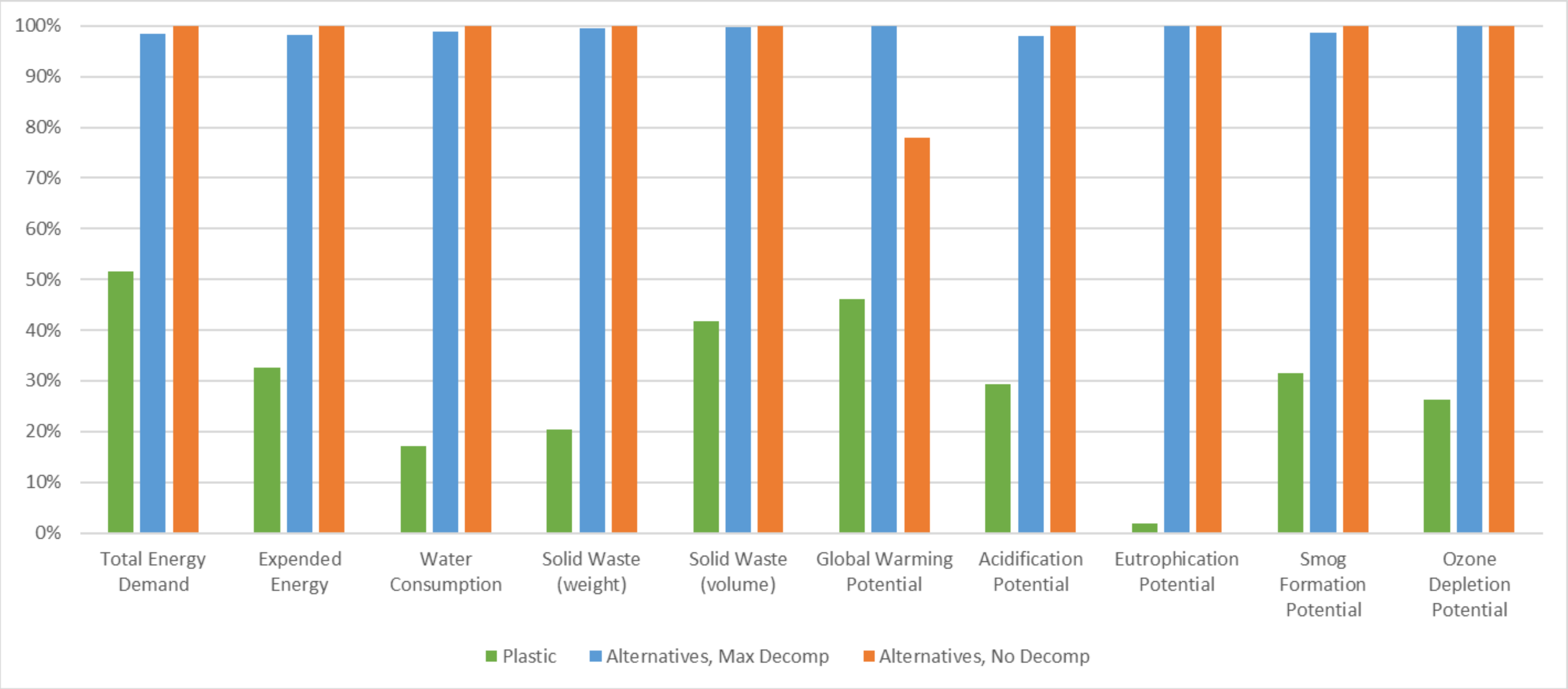

Figure ES–3. Normalized US Results for Plastic Packaging and Substitutes

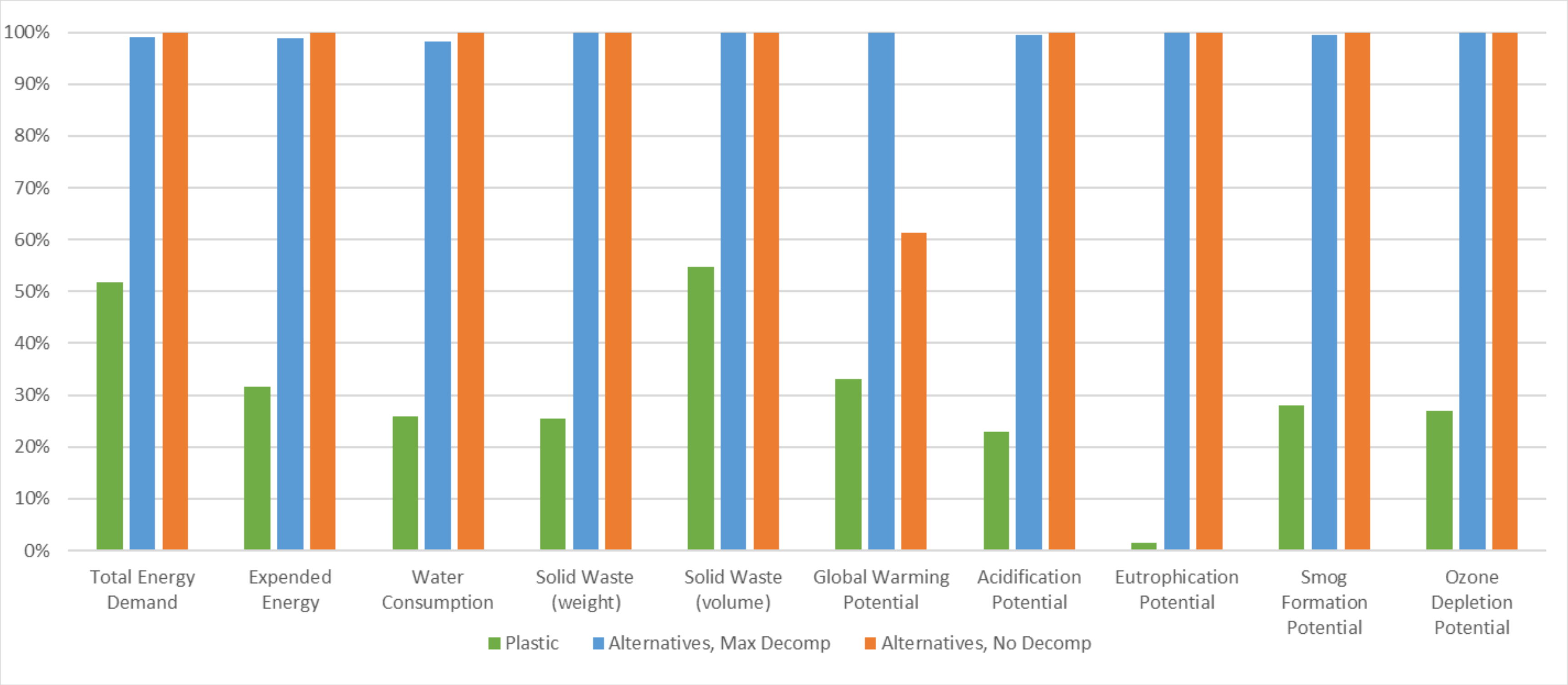

Figure ES–4. Normalized Canadian Results for Plastic Packaging and Substitutes

Results for US and Canadian packaging generally show similar trends by impact category and by packaging category; however, there are some differences. Factors influencing differences in results for US and Canada include:

- Less packaging used (lower population) in Canada
- Canadian electricity is less fossil fuel intensive (lower energy, emissions, and fuel-related solid waste) but more hydropower dependent (higher evaporative losses of water)
- Recycling rates for some types of packaging are higher in Canada, so a smaller share of packaging is sent to landfill
- For packaging that is not recycled, there is more landfilling, less landfill gas recovery, and less waste-to-energy combustion of solid waste in Canada
    - More landfilling means more carbon sequestration credit for disposed biomass-derived materials that don't decompose, but more methane emissions for biomass-derived materials that do decompose
    - Less energy recovery credits for all materials, since less waste-to-energy disposal of unrecycled waste.

Plastic packaging results expressed as a percentage of substitute packaging results are shown in Table ES-3, and savings for plastic packaging compared to substitute packaging at the US and Canadian national demand levels are summarized in Table ES-4.

Table ES–3. Plastic Packaging Results Compared to Substitutes

	US Plastics Results		Canadian Plastics Results	
Results Category	Percent of Substitutes with Max Decomp	Percent of Substitutes with No Decomp	Percent of Substitutes with Max Decomp	Percent of Substitutes with No Decomp
Total Energy Demand	52.3%	51.5%	52.2%	51.7%
Expended Energy	33.2%	32.6%	31.9%	31.6%
Water Consumption	17.4%	17.2%	26.3%	25.9%
Solid Waste by Weight	20.4%	20.3%	25.6%	25.6%
Solid Waste by Volume	42.0%	41.9%	54.8%	54.8%
Global Warming Potential	26.2%	59.3%	27.0%	54.0%
Acidification Potential	30.0%	29.4%	23.0%	22.9%
Eutrophication Potential	1.9%	1.9%	1.5%	1.5%
Smog Formation Potential	31.9%	31.5%	28.1%	27.9%
Ozone Depletion Potential	26.2%	26.2%	27.0%	27.0%

Table ES–4. Summary of Savings for Plastic Packaging Compared to Substitutes

		US Savings		Canadian Savings	
Results Category	Units	Compared to Substitutes with Max Decomp	Compared to Substitutes with No Decomp	Compared to Substitutes with Max Decomp	Compared to Substitutes with No Decomp
Total Energy Demand	billion MJ	1,196	1,235	121	123
Expended Energy	billion MJ	1,396	1,435	143	145
Water Consumption	billion liters	1,106	1,121	130	133
Solid Waste by Weight	thousand metric tons	52,887	53,162	4,044	4,050
Solid Waste by Volume	million cubic meters	55.1	55.4	3.73	3.74
Global Warming Potential	million metric tonnes CO_2 eq	67.1	39.5	8.66	3.65
Acidification Potential	thousand metric tonnes SO_2 eq	526	541	52.3	52.7
Eutrophication Potential	thousand metric tonnes N eq	340	341	37.4	37.4
Smog Formation Potential	thousand metric tonnes O_3 eq	6,549	6,682	666	670
Ozone Depletion Potential	metric tonnes CFC-11 eq	1.15	1.15	0.13	0.13

Although expended energy is a subset of total energy demand, Table ES-4 shows that expended energy savings are greater than total energy savings. Feedstock energy is a much greater share of total energy demand for plastics compared to substitutes; therefore, the difference in expended energy (total energy demand minus feedstock energy) for plastics compared to substitutes is greater than the difference in total energy results.

GWP savings for plastics compared to substitutes are higher for the substitute maximum decomposition scenario than for the no decomposition scenario. Substitute packaging GWP results are higher in the maximum decomposition scenario due to methane emissions from landfill decomposition of some of the biomass-derived packaging. However, the energy savings for plastics are slightly smaller for the substitute maximum decomposition scenario than for the no decomposition scenario. This is because the maximum decomposition scenario for substitutes includes some energy credits for energy recovered from combustion of captured landfill gas from biomass-based substitute packaging that decomposes.

Because the magnitude of the savings results shown in Table ES-4 may be difficult to interpret, equivalency factors are used to provide perspective for the study results. The equivalency factors are derived from the US EPA Greenhouse Gas Equivalencies Calculator[14] and other published sources. A summary of savings equivalents for several results categories are shown in Table ES-5.

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[14] https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Table ES–5. Savings Equivalents for Plastic Packaging Compared to Substitutes

		US Savings		Canadian Savings	
Results Category	**Equivalence Factor**	Plastics compared to Substitutes with Max Decomp	Plastics compared to Substitutes with No Decomp	Plastics compared to Substitutes with Max Decomp	Plastics compared to Substitutes with No Decomp
Total Energy	Million passenger vehicles per year	18	18	1.8	1.8
	Thousand tanker trucks of gasoline	1,073	1,108	108	110
Global Warming Potential	Million passenger vehicles per year	14	8.5	1.9	0.8
	Thousand tanker trucks of gasoline	889	523	115	48
Water Consumption	Thousand Olympic swimming pools	461	467	54	55
Solid Waste by Weight	Thousand 747 airplanes	290	291	22	22
Solid Waste by Volume	U.S. Capitol Rotundas	1,496	1,505	101	102
Acidification	Thousand railcars of coal	292	301	29	29

Plastics have many properties that make them a popular choice in packaging applications. Properties such as light weight, durability, flexibility, cushioning, and barrier properties make plastic packaging well suited for efficiently containing and protecting many types of products during shipment and delivery to customers without leaks, spoilage, or other damage. The results of this substitution analysis show that plastic packaging is also an efficient packaging choice in terms of a variety of environmental impacts.

CHAPTER 1. GOAL & SCOPE DEFINITION

1.1. GOAL

The entire supply chain or value chain should be considered when evaluating the sustainability of a product system. Life Cycle Assessment (LCA) has been recognized as a scientific method for making comprehensive, quantified evaluations of the environmental benefits and tradeoffs for the entire life cycle of a product system, beginning with raw material extraction and continuing through disposition at the end of its useful life. LCA creates the basic environmental information for any product, package, or process.

The goal of the original study was to assess the energy consumption and greenhouse gas emissions of plastics packaging relative to alternative packaging in North America using the LCA methodology. The substitution analysis assessed the life cycle impacts of plastic packaging relative to alternative materials to answer the question: "If plastic packaging were replaced with alternative types of packaging, how would energy consumption and greenhouse gas emissions be affected?"

For a more comprehensive understanding of the environmental benefits and tradeoffs for substituting alternative packaging for plastic packaging, this updated and expanded version of the study adds comparative results for several other important environmental indicators:

- Water Consumption
- Solid Waste
- Acidification Potential
- Eutrophication Potential
- Smog Formation Potential
- Ozone Depletion Potential

Besides expanding the scope of the analysis to include additional results categories, this analysis also incorporates available updated industry data on material production, updated electricity grid mixes, updates to landfill gas management practices, and revisions to system expansion recycling credits to better reflect the credits for recycled paper products (i.e., so that recycled paper receives credits not only for displacing material inputs to virgin paper production but also receives credits for displacing chemical pulping of the virgin inputs). An update was also made to the method used in the modeling for toggling between use of US and Canadian electricity for the country-specific scenarios. The method used in the original analysis had overstated the contribution of Canadian electricity to results for Canadian systems.

The theoretical substitution analysis takes into account the mix of plastic resins and substitutes for plastic packaging in each packaging market sector. Because of the extensive level of effort and resources required to develop the substitution model, the substitution model itself (types and weights of plastic resins used in each packaging category and types and weights of alternative packaging materials that would substitute them) was not updated.

The geographic scope of this study is for packaging materials of the selected applications produced and sold in the US and Canada. The boundaries for this study incorporate raw material extraction through production of the packaging materials, their distribution, and their end-of-life management.

This analysis was conducted to provide ACC and CPIA with transparent, detailed Life Cycle Assessment (LCA) results serving several purposes:

1. To provide stakeholders with valuable information about the relative life cycle environmental impacts of plastic packaging and alternative packaging materials that might be used to substitute for plastic packaging in applications in the US and Canada,
2. To communicate plastics packaging sustainability information, important for customer purchasing and procurement, to ACC and CPIA, their member companies, and the plastics value chain, and
3. To provide the North American market with key regional data for plastic packaging to show plastics' contribution to sustainable development.

The primary intended use of this substitution analysis report is to quantify and communicate the environmental impacts of plastic packaging materials relative to a mix of alternative packaging materials that would be used to substitute plastic on a functionally equivalent basis.

1.2. SCOPE OF THE STUDY

This chapter discusses the overall scope of the study necessary to accomplish the stated goal. The LCA components covered include the functional unit, product systems studied, study boundaries, sensitivity analysis, data requirements, data sources, allocation, impact assessment methodology, assumptions and limitations, and critical review.

1.2.1. Functional Unit

In any life cycle study, products are compared on the basis of providing the same defined function or unit of service (called the functional unit). This study uses a modeling approach to account for the standard LCI basis of product functionality for packaging materials. The general functional unit of the overall study is the substitution of total consumption of plastic used in each packaging category for the data year in which the most recent market data is available. Because the requirements for plastic packaging products differ amongst the investigated packaging categories, the functional unit is unique for each packaging application.

Table 1-1 summarizes the functional unit considered for each packaging category. The reference unit is based upon the function of the products, so that comparisons of different products are made on a uniform basis. This common basis, or functional unit, is used to normalize the inputs and outputs of the LCI. Results of the LCI are then expressed in terms of this functional unit.

Table 1-1. Functional Unit of Comparison for Investigated Packaging Categories

Category:	Functional Unit of Comparison for Alternative Material Weight Required:
Other Rigid	Volume Capacity for Non-Bulk & Bulk Rigid Packaging
	Protective Performance for Protective Packaging
Other Flexible	Volume Capacity for Converted & Bulk Packaging (except strapping)
	Protective Performance for Protective Packaging
	Unitizing Performance for Flexible Bulk Strapping
Beverage Containers	Volume Capacity
Carrier Bags	Number of Units (adjusted for difference in capacity)
Stretch & Shrink	Square Footage adjusted for performance
Caps & Closures	Number of Units

1.2.2. Product Systems Studied

The LCA models plastic packaging substitution for the following predominant packaging resins:

- Low-Density Polyethylene (LDPE)
- High-Density Polyethylene (HDPE)
- Polypropylene (PP)
- Polyvinyl Chloride (PVC)
- Polystyrene (PS)
- Expanded Polystyrene (EPS)
- Polyethylene Terephthalate (PET)

Other resins, including specialty copolymers, biopolymers, etc. are not included. This scope keeps the analysis focused on resins that represent the largest share of plastic packaging and for which data are readily available.

Substitutes for plastic packaging vary depending on the market sector and packaging application. The primary alternative materials for many different types of plastic packaging are paper-based packaging (including coated and uncoated formats), glass, steel, and aluminum. Smaller amounts of textiles, rubber, and cork compete with plastics in specific packaging markets.

The plastic packaging sector is the system studied, and this sector is divided into the following categories, presented in decreasing order of mass of plastic packaging:

- Other rigid packaging (includes the subcategories non-bulk rigid packaging, rigid protective packaging, and rigid bulk packaging)
- Other flexible packaging (includes the subcategories converted flexible packaging, flexible protective packaging, and flexible bulk packaging)
- Beverage packaging
- Carrier bags
- Shrink and stretch film
- Caps and closures

Table 1-2 presents the details on the data year(s) and types of plastic packaging included and excluded from each investigated category in the analysis.

Table 1-2. Details on Contents of Plastic Packaging Categories

CATEGORY		DATA YEAR	PRIMARY PLASTIC PACKAGING PRODUCTS INCLUDED:	PACKAGING PRODUCTS EXCLUDED:
OTHER RIGID	**Non-Bulk**	**US 2009; Canadian 2011**	Non-beverage bottles and jars; tubs, cups and bowls; pails; food trays; cans; egg cartons; squeeze tubes; and others such as plastic boxes; food, household cleaning chemicals, cosmetics and toiletries, pharmaceuticals, automotive chemicals, industrial and institutional cleaning chemicals, and others such as adhesives and agricultural chemicals	Beverage container packaging (e.g., bottles) -see Beverage Container category; laminate-type squeeze tubes; foodservice packaging such as clamshells, pails, and baskets; decorative tins, medical device packaging, blister packaging, injection molded cosmetic packaging such as lipstick and compact cases; compact disc cases; separately sold caps and closures; protective and bulk rigid packaging; and home storage containers such as TUPPERWARE containers
	Protective	**2011**	Protective packaging shapes and other rigid packaging providing cushioning, blocking and bracing, insulating, and void-filling for the manufacturing and non-manufacturing markets (e.g., insulated shipping containers and foamed shipping protectors)	Flexible protective packaging such as shipping sacks or strapping (see flexible protective packaging category); and insulated shipping packaging requiring electricity or another power source to maintain a temperature-controlled environment inside an insulated enclosure
	Bulk	**2010**	Drums, pails, bulk boxes, material handling containers (MH Cs) and bulk boxes, and rigid intermediate bulk containers (RIBCs) for chemical and pharmaceutical, food, plastic, rubber, fiber, petroleum and lubricant, agricultural and horticultural, durable, and hazardous waste storage and handling markets	Pallets; corrugated boxes other than bulk and corrugated RIBCs; cans, bottles, jars, and tubs used for packaging bulk size food or other consumer goods*
OTHER FLEXIBLE	**Converted**	**US 2010; Canadian 2008**	Single-ply or multiple plies of materials laminated together by an adhesive system or coextruded to fabricate bags, pouches, and other pre-formed packages or rollstock that are converted for food and non-food applications; also, printed, coated, or otherwise converted overwraps	Beverage container packaging (e.g., pouches) -see Beverage Container category; packaging formed by slitting alone, any uncoated single web material that is neither preformed nor printed; wrappers which are unconverted flexible materials such as shrink and stretch film, plain film, and related products (see shrink & stretch wrap category); retail, grocery, and novelty bags and sacks (see carrier/retail bags category); paperyard waste and refuse sacks, trashbags; household and institutional plastic storage bags or rolls of film; money bags; envelopes used for mailing; sausage casings; shrink sleeve and other labels; lidding, foodservice disposable packaging such as sandwich wraps; and secondary and tertiary packaging**
	Protective	**2011**	Cushioning, void-filling, and lining packaging products such as protective mailers, protective packaging fill, and dunnage bags for the manufacturing and non-manufacturing markets.	Rigid protective packaging shapes such as foam shipping braces (see rigid protective packaging category)
	Bulk	**2011**	Shipping sacks, strapping, flexible intermediate bulk containers (FIBCs), and bulk drum, bin and box liners and rolls for the food/beverage, chemical, agricultural, and horticultural markets	Non-packaging applications such as money bags and sand bags; film wrap used for bulk applications (see stretch & shrink film category)

* Data providers were unable to clarify if specific types of rigid bulk packaging excluded from the bulk category are included in other categories (e.g., bulk jars in bottles & jars). Franklin Associates assumes that these items are captured in other categories.

** Secondary and tertiary packaging materials are those which are not in direct contact with food or other contained products; materials which do not function to contain, protect, and store products for future consumption but are used instead for unitizing and distribution products contained in primary packaging (e.g., crates, pallet wrap, strapping). Unless otherwise noted in this table (e.g., pallets), secondary and tertiary packaging materials are included in the substitution model--in appropriate subcategories.

Table 1-2 (cont.). Details on Contents of Plastic Packaging Categories

CATEGORY	DATA YEAR	PRIMARY PLASTIC PACKAGING PRODUCTS INCLUDED:	PACKAGING PRODUCTS EXCLUDED:
BEVERAGE CONTAINERS	**2007**	Aluminum cans and bottles; steel cans; plastic bottles, pouches, and cans; glass bottles; and paperboard containers e.g., gabletop and bag-in-box cartons, aseptic boxes and composite cans, intended for disposal after use for the following markets: carbonated soft drinks including flavored and soda waters; beer and other malt beverages; still and sparkling bottled water; both frozen and shelf-stable fruit beverages; other ready-to-drink (RTD) non-alcoholic beverages; RTD tea; milk and eggnog including non-beverage use of fluid milk; sports beverages; wine including wine-based coolers and hard ciders; distilled spirits; and soy and other non-dairy milk	All non-liquid beverages including: dried coffee and tea; powdered and condensed milk; powdered fruit drinks and sports beverages; also excluded: vegetable and tomato drinks; infant formula; packaged milk shakes and liquid nutritional supplements (see non-bulk rigid containers category); and all secondary beverage container packaging** e.g., corrugated boxes and paperboard beverage carriers; bulk containers not intended primarily for in-home use; bottled water containers larger than 2.5 gallons are excluded
CARRIER/ RETAIL BAGS	**2009**	Retail bags and sacks	Large bags and sacks used for bulk shipments (see bulk flexible category)
CAPS & CLOSURES	**2009**	Standard threaded, pressure screw vacuum threaded, unthreaded, and synthetic cork caps and closures utilized on containers intended for disposal after use in beverage, food, pharmaceutical and other health-care product, cosmetic and toiletry, household chemical, automotive chemical, and other packaging markets	Non-substitutable caps and closures (i.e., dispensing and child-resistant types); caps or closures that are an integral part of the container (e.g., aerosol can valve assemblies); home canning and bottling closures; most glass closures; caps and closures used on industrial bulk containers; flexible (e.g., aluminum foil, twist tie) closures; champagne overcaps and capsules; and caps and closures employed in nonpackaging applications such as valve covers, distributor caps, pen caps, food and other storage container lids, etc.
STRETCH & SHRINK FILM	**2010**	Wrap, stretch labels and sleeves, and hoods (e.g., pallet caps) used in product packaging and storage and distribution markets	Converted or multi-layer films (see converted flexible category)

** Secondary and tertiary packaging materials are those which are not in direct contact with food or other contained products; materials which do not function to contain, protect, and store products for future consumption but are used instead for unitizing and distribution products contained in primary packaging (e.g., crates, pallet wrap, strapping). Unless otherwise noted in this table (e.g., pallets), secondary and tertiary packaging materials are included in the substitution model--in appropriate subcategories.

1.2.3. System Boundary

This LCA focuses on plastic packaging applications and the plastic materials which are substitutable by alternative materials. The following life cycle stages are included for each packaging material application:

1. **Raw material production** of the packaging materials, which consists of all steps from resource extraction through raw material production, including all transportation,
2. **Fabrication of the packaging** from their raw materials and the subsequent transportation of empty packaging from the fabrication site to the commodity filling site,
3. **Distribution transport** of commodity and packaging from the commodity filling site to the use site (focusing on differences in impacts due to packaging itself),
4. **Postconsumer disposal** of packaging in a landfill or waste-to-energy incineration, and/or
5. **Recycling** of packaging, including transport from the use site to recycling facilities, where applicable.

If the plastic packaging for a specific packaging application is made of more than one polymer, the market shares of the relevant polymers are considered. Likewise, if more than one alternative packaging material could substitute the analyzed plastic packaging, the national market shares of these materials are included in the calculations. The analysis focuses on the primary material components of each package and does not include small amounts of substances such as adhesives, labels, and inks.

For the US or Canadian geographic context, average national recycling rates and pathways for packaging used in the analyzed applications have been developed from research, recent publications, and previous work conducted by Franklin Associates. For the US geographic scope, postconsumer disposal of the percentage of packaging not recycled is modeled with current US EPA statistics for waste management.[15] For the Canadian geographic scope, average recycling rates and pathways for packaging used in Canada are modeled with current Canadian national waste management statistics.[16]

A summary flow diagram of the boundaries for the packaging applications is shown in Figure 1-1. These boundaries are identical for either the US or Canadian geographic scope. The boundaries account for transportation requirements between all life cycle stages and industrial waste disposal and recycling occurring at each of the life cycle steps. The boundaries account for transportation requirements between all life cycle stages. Because of the very broad scope of packaging products covered by the project, some broad

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[15] US Environmental Protection Agency. Municipal Solid Waste Generation, Recycling, and Disposal in the United States, see: http://www.epa.gov/wastes/nonhaz/municipal/msw99.htm.

[16] Statistics Canada (2012). Human Activity and the Environment: Waste Management in Canada, 2012 – Updated, Statistique Canada, Catalogue no. 16-201-X, Ministry of Industry, September 2012.

simplifying assumptions have been made regarding transportation distances and modes for shipping packaging from converters to fillers in both the US and Canada.

Processes excluded from the analysis are shown in dotted lines. Filling requirements for the products contained in the investigated packaging applications are excluded from the boundaries of this study as they are beyond the scope of this study. Storage and/or freezing/refrigeration requirements as well as the burdens associated with the product use phase are also outside of the boundaries of this project. Exclusions are discussed in the next section.

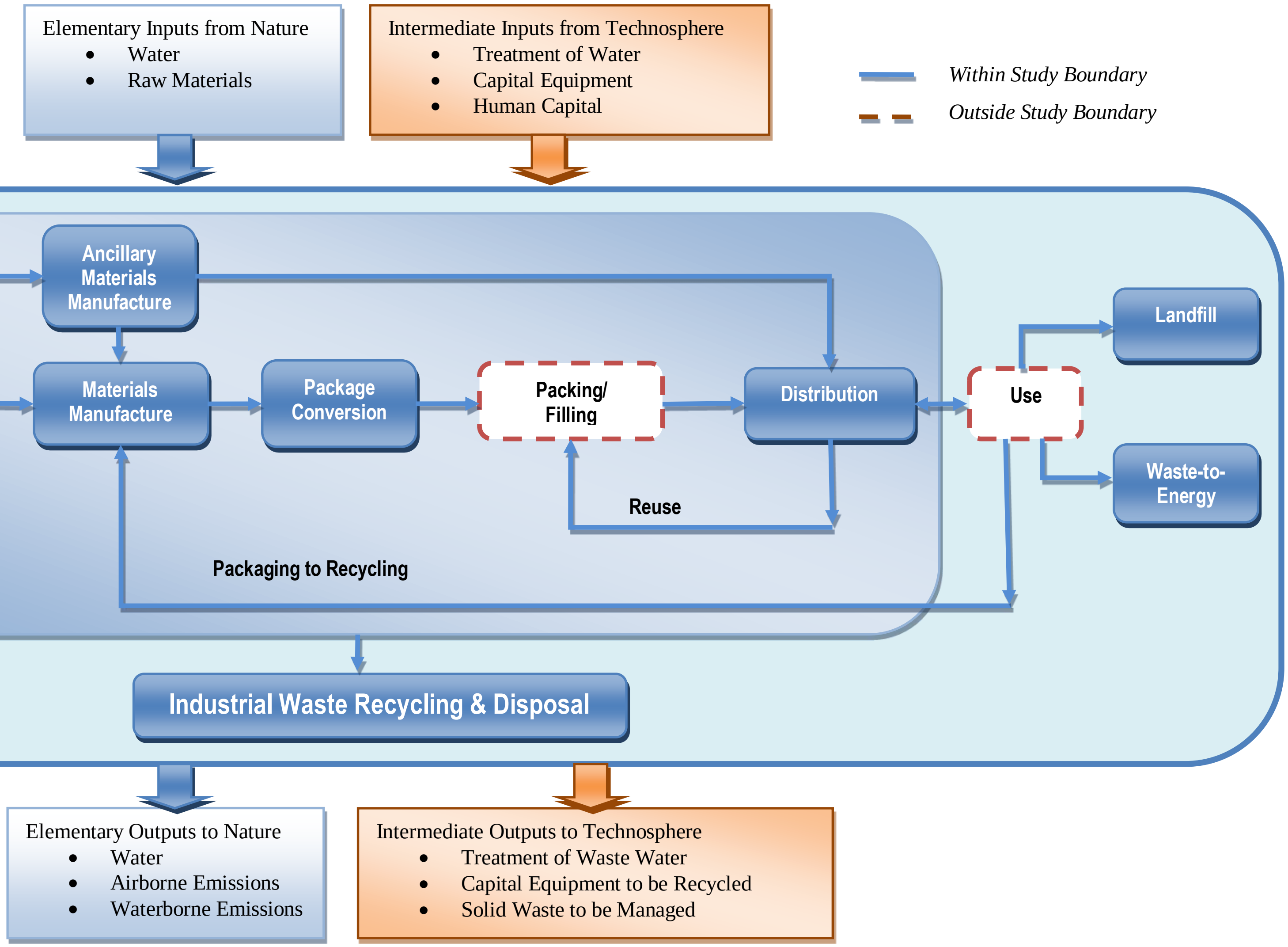


Figure 1-1. Packaging Product System Boundaries

1.2.3.1. System Components Excluded

The following components of each system are not included in this study:

Product Manufacturing. The focus of this study is the life cycle of the commodities' packaging; therefore, all burdens associated with production of the products inside the packages are excluded from the analysis.

Filling and/or Packing. The analysis does not include processes for packing, filling, or wrapping processes required to put package contents into the packaging products analyzed.

Storage, Freezing and/or Refrigeration. Frozen or refrigerated storage is a requirement for some of the products contained in packaging (e.g., food, beverage, pharmaceutical applications) in this analysis. In this analysis, the substitution modeling is limited to direct substitution, e.g., replacement of the primary package with an alternative package that is used in the same way. For example, refrigerated products packaged in plastic (e.g., milk in HDPE jugs) are assumed to be replaced with other types of packaging that are refrigerated (e.g., paperboard cartons), rather than replaced by aseptic packages that have different product heating and filling requirements and do not require refrigeration during post-filling transportation and storage. Therefore, where the product requires freezing and/or refrigeration, these requirements for the substitute package are assumed equivalent and are not included as a differentiating factor in comparisons of packaging materials.

Inks, Labels, and Printing. Different packaging material schemes may use ancillary materials for printing and labeling (e.g., inks, adhesives, and tags). However, decoration of packaging is at the discretion of the user rather than a consistent functional feature across packaging types within each category, and amounts of these materials are generally small in comparison to the primary packaging material weight. Inks, labels, and printing are therefore excluded from the scope of the analysis

Capital Equipment, Facilities, and Infrastructure. The energy and wastes associated with the manufacture of buildings, roads, pipelines, motor vehicles, industrial machinery, etc. are not included. The energy and emissions associated with production of capital equipment, facilities, and infrastructure generally become negligible when averaged over the total output of product or service provided over their useful lifetimes.

Product Damage. The analysis is based on the amounts of alternative packaging required to provide the same basic functionality as the plastic packaging being substituted. For example, the amount of crumpled or shredded paper required to substitute for protective plastic packaging such as polystyrene foam loose fill shapes is based on equivalent volume needed to fill the same amount of void space surrounding a packaged product. The analysis does not make any assumptions or projections about differences in product damage or breakage when substituting plastic packaging with other types of packaging. Not only would this require broad assumptions about comparative properties and performance of plastic and alternative packaging types in all applications, but the energy and wastes associated with product repair or replacement depend on the specific product content that must be repaired or replaced. For example, the energy and emissions for repairing or replacing a damaged computer are very different from the impacts of replacing a broken glass vase. It is not feasible to try to evaluate potential comparative damage impacts for the full scope of packaging applications included in this analysis.

Support Personnel Requirements. The energy and wastes associated with research and development, sales, and administrative personnel or related activities have not been included in this study, as energy requirements and related emissions are assumed to be quite small for support personnel activities.

1.2.4. Allocation Procedures

This LCA follows the guidelines for allocating co-product credit shown in the ISO 14044: 2006 standard on life cycle assessment requirements and guidelines. In this standard, the preferred hierarchy for handling allocation is (1) avoid allocation where possible, (2) allocate flows based on direct physical relationships to product outputs, (3) use some other relationship between elementary flows and product output. No single allocation method is suitable for every scenario. How product allocation is made will vary from one system to another but the choice of parameter is not arbitrary. ISO 14044 section 4.3.4.2 states “the inventory is based on material balances between input and output. Allocation procedures should therefore approximate as much as possible such fundamental input/output relationships and characteristics.”

Some processes lend themselves to physical allocation because they have physical parameters that provide a good representation of the environmental burdens of each co-product. Examples of various allocation methods are mass, stoichiometric, elemental, reaction enthalpy, and economic allocation. Simple mass and enthalpy allocation have been chosen as the common forms of allocation in this analysis. However, these allocation methods are not selected as a default choice, but made on a case by case basis after due consideration of the chemistry and basis for production.

In the sequence of processes used to produce plastic resins from natural gas and petroleum feedstocks, some processes produce material or energy co-products. When the co-product is heat or steam or a co-product sold for use as a fuel, the energy content of the exported heat, steam, or fuel is treated as an energy credit for that process (i.e., allocation by energy content). When the co-product is a material, the process inputs and emissions are allocated to the primary product and co-product material(s) on a mass basis. Allocation based on economic value can also be used to partition process burdens among useful co-products; however, this approach is less preferred under ISO life cycle standards, as it depends on the economic market, which can change dramatically over time depending on many factors unrelated to the chemical and physical relationships between process inputs and outputs.

1.2.5. Recycling Methodology

When material is used in one system and subsequently recovered, reprocessed, and used in another application, there are different methods that can be used to allocate environmental burdens among different useful lives of the material. System expansion is the approach used in this analysis. The types and quantities of materials that are displaced by the recovery and processing of postconsumer material determine the types and quantities of avoided environmental burdens. An overview of the system expansion approach used in this analysis is presented in Figure 1-2.

For packaging made with postconsumer recycled content, burdens associated with recycled content include collection, transport, and reprocessing of the postconsumer material. None of the virgin production burdens for the material are allocated to its secondary use(s).

For packaging materials that are recycled at end of life, the recycling is modeled as a mix of closed- and open-loop recycling, as appropriate for each packaging application and/or material. System expansion is the approach used to avoid allocation in this analysis. Under the system expansion approach, the types and quantities of materials that are displaced by the recovered post-consumer material determine the types and quantities of avoided material production credits or debits.

Systems with Recovery Rate > Recycled Content

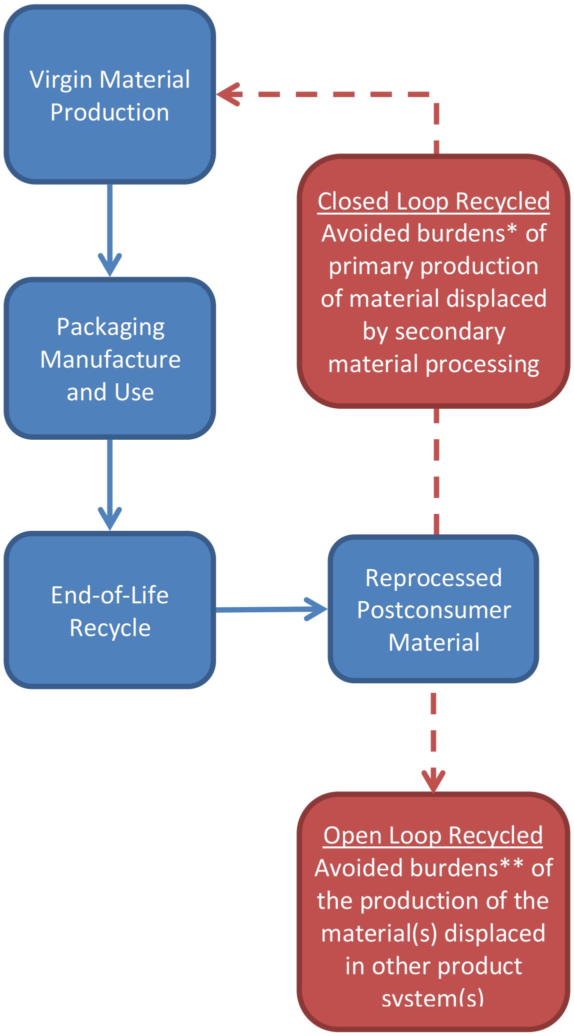
- Packaging products that are recovered at a rate greater than the level needed to sustain their recycled content are considered net ***producers*** of secondary material, and are credited with avoided production burdens for the material that is displaced by the excess amount of secondary material produced. The credit is based on the amount of net material displacement at the end of the material’s current life cycle as a packaging product. No further adjustments are made based on projections about previous use cycles of the material prior to its use in the packaging product or potential additional future cycles of reuse/recycling of the material after its use in product systems subsequent to its useful life in the packaging product.
- When recovery exceeds the amount of material needed to maintain a system’s recycled content (closed-loop recycling), the open-loop recycled portion of the material receives displacement credit based on the mix of virgin and secondary material it would displace. For example, recycled postconsumer packaging paper is currently utilized in many products that are made from a mix of virgin and secondary fiber. The recycled packaging material receives virgin displacement credit for the percentage of virgin material that it displaces, but does not get virgin material displacement credit for the portion of excess secondary material that would be used as a substitute for other secondary material.

Systems with Recycled Content > Recovery Rate

- Systems using postconsumer materials drawn from a pool of secondary material that is currently fully utilized (e.g., metals, resins) are considered net ***consumers*** of secondary material if their use of postconsumer material exceeds their recovery rate. If a packaging system’s recovery rate is not sufficient to sustain its recycled content, the system is charged with burdens for the virgin material that would be required to make up for its net withdrawal from the current available supply of secondary material.

- No makeup virgin material burdens are assigned to systems whose recycled content is higher than their recovery rate if the net consumption of the secondary material would be substituted by other secondary material. An example would be molded pulp cartons or packaging shapes that are made from 100% postconsumer newspaper but that have recovery rates less than 100%. The molded pulp packaging's net withdrawal from the available supply of postconsumer newspaper would likely be made up not by increased use of virgin fiber but by utilization of other available grades of postconsumer fiber.

The same material can have different system expansion credits/charges in different applications. For example, container glass has an average recycled content of 25%. Beer and soft drink bottles with a 41.4% US recovery rate are net producers of secondary material and receive virgin material displacement credit for the excess recovered material. Wine and liquor bottles have a 24.7% US recovery rate that essentially matches their recycled content, so recycling credits are negligible. Other glass containers, which have an average US recovery rate of 18.1%, are not recovered at a rate high enough to sustain the average recycled content. As a result, they are net consumers of secondary material and are charged with additional virgin glass production burdens to make up for the 7% deficit.



*Avoided burden depends on ratio of container recycled content and recycling rate

**Devaluation factor applied due to the cascading nature of this portion of the reprocessed postconsumer material

Figure 1-2. System Expansion Recycling Method (100% Recycling)

1.2.6. Data Requirements

ISO standards 14040 and 14044 detail various aspects of data quality and data quality analysis. These ISO Standards state: “descriptions of data quality are important to understand the reliability of the study results and properly interpret the outcome of the study.” These ISO Standards list three critical data quality requirements: time-related coverage, geographical coverage, and technology coverage. The study goals for these three data quality requirements are discussed in the next sections.

1.2.6.1. Geographic Coverage

The geographic scope of this study is North American (limited in this analysis to the US and Canada); however, the scope does include raw material sourced from other regions of the world (this primarily applies to crude oil imports). The main sources of data and information for geography-dependent processes (e.g. energy production) are drawn from North American specific reports and databases.

For materials where production data specific to commodities sold in North America were not available (e.g., converting cotton yarn to textiles), data were adapted from the ecoinvent LCI Database for the North American context. The following (foreground and background) material and fuel unit processes within the European module were substituted with those inventoried in North America:

- Transport processes
- Fossil fuels extraction, processing, and combustion
- Mineral and metals extraction and fabrication processes
- Plastic resin production, plastics fabrication, and plastics recycling processes
- Paper and paperboard products production
- Organic chemicals production
- Inorganic chemicals production

Also, adapted ecoinvent LCI processes have been modified to be consistent with the system boundaries of the US data and within this project (for details on these aspects, see the following section 1.2.7 Data Sources).

1.2.6.2. Technology Coverage

Life cycle inventory (LCI) data for materials and energy production, materials conversion processes, transportation requirements, and recycling and disposal processes were compiled from the most recent average North American technology. Data are utilized as is appropriate for the US and Canadian geographic scope.

1.2.6.3. Temporal Coverage

Total plastic resin weight currently utilized in the US and Canada and the current market share of plastic represented relative to competing packaging materials is based on market report data for years 2007-2011. For LCI data, the most current publicly available data for North America is utilized. A goal of this study is to use data with six or less years of difference to the reference year (2011). Six years is chosen as the goal because it meets the top two data scores for temporal correlation as identified in the pedigree matrix.[17]

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[17] Weidema B and Wesnaes MS (1996). Data quality management for life cycle inventories - an example of using data quality indicators. *International Journal of Cleaner Production,* 4: 167-74.

1.2.7. Data Sources

Summaries of the market and LCI data sources used for the US and Canadian geographic scope are presented in Table 1-3.

Foreground data for production of plastic resins used in North America are from Franklin Associates' virgin and recycled resin data compiled for the American Chemistry Council updated in 2011.[18] LCI data for production of primary aluminum are from the Aluminum Association's 2013 report on semi-finished products[19], and secondary aluminum data are from the Aluminum Association's 2010 aluminum can report.[20] Data for production of fiber corrugated materials are adapted from a gate-to-gate inventory of converted corrugated boxes published by the Corrugated Packaging Alliance (CPA) in 2014.[21] The LCI data for producing lumber products utilize updated forestry LCI data from CORRIM Phase I and Phase II reports.[22,23] The updated CORRIM LCI data include seeding, cultivation, and harvesting of lumber from four US forestry regions: the South East (SE), the Pacific North West (PNW), the Inland North West (INW), and the North East-North Central (NE-NC) areas. Data for the production of blast oxygen furnace (BOF) and electric arc furnace (EAF) steel, virgin and recycled glass, virgin and recycled unbleached and bleached paperboard, natural rubber, and cellophane are from Franklin Associates' Private LCI Database.[24] Cotton textile and cork data are adapted from ecoinvent.

Transport distances and logistics during the life cycle of the plastic and alternative packaging materials were estimated by Franklin Associates based on average requirements for product category life cycles in the US and Canada. Data for average fuel requirements of transport per ton-mile or tonne-km have been compiled by Franklin Associates for the US LCI Database.[25]

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[18] American Chemistry Council (2011). Cradle-to-Gate LCI of Nine Plastic Resins and Two Polyurethane Precursors. Revised Final Report. Franklin Associates, A Division of ERG.

[19] Aluminum Association. December 2013. The Environmental Footprint of Semi-Finished Aluminum Products in North America, see: http://www.aluminum.org/sites/default/files/LCA_Report_Aluminum_Association_12_13.pdf.

[20] Aluminum Association (2010). Life Cycle Impact Assessment of Aluminum Beverage Cans, May 2010. Available at: http://www.aluminum.org/Content/ContentFolders/LCA/LCA_REPORT.pdf.

[21] NCASI (2014). Life Cycle Assessment of U.S. Average Corrugated Product, Final Report. Prepared for the Corrugated Packaging Alliance (CPA), a joint venture of the American Forest & Paper Association (AF&PA), the Fibre Box Association (FBA), the Association of Independent Corrugated Converters (AICC), and TAPPI. April 24, 2014.

[22] Bowyer J, Briggs D, Lippke B, Perez-Garcia J, Wilson J (2004). Life Cycle Environmental Performance of Renewable Materials in Context of Residential Building Construction: Phase I Research Report. Consortium for Research on Renewable Industrial Materials, CORRIM Inc. Seattle, WA. Report modules accessed at: http://www.corrim.org/pubs/reports/2005/Phase1/index.asp.

[23] Lippke B, Wilson J, Johnson L, Puettmann M (2009). Phase II Research Report. Life Cycle Environmental Performance of Renewable Materials in the Context of Building Construction. Consortium for Research on Renewable Industrial Materials, CORRIM Inc. Seattle, WA. Report modules accessed at: http://www.corrim.org/pubs/index.asp.

[24] Franklin Associates (2010). Franklin Associates' Private LCI Database

[25] National Renewable Energy Lab (NREL). US LCI Database. See: http://www.nrel.gov/lci/database/default.asp.

Where LCI data is adapted from databases other than Franklin Associates' Private LCI Database or the US LCI Database (e.g., public study or ecoinvent LCI data) for use in either the US and Canadian geographic scope, it has been modified to ensure consistency within the system boundaries of this project. The following aspects were considered:

- Capital/Infrastructure requirements are removed, if necessary.
- Biomass raw material credits for carbon dioxide inputs from nature (e.g., reflecting carbon uptake during growth) are replaced with end of life net storage credits, as appropriate for each product. Franklin Associates' methodology for carbon balance of forestry and agricultural products reflects carbon sequestration and/or storage specific to the lifespan of the product application incorporating the biomass-derived material(s). Carbon storage in products is considered only when the carbon in the bio-component of the product is not biodegradable and/or is not re-emitted to the atmosphere within the 100-year assessment period. For products that meet these requirements, Franklin Associates assigns a carbon storage credit to the fraction of bio-component contained in the closed-loop recycled content of the product.
- In adapting ecoinvent LCI data sets for this analysis, the following global warming air emissions have been removed from ecoinvent crude oil production processes:
    - methane, bromotrifluoro (a.k.a. bromochlorotrifluoromethane or Halon 1301;
    - methane, bromochlorodifluoro (a.k.a. bromochlorodifluoromethane or Halon 1211).

  Corresponding data sets used to model crude oil production in the US LCI Database do not report these emissions. Because this likely reflects a difference in data availability/reporting rather than actual process differences in crude oil extraction, the ecoinvent emissions have been removed for consistency in GWP results using the two LCI databases.

Table 1-3. Summary of Data Sources

	Temporal Information	Geographical Coverage	Technological Coverage	Data Sources
Electrical & Energy Sources	Energy source data from late 1990s to 2008. Electricity is 2014 generating mix	Based on average US or Canadian grid	The most representative technologies	EPA eGRID 2014 generating fuel mix for US[26], IEA 2014 generating fuel mix for Canada[27], with generation data for each fuel modeled using data from US LCI database.
Raw Materials (Natural Gas and Oil)	Data from late 1990s to 2011	Natural Gas and Crude Oil based on North American data; transport represents average amounts of domestic and foreign oil.	The most representative technologies.	Compiled by Franklin Associates; publicly available in the US LCI Database
Raw Materials for Lumber & Fiber Pulp	Data from 2004 – 2009	Tree harvesting and processing based on CORRIM Phase I and II covering US SE, PNW, INW, & NENC	The most representative technologies.	CORRIM Phase I and II LCI data publicly available in the US LCI Database
Virgin Resins Production	Data from 2003-2007, updated in 2011	North American average	The most representative technologies.	Franklin Associates virgin resin data compiled for the American Chemistry Council (ACC)[28]
Recycled Resins Production	Data from 2010	North American average	The most representative technologies.	Franklin Associates recycled resin data compiled for ACC (2010 Recycled Resins report)

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[26] Based on eGRID 2014 tables accessed at https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid in November 2017.

[27] Based on IEA 2014 electricity generation data for Canada accessed at http://www.iea.org/statistics/statisticssearch/report/?country=CANADA=&product=electricityandheat in November 2017.

[28] American Chemistry Council. 2011. Cradle-to-Gate LCI of Nine Plastic Resins and Two Polyurethane Precursors. Revised Final Report. Franklin Associates, A Division of ERG. Accessible at https://plastics.americanchemistry.com/LifeCycle-Inventory-of-9-Plastics-Resins-and-4-Polyurethane-Precursors-Rpt-Only/.

Table 1-3 (cont.). Summary of Data Sources

	Temporal Information	Geographical Coverage	Technological Coverage	Data Sources
Primary & Secondary Aluminum	2010 and 2013	North American average	The most representative technologies	Aluminum Association reports. Primary aluminum data are from 2013 report on semi-finished products[29], secondary aluminum data adapted from 2010 LCI on aluminum cans[30]
BOF & EAF Steel Production	1999	North American average	The most representative technologies	Franklin Associates' Private LCI Database
Glass Production	1997	North American average	The most representative technologies	Franklin Associates' Private LCI Database
Average Corrugated Material Production	Data from 2010	North American average	The most representative technologies.	Adapted from Corrugated Packaging Alliance 2014 LCA[31]; Franklin Associates' Private LCI Database
Cotton Cultivation & Textile Converting	1999 & 2007	North American average	The most representative technologies	Cotton from US LCI Database & Converting adapted from ecoinvent
Cork Cultivation & Treatment	2007	European average for cultivation in Portugal/treatment in Europe	The most representative technologies	Adapted from ecoinvent

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[29] Aluminum Association. December 2013. The Environmental Footprint of Semi-Finished Aluminum Products in North America, see: http://www.aluminum.org/sites/default/files/LCA_Report_Aluminum_Association_12_13.pdf.

[30] Aluminum Association. May 2010. Life Cycle Impact Assessment of Aluminum Beverage Cans, see: http://www.aluminum.org/Content/ContentFolders/LCA/LCA_REPORT.pdf.

[31] NCASI (2014). Life Cycle Assessment of U.S. Average Corrugated Product, Final Report. Prepared for the Corrugated Packaging Alliance (CPA), a joint venture of the American Forest & Paper Association (AF&PA), the Fibre Box Association (FBA), the Association of Independent Corrugated Converters (AICC), and TAPPI. April 24, 2014.

Table 1-3 (cont.). Summary of Data Sources

	Temporal Information	Geographical Coverage	Technological Coverage	Data Sources
Natural Rubber Production	1995-1999	North American average	The most representative technologies.	Franklin Associates' Private LCI Database
Paper & Paperboard Production	2006-2010	North American average	The most representative technologies	Franklin Associates' Private LCI Database based on Environmental Paper Network (EPN) Paper Calculator
Material Converting Processes	Data from 1997 -2010	North American average	The most representative technologies.	Franklin Associates' Private LCI Database, US LCI Database, or adapted from ecoinvent
Transport Processes	Data from 2003-2010	Supply chain and geography specific	The most representative technologies.	Distances supply chain and geography-specific national averages compiled by Franklin Associates; LCI data for transport modes from Franklin Associates compiled for the US LCI Database[32]
Landfilling, Energy Recovery	Data from 2010-2011	US and Canadian national averages	National average management	Publicly available from the US EPA (originally compiled by Franklin Associates)[33] for US scope and from Statistics Canada for Canadian scope[34]
Landfill Gas Management	Data for 2014	US and Canadian national averages	National average management	Publicly available national greenhouse gas inventories for the US[35] and Canada[36]

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[32] National Renewable Energy Lab (NREL). US LCI Database. See: http://www.nrel.gov/lci/database/default.asp.

[33] US Environmental Protection Agency. Municipal Solid Waste Generation, Recycling, and Disposal in the United States, see: http://www.epa.gov/wastes/nonhaz/municipal/msw99.htm.

[34] Statistics Canada (2012). Human Activity and the Environment: Waste Management in Canada, 2012 – Updated, Statistique Canada, Catalogue no. 16-201-X, Ministry of Industry, September 2012.

[35] US Environmental Protection Agency. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015. Landfill gas management for 2014 from Table 7-3 CH_4 Emissions from Landfills (MMT CO_2 eq)

[36] Environment and Climate Change Canada. National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada. Canada's Submission to the United Nations Framework Convention on Climate Change. Part 2. Landfill gas management for 2014 from Table A3-69 Estimated MSW CH_4 Generated, Captured, Flared, and Emitted for 1990-2015.

1.2.8. Impact Assessment

The output of a life cycle inventory is a lengthy and diverse list of elementary and intermediate inputs and outputs, making it difficult to interpret systems' differences in impacts in a concise and meaningful manner. Life Cycle Impact Assessment (LCIA) helps with interpretation of the emissions inventory. LCIA is defined in ISO 14044 section 3.4 as the "phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product." In the LCIA phase, the inventory of emissions is first classified into categories in which the emissions may contribute to impacts on human health or the environment. Within each impact category, the emissions are then normalized to a common reporting basis, using characterization factors that express the impact of each substance relative to a reference substance.

Characterization factors have been defined to estimate the amount of impact potential of LCI results. Impacts can be characterized as midpoint or endpoint indicators. The 'midpoint' approach links results to categories of commonly defined environmental concerns like eutrophication and climate change. The 'endpoint' approach further models the causality chain of environmental stressors to link LCI results to environmental damages (e.g., to human and ecosystem health). ISO standards allow the use of either method in the LCIA characterization step. Overall, indicators close to the inventory result (midpoint) have a higher level of scientific consensus, as less of the environmental mechanism is modeled. Conversely, endpoint and damage-oriented characterization models inevitably include much aggregation and some value-based weighting of parameters. To reduce uncertainty in communication of the results, this study focuses on indicators at the midpoint level.

1.2.8.1. Scope of Impact Assessment

This study evaluates the comparative performance of plastic and alternative material packaging systems for a variety of environmental indicators. The indicators, along with brief descriptions, evaluation methodology, and reporting units, are shown in Table 1-4.

Table 1-4. Environmental Indicators Evaluated

	Impact/Inventory Category	Description	Unit	LCIA/LCI Methodology
LCI Categories	**Total energy demand**	Measures the total energy from point of extraction; results include both renewable and non-renewable energy sources	MJ	Cumulative energy inventory
	Expended energy	Energy irretrievably consumed; calculated as total energy minus the potentially recoverable energy embodied in the material.	MJ	Cumulative energy inventory minus energy embodied in material
	Water consumption	Freshwater withdrawals which are evaporated, incorporated into products and waste, transferred to different watersheds, or disposed into the sea after usage	liters H_2O	Cumulative water consumption inventory
	Solid waste by weight	Measures quantity of fuel, process and postconsumer waste to a specific fate (e.g., landfill, WTE) for final disposal on a mass basis	kg	Cumulative solid waste inventory
	Solid waste by volume	Measures quantity of fuel, process and postconsumer waste to a specific fate (e.g., landfill, WTE) for final disposal on a volume basis	m^3	Cumulative solid waste inventory
LCIA Categories	**Global warming potential (GWP)**	Represents the heat trapping capacity of the greenhouse gases. Important emissions: CO_2 fossil, CH_4, N_2O	kg CO_2 equivalents (eq)	IPCC (2013) GWP 100a
	Acidification potential	Quantifies the acidifying effect of substances on their environment. Important emissions: SO_2, NO_x, NH_3, HCl, HF, H_2S	kg SO_2 eq	TRACI v2.1
	Eutrophication potential	Assesses impacts from excessive load of macro-nutrients to the environment. Important emissions: NH_3, NO_x, COD and BOD, N and P compounds	kg N eq	TRACI v2.1
	Smog formation potential	Determines the formation of reactive substances (e.g. tropospheric ozone) that cause harm to human health and vegetation. Important emissions: NO_x, BTEX, NMVOC, CH_4, C_2H_6, C_4H_{10}, C_3H_8, C_6H_{14}, acetylene, Et-OH, formaldehyde	kg O_3 eq	TRACI v2.1
	Ozone depletion potential	Measures stratospheric ozone depletion. Important emissions: CFC compounds and halons	kg CFC-11 eq	TRACI v2.1

1.2.8.2. Energy Demand Accounting

Franklin Associates uses its own method to assess energy demand. The energy demand method is not an impact assessment, but rather is a cumulative inventory of energy extracted and utilized, including both renewable and non-renewable energy. Non-renewable fuels include fossil fuels (i.e., natural gas, petroleum, and coal) and nuclear energy, while fuels classified as renewable include hydroelectric energy, wind energy, hydropower, geothermal energy, and biomass energy. All of the results for energy demand are expressed in units of mega joule (MJ) equivalents.

Energy demand results include consumption of fuels for process and transportation energy, as well as the fuel-energy equivalent for materials that are derived from fossil fuels or biomass. The energy value of resources used as material feedstock is referred to as energy of material resource, or EMR. EMR is not expended energy (i.e., energy that is consumed through combustion) but the energy value of resources with fuel value (e.g., oil, natural gas, wood) that are used to provide material content for products such as plastic resins or corrugated boxes. Some of this energy remains embodied in the material produced rather than being irretrievably expended through combustion, as is the case for process and transportation fuels. In this study, EMR applies to the crude oil and natural gas used to produce the plastic packaging. A fuel-energy equivalent (biomass EMR) is also assigned to biomass materials used as material feedstock in substitute packaging (e.g., corrugated fiber).

The energy values for fuels and electricity consumed in each industrial process are summed and categorized into an energy profile including the energy types (i.e., sources) listed below:

- Natural gas
- Petroleum
- Coal
- Nuclear
- Hydropower
- Biomass
- Other non-fossil
- Other fossil

The “other non-fossil” category includes sources such as solar, wind, and geothermal energy. The “other fossil” category refers to other fuels derived from fossil fuel sources such as combustion of fossil-derived plastics and rubbers in municipal solid waste.

All conversions for fuel inputs reflect the fuels’ higher heating values (HHV). Fuel production is from the Franklin Associates Private LCI Database. The values for densities and heat of combustion for coal and fossil fuels are calculated using data published in version 1.8b of Argonne National Laboratory's GREET model.[37] The fuels and energy LCI data used by Franklin Associates is based on modules available in the US LCI Database, with more recent updates from eGRID 2014 and GREET 1.8b.

1.2.8.3. Global Warming Potential

For GWP in both geographic scopes, contributing elementary flows are characterized using factors reported by the Intergovernmental Panel on Climate Change (IPCC) in 2013 with a 100 year time horizon. The primary 100-year GWPs used in the models are fossil carbon dioxide—1, methane—28, and nitrous oxide—265 as developed by the Intergovernmental Panel on Climate Change (IPCC) in 2013. Carbon dioxide emissions resulting from landfill decomposition of biomass-derived packaging in landfills are considered carbon neutral, as the biomass carbon is returned to the atmosphere in the same form that it was removed during the plant's growth. Therefore, biogenic CO_2 emissions are not included in the net GWP calculations. However, biogenic methane emissions from decomposition are included, since the biogenic methane has higher global warming impacts in the atmosphere until it converts to CO_2. Consistent with the TRACI methodology, a lower GWP factor is used for biogenic methane (25.25, compared to 28 for fossil methane) to adjust for the eventual atmospheric transformation of biogenic methane to carbon-neutral biogenic CO_2.[38]

1.2.8.4. Plastic Packaging Substitution Footprint

The results are scaled to represent the annual impacts for plastics versus alternative material packaging at both US and Canadian demand levels. The material substitution footprint is only for the specified plastic packaging product groups as designated in Section 1.2.3. System Boundaries in the US and Canada; these scaled-up results should not be interpreted as totals for alternative geographic scopes or for global packaging systems.

1.2.8.5. Interpretation of Results Using Equivalencies

The magnitude of impact assessment results can be difficult to interpret. Equivalencies can be used as an aid for providing perspective on results. Factors from sources such as the US EPA Greenhouse Gas Equivalencies Calculator[39] are used in this analysis to convert savings into more easily visualized terms, such as the equivalent number of passenger vehicles' annual use, railcars of coal burned, etc. Equivalency factors are presented in Chapter 4.

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[37] GREET Version 1.6. Developed by Michael Wang. Center for Transportation Research, Argonne National Laboratory. October 2001. Updates from Version 1.8b.

[38] EPA (2010). Methane and Nitrous Oxide Emissions from Natural Sources, Office of Atmospheric Programs, Washington DC. US Environmental Protection Agency, Report EPA 430-R-10-001. April 2010. Available at: http://www.epa.gov/outreach/pdfs/Methane-and-Nitrous-Oxide-Emissions-From-Natural-Sources.pdf.

[39] Accessed at http://www.epa.gov/cleanenergy/energy-resources/calculator.html

1.2.9. Assumptions and Limitations

Although the foreground material production, converting, recycling, transportation, and disposal processes in this analysis were populated with data from reliable, most analyses still have limitations. Further, it is necessary to make a number of assumptions when modeling, which could influence the final results of a study. Key limitations and assumptions of this analysis are described in this section.

1.2.9.1. LCI Composition and Weight Factors

Material weights for plastic packaging are provided by Freedonia market data for the years 2007-2011. These data were cross-checked with totals indicated in other reliable publications.[40,41] The weights of alternative packaging materials projected for plastic packaging substitution are compiled by Franklin Associates using: 1) case study examples in packaging studies, 2) primary data from previous public and private LCAs performed by Franklin Associates, and/or 3) publicly available specifications from packaging providers. It was assumed that the product contained/unitized by the packaging would not be changed or altered in any way. For example, substitution of a liquid product packaged in a plastic bottle (e.g., liquid hand soap or laundry detergent) with a solid form of the product packaged in a different material (e.g., a bar of hand soap in a paper wrapper, powdered detergent granules in a paperboard box) are not accepted substitutions. The substitution modeling is also limited to direct substitution, e.g., replacement of the primary package with an alternative package that is used in the same way. For example, refrigerated products packaged in plastic (e.g., milk in HDPE jugs) are assumed to be replaced with other types of packaging that are refrigerated (e.g., paperboard cartons), rather than replaced by aseptic packages that have different product heating and filling requirements and do not require refrigeration during post-filling transportation and storage.

In some types of substitute packaging, some use of plastic is still required for functionality, e.g., plastic coatings on gable-top cartons for liquids, laminated plastic coatings on aseptic cartons, and plastic liners used inside of rigid paper-based containers used with liquid contents. In all cases, the plastic content in substitute packaging is less than half of its mass.

1.2.9.2. Electricity Grid Profile

It is generally not possible to determine the mix of locations for supply chain sourcing for all the materials and processes contributing to the life cycle of a given product. In addition, electricity production and distribution systems in North America are interlinked; there are imports and exports of generated electricity between regions so that the mix of fuels used to *generate* electricity in a specific area is not necessarily the same as the generating mix for the electricity *consumed* in that area. The generating mix used for US packaging

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[40] ACC (2012). The Resin Review: The Annual Statistical Report of the North American Plastics Industry, American Chemistry Council, 2012 Edition.

[41] EPA (2011). Municipal Solid Waste Generation, Recycling, and Disposal in the United States, Detailed Tables and Figures for 2010. Compiled by Franklin Associates, A Division of ERG for the US Environmental Protection Agency.

systems is modeled using U.S. EPA eGRID tables for 2014[42], which was the most recent eGRID data available during the modeling for this analysis. For temporal consistency, the Canadian electricity grid is modeled with 2014 generating data from the International Energy Agency[43] All foreground processes (e.g., packaging conversion, re-processing, and disposal processes) are assumed to be supplied with US and Canadian average grid mix, for the US and Canadian geographic scope, respectively.

The electricity grids used in this analysis are not specific to a type of industry, with the exception of the primary aluminum supply chain, which has specific geographic sourcing for raw materials and intermediate processing steps. For the primary aluminum supply chain, the fuel profile for electricity supplied for bauxite mining and alumina production is modeled with the electricity grids of its corresponding geographies (including Australia and Jamaica). All electricity grids were modeled to take into account line losses during transmission.

1.2.9.3. Transportation

The data in the Franklin Associates LCI models include transportation requirements between manufacturing steps. For upstream processes (such as crude oil extraction, petrochemical production, etc.) the transportation modes and distances are based on average industry data. For the foreground converting steps of producing plastic and alternative material packaging products, the transportation requirements were based on the transportation modes and distances typical for each supply chain in each geographic scope. Data for these transport distances and modalities were compiled by Franklin Associates based on previous public and private LCA studies and publicly available transportation reports. Only the weights of the packages, not the weights of the products contained in the packaging materials, are included in the transportation calculations. For either geographic scoping, the boundaries of this LCA include the environmental burdens of the packaging, not the environmental burdens of the product inside the packaging.

1.2.9.4. Waste Management

In this portion of the study, estimates of the end results of landfilling and waste-to-energy (WTE) combustion are limited to global warming potential (GWP) effects, electricity credits, and requirements for transporting waste to a landfill and operating landfill equipment. Recycling energy requirements are also taken into account.

In the US, municipal solid waste (MSW) that is not recovered for recycling or composting is managed 82 percent by weight to landfill (LF) and 18 percent by weight to waste-to-

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[42] Based on eGRID 2014 tables accessed at https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid in November 2017.

[43] Based on IEA 2014 electricity generation data for Canada accessed at http://www.iea.org/statistics/statisticssearch/report/?country=CANADA=&product=electricityandheat in November 2017.

energy (WTE) incineration.[44] In Canada, 95 percent by weight of disposed weight goes to LF, three percent to WTE, and the remaining two percent to incineration without energy recovery.[45] Thus, the calculations of the GWP impacts for the portion of packaging that is discarded are based on a scenario in which 82 percent of the postconsumer packaging that is not recycled goes to LF and 18 percent to WTE combustion in the US and 95 percent of packaging that is not recycled goes to LF, three percent to WTE, and the remaining two percent to incineration without energy recovery in Canada. The following factors are considered in modeling the landfilling and WTE processes:

- The ash resulting from WTE combustion is later landfilled, but does not result in landfill gas emissions. The US EPA's Landfill Methane Outreach Program (LMOP) Landfill Database[46] and Environment Canada[47] indicate that the majority of landfill gas burned with energy recovery is used to produce electricity. The gross energy recovered from combustion of LF gas (calculated per material for each geographic scope) is modeled to be converted to displaced quantities of grid electricity for each geographic scope using an efficiency factor of 1 kWh generated per 11,700 Btu of LF gas burned.[48]
- The HHV (higher heating value) was used for the modeling of energy recovery from the combustion of postconsumer waste. These heating values are calculated based on the material composition of the disposed container components.
- GWP contributions from WTE combustion of postconsumer packaging and from fugitive emissions of landfill methane from anaerobic decomposition of biomass-derived materials are included. Credits for grid electricity displaced by the generation of electricity from WTE combustion of postconsumer containers and from WTE combustion of methane recovered from decomposition of landfilled corrugated board are also included. Some carbon is also sequestered in the biomass-derived materials that do not decompose. The US EPA greenhouse gas accounting methodology does not assign a carbon sequestration credit to landfilling of fossil-derived materials because this is considered a transfer between carbon stocks (from oil deposit to landfill) with no net change in the overall amount of carbon stored.[49]

Decomposition of landfilled paper and paperboard can vary, depending not only upon the conditions in individual landfills (e.g., temperature, moisture, microbial activity) but also

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[44] US EPA. Municipal Solid Waste Facts and Figures 2011. Accessible at http://www.epa.gov/msw/msw99.htm.

[45] Statistics Canada (2012). Human Activity and the Environment: Waste Management in Canada, 2012 – Updated, Statistique Canada, Catalogue no. 16-201-X, Ministry of Industry, September 2012.

[46] Operational LFG energy projects spreadsheet, sorted by LFGE utilization type and project type. Accessible at http://www.epa.gov/lmop/proj/#1.

[47] Jackson (2005). Landfill Gas Management in Canada: What's Going on North of the Border? Presentation by Dennis Jackson of the National Office of Pollution Prevention, Environment Canada at the 8th Annual LMOP Conference, January 2005. Accessible at: http://www.epa.gov/lmop/documents/pdfs/conf/8th/presentation-jackson.pdf.

[48] LMOP Benefits Calculator. Calculations and References tab. Accessible at http://www.epa.gov/lmop/documents/xls/lfge_benefitscalc.xls.

[49] US EPA. **Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks.** Third Edition. September 2006. Section 1.3, subsection Carbon Stocks, Carbon Storage, and Carbon Sequestration. Page 6.

on the presence or absence of coatings, laminations, or additives that inhibit decomposition. This analysis presents results for two landfill decomposition scenarios for paper and paperboard packaging:

- A conservative scenario in which there is no decomposition of landfilled paper/paperboard and all the biogenic carbon content is sequestered.
- A scenario in which the fiber content of uncoated paper/paperboard packaging decomposes to the maximum degree, and fiber content in coated and laminated paper/paperboard does not decompose.

The maximum decomposition of landfilled paper and paperboard packaging in this analysis is modeled based on the maximum decomposition of corresponding types of paper-based materials in landfill simulation experiments conducted by William Eleazer, et al.[50] Landfill simulation experiments conducted by Eleazer, et al. analyzed decomposition of office paper, clay-coated magazine paper, newspaper, and corrugated material. For paper-based materials, the cellulose and hemicellulose fractions of the material decompose to some extent, while the lignin fraction of the material tends to decompose to a much lesser extent under anaerobic conditions. Thus, the potentially degradable carbon content of the landfilled material is based on its cellulose and hemicellulose content. This analysis uses experimental data on office paper to estimate decomposition of bleached kraft paperboard in packaging materials (e.g., paperboard cartons). Experimental data on decomposition of corrugated is used to estimate decomposition of all types of uncoated unbleached paper and paperboard packaging, while experimental data on decomposition of newspaper is used to represent molded fiber products made from postconsumer newspaper (e.g., molded pulp egg cartons and packaging shapes). Based on the cellulose, hemicellulose, and lignin percentages in each material, and the carbon content of each fraction, the total carbon content of bleached office paper is calculated as 44.1 percent by weight (42.6 percent potentially degradable carbon in the cellulose and hemicellulose fractions, 1.5 percent carbon in lignin); for corrugated, the total carbon content of corrugated is calculated as 43.2 percent (29.9 percent potentially degradable, 13.3 percent in lignin); and the total carbon content of newspaper is calculated as 40.9% by weight (25.6% potentially degradable carbon in the cellulose and hemicellulose fractions, 15.2% carbon in lignin). Plastic-coated paperboard items were not included in the simulated landfill experiments, but it is likely that the coating on the containers will delay or significantly inhibit decomposition of the paper; therefore, this analysis uses a conservative approach in assuming that the fiber content of paper and paperboard packaging does not decompose. Because the landfill simulation experiments were designed to maximize decomposition, the baseline estimates in this study for uncoated paper and paperboard packaging should be considered an **upper limit** for landfill gas generation from decomposition.

In the experiments conducted by Eleazer, et al., the following conditions were used to simulate enhanced decomposition in a landfill: addition of a seed of well-decomposed refuse to help initiate decomposition, incubation at about 40°C, and leachate recycling and

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[50] Eleazer, William, et al. “Biodegradability of Municipal Solid Waste Components in Laboratory-Scale Landfills.” Published in Environmental Science & Technology. Volume 31, Number 3, 1997.

neutralization. The maximum degree of decomposition for the cellulose and hemicellulose fractions of office paper was 98 percent and 86 percent, respectively. In the corrugated samples, the degree of decomposition was 64 percent for the cellulose and 62 percent for the hemicellulose. The maximum degree of decomposition for the cellulose and hemicellulose fractions of newspaper were 27% and 54%, respectively. Overall, 41 percent by weight of the office paper, 19 percent by weight of the corrugated, and 8 percent of the newspaper degraded to produce CO_2 and methane. The remaining biomass carbon content of each material did not degrade. It is assumed that all the carbon that degrades produces methane and CO_2.

Biomass CO_2 released directly from decomposition of paper products or indirectly from oxidation of biomass-derived methane to CO_2 is considered carbon neutral, as the CO_2 released represents a return to the environment of the carbon taken up as CO_2 during the plant's growth cycle and does not result in a net increase in atmospheric CO_2. Thus, biomass-derived CO_2 is not included in the GHG results shown in this analysis. Methane releases to the environment from anaerobic decomposition of biomass are **not** considered carbon neutral, however, because these releases resulting from human intervention have a higher GWP than the CO_2 taken up or released during the natural carbon cycle.

The gross energy recovered from combustion of LF gas from each material in both the US and Canada is converted to displaced quantities of grid electricity using an efficiency factor of 1 kWh generated per 11,700 Btu of LF gas burned.[51] Each packaging system is credited with avoiding the GWP associated with production of the offset quantity of grid electricity. The grid electricity offset was assumed to be the average US electricity grid for the US geographic scope and average Canadian electricity grid for the Canadian geographic scope.

For the carbon that remains fixed in the landfilled biomass-derived material (e.g., in the undecomposed portion of the corrugated packaging), a sequestration credit is given for the equivalent pounds of CO_2 that the sequestered carbon could produce.

Waste-to-energy combustion of postconsumer material is modeled using a similar approach to the landfill gas combustion credit. However, for WTE combustion of packaging, the CO_2 releases are modeled based on the **total** carbon content of the material oxidizing to CO_2. For combustion of fiber-based corrugate, the CO_2 produced is considered carbon-neutral biomass CO_2, while the CO_2 from combustion of plastics is fossil CO_2.

The gross heat produced from WTE combustion is calculated based on the pounds of material burned and the higher heating value of the material. The heat is converted to kWh of electricity using a conversion efficiency of 1 kWh per 19,120 Btu for mass burn facilities[52], and a credit is given for avoiding the GWP associated with producing the equivalent amount of grid electricity.

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[51] LMOP Benefits Calculator. Calculations and References tab. Accessible at http://www.epa.gov/lmop/res/lfge_benefitscalc.xls.

[52] US EPA. **Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks.** Third Edition. September 2006. Chapter 5 Combustion, section 5.1.5. Calculation is based on 550 kWh produced per ton of MSW burned, with a heat value of 5,000 Btu per

The net end-of-life GWP for each system is calculated by summing the individual impacts and credits described above.

As noted, the landfill methane calculations in this analysis are based on the **aggregated** emissions of methane that may result from decomposition of the degradable carbon content of the landfilled material. The long time frame over which those emissions occur has implications that result in additional uncertainties for the landfill methane GWP estimates.

- In this analysis, the management of the aggregated landfill methane emissions is modeled based on current percentages of flaring, WTE combustion, and uncaptured releases for each geographic scope. Over time, it is likely that efforts to mitigate global warming will result in increased efforts to capture and combust landfill methane. Combustion of biomass-derived methane converts the carbon back to CO_2, neutralizing the net global warming impact. In addition, if the combustion energy is recovered and used to produce electricity, there would be credits for displacing grid electricity. With increased future capture and combustion of landfill methane, the future net effect of landfill methane could gradually shift from a negative impact to a net credit.
- Although landfill methane releases from decomposition occur gradually over many years, the modeling approach used to calculate the impacts of the aggregated emissions use 100-year global warming potentials. This is consistent with the use of 100-year global warming potentials used for all other life cycle greenhouse gas emissions. The total GWP for landfill decomposition over time is reported as a single cumulative value. Future refinements to end-of-life modeling may include time-scale modeling of landfill methane emissions; however, this is not part of the current study.
- Energy and emissions associated with releases or treatment of leachate are not included in this model due to lack of available data.

1.2.10. Critical Review of the Substitution Model Methodology

The substitution model defining the weight factors for substitution of plastic packaging relative to alternative packaging materials as well as the national recycling and EOL statistics used in modeling were reviewed by the following LCA experts:

1. Harald Pilz, Denkstatt GmbH
2. Roland Hischier, Empa Research Institute

The reviewers examined the details of the substitution model methodology, including description of data sources used, modeling assumptions, and general approach to ensure that the substitution modeling is reasonable and robust.

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pound of MSW. For mass burn facilities, 523 kWh of electricity are delivered per 550 kWh generated. Full report and individual chapters of the report are accessible at http://www.epa.gov/climatechange/wycd/waste/SWMGHGreport.html.

CHAPTER 2. SUBSTITUTION MODEL

2.1. INTRODUCTION

Franklin Associates first conducted a life cycle energy analysis of US plastic packaging and alternatives in 1990 for the Society of the Plastics Industry. The current analysis employs a similar but more detailed approach compared to the 1990 study and is expanded here to include the Canadian geographic scope as well as both energy demand and greenhouse gas (GHG) emissions. The current study is also patterned after a 2010 study on plastics and alternatives commissioned by PlasticsEurope.[53] The primary similarities and differences between the European and North American analyses assessing effects of a theoretical substitution of plastics packaging are summarized below.

2.1.1. Similarities

- **Goal.** Though the European study also investigated plastic products other than packaging, the goal of both the packaging section of the European analysis and this North American study is to assess the effect of a theoretical substitution of plastic packaging at a national/continental level.
- **Plastics examined:** Both analysis assessed the theoretical substitution of predominant packaging resins: low- and high-density polyethylene, polypropylene, polyvinylchloride, polystyrene, expanded polystyrene, and polyethylene terephthalate.
- **Functional unit.** The substitution model in both of the analyses considered the functional unit to be the mass of material(s) required to provide the same packaging function or service as the theoretically substituted plastic package.
- **Results reported.** The European study and the original North American study focused on energy and global warming potential (GWP) impacts; other life cycle impact assessment categories were not included in the scope of the analyses. However, this expansion of the North American study includes additional impact categories.
- **Life cycle approach**. Both analyses include all stages of the packaging life cycle, from raw material extraction through end-of-life management and recycling.
- **System expansion credit**. For plastic and non-plastic packaging with recycling rates that are higher than their recycled content (i.e., that are net producers of recycled material), both analyses assign credits for the amount of recovered material that displaces virgin material. Energy and greenhouse gas credits are also given for waste-to-energy combustion of packaging that displaces production and combustion of other types of fuel.

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[53] Pilz H, Brandt B, Fehringer R (2010). The Impact of Plastics on Life Cycle Energy Consumption and Green-House Gas Emissions in Europe, Part 1: Effects of a Theoretical Substitution of Plastics. Prepared by Denkstatt GmbH for PlasticsEurope Association of Plastics Manufacturers Association and Sustainable Energy Europe, Final Report June 2010.

- **Non-substitutable packaging**. Both analyses classify some types of plastic packaging as non-substitutable; that is, plastic packaging with functional performance that cannot be duplicated by non-plastic alternatives. Non-substitutable packaging is excluded from the analysis to the extent possible.

2.1.2. Differences

- **Data sources for substitution model.** The European analysis primarily utilized the extensive private German GVM database on packaging to determine the types and weights of packaging that would substitute for plastic packaging. The North American study primarily utilizes market data purchased from the Freedonia Group, supplemented with data from Franklin Associates' extensive history of North American LCA studies and additional packaging weight data from manufacturers' websites and published studies.
- **Packaging categories**. Both the European and North American analyses break the substitution analysis out into several packaging categories. Based on the packaging categories available in the Freedonia market reports, the North American analysis uses somewhat different categories than the European study, as summarized in the table below.
- **Alternative materials included**. Because the European study of plastics and alternatives included not only packaging but many other types of plastic products, the study necessarily limited the level of detail in the types of substitute material options modeled. Because the North American study is focused *only* on packaging, there is more detail in the alternative packaging categories modeled (for example, different types of coated and uncoated paper, paperboard, and cartons; modeling of individual materials such as cork, wood, cellophane, etc.).
- **Geographic differences**. Each report uses modeling parameters that are specific to the region of interest (e.g., packaging market shares; electricity grid fuel mix for LCI modeling of average kWh; prevalence of refillable beverage bottles; transportation distances for packaging distribution; packaging recycling rates; percentages of solid waste that are managed by landfilling and combustion with and without energy recovery; level of landfill methane capture).
- **Study boundaries.** While the European analysis does make modeling assumptions for differences between plastic and alternative material packaging in the use phase of the packaging products (e.g., prevented food losses and transport volume for beverage packaging), differences in storage requirements were not considered. The North American analysis does not include evaluation of energy and greenhouse gas differences associated with possible differences in filling processes or consumer use of the alternative package. The comparative effect of such use phase exclusions is minimized by using direct substitutions wherever possible (e.g., replacement of the primary package with an alternative package that is used in the same way). For example, refrigerated plastic containers are assumed to be replaced by similar volume containers that are also refrigerated. No estimates of food losses prevented by use of plastic packaging are made in this study.

Table 2-1. Differences in Packaging Categories Investigated in the Current North American and 2010 European Analyses

Type of Plastic Packaging	North American Study	European Study
Caps and Closures	Reported as a separate category	Included in *Small Packaging* category
Bottles	All types of beverage bottles reported in category *Beverage Packaging; Other Rigid* packaging category has subcategory *Bottles and Jars* reporting non-beverage bottles and jars	Category *Beverage Bottles* includes only PET containers; non-PET beverage containers included in *Other Bottles* category along with other types of non-beverage bottles and jars
Small Rigid Packaging	Reported in *Other Rigid* category, *Non-Bulk* and *Protective* subcategories	Included in *Small Packaging* category
Small Flexible Packaging	In *Other Flexible* category, *Converted* and *Protective* subcategories	Included in *Small Packaging* category

2.2. SUBSTITUTION MODEL OVERVIEW

The goal of the substitution analysis is to answer the question: "If plastic packaging were replaced with alternative types of packaging, how would energy consumption and greenhouse gas emissions be affected?" The primary alternative materials for many different types of plastic packaging are paper and paperboard, glass, steel, and aluminum. Smaller amounts of textiles, rubber, and cork compete with plastics in specific packaging markets such as reusable bags, and caps and closures.

In this study, comparisons were made between current amounts of plastic packaging products and a scenario in which plastic packaging is substituted by alternative materials up to a theoretical maximum. It was assumed that the product contained/unitized by the packaging would not be changed or altered in any way. For example, substitution of a liquid product packaged in a plastic bottle (e.g., liquid hand soap or laundry detergent) with a solid form of the product packaged in a different material (e.g., a bar of hand soap in a paper wrapper, powdered detergent granules in a paperboard box) are not accepted substitutions.

Polymer coatings or liners are not analyzed as plastic packaging to be replaced. The intent of the analysis is to evaluate substitutes for packaging that is predominantly plastic (e.g., >50% by weight plastic). Some substitute packaging does include plastic components as part of their composition (e.g., coatings and laminations on gable-top and aseptic cartons used for liquid packaging).

The substitution modeling is also limited to direct substitution, e.g., replacement of the primary package with an alternative package that is used in the same way. For example, refrigerated products packaged in plastic (e.g., refrigerated milk in HDPE jugs) are assumed to be replaced packaging that may also contain refrigerated product (e.g., refrigerated milk in paperboard gable-top cartons), rather than being replaced by a package that enables a non-refrigerated shelf-life (e.g., aseptic packages); as these types of packages would have different product heating and filling requirements and do not require refrigeration during post-filling transportation and storage.

It should be noted that substitution calculations are limited to replacement of the primary package component(s). The scope of the study does not include evaluation of energy and greenhouse gas differences associated with possible differences in filling processes or consumer use of the alternative package. Refrigeration of filled plastic and alternative containers during transport and storage is not included. End-of-life management (reuse, recycling, landfill, and waste-to-energy combustion) for each type of plastic and alternative packaging is modeled based on national average statistics for packaging waste management in the US and Canada.

Some plastic packaging is considered ‘not-substitutable’ and has not been included in this analysis (e.g., aerosol can valve assemblies, blister packaging, medical device packaging). For the plastic packaging products considered ‘not-substitutable’, there was no data available from Freedonia to estimate the market share that these products have relative to overall plastic packaging, so it is not possible to estimate the quantities or percentage of total plastic packaging that is excluded. A recent European study on plastic packaging substitution estimated that 2.1% of plastic packaging is non-substitutable.[54]

Table 2-2 and Table 2-3 present an overview of the investigated packaging categories, and for each category: the functional unit of comparison for plastic versus alternative materials, the total plastic resin weight currently utilized in the US and Canada, respectively (i.e., based on market report data for years 2007-2011), and the current market share of plastic represented relative to competing packaging materials for that category. Note that for the packaging categories, plastic currently makes up approximately 43 to 100 percent of the market share by functional unit. The demand for shrink and stretch film packaging is currently met 100 percent by plastic resins; thus, 100 percent of the current demand for stretch and shrink films is modeled to be substituted by alternative packaging materials. By volume, approximately 60 percent of beverages are sold in plastic containers; thus, 60 percent of current beverage volume is modeled to be contained in alternative material packaging in the substitution model. Table 2-4 presents the details on the data year(s) and types of plastic packaging included and excluded from each investigated category in the analysis.

Where data sources have provided both historical and projected values, the most recent actual data years have been selected (i.e., data year ranges from 2007-2010 with no projected values incorporated). This section describes the alternatives for plastic packaging products as well as the weight ratio of alternative materials to those plastic packaging

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[54] Pilz H, Brandt B, Fehringer R (2010). The Impact of Plastics on Life Cycle Energy Consumption and Green-House Gas Emissions in Europe, Part 1: Effects of a Theoretical Substitution of Plastics, Section 2.2.1, Prepared by Denkstatt GmbH for PlasticsEurope Association of Plastics Manufacturers Association and Sustainable Energy Europe, Final Report June 2010.

products. With this information, and the weight of resin in each market, the weight of alternative materials can be calculated.

Table 2-2. Investigated Packaging Categories and Overview of US Plastic Packaging

Category:	Functional Unit of Comparison for Alternative Material Weight Required:	Market Share Plastic for the Category (Per Functional Unit)	Total Weight Plastic to be Replaced	
			(million kg)	*(% of Total)*
Other Rigid	Volume Capacity for Non-Bulk & Bulk Rigid Packaging	43%	4,264	29.6%
	Protective Performance for Protective Packaging			
Other Flexible	Volume Capacity for Converted & Bulk Packaging (except strapping)	67%	4,226	29.3%
	Protective Performance for Protective Packaging			
	Unitizing Performance for Flexible Bulk Strapping			
Beverage Containers	Volume Capacity	60%	3,095	21.5%
Carrier Bags	Number of Units (adjusted for difference in capacity)	83%	1,297	9.00%
Stretch & Shrink	Square Footage adjusted for performance	100%	748	5.19%
Caps & Closures	Number of Units	72%	779	5.41%

Table 2-3. Investigated Packaging Categories and Overview of Canadian Plastic Packaging

Category:	Functional Unit of Comparison for Alternative Material Weight Required:	Market Share Plastic for the Category (Per Functional Unit)	Total Weight Plastic to be Replaced	
			(million kg)	*(% of Total)*
Other Rigid	Volume Capacity - Bottles & Jars, Tubs/Cups/Bowls; Other Non-Bulk & Bulk	43%	470	28.8%
	Protective Performance - Protective Packaging			
Other Flexible	Volume Capacity - Converted Flexible; Flexible Bulk Packaging (except strapping)	69%	532	32.6%
	Protective Performance - Protective Packaging			
	Unitizing Performance - Flexible Bulk Strapping			
Beverage Containers	Volume Capacity	60%	342	21.0%
Carrier Bags	Number of Units (adjusted for difference in capacity)	83%	143	8.76%
Stretch & Shrink	Square Footage adjusted for performance	100%	83	5.06%
Caps & Closures	Number of Units	53%	62	3.83%

Table 2-4. Details on Contents of Plastic Packaging Categories

CATEGORY		DATA YEAR	PRIMARY PLASTIC PACKAGING PRODUCTS INCLUDED:	PACKAGING PRODUCTS EXCLUDED:
OTHER RIGID	**Non-Bulk**	**US 2009; Canadian 2011**	Non-beverage bottles and jars; tubs, cups and bowls; pails; food trays; cans; egg cartons; squeeze tubes; and others such as plastic boxes; food, household cleaning chemicals, cosmetics and toiletries, pharmaceuticals, automotive chemicals, industrial and institutional cleaning chemicals, and others such as adhesives and agricultural chemicals	Beverage container packaging (e.g., bottles) -see Beverage Container category; laminate-type squeeze tubes; foodservice packaging such as clamshells, pails, and baskets; decorative tins, medical device packaging, blister packaging, injection molded cosmetic packaging such as lipstick and compact cases; compact disc cases; separately sold caps and closures; protective and bulk rigid packaging; and home storage containers such as TUPPERWARE containers
	Protective	**2011**	Protective packaging shapes and other rigid packaging providing cushioning, blocking and bracing, insulating, and void-filling for the manufacturing and non-manufacturing markets (e.g., insulated shipping containers and foamed shipping protectors)	Flexible protective packaging such as shipping sacks or strapping (see flexible protective packaging category); and insulated shipping packaging requiring electricity or another power source to maintain a temperature-controlled environment inside an insulated enclosure
	Bulk	**2010**	Drums, pails, bulk boxes, material handling containers (MH Cs) and bulk boxes, and rigid intermediate bulk containers (RIBCs) for chemical and pharmaceutical, food, plastic, rubber, fiber, petroleum and lubricant, agricultural and horticultural, durable, and hazardous waste storage and handling markets	Pallets; corrugated boxes other than bulk and corrugated RIBCs; cans, bottles, jars, and tubs used for packaging bulk size food or other consumer goods*
OTHER FLEXIBLE	**Converted**	**US 2010; Canadian 2008**	Single-ply or multiple plies of materials laminated together by an adhesive system or coextruded to fabricate bags, pouches, and other pre-formed packages or rollstock that are converted for food and non-food applications; also, printed, coated, or otherwise converted overwraps	Beverage container packaging (e.g., pouches) -see Beverage Container category; packaging formed by slitting alone, any uncoated single web material that is neither preformed nor printed; wrappers which are unconverted flexible materials such as shrink and stretch film, plain film, and related products (see shrink & stretch wrap category); retail, grocery, and novelty bags and sacks (see carrier/retail bags category); paperyard waste and refuse sacks, trashbags; household and institutional plastic storage bags or rolls of film; money bags; envelopes used for mailing; sausage casings; shrink sleeve and other labels; lidding, foodservice disposable packaging such as sandwich wraps; and secondary and tertiary packaging**
	Protective	**2011**	Cushioning, void-filling, and lining packaging products such as protective mailers, protective packaging fill, and dunnage bags for the manufacturing and non-manufacturing markets.	Rigid protective packaging shapes such as foam shipping braces (see rigid protective packaging category)
	Bulk	**2011**	Shipping sacks, strapping, flexible intermediate bulk containers (FIBCs), and bulk drum, bin and box liners and rolls for the food/beverage, chemical, agricultural, and horticultural markets	Non-packaging applications such as money bags and sand bags; film wrap used for bulk applications (see stretch & shrink film category)

* Data providers were unable to clarify if specific types of rigid bulk packaging excluded from the bulk category are included in other categories (e.g., bulk jars in bottles & jars). Franklin Associates assumes that these items are captured in other categories.

** Secondary and tertiary packaging materials are those which are not in direct contact with food or other contained products; materials which do not function to contain, protect, and store products for future consumption but are used instead for unitizing and distribution products contained in primary packaging (e.g., crates, pallet wrap, strapping). Unless otherwise noted in this table (e.g., pallets), secondary and tertiary packaging materials are included in the substitution model--in appropriate subcategories.

Table 2-4 (cont.). Details on Contents of Plastic Packaging Categories

CATEGORY	DATA YEAR	PRIMARY PLASTIC PACKAGING PRODUCTS INCLUDED:	PACKAGING PRODUCTS EXCLUDED:
BEVERAGE CONTAINERS	2007	Aluminum cans and bottles; steel cans; plastic bottles, pouches, and cans; glass bottles; and paperboard containers e.g., gabletop and bag-in-box cartons, aseptic boxes and composite cans, intended for disposal after use for the following markets: carbonated soft drinks including flavored and soda waters; beer and other malt beverages; still and sparkling bottled water; both frozen and shelf-stable fruit beverages; other ready-to-drink (RTD) non-alcoholic beverages; RTD tea; milk and eggnog including non-beverage use of fluid milk; sports beverages; wine including wine-based coolers and hard ciders; distilled spirits; and soy and other non-dairy milk	All non-liquid beverages including: dried coffee and tea; powdered and condensed milk; powdered fruit drinks and sports beverages; also excluded: vegetable and tomato drinks; infant formula; packaged milk shakes and liquid nutritional supplements (see non-bulk rigid containers category); and all secondary beverage container packaging** e.g., corrugated boxes and paperboard beverage carriers; bulk containers not intended primarily for in-home use; bottled water containers larger than 2.5 gallons are excluded
CARRIER/ RETAIL BAGS	2009	Retail bags and sacks	Large bags and sacks used for bulk shipments (see bulk flexible category)
CAPS & CLOSURES	2009	Standard threaded, pressure screw vacuum threaded, unthreaded, and synthetic cork caps and closures utilized on containers intended for disposal after use in beverage, food, pharmaceutical and other health-care product, cosmetic and toiletry, household chemical, automotive chemical, and other packaging markets	Non-substitutable caps and closures (i.e., dispensing and child-resistant types); caps or closures that are an integral part of the container (e.g., aerosol can valve assemblies); home canning and bottling closures; most glass closures; caps and closures used on industrial bulk containers; flexible (e.g., aluminum foil, twist tie) closures; champagne overcaps and capsules; and caps and closures employed in nonpackaging applications such as valve covers, distributor caps, pen caps, food and other storage container lids, etc.
STRETCH & SHRINK FILM	2010	Wrap, stretch labels and sleeves, and hoods (e.g., pallet caps) used in product packaging and storage and distribution markets	Converted or multi-layer films (see converted flexible category)

** Secondary and tertiary packaging materials are those which are not in direct contact with food or other contained products; materials which do not function to contain, protect, and store products for future consumption but are used instead for unitizing and distribution products contained in primary packaging (e.g., crates, pallet wrap, strapping). Unless otherwise noted in this table (e.g., pallets), secondary and tertiary packaging materials are included in the substitution model--in appropriate subcategories.

For each plastic packaging category, the current market share of plastic resins (in terms of the functional unit for that category) determines the weight of resin to be replaced by alternative materials in the substitution model. For example: ~1,105 million pounds of resin were used in rigid non-bulk food bottles and jars in 2009; because the market data indicate that ~47 percent of alternative materials volume market share for rigid non-bulk bottles and jars is glass, 47 percent of the plastic resin weight (i.e., ~516 of 1,105 million pounds of resin) used for the food bottles and jars is modeled to be replaced by glass bottles and jars. A plastic packaging product has been selected to represent each packaging subcategory. The weight of the representative plastic packaging product is then compared to the weights of an alternative material package providing the same functional unit. For each subcategory, the total weight of resin to be theoretically substituted by alternative packaging materials is multiplied by a weight ratio determined by the relative weights of the representative product for that subcategory (e.g., relative weight of an impact-resistant, wide-mouth plastic food jar and a glass food jar of equivalent volume capacity). The relative weights of the plastic versus alternative material products are derived from industry contacts, publisher data sources, and actual measurements. The weight of replaced resin multiplied by the substitute alternative material-to-plastic weight ratio provides the weight of each alternative packaging material to substitute for the associated portion of plastic resin in each subcategory.

The approach for estimating total pounds of alternative packaging materials is described for each investigated packaging category in the following sections. The categories are presented in descending order of plastic packaging weight, e.g., from highest to lowest percent share of the total weight of current plastic packaging:

- Other rigid packaging (includes the subcategories non-bulk rigid packaging, rigid protective packaging, and rigid bulk packaging)
- Other flexible packaging (includes the subcategories converted flexible packaging, flexible protective packaging, and flexible bulk packaging)
- Beverage packaging
- Carrier bags
- Shrink and stretch film
- Caps and closures

At the end of each section, tables are presented summarizing the relative shares of substitutable plastic packaging and alternative packaging **currently used** in the US and Canada, respectively, as well as tables showing the amounts and types of alternative packaging that would be used to **substitute** plastic packaging in the US and Canada.

The current market share tables at the end of each section summarize the current market shares of plastics and competing packaging materials for each packaging category and their respective subcategories. For transparency, vertical columns in these tables show the market share that each category contributes to overall packaging as well as the market share that each subcategory contributes to its parent category. Horizontal rows in this table also show the market share of each material within each category and their respective subcategories and product markets.

In both the current market share and substitution tables, some alternatives materials column headings cover a mix of several types of packaging. For example, the category "paper" includes the total weight of corrugated board, coated and uncoated bleached and unbleached kraft paper, coated paper cartons, laminated aseptic cartons, and molded fiber used as substitutes for each packaging application. The category "aluminum" includes aluminum cans, rigid containers, and foil.

Tables are presented in the following order at the end of each section:

- Current market share table, US
- Substitution table, US
- Current market share table, Canada
- Substitution table, Canada

2.3. OTHER RIGID PACKAGING MARKETS

2.3.1. Introduction

Aside from beverage bottles and caps and closures (modeled as separate categories), other rigid packaging markets include non-bulk rigid packaging, protective rigid packaging, and bulk rigid packaging. The main alternatives for these types of plastic rigid packaging are glass, several types of paper products (i.e., kraft paper, paperboard, molded fiber, and corrugated cardboard), steel, and aluminum.

Caps and closures for rigid packaging products are examined separately in the caps and closures category and therefore are not included in this market category.

The alternative-to-plastic weight ratio estimated for each material is multiplied by the amount of resin replaced by that alternative. This approach results in the weights of alternative materials estimated to substitute for each plastic packaging category. The tables with current market share and substitution amounts are presented at the very end of the Other Rigid Packaging section, after the discussions of the rigid packaging subcategories.

2.3.2. Non-Bulk Rigid Packaging

Besides beverage containers (modeled as a separate category), non-bulk rigid packaging includes: bottles and jars; tubs, cups, and bowls, and other non-bulk rigid containers/packaging. Excluded from this category are: foodservice packaging, clamshells, baskets, decorative tins, canning jars, home storage containers, medical device packaging, pharmaceutical vials, blister packaging, injection molded cosmetic packaging such as lipstick and compact cases, compact disc cases, bulk water and oil bottles, and food storage items. The overall weights of materials used for bottles, jars, tubs, cups, bowls, and other rigid non-bulk packaging in the US are compiled by cross-checking data from two

Freedonia market reports.[55,56] These Freedonia data also provided the relative US dollar demand for individual types of product applications within the subcategories of non-bulk rigid packaging. The plastic report indicates total weight, number of units, and relative share of each resin used for *plastic* non-bulk containers; whereas, data for *non-plastic* non-bulk containers are from the World Rigid study and are only available in monetary terms. Average pounds of various rigid container materials per dollar are estimated using average price per unit and weight per unit data available from the caps and closures Freedonia reports. These averages are used to determine the overall weights of non-plastic materials used in non-bulk rigid container markets. Franklin Associates selected this approach because comparative *raw material* price indices would not have reflected the cost/value of *converting* raw materials to packaging products. For each plastic and alternative packaging commodity, price-per-unit data in the reports compiled by Freedonia (e.g., available for caps and closures) reflect the relative cost/value of both raw material and converting processes. This approach also minimizes potential inaccuracies that can be realized with the use of multiple data sources (i.e., due variation in how data sources may define material types or packaging categories).

Because this analysis presents results for rigid beverage containers in a separate beverage containers category, the weights of rigid beverage containers and their associated material shares (i.e., plastic resins, aluminum cans, glass, paperboard cartons, and steel) were extracted from the compiled market share and weight data for non-bulk rigid containers. Thus, bottles and jars are broken out into the non-beverage subcategories of food, household chemical, cosmetic and toiletry, pharmaceutical, institutional and industrial chemical, automotive chemical, and other bottle and jar applications. Other non-bulk container/packaging applications include pails, trays, cans, egg cartons, and squeeze tubes. The overall weights of materials used for non-bulk rigid packaging in Canada are also provided from the Freedonia World Rigid report. However, because further granularity on relative shares of non-bulk rigid packaging for individual subcategory applications were not available for Canada, a US-to-Canada population scaling factor and US relative shares were used to estimate and exclude Canadian demand for beverage packaging and as a proxy to break out types and materials per subcategory.

The Freedonia data report the relative weights of resins used for plastic containers as PET, HDPE, PP, PVC, LDPE, and other. Franklin Associates approximates ‘other’ resins with an equivalent weight of PS. Depending on the packaging application, the PS is modeled as solid PS (e.g., food bowls) or foamed PS (e.g., egg cartons). Also per the Freedonia data, tubs, cups, and bowls are broken out by relative PP, PS, HDPE, and PET weights.[57] Granularity on the current relative weights of individual resins and alternative materials used within each of the other non-bulk rigid packaging subcategories were obtained by

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[55] Freedonia (2010). Plastic Containers: US Industry Study w/ Forecasts for 2014 & 2019, Study #2672 Prepared by The Freedonia Group, August 2010.

[56] Freedonia (2012). World Rigid Packaging: US Industry Study w/ Forecasts for 2016 & 2021, Study #2909 Prepared by The Freedonia Group, July 2012.

[57] PLA and other resins are excluded as they are outside the defined scope of this study and contribute less than one percent to overall tubs, cups, and bowls weight demand in the investigated data year (2009).

cross-checking qualitative data from more detailed Freedonia table outlines with quantitative data from previous work performed by Franklin Associates.[58] This check was also performed for each resin to estimate the relative weight share and identity of materials that would substitute for each plastic resin in each product application. Per these estimates, non-bulk rigid containers and packaging are expected to be replaced by a mix of paperboard, glass, steel and aluminum. For food and pharmaceutical bottles and jars, tubs, cups, and bowls, paper substitute packaging is considered to be virgin; whereas, non-food applications are substituted with paper having recycled content. The exception to this generalization is for egg cartons and/or molded pulp trays as per previous modeling experience, Franklin Associates assumes these packaging products to be comprised of old-newspaper and other recovered paper-based materials. Recycled content and recovery rates for paper packaging are described in Chapter 3.

To determine substitution weight factors for each type of non-bulk rigid plastic packaging, the functional unit is volume of capacity of the package. Within each non-bulk rigid packaging subcategory (i.e. for each of the 15 types/lines in the tables presented below), a representative plastic packaging product was selected. The weights of the representative plastic packages were determined from: 1) case study examples in a recent packaging efficiency study,[59] 2) primary data from previous public and private LCAs performed by Franklin Associates, and/or 3) publicly available specifications from packaging providers. It is acknowledged that a distribution of sizes exists within each container application. Though data on relative distribution of sizes for each of the examined product applications were not available, a range of container/packaging sizes and average weight-per-capacity factors were compiled for each material in each product application. These container/packaging-weight-to-volume capacity ratios are used for each alternative material and each subcategory to determine the cumulative weights of each alternative material estimated to substitute for all currently demanded plastic in the non-bulk rigid containers/packaging products market.

For non-bulk rigid packaging, there are three primary applications: bottles and jars; tubs, cups, and bowls; and other packaging. For non-bulk rigid bottles and jars, applications included: food; household chemicals; cosmetics and toiletries; pharmaceuticals; industrial and institutional cleaning chemicals; automotive chemicals; and other. Representative plastic products evaluated included wide-mouth jars; oval, tapered oval, slant, slant-handled, cylinder, oblong, round, and pharmaceutical bottles; utility jugs; round tubs; open- and closed-head pails; trays, cans, and bins; expanded foam cartons and trays; and squeeze tubes. Non-bulk steel container substitutes include steel cans, bottles, tins, and pails; glass containers substitutes include leak-proof and temperature resistant jars, oval bottles, chemical bottles, and wide-mouth jars. Photosensitive-type glass jars were selected as appropriate substitutes for plastic containers used in some household chemical (e.g., kitchen and bath cleaners, bleach), cosmetic and toiletry (e.g., skin care), pharmaceutical liquid, and industrial and institutional chemical markets. Aluminum substitutes include

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[58] Franklin Associates (1990). Appendix C. Market Shares and Weight Ratios for Plastics & Alternative Materials in Packaging and Disposable Consumer Goods Prepared for SPI.

[59] ULS Report (2007). A Study of Packaging Efficiency as it Relates to Waste Prevention, Prepared by the Editors of The ULS Report, February 2007.

aluminum bottles, laminate foil, foil trays, and collapsible aluminum tubes. Paper substitutes include gable-top cartons, aseptic-type rectangular cartons, old corrugated cardboard (OCC) fiber molded shell containers, kraft sacks, and molded pulp trays. As an example of how substitution ratios were determined, the following section describes the approach for automotive chemical applications in non-bulk rigid bottle and jar applications.

Franklin Associates selected representative plastic bottles for two primary products in automotive chemical non-bulk rigid bottle and jar applications: motor lubricant and antifreeze/coolant, two primary automotive chemicals sold in plastic bottles. The representative volume of these containers was determined by considering a typical container type and size for each of the products in North America. For lubricant oil, a quart-sized (20 ounces or 0.59 liter) tapered oval plastic bottle weighing ~ 0.14 pounds or 64 grams was considered to obtain a typical weight-to-volume ratio for this application; for antifreeze/coolant, a gallon (128 ounces or 3.79 liter) sized slant-handled (i.e., F-style) chemical plastic bottle weighing ~0.33 pounds or 148 grams was considered. In order for steel to substitute for either of these plastic packaging applications, the relative weight-to-volume ratio of a light-weight steel bottle (average ~0.021 pounds per ounce or 330 grams per liter) was considered suitable. These relative weights were used to determine the plastic-to-steel packaging weight ratio for each of these applications. Given its share of current packaging demand for these applications, steel is considered to substitute for 59 percent of the plastic weight currently supplying packaging in these applications. No equivalent glass bottles and jars were compared as the fragility of glass was considered to be unsuitable for automotive chemical applications. Franklin Associates considers that the remaining 41 percent of the plastic weight for these applications would be substituted by fiber molded shell containers with laminate aluminum foil liners. The weight-to-volume ratios of molded fiber shells and of other suitable fiber-based cartons[60] were used to determine the plastic-to-paper weight ratio for these applications. The weight-to-area ratio for aluminum foil for laminates[61] and estimates of the interior surface area dimensions of each of the representative lubricant and antifreeze/coolant containers were used to determine the aluminum-to-paper weight ratio that must accompany the paper packaging substitution. The relative share of sales volume (i.e., sales volume ratio of lubricant-to-antifreeze/coolant automotive chemicals), 96.3 to 3.7, was obtained based on publicly available market statistics for automotive chemicals. This ratio is used to calculate weight amounts of each alternative packaging material determined to substitute for plastic packaging in order to obtain the overall amount of each alternative packaging material modeled to substitute for plastic packaging in automotive chemical non-bulk rigid bottle and jar applications.

2.3.3. Rigid Protective Packaging

Rigid protective packaging includes protective packaging shapes providing cushioning, blocking and bracing, insulating, and void-filling for the manufacturing and non-manufacturing markets. Protective packaging shapes include packaging products such as insulated shipping containers, rigid loose-fill, and rigid foam products (e.g., molded, foam-

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[60] Per private LCA studies previously compiled by Franklin Associates, a Division of ERG.

[61] Per private LCA studies previously compiled by Franklin Associates, a Division of ERG.

in-place, rolled foam, and foamed loose-fill products). Insulated shipping packaging requiring electricity or another power source to maintain temperature control is excluded from this category. The overall weights of materials used for rigid protective packaging are as provided by Freedonia market data.[62] Freedonia data also provided the relative US dollar demand for individual types of product applications within the rigid protective packaging categories. As the average price per unit for each type of packaging product is not provided, it is assumed that the relative market demand for each type correlates linearly with the relative weight of each plastic package type (i.e., price per pound of the plastic package is similar among rigid protective packaging applications). Because some of the Freedonia data for protective packaging are presented as an aggregate for both rigid and flexible plastic products, the flexible packaging weights are disaggregated and included in the flexible protective packaging category. Also, because no overall or detailed data on protective rigid packaging in Canada were available, a US-to-Canada population scaling factor and US relative shares were used to estimate Canadian demand per subcategory.

Protective packaging shapes are EPS and kraft paperboard or molded pulp as indicated by the reported Freedonia data. The material breakout for individual resins and non-plastic materials was cross-checked with qualitative and quantitative data from previous work performed by Franklin Associates.[63] The compiled data is used to estimate the relative weight share and identity of materials that would substitute for plastics in each product application. The current market share of rigid protective packaging is 55.6 percent plastic and 44.4 percent paper materials. Because paper-based packaging is the main competing material in this category, rigid protective plastic packaging is expected to be replaced 100 percent by kraft paper packaging (e.g., molded fiber forms substituting for EPS forms). Recycled content and recovery rates for paper-based packaging are described in Chapter 3.

To determine substitution weight factors for each type of rigid protective packaging, the functional unit was protective performance of packaging product. Within each rigid protective packaging subcategory, a representative plastic packaging product was selected. The weights of the representative plastic packaging were determined from primary data from previous LCAs performed by Franklin Associates and/or publicly available specifications from packaging providers. For protective packaging shapes, the weight ratio of foamed polystyrene to molded pulp required for egg cartons is used as a proxy for protective performance of plastic to paper.[64] This ratio is applied to the weight indicated for the equivalent volume of paper fill to reflect not only comparative weights of equivalent sizes of product but also protective performance of the plastic versus paper product. For other rigid protective packaging, a similar approach was used.

Given equivalency in protective performance, the paper-to-plastic rigid weight ratio determined for each subcategory is used to determine the overall weight of each type of paper required to substitute for plastics in this product market.

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[62] Freedonia (2012). Protective Packaging: US Industry Study with Forecasts for 2016 & 2021, Study #2839 Prepared by The Freedonia Group, January 2012.

[63] Franklin Associates (1990). Appendix C. Market Shares and Weight Ratios for Plastics & Alternative Materials in Packaging and Disposable Consumer Goods Prepared for SPI.

[64] Actual weight ratio per measurements.

As an example of how substitution ratios were determined, this section briefly describes the approach for modeling substitution of rigid EPS foam inserts in rigid protective packaging applications. Franklin Associates uses rigid EPS foam density, six pounds per cubic foot or ~96 kilograms per cubic meter, to compare the weight of one cubic foot of EPS foam insert for insulated shipping containers to the weight of one cubic foot of molded fiber forms. The weight of the cubic foot of molded fiber forms is scaled up to reflect the relative ratio of protective performance. As mentioned, the weight ratio of foamed polystyrene to molded pulp required for egg cartons is used as a proxy for protective performance of plastic to paper.[65] The relative weights of a cubic foot of EPS and molded foam (scaled to reflect relative protective performance) for insulated shipping containers are used to determine the overall paper-to-plastic packaging substitution ratio for this subcategory in protective rigid packaging.

2.3.4. Rigid Bulk Packaging

Rigid bulk packaging includes drums, pails, bulk boxes, material handling containers (MHCs) and bulk boxes, and rigid intermediate bulk containers (RIBCs) for chemical and pharmaceutical, food, plastic, rubber, fiber, petroleum and lubricant, agricultural and horticultural, durable, and hazardous waste storage and handling markets. Not included in this category are pallets and wood containers, corrugated and solid fiberboard boxes except bulk and corrugated RIBCs. The overall weights of materials used for rigid bulk packaging in are as reported by Freedonia market data.[66] Freedonia data also provided the relative US dollar demand for individual types of product applications within the rigid bulk packaging subcategories. As the average price per unit for each type of packaging product is not provided, it is assumed that the relative market demand for each type correlates linearly with the relative weight of each package type (i.e., price per pound of plastic package is similar among rigid bulk packaging applications). The overall weights of materials used for rigid bulk packaging in Canada and further granularity on relative shares of rigid bulk packaging per subcategory were not available for Canada. A US-to-Canada population scaling factor and US relative shares were used to estimate weights of materials used within each subcategory for Canadian demand.

Relative overall shares of plastic and each alternative material used in rigid bulk packaging are as reported by Freedonia. Resin breakout for rigid bulk packaging was not provided by the Freedonia data and was estimated by Franklin Associates to be split evenly between HDPE and PP resins, based on publicly available specifications on bulk plastic drums, pails, boxes, MHCs, and RIBCs. The material breakout for individual resins and non-plastic materials was cross-checked with qualitative and quantitative data from previous work performed by Franklin Associates.[67] The compiled data are used to estimate the relative weight share and identity of materials that would substitute for plastics in each subcategory application. Rigid bulk packaging is expected to be replaced by a mix of steel,

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[65] Actual weight ratio per measurements.

[66] Freedonia (2011). Rigid Bulk Packaging: US Industry Study with Forecasts for 2015 & 2020, Study #2737 Prepared by The Freedonia Group, February 2011.

[67] Franklin Associates (1990). Appendix C. Market Shares and Weight Ratios for Plastics & Alternative Materials in Packaging and Disposable Consumer Goods Prepared for SPI.

molded fiber, corrugated cardboard, and wood panels. All rigid bulk paper packaging substitutes are assumed to have the average recycled content for paper packaging based on recovery rates in the EPA MSW Characterization in 2010.[68]

To determine substitution weight factors within each type of rigid bulk packaging, the functional unit was volume capacity. Within each rigid bulk packaging subcategory, a representative plastic packaging product was selected. The weights of the representative plastic packaging were determined from primary data from previous LCAs performed by Franklin Associates and/or publicly available specifications from packaging providers. For drums, a plastic drum suitable for hazardous material was compared to steel and molded fiber drums (with liners) of equivalent volume. For pails, plastic pails were compared to steel pails. For material handling containers and bulk boxes, plastic corrugated shipping boxes and forkliftable bulk containers are compared to fiber corrugated shipping boxes and steel shipping containers, respectively, of equivalent volume. For reusable plastic containers substituted by other reusable containers, one plastic box is assumed to be substituted by one alternative reusable container. For reusable plastic boxes substituted by fiber corrugated boxes, a conservative lifetime trip rate of 10 is used for the reusable plastic boxes, so that one plastic box is assumed to be substituted over its life cycle by 10 equivalent size corrugated boxes. In efficiently operated closed-loop reuse systems, reusable bulk containers can make 50 or more lifetime trips.

Given equivalency in volume capacity, the alternative material-to-plastic rigid weight ratios determined for each subcategory are used to determine the overall weight of each type of alternative material required to substitute for plastics in this product market.

For bulk rigid packaging, there are four primary applications: drums; pails; material handling and bulk boxes; and rigid intermediate bulk containers. As an example of how substitution ratios were determined, the following section describes the approach for pail applications in bulk rigid applications.

Franklin Associates selected a seven gallon (26.5 liter) plastic pail weighing 2.94 pounds or 1.33 kilograms as a representative container for this application. The weight-to-volume ratio of this ‘typical’ plastic container was compared to that of a five gallon (18.9 liter) steel pail weighing 6.44 pounds or 2.92 kilograms. Steel is the only alternative packaging material considered to substitute plastic in this application. The relative weight-to-volume ratios for the representative plastic and steel pails are used to determine the overall substitution ratio (2.19) for steel versus plastic. This ratio is used to determine the overall weight of steel required to substitute for the weight of plastic resin currently used in pail-type applications in bulk rigid packaging.

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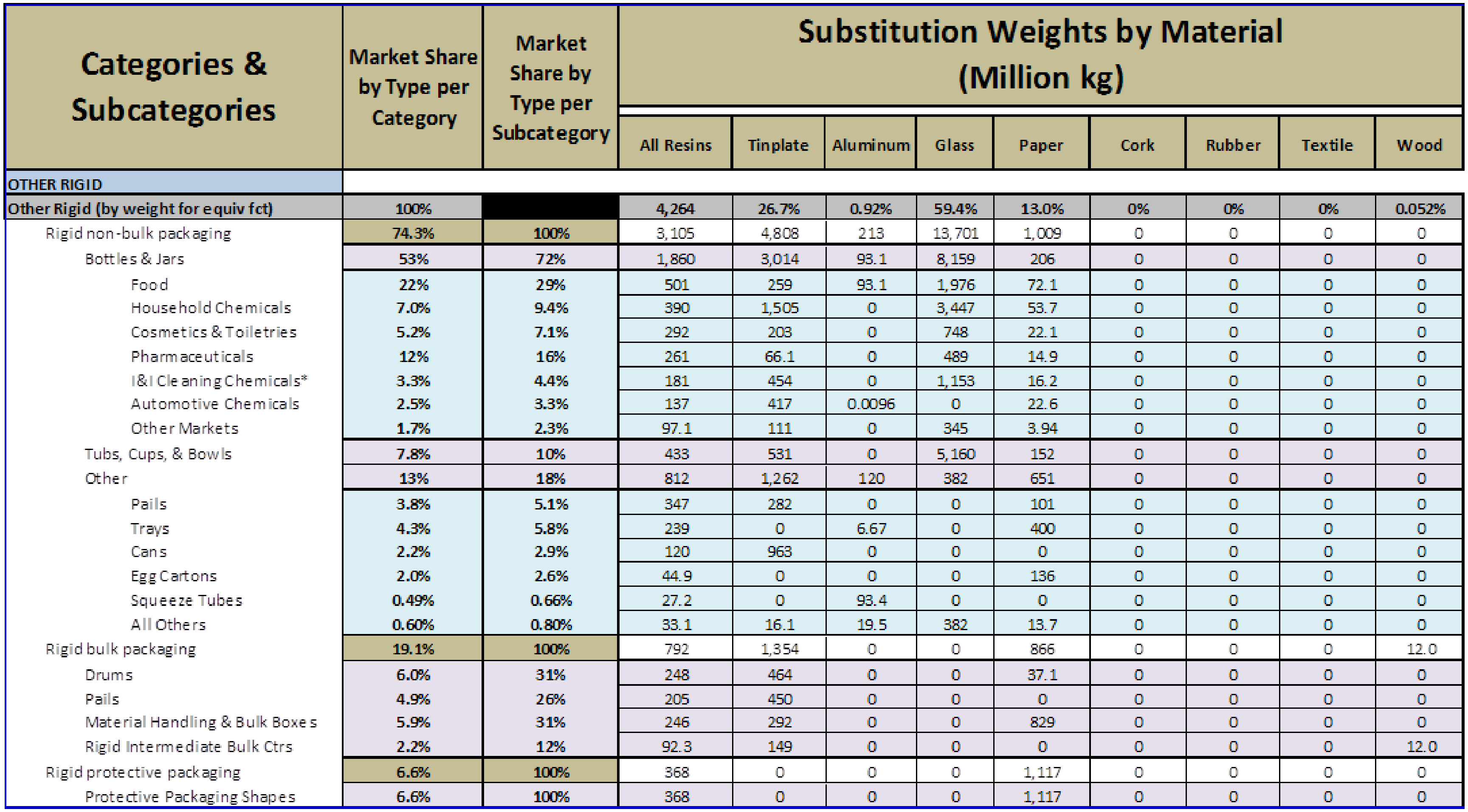
[68] US Environmental Protection Agency. 2011. Municipal Solid Waste Generation, Recycling, and Disposal in the United States Detailed Tables and Figures for 2010. Compiled by Franklin Associates, A Division of ERG.

Table 2-5. US Other Rigid Packaging - Current Market Share by Material

Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Current Market Share by Material (% Per Functional Unit)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
OTHER RIGID											
Other Rigid (by weight)	100%		42.7%	15.05%	1.70%	17.4%	22.9%	0%	0%	0%	0%
Rigid non-bulk packaging	74.3%	100%	41.9%	11.7%	2.29%	23.4%	20.6%	0%	0%	0%	0%
Bottles & Jars	53%	72%	35.0%	13.7%	2.53%	29.6%	19.1%	0%	0%	0%	0%
Food	22%	29%	23.0%	13.5%	5.84%	36.0%	21.7%	0%	0%	0%	0%
Household Chemicals	7.0%	9.4%	55.7%	10.9%	0.152%	19.7%	13.5%	0%	0%	0%	0%
Cosmetics & Toiletries	5.2%	7.1%	55.7%	10.8%	0.110%	19.7%	13.6%	0%	0%	0%	0%
Pharmaceuticals	12%	16%	22.5%	19.0%	0.370%	34.6%	23.6%	0%	0%	0%	0%
I&I Cleaning Chemicals*	3.3%	4.4%	55.7%	10.9%	0.152%	19.7%	13.5%	0%	0%	0%	0%
Automotive Chemicals	2.5%	3.3%	55.7%	26.1%	0.152%	0.0%	18.0%	0%	0%	0%	0%
Other Markets	1.7%	2.3%	55.7%	10.7%	0.127%	19.2%	14.3%	0%	0%	0%	0%
Tubs, Cups, & Bowls	7.8%	10%	55.7%	1.47%	0.544%	16.5%	25.8%	0%	0%	0%	0%
Other	13%	18%	61.3%	9.68%	2.37%	2.73%	23.7%	0%	0%	0%	0%
Pails	3.8%	5.1%	92.4%	3.75%	0%	0.00%	3.87%	0%	0%	0%	0%
Trays	4.3%	5.8%	55.7%	0%	5.89%	0%	38.4%	0%	0%	0%	0%
Cans	2.2%	2.9%	55.7%	44.3%	0%	0%	0%	0%	0%	0%	0%
Egg Cartons	2.0%	2.6%	23.0%	0%	0%	0%	77.0%	0%	0%	0%	0%
Squeeze Tubes	0.49%	0.66%	55.7%	0%	44.3%	0%	0%	0%	0%	0%	0%
All Others	0.60%	0.80%	55.7%	4.31%	4.98%	19.1%	15.8%	0%	0%	0%	0%
Rigid bulk packaging	19.1%	100%	41.5%	33.3%	0%	0%	24.4%	0%	0%	0%	0.762%
Drums	6.0%	31%	21.9%	61.6%	0%	0%	16.5%	0%	0%	0%	0%
Pails	4.9%	26%	79.9%	20.1%	0%	0%	0%	0%	0%	0%	0%
Material Handling & Bulk Boxes	5.9%	31%	16.6%	49.7%	0%	0%	33.7%	0%	0%	0%	0%
Rigid Intermediate Bulk Ctrs	2.2%	12%	39.1%	49.5%	0%	0%	0%	0%	0%	0%	11.4%
Rigid protective packaging	6.6%	100%	55.6%	0%	0%	0%	44.4%	0%	0%	0%	0%
Protective Packaging Shapes	6.6%	100%	55.6%	0%	0%	0%	44.4%	0%	0%	0%	0%

Table 2-6. US Other Rigid Packaging - Substitution Weights by Material



Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Substitution Weights by Material (Million kg)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
OTHER RIGID											
Other Rigid (by weight for equiv fct)	100%		4,264	26.7%	0.92%	59.4%	13.0%	0%	0%	0%	0.052%
Rigid non-bulk packaging	74.3%	100%	3,105	4,808	213	13,701	1,009	0	0	0	0
Bottles & Jars	53%	72%	1,860	3,014	93.1	8,159	206	0	0	0	0
Food	22%	29%	501	259	93.1	1,976	72.1	0	0	0	0
Household Chemicals	7.0%	9.4%	390	1,505	0	3,447	53.7	0	0	0	0
Cosmetics & Toiletries	5.2%	7.1%	292	203	0	748	22.1	0	0	0	0
Pharmaceuticals	12%	16%	261	66.1	0	489	14.9	0	0	0	0
I&I Cleaning Chemicals*	3.3%	4.4%	181	454	0	1,153	16.2	0	0	0	0
Automotive Chemicals	2.5%	3.3%	137	417	0.0096	0	22.6	0	0	0	0
Other Markets	1.7%	2.3%	97.1	111	0	345	3.94	0	0	0	0
Tubs, Cups, & Bowls	7.8%	10%	433	531	0	5,160	152	0	0	0	0
Other	13%	18%	812	1,262	120	382	651	0	0	0	0
Pails	3.8%	5.1%	347	282	0	0	101	0	0	0	0
Trays	4.3%	5.8%	239	0	6.67	0	400	0	0	0	0
Cans	2.2%	2.9%	120	963	0	0	0	0	0	0	0
Egg Cartons	2.0%	2.6%	44.9	0	0	0	136	0	0	0	0
Squeeze Tubes	0.49%	0.66%	27.2	0	93.4	0	0	0	0	0	0
All Others	0.60%	0.80%	33.1	16.1	19.5	382	13.7	0	0	0	0
Rigid bulk packaging	19.1%	100%	792	1,354	0	0	866	0	0	0	12.0
Drums	6.0%	31%	248	464	0	0	37.1	0	0	0	0
Pails	4.9%	26%	205	450	0	0	0	0	0	0	0
Material Handling & Bulk Boxes	5.9%	31%	246	292	0	0	829	0	0	0	0
Rigid Intermediate Bulk Ctrs	2.2%	12%	92.3	149	0	0	0	0	0	0	12.0
Rigid protective packaging	6.6%	100%	368	0	0	0	1,117	0	0	0	0
Protective Packaging Shapes	6.6%	100%	368	0	0	0	1,117	0	0	0	0

Table 2-7. Canadian Other Rigid Packaging - Current Market Share by Material

Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Current Market Share by Material (% Per Functional Unit)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
OTHER RIGID											
Other Rigid (by weight)	**100%**		**42.7%**	**15.1%**	**1.70%**	**17.4%**	**22.9%**	**0%**	**0%**	**0%**	**0%**
Rigid non-bulk packaging	**74.3%**	**100%**	41.9%	11.7%	2.29%	23.4%	20.6%	0%	0%	0%	0%
Bottles & Jars	**53%**	**72%**	35.0%	13.7%	2.53%	29.6%	19.1%	0%	0%	0%	0%
Food	**22%**	**29%**	23.0%	13.5%	5.84%	36.0%	21.7%	0%	0%	0%	0%
Household Chemicals	**7.0%**	**9.4%**	55.7%	10.9%	0.152%	19.7%	13.5%	0%	0%	0%	0%
Cosmetics & Toiletries	**5.2%**	**7.1%**	55.7%	10.8%	0.110%	19.7%	13.6%	0%	0%	0%	0%
Pharmaceuticals	**12%**	**16%**	22.5%	19.0%	0.370%	34.6%	23.6%	0%	0%	0%	0%
I&I Cleaning Chemicals*	**3.3%**	**4.4%**	55.7%	10.9%	0.152%	19.7%	13.5%	0%	0%	0%	0%
Automotive Chemicals	**2.5%**	**3.3%**	55.7%	26.1%	0.152%	0.0%	18.0%	0%	0%	0%	0%
Other Markets	**1.7%**	**2.3%**	55.7%	10.7%	0.127%	19.2%	14.3%	0%	0%	0%	0%
Tubs, Cups, & Bowls	**7.8%**	**10%**	55.7%	1.47%	0.544%	16.5%	25.8%	0%	0%	0%	0%
Other	**13%**	**18%**	61.3%	9.68%	2.37%	2.73%	23.7%	0%	0%	0%	0%
Pails	**3.8%**	**5.1%**	92.4%	3.75%	0%	0%	3.87%	0%	0%	0%	0%
Trays	**4.3%**	**5.8%**	55.7%	0%	5.89%	0%	38.4%	0%	0%	0%	0%
Cans	**2.2%**	**2.9%**	55.7%	44.3%	0%	0%	0%	0%	0%	0%	0%
Egg Cartons	**2.0%**	**2.6%**	23.0%	0%	0%	0%	77.0%	0%	0%	0%	0%
Squeeze Tubes	**0.49%**	**0.66%**	55.7%	0%	44.3%	0%	0%	0%	0%	0%	0%
All Others	**0.60%**	**0.80%**	55.7%	4.31%	4.98%	19.1%	15.8%	0%	0%	0%	0%
Rigid bulk packaging	**19.1%**	**100%**	41.5%	33.3%	0%	0%	24.4%	0%	0%	0%	0.762%
Drums	**6.0%**	**31%**	21.9%	61.6%	0%	0%	16.5%	0%	0%	0%	0%
Pails	**4.9%**	**26%**	79.9%	20.1%	0%	0%	0%	0%	0%	0%	0%
Material Handling & Bulk Boxes	**5.9%**	**31%**	16.6%	49.7%	0%	0%	33.7%	0%	0%	0%	0%
Rigid Intermediate Bulk Ctrs	**3.0%**	**16%**	39.1%	49.5%	0%	0%	0%	0%	0%	0%	11.4%
Rigid protective packaging	**6.6%**	**100%**	55.6%	0%	0%	0%	44.4%	0%	0%	0%	0%
Protective Packaging Shapes	**6.6%**	**100%**	55.6%	0%	0%	0%	44.4%	0%	0%	0%	0%

Table 2-8. Canadian Other Rigid Packaging - Substitution Weights by Material

Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Substitution Weights by Material (Million kg)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
OTHER RIGID											
Other Rigid (by weight for equiv fct)	100%		470	24.4%	1.08%	69.4%	5.11%	0%	0%	0%	0%
Rigid non-bulk packaging	74%	100%	343	530	23.5	1,512	111	0	0	0	0
Bottles & Jars	53%	72%	205	333	10.3	900	22.7	0	0	0	0
Food	22%	29%	55.3	28.6	10.3	218	7.96	0	0	0	0
Household Chemicals	7.0%	9.4%	43.0	166	0	380	5.92	0	0	0	0
Cosmetics & Toiletries	5.2%	7.1%	32.2	22.4	0	82.5	2.44	0	0	0	0
Pharmaceuticals	12%	16%	28.8	7.29	0	54.0	1.64	0	0	0	0
I&I Cleaning Chemicals*	3.3%	4.4%	20.0	50.0	0	127	1.79	0	0	0	0
Automotive Chemicals	2.5%	3.3%	15.2	46.0	0.0011	0	2.50	0	0	0	0
Other Markets	1.7%	2.3%	10.7	12.2	0	38.1	0.44	0	0	0	0
Tubs, Cups, & Bowls	7.8%	10%	47.8	58.6	0	569	16.8	0	0	0	0
Other	13%	18%	89.6	139	13.2	42.1	71.8	0	0	0	0
Pails	3.8%	5.1%	38.3	31.1	0	0	11.2	0	0	0	0
Trays	4.3%	5.8%	26.4	0	0.74	0	44.1	0	0	0	0
Cans	2.2%	2.9%	13.3	0	0	0	0	0	0	0	0
Egg Cartons	2.0%	2.6%	4.95	0	0	0	15.0	0	0	0	0
Squeeze Tubes	0.49%	0.66%	3.00	0	10.3	0	0	0	0	0	0
All Others	0.60%	0.80%	3.65	1.77	2.15	42.1	1.51	0	0	0	0
Rigid bulk packaging	19%	100%	87.3	149	0	0	95.5	0	0	1.33	0
Drums	6.0%	31%	27.3	51.2	0	0	4.09	0	0	0	0
Pails	4.9%	26%	22.6	49.6	0	0	0	0	0	0	0
Material Handling & Bulk Boxes	5.9%	31%	27.2	32.2	0	0	91.4	0	0	0	0
Rigid Intermediate Bulk Ctrs	3.0%	16%	10.2	16.4	0	0	0	0	0	1.33	0
Rigid protective packaging	6.6%	100%	40.6	0	0	0	123	0	0	0	0
Protective Packaging Shapes	6.6%	100%	40.6	0	0	0	123	0	0	0	0

2.4. OTHER FLEXIBLE PACKAGING MARKETS

2.4.1. Introduction

Aside from retail bags and shrink/stretch films, which are modeled as separate categories, other flexible packaging markets include converted flexible packaging, protective flexible packaging, and bulk flexible packaging. The main alternatives for these types of plastic flexible packaging are types of cellulose-based products (i.e., kraft paper, waxed paper, cellophane), aluminum foil, and steel.

Though it is assumed that adhesive materials and heat sealing would be required for alternative materials as it is for plastic converted films, adhesives and/or ancillary materials are excluded from the analysis. This analysis focuses on the main packaging materials and does not attempt to evaluate differences in amounts of ancillary materials required for packaging of varying materials.

The alternative-to-plastic weight ratio for each alternative packaging type that replaces plastic packaging is multiplied by the amount of resin replaced by that alternative. This approach results in the weights of alternative materials estimated to substitute for each plastic packaging category. The tables with current market share and substitution amounts are presented at the very end of the Other Flexible Packaging section, after the discussions of the flexible packaging subcategories.

2.4.2. Converted Flexible Packaging

Converted flexible packaging includes bags, pouches, and other layered plies and films for food and non-food applications. Unconverted stretch and shrink or retail grocery bags and bulk packaging are excluded from the converted flexible packaging category, as these types of packaging are included in other categories. The overall weights of materials used for food and non-food converted flexible packaging in the US are determined from Freedonia market data.[69] These Freedonia data also provided the relative US dollar demand for individual types of product applications within the food and non-food categories. The total weight of materials are reported for converted flexible packaging materials, but data for relative shares of types used in food and non-food applications are only reported in the monetary demand terms. As the average price per unit for each type of plastic packaging product is not provided, it is assumed that the relative market demand for each type correlates linearly with the relative weight of each package type (i.e., price per pound of package is similar among converted flexible packaging types). Because the weight of all pouches and preform packaging used for beverages are included in the beverage containers category, these weights and their associated material shares (i.e., plastic film resins and aluminum foil) were extracted from the market share and weight data provided by Freedonia. Thus, food markets include non-beverage categories: meat and related products, baked goods, snack food, grain mill products, produce, candy and confections, frozen foods, dairy products, and other food products. Non-food applications include:

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[69] Freedonia (2011). Converted Rigid Packaging: US Industry Study w/ Forecasts for 2015 & 2020, Study #2807 Prepared by The Freedonia Group, October 2011.

pharmaceuticals, medical products, paper and textile products, agricultural and horticultural products, chemicals, rack and counter packaging, and other nonfood products. The overall weights of materials used for converted flexible packaging in Canada are also provided from Freedonia market data.[70] However, because further granularity on relative shares of converted flexible packaging for individual food and non-food subcategories of packaging were not available for Canada, a US-to-Canada population scaling factor and US relative shares were used to estimate and exclude Canadian demand for beverage packaging and as a proxy to break out types and materials per subcategory.

The Freedonia data only indicate ‘polyethylene’ mass totals for plastic film resins used in converted flexible packaging. Franklin Associates uses data from the ACC 2012 Resin Review[71] to determine the relative share of HDPE, LDPE, and LLDPE resins used in packaging films as a proxy for polyethylene resin shares in converted flexible packaging. The Freedonia reports indicate weights of PVC, PVDC, and EVOH for converted flex packaging products; however, Franklin Associates considers the life cycle requirements for production of PVC as proxy for the total weight of PVC, PVDC, and EVOH resins. The Freedonia data also indicate ‘other’ resin weights for converted flexible packaging; for these materials, Franklin Associates considers the production of PET to be an appropriate proxy for life cycle requirements. These proxy assumptions are not expected to significantly affect the results, as the weights of ‘other’ resins together account for less than five percent of total resin use for converted flexible packaging.

Granularity on the current relative weights of individual resins and alternative materials used within each of the food and non-food product applications were obtained by cross-checking qualitative data from more detailed Freedonia table shells with quantitative data from previous work performed by Franklin Associates.[72] This check was also performed for each resin to estimate the relative weight share and identity of materials that would substitute for each plastic resin in each product application. Per these estimates, plastic converted flexible packaging is expected to be replaced by a mix of aluminum, paper, and cellophane. For food applications, paper substitute packaging is considered to be virgin; whereas, kraft or waxed paper alternatives with recycled content were considered to replace non-food applications. The average recycled content for paper packaging based on recovery rates in the EPA MSW Characterization in 2010 is assumed for all non-food paper packaging substitutes.[73]

To determine substitution weight factors for each type of converted flexible plastic packaging, the functional unit is volume (capacity) of the package. Within each converted flexible packaging subcategory, a representative plastic packaging product was selected.

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[70] Freedonia (2009). World Converted Rigid Packaging: Industry Study w/ Forecasts for 2013 & 2018, Study #2556 Prepared by The Freedonia Group, September 2009.

[71] ACC (2012). The Resin Review: The Annual Statistical Report of the North American Plastics Industry, American Chemistry Council, 2012 Edition.

[72] Franklin Associates (1990). Appendix C. Market Shares and Weight Ratios for Plastics & Alternative Materials in Packaging and Disposable Consumer Goods Prepared for SPI.

[73] US Environmental Protection Agency. 2011. Municipal Solid Waste Generation, Recycling, and Disposal in the United States Detailed Tables and Figures for 2010. Compiled by Franklin Associates, A Division of ERG.

The weights of the representative plastic packages were determined from: 1) case study examples in a recent packaging efficiency study,[74] 2) primary data from previous LCAs performed by Franklin Associates, and/or 3) publicly available specifications from packaging providers. The surface area of plastic film required for each representative package was estimated from the representative package's dimensions and used as the basis to determine weight of alternative materials required. It is acknowledged that there are multi-layer converted flexible package products containing more than one type of material. However, for simplicity, this analysis assumes that an equivalent surface area of the alternative cellulose-based materials provide an equivalent volume capacity as that of the converted plastic film. In other words, one layer of wax paper (e.g., butcher paper), kraft paper (e.g., unbleached uncoated sack with high wet strength), or cellophane is assumed to provide equivalent strength and/or protective properties for the volume of product contained as the equivalent surface area of one layer of purely plastic converted flexible film. The thickness (a.k.a., basis weight for paper materials) of the alternative material layer is determined based on specifications indicated for each representative product in the source data. The weight of the given surface area of each cellulose-based material layer was then determined also from its basis weight. For the percent of currently demanded plastic converted film expected to be replaced by a laminate containing aluminum, a laminate aluminum foil gauge and equivalent surface area of aluminum foil are used to determine the weight of aluminum contributing to substitution of plastic products. These weights are used to determine the overall alternative-to-plastic material weight ratio for each product application. Within each product application, the relative current market share of alternative materials used in converted flexible packaging was considered to be the representative of the materials that would substitute for these plastic packaging products. In other words, the relative percent of paper and aluminum materials currently demanded in converted flexible packaging markets, including use in composite material laminates (e.g., of aluminum foil and paper), is applied to the individual subcategory weight substitution ratios. For each alternative material, these weights are then summed to determine the overall weight of alternative material that will substitute for the overall weight of plastic currently demanded in the converted flexible packaging products market. Representative plastic products included: cold cut, cookies, crackers, cereal, spinach, candy, frozen fruit, and cheese pouches; individual pill and medical supply packages; film wrap for copy paper; potting soil bags; clothing film bags, and converted film bag rolls. As an example of how substitution ratios were determined, the following section describes the approach for snack food applications in converted flexible applications.

Franklin Associates selected a nine ounce crackers package having approximately 3.25 square feet or 0.30 square meters area of converted plastic film. An average weight-to-area ratio for converted plastic flexible films in food and non-food applications was obtained by using densities for resin films weighted by the market share of each resin in converted flexible films per publicly available and the Freedonia data, respectively. This average ratio, 0.00487 pounds per square foot or 0.0238 kilograms per square meter, is applied to the plastic film area for the representative snack food package to obtain the weight of the plastic snack food package, 0.0158 pounds or 0.00719 kilograms. One layer of waxed paper

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[74] ULS Report (2007). A Study of Packaging Efficiency as it Relates to Waste Prevention, Prepared by the Editors of The ULS Report, February 2007.

(e.g., butcher paper) is considered to substitute 15.3 percent of the plastic snack food films with a weight-to-area ratio of 0.0400 pounds per square foot or 0.200 kilograms per square meter. One layer of fiber-based cellophane (e.g., of a one mil film thickness) is considered to substitute 36.7 percent of the plastic snack food films with a weight-to-area ratio of 0.0076 pounds per square foot or 0.0369 kilograms per square meter. One layer of thin aluminum foil (e.g., used in laminates) is considered to substitute 12.2 percent of the plastic snack food films with a weight-to-area ratio of 0.0039 pounds per square foot or 0.0190 kilograms per square meter. One layer of natural kraft paper (e.g., used in standard paper sacks) is considered to substitute 35.8 percent of the plastic snack food films with a weight-to-area ratio of 0.0023 pounds per square foot or 0.0113 kilograms per square meter. These values determine the substitution weight factors for plastics and alternative packaging materials for snack food applications in the converted flexible film category.

2.4.3. Flexible Protective Packaging

Flexible protective packaging includes cushioning, void-filling, and lining packaging products such as protective mailers, protective packaging void-fill, and dunnage bags for the manufacturing and non-manufacturing markets. The overall weights of materials used for flexible protective packaging are as provided by Freedonia market data.[75] Freedonia data also provided the relative US dollar demand for individual types of product applications within the flexible protective packaging categories. As the average price per unit for each type of packaging product is not provided, it is assumed that the relative market demand for each type correlates linearly with the relative weight of each plastic package type (i.e., price per pound of package is similar among flexible protective packaging types). Because some of the data for protective packaging is presented as an aggregate of flexible, rigid, and foamed plastics, the rigid and foam weights are disaggregated, removed from the flexible packaging category and included in the rigid protective packaging category. Also, because no overall or detailed data on flexible protective packaging in Canada were available, a US-to-Canada population scaling factor and US relative shares were used to estimate Canadian demand per subcategory.

Protective mailers include LDPE plastic with coextruded HDPE air retention barrier and/or bubble packaging or paperboard with plastic adhesive strips; Franklin Associates assumes a 40% paper, 50% LDPE, and 10% HDPE material mix for this product subcategory based on publicly available product specifications and cross-checking with overall category weights provided by the Freedonia data. Protective packaging fill includes bubble packaging, air pillows, and paper fill used in void-filling applications. Per the ACC 2012 Resin Review, bubble packaging and air pillows are assumed to be 100% LDPE and HDPE, respectively.[76] Paper fill is assumed to be crumpled kraft paper with average recycled content and the density assumed for these products per a previous study performed

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[75] Freedonia (2012). Protective Packaging: US Industry Study with Forecasts for 2016 & 2021, Study #2839 Prepared by The Freedonia Group, January 2012.

[76] ACC (2012). The Resin Review: The Annual Statistical Report of the North American Plastics Industry, American Chemistry Council, 2012 Edition.

by Franklin Associates.[77] The category including dunnage bags and other flexible protective packaging includes woven, laminated paper, paper lined with plastic, and vinyl dunnage bags and other packaging used for shipping and securing cargo. This subcategory is estimated to be 50% kraft paper, 24% PP, 24% PVC, and 2.0% HDPE or LDPE based on publicly available product specifications.

The material breakout for individual resins and non-plastic materials was cross-checked with qualitative and quantitative data from previous work performed by Franklin Associates.[78] The compiled data is used to estimate the relative weight share and identity of materials that would substitute for plastics in each product application. Because current market share is 55.6 percent plastic and 44.4 percent paper, all flexible protective plastic packaging is expected to be replaced by kraft paper packaging: kraft mailers with shredded newspaper padding for protective mailers, crumpled kraft paper for protective packaging fill, and unpadded kraft shipping bags for dunnage bags and other converted flexible packaging. Because the flexible protective paper packaging does not have direct contact with food items, all paper packaging substitutes are assumed to have the average recycled content for paper packaging based on recovery rates in the EPA MSW Characterization in 2010.[79]

To determine substitution weight factors for each type of flexible protective packaging, the functional unit was protective performance of packaging product. Within each flexible protective packaging subcategory, a representative plastic packaging product was selected. The weights of the representative plastic packaging were determined from primary data from previous LCAs performed by Franklin Associates and/or publicly available specifications from packaging providers. For protective mailers, a representative size of bubble-lined paper mailer was compared to an equivalent size of paper mailer padded with shredded paper. In addition to the comparative weights obtained from previous studies and industry reports, the protective performance of bubble-lined mailers relative to shredded-paper-stuffed mailers was considered. The weight ratio of polystyrene to molded pulp required for egg cartons is used as a proxy for flexible protective performance of plastic to paper mailers.[80] This ratio is applied to the weight indicated for the equivalent sized paper mailer to reflect not only comparative weights of equivalent sizes of product but also protective performance of the plastic versus paper product. For flexible protective packaging fill, a similar approach was used for various types of plastic protective packaging. For dunnage bags and other flexible protective packaging, an unpadded film shipping bag is assumed to be substituted with an unpadded kraft shipping bag.

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[77] Franklin Associates (2004). Final Peer-Reviewed Appendix to Life Cycle Inventory of Packaging Options for Shipment of Retail Mail-Order Soft Goods, Prepared for Oregon Department of Environmental Quality (DEQ) and US EPA Environmentally Preferable Purchasing Program by Franklin Associates, A Division of ERG, Prairie Village, KS, April 2004. Available at: http://www.deq.state.or.us/lq/sw/packaging/lifecyclereport.htm.

[78] Franklin Associates (1990). Appendix C. Market Shares and Weight Ratios for Plastics & Alternative Materials in Packaging and Disposable Consumer Goods Prepared for SPI.

[79] US Environmental Protection Agency. 2011. Municipal Solid Waste Generation, Recycling, and Disposal in the United States Detailed Tables and Figures for 2010. Compiled by Franklin Associates, A Division of ERG.

[80] Actual weight ratio per measurements.

Given equivalency in protective performance, the paper-to-plastic flexible weight ratio determined for each subcategory is used to determine the overall weight of each type of paper required to substitute for plastics in this product market. As an example of how substitution ratios were determined, the following section describes the approach for developing substitution weight factors in protective mailer applications in the protective flexible packaging subcategory.

Franklin Associates selected a 10.5 by 16 inch mailer with an outer envelope comprised of 55 pound kraft paper with a 3/16 inch bubble lining as the representative product for protective mailers. This mailer has approximately 2.33 square feet or 0.217 square meters of protective flexible bubble lining. The weight of this mailer, 0.095 pounds or 0.043 kilograms per unit, was compared that of the same size and type of mailer containing 45 pound shredded paper padding instead of the plastic bubble lining, 0.300 pounds or 0.136 kilograms per unit. The difference between the weights of the mailers is attributed to the difference in the weight of the bubble lining and shredded paper padding; Franklin Associates makes the conservative assumption that this difference in weight also occurs because the mailers must offer similar levels of protective performance. This difference is used as a proxy for the plastic-to-paper substitution weight ratio and applied to the overall amount of plastic resin to be replaced by paper in protective mailer applications of the protective flexible packaging subcategory. Plastic used in protective flexible mailers is modeled to be replaced with 100 percent paper-based materials.

2.4.4. Flexible Bulk Packaging

Flexible bulk packaging includes shipping sacks, strapping, flexible intermediate bulk containers (FIBCs), and bulk liners and rolls for the food/beverage, chemical, agricultural, and horticultural markets. Non-packaging applications such as money bags and sand bags are not included. The overall weights of materials used for flexible bulk packaging are as reported by Freedonia market data.[81] Because all film wrap used for bulk applications is included in the separate stretch and shrink wrap category, these weights (i.e., storage and distribution type stretch and shrink film) and their associated resin material shares (i.e., LDPE, HDPE, and PVC) were disaggregated and excluded from the reported market share and weight data for flexible bulk packaging. Freedonia data also provided the relative US dollar demand for individual types of product applications within the flexible protective packaging subcategories. As the average price per unit for each type of packaging product is not provided, it is assumed that the relative market demand for each type correlates linearly with the relative weight of each plastic package type (i.e., price per pound of package is similar among flexible bulk packaging types). The overall weights of materials used for flexible bulk packaging in Canada and further granularity on relative shares of flexible bulk packaging per subcategory were not available for Canada. A US-to-Canada population scaling factor and US relative shares were used to estimate weights of materials used within each subcategory for Canadian demand.

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[81] Freedonia (2007). Flexible Bulk Packaging: US Industry Study with Forecasts for 2011 & 2016, Study #2238 Prepared by The Freedonia Group, September 2007.

Relative overall shares of plastic and each alternative material used in flexible bulk packaging are as reported by Freedonia. Per these data: shipping sacks are PP, paper, or textile materials; strapping,[82] PP, or steel; drum, box, and bin liners are HDPE and LDPE; and FIBCs are PP, PVC, and textile materials. The material breakout for individual resins and non-plastic materials was cross-checked with qualitative and quantitative data from previous work performed by Franklin Associates.[83] The compiled data are used to estimate the relative weight share and identity of materials that would substitute for plastics in each subcategory application. Flexible bulk packaging is expected to be replaced by kraft paper packaging, steel, and textile materials. All flexible bulk paper packaging substitutes are assumed to have the average recycled content for paper packaging based on recovery rates in the EPA MSW Characterization in 2010.[84]

To determine substitution weight factors within each type of flexible bulk packaging, the functional unit was volume capacity. The exception to this approach is for flexible strapping—in which case, the functional unit of comparison was unitizing performance. Within each flexible bulk packaging subcategory, a representative plastic packaging product was selected. The weights of the representative plastic packaging were determined from primary data from previous LCAs performed by Franklin Associates and/or publicly available specifications from packaging providers. For shipping sacks and bulk liners and rolls, a representative plastic film bag was compared to a kraft paper shipping bag of equivalent volume. For strapping, a representative plastic strapping length was compared an equivalent length of steel strapping with a similar break or tensile strength.

Given equivalency in volume capacity, or unitizing performance in the case of strapping, the alternative material-to-plastic flexible weight ratios determined for each subcategory are used to determine the overall weight of each type of alternative material required to substitute for plastics in this product market. As an example of how substitution ratios were determined, the following section describes the approach for developing substitution weight factors in strapping applications in the flexible bulk packaging subcategory.

Franklin Associates selected a flexible plastic strapping with a 5/8 inch width, 0.030 inch thickness, and break strength of 1100 pounds as the representative product for plastic strapping applications. Each roll weighs 21 pounds (~9.1 kilograms) and contains 1800 feet of strapping. Therefore, the representative plastic strapping product has 93.8 square feet or 8.71 square meters of area (i.e., a weight-to-area ratio of 0.224 pounds per square foot or 1.09 kilograms per square meter). Plastic used in strapping applications of bulk flexible packaging is modeled to be replaced with 100 percent steel strapping. Steel strapping of slightly higher break strength, 1150 pounds, is used to account for the higher flexibility performance of plastic strapping. The steel strapping used to obtain a plastic-to-

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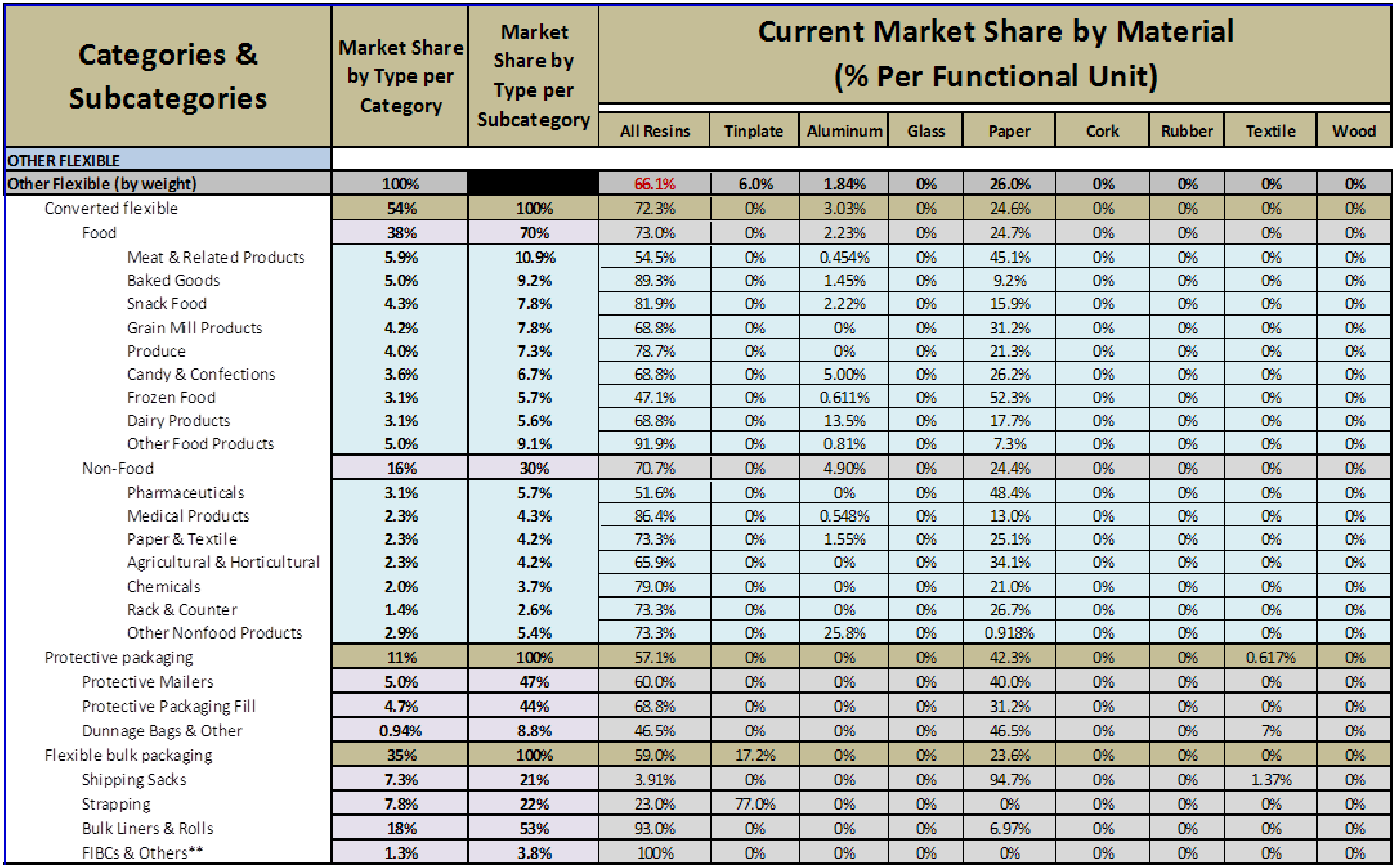
[82] Franklin Associates considers the production of PET to be an appropriate proxy for life cycle requirements of all non-polypropylene (PP) strapping resins (less than five percent).

[83] Franklin Associates (1990). Appendix C. Market Shares and Weight Ratios for Plastics & Alternative Materials in Packaging and Disposable Consumer Goods Prepared for SPI.

[84] US Environmental Protection Agency. 2011. Municipal Solid Waste Generation, Recycling, and Disposal in the United States Detailed Tables and Figures for 2010. Compiled by Franklin Associates, A Division of ERG.

steel substitution weight ratio is standard grade stainless steel strapping of ½ inch width, 0.51 mil thickness, on rolls 2940 feet long. The example volume of steel and the steel gauge are used to determine the weight-to-area ratio of steel strapping: 0.820 pounds per square foot or 3.99 kilograms per square meter. Equivalent areas (and break strength) of plastic and steel strapping are compared to obtain the plastic-to-steel substitution weight ratio, 3.65 for this product application in bulk flexible packaging.

Table 2-9. US Other Flexible Plastic Packaging - Current Market Share by Material



Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Current Market Share by Material (% Per Functional Unit)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
OTHER FLEXIBLE											
Other Flexible (by weight)	100%		66.1%	6.0%	1.84%	0%	26.0%	0%	0%	0%	0%
Converted flexible	54%	100%	72.3%	0%	3.03%	0%	24.6%	0%	0%	0%	0%
Food	38%	70%	73.0%	0%	2.23%	0%	24.7%	0%	0%	0%	0%
Meat & Related Products	5.9%	10.9%	54.5%	0%	0.454%	0%	45.1%	0%	0%	0%	0%
Baked Goods	5.0%	9.2%	89.3%	0%	1.45%	0%	9.2%	0%	0%	0%	0%
Snack Food	4.3%	7.8%	81.9%	0%	2.22%	0%	15.9%	0%	0%	0%	0%
Grain Mill Products	4.2%	7.8%	68.8%	0%	0%	0%	31.2%	0%	0%	0%	0%
Produce	4.0%	7.3%	78.7%	0%	0%	0%	21.3%	0%	0%	0%	0%
Candy & Confections	3.6%	6.7%	68.8%	0%	5.00%	0%	26.2%	0%	0%	0%	0%
Frozen Food	3.1%	5.7%	47.1%	0%	0.611%	0%	52.3%	0%	0%	0%	0%
Dairy Products	3.1%	5.6%	68.8%	0%	13.5%	0%	17.7%	0%	0%	0%	0%
Other Food Products	5.0%	9.1%	91.9%	0%	0.81%	0%	7.3%	0%	0%	0%	0%
Non-Food	16%	30%	70.7%	0%	4.90%	0%	24.4%	0%	0%	0%	0%
Pharmaceuticals	3.1%	5.7%	51.6%	0%	0%	0%	48.4%	0%	0%	0%	0%
Medical Products	2.3%	4.3%	86.4%	0%	0.548%	0%	13.0%	0%	0%	0%	0%
Paper & Textile	2.3%	4.2%	73.3%	0%	1.55%	0%	25.1%	0%	0%	0%	0%
Agricultural & Horticultural	2.3%	4.2%	65.9%	0%	0%	0%	34.1%	0%	0%	0%	0%
Chemicals	2.0%	3.7%	79.0%	0%	0%	0%	21.0%	0%	0%	0%	0%
Rack & Counter	1.4%	2.6%	73.3%	0%	0%	0%	26.7%	0%	0%	0%	0%
Other Nonfood Products	2.9%	5.4%	73.3%	0%	25.8%	0%	0.918%	0%	0%	0%	0%
Protective packaging	11%	100%	57.1%	0%	0%	0%	42.3%	0%	0%	0.617%	0%
Protective Mailers	5.0%	47%	60.0%	0%	0%	0%	40.0%	0%	0%	0%	0%
Protective Packaging Fill	4.7%	44%	68.8%	0%	0%	0%	31.2%	0%	0%	0%	0%
Dunnage Bags & Other	0.94%	8.8%	46.5%	0%	0%	0%	46.5%	0%	0%	7%	0%
Flexible bulk packaging	35%	100%	59.0%	17.2%	0%	0%	23.6%	0%	0%	0%	0%
Shipping Sacks	7.3%	21%	3.91%	0%	0%	0%	94.7%	0%	0%	1.37%	0%
Strapping	7.8%	22%	23.0%	77.0%	0%	0%	0%	0%	0%	0%	0%
Bulk Liners & Rolls	18%	53%	93.0%	0%	0%	0%	6.97%	0%	0%	0%	0%
FIBCs & Others**	1.3%	3.8%	100%	0%	0%	0%	0%	0%	0%	0%	0%

Table 2-10. US Other Flexible Packaging - Substitution Weights by Material

Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Substitution Weights by Material (Million kg)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
OTHER FLEXIBLE											
Other Flexible (by wt for equiv fct)	100%		4,226	2.46%	9.02%	0%	88.5%	0%	0%	0%	0%
Converted flexible	54%	100%	2,498	0	1519	0	10,655	0	0	0	0
Food	38%	70%	1,767	0	834	0	8,248	0	0	0	0
Meat & Related Products	5.9%	10.9%	204	0	13.27	0	1335	0	0	0	0
Baked Goods	5.0%	9.2%	283	0	153.1	0	1276	0	0	0	0
Snack Food	4.3%	7.8%	222	0	118	0	716	0	0	0	0
Grain Mill Products	4.2%	7.8%	185	0	0	0	904	0	0	0	0
Produce	4.0%	7.3%	198	0	0	0	679	0	0	0	0
Candy & Confections	3.6%	6.7%	159	0	131.8	0	915	0	0	0	0
Frozen Food	3.1%	5.7%	91.9	0	8.00	0	706	0	0	0	0
Dairy Products	3.1%	5.6%	134	0	298.8	0	442	0	0	0	0
Other Food Products	5.0%	9.1%	289	0	111.7	0	1274	0	0	0	0
Non-Food	16%	30%	731	0	684	0	2407	0	0	0	0
Pharmaceuticals	3.1%	5.7%	102	0	0	0	348.3	0	0	0	0
Medical Products	2.3%	4.3%	127	0	21.03	0	429	0	0	0	0
Paper & Textile	2.3%	4.2%	107	0	30.01	0	387	0	0	0	0
Agricultural & Horticultural	2.3%	4.2%	95.1	0	0	0	504	0	0	0	0
Chemicals	2.0%	3.7%	101	0	0	0	444	0	0	0	0
Rack & Counter	1.4%	2.6%	64.7	0	0	0	283.5	0	0	0	0
Other Nonfood Products	2.9%	5.4%	136	0	633	0	11.23	0	0	0	0
Protective packaging	11%	100%	423	0	0	0	1,572	0	0	0	0
Protective Mailers	5.0%	47%	189	0	0	0	595	0	0	0	0
Protective Packaging Fill	4.7%	44%	206	0	0	0	915	0	0	0	0
Dunnage Bags & Other	0.94%	8.8%	27.6	0	0	0	61.9	0	0	0	0
Flexible bulk packaging	35%	100%	1,305	413	0	0	2,667	0	0	3.13	0
Shipping Sacks	7.3%	21%	18.1	0	0	0	40.0	0	0	3.13	0
Strapping	7.8%	22%	113	413	0	0	0	0	0	0	0
Bulk Liners & Rolls	18%	53%	1,090	0	0	0	2,440	0	0	0	0
FIBCs & Others**	1.3%	3.8%	83.5	0	0	0	187	0	0	0	0

Table 2-11. Canadian Other Flexible Plastic Packaging - Current Market Share by Material

Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Current Market Share by Material (% Per Functional Unit)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
OTHER FLEXIBLE											
Other Flexible (by weight)	100%		69.3%	5.5%	1.92%	0%	23.2%	0%	0%	0%	0%
Converted flexible	54%	100%	76.9%	0%	3.27%	0%	19.9%	0%	0%	0%	0%
Food	38%	70%	77.6%	0%	1.85%	0%	20.5%	0%	0%	0%	0%
Meat & Related Products	5.9%	10.9%	57.9%	0%	0.420%	0%	41.7%	0%	0%	0%	0%
Baked Goods	5.0%	9.2%	94.9%	0%	0.69%	0%	4.4%	0%	0%	0%	0%
Snack Food	4.3%	7.8%	87.1%	0%	1.58%	0%	11.3%	0%	0%	0%	0%
Grain Mill Products	4.2%	7.8%	73.1%	0%	0%	0%	26.9%	0%	0%	0%	0%
Produce	4.0%	7.3%	83.7%	0%	0%	0%	16.3%	0%	0%	0%	0%
Candy & Confections	3.6%	6.7%	73.1%	0%	4.31%	0%	22.5%	0%	0%	0%	0%
Frozen Food	3.1%	5.7%	50.0%	0%	0.577%	0%	49.4%	0%	0%	0%	0%
Dairy Products	3.1%	5.6%	73.1%	0%	11.6%	0%	15.2%	0%	0%	0%	0%
Other Food Products	5.0%	9.1%	97.6%	0%	0.24%	0%	2.1%	0%	0%	0%	0%
Non-Food	16%	30%	75.1%	0%	4.16%	0%	20.7%	0%	0%	0%	0%
Pharmaceuticals	3.1%	5.7%	54.8%	0%	0%	0%	45.2%	0%	0%	0%	0%
Medical Products	2.3%	4.3%	91.8%	0%	0.329%	0%	7.8%	0%	0%	0%	0%
Paper & Textile	2.3%	4.2%	77.9%	0%	1.28%	0%	20.8%	0%	0%	0%	0%
Agricultural & Horticultural	2.3%	4.2%	70.0%	0%	0%	0%	30.0%	0%	0%	0%	0%
Chemicals	2.0%	3.7%	84.0%	0%	0%	0%	16.0%	0%	0%	0%	0%
Rack & Counter	1.4%	2.6%	77.9%	0%	0%	0%	22.1%	0%	0%	0%	0%
Other Nonfood Products	2.9%	5.4%	77.9%	0%	21.3%	0%	0.760%	0%	0%	0%	0%
Protective packaging	11%	100%	57.1%	0%	0%	0%	42.3%	0%	0%	0.617%	0%
Protective Mailers	5.0%	47%	60.0%	0%	0%	0%	40.0%	0%	0%	0%	0%
Protective Packaging Fill	4.7%	44%	68.8%	0%	0%	0%	31.2%	0%	0%	0%	0%
Dunnage Bags & Other	0.94%	8.8%	46.5%	0%	0%	0%	46.5%	0%	0%	7%	0%
Flexible bulk packaging	35%	100%	59.0%	17.2%	0%	0%	23.6%	0%	0%	0%	0%
Shipping Sacks	7.3%	21%	3.91%	0%	0%	0%	94.7%	0%	0%	1.37%	0%
Strapping	7.8%	22%	23.0%	77.0%	0%	0%	0%	0%	0%	0%	0%
Bulk Liners & Rolls	18%	53%	93.0%	0%	0%	0%	6.97%	0%	0%	0%	0%
FIBCs & Others**	1.3%	3.8%	100%	0%	0%	0%	0%	0%	0%	0%	0%

Table 2-12. Canadian Other Flexible Packaging - Substitution Weights by Material

Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Substitution Weights by Material (Million kg)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
OTHER FLEXIBLE											
Other Flexible (by wt for equiv fct)	100%		537	2.3%	11.2%	0%	86%	0%	0%	0.02%	0%
Converted flexible	54%	100%	346	0	220	0	1,490	0	0	0	0
Food	38%	70%	245	0	123	0	1,158	0	0	0	0
Meat & Related Products	5.9%	10.9%	28.3	0	1.38	0	139	0	0	0	0
Baked Goods	5.0%	9.2%	39.2	0	26.2	0	218	0	0	0	0
Snack Food	4.3%	7.8%	30.7	0	18.5	0	112	0	0	0	0
Grain Mill Products	4.2%	7.8%	25.7	0	0	0	119	0	0	0	0
Produce	4.0%	7.3%	27.4	0	0	0	102	0	0	0	0
Candy & Confections	3.6%	6.7%	22.0	0	17.4	0	121	0	0	0	0
Frozen Food	3.1%	5.7%	12.7	0	0.72	0	63.6	0	0	0	0
Dairy Products	3.1%	5.6%	18.5	0	39.4	0	58.3	0	0	0	0
Other Food Products	5.0%	9.1%	40.1	0	19.6	0	224	0	0	0	0
Non-Food	16%	30%	101	0	96.6	0	332	0	0	0	0
Pharmaceuticals	3.1%	5.7%	14.1	0	0	0	34.4	0	0	0	0
Medical Products	2.3%	4.3%	17.6	0	3.48	0	70.9	0	0	0	0
Paper & Textile	2.3%	4.2%	14.8	0	4.21	0	54.4	0	0	0	0
Agricultural & Horticultural	2.3%	4.2%	13.2	0	0	0	63.6	0	0	0	0
Chemicals	2.0%	3.7%	13.9	0	0	0	67.2	0	0	0	0
Rack & Counter	1.4%	2.6%	8.97	0	0	0	39.8	0	0	0	0
Other Nonfood Products	2.9%	5.4%	18.8	0	88.9	0	1.58	0	0	0	0
Protective packaging	11%	100%	46.7	0	0	0	173	0	0	0	0
Protective Mailers	5.0%	47%	20.8	0	0	0	65.7	0	0	0	0
Protective Packaging Fill	4.7%	44%	22.8	0	0	0	101	0	0	0	0
Dunnage Bags & Other	0.94%	8.8%	3.05	0	0	0	6.83	0	0	0	0
Flexible bulk packaging	35%	100%	144	45.6	0	0	25.0	0	0	0.35	0
Shipping Sacks	7.3%	21%	2.00	0	0	0	4.42	0	0	0.35	0
Strapping	7.8%	22%	12.5	45.6	0	0	0	0	0	0	0
Bulk Liners & Rolls	18%	53%	120	0	0	0	0	0	0	0	0
FIBCs & Others**	1.3%	3.8%	9.21	0	0	0	20.6	0	0	0	0

2.5. BEVERAGE PACKAGING MARKETS

Data on the total number of plastic beverage containers by beverage category was obtained from Freedonia tables.[85] The total volume of each type of beverage sold packaged in plastic was calculated based on the reported number of plastic containers sold and average volume per plastic container. The size distribution of plastic and non-plastic containers for each beverage category was obtained from Beverage Marketing Corporation data.[86] The number and types of alternative containers that would be used as substitute packaging for the gallons of beverage currently packaged in plastic containers was based on the current mix of alternative container materials and types, as well as some projections about additional use of aseptic containers in some categories such as sports beverages.

The materials type(s) and size distribution of alternative containers required to package the volume of beverage currently packaged in plastic varied by beverage category. In some categories, there was only one major alternative to plastic containers (e.g., aluminum cans for carbonated soft drinks, and cartons for milk). For both of those categories, glass accounts for a very small share of the total volume of beverage currently sold. The category of ready-to-drink fruit beverages (comprising chilled juices, chilled juice drinks, shelf-stable juice, and shelf-stable juice drinks, in a range of single-serve and multi-serve sizes) had the greatest number of types and sizes of substitute packaging options, including glass bottles, steel cans, aluminum cans, coated gable-top cartons, and aseptic cartons.

For non-carbonated beverages, plastic container sizes up to 64 fluid ounces (oz) were assumed to be replaceable by a single alternative material container. Since non-plastic beverage containers larger than 64 oz are not commonly used, multiple alternative containers were assumed to be required to substitute for individual plastic containers larger than 64 oz (one half gallon). For example, two 64-oz gable-top milk cartons would substitute for one 1-gallon plastic jug.

The category of sports drinks is currently almost exclusively packaged in plastic containers. Based on information from representatives of a major beverage company, other types of containers that could be used for sports drinks include glass bottles, aluminum cans, and aseptic cartons. Most sports drinks are consumed away from home and are often taken to sporting events in coolers filled with ice. Although some consumers will prefer clear (glass) containers that allow them to view the contents, it is assumed that most consumers will prefer containers that are light and non-breakable (cans and aseptic cartons); therefore, the volume share of sports beverage packed in alternative containers was modeled as 40% cans, 40% aseptic cartons, and 20% glass.

The substitution weight ratios take into account the difference in size, weight, and number of alternative containers required to package the volume of beverage currently packaged in plastic. In some cases, the substitute containers were the same size as the plastic container, so the same number of substitute containers was required, and alternative

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[85] Freedonia (2008). Beverage Containers: US Industry Study with Forecasts for 2012 & 2017, Study #2423 Prepared by The Freedonia Group, November 2008.

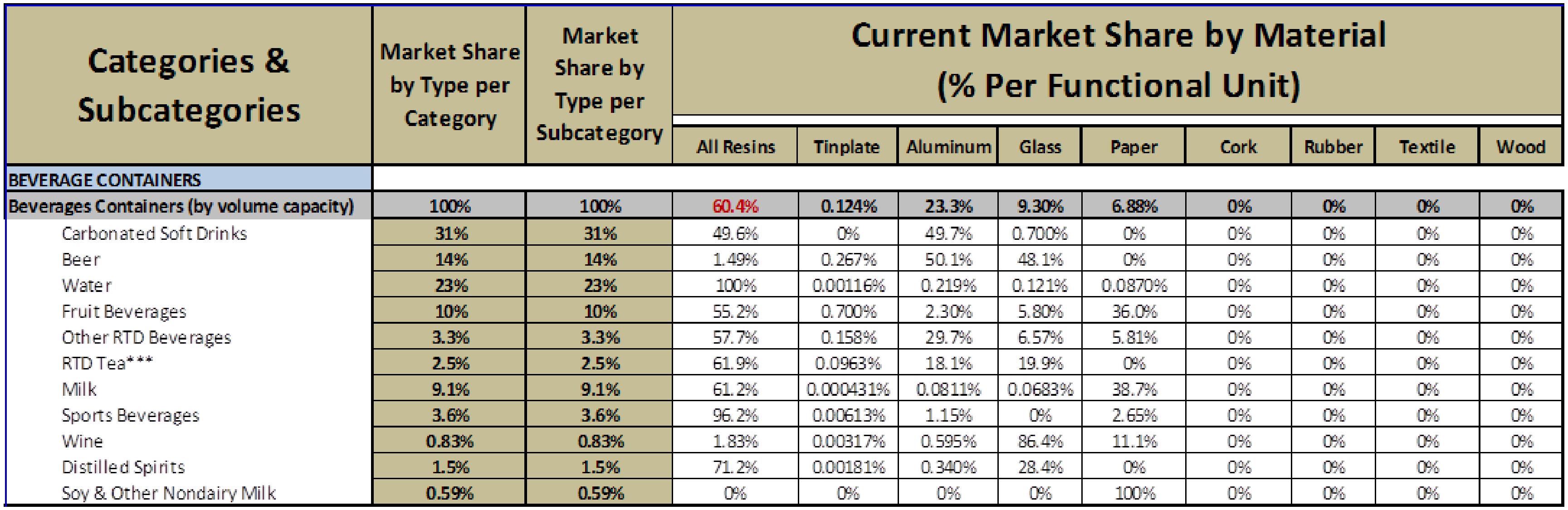
[86] Beverage Marketing Corporation. Beverage Packaging in the U.S. 2005 Edition. November 2005.

packaging weight ratios were based only on the difference in weight of the same-size alternative containers. Where plastic container and substitute container volumes were similar but not identical, substitute weights were calculated using the average grams of container material per fluid ounce of beverage in the package.

In other cases, multiple units of alternative containers were required to substitute for large plastic containers. For example, in the category of carbonated soft drinks, there are no resealable multi-serving substitutes for 2-liter plastic bottles, so multiple 12-oz aluminum cans were assumed to substitute for 2-liter plastic bottles. It takes 5.8 12-oz cans with an average weight of 12.9 grams each to package the same amount of beverage that is contained in a 2-liter bottle weighing 45.1 grams, so the substitute weight of aluminum cans for 2 liters of carbonated soft drink is 1.66 times the weight of each 2-liter plastic bottle.

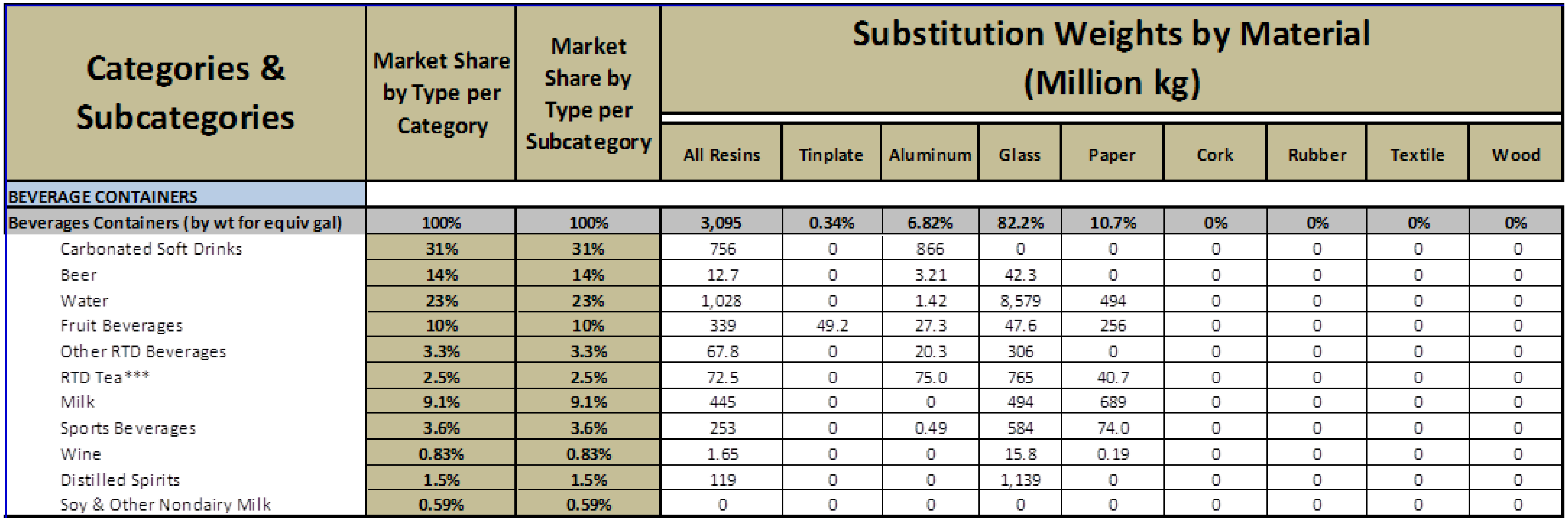
These calculations were applied to each beverage category to determine the relative weights of alternate materials required to packaging the volume of each type of beverage currently packaged in plastic. As noted in the Introduction to the substitution modeling discussion, substitution calculations are limited to replacement of the primary package component(s). The scope of the study does not include evaluation of energy and greenhouse gas differences associated with possible differences in filling processes for plastic and substituted beverage containers, or consumer choices about refrigerating plastic containers and substitute containers that do not require refrigeration as well as differences between refrigeration between the US and Canadian beverage sector.

Table 2-13. US Beverage Containers - Current Market Share by Material



Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Current Market Share by Material (% Per Functional Unit)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
BEVERAGE CONTAINERS											
Beverages Containers (by volume capacity)	**100%**	**100%**	**60.4%**	**0.124%**	**23.3%**	**9.30%**	**6.88%**	**0%**	**0%**	**0%**	**0%**
Carbonated Soft Drinks	**31%**	**31%**	49.6%	0%	49.7%	0.700%	0%	0%	0%	0%	0%
Beer	**14%**	**14%**	1.49%	0.267%	50.1%	48.1%	0%	0%	0%	0%	0%
Water	**23%**	**23%**	100%	0.00116%	0.219%	0.121%	0.0870%	0%	0%	0%	0%
Fruit Beverages	**10%**	**10%**	55.2%	0.700%	2.30%	5.80%	36.0%	0%	0%	0%	0%
Other RTD Beverages	**3.3%**	**3.3%**	57.7%	0.158%	29.7%	6.57%	5.81%	0%	0%	0%	0%
RTD Tea***	**2.5%**	**2.5%**	61.9%	0.0963%	18.1%	19.9%	0%	0%	0%	0%	0%
Milk	**9.1%**	**9.1%**	61.2%	0.000431%	0.0811%	0.0683%	38.7%	0%	0%	0%	0%
Sports Beverages	**3.6%**	**3.6%**	96.2%	0.00613%	1.15%	0%	2.65%	0%	0%	0%	0%
Wine	**0.83%**	**0.83%**	1.83%	0.00317%	0.595%	86.4%	11.1%	0%	0%	0%	0%
Distilled Spirits	**1.5%**	**1.5%**	71.2%	0.00181%	0.340%	28.4%	0%	0%	0%	0%	0%
Soy & Other Nondairy Milk	**0.59%**	**0.59%**	0%	0%	0%	0%	100%	0%	0%	0%	0%

Table 2-14. US Beverage Containers - Substitution Weights by Material



Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Substitution Weights by Material (Million kg)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
BEVERAGE CONTAINERS											
Beverages Containers (by wt for equiv gal)	**100%**	**100%**	**3,095**	**0.34%**	**6.82%**	**82.2%**	**10.7%**	**0%**	**0%**	**0%**	**0%**
Carbonated Soft Drinks	**31%**	**31%**	756	0	866	0	0	0	0	0	0
Beer	**14%**	**14%**	12.7	0	3.21	42.3	0	0	0	0	0
Water	**23%**	**23%**	1,028	0	1.42	8,579	494	0	0	0	0
Fruit Beverages	**10%**	**10%**	339	49.2	27.3	47.6	256	0	0	0	0
Other RTD Beverages	**3.3%**	**3.3%**	67.8	0	20.3	306	0	0	0	0	0
RTD Tea***	**2.5%**	**2.5%**	72.5	0	75.0	765	40.7	0	0	0	0
Milk	**9.1%**	**9.1%**	445	0	0	494	689	0	0	0	0
Sports Beverages	**3.6%**	**3.6%**	253	0	0.49	584	74.0	0	0	0	0
Wine	**0.83%**	**0.83%**	1.65	0	0	15.8	0.19	0	0	0	0
Distilled Spirits	**1.5%**	**1.5%**	119	0	0	1,139	0	0	0	0	0
Soy & Other Nondairy Milk	**0.59%**	**0.59%**	0	0	0	0	0	0	0	0	0

Table 2-15. Canadian Beverage Containers - Current Market Share by Material

Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Current Market Share by Material (% Per Functional Unit)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
BEVERAGE CONTAINERS											
Beverages Containers (by volume capacity)	100%	100%	60.4%	0.124%	23.3%	9.30%	6.88%	0%	0%	0%	0%
Carbonated Soft Drinks	31%	31%	49.6%	0%	49.7%	0.700%	0%	0%	0%	0%	0%
Beer	14%	14%	1.49%	0.267%	50.1%	48.1%	0%	0%	0%	0%	0%
Water	23%	23%	100%	0.00116%	0.219%	0.121%	0.0870%	0%	0%	0%	0%
Fruit Beverages	10%	10%	55.2%	0.700%	2.30%	5.80%	36.0%	0%	0%	0%	0%
Other RTD Beverages	3.3%	3.3%	57.7%	0.158%	29.7%	6.57%	5.81%	0%	0%	0%	0%
RTD Tea***	2.5%	2.5%	61.9%	0.0963%	18.1%	19.9%	0%	0%	0%	0%	0%
Milk	9.1%	9.1%	61.2%	0.000431%	0.0811%	0.0683%	38.7%	0%	0%	0%	0%
Sports Beverages	3.6%	3.6%	96.2%	0.00613%	1.15%	0%	2.65%	0%	0%	0%	0%
Wine	0.83%	0.83%	1.83%	0.00317%	0.595%	86.4%	11.1%	0%	0%	0%	0%
Distilled Spirits	1.5%	1.5%	71.2%	0.00181%	0.340%	28.4%	0%	0%	0%	0%	0%
Soy & Other Nondairy Milk	0.59%	0.59%	0%	0%	0%	0%	100%	0%	0%	0%	0%

Table 2-16. Canadian Beverage Containers - Substitution Weights by Material

Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Substitution Weights by Material (Million kg)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
BEVERAGE CONTAINERS											
Beverages Containers (by wt for equiv gal)	100%	100%	341.5	0.34%	6.82%	82.2%	10.7%	0%	0%	0%	0%
Carbonated Soft Drinks	31%	31%	83.4	0	95.5	0	0	0	0	0	0
Beer	14%	14%	1.40	0	0.35	4.66	0	0	0	0	0
Water	23%	23%	113	0	0.16	946	54.5	0	0	0	0
Fruit Beverages	10%	10%	37.4	5.43	3.01	5.26	28.2	0	0	0	0
Other RTD Beverages	3.3%	3.3%	7.48	0	2.25	33.7	0	0	0	0	0
RTD Tea***	2.5%	2.5%	8.00	0	8.27	84.4	4.49	0	0	0	0
Milk	9.1%	9.1%	49.0	0	0	54.5	76.1	0	0	0	0
Sports Beverages	3.6%	3.6%	28.0	0	0.054	64.4	8.16	0	0	0	0
Wine	0.83%	0.83%	0.18	0	0	1.74	0.020	0	0	0	0
Distilled Spirits	1.5%	1.5%	13.1	0	0	126	0	0	0	0	0
Soy & Other Nondairy Milk	0.59%	0.59%	0	0	0	0	0	0	0	0	0

2.6. CARRIER BAGS PACKAGING MARKETS

Carrier bags include only bags and sacks provided by retailers (e.g., grocery, convenience, department stores, etc.) or used by consumers at retailers (in the case of reusable bags) for the consumer to use in transporting their purchased products. Large bags and sacks used for bulk shipments are included in the flexible bulk packaging category. The overall weights of one-way plastic and paper carrier bags are as reported by Freedonia market data.[87] These data consider only markets in which paper and plastic materials compete. These Freedonia data also provided the relative number of one-way paper and plastic retail bag and sack units. From the data, Franklin Associates determined the average weight of one-way plastic retail bag and sacks per unit (0.014 pounds or 6.43 grams) and compared this per unit data with other publicly available data to estimate that reusable bags can make up a significant portion of total units of retails bags and sacks—nearly five percent.[88] Because the use of reusable cotton and plastic retail bags has recently become significant, overall weights for these materials are reflected in the current market share and substitution model. As the overall weights of materials or granularity on relative share of resins used for both one-way or reusable retail bags and sacks in Canada were not available, a US-to-Canada population scaling factor and US relative shares were used to estimate weights of materials used in Canadian demand.

In general, relative materials shares for each type of retail bag and sack material are compiled from cross-checking the Freedonia data with other publicly available data. As mentioned, the relative percentage of reusable bags is per the AECOM 2010 study. To obtain granularity on the types, relative capacity, and weight-per-unit of reusable bags, Franklin Associates uses data compiled for an LCA on carrier bags performed by Boustead Consulting in 2006.[89] Per the compiled data on both one-way and reusable bags and sacks, Franklin Associates estimates that by units, about 80 percent are one-way plastic, 15 percent are one-way paper, 3.4 percent are reusable plastic, and the remainders are reusable cotton. The plastic one-way retail bags and sacks are made of LDPE and HDPE, while the plastic reusable types are made of LDPE and PP. The material breakout for individual resins and non-plastic materials was cross-checked with qualitative and quantitative data from the ACC 2012 Resins Review and previous work performed by Franklin Associates.[90] The compiled data are used to estimate the relative weight share and identity of materials that would substitute for plastic one-way and reusable bags and sacks in retail applications. kraft paper bags are assumed to substitute for one-way plastic bags, while cotton bags are assumed to substitute for reusable plastic bags. All paper retail bags and sacks are assumed

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[87] Freedonia (2010). Paper versus Plastic in Packaging: US Industry Study with Forecasts for 2014 & 2019, Study #2698 Prepared by The Freedonia Group, November 2010.

[88] AECOM (2010). Table 5: Distribution of Bags at Checkout (Los Angeles), Project Report No. 18373 Economic Impact Analysis of Proposed Ban on Plastic Carryout Bags in Los Angeles County, Prepared for Sapphos Environmental, Inc. in Pasadena California by AECOM Technical Services (AECOM) November 3, 2010.

[89] Boustead Consulting (2007). Life Cycle Assessment for Three Types of Grocery Bags – Recyclable Plastic; Compostable, Biodegradable Plastic; and Recycled, Recyclable Paper, Prepared for the Progressive Bag Alliance by Boustead Consulting & Associates Ltd.

[90] Franklin Associates (1990). Appendix C. Market Shares and Weight Ratios for Plastics & Alternative Materials in Packaging and Disposable Consumer Goods Prepared for SPI.

to have the average recycled content for paper packaging based on recovery rates in the EPA MSW Characterization in 2010.[91] No information is available on the mix of retail bags/sacks that are made from bleached versus unbleached paper. Grocery and retail bags constitute over 40 percent of the category "packaging paper", which also includes multi-wall shipping sacks and wrapping/converting paper. The most recent publicly available data indicates that about 85 percent of packaging paper is unbleached and 15 percent is bleached. This mix of bleached and unbleached paper is assumed for modeling the fiber content of paper bags and sacks that would substitute plastic retail bags.

To determine substitution weight factors for each type of retail bag and sack, the functional unit is number of bags (i.e., units) adjusted for differences in volume capacity. Franklin Associates estimates that 80 percent of bag units are filled to capacity and this portion of total bag units are adjusted for differences in capacity; the remaining 20 percent of units are assumed to be filled to less than full capacity and so are compared on a one-to-one basis. However, where a standard size plastic bag may be used to contain only one or two items (i.e., not filled to capacity), a smaller paper bag is expected to be used for only one or two items due to the expense and weight of the paper bags. The weights of paper sacks and bags are adjusted to account for the higher volume capacity per unit per trip for paper relative to plastic sacks and bags (i.e., average size of plastic bags hold a volume of goods about 1.8 times less than the average sized paper bag).[92] Though cotton reusable bags are heavier than non-woven PP and heavy duty LDPE reusable bags, the cotton bags have a higher volume capacity; ~1.09 times that of plastic reusable bags.[93] While these durable reusable plastic and non-plastic bags can replace many single-use carrier bags over their lifetime, Franklin Associates does not attempt to distinguish between trip numbers for reusable woven plastic versus cotton retail sacks and bags, so that one reusable plastic bag is assumed to be substituted by one reusable cotton bag. Carrier bag substitution weights are determined by compiling one-way paper-to-plastic bag or reusable cotton-to-plastic bag weight ratios given the previously mentioned adjustments for differences in weight per unit and volume capacity for each retail bag and sack type.

Given equivalency in units as adjusted for volume capacity per trip, the alternative material-to-plastic retail bag and sack weight ratios determined for each type are used to estimate the overall weight of each type of alternative material required to substitute for plastics in this product market. Table 2-17 and Table 2-19 show that plastic bags currently account for 83 percent of the total *number* of carrier/retail bags in use; however, because plastic bags are lighter than functionally equivalent paper and textile bags, plastic bags account for only 56 percent of the total *weight* of the carrier/retail bags currently used.

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[91] US Environmental Protection Agency. 2011. Municipal Solid Waste Generation, Recycling, and Disposal in the United States Detailed Tables and Figures for 2010. Compiled by Franklin Associates, A Division of ERG.

[92] Capacity factor compiled by Franklin Associates per a previous LCI study on paper versus plastic retail grocery bags.

[93] Boustead Consulting (2007). Ibid.

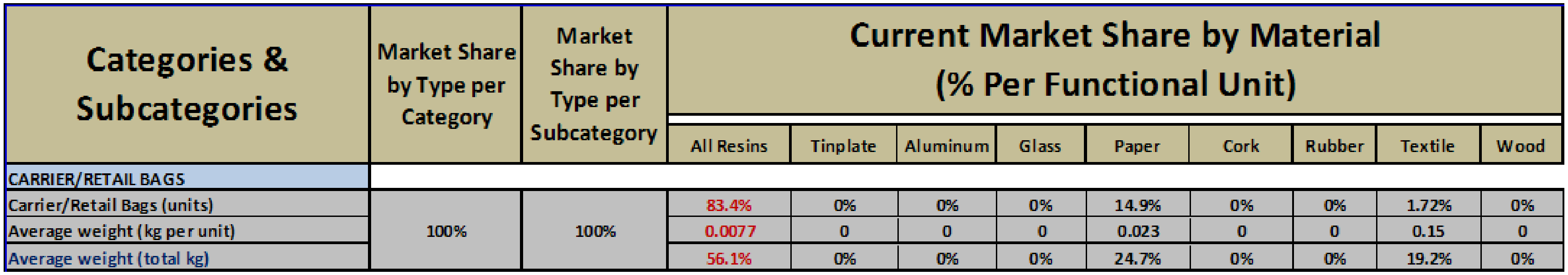
Table 2-17. US Carrier/Retail Bags - Current Market Share by Material

Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Current Market Share by Material (% Per Functional Unit)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
CARRIER/RETAIL BAGS											
Carrier/Retail Bags (units)	100%	100%	83.4%	0%	0%	0%	14.9%	0%	0%	1.72%	0%
Average weight (kg per unit)			0.0077	0	0	0	0.023	0	0	0.15	0
Average weight (total kg)			56.1%	0%	0%	0%	24.7%	0%	0%	19.2%	0%

Table 2-18. US Carrier/Retail Bags - Substitution Weights by Material

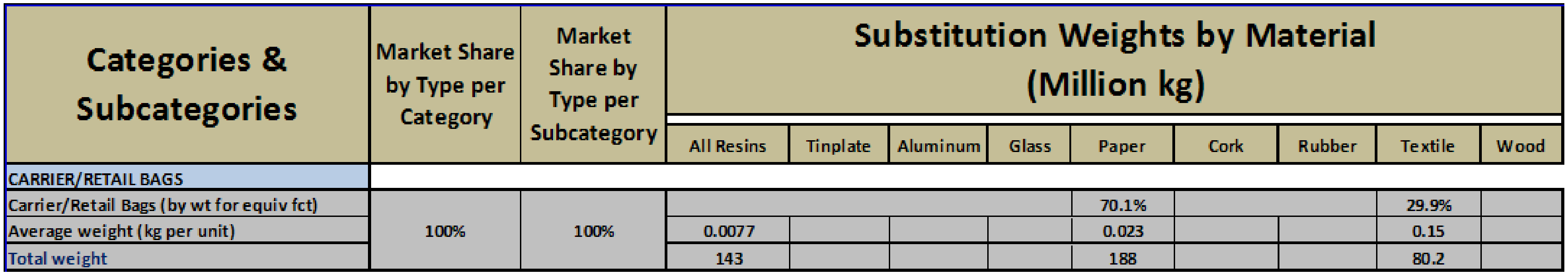
Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Substitution Weights by Material (Million kg)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
CARRIER/RETAIL BAGS											
Carrier/Retail Bags (by wt for equiv fct)	100%	100%					70.1%			29.9%	
Average weight (kg per unit)			0.0077				0.023			0.15	
Total weight			1,297				1,709			727	

Table 2-19. Canadian Carrier/Retail Bags - Current Market Share by Material



Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Current Market Share by Material (% Per Functional Unit)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
CARRIER/RETAIL BAGS											
Carrier/Retail Bags (units)	100%	100%	83.4%	0%	0%	0%	14.9%	0%	0%	1.72%	0%
Average weight (kg per unit)			0.0077	0	0	0	0.023	0	0	0.15	0
Average weight (total kg)			56.1%	0%	0%	0%	24.7%	0%	0%	19.2%	0%

Table 2-20. Canadian Carrier/Retail Bags - Substitution Weights by Material



Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Substitution Weights by Material (Million kg)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
CARRIER/RETAIL BAGS											
Carrier/Retail Bags (by wt for equiv fct)	100%	100%					70.1%			29.9%	
Average weight (kg per unit)			0.0077				0.023			0.15	
Total weight			143				188			80.2	

2.7. CAPS AND CLOSURES MARKETS

The caps and closure packaging category includes all caps and closures utilized on containers intended for disposal after use in beverage, food, pharmaceutical, cosmetic and toiletry, household chemical, automotive chemical, and other packaging markets. The overall weights of and number of units of caps and closures for each material type are as reported by Freedonia market data.[94] The Freedonia data are provided in terms of overall weights of the plastic, steel and tin, aluminum, rubber, cork, and paperboard used in caps and closures. The Freedonia data also provide the number of units of each type of material used in the individual product applications and average weight per unit factors for plastic and metal caps and closures. Per the Freedonia data, cork closures are only used in beverage markets. Franklin Associates uses actual measurements of various types of beverage corks cross-checked with publicly available data to determine an average weight per unit factor for natural and synthetic corks closures.[95] Per the Freedonia data, paperboard is only used in caps and closures for food packaging applications (i.e., a very small weight of material relative to other alternative caps and closures material). Franklin Associates assumes paperboard use in caps and closures is for lidded paperboard closures on cylindrical paperboard containers, as seals on container openings, or as paperboard lid liners inserted into caps and closures of more rigid material. As there is little-to-no data available for size distribution in these products, Franklin Associates applies a weight-per-unit factor that is half of that provided in the Freedonia data for plastic caps and closures. This estimate is cross-checked with publicly available specifications for paper closures and paper basis weight calculations. Per the Freedonia data, rubber closures are used only in pharmaceutical markets. Franklin Associates uses publicly available research to estimate an average weight-per-unit factor for natural and synthetic rubber caps and closures.[96]

The Freedonia plastic data are also presented by relative market share and number of plastic cap and closure units broken out by types: standard threaded, unthreaded, vacuum threaded, pressurized threaded, dispensing and child-resistant. Examples of plastic dispensing caps are for disc tops, spouts, bulbs for glass droppers, snap tops, sifter caps, ball rod caps, push/pull caps, Yorker dispensing caps, and press or trigger type spray nozzles. Examples of resin use in child-resistant caps and closures are for safe-lock ribbed caps and jigger style squeeze and turn caps. Per research and a related European study[97], Franklin Associates considers that the dispensing and child-resistant type plastic caps and closures are ‘unsubstitutable’. In other words, no alternative materials are considered to be capable

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[94] Freedonia (2010). Caps & Closures: US Industry Study with Forecasts for 2014 & 2019, Study #2688 Prepared by The Freedonia Group, October 2010.

[95] PwC/Ecobilan (2008). Evaluation of the Environmental Impacts of Cork Stoppers versus Aluminum and Plastic Closures: Analysis of the Life Cycle of Cork, Aluminum and Plastic Wine Closures, Report prepared for Corticeira Amorim, SGPS, SA by PricewaterhouseCoopers/ECOBILAN, October 2008.

[96] Landi S, Held HR (1965). Prevention of Chinosol Absorption by Rubber Stoppers Used to Seal Glass Vials Containing Tuberculin PPD Mantoux Solutions, Bull. Wld Hlth Org. 33: 395-404.

[97] Pilz H, Brandt B, Fehringer R (2010). The Impact of Plastics on Life Cycle Energy Consumption and Green-House Gas Emissions in Europe, Part 1: Effects of a Theoretical Substitution of Plastics, Prepared by Denkstatt GmbH for PlasticsEurope Association of Plastics Manufacturers Association and Sustainable Energy Europe, Final Report June 2010.

of providing the same functional service as dispensing or child-resistant caps and closures made of plastic. The plastic weight and share of resins used (mostly PP and LDPE) in these types of caps and closures are disaggregated from the provided Freedonia data and removed from the model.

The overall weights of materials for caps and closures in Canada were also available from Freedonia market tables.[98] However, further granularity on the amounts of caps and closures used in each product application or relative shares of resin in each product application were not available for Canadian cap and closure demand. A US-to-Canada population scaling factor, US relative shares by material, and relative percent shares of resins used in US dispensing and child-resistant caps were used to estimate weights of unsubstitutable plastics to remove and remaining weights of each material used in Canadian demand for each product category application.

In general, relative materials shares for each cap and closure application were compiled by cross-checking the Freedonia data and ACC Resin Review[99] data with publicly available specifications on cap and closure products and from previous public and private LCA work performed by Franklin Associates. These sources are also consulted to obtain further granularity on the relative shares of resins in each subcategory product application. For beverage markets, Franklin Associates considers data for the plastic resins used in caps and closures for: carbonated beverages, beer and malt beverages, bottle water, fruit beverages, RTD beverages, RTD tea, milk, sports drinks, wine, distilled spirits, and soy and other nondairy milk. Multiple data sources were also consulted for resins used in non-dispensing and non-child-resistant type caps and closures for food markets (e.g., food bottle and jar caps, condiment caps), pharmaceutical markets (e.g., threaded pill bottle tops), cosmetic and toiletry markets (e.g., high moisture resistance caps), household cleaning and automotive chemical markets (e.g., strong impact and chemical resistant), and other markets (e.g., computer screen cleaner caps). Per the compiled data, Franklin Associates estimates that by units, about 77 percent of caps and closures are plastic; of which, 46 percent are PP, 11 percent are LDPE, 10 percent are PS, six percent are HDPE, and less than four percent are PVC or PET. For beverage caps, the overall resin share is about 60 percent PP, 14 percent LDPE, 13 percent PS, 8.0 percent HDPE, 2.3 percent PCV, and 2.3 percent PET. For food products, Franklin Associates assumes 75 percent PP, 20 percent LDPE, 2.7 percent PS, and 2.5 percent HDPE. For pharmaceutical, cosmetic, and toiletry applications, Franklin Associates estimates 60 percent PP, 20 percent LDPE, 10 percent PVC, 9.0 percent HDPE, and one percent PS. Given the overall material breakout provided by the Freedonia data (sans dispensing and child-resistant caps and closures), other caps and closures are about 35 percent HDPE, 30 percent PP, 17 percent PET, ten percent PS, five percent PVC, and three percent LDPE. The compiled data are used to estimate the relative weight share and identity of materials that would substitute for each resin used in caps and closures for various product applications. Steel, rubber, aluminum, cork, and paperboard materials are expected to replace these plastic caps and closures. All paper cap

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[98] Freedonia (2011). World Caps & Closures: Industry Study with Forecasts for 2014 & 2019, Study #2719 Prepared by The Freedonia Group, January 2011.

[99] ACC (2012). The Resin Review: The Annual Statistical Report of the North American Plastics Industry, American Chemistry Council, 2012 Edition.

and closure substitute materials are assumed to have the average recycled content for paper packaging per the EPA MSW Characterization in 2010 except for those in the food and beverage subcategories (which are composed of virgin paper only).[100]

For cap and closure products, the functional unit of comparison is number of units (i.e., one unit of alternative materials substitutes for one plastic cap or closure). Plastic caps and closures are used on both plastic containers and non-plastic containers. The substitution model for plastic caps and closures described below is based on substituting the plastic caps used for the *current mix* of plastic and non-plastic containers. The caps and closures substitution model does not take into account the effect of substitutions for plastic containers on which plastic caps are currently used. In other words, the substitution of caps and closures is treated as an *independent* substitution analysis rather than a *simultaneous* substitution analysis. Discussion of a simultaneous substitution analysis is provided at the end of this section.

In the cap substitution model, the ratio of the average weight-per-unit factor for each alternative material to the average weight-to-unit factor of the plastic cap and closure along with the number of plastic units to be substituted are used to determine the weight of each alternative material estimated to substitute for the currently demanded weight of plastic resins. This approach is applied to each plastic resin for each cap and closure product application.

Given a one-to-one assumption of equivalency in number of units[101] and the average weight-per-unit factors as compiled by Franklin Associates, the alternative material-to-plastic cap and closure weight ratios determined for each type are used to estimate the overall weight of each type of alternative material required to substitute for plastics in this product market. As an example of how substitution ratios were determined, the following section describes the approach for developing substitution weight factors in pharmaceutical cap and closure applications.

Franklin Associates uses the material and market application breakout data (monetary and physical units) as compiled from the Freedonia data to determine what fraction of total cap and closure units are currently supplied by each packaging material in pharmaceutical cap and closure applications. Per this data, of the total current market share of materials alternative to plastic in pharmaceutical caps and closures are as follows: 87 percent rubber; 9.6 percent steel; 3.5 percent aluminum. Franklin Associates assumes that a material profile similar to the current relative shares of alternative materials would replace plastic caps and closures in the theoretical substitution model. The current relative percent shares of alternative materials are in terms of cap and closure units and so applied to the total units of plastic pharmaceutical caps and closures; in other words, of the ~6.99 billion units of plastic pharmaceutical caps and closures, 87 percent, 9.6 percent, and 3.5 percent are

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[100] US Environmental Protection Agency. 2011. Municipal Solid Waste Generation, Recycling, and Disposal in the United States Detailed Tables and Figures for 2010. Compiled by Franklin Associates, A Division of ERG.

[101] Aside from dispensing and child-resistant type plastic caps and closures which are considered to be unsubstitutable.

modeled to be replaced on a one-to-one unit basis with rubber, steel, and aluminum, respectively. Franklin Associates then used the average weight-per-unit data indicated in the Freedonia market report for plastic and metals along with data compiled by Franklin Associates for average weight of rubber cap and closure units[102] to determine the relative weights of plastic versus alternative materials in the substitution scenario.

2.7.1. Simultaneous Substitution Analysis

In order to evaluate substitutions in plastic caps and closures simultaneously with substitutions of plastic containers on which some of the plastic caps are currently used, a multi-step process would be required. It would first be necessary to separate the amounts and types of plastic caps used on plastic containers from the amounts and types of plastic caps used on non-plastic containers. The available market data on caps and closures are not provided at this level of detail. Next, the amounts and types of plastic containers that use plastic caps would need to be identified within each packaging category. The simultaneous analysis of plastic cap substitutions and plastic container substitutions would then need to take into account the mix of container materials and configurations that are used to substitute for the plastic containers that use plastic caps. Finally, assumptions would need to be made about the types of non-plastic caps that would be used on the substitute containers. Simultaneous substitution analysis for caps and closures was therefore not conducted as it would involve complex projections with compounded uncertainties (first, about the split of caps used on plastic versus non-plastic containers; second, assumptions about what type of container replaces each type of plastic container that uses a plastic cap; and third, assumptions about what type of non-plastic cap is used on the substitute container). However, some general projections can be made regarding simultaneous substitution:

- In cases where plastic containers are substituted with food or beverage cans made of aluminum or steel, the closure for the metal container would be included as part of the substitute container, so the plastic caps/closures on the current plastic container would be substituted by 0 separate caps/closures for the substitute metal container.
- Similarly, “minimal plastic” versions of gable-top and aseptic cartons might involve removal of the plastic pour spout and cap and a return to using a fold-out carton spout with no additional closure – which would also result in replacing the plastic caps/closures on the current plastic container with no alternative cap/closure on the substitute container.
- For cases where plastic containers are substituted with glass containers, metal containers other than food/beverage cans, or rigid paperboard containers, the substitute container would still require a cap. In most cases this would likely be a metal cap, or in some cases, a fitted paperboard overcap (e.g., on paperboard canisters), or a rubber cap or stopper for some beverages, pharmaceuticals, or chemicals.

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[102] Landi S, Held HR (1965). Prevention of Chinosol Absorption by Rubber Stoppers Used to Seal Glass Vials Containing Tuberculin PPD Mantoux Solutions, Bull. Wld Hlth Org. 33: 395-404.

- Given relative share of metal bottles and jars to substitute for plastic beverage or food bottles and jars, Franklin Associates can roughly estimate the potential effects of a simultaneous substitution:
    - A maximum of 59 percent of plastic beverage bottle volume and 7.6 percent of plastic food bottles and jars may be modeled to be replaced with aluminum cans which have embedded aluminum closures and tabs (i.e., roughly 59 and 7.6 percent of aluminum cap and closure units modeled to substitute plastic cap and closure units for beverage and food bottle/jar applications, respectively, might be overstated or double-counted in the other categories);
    - A maximum of 0.31 percent of plastic beverage bottle volume and 18 percent of plastic food bottles and jars may be modeled to be replaced with steel cans which have embedded steel closures and/or tabs (i.e., roughly 0.31 and 18 percent of steel cap and closure units modeled to substitute plastic cap and closure units for beverage and food bottle/jar applications, respectively, might be overstated or double-counted in the other categories); and
    - A maximum of 17 percent of plastic beverage bottle volume and 28 percent of plastic food bottles and jars are modeled to be replaced with paperboard cartons which, in a theoretical substitution scenario where no plastic is used, would no longer have plastic closures but would revert to an embedded paperboard gable top-type closure (i.e., roughly 17 and 28 percent of alternative material cap and closure units modeled to replace plastic units for beverage and food bottle/jar applications, respectively, might be overstated).

With simultaneous substitution of plastic beverage and food bottles and jars and plastic caps and closures, the overall weight of aluminum and steel required to replace plastic caps and closures decreases by 41 and 15 percent, respectively.

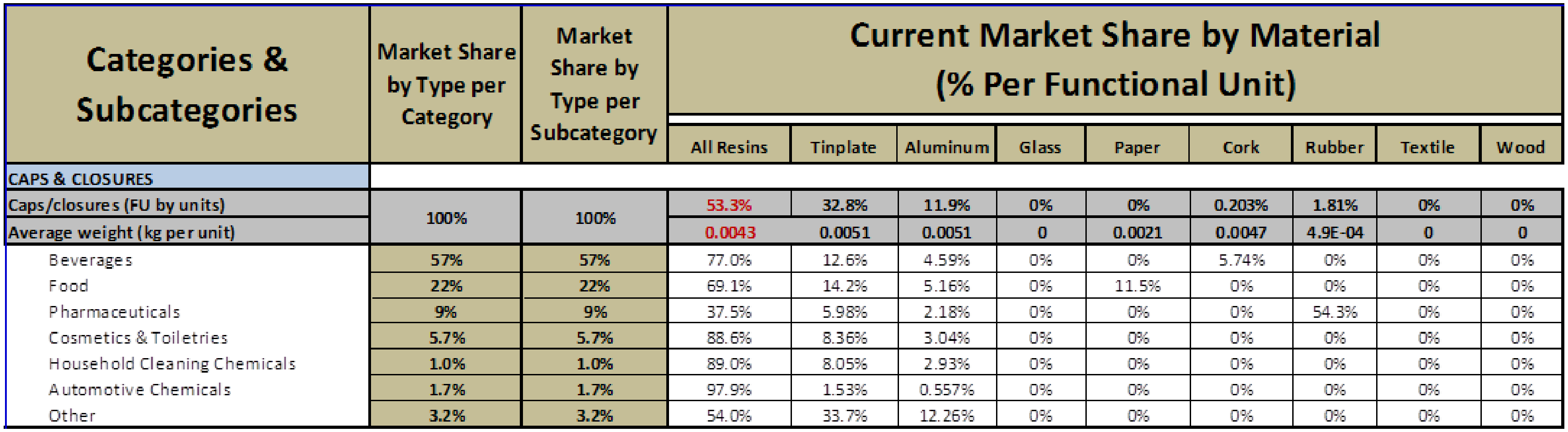
Table 2-21. US Caps & Closures - Current Market Share by Material

Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Current Market Share by Material (% Per Functional Unit)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
CAPS & CLOSURES											
Caps/closures (FU by units)	100%	100%	72.3%	12.5%	4.55%	0%	2.316%	3.503%	4.85%	0%	0%
Average weight (kg per unit)			0.0043	0.0051	0.0051	0	0.0021	0.0047	4.9E-04	0	0
Beverages	61%	61%	77.0%	12.6%	4.59%	0%	0%	5.74%	0%	0%	0%
Food	20%	20%	69.1%	14.2%	5.16%	0%	11.5%	0%	0%	0%	0%
Pharmaceuticals	9%	9%	37.5%	5.98%	2.18%	0%	0%	0%	54.3%	0%	0%
Cosmetics & Toiletries	4.9%	4.9%	88.6%	8.36%	3.04%	0%	0%	0%	0%	0%	0%
Household Cleaning Chemicals	0.8%	0.8%	89.0%	8.05%	2.926%	0%	0%	0%	0%	0%	0%
Automotive Chemicals	1.5%	1.5%	97.9%	1.53%	0.557%	0%	0%	0%	0%	0%	0%
Other	2.7%	2.7%	54.0%	33.7%	12.26%	0%	0%	0%	0%	0%	0%

Table 2-22. US Caps & Closures - Substitution Weights by Material

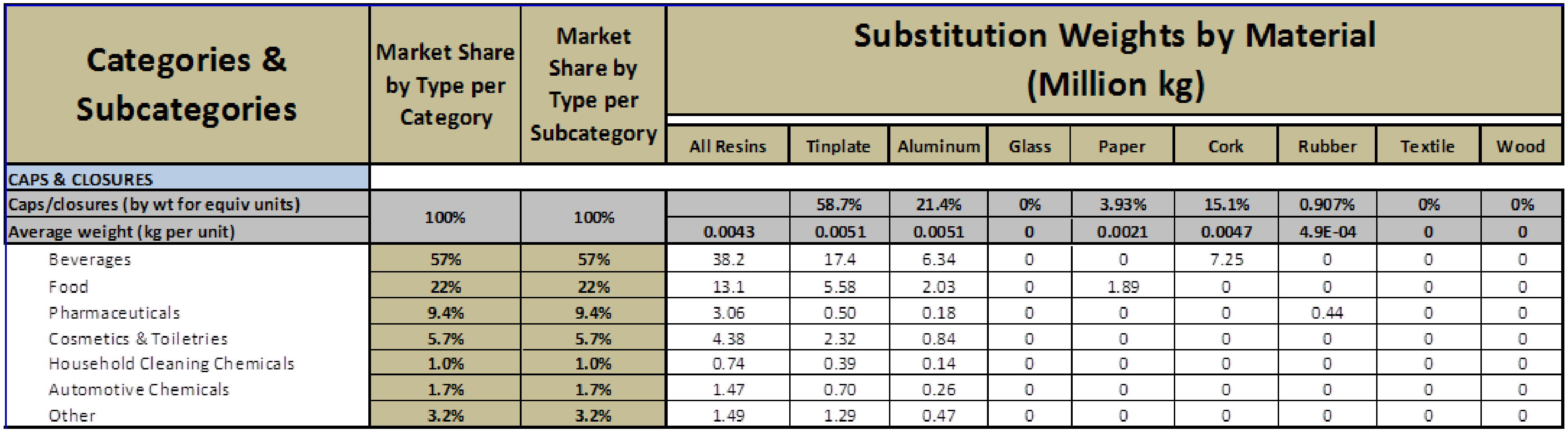
Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Substitution Weights by Material (Million kg)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
CAPS & CLOSURES											
Caps/closures (by wt for equiv units)	100%	100%		53.2%	19.3%	0%	7.18%	16.3%	4.03%	0%	0%
Average weight (kg per unit)			0.0043	0.0051	0.0051	0	0.0021	0.0047	4.9E-04	0	0
Beverages	61%	61%	528	275	100	0	0	125	0	0	0
Food	20%	20%	123	68.0	24.7	0	55.2	0	0	0	0
Pharmaceuticals	9%	9%	37.6	3.41	1.24	0	0	0	31.0	0	0
Cosmetics & Toiletries	4.9%	4.9%	49.0	34.0	12.4	0	0	0	0	0	0
Household Cleaning Chemicals	0.8%	0.8%	8.30	5.77	2.10	0	0	0	0	0	0
Automotive Chemicals	1.5%	1.5%	16.4	11.4	4.14	0	0	0	0	0	0
Other	2.7%	2.7%	16.6	11.6	4.20	0	0	0	0	0	0

Table 2-23. Canadian Caps & Closures - Current Market Share by Material



Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Current Market Share by Material (% Per Functional Unit)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
CAPS & CLOSURES											
Caps/closures (FU by units)	100%	100%	53.3%	32.8%	11.9%	0%	0%	0.203%	1.81%	0%	0%
Average weight (kg per unit)			0.0043	0.0051	0.0051	0	0.0021	0.0047	4.9E-04	0	0
Beverages	57%	57%	77.0%	12.6%	4.59%	0%	0%	5.74%	0%	0%	0%
Food	22%	22%	69.1%	14.2%	5.16%	0%	11.5%	0%	0%	0%	0%
Pharmaceuticals	9%	9%	37.5%	5.98%	2.18%	0%	0%	0%	54.3%	0%	0%
Cosmetics & Toiletries	5.7%	5.7%	88.6%	8.36%	3.04%	0%	0%	0%	0%	0%	0%
Household Cleaning Chemicals	1.0%	1.0%	89.0%	8.05%	2.93%	0%	0%	0%	0%	0%	0%
Automotive Chemicals	1.7%	1.7%	97.9%	1.53%	0.557%	0%	0%	0%	0%	0%	0%
Other	3.2%	3.2%	54.0%	33.7%	12.26%	0%	0%	0%	0%	0%	0%

Table 2-24. Canadian Caps & Closures - Substitution Weights by Material



Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Substitution Weights by Material (Million kg)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
CAPS & CLOSURES											
Caps/closures (by wt for equiv units)	100%	100%		58.7%	21.4%	0%	3.93%	15.1%	0.907%	0%	0%
Average weight (kg per unit)			0.0043	0.0051	0.0051	0	0.0021	0.0047	4.9E-04	0	0
Beverages	57%	57%	38.2	17.4	6.34	0	0	7.25	0	0	0
Food	22%	22%	13.1	5.58	2.03	0	1.89	0	0	0	0
Pharmaceuticals	9.4%	9.4%	3.06	0.50	0.18	0	0	0	0.44	0	0
Cosmetics & Toiletries	5.7%	5.7%	4.38	2.32	0.84	0	0	0	0	0	0
Household Cleaning Chemicals	1.0%	1.0%	0.74	0.39	0.14	0	0	0	0	0	0
Automotive Chemicals	1.7%	1.7%	1.47	0.70	0.26	0	0	0	0	0	0
Other	3.2%	3.2%	1.49	1.29	0.47	0	0	0	0	0	0

2.8. SHRINK AND STRETCH FILM PACKAGING MARKETS

Shrink and stretch film packaging includes wrap, stretch labels and sleeves, and hoods (e.g., pallet caps) used in product packaging and storage and distribution markets. The product packaging market is disaggregated by food, beverage, paper and textile, consumer, and other product applications; whereas, storage and distribution markets are for bulk applications such as pallet wrap. The overall weights of materials used for shrink and stretch packaging in the US are determined from Freedonia market data.[103] These Freedonia data also provided the relative US dollar demand for stretch and shrink wraps and film within the product packaging and storage and distribution market categories. The total weight of individual resins are reported for stretch and shrink packaging materials but data for relative shares within the product packaging and storage and distribution market categories are only reported in terms of monetary demand. As the average price per unit for each type of stretch and shrink packaging product is not provided, it is assumed that the relative market demand for each type correlates linearly with the relative weight of each package type (i.e., price per pound of package is similar among stretch and shrink films and wraps despite market served). The overall weights of materials used for stretch and shrink film packaging in Canada are not available, so a US-to-Canada population scaling factor and US relative shares were used as a proxy to break out types and materials per subcategory and market application.

100 percent of stretch and shrink film demand is currently met with plastic materials. The Freedonia data indicate that stretch and shrink films are LLDPE, LDPE, PVC, and other resins. Franklin Associates assumes that ‘other’ resins are HDPE.

To determine substitution weight factors for each type of stretch or shrink film, the functional unit is square footage of film adjusted for performance. Within each stretch or shrink film packaging subcategory, a representative plastic film product was selected. The weights of the representative plastic packages were determined from: 1) primary data from previous LCAs performed by Franklin Associates, and/or 2) publicly available specifications from packaging providers. The surface area of plastic film required for each representative package was estimated from the representative package’s dimensions and used, along with the performance specifications of the product application, as a basis to determine weight of alternative materials required. In cases where plastic film was used to unitize retail multi-packs of individual product (e.g., multi-packs of single-serve juice drinks), the alternative was assumed to be a paper overwrap or paperboard sleeve, while in cases where the plastic film was used to secure cases of product to pallets, the alternative product was assumed to be steel strapping.

For plastic film applications substituted by paper and paperboard wraps, sleeves, or closed boxes (e.g., a box replacing a tray with film overwrap), the thickness (a.k.a., basis weight) for the alternative paper or paperboard layer is determined based on specifications indicated for each representative product in the source data. The weight of the given surface area of each alternative material layer was then determined based on its thickness. These

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[103] Freedonia (2011). Stretch & Shrink Film: US Industry Study w/ Forecasts for 2015 & 2020, Study #2830 Prepared by The Freedonia Group, December 2011.

weights are used to determine the overall paper-to-plastic material weight ratio for each product application. For each alternative material, these weights are then summed to determine the overall weight of alternative material that will substitute for the overall weight of plastic currently demanded in the shrink and stretch film retail packaging market. As an example of how substitution ratios were determined, the following section describes the approach for developing substitution weight factors in stretch film storage and distribution machine and manual pallet wrap applications.

Plastic stretch film products for storage and distribution applications are divided into 'pallet wrap' and 'bundling and other' sub-applications; pallet wrap is split into sub-product categories: machine wrap and hand wrap. Franklin Associates estimated stretch wrap surface area required for a standard-size pallet (48 by 20 by 6 inches), loaded at to an average height (5 feet), assuming a standard wrapping technique[104] for plastic stretch film securing an average pallet configuration with an average load weight of 1,440 pounds or 653.2 kilograms as the basis to which to compare alternative packaging material requirements. Common pallet wrap film gauges for machine wrap are 50, 60, 70, and 80; whereas, irregular loads may (i.e., manual wrapping) may require a thicker film such as gauge 80, 100, or up to 120.[105] Franklin Associates assumes a median value of these gauges, 65 (323 square feet per pound or 66.1 square meters per kilogram of plastic film) and 100 (208 square feet per pound or 42.7 square meters per kilogram of plastic film) for machine and manual pallet wraps, respectively. Given the configurations of the standard sized/loaded pallet and standard wrapping techniques (i.e., film surface area) and stretch film gauge assumed for the machine and manual pallet stretch wraps, the weight of stretch film is determined for each application. Franklin Associates assumes a six-to-four ratio of machine-to-manual stretch film wrap in the pallet wrap submarket of storage and distribution applications. Plastic used in pallet wrap applications for stretch film storage and distribution is modeled to be replaced 100 percent with a combination of steel strapping with fiber corrugated slip sheets required in 50 percent of cases to provide equivalent product unitizing and protective performance. Steel strapping of break strength, 1,825 pounds, is used to account for the average pallet load weight of 1,440 pounds. The steel strapping used to obtain a plastic-to-steel substitution weight ratio is standard grade stainless steel strapping of ½ inch width, 0.51 mil thicknesses, on rolls 2940 feet long. The example volume of steel, the steel gauge, and standard strapping techniques[106] for pallets are used to determine the steel-to-plastic weight ratios for stretch machine and manual pallet wrap, ~17.8 and ~11.5, respectively. For corrugated slip sheets, Franklin Associates assumes a requirement of two slip sheets of area equivalent to the pallet top-view per pallet; slip sheets are corrugated containerboard with an average grammage of 375 (i.e., 0.077 pounds per square foot or 0.375 kilograms per square meter). The example surface area of corrugated slip sheets and their grammage are used to determine the corrugated-to-plastic

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[104] FedEx (2012). Packaging Guidelines for Shipping Freight: FedEx Guidelines for Shipments Weighting More Than 150 Lbs. Available at: http://images.fedex.com/us/services/pdf/FreightPackagingGuidelines.pdf.

[105] Shorr Packaging Corporation (2013). Pallet stretch wrap terms Available at: http://www.shorr.com/pallet-stretch-wrap-terms.

[106] FedEx (2012). Packaging Guidelines for Shipping Freight: FedEx Guidelines for Shipments Weighting More Than 150 Lbs. Available at: http://images.fedex.com/us/services/pdf/FreightPackagingGuidelines.pdf.

weight ratios for stretch machine and manual pallet wrap, ~7.00 and ~4.52, respectively, in 50 percent of plastic pallet wrap substitution cases.

Per the compiled estimates, shrink and stretch film packaging is expected to be replaced by a mix of steel, corrugated cardboard, virgin kraft paper (for food applications), and kraft paper with recycled content (for non-food applications). Recycled content and recovery rates for substitute materials are described in Chapter 3.

Table 2-25. US Stretch & Shrink Film - Current Market Share by Material

Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Current Market Share by Material (% Per Functional Unit)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
STRETCH & SHRINK FILM											
Stretch & Shrink Film (weight kg)	100%		100%	0%	0%	0%	0%	0%	0%	0%	0%
Stretch film	61%	100%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Product Packaging	29%	48%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Storage & Distribution	32%	52%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Shrink film	39%	100%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Product Packaging	19%	48%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Storage & Distribution	21%	52%	100%	0%	0%	0%	0%	0%	0%	0%	0%

Table 2-26. US Stretch & Shrink Film - Substitution Weights by Material

Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Substitution Weights by Material (Million kg)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
STRETCH & SHRINK FILM											
Stretch & Shrink Film (by wt for equiv fct)	100%		748	54.3%	0%	0%	45.7%	0%	0%	0%	0%
Stretch film	61%	100%	488	2,576	0	0	1,925	0	0	0	0
Product Packaging	29%	48%	216	123	0	0	1,498	0	0	0	0
Storage & Distribution	32%	52%	238	2,453	0	0	427	0	0	0	0
Shrink film	39%	100%	261	910	0	0	1,007	0	0	0	0
Product Packaging	19%	48%	140	142	0	0	653	0	0	0	0
Storage & Distribution	21%	52%	154	767	0	0	354	0	0	0	0

Table 2-27. Canadian Stretch & Shrink Film - Current Market Share by Material

Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Current Market Share by Material (% Per Functional Unit)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
STRETCH & SHRINK FILM											
Stretch & Shrink Film (weight kg)	100%		100%	0%	0%	0%	0%	0%	0%	0%	0%
Stretch film	61%	100%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Product Packaging	29%	48%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Storage & Distribution	32%	52%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Shrink film	39%	100%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Product Packaging	19%	48%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Storage & Distribution	21%	52%	100%	0%	0%	0%	0%	0%	0%	0%	0%

Table 2-28. Canadian Stretch & Shrink Film - Substitution Weights by Material

Categories & Subcategories	Market Share by Type per Category	Market Share by Type per Subcategory	Substitution Weights by Material (Million kg)								
			All Resins	Tinplate	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
STRETCH & SHRINK FILM											
Stretch & Shrink Film (by wt for equiv fct)	100%		82.6	54.3%	0%	0%	45.7%	0%	0%	0%	0%
Stretch film	61%	100%	53.8	284	0	0	212	0	0	0	0
Product Packaging	29%	48%	23.8	13.6	0	0	165	0	0	0	0
Storage & Distribution	32%	52%	26.3	271	0	0	47.1	0	0	0	0
Shrink film	39%	100%	28.8	100	0	0	111	0	0	0	0
Product Packaging	19%	48%	15.4	15.7	0	0	72.0	0	0	0	0
Storage & Distribution	21%	52%	17.0	84.6	0	0	39.1	0	0	0	0

CHAPTER 3. LIFE CYCLE INVENTORY

3.1. OVERVIEW

This life cycle inventory (LCI) quantifies the total energy requirements, energy sources, and atmospheric pollutants from the life cycle of the material packaging systems investigated in this analysis. The purpose of this chapter is to define the LCI model construction and data sources for the investigated types of plastic and non-plastic packaging. For each packaging type, the chapter describes the product system specifications and a discussion of the life cycle models constructed by life cycle stage.

3.1.1. Methodology for Data Compilation/Verification

The accuracy of the study is directly related to the quality of input data. The data-gathering process for each system considered the identity of materials and processes necessary to manufacture, distribute, recycle, and dispose of the investigated packaging types. During the data compilation phase, Franklin Associates had correspondence with ACC, CPIA, and other industry experts to ensure that all aspects of the substitution model and assumptions made in the selection of LCI data were clearly understood and consistent with the system boundaries of this study.

Each unit process in the life cycle study is constructed independently of all other processes. This allows objective review of individual data sets before their contribution to the overall life cycle results has been determined. Also, because these data are reviewed individually, assumptions are reviewed based on their relevance to the process rather than their effect on the overall outcome of the study. LCI Data from credible published sources or licensable databases are used wherever possible to maximize transparency and duplicatability. Data sets from Franklin Associates' North American industry average database were used for processes and materials where reliable current published data were not available. This database has been developed over a period of years through research for many LCI projects encompassing a wide variety of products and materials. Another advantage of the database is that it is continually updated. For each ongoing LCI project, verification and updating is carried out for the portions of the database that are accessed by that project.

3.2. COMPARISON OF PACKAGING SYSTEM DISTRIBUTION SPECIFICATIONS

The boundaries account for transportation requirements between all life cycle stages. Because of the very broad scope of packaging products covered by the project, some broad simplifying assumptions have been made regarding transportation distances and modes for shipping packaging from converters to fillers in both the US and Canada. These data were compiled by Franklin Associates from existing public and private LCA studies and national census data and are representative of average requirements for US and Canadian supply chains for packaging materials, respectively. These specifications include: 1) average distances from resource extraction and/or processing to materials fabrication and/or package converting facilities in the production and recycling phases, and 2) average distances and packer truck densities for disposal management in the EOL phase. North American Industry Classification System (NAICS) codes were used to estimate distances for transport of finished packaging to fillers for each country based on the number of manufacturing facilities for each type of packaging in each country. The compiled data were used by Franklin Associates to calculate average transportation requirements for each life cycle step in each geographic scope. Truck transport in North America is then modeled as tonne-km of combination truck transport, fueled by fossil-derived diesel.

3.3. PLASTIC PACKAGING SYSTEMS

3.3.1. Production of Plastic Resins

Cradle-to-virgin conventional PET resin production is based on a life cycle inventory Franklin Associates conducted for the Plastics Division of the American Chemistry Council (2010).[107] This data represents the most recent LCI data for plastics production in North America. These data are publicly available through the US LCI database (www.nrel.gov/lci) and include production of the investigated resins:

- Low-Density Polyethylene (LDPE)
- High-Density Polyethylene (HDPE)
- Polypropylene (PP)
- Polyvinyl Chloride (PVC)
- Polystyrene (PS)
- Expanded Polystyrene (EPS)
- Polyethylene Terephthalate (PET)

3.3.2. Plastic Converting Processes

This analysis uses plastic converting LCI data from Franklin Associates' Private LCI Database.

3.3.2.1. Film & Sheet Extrusion

Plastic film is made by the extrusion of resin followed by the pulling and cooling of film. Plastics extrusion is a manufacturing process in which raw plastic material is melted and formed into a continuous profile. In the extrusion of plastics, resin is gravity fed from a top-mounted hopper into the barrel of the extruder. The material enters through the feed throat and comes in contact with the screw. The rotating screw (turning at approximately120 rpm) forces the resin into a heated barrel. The molten plastic leaves the screw and travels through a screen that removes contaminants. The molten plastic is then forced through an annular slit die, usually vertically, to form a thin walled tube. Air is blown through a hole in the center of the die to blow up the tube. A high-speed air ring is

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[107] American Chemistry Council. 2010. Cradle-to-Gate LCI of Nine Plastic Resins and Two Polyurethane Precursors. Franklin Associates, A Division of ERG.

on top of the die and blows onto the hot film to cool it. The tube of film then continues upwards, continually cooling, until it passes through nip rolls where the tube is flattened. The edges of the tube are slit to produce two flat film sheets. The film is then wound onto reels. Data for film extrusion are based on confidential industry data collected from 1992 through 2005 and APME data collected in the 1990s.[108,109]

3.3.2.2. Blow Molding

Hollow plastic parts are formed by a process called blow molding. Melted plastic is extruded into a hollow tube (a parison) and captured by closing it into a cooled metal mold. Low-pressure air (typically 25 to 150 psi) is blown into the parison, inflating it into the shape of the desired container. Once the plastic has cooled, the mold can be opened and the part ejected. Data for extrusion blow molding are based on confidential industry data collected from 1992 through 2005 and APME data collected in the 1990s.[110,111]

3.3.2.3. Injection Stretch Blow Molding

The first step in the injection stretch blow molding (ISBM) process is production of a preform using the injection mold process (see Injection Molding). The preform is made up of a fully formed bottle/jar neck with a thick tube of polymer attached, which eventually forms the body. The preform is heated above the glass transition temperature and stretched mechanically with a core rod. First, low pressure air is introduced to blow a bubble. After the stretch rod is fully extended, high-pressure air blows the expanded plastic bubble into the shape of the blow mold. Injection stretch blow molding is commonly used to produce polyethylene terephthalate (PET) beverage bottles, as the polymer is strengthened when stretched, allowing it to keep its shape under pressures e.g., created by carbonated beverages. ISBM data are based on confidential industry data collected from 1992 through 2005 and APME data collected in the 1990s.[112,113]

3.3.2.4. Thermoforming

Like injection molding, thermoforming is a principal fabrication technique for rapidly creating large quantities of plastic articles. This technique is relatively simple and well established. A sheet of extruded plastic is fed, usually on a roll or from an extruder, into a heated chamber where the plastic is softened. The sheet is then clamped over a negative mold while in a softened state and then cooled. A punch loosens the plastic forms and eliminates sheet webbing that may be recycled back into the process. Thin-gauge sheet or

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[108] Franklin Associates, A Division of ERG. Data from industry sources collected from 1992 through 2005.

[109] Boustead (1997). Eco-Profiles of the European Plastics Industry, Report 10: Polymer Conversion. Association of Plastics Manufacturers in Europe (APME).

[110] Franklin Associates, A Division of ERG. Ibid.

[111] Boustead (1997). Ibid.

[112] Franklin Associates, A Division of ERG. Data from industry sources collected from 1992 through 2005.

[113] Boustead (1997). Eco-Profiles of the European Plastics Industry, Report 10: Polymer Conversion. Association of Plastics Manufacturers in Europe (APME).

film is used in thermoforming to produce disposable/recyclable food, medical and general retail products such as containers, cups, lids, and trays. Thick-gauge sheet is used to produce larger, usually more permanent, items such as plastic pallet, truck beds, and spas. Thermoforming data are based on primary data that were compiled for the Rigid Plastics Packaging Group (RPPG) in 2011 and are available through the US LCI Database.[114]

3.3.2.5. Injection Molding

Injection molding is one of the primary fabrication techniques for rapidly creating large quantities of plastic articles ranging from disposable food containers to high precision engineering components. For this manufacturing process, plastic is fed by a rotating screw under high pressure into a mold that is the inverse shape of the desired product shape. The melted plastic solidifies when it comes into contact with the cooled wall of the mold. The mold opens and the finished part is ejected, completing the cycle. Injection molding data are based on primary data that were compiled for the Rigid Plastics Packaging Group (RPPG) in 2011 and are available through the US LCI Database.[115]

3.4. NON-PLASTIC PACKAGING SYSTEMS

3.4.1. Steel Packaging

3.4.1.1. Steel Production

This analysis uses steel data from Franklin Associates' private LCI database. The basic raw material for steel manufacture is iron ore. This material is usually found in flat-lying or gently sloping beds not more than 20 feet thick. Open pit mining accounts for 90 percent of the iron ore extracted at present, with the remainder being recovered from deep vertical shaft mines. For production of virgin pig iron, iron-ore, coke, and fluxes are charged into a blast furnace, where the iron ore is reduced. The reduced iron melts and runs down to the bottom of the hearth. The flux combines with the impurities in the ore to produce a slag which also melts and accumulates on top of the liquid iron in the hearth

Since the mid 1970s, the blast oxygen furnace (BOF) process has seen widespread use in steel making. This process offers the advantage of using both virgin pig iron and scrap or recycled steel as feedstock. In the oxygen steelmaking process, high-purity oxygen is blown under pressure through, onto or over a bath containing hot metal, steel scrap and fluxes to produce steel.[116] Hot metal composition and temperature are the most important variables that determine the percentage of scrap that can be charged to a heat. Typically, most pneumatic furnaces (of which the BOF is an outgrowth) consume 20 to 35 percent of

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[114] RPPG (2011). Life Cycle Inventory of Plastic Fabrication Processes: Injection Molding and Thermoforming, Prepared by Franklin Associates, A Division of ERG for the Rigid Plastic Packaging Group (RPPG) of the American Chemistry Council (ACC), September, 2011.

[115] RPPG (2011). Life Cycle Inventory of Plastic Fabrication Processes: Injection Molding and Thermoforming, Prepared by Franklin Associates, A Division of ERG for the Rigid Plastic Packaging Group (RPPG) of the American Chemistry Council (ACC), September, 2011.

[116] US Steel (1985). The Making, Shaping and Treating of Steel, 10th Edition. United States Steel Corporation. Published by the Association of Iron and Steel Engineers. Pittsburgh, PA. 1985.

the total metallic charge as cold scrap.[117] On average, about 28.5 percent of the total metallic material charged to BOFs in North America is cold scrap.[118] About 60 percent of North American steel production is by the BOF route.

The primary sources of heat for oxygen steel making processes are from the hot metal charged to the furnace and from the oxidation of carbon, silicon, manganese, phosphorus, iron and other elements contained in the hot metal charge. Minimal quantities of natural gas and coke oven gas are used to supply supplemental heat to the furnace and to preheat ladles and casters. The following assumptions were made in analyzing available data for the production of raw steel from the BOF route:

- Coke oven gas is used as a fuel at a rate of 1.23 kilograms of gas per 1,000 kilograms of raw steel. A density of 0.43 kilograms per cubic meter is assumed for the gas;[119]
- Energy requirements and environmental emissions for heating and operating ladles and casters are included with those for the BOF;
- Coproduct credit is given on a weight basis for the slag produced in the BOF. This material is used as an input to sinter production and directly into the blast furnace for its iron content. Because the coproduct credit is given on a weight basis, the output from the BOF is increased to account for the input of BOF slag into sinter production and the blast furnace.
- Carbon dioxide emissions from the oxidation of carbon in the pig iron are calculated assuming the pig iron enters the BOF with a carbon content of about 4.5 percent[120] and the raw steel leaving the BOF has a carbon content of about 0.75 percent. It is also assumed that all of the carbon is oxidized to carbon dioxide.

While a blast furnace and BOF are used to produce raw steel from mainly virgin materials, an EAF is used for making raw steel from process and recycled scrap. LCI data for production of steel from an EAF are also from Franklin Associates’ private LCI database. The EAF is capable of accepting a charge of nearly 100 percent scrap. The EAF model reflects a charge to the electric furnace of virtually all scrap with small amounts of limestone and lime added. These materials are melted by the conversion of electric energy into heat. Current is brought to the furnace through large carbon electrodes, and the energy is converted to heat in the furnace. Approximately, 40 percent of US steel production is by the EAF route.

3.4.1.2. Steel Sheet Manufacture & Sheet Converting

This analysis uses steel sheet manufacturing data from Franklin Associates’ private LCI database. After the raw steel leaves the BOF, it proceeds through a series of milling processes before emerging as steel strip. A vacuum degassing process refines the steel from

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[117] US Steel (1985). Ibid.

[118] Information conveyed through personal conversation with Bill Heenan, The Steel Recycling Institute. Pittsburgh, Pennsylvania. May through August, 1994.

[119] Loison, Roger (1989). Coke- Quality and Production, Buttersworth Books, London.

[120] USBM (1984). Mineral Facts and Problems, Bureau of Mines, US Department of Interior.

the furnace before it enters the casting step. Continuous casting is used almost exclusively to produce slabs for flat rolled products from raw steel produced in the basic oxygen process.[121] The continuously cast slabs pass through the hot rolling mill and then the cold rolling mill to produce sheet. The surface of the steel is cleaned by an acid treatment (using hydrochloric acid) called pickling. Finally, the steel strip is coated with a layer of tin. The tin provides a barrier to corrosion at a relatively low cost. For this data module, it is assumed that 3 kilograms of tin are applied per 1,000 kilograms of steel, or 0.3 percent of the weight of the finished steel.

Available data for steel milling operations indicated the use of coke oven gas to supply energy for reheating the steel during hot milling. For this analysis, this heat is assumed to be supplied by natural gas instead of coke oven gas.

Steel caps for containers are modeled based on Franklin Associates' private LCI database and are representative of steel production in a basic oxygen furnace (BOF). Cap production also includes the processes of steel sheet manufacture and steel cap stamping.

Fabrication data for two-piece cans are adapted from ecoinvent steel forming processes to the North American context by linking ecoinvent process and transportation energy requirements to North American data sets for production and combustion of corresponding process and transportation fuels.

3.4.2. Aluminum Packaging

3.4.2.1. Primary & Secondary Aluminum Production

This analysis uses aluminum data from Franklin Associates' private LCI database adapted from a 2013 LCA on semi-finished aluminum products conducted for the Aluminum Association.[122] Before it can be used in the manufacture of metallic aluminum, bauxite ore must be refined to nearly pure aluminum oxide, usually called alumina. The Bayer process is the preferred method for bauxite refining. Bauxite is crushed and dissolved in digesters using strong caustic soda and lime solution. The undissolved residue, known as red mud, is filtered out. Sodium aluminate remains in solution, where it is hydrolyzed and precipitated as aluminum hydroxide, which is then calcined to alumina in a rotary kiln. Smelting is the reduction of refined alumina to metallic aluminum by the electrolytic separation of aluminum from its oxide. The process is carried out in a long series of electrolytic cells carrying direct current. The alumina is dissolved in a molten bath of cryolite (an electrolyte) and aluminum fluoride (which increases the conductivity of the electrolyte). Molten aluminum is discharged from a smelter into the holding and ingot casting facility. In this step, molten metal is typically combined with high quality, in-house scrap and then cast into aluminum ingots.

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[121] Information conveyed through personal conversation with Bill Heenan, The Steel Recycling Institute. Pittsburgh, Pennsylvania. May through August, 1994.

[122] Aluminum Association. December 2013. The Environmental Footprint of Semi-Finished Aluminum Products in North America, see: http://www.aluminum.org/sites/default/files/LCA_Report_Aluminum_Association_12_13.pdf.

Specific electrical grids used in the aluminum life cycle model are shown in Table 3-1. As shown in Table 3-2 the bauxite grid mix is a composite of country grid mixes from where the material is sourced. Similarly, alumina production grids are modeled based on a mix of geographic locations (also shown in Table 3-2). Separate smelting electrical grid models are applicable for North America and imports based on the consumption of the aluminum industry reported in the Aluminum Association LCA (actual unit process data assumed to be equivalent for North America and imports from other countries). Since smelting is a very energy intensive process, facilities are typically located to take advantage of hydropower resources.

Table 3-1. Electricity Grids Specific to Steps in the Production of Primary Aluminum[123]

Energy Source	Bauxite Mining	Alumina Production	Aluminum Smelting, Imported	Aluminum Smelting, Domestic
Coal	10.6%	37.9%	7.5%	24.0%
Hydro	22.3%	22.2%	72.3%	75.1%
Nuclear	1.1%	12.0%	2.8%	0.5%
Oil	52.8%	4.9%	0.1%	0%
Natural Gas	9.5%	18.7%	17.2%	0.5%
Solar PV	0.01%	0.1%	0%	0%
Wind	0.85%	1.8%	0%	0%
Biomass	2.0%	1.9%	0%	0%
Geothermal	0.06%	0.2%	0%	0%

Table 3-2. Bauxite Sourcing[124] **& Alumina Production by Country**[125]

Country	Bauxite Sourcing	Alumina Production
Australia	----	16.6%
Brazil	20.3%	6.8%
Canada	----	1.8%
France	----	0.7%
Germany	----	2.4%
Guinea	26.4%	----
Jamaica	53.3%	2.4%
North America	----	53.6%
Suriname	----	14.2%
Venezuela	----	1.6%

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[123] Ibid.

[124] Ibid.

[125] Ibid.

Secondary aluminum production processes are modeled based on data from the 2010 aluminum can LCA report sponsored by the Aluminum Association. Processes include scrap preparation (i.e. shredding, decoating) as well as remelting and secondary ingot casting. There is a 4.6 percent loss of scrap material during the remelting and secondary ingot casting process.

3.4.2.2. Aluminum Converting

Data for converting aluminum into can sheet and finished cans are derived from Franklin Associates' adaptation of process data in the Aluminum Association 2010 US LCA update.[126] The average aluminum can recycled content is 67.8% based on data from the Aluminum Association 2010 LCA. Aluminum foil converting data is from a 2013 European study[127], adapted to use North American data sets for modeling inputs.

3.4.3. Glass Packaging

This analysis uses glass data from Franklin Associates' private LCI database based information from the Glass Packaging Institute. Glass sand, the predominant raw material for glass manufacture, is the source of almost all of the silicon dioxide present in the finished glass. Silicon dioxide accounts for approximately 70 percent by weight of finished glass. Glass sand is a high purity quartz sand with high silica content and typically less than one percent of iron oxide, chromium compounds, and alumina, calcium, or magnesium oxides.

Glass is manufactured by mixing glass sand, limestone, soda ash, feldspar, small amounts of other minerals and "cullet"[128] into a homogenous mixture, which is then fed to the melting furnace. This is typically a natural gas-fired, continuous melting, regenerative furnace. Fuel is conserved by using brick checkers to collect furnace exhaust gas heat, then using the hot checkers to preheat the furnace combustion air. The melting furnace contributes over 99 percent of the total air emissions from a glass plant, including particulates, sulfur oxides, nitrogen oxides, volatile organic compounds, and carbon monoxide. The molten glass is directed to forming machines where it is cut into sections called gobs and shaped into containers. The container undergoes finishing, annealing, inspection, and then preparation for shipment.

In-house cullet is melted in a glass furnace in a manner similar to the virgin inputs to a conventional batch operation. It is widely recognized that cullet melts at a lower temperature than virgin glass materials. Because the glass furnace accounts for a large

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[126] Aluminum Association. May 2010. Life Cycle Impact Assessment of Aluminum Beverage Cans, see: http://www.aluminum.org/Content/ContentFolders/LCA/LCA_REPORT.pdf

[127] European Aluminium Association. April 2013. Environmental Profile Report for the European Aluminium Industry, see: https://european-aluminium.eu/media/1329/environmental-profile-report-for-the-european-aluminium-industry.pdf

[128] Cullet is imperfect articles of glass, trim, or other glass pieces that are melted and used in new glass products.

portion of the manufacturing energy for the container, any energy savings in the furnace can significantly affect the total energy demand. Cullet generated in-house is returned to the furnace. Although in-house scrap has been the major source of cullet for many plants, mandatory deposit conditions and more active collection programs have increased the amount of postconsumer cullet recovered (see Section 3.5.1. Plastic Recycling). Postconsumer cullet must be recovered, sorted, and crushed before it is added to the virgin material. The average glass containers in this study are made with 27 percent postconsumer cullet. After adjustment for converting yield, the average container glass recycled content in the US is modeled as 25 percent. [129,130]

3.4.4. Paper, Paperboard, & Corrugated Packaging

3.4.4.1. Raw Pulp Material Inputs

Raw materials for production of paper, paperboard, and corrugated packaging include: virgin pulpwood, either purchased or cut from forestry resources and delivered to pulp and paper or containerboard mills; and recovered fiber from postconsumer fiber-based packaging.[131] Recovered fibers must be sorted, de-contaminated, and cleaned mechanically before being processed.

The ratio of each type of forest product (i.e., soft- and hardwood logs, chips, and residues) from forest regions that are used as virgin inputs at North American pulp and paper or containerboard mills are estimates compiled by Franklin Associates from publicly available statistics compiled by the American Forest & Paper Association (AF&PA) and the US International Trade Commission (USITC).[132,133] The LCI data for producing the virgin material and hogfuel inputs to the pulp and paper and containerboard mills are represented by updated forestry LCI data from CORRIM Phase I and Phase II reports.[134,135] The updated CORRIM LCI data include seeding, cultivation, and harvesting of lumber

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[129] Owens-Illinois, Inc. 2011. Life Cycle Assessment of Glass, Aluminum, and PET Containers.

[130] US EPA. The Quest for Less. EPA530-R-05-005 June 2005.

[131] Note there is a distinction between virgin pulpwood, resources extracted from forestry operations, and virgin woodpulp, pulp produced in a digester from virgin pulpwood.

[132] AF&PA (2009). Table 17. Pulpwood Consumed in Wood Pulp Manufacture, Paper, Paperboard, & Pulp, 2008 Statistical Summary. American Forest & Paper Association, Washington, DC, September 2009.

[133] USITC (2002). Table 2. US Annual Wood-Pulping Capacity by Region, 2000, Industry & Trade Summary, Wood Pulp and Waste Paper, Office of Industries, US International Trade Commission, Washington, DC. USITC Publication 3490, February 2002. Original Source of data quoted as: 2000 Lockwood-Post Directory, San Francisco, Miller Freeman, Inc. 1999. Pp. 37-152.

[134] Bowyer J, Briggs D, Lippke B, Perez-Garcia J, Wilson J (2004). Life Cycle Environmental Performance of Renewable Materials in Context of Residential Building Construction: Phase I Research Report. Consortium for Research on Renewable Industrial Materials, CORRIM Inc. Seattle, WA. Report modules accessed at: http://www.corrim.org/pubs/reports/2005/Phase1/index.asp.

[135] Lippke B, Wilson J, Johnson L, Puettmann M (2009). Phase II Research Report. Life Cycle Environmental Performance of Renewable Materials in the Context of Building Construction. Consortium for Research on Renewable Industrial Materials, CORRIM Inc. Seattle, WA. Report modules accessed at: http://www.corrim.org/pubs/index.asp.

from four US forestry regions: the South East, the Pacific North West, the Inland North West, and the North East-North Central areas.
Franklin Associates uses LCI data compiled for the Environmental Defense Fund (EDF) ‘Paper Calculator’ (now maintained by the Environmental Paper Network, EPN) to reflect the composition of bleaching chemicals for pulp inputs. Elemental chlorine gas was banned for use in pulp bleaching by the US Environmental Protection Agency (EPA) in the 1990s Pulp and Paper Cluster Rules and the EDF data indicate that the average bleaching methods used are elemental chlorine free (ECF) and use chlorine dioxide (D) and oxygen (O) as the bleaching agents. These agents work in oxidation reactions that break apart the lignin molecules that would otherwise lead to emissions such as dioxin and other chlorinated organics, leaving only water-soluble organic compounds and/or chloride salts.

Wood energy of material resources (EMR) differentiates the energy of wood used as material input to the paper, paperboard, and/or corrugated product (e.g., virgin pulpwood) from the energy of wood that is expended (e.g., hogfuel used at production). The total energy value of the wood input to the mills was calculated by multiplying the quantity of wood inputs by its higher heating value (HHV). The HHV assumed in this analysis, based on information from the US EPA, was 9,000,000 Btu per tonne or 10.5 MJ per kilogram of greenwood assuming average moisture content of 50 percent.[136] The portion of the wood energy considered EMR was determined based on the amount of input wood fiber that ends up in the output paper and paperboard; the remainder of the wood input is assumed to be converted to process energy at the mill, e.g., through combustion of bark and other wood wastes as well as combustion of black liquor containing lignin from the pulping process.

The CORRIM forestry LCI data used to model production of virgin fiber inputs for paper, paperboard, and corrugate material indicate a carbon sequestration credit at the forest. Franklin Associates’ has removed these credits for the modeling of the paper, paperboard, and corrugated materials. Franklin Associates’ methodology for carbon balance of forestry and agricultural products is to reflect carbon storage specific to the lifespan of the product and carbon sequestration specific to the composition of the product incorporating the biomass-derived materials. Carbon storage/sequestration in a product is considered only when the carbon in the bio-component of the fiber-based product is not biodegradable and/or is not re-emitted to the atmosphere within the 100-year assessment period. For example, carbon storage is considered to occur in the production phase of corrugated materials due to the average level of retention of recovered fiber in these products (i.e., the technosphere). This storage is reflected by considering the carbon portion of recovered fiber—46 percent—multiplied by the average amount of recovered fiber material that is incorporated into the production of a fiber corrugated materials (i.e., average recycled content of fiber corrugated liner and medium per the CPA LCI—41.8 percent). The recovered fiber in corrugated materials is assigned a carbon dioxide storage credit according to the carbon dioxide-to-carbon mass ratio—44 to 12—because it is retained in the technosphere and not released in the assessment period (i.e., closed-loop recycled into the fiber corrugated material system). In modeling corrugate materials, the portion of

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[136] AP-42 Emission Factors. External Combustion Sources. Section 1.6 - Wood Residues Combustion in Boilers. Supplement G, 2001.

carbon in fiber that leaves the corrugated product system and cascades to other fiber–based product systems (e.g., paperboard) receives neither carbon dioxide credits nor burdens.

3.4.4.2. Paper & Paperboard Production

LCI data for the production of virgin and recycled paper and paperboard used in this model was originally developed by Franklin Associates for the final version of the new Full Paper Calculator Model submitted to Environmental Paper Network (EPN).[137] Where applicable, paper and/or paperboard coatings contain kaolin clay, titanium dioxide, and various binders and extenders. According to the Carton Council[138], polyethylene coatings are used on refrigerated cartons for beverages such as milk and juice, with an average carton composition of 20% polyethylene and 80% bleached paperboard. The average composition of aseptic cartons, used for various beverages, soups, etc., is 74% paperboard, 4% aluminum, and 22% polyethylene, also according to the Carton Council.

Carton converting data is based on primary data from Franklin Associates' private LCI Database. Carton converting processes include cutting the laminated and printed boardstock into carton blanks and forming the bottom seal. The folded blanks are then shipped to the filling location.

3.4.4.3. Corrugated Material Production

Foreground data for average North American corrugated materials are adapted from a gate-to-gate peer-reviewed life cycle inventory of converted corrugated boxes conducted for the Corrugated Packaging Alliance (CPA) in 2014.[139] LCI data for containerboard liner and medium are based on information gathered from 46 mills representing 78 percent of overall US production in 2010. LCI data for box conversion are based on data from 173 converting facilities representing nearly 30 percent of overall US production in 2010. The CPA study indicates the presence of bleached pulp inputs to average corrugated materials. Franklin Associates estimates that about ten percent of pulp inputs to the containerboard mill are bleached pulp based on US exports of corrugated liner board in 2006.[140]

At the containerboard mills, the raw virgin and recovered materials are cooked in a digester with pulping chemicals to produce wood pulp and liquor. The pulp is removed and refined n a series of screening and washing steps for the containerboard machine, while the spent liquor can be recycled as fuel for the digester. At the containerboard machine, the final pulp slurry is spread out to drain and then fed through a series of drying rollers and refined with the desired starch, chemical additives, and/or coatings/

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[137] Environmental Paper Network. Paper Calculator. (See: http://www.papercalculator.org/).

[138] http://www.recyclecartons.com/why-juice-box-milk-carton-recycling-matter/#text-20

[139] NCASI (2014). Life Cycle Assessment of U.S. Average Corrugated Product, Final Report. Prepared for the Corrugated Packaging Alliance (CPA), a joint venture of the American Forest & Paper Association (AF&PA), the Fibre Box Association (FBA), the Association of Independent Corrugated Converters (AICC), and TAPPI. April 24, 2014.

[140] United States International Trade Commission, US Domestic Exports Annual Data for 2006.

The rolls of containerboard produced at the mill are shipped to converting plants, where they are processed and converted into corrugated products. The containerboard medium is heated and steam–treated to soften the material and then drawn between gear-like cylinders to give it shape. Starch is applied and the flutes are glued to liners in layers. The corrugated product is dried, cut, and converted to box sheet which is stacked on pallets for shipping.

3.4.4.4. Molded Pulp Production

Molded pulp packaging items are typically made from old newspaper (ONP) and/or fiber from recovered corrugated material, i.e. old corrugated cardboard (OCC). These recovered fiber materials are pulped, formed, and dried to produce containers, packaging shapes, cartons, and trays.

3.4.5. Cork, Rubber, Textile, Wood, and Cellophane Packaging

3.4.5.1. Cork Production

Data for the production of raw cork is from the ecoinvent v.2.0 LCI database.[141] Cork is extracted from wild cork oak trees. It is primarily produced in the Mediterranean and in Northern Africa. No chemical products are used for the cultivation or stripping, i.e., harvesting steps. For use in beverage container applications, cork planks must be seasoned or boiled to remove organic solids and render the correct moisture content in the cork material. Once the cork planks are seasoned, they may be punched with molding cylinders and the resulting stoppers are washed in hydrogen peroxide and dried.[142] Per the incorporation of the ecoinvent data, cork production in this analysis includes the decadal, manual harvesting of cork and motor-manual thinning and final cutting of the trees. Transport for harvesting and thinning processes are also included. German and Portuguese forestry processes are used as a proxy to represent European cork production.

3.4.5.2. Rubber Production

Data for the production of rubber in North America is based on the process of natural rubber production from Franklin Associates' Private LCI Database.

3.4.5.3. Textile Production

Data for the production of cotton in North America are based on cotton cultivation and harvesting processes as available in the US LCI Database. The data reflects seed production, tillage, fertilizer and pesticide application, crop residue management, irrigation, and harvesting. The process is representative of cotton production in the US for

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[141] Ecoinvent Centre (2007). Ecoinvent data v.2.0 Final reports ecoinvent 2000. No. 1-15. Swiss Centre for Life Cycle Inventories, Dubendorf, 2007, retrieved from: www.ecoinvent.ch.

[142] PwC/Ecobilan (2008). Evaluation of the Environmental Impacts of Cork Stoppers versus Aluminum and Plastic Closures: Analysis of the Life Cycle of Cork, Aluminium and Plastic Wine Closures, Report Prepared for Corticeira Amorim, SGPS, SA by PricewaterhouseCoopers/ECOBILAN, October 2008.

the data years 1998 to 2000. The impacts of producing a kilogram of seed are assumed equivalent to producing a kilogram of lint.

Data for textile fabrication from cotton are adapted to the North American context from the ecoinvent v.2.0 LCI Database. These processes reflect carding, spinning, and mechanical cleaning of cotton yarn as well as the weaving of cotton yarn into textile.

3.4.5.4. Wood Production

The LCI data for producing the dried lumber used in plastic packaging substitutes are represented by updated forestry LCI data from CORRIM Phase I and Phase II reports.[143,144] The updated CORRIM LCI data include seeding, cultivation, and harvesting of lumber from four US forestry regions: the South East, the Pacific North West, the Inland North West, and the North East-North Central areas. Wood packaging material substitutes only apply to rigid intermediate bulk containers (RIBCs) projected to be replaced by wooden IBCs. Data for the conversion of dried lumber and particle board into wood pallets from Franklin Associates' Private LCI Database are used as a proxy for the production of wooden shipping crates.

3.4.5.5. Cellophane Production

Cellophane is produced from bleached wood pulp using a viscose process. After the pulp slurry ages in caustic bath to open the cellulose crystallites, carbon disulfide is added to form a thick viscose liquid. The viscose is filtered, spread into sheets, and de-aerated using vacuum. The cellophane film is formed when the viscose is pushed through blades placed in a weak sulfuric acid bath. After removal from the bath, the film is cleaned, bleached, softened, and dried. It is then coated with solvents for waterproofing and heat sealing and cut to order. Data for the production of cellophane in North America is based on Franklin Associates' Private LCI Database.

3.5. RECYCLING & END-OF-LIFE WASTE MANAGEMENT

3.5.1. Plastic Recycling

3.5.1.1. Plastic Packaging Recovery Rates

Recovery rates for plastic packaging are based on national statistics for individual resins in various types of packaging applications. For the US, recovery rates are based on recovery

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[143] Bowyer J, Briggs D, Lippke B, Perez-Garcia J, Wilson J (2004). Life Cycle Environmental Performance of Renewable Materials in Context of Residential Building Construction: Phase I Research Report. Consortium for Research on Renewable Industrial Materials, CORRIM Inc. Seattle, WA. Report modules accessed at: http://www.corrim.org/pubs/reports/2005/Phase1/index.asp.

[144] Lippke B, Wilson J, Johnson L, Puettmann M (2009). Phase II Research Report. Life Cycle Environmental Performance of Renewable Materials in the Context of Building Construction. Consortium for Research on Renewable Industrial Materials, CORRIM Inc. Seattle, WA. Report modules accessed at: http://www.corrim.org/pubs/index.asp.

and generation statistics for plastic municipal solid waste (MSW) in the US.[145] For the Canadian geographic scope, recovery rates are calculations based on various national statistics or reflect US rates as proxies if Canadian data were unavailable. Tables with recovery rates for plastic and substitute packaging in the US and Canada are presented at the end of Section 3.5.1. Zeroes in the tables either mean that the recovery rate is zero or that there is no recovery because there is no packaging of that type in that category to be recovered. The life cycle models take into account the losses that occur during reprocessing of the recovered material, so that recycling credits are given only for the net amount of useful secondary material produced from the recovered material.

US Plastic Recovery Rates:

- Beverage Containers, Bottles and Jars: The MSW data indicates that recovery rates specifically for HDPE, PP, and PET *bottles/jars* are 27.5, 8.33, and 29.2 percent, respectively, and these rates are assumed for these resins in both beverage and non-beverage packaging applications. As the *bottle/jar* category does not track any other resins explicitly, Franklin Associates assumes recovery for any LDPE, PVC, and PS beverage and non-beverage bottles and jars is negligible.
- Caps & Closures: The MSW table notes that PP caps and lids are recovered with PET *bottles/jars* and included in that recovery estimate, so a 29.2 percent recovery rate is applied to PP caps and closures used on PET bottles and jars. Franklin Associates assumes the recovery rates indicated for HDPE, PP, and PS *other plastic packaging*, 6.67, 1.80, and 5.88 percent, respectively, apply to these caps and closures applications.
- Carrier Bags/Stretch & Shrink: The recovery rates indicated for LDPE and HDPE *bags/sacks/wraps*, 17.6 and 4.35 percent, respectively, have been applied to both carrier bags and stretch and shrink film product categories in this analysis.
- Other Rigid: *Other plastic containers* recovery rates are 19.3 and 8.33 percent, for HDPE and PP respectively, and these rates are applied to these resins in all rigid bulk container and non-bulk plastic tub, cup, and bowl applications with the exception of PP tubs/cups/bowls with a rate of 5.25%, reflecting negligible recovery rates for PP *nondurable goods, plastic plates, and cups*. The overall *other plastic packaging* recovery rate of 16.4 percent is assumed for PET tubs/cups/bowls as the MSW source data aggregates PET cups into this category. The MSW recovery rates indicated for HDPE, PP, and PS/EPS *other plastic packaging*, 19.3, 8.33, and 5.88 percent, respectively, are assumed to apply to other non-bulk and protective rigid packaging.
- Other Flexible: Recovery rates indicated for HDPE, PP, and PS *other plastic packaging*, 6.67, 1.80, and 5.88 percent, respectively, apply to all other flexible packaging (i.e., converted flexible packaging; protective flexible packaging; and bulk flexible packaging). The recovery rate for PET strapping is assumed to be the same as for PP strapping.

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[145] US EPA (2011). Table 7. Plastics in Products in MSW, 2010, Municipal Solid Waste Generation, Recycling, and Disposal in the United States Detailed Tables and Figures for 2010. Compiled by Franklin Associates, A Division of ERG.

Canadian Plastic Recovery Rates:

- Beverage Containers, Bottles and Jars: The recovery rates applied — 25.7 and 58 percent for HDPE and PET beverage containers, respectively, and 21.7, 18.3, and 39.1 percent for HDPE, PP, and PET non-beverage bottles and jars, respectively, with a higher PET recovery rate, 62 percent, for beer and soft drinks and a higher HDPE recovery rate, 52.8 percent, for milk jugs — are calculated from total recovered weight as a percent of total weight generated as reported by Canadian provinces in EPIC 2004 and CM Consulting.[146,147]
- Caps & Closures: The recovery rates applied, 6.67, 1.80, and 5.88, percent for HDPE, PP, and PS, respectively, are proxies from the US EPA MSW 2010 data; for PET caps, the recovery rate is assumed to be equivalent to that calculated for PET beverage containers, 62.0 percent, as these caps are commonly recovered with their containers.
- Stretch & Shrink: The rates indicated for LDPE and HDPE *bags/sacks/wraps*, 17.6 and 4.35 percent, respectively, in the US EPA MSW 2010 data are used as proxies for Canadian recovery of films in this analysis.
- Carrier Bags: The average of the recovery rates reported by CPIA for polyethylene carrier bags in four provinces was 43.5 percent.[148]
- Other Rigid: *Other plastic containers* recovery rates, 19.3 and 8.33 percent, for HDPE and PP respectively, from the US EPA MSW 2010 data are used as proxies for recovery of the following packaging types in Canada: rigid bulk container and non-bulk plastic bottle, jar, cup, and bowl applications. The overall *other plastic packaging* recovery rate of 16.4 is assumed for PET tubs/cups/bowls as the US EPA MSW 2010 source data aggregates PET cups into this category. The recovery rates indicated for HDPE, PP, and PS/EPS *other plastic packaging*, 19.3, 8.33, and 5.88 percent, respectively, also in the US EPA MSW 2010 data, are used as proxies for recovery of the following packaging types in Canada: other non-bulk and protective rigid packaging.
- Other Flexible: Recovery rates indicated for HDPE, PP, and PS *other plastic packaging*, 6.67, 1.80, and 5.88 percent, respectively, from US EPA MSW 2010 are used as proxies for recovery of the following plastic product applications in Canada: converted flexible packaging; protective flexible packaging; and bulk flexible packaging.

3.5.1.2. Plastic Packaging Recycling LCI

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[146] EPIC (2004). An Overview of Plastic Bottle Recycling in Canada, Prepared for Environment and Plastics Industry Council (EPIC) by CM Consulting, Updated in 2004.

[147] CM Consulting (2012). Who Pays What™: An Analysis of Beverage Container Collection and Costs in Canada, Prepared by CM Consulting, August 2012.

[148] Information on plastic bag recovery rates in Alberta, British Columbia, Nova Scotia, and Prince Edward Island. Accessed at http://www.plastics.ca/Recycling/PlasticBags/ReuseRecycling/index.php

Data for the recycling of plastic resins in North America are based on data compiled by Franklin Associates and available through the US LCI Database.[149] The steps for production of postconsumer recycled resin are divided into three main stages: 1) Recovery: Collection of postconsumer plastic; 2) Sorting and Separation: Sorting of plastics from other co-collected recovered materials (such as paper, steel, and aluminum), and separating mixed plastics into individual resins; and 3) Reclaimer Operations: Processing of the resin by a reclaimer to convert the received material into clean resin ready to be converted into a product.

Postconsumer products that are recovered for recycling are primarily packaging products, including soft drink and milk bottles, other bottles and containers, and other packaging. Collection of these materials occurs through residential curbside or drop-off programs, deposit redemption systems, and commercial collection programs. Once the postconsumer plastics have been collected, they must be separated from other co-collected materials and plastics. Although some recovered plastic is separated by curbside sorting and the use of separate bins at drop-off recycling centers, sorting and separation of plastics most commonly takes place at material recovery facilities (MRFs). Sorting operations at MRFs range from manual sorting of items on a conveyor to highly automated systems using magnets, air classifiers, optical sorters, and other technologies to sort and separate mixed incoming materials. Postconsumer plastics may be separated and baled as mixed plastics, or the facility may have the capability to further sort down to individual resin bales.

Sorted post-consumer plastic is received at manufacturing facilities (e.g., as individual resin bales) and must be disassembled and sorted to remove foreign material. A typical processing sequence includes debaling, grinding, washing, drying, extruding and pelletizing. All reclaimed flake is washed as part of the reclaimer processing operations. Material may be washed before grinding, after grinding, or both. Though reclaimers may use small amounts of various chemicals in the washing process, the amounts are assumed equivalent to less than one percent of the weight of the material washed for this analysis. Clean postconsumer resin is sold in pellet form or as resin flake.

3.5.2. Alternative Packaging Recycling

3.5.2.1. Steel Recovery Rates

The recovery rate for *steel cans* in the US is 67.0 percent as indicated in the US EPA 2010 MSW tables.[150] Franklin Associates assumes this rate applies to all steel use in beverage containers, non-beverage steel bottles and jars, and because they are ferro-magnetic, to steel lids, caps, and closures as well. Per the US EPA MSW data, *other steel packaging* has

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[149] ACC/APR/NAPCOR/PETRA (2011). Life Cycle Inventory of 100% Postconsumer HDPE and PET Recycled Resin from Postconsumer Containers and Packaging, Report prepared by Franklin Associates, A Division of ERG for the Plastics Division of the American Chemistry Council (ACC), the Association of Postconsumer Plastic Recyclers (APR), the National Association for PET Container Resources (NAPCOR), and the PET Resin Association (PETRA), January 2011.

[150] US EPA (2011). Table 7. Plastics in Products in MSW, 2010, Municipal Solid Waste Generation, Recycling, and Disposal in the United States Detailed Tables and Figures for 2010. Compiled by Franklin Associates, A Division of ERG.

a 79.5 percent recovery rate. This rate is assumed to apply to all other steel packaging including use of steel in bulk flexible strapping, rigid tubs/cups/bowls, other non-bulk rigid packaging, and rigid bulk packaging.

The Canadian Steel Producers Association (CSPA) indicates that the recovery rate for steel cans "stands in excess of 60 percent" in 2010.[151] Also, the Steel Recycling Institute (SRI) indicates that the recovery rate for steel cans is 67.1 percent for North America.[152] As in the US geographic scope, Franklin Associates applies a rate of 67.1 percent to recovery of steel beverage containers, non-beverage steel bottles and jars, and to steel lids, caps, and closures in Canada. Per cross-checking SRI with the US EPA MSW data, other steel packaging has a 79.5 percent recovery rate.[153] This rate is assumed to apply to all other steel packaging including use of steel in bulk flexible strapping, rigid tubs/cups/bowls, other non-bulk rigid packaging, and rigid bulk packaging in Canada.

3.5.2.2. Steel Packaging Recycling LCI

Data for steel recycling in North America are based on processes from Franklin Associates' private LCI database. The recycling of metallic scrap as feed for steel furnaces has long been an economically viable means of utilizing ferrous waste materials. In fact, one-half of the metallic input to steel furnaces is in the form of scrap. Much of the scrap recovered is generated within the mills themselves; thus, the energy requirements and emissions associated with their recovery are included with normal iron and steel mill operations. However, substantial quantities of scrap are transported to iron and steel mills from external sources (including other mills at different sites).

In general, most metallic scrap undergoes similar processing prior to consumption. It is usually manually or semi-manually handled to remove valuables (e.g., tin plating, copper wire, chrome, etc.), and some contaminants (e.g., chemical impurities, organic materials). Subsequent processing includes flattening, shredding, magnetic separation, and all necessary transportation steps, including transport from the flattener to the shredder and the transport of steel scrap from the shredder to the furnace.

An EAF may accept scrap not of a quality suitable for the BOF. Thus, packaging steel scrap is modeled to be processed at an EAF furnace. The resulting secondary steel displaces demand for the BOF steel processing.

The system expansion credit for the recycled steel can and bulk packaging materials such as drums and strapping are based on the difference between the postconsumer recycled content of the steel packaging and the postconsumer recycling rate. The postconsumer content of the BOF steel used to make the steel packaging is approximately 35 percent; 79.5, and 67.0 percent of the bulk steel packaging (e.g., strapping, drums) and steel cans,

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[151] CSPA (2013). Steel Facts, Recycling, Canadian Steel Producers Association. Available at: http://canadiansteel.ca/steel-facts/#recycling.

[152] SRI (2013). Steel Can and Overall Steel Recycling Rate, Steel Recycling Institute, a unit of the American Iron and Steel Institute (AISI). Available at: http://www.recycle-steel.org/.

[153] SRI (2013). Ibid.

respectively, are recycled at end of life. Since the amount of recycled steel produced from the steel packaging is greater than the amount of recycled steel used to make either bulk packaging or steel cans, the steel packaging systems are both net producer of recycled steel. The steel packaging recovery which is in excess of the recycled content of the steel packaging is assumed to be processed in an EAF furnace and is given credit for displacing the corresponding amount of BOF steel production.

3.5.2.3. Aluminum Recovery Rates

The recovery rate for *aluminum beer and soft drink cans* in the US, not including import of used beverage containers (UBCs), is 49.6 percent as indicated in the US EPA 2010 MSW tables.[154] This recovery rate is applied to aluminum beverage cans and non-beverage aluminum bottles and jars. This rate is lower than the 58.1 or 65.1 percent indicated for the 2010 and 2011 data years, respectively, by Aluminum Association, the Can Manufacturers Institute (CMI), and the Institute of Scrap Recycling Industries (ISRI); however, the higher rates do include the import of UBCs from Mexico, Canada, and other countries. Per the US EPA MSW data, the *overall aluminum packaging* recovery rate is 19.9 percent. This rate is applied to other rigid non-bulk aluminum packaging, including use of aluminum in rigid tubs/cups/bowls; however, aluminum foil and aluminum materials used in caps and closures are assumed to have a zero recovery rate in the substitution model.

Recovery rates applied to aluminum containers, bottles, and jars in Canada are as calculated from a case study of container recovery in the Canadian provinces. Franklin Associates weights the recovery rates reported for each province by the province population to obtain a Canadian overall high (for beer and soft drink cans) and low beverage can recovery rate of 75.0 and 73.0 percent, respectively.[155] For the remaining aluminum packaging categories, the same recovery rates are used for Canada as for corresponding packaging types in the US.

3.5.2.4. Aluminum Packaging Recycling LCI

Aluminum recycling processes in North America are based on data from the Aluminum Association 2010 LCA on aluminum cans. This data source indicates an average aluminum can recycled content of 67.8 percent. Because the average US recovery rate for aluminum cans is lower than the average recycled content of the cans, US aluminum can recovery does not supply enough secondary aluminum to sustain its recycled content, so there is no net system expansion credit. Instead, the can system is assigned burdens for the amount of virgin material required to make up the excess share of the secondary aluminum supply that is used for can production. In Canada, however, the recovery rates for aluminum cans are higher than the average recycled content, so the excess amount of Canadian aluminum cans recovered receives some credit for displacing virgin aluminum. All aluminum foil

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[154] US EPA (2011). Table 6. Metal Products in MSW, 2010, Municipal Solid Waste Generation, Recycling, and Disposal in the United States Detailed Tables and Figures for 2010. Compiled by Franklin Associates, A Division of ERG.

[155] CM Consulting (2012). Who Pays What™: An Analysis of Beverage Container Collection and Costs in Canada, Prepared by CM Consulting, August 2012.

materials are modeled as virgin products disposed after use, and receive no system expansion credits or penalties.

3.5.2.5. Glass Recovery Rates

The recovery rate for *glass beer and soft drink containers* in the US is 41.4 percent as indicated in the US EPA 2010 MSW tables.[156] However, the data indicate different recovery rates for *glass wine and liquor containers* and *glass other bottles and jars* in the US, 24.7 and 18.1 percent, respectively.[157] Franklin Associates applies the rate for *glass other bottles and jars* to both beverage and non-beverage glass containers other than those explicitly indicated for beer, soft drinks, wine, and liquor.

Recovery rates applied to glass bottles and jars in Canada are as calculated from a case study of container recovery in the Canadian provinces. Franklin Associates weights the recovery rates reported for each province by the province population to obtain a Canadian overall high (for beer, soft drink, wine, and liquor containers) and low glass beverage container recovery rate of 83.0 and 80.0 percent, respectively.[158] The lower recovery rate is also applied to non-beverage glass containers.

3.5.2.6. Glass Containers Recycling LCI

Glass recycling processes in North America are based on data from Franklin Associates' private LCI database. Postconsumer glass containers are typically recovered in municipal recycling programs. Consumers leave used containers either at drop-off sites or at the curb for curbside pickup. Postconsumer glass is typically sorted by color and then crushed into "cullet"[159] in order to densify it for more economical transportation to glass plants.

Theoretically, a glass plant can produce new containers entirely from cullet; however, no plants currently operate at this level. Postconsumer cullet must be recovered, sorted, and crushed before it is added to the virgin material. Substantial amounts of postconsumer cullet can be used if it meets the standards for purity and color. Although cullet specifications vary by company, the industry uses the ASTM standards as a basis. The ASTM requirements do allow some color mixing; however, glass plants typically request color separation of incoming cullet. This allows the glass plant to control the level of color mixing. Many glass plants are now investing in expensive front-end beneficiation systems which remove contaminants from postconsumer containers and provide the plant with furnace-ready cullet. As more glass plants incorporate this capability, processing problems for recyclers of glass will be slightly alleviated, and an increase in material processing may be observed.

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[156] US EPA (2011). Table 5. Glass Products in MSW, 2010, Municipal Solid Waste Generation, Recycling, and Disposal in the United States Detailed Tables and Figures for 2010. Compiled by Franklin Associates, A Division of ERG.

[157] US EPA (2011). Ibid.

[158] CM Consulting (2012). Who Pays What™: An Analysis of Beverage Container Collection and Costs in Canada, Prepared by CM Consulting, August 2012.

[159] Cullet is imperfect articles of glass, trim, or other glass pieces that are melted and used in new glass products.

Cullet is added to a glass furnace along with the virgin inputs to a conventional batch operation. The composition of glass varies by type. For instance, container glass (used for food and beverage containers) has a different composition from plate or flat window glass. Therefore, only compatible cullet may be used in a furnace. Typical losses from the recovery system are 10 percent of the material recovered. The average glass containers in this study are made with inputs of 27 percent postconsumer cullet and an average recycled content of 25 percent.

All Canadian glass containers have a recovery rate that exceeds the average glass container recycled content and thus receives credit for virgin glass displacement. In the US, the recovery rate for beer and soft drink bottles is higher than the 25 percent recycled content and receives virgin displacement credit, while glass wine and liquor bottles have a recovery rate that is essentially equivalent to their recycled content (no credit or penalty), and other glass containers have a recovery rate that is lower than the amount needed to sustain their recycled content and thus are assigned some virgin material burdens to make up the deficit.

3.5.2.7. Paper & Paperboard Recovery Rates

The US MSW recovery rate for the category *paper containers and packaging excluding corrugated boxes* includes gable top cartons, folding cartons, bags, sacks, and other paperboard packaging; this rate in the US is 25.0 percent as indicated in the US EPA 2010 MSW tables.[160] However, the rate assumed for aseptic cartons, 6.5 percent recovery, is per previous public and private LCA case studies performed by Franklin Associates. Franklin Associates applies the MSW rate of 25 percent to all paper packaging categories except beverage cartons, flexible food packaging, and non-bulk rigid bottles and jars; for these categories, the aseptic carton recovery rate is applied.

Recovery rates applied to paper and paperboard packaging in Canada are calculated from a case study of container recovery in the Canadian provinces. Franklin Associates weighted the recovery rates reported for each province by the province population to obtain Canadian overall high and low paperboard beverage container recovery rate of 42.3 and 30.7 percent, respectively.[161] The higher recovery rate is applied to paperboard-based containers for wine, while the lower recovery rate is applied to paperboard-based containers for other non-carbonated and non-alcoholic beverages as well as converted flexible paper-based packaging and paper substitutes for non-beverage bottles and jars. The overall paper packaging recovery rate indicated by the Paper Recycling Association (PRA) for Canada is 49.1 percent, and this rate is applied to flexible protective packaging, bulk flexible shipping sacks, liners, and rolls.[162]

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[160] US EPA (2011). Table 4. Paper and Paperboard Products in MSW, 2010, Municipal Solid Waste Generation, Recycling, and Disposal in the United States Detailed Tables and Figures for 2010. Compiled by Franklin Associates, A Division of ERG.

[161] CM Consulting (2012). Who Pays What™: An Analysis of Beverage Container Collection and Costs in Canada, Prepared by CM Consulting, August 2012.

[162] PRA (2006). Paper Recycling Association: Overview of the Recycling Industry, Updated September 18, 2007. Available at: http://www.pppc.org/en/2_0/2_4.html.

3.5.2.8. Paper & Paperboard Recycling LCI

Processes for collection and re-pulping postconsumer paper and paperboard in North America are based on data from Franklin Associates' private LCI database. Recovered fibers must be sorted, de-contaminated, and cleaned mechanically before being processed. As a default, average paperboard is modeled to be 50 percent virgin fiber and 50 percent recycled fiber based on Franklin Associates' experience with paperboard recycled content in LCA case studies.

Coated or laminated paperboard carton packaging is repulped in a hydropulping process, in which the coating materials are separated from the paper fiber. For recycling of paperboard cartons, it was assumed that 85% of the fiber content was recovered. The recovered fiber was credited with displacing an equivalent quantity of virgin bleached pulp. The recovered coatings were assumed to be burned for energy recovery, and a credit was given for displacing the amount of boiler fuel that would provide the equivalent energy value.

3.5.2.9. Corrugated Packaging Recovery Rates

The recovery rate for *corrugated boxes* in the US is 85.0 percent as indicated in the US EPA 2010 MSW tables.[163] Franklin Associates applies the MSW rate to all corrugated packaging modeled to substitute for plastic packaging in the US (i.e., bulk boxes). Recovery rates applied to corrugated boxes in Canada are 82.0 percent per the Paper & Paperboard Packaging Environmental Council (PPEC).[164]

3.5.2.10. Corrugated Packaging Recycling LCI

Collection and sorting of corrugate materials in North America are based on data from Franklin Associates Private LCI Database; whereas, re-processing recovered fiber in North America is based on the CPA 2010 LCA for containerboard mills in the US. Franklin Associates accounts for the burdens associated with the collection and processing of postconsumer corrugated material. Energy requirements for the collection of old corrugated cardboard (OCC) in the US are from Franklin Associates' private database. Recovered fibers must be sorted, de-contaminated, and cleaned mechanically before being processed, and these requirements are reflected in the data for production of corrugated liner and medium.

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[163] US EPA (2011). Table 4. Paper and Paperboard Products in MSW, 2010, Municipal Solid Waste Generation, Recycling, and Disposal in the United States Detailed Tables and Figures for 2010. Compiled by Franklin Associates, A Division of ERG.

[164] PPEC (2011). Paper Recycling Rates, PPEC Factsheet 21-2011, Paper & Paperboard Packaging Environmental Council (PPEC). Available at: http://www.ppec-paper.com/pdfFiles/factsheets/factsheet21-2011.pdf.

According to the CPA report, the average postconsumer content of North American corrugated containers is 41.8 percent. The corrugated recovery rate in both US and Canada is higher than the recycled content, so corrugated packaging systems receive material displacement credit. However, the end use paper grades that utilize open-loop recycled corrugated are composed of about half virgin and half secondary fiber, so virgin fiber displacement credit is only assigned to the amount of excess recycled corrugated that displaces virgin fiber.

3.5.2.11. Cork, Rubber, & Textile Recovery Rates & Recycling LCI

The recovery rate for *non-durable rubber and leather goods* is 15 percent of generation in the US as indicated in the US EPA 2010 MSW tables.[165] Recycling rates for cork and natural rubber are assumed to be negligible as in a recent LCA case study on beverage container closures.[166] There is also assumed to be negligible recycling of textile materials modeled to substitute for plastic packaging. Because use of these materials as substitutes for plastic packaging is very low, assumptions about recycling of these materials will not significantly affect overall results.

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[165] US EPA (2011). Table 8. Rubber and Leather Products in MSW, 2010, Municipal Solid Waste Generation, Recycling, and Disposal in the United States Detailed Tables and Figures for 2010. Compiled by Franklin Associates, A Division of ERG.

[166] PwC/Ecobilan (2008). Evaluation of the Environmental Impacts of Cork Stoppers versus Aluminum and Plastic Closures: Analysis of the Life Cycle of Cork, Aluminum and Plastic Wine Closures, Report Prepared for Corticeira Amorim, SGPS, SA by PricewaterhouseCoopers/ECOBILAN, October 2008.

Table 3-3. Recovery Rates for US Plastic and Substitute Packaging

Package Type	**Plastics Recycling**							**Alternative Materials Recycling**							
	LDPE	HDPE	PP	PVC	PS	EPS	PET	Tinplate /Steel	Alumi- num	Glass	Paper	Cork	Rubber	Textile	Wood
Caps & Closures	0%	6.67%	1.80%	0%	5.88%	0%	29.2%	67.0%	0%	0%	0%	0%	0%	0%	0%
Beverage Containers															
Carbonated Soft Drinks	0%	27.5%	0%	0%	0%	0%	29.2%	67.0%	49.6%	41.4%	0%	0%	0%	0%	0%
Beer	0%	27.5%	0%	0%	0%	0%	29.2%	67.0%	49.6%	41.4%	0%	0%	0%	0%	0%
Water	0%	27.5%	0%	0%	0%	0%	29.2%	67.0%	49.6%	18.1%	6.50%	0%	0%	0%	0%
Fruit Beverages	0%	27.5%	0%	0%	0%	0%	29.2%	67.0%	49.6%	18.1%	6.50%	0%	0%	0%	0%
Other RTD Beverages	0%	27.5%	0%	0%	0%	0%	29.2%	67.0%	49.6%	18.1%	6.50%	0%	0%	0%	0%
RTD Tea	0%	27.5%	0%	0%	0%	0%	29.2%	67.0%	49.6%	18.1%	0%	0%	0%	0%	0%
Milk	0%	27.5%	0%	0%	0%	0%	29.2%	67.0%	49.6%	18.1%	6.50%	0%	0%	0%	0%
Sports Beverages	0%	27.5%	0%	0%	0%	0%	29.2%	67.0%	49.6%	0%	6.50%	0%	0%	0%	0%
Wine	0%	27.5%	0%	0%	0%	0%	29.2%	67.0%	49.6%	24.7%	6.50%	0%	0%	0%	0%
Distilled Spirits	0%	27.5%	0%	0%	0%	0%	29.2%	0%	0%	24.7%	0%	0%	0%	0%	0%
Soy & Other Nondairy Beverages	0%	27.5%	0%	0%	0%	0%	29.2%	0%	0%	18.1%	6.50%	0%	0%	0%	0%
Stretch & Shrink Film	17.6%	4.35%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Carrier Bags	17.6%	4.35%	0%	0%	0%	0%	0%	0%	0%	0%	25.0%	0%	0%	0%	0%
Other Flexible															
Converted Flexible															
Food	0%	6.67%	1.80%	0%	5.88%	0%	0%	0%	0%	0%	6.50%	0%	0%	0%	0%
Non-Food	0%	6.67%	1.80%	0%	5.88%	0%	0%	0%	0%	0%	25.0%	0%	0%	0%	0%
Protective															
Fill	0%	6.67%	1.80%	0%	5.88%	0%	0%	0%	0%	0%	25.0%	0%	0%	0%	0%
Dunnage	0%	6.67%	1.80%	0%	5.88%	0%	0%	0%	0%	0%	25.0%	0%	0%	0%	0%
Other	0%	6.67%	1.80%	0%	5.88%	0%	0%	0%	0%	0%	25.0%	0%	0%	0%	0%
Bulk Flexible															
Shipping Sacks	0%	6.7%	1.80%	0%	0%	0%	0%	0%	0%	0%	25.0%	0%	0%	0%	0%
Strapping	0%	0%	1.80%	0%	0%	0%	1.80%	79.5%	0%	0%	0%	0%	0%	0%	0%
BulkLiners & Rolls	0%	6.67%	1.80%	0%	5.88%	0%	0%	0%	0%	0%	25.0%	0%	0%	0%	0%
FIBCs & Others	0%	6.67%	1.80%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 3-3. Recovery Rates for US Plastic and Substitute Packaging (continued)

Package Type	Plastics Recycling							Alternative Materials Recycling								
	LDPE	HDPE	PP	PVC	PS	EPS	PET	Tinplate /Steel	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
Other Rigid															
Non-Bulk															
Bottles & Jars	0%	27.5%	8.33%	0%	0%	0%	29.2%	67.0%	19.9%	18.1%	6.50%	0%	0%	0%	0%
Tubs/Cups/Bowls	0%	19.3%	5.26%	0%	0%	0%	16.4%	67.0%	19.9%	18.1%	25.0%	0%	0%	0%	0%
Other	0%	19.3%	8.33%	0%	5.88%	5.88%	0%	67.0%	19.9%	18.1%	25.0%	0%	0%	0%	0%
Rigid Bulk															
Drums	0%	19.3%	8.33%	0%	0%	0%	0%	79.5%	0%	0%	85.0%	0%	0%	0%	0%
Pails	0%	19.3%	8.33%	0%	0%	0%	0%	79.5%	0%	0%	85.0%	0%	0%	0%	0%
Material Handling & Bulk Boxe	0%	19.3%	8.33%	0%	0%	0%	0%	79.5%	0%	0%	85.0%	0%	0%	0%	0%
RIBCs	0%	19.3%	8.33%	0%	0%	0%	0%	79.5%	0%	0%	85.0%	0%	0%	0%	40.0%
Protective															
Shapes	0%	0%	0%	0%	0%	5.88%	0%	0%	0%	0%	25.0%	0%	0%	0%	0%
Others	0%	0%	0%	0%	0%	5.88%	0%	0%	0%	0%	25.0%	0%	0%	0%	0%

Table 3-4. Recovery Rates for Canadian Plastic and Substitute Packaging

Package Type	**Plastics Recycling**							**Alternative Materials Recycling**							
	LDPE	HDPE	PP	PVC	PS	EPS	PET	Tinplate /Steel	Alumi-num	Glass	Paper	Cork	Rubber	Textile	Wood
Caps & Closures	0%	6.67%	1.80%	0%	5.88%	0%	62.0%	67.1%	0%	0%	0%	0%	0%	0%	0%
Beverage Containers															
Carbonated Soft Drinks	0%	25.7%	0%	0%	0%	0%	62.0%	67.1%	75.0%	83.0%	0%	0%	0%	0%	0%
Beer	0%	25.7%	0%	0%	0%	0%	62.0%	67.1%	75.0%	83.0%	0%	0%	0%	0%	0%
Water	0%	25.7%	0%	0%	0%	0%	58.0%	67.1%	73.0%	80.0%	30.7%	0%	0%	0%	0%
Fruit Beverages	0%	25.7%	0%	0%	0%	0%	58.0%	67.1%	73.0%	80.0%	30.7%	0%	0%	0%	0%
Other RTD Beverages	0%	25.7%	0%	0%	0%	0%	58.0%	67.1%	73.0%	80.0%	30.7%	0%	0%	0%	0%
RTD Tea	0%	25.7%	0%	0%	0%	0%	58.0%	67.1%	73.0%	80.0%	0%	0%	0%	0%	0%
Milk	0%	52.8%	0%	0%	0%	0%	58.0%	67.1%	73.0%	80.0%	30.7%	0%	0%	0%	0%
Sports Beverages	0%	25.7%	0%	0%	0%	0%	58.0%	67.1%	73.0%	0%	30.7%	0%	0%	0%	0%
Wine	0%	25.7%	0%	0%	0%	0%	58.0%	67.1%	73.0%	83.0%	42.3%	0%	0%	0%	0%
Distilled Spirits	0%	25.7%	0%	0%	0%	0%	58.0%	0%	0%	83.0%	0%	0%	0%	0%	0%
Soy & Other Nondairy Beverages	0%	25.7%	0%	0%	0%	0%	58.0%	0%	0%	80.0%	30.7%	0%	0%	0%	0%
Stretch & Shrink Film	17.6%	4.35%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Carrier Bags	43.5%	43.5%	0%	0%	0%	0%	0%	0%	0%	0%	49.1%	0%	0%	0%	0%
Other Flexible															
Converted Flexible															
Food	0%	6.67%	1.80%	0%	5.88%	0%	0%	0%	0%	0%	30.7%	0%	0%	0%	0%
Non-Food	0%	6.67%	1.80%	0%	5.88%	0%	0%	0%	0%	0%	30.7%	0%	0%	0%	0%
Protective															
Fill	0%	6.67%	1.80%	0%	5.88%	0%	0%	0%	0%	0%	49.1%	0%	0%	0%	0%
Dunnage	0%	6.67%	1.80%	0%	5.88%	0%	0%	0%	0%	0%	49.1%	0%	0%	0%	0%
Other	0%	6.67%	1.80%	0%	5.88%	0%	0%	0%	0%	0%	49.1%	0%	0%	0%	0%
Bulk Flexible															
Shipping Sacks	0%	6.67%	1.80%	0%	0%	0%	0%	0%	0%	0%	49.1%	0%	0%	0%	0%
Strapping	0%	0%	1.80%	0%	0%	0%	1.80%	79.5%	0%	0%	0%	0%	0%	0%	0%
BulkLiners & Rolls	0%	6.67%	1.80%	0%	5.88%	0%	0%	0%	0%	0%	49.1%	0%	0%	0%	0%
FIBCs & Others	0%	6.67%	1.80%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 3-4. Recovery Rates for Canadian Plastic and Substitute Packaging (continued)

Package Type	**Plastics Recycling**							**Alternative Materials Recycling**							
	LDPE	HDPE	PP	PVC	PS	EPS	PET	Tinplate /Steel	Aluminum	Glass	Paper	Cork	Rubber	Textile	Wood
Other Rigid															
Non-Bulk															
Bottles & Jars	0%	21.7%	18.3%	0%	0%	0%	39.1%	67.1%	19.9%	80.0%	30.7%	0%	0%	0%	0%
Tubs/Cups/Bowls	0%	19.3%	5.26%	0%	0%	0%	16.4%	67.0%	19.9%	80.0%	49.1%	0%	0%	0%	0%
Other	0%	19.3%	18.3%	0%	5.88%	5.88%	0%	67.0%	19.9%	80.0%	49.1%	0%	0%	0%	0%
Rigid Bulk															
Drums	0%	19.3%	8.33%	0%	0%	0%	0%	79.5%	0%	0%	82.0%	0%	0%	0%	0%
Pails	0%	19.3%	8.33%	0%	0%	0%	0%	79.5%	0%	0%	82.0%	0%	0%	0%	0%
Material Handling & Bulk Boxe	0%	19.3%	8.33%	0%	0%	0%	0%	79.5%	0%	0%	82.0%	0%	0%	0%	0%
RIBCs	0%	19.3%	8.33%	0%	0%	0%	0%	79.5%	0%	0%	82.0%	0%	0%	0%	40.0%
Protective															
Shapes	0%	0%	0%	0%	0%	5.88%	0%	0%	0%	0%	49.1%	0%	0%	0%	0%
Others	0%	0%	0%	0%	0%	5.88%	0%	0%	0%	0%	49.1%	0%	0%	0%	0%

3.5.3. Disposal

This analysis uses disposal process data from Franklin Associates' private LCI database. In this portion of the study, estimates of the end results of landfilling and waste-to-energy (WTE) combustion are limited to global warming potential (GWP) effects, electricity credits, and requirements for transporting waste to a landfill and operating landfill equipment.

In the US, municipal solid waste (MSW) that is not recovered for recycling or composting is managed 82 percent by weight to landfill (LF) and 18 percent by weight to waste-to-energy (WTE) incineration.[167] In Canada, 95 percent by weight of disposed weight goes to LF, three percent to WTE, and the remaining two percent to incineration without energy recovery.[168] In both the US and Canadian geographic scope, the composition of landfill gas as generated is approximately 50 percent by volume methane and 50 percent by volume CO_2. Currently in the US, about 71.2 percent of methane generated from solid waste LFs is converted to CO_2 before it is released to the environment: 10.6 percent is flared, 56.8 percent is burned with energy recovery, and about 3.8 percent is oxidized as it travels through the landfill cover.[169] In Canada, about 44.3 percent of methane generated from solid waste LFs is converted to CO_2: 18.9 percent is flared, 19.2 percent is burned with energy recovery, and about 6.2 percent is oxidized as it travels through the landfill cover.[170]

Table 3-5. National Waste Management Statistics

	US	Canada
Landfilled	82%	95%
Waste-to-Energy Incineration (with energy recovery)	18%	3%
Incineration without energy recovery	0%	2%
Landfill methane captured and used for energy recovery	56.8%	19.2%
Landfill methane captured and flared	10.6%	18.9%
Landfill methane oxidized through landfill cover	3.8%	6.2%
Landfill methane that escapes into the atmosphere	28.8%	55.7%

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[167] US EPA (2012) Municipal Solid Waste Facts and Figures 2011.Accessible at http://www.epa.gov/msw/msw99.htm.

[168] Statistics Canada (2012). Human Activity and the Environment: Waste Management in Canada, 2012 – Updated, Statistique Canada, Catalogue no. 16-201-X, Ministry of Industry, September 2012.

[169] US Environmental Protection Agency. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015. Landfill gas management for 2014 from Table 7-3 CH_4 Emissions from Landfills (MMT CO_2 eq).

[170] Environment and Climate Change Canada. National Inventory Report 1990-2015: Greenhouse Gas Sources and Sinks in Canada. Canada's Submission to the United Nations Framework Convention on Climate Change. Part 2. Landfill gas management for 2014 from Table A3-69 Estimated MSW CH_4 Generated, Captured, Flared, and Emitted for 1990-2015. Adjusted by Franklin Associates to use same landfill oxidation assumption as US Greenhouse Gas Inventory (ten percent of the CH_4 generated that is not recovered is assumed to oxidize to CO_2 as it passes through the landfill cover).

Biomass CO_2 released from decomposition of biomass-derived materials or from oxidation of biomass-derived methane to CO_2 is considered carbon neutral, as the CO_2 released represents a return to the environment of the carbon taken up as CO_2 during the plant's growth cycle and does not result in a net increase in atmospheric CO_2. Thus, biomass-derived CO_2 is not included in the GHG results shown in this analysis except to account for carbon storage due to landfilling of carbon-based materials. Methane releases to the environment from anaerobic decomposition of biomass are *not* considered carbon neutral, however, since these releases resulting from human intervention have a higher GWP than the CO_2 taken up or released during the natural carbon cycle. Landfill decomposition modeling and biogenic CO_2 storage credits are described in detail in the Waste Management section of Chapter 1. That section also provides a detailed description of modeling for disposal by combustion and WTE combustion.

In the modeling of landfilling and WTE processes, GWP contributions from WTE combustion of postconsumer packaging and from fugitive emissions of landfill methane from anaerobic decomposition of biomass-derived materials are included. Credits for grid electricity displaced by the generation of electricity from WTE combustion of postconsumer packaging and from WTE combustion of methane recovered from decomposition of landfilled biomass-derived materials are also included. Some carbon is also sequestered in the biomass-derived materials that do not decompose. The US EPA greenhouse gas accounting methodology does not assign a carbon sequestration credit to landfilling of fossil-derived materials because this is considered a transfer between carbon stocks (from oil deposit to landfill) with no net change in the overall amount of carbon stored.[171] The net end-of-life GWP for the landfilled materials is calculated by summing the individual impacts and credits.

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[171] US EPA. Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks. Third Edition. September 2006**. Section 1.3, subsection** Carbon Stocks, Carbon Storage, and Carbon Sequestration. Page 6.

CHAPTER 4. RESULTS FOR PACKAGING SYSTEMS

4.1. INTRODUCTION

This chapter presents results for the life cycle of plastic and substitute packaging in the US and Canada. The following results categories are evaluated:

Life Cycle Inventory Indicators

- Energy demand (cumulative energy demand and expended energy)
- Water consumption
- Solid waste (by weight and by volume)

Life Cycle Impact Assessment Indicators

- Global warming potential
- Acidification potential
- Eutrophication potential
- Smog formation potential
- Ozone depletion potential

4.2. COMPARATIVE WEIGHTS

For US packaging, Table 4-1 shows that the combined weight of alternative packaging that would be needed to substitute US plastic packaging is about 4.5 times as high as the weight of the plastic packaging replaced. The ratio is similar for Canada, as shown in Table 4-2**.** The weight ratio of substitutes to plastic varies considerably across packaging categories. The lowest ratio is seen for caps and closures, where plastic caps and closures are comparable in weight to substitutes. The highest weight ratio is seen for stretch and shrink film, where lightweight plastic film is primarily replaced by paper and steel strapping, both with higher weight per unit area compared to film.

Table 4-1. Weights of US Plastic and Substitute Packaging

	Weight (million kg)		
	Plastic Packaging	Substitutes	Ratio
Caps & Closures	779	769	1.0
Beverage Containers	3,095	14,568	4.7
Stretch & Shrink	748	6,418	8.6
Carrier Bags	1,297	2,436	1.9
Other Flexible	4,188	16,830	4.0
Other Rigid	4,264	23,079	5.4
Total	**14,373**	**64,100**	**4.5**

Table 4-2. Weights of Canadian Plastic and Substitute Packaging

	Weight (million kg)		
	Plastic Packaging	Substitutes	Ratio
Caps & Closures	62	48	0.8
Beverage Containers	341	1,603	4.7
Stretch & Shrink	83	708	8.6
Carrier Bags	143	269	1.9
Other Flexible	532	1,954	3.7
Other Rigid	470	2,546	5.4
Total	**1,633**	**7,128**	**4.4**

For each environmental indicator, the weights of the plastic and substitute packaging in each category are multiplied by the indicator results per kg of each type of packaging from the LCA model to arrive at the indicator results for each category. The table below provides an example of the calculation of total energy demand results for US carrier bags for the maximum decomposition scenario. From Table 2-18, the weight of plastic carrier bags in the US is 1,297 million kg. The same table shows that this weight of plastic bags would be substituted by 1,709 million kg of paper bags and 727 million kg of textile bags. The life cycle energy demand per kilogram for each type of plastic and substitute packaging, based on average US recycled content, recycling rates, and percentages of landfill and WTE disposal for each type of packaging in the US, come from the life cycle models described in Chapter 3. The total kg of each type of packaging is multiplied by the life cycle energy impacts per kg of that packaging type to calculate the total energy impacts for the quantities of plastic and alternative packaging shown in the results tables and figures in this chapter.

Table 4-3. Example Calculation of Life Cycle Energy Results for US Carrier Bags

	Million kg (Table 2-18)	**Life Cycle MJ/kg (avg US recycled content & recycling rate)**	**Billion MJ**
Plastic bags	1,297	85.4	**111**
Paper bags	1,709	38.6	65.9
Textile bags	727	219	159
			225
Savings for US plastic bags compared to substitutes:			**114**

4.3. OVERVIEW OF RESULTS

Figure 4-1 and Figure 4-2 show normalized total results graphically for all results categories evaluated. For each results indicator, the values are displayed on a percentage basis relative to the system that has the maximum value for that indicator. Figure 4-1 shows normalized results for US packaging, while Figure 4-2 shows normalized results for LCI and LCIA indicators for Canadian packaging.

As described in Chapter 1, two decomposition scenarios are analyzed for substitute packaging. The "no decomposition" scenario includes biogenic CO_2 sequestration credit for all the biogenic carbon in landfilled packaging (i.e., no decomposition over time of any landfilled biomass-derived packaging), while the "maximum decomposition" scenario is based on maximum decomposition of uncoated paper and paperboard packaging that is disposed in landfills. For coated/laminated paper and paperboard products, the barrier layers are assumed to minimize any decomposition of the fiber content; therefore, to use a conservative approach, no decomposition of the fiber content of coated/laminated paper-based packaging is modeled in either decomposition scenario.

The figures show that plastic packaging has lower impacts than substitute packaging for all impacts evaluated for both the US and Canadian scenarios. This is largely due to the light weight of plastic packaging. Although the impacts per kg of plastic packaging may in some cases be higher than impacts per kg of substitute packaging, significantly more kg of substitute packaging are required to perform the same function, as shown in Table 4-1 and Table 4-2. The only category where plastic packaging weighs the same or slightly more than substitute packaging is in the category of caps and closures, which accounts for only 4-5% of the total weight of plastic packaging for the US and Canada.

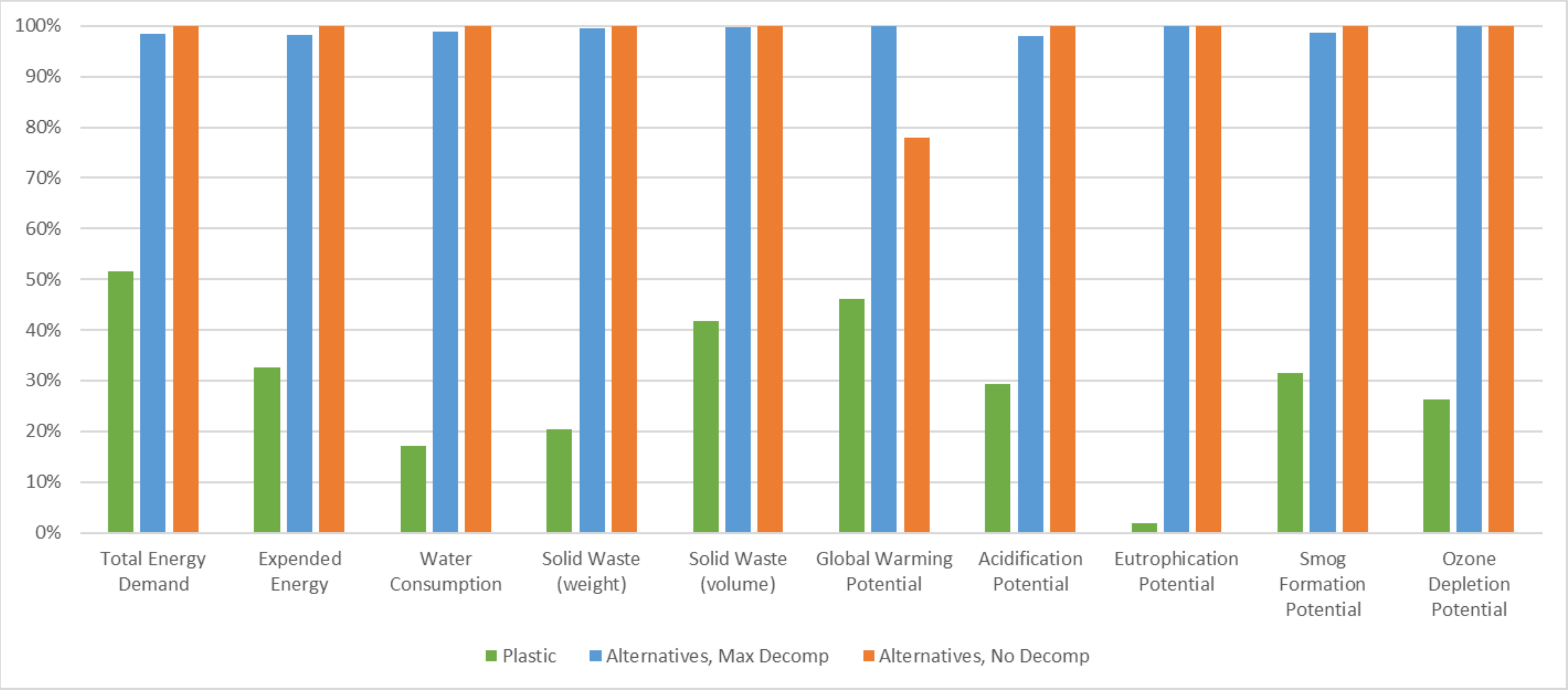

Figure 4-1. Normalized US Results for Plastic Packaging and Substitutes

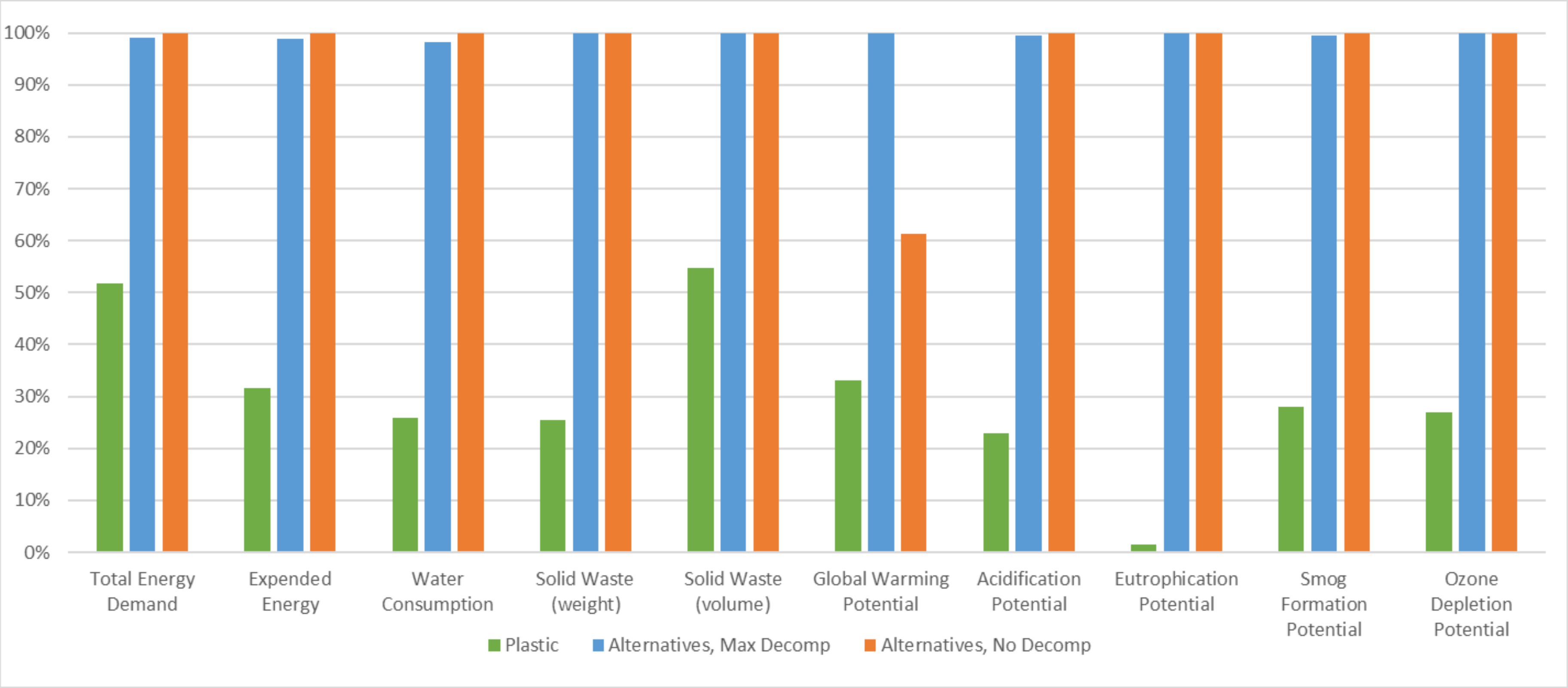

Figure 4-2. Normalized Canadian Results for Plastic Packaging and Substitutes

The figures also show that results for the maximum decomposition scenario for substitute packaging (blue bars in figures) are generally equivalent to or somewhat lower than results for the no decomposition scenario (orange bars). Maximum decomposition means more landfill gas is generated, and the results include credits for the share of methane that is captured and used for energy recovery, displacing grid electricity impacts. GWP is the only category where the no decomposition results are significantly lower than the maximum decomposition results, due to credits for biogenic carbon storage in landfilled biomass-derived packaging that does not decompose.

The introductory table and figures are provided to give a general overview of comparative results for plastic and alternative packaging. The remainder of this chapter discusses each results category in more detail. There are several overarching factors that affect results across all categories:

- **Factors influencing differences in results for plastics and alternative packaging types**
  - Less weight of plastic packaging to perform same function
  - Higher embodied energy for plastics compared to substitute materials
  - Lower water consumption per kg for plastic materials compared to alternatives
  - No decomposition (and therefore, no associated methane releases) for landfilled plastics
  - Carbon sequestration credits for landfilled material is only assigned to biomass-based carbon content (e.g., in paper, paperboard, wood) and not to fossil fuel-derived carbon content in plastic packaging
  - Higher embodied energy/kg for plastics, so higher energy credits for plastics disposed via waste-to-energy combustion.

- **Factors influencing differences in results for US and Canada**
  - Less packaging used (lower population) in Canada
  - Canadian electricity is less fossil fuel intensive (lower energy, emissions, and fuel-related solid waste) but more hydropower dependent (higher evaporative losses of water)
  - Higher recycling rates for Canada, so a smaller share of packaging is sent to landfill
  - For packaging that is not recycled, there is more landfilling, less landfill gas recovery, and less waste-to-energy combustion of solid waste in Canada
    - More landfilling means more carbon sequestration credit for disposed biomass-derived materials that don't decompose, but more methane emissions for biomass-derived materials that do decompose
    - Less energy recovery credits for all materials, since less waste-to-energy disposal of unrecycled waste

4.4. ENERGY RESULTS

Energy results are presented for cumulative energy demand as well as expended energy, to distinguish between energy resources that are expended by combustion of process and transportation fuels, and feedstock energy that is embodied in the product, which is still potentially available for recovery.

4.4.1. Cumulative Energy Demand

Cumulative Energy Demand (CED) includes expended process energy and transportation energy as well as energy of material resource (EMR, or feedstock energy) embodied in the packaging material. US results are shown in Table 4-4 and Figure 4-3, and Canadian results are shown in Table 4-5 and Figure 4-4**.** The tables show that CED for substitutes is over 90% higher than plastic packaging for both regions. The choice of decomposition scenario does not have much effect on the total energy results.

The CED ratios vary considerably for different packaging categories, depending not only on the relative masses of the plastic and substitute packaging but also on the CED for the mix of material types used in each packaging category. For example, US beverage packaging has a high substitutes-to-plastic *weight* ratio (4.7 in Table 4-1) but a smaller substitutes-to-plastic *CED* ratio (1.6 in Table 4-4). Substitution of glass bottles for a share of plastic bottles drives up the weight ratio, but since CED per kg of glass bottle is lower than CED per kg of plastic bottle, the CED difference is not as high as the weight ratio.

To provide some perspective on the magnitude of the energy savings for plastic packaging compared to substitutes, equivalencies are shown at the bottom of the tables. US CED savings of over 1,000 billion MJ is equivalent to the energy saved by taking 18 million passenger vehicles off the road for a year, or the energy content of over 1 million tanker trucks of gasoline.[172] The Canadian CED savings of over 120 billion MJ is equivalent to the energy saved by taking 1.8 million passenger vehicles off the road for a year, or the energy content of over 100,000 tanker trucks of gasoline.

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[172] Equivalencies are based on the US EPA's Greenhouse Gas Equivalencies calculator at https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator.

Table 4-4. Cumulative Energy Demand for US Plastic Packaging and Substitutes (billion MJ)

	Plastic Packaging	Substitutes, Max Decomp	Substitutes, No Decomp	Ratio, Max Decomp	Ratio, No Decomp	Savings, Max Decomp	Savings, No Decomp
Caps & Closures	78.9	40.1	40.4	0.5	0.5	-38.9	-38.5
Beverage Containers	255	404	407	1.6	1.6	150	152
Stretch & Shrink	58.5	250	255	4.3	4.4	191	196
Carrier Bags	111	225	228	2.0	2.1	114	117
Other Flexible	384	1,056	1,083	2.8	2.8	673	699
Other Rigid	423	530	531	1.3	1.3	107	108
TOTAL	**1,309**	**2,505**	**2,544**	**1.9**	**1.9**	**1,196**	**1,235**
Substitutes % Higher than Plastics		91%	94%				
Plastic Results as % of Substitutes		52%	51%				
Savings Equivalencies							
Million passenger vehicles per year						18	18
Thousand tanker trucks of gasoline						1,073	1,108

Table 4-5. Cumulative Energy Demand for Canadian Plastic Packaging and Substitutes (billion MJ)

	Plastic Packaging	Substitutes, Max Decomp	Substitutes, No Decomp	Ratio, Max Decomp	Ratio, No Decomp	Savings, Max Decomp	Savings, No Decomp
Caps & Closures	5.96	2.47	2.47	0.4	0.4	-3.49	-3.48
Beverage Containers	20.0	33.3	33.5	1.7	1.7	13.3	13.5
Stretch & Shrink	7.05	26.0	26.4	3.7	3.7	19.0	19.4
Carrier Bags	9.29	17.7	17.9	1.9	1.9	8.43	8.60
Other Flex	46.9	124	125	2.6	2.7	76.8	78.4
Other Rigid	42.7	49.4	49.4	1.2	1.2	6.68	6.75
TOTAL	**132**	**253**	**255**	**1.9**	**1.9**	**121**	**123**
Substitutes % Higher than Plastics		91%	93%				
Plastic Results as % of Substitutes		52%	52%				
Savings Equivalencies							
Million passenger vehicles per year						1.8	1.8
Thousand tanker trucks of gasoline						108	110

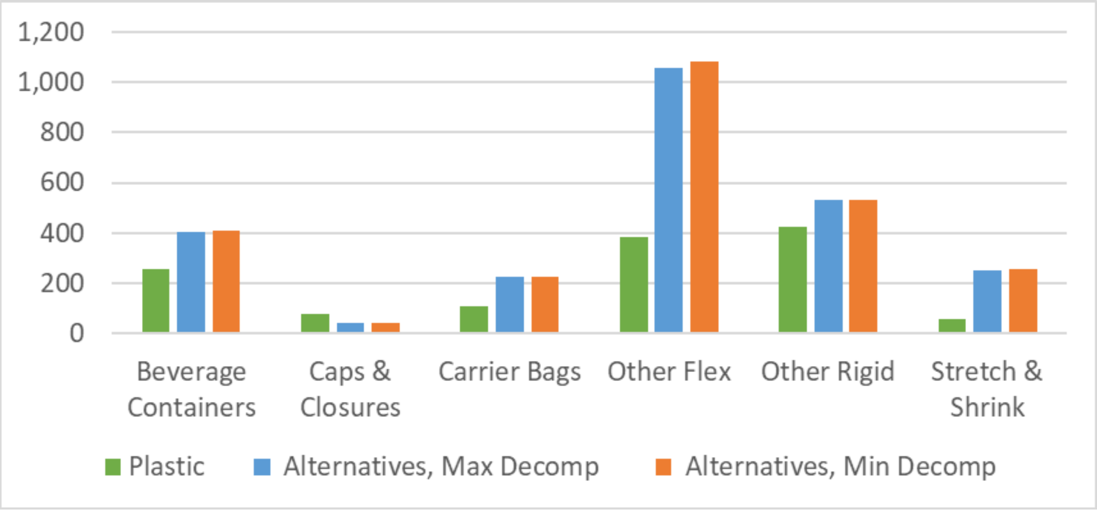

Figure 4-3. Cumulative Energy Demand by Category for US Plastic Packaging and Substitutes (billion MJ)

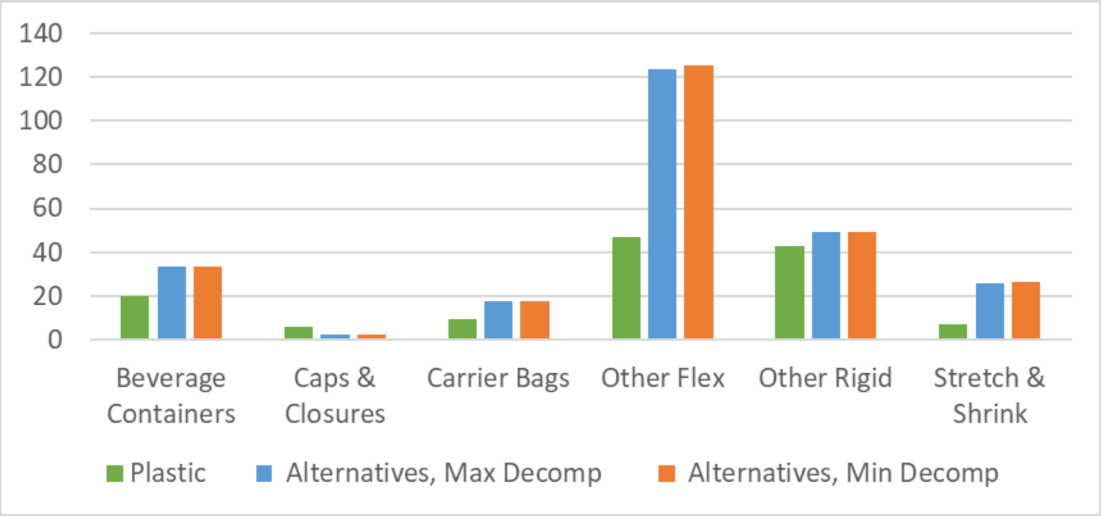

Figure 4-4. Cumulative Energy Demand by Category for Canadian Plastic Packaging and Substitutes (billion MJ)

4.4.2. Expended Energy

Table 4-6 and Table 4-7 show results for expended energy (CED minus the energy embodied in the packaging material). This distinction is particularly relevant for plastics, because embodied EMR is still potentially available for future use (e.g., via material recycling or material combustion with energy recovery), as opposed to the expended energy. Because plastics use fossil fuels as material feedstocks, a high percentage of CED for plastic packaging is EMR. Of the non-plastic substitute packaging, paper packaging is the only type that has significant feedstock energy. Table 4-6 and Table 4-7 show that the overall life cycle expended (unrecoverable) energy for substitutes is about 3 times as high as the expended energy for plastic packaging, although the ratio varies considerably by packaging category, based on the mix of substitute materials in each packaging category.

Savings equivalencies for plastic packaging compared to substitutes are shown at the bottom of each table. US expended energy savings of over 1,300 billion MJ is equivalent to the energy consumed by 20 million passenger vehicles in a year, or the energy content of 1.2 million tanker trucks of gasoline. The Canadian expended energy savings of over 140 billion MJ is equivalent to the energy consumed by about 2.1 million passenger vehicles in a year, or the energy content of about 130,000 tanker trucks of gasoline.

Figure 4-5 and Figure 4-6 show the comparisons of expended energy for individual categories of plastic and substitute packaging for the US and Canada, respectively. Figure 4-7 and Figure 4-8 show expended energy as a percent of total energy for plastics and substitutes in individual packaging categories.

Table 4-6. Expended Energy for US Plastic Packaging and Substitutes (billion MJ)

	Plastic Packaging	Substitutes, Max Decomp	Substitutes, No Decomp	Ratio, Max Decomp	Ratio, No Decomp	Savings, Max Decomp	Savings, No Decomp
Caps & Closures	39.4	38.9	39.3	1.0	1.0	-0.54	-0.18
Beverage Containers	159	377	380	2.4	2.4	218	221
Stretch & Shrink	27.6	195	200	7.1	7.2	167	172
Carrier Bags	46.9	197	200	4.2	4.3	150	153
Other Flexible	178	771	798	4.3	4.5	593	619
Other Rigid	241	509	510	2.1	2.1	268	269
TOTAL	**693**	**2,088**	**2,127**	**3.0**	**3.1**	**1,396**	**1,435**
Substitutes % Higher than Plastics		202%	207%				
Plastic Results as % of Substitutes		33%	33%				
Savings Equivalencies							
Million passenger vehicles per year						20	21
Thousand tanker trucks of gasoline						1,252	1,287

Table 4-7. Expended Energy for Canadian Plastic Packaging and Substitutes (billion MJ)

	Plastic Packaging	Substitutes, Max Decomp	Substitutes, No Decomp	Ratio, Max Decomp	Ratio, No Decomp	Savings, Max Decomp	Savings, No Decomp
Caps & Closures	2.78	2.43	2.43	0.9	0.9	-0.35	-0.35
Beverage Containers	13.2	31.0	31.2	2.4	2.4	17.9	18.0
Stretch & Shrink	3.11	19.8	20.2	6.4	6.5	16.7	17.1
Carrier Bags	4.12	15.6	15.8	3.8	3.8	11.5	11.7
Other Flex	20.9	93.5	95.1	4.5	4.6	72.6	74.2
Other Rigid	22.8	47.2	47.3	2.1	2.1	24.4	24.5
TOTAL	**66.9**	**210**	**212**	**3.1**	**3.2**	**143**	**145**
Substitutes % Higher than Plastics		213%	217%				
Plastic Results as % of Substitutes		32%	32%				
Savings Equivalencies							
Million passenger vehicles per year						2.1	2.1
Thousand tanker trucks of gasoline						128	130

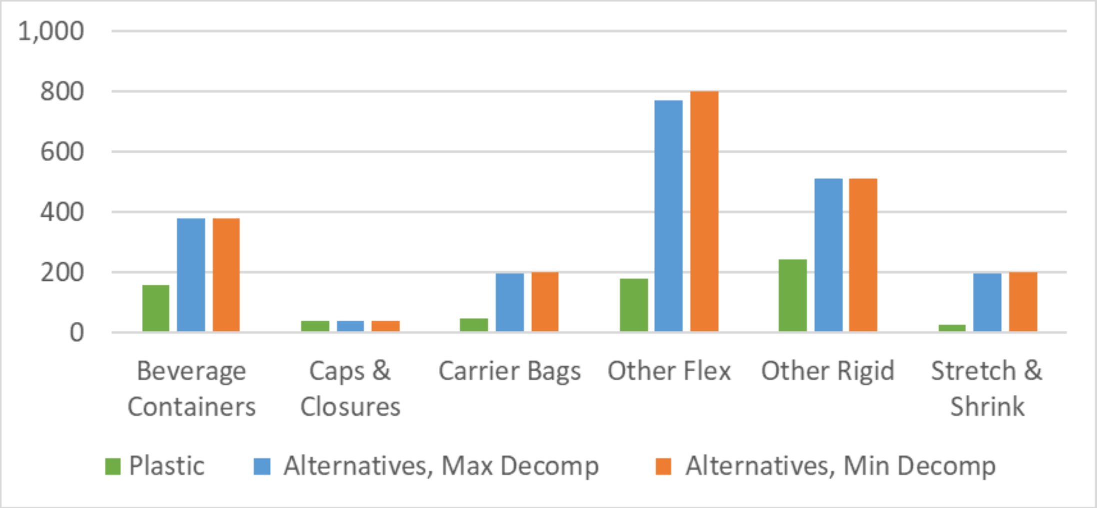

Figure 4-5. Expended Energy by Category for US Plastic Packaging and Substitutes (billion MJ)

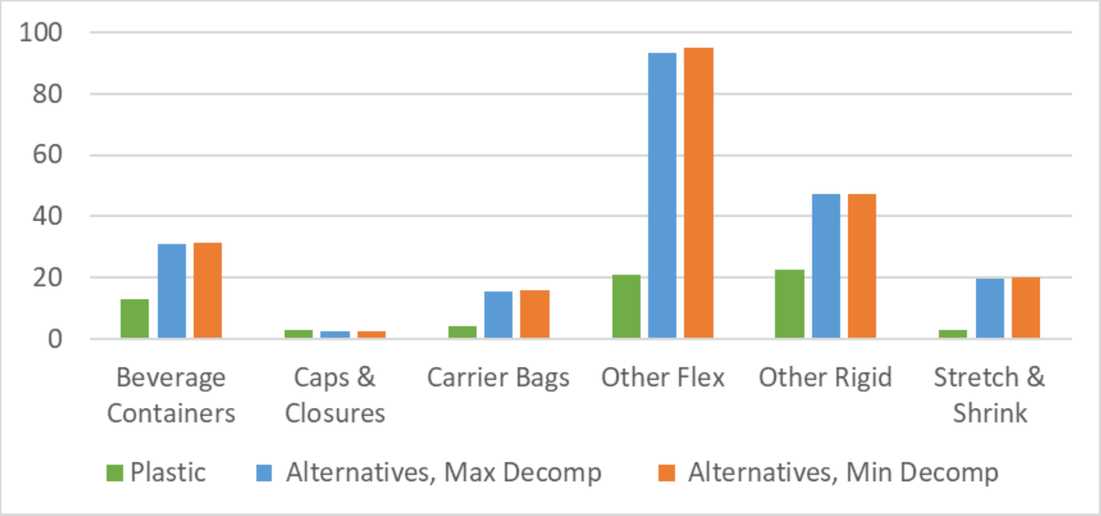

Figure 4-6. Expended Energy by Category for Canadian Plastic Packaging and Substitutes (billion MJ)

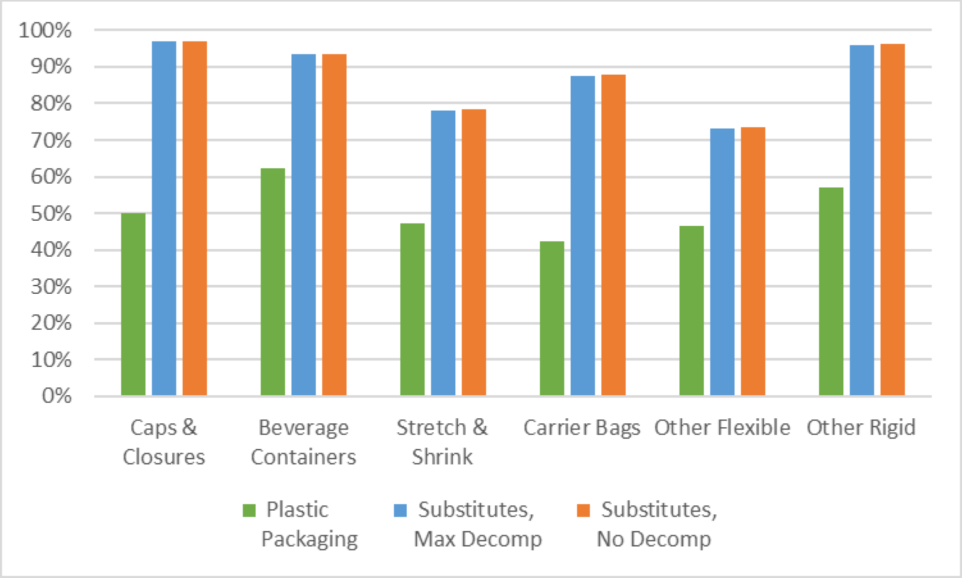

Figure 4-7. Expended Energy as a Percent of Total Energy for US Plastic Packaging and Substitutes

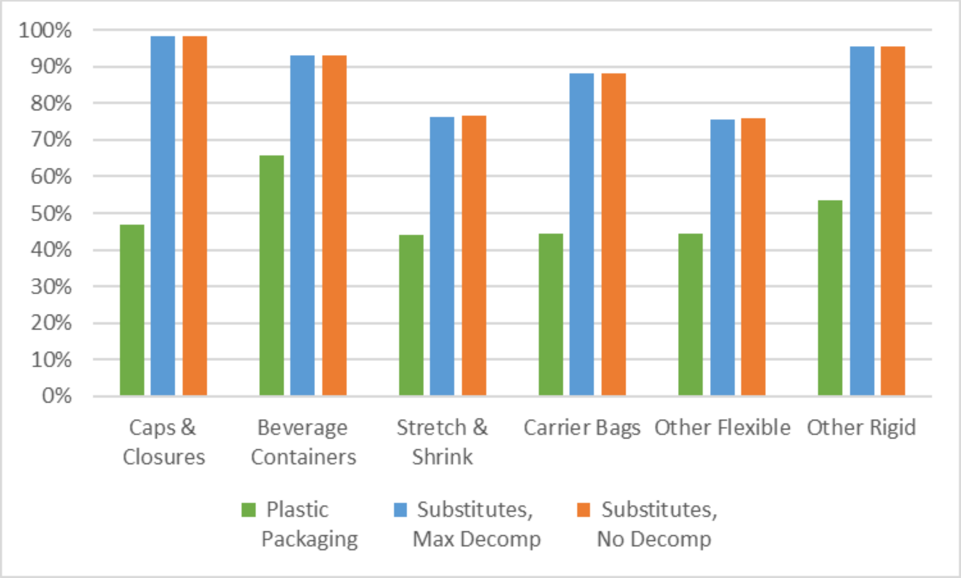

Figure 4-8. Expended Energy as a Percent of Total Energy for Canadian Plastic Packaging and Substitutes

4.5. WATER CONSUMPTION RESULTS

Consumptive use of water includes freshwater that is withdrawn from a water source or watershed and not returned to that source. Consumptive water use includes water consumed in chemical reactions, water that is incorporated into a product or waste stream, water that becomes evaporative loss, and water that is discharged to a different watershed or water body than the one from which it was withdrawn. Water consumption results shown for each life cycle stage include process water consumption as well as water consumption associated with production of the electricity and fuels used in that stage.

Production of plastic resins and plastic converting processes consume less water per kg than production of substitute packaging such as paper and paperboard, textiles, metals, and glass, leading to significant water consumption savings for plastic packaging. Savings are most notable in the category of carrier bags, where plastic bags would be substituted by paper and textile bags.

Overall, the substitutes that would replace US plastic packaging would consume almost 6 times as much water, and Canadian substitutes would consume almost 4 times as much water. The ratio is somewhat lower for Canada due to the influence of a more water-intensive electricity grid, which affects results for both plastics and substitutes. The savings in water consumption expressed as the equivalent number of Olympic swimming pools are 460,000 Olympic pools for US plastic packaging and about 55,000 Olympic pools for Canadian packaging.[173]

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[173] Based on Olympic pool dimensions of 50 meters long, 25 meters wide, and 2 meters deep.

Table 4-8. Water Consumption for US Plastic Packaging and Substitutes (thousand cubic meters)

	Plastic Packaging	Substitutes, Max Decomp	Substitutes, No Decomp	Ratio, Max Decomp	Ratio, No Decomp	Savings, Max Decomp	Savings, No Decomp
Caps & Closures	13,684	7,348	7,485	0.5	0.5	-6,336	-6199
Beverage Containers	55,936	101,675	102,768	1.8	1.8	45,739	46,832
Stretch & Shrink	8,898	69,112	70,983	7.8	8.0	60,214	62,085
Carrier Bags	15,412	717,932	719,051	46.6	46.7	702,519	703,639
Other Flexible	56,342	187,641	197,832	3.3	3.5	131,299	141,490
Other Rigid	82,572	255,247	255,696	3.1	3.1	172,675	173,124
TOTAL	**232,845**	**1,338,955**	**1,353,815**	**5.8**	**5.8**	**1,106,110**	**1,120,971**
Substitutes % Higher than Plastics		475%	481%				
Plastic Results as % of Substitutes		17%	17%				
Savings Equivalency							
Thousands of Olympic swimming pools						461	467

Table 4-9. Water Consumption for Canadian Plastic Packaging and Substitutes (thousand cubic meters)

	Plastic Packaging	Substitutes, Max Decomp	Substitutes, No Decomp	Ratio, Max Decomp	Ratio, No Decomp	Savings, Max Decomp	Savings, No Decomp
Caps & Closures	1,910	775	781	0.4	0.4	-1,135	-1,129
Beverage Containers	11,675	14,651	14,905	1.3	1.3	2,976	3,230
Stretch & Shrink	1,695	10,833	11,359	6.4	6.7	9,138	9,664
Carrier Bags	2,694	87,313	87,533	32.4	32.5	84,619	84,839
Other Flex	11,958	25,990	28,096	2.2	2.3	14,033	16,139
Other Rigid	16,547	36,876	36,959	2.2	2.2	20,329	20,412
TOTAL	**46,479**	**176,440**	**179,634**	**3.8**	**3.9**	**129,961**	**133,155**
Substitutes % Higher than Plastics		280%	286%				
Plastic Results as % of Substitutes		26%	26%				
Savings Equivalency							
Thousands of Olympic swimming pools						54	55

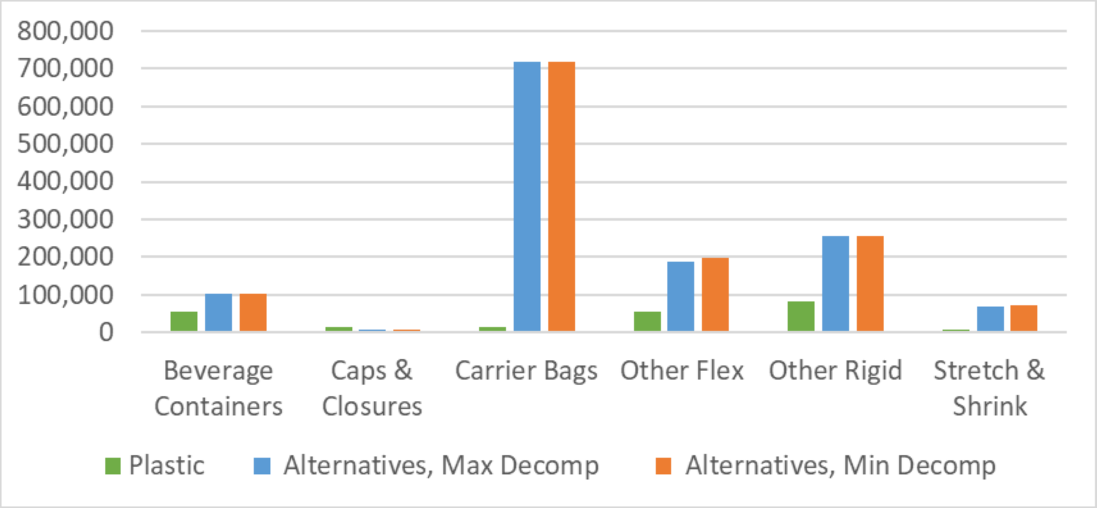

Figure 4-9. Water Consumption by Category for US Plastic Packaging and Substitutes (thousand cubic meters)

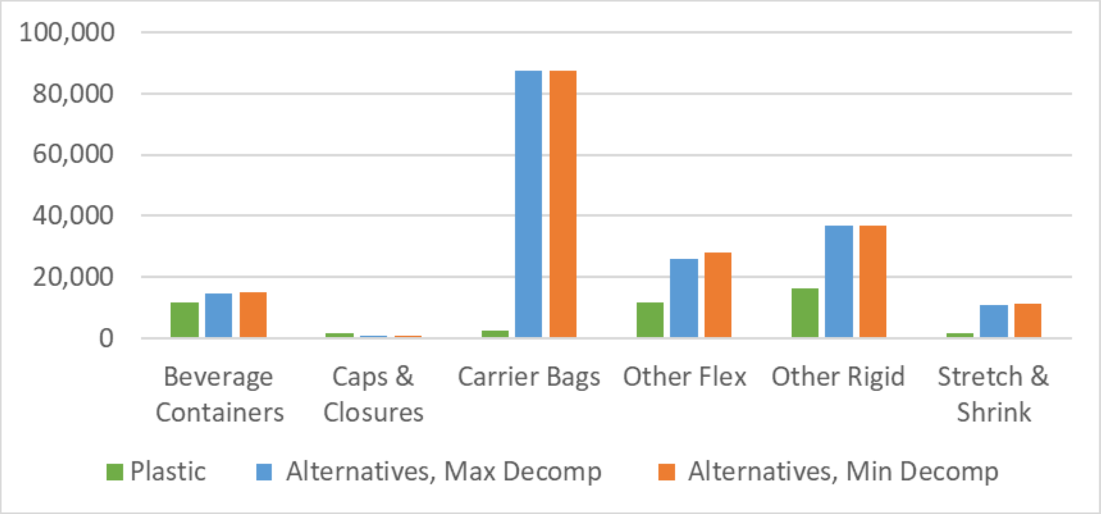

Figure 4-10. Water Consumption for Canadian Plastic Packaging and Substitutes (thousand cubic meters)

4.6. SOLID WASTE RESULTS

4.6.1. Weight of Solid Waste

Solid waste includes sludges and residues from chemical reactions and material processing steps, wastes associated with production and combustion of fuels (e.g., refinery wastes, coal combustion ash from power generation), and postconsumer packaging that is disposed rather than recycled.

Solid waste tends to be significantly higher for substitute packaging (e.g., paper, metals, glass, etc.) since more kg of substitute packaging are generally required to perform the same function as plastic packaging, as was shown in Table 4-1 and Table 4-2. Disposal of unrecycled packaging is the largest contributor for both plastics and alternatives. However, the solid waste results also include the effect of reductions due to recycling, as well solid waste contributions from production and combustion of process fuels and solid wastes from material production and converting processes. Process solid wastes for plastics tend to be lower than solid wastes for materials like paper, paperboard, and metals, which produce sludges, mining residues, and slags.

Similar trends are seen for US and Canada, although the effect of higher recycling rates in Canada can be seen by comparing results for beverage container and other rigids in
Figure 4-11 and
Figure 4-12. Canadian solid waste results for these categories show significantly lower solid wastes relative to US results. Higher recycling rates means less material disposed in landfills and more credits for recycled material displacing virgin material.

The overall solid waste weight ratio for plastic packaging compared to substitute packaging is 4.9 for the US and 3.9 for Canada. The savings in weight of solid waste expressed as the equivalent number of 747 aircraft are 290,000 747s for US plastic packaging and about 22,000 747s for Canadian packaging.[174]

Table 4-10. Solid Waste by Weight for US Plastic Packaging and Substitutes (thousand metric tonnes)

	Plastic Packaging	Substitutes, Max Decomp	Substitutes, No Decomp	Ratio, Max Decomp	Ratio, No Decomp	Savings, Max Decomp	Savings, No Decomp
Caps & Closures	805	1,074	1,077	1.3	1.3	269	271
Beverage Containers	2,675	16,706	16,727	6.2	6.3	14,032	14,052
Stretch & Shrink	636	4,447	4,482	7.0	7.1	3,811	3,846
Carrier Bags	1,217	2,984	3,005	2.5	2.5	1,767	1,788
Other Flexible	4,183	21,596	21,785	5.2	5.2	17,413	17,602
Other Rigid	4,047	19,642	19,650	4.9	4.9	15,595	15,604
TOTAL	**13,563**	**66,450**	**66,725**	**4.9**	**4.9**	**52,887**	**53,162**
Substitutes % Higher than Plastics		390%	392%				
Plastic Results as % of Substitutes		20%	20%				
Savings Equivalency							
Thousands of 747 Airplanes						290	291

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[174] Empty weight of a 747-400 airplane with General Electric engines is 182,480 kg, per http://www.boeing.com/resources/boeingdotcom/company/about_bca/startup/pdf/historical/747-400-passenger.pdf
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Table 4-11. Solid Waste by Weight for Canadian Plastic Packaging and Substitutes (thousand metric tonnes)

	Plastic Packaging	Substitutes, Max Decomp	Substitutes, No Decomp	Ratio, Max Decomp	Ratio, No Decomp	Savings, Max Decomp	Savings, No Decomp
Caps & Closures	64.6	67.5	67.5	1.0	1.0	2.89	2.90
Beverage Containers	177	776	776	4.4	4.4	599	600
Stretch & Shrink	74.0	492	493	6.7	6.7	418	419
Carrier Bags	105	264	264	2.5	2.5	159	159
Other Flex	554	2,757	2,761	5.0	5.0	2,203	2,207
Other Rigid	417	1,079	1,079	2.6	2.6	662	662
TOTAL	**1,391**	**5,435**	**5,441**	**3.9**	**3.9**	**4,044**	**4,050**
Substitutes % Higher than Plastics		291%	291%				
Plastic Results as % of Substitutes		26%	26%				
Savings Equivalency							
Thousands of 747 Airplanes						22	22

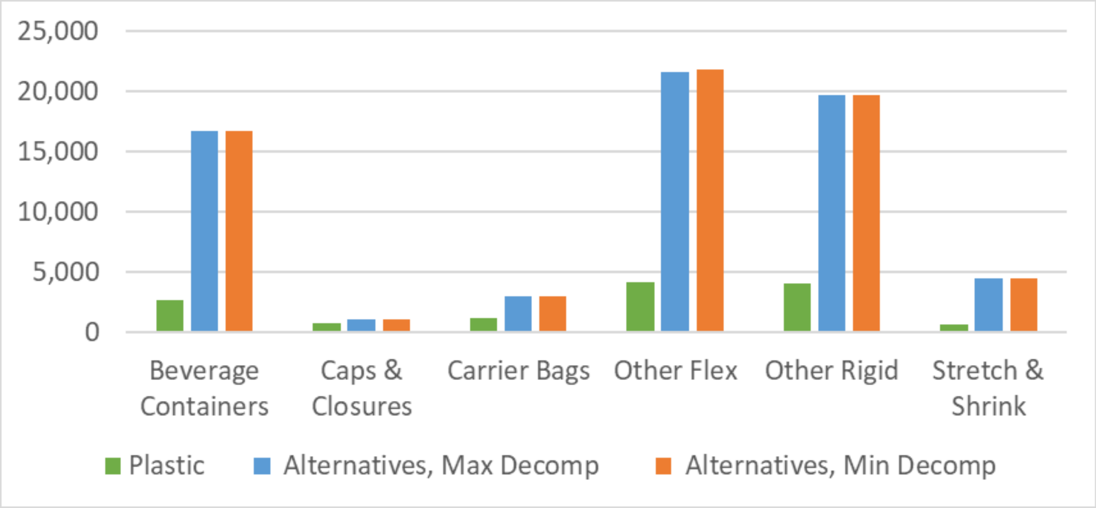

Figure 4-11. Solid Waste by Weight by Category for US Plastic Packaging and Substitutes (thousand metric tonnes)

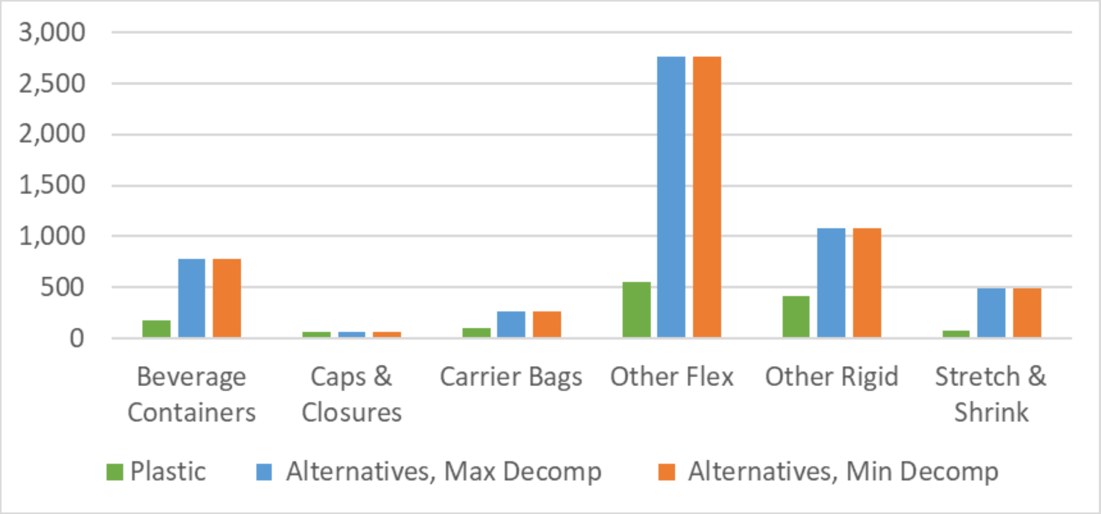

Figure 4-12. Solid Waste by Weight by Category for Canadian Plastic Packaging and Substitutes (thousand metric tonnes)

4.6.2. Volume of Solid Waste

Weights of solid waste are converted to volume using landfill density factors for corresponding products and materials derived from landfill samples and compaction tests. Industrial wastes from raw material production processes and fuel-related wastes are generally higher in density than postconsumer packaging, so the relative solid waste contributions for process and fuel-related wastes are smaller on a volume basis than on a weight basis. For postconsumer packaging solid waste, plastic rigids (in categories such as beverage containers, caps and closures, and other rigid packaging) show less savings in solid waste volume compared to solid waste weight. This is due to the lower landfill density of rigid plastics, particularly where plastic is substituted with paper, which compacts more densely in a landfill. As shown in Table 4-12 and Table 4-13, the overall solid waste weight ratio for plastic packaging compared to substitute packaging is 4.9 for the US and 3.9 for Canada. The weight of solid waste is expressed in terms of the volume of a well-known landmark, the US Capitol Rotunda. The volume of solid waste savings for the US equates to the volume to fill the Capitol Rotunda approximately 1,500 times, and the savings for Canadian packaging is the equivalent to over 100 Capitol Rotunda volumes.[175]

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[175] The volume of the US Capitol Rotunda is 1.3 million cubic feet, per https://www.aoc.gov/facts/capitol-hill#CP_JUMP_8210.

Table 4-12. Solid Waste by Volume for US Plastic Packaging and Substitutes (million cubic meters)

	Plastic Packaging	Substitutes, Max Decomp	Substitutes, No Decomp	Ratio, Max Decomp	Ratio, No Decomp	Savings, Max Decomp	Savings, No Decomp
Caps & Closures	2.04	1.38	1.38	0.7	0.7	-0.66	-0.66
Beverage Containers	9.63	21.9	22.0	2.3	2.3	12.3	12.3
Stretch & Shrink	1.42	7.21	7.25	5.1	5.1	5.78	5.82
Carrier Bags	2.13	4.57	4.60	2.2	2.2	2.44	2.47
Other Flexible	8.83	34.9	35.1	4.0	4.0	26.1	26.3
Other Rigid	15.8	25.0	25.0	1.6	1.6	9.14	9.15
TOTAL	**39.9**	**95.0**	**95.3**	**2.4**	**2.4**	**55.1**	**55.4**
Substitutes % Higher than Plastics		138%	139%				
Plastic Results as % of Substitutes		42%	42%				
Savings Equivalency							
U.S. Capitol Rotundas						1,496	1,505

Table 4-13. Solid Waste by Volume for Canadian Plastic Packaging and Substitutes (million cubic meters)

	Plastic Packaging	Substitutes, Max Decomp	Substitutes, No Decomp	Ratio, Max Decomp	Ratio, No Decomp	Savings, Max Decomp	Savings, No Decomp
Caps & Closures	0.18	0.086	0.086	0.5	0.5	-0.097	-0.097
Beverage Containers	0.71	1.08	1.08	1.5	1.5	0.37	0.37
Stretch & Shrink	0.18	0.83	0.83	4.7	4.7	0.65	0.65
Carrier Bags	0.25	0.44	0.44	1.8	1.8	0.19	0.19
Other Flex	1.33	4.42	4.42	3.3	3.3	3.08	3.09
Other Rigid	1.88	1.41	1.41	0.7	0.7	-0.47	-0.47
TOTAL	**4.53**	**8.26**	**8.27**	**1.8**	**1.8**	**3.73**	**3.74**
Substitutes % Higher than Plastics		82%	83%				
Plastic Results as % of Substitutes		55%	55%				
Savings Equivalency							
U.S. Capitol Rotundas						101	102

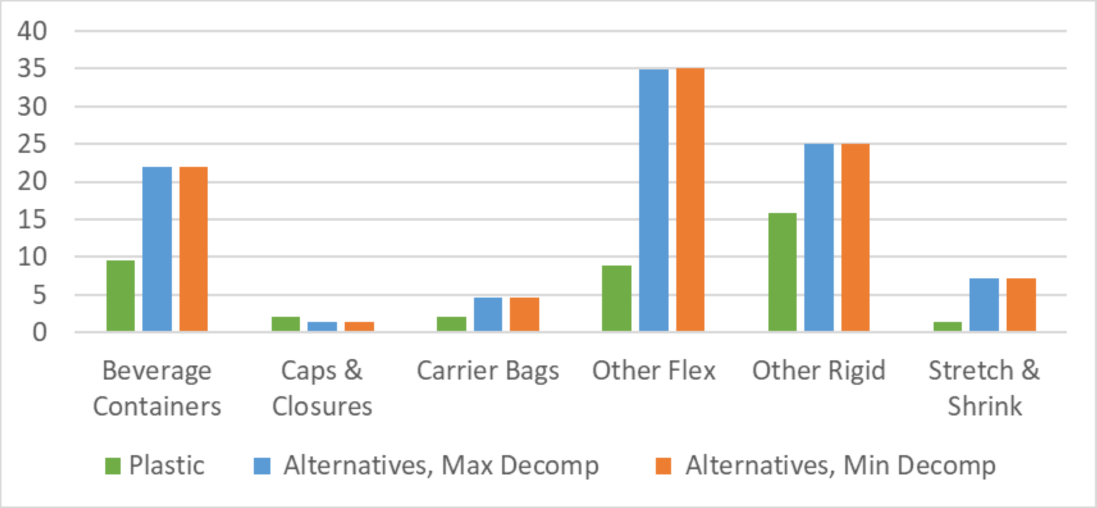

Figure 4-13. Solid Waste by Volume by Category for US Plastic Packaging and Substitutes (million cubic meters)

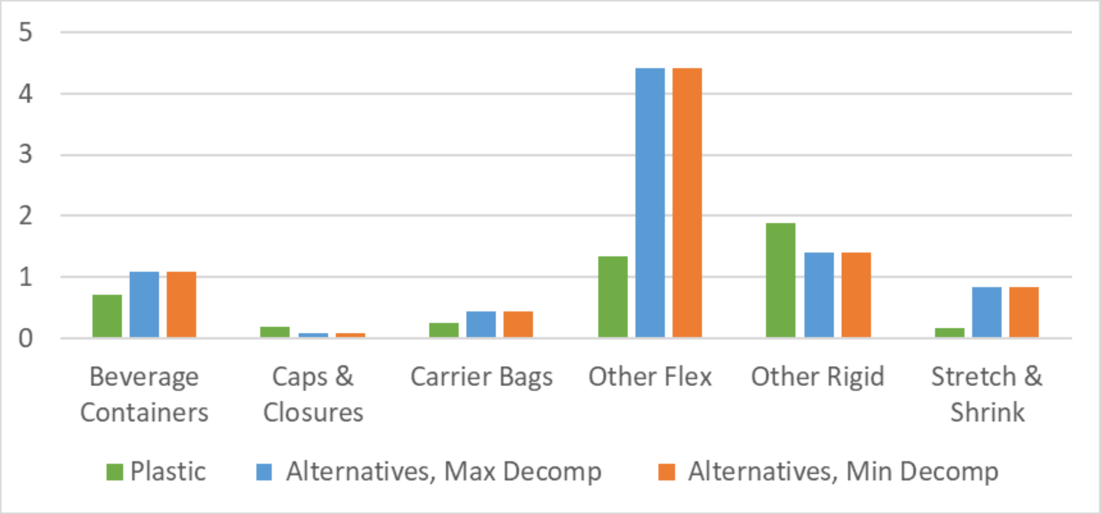

Figure 4-14. Solid Waste by Volume by Category for Canadian Plastic Packaging and Substitutes (million cubic meters)

4.7. GWP RESULTS

Life cycle global warming potential results for packaging materials include the impacts of process emissions (e.g., fugitive or direct emissions from chemical reactions or converting operations); emissions from the extraction, processing, and combustion of fuels; and emissions associated with end-of-life management (e.g., biogenic methane from decomposition of landfilled products, fossil CO_2 emissions from products disposed by combustion, and emission credits for grid electricity displaced by energy recovered from waste-to-energy combustion of materials or landfill gas).

As described in Chapter 1, two decomposition scenarios are analyzed for substitute packaging. The "no decomposition" scenario includes biogenic CO_2 sequestration credit for all the biogenic carbon in landfilled packaging (i.e., no decomposition over time of any landfilled biomass-derived packaging), while the "maximum decomposition" scenario is based on maximum decomposition of uncoated paper and paperboard packaging that is disposed in landfills. For coated/laminated paper and paperboard products, the barrier layers are assumed to minimize any decomposition of the fiber content; therefore, to use a conservative approach, no decomposition of the fiber content of coated/laminated paper-based packaging is modeled in either decomposition scenario.

Table 4-14 and Table 4-15 show life cycle global warming potential results for plastics and alternatives in the US and Canada, respectively. The results are also presented graphically in Figure 4-15 and Figure 4-16. For the entire packaging sector, life cycle GWP results for US substitutes are 1.7 times higher than plastic packaging under the no decomposition scenario (with biomass carbon storage credits for landfilled paper, paperboard, and wood packaging) and 2.2 times higher than plastic packaging for the maximum decomposition scenario. For Canada, substitute packaging GWP is 1.9 times greater than plastic packaging for the no decomposition scenario and 3 times greater for the maximum decomposition scenario. The Canadian ratio for the maximum decomposition scenario is higher than for the US because less landfill gas is captured and utilized in Canada, so net landfill methane emissions are higher.

The total life cycle GWP savings for use of plastic packaging compared to substitutes can be visualized using factors from the US EPA Greenhouse Gas Equivalencies Calculator. US GWP savings of 39.5 million metric tonnes of CO_2 eq for the conservative no decomposition scenario for substitutes is equivalent to the GHG emissions saved by taking 8.5 million passenger vehicles off the road for a year, or the annual GHG emissions from the combustion of the gasoline in 523,000 tanker trucks. US savings for the maximum decomposition scenario are substantially higher, 67 million metric tonnes CO_2 eq, equivalent to 14 million passenger vehicles and almost 890,000 tanker trucks of gasoline. The Canadian GWP savings of 3.6 million metric tonnes CO_2 eq for the no decomposition scenario is equivalent to the emissions from 800,000 passenger vehicles or 48,000 tanker trucks of gasoline, while savings for the maximum decomposition scenario are over twice as high at 8.7 million metric tonnes CO_2 eq, equivalent to almost 2 million passenger vehicles or 115,000 tanker trucks of gasoline.

Table 4-14. GWP Results for US Plastic and Substitute Packaging (million metric tonnes CO_2 eq)

	Plastic Packaging	Substitutes, Max Decomp	Substitutes, No Decomp	Ratio, Max Decomp	Ratio, No Decomp	Savings, Max Decomp	Savings, No Decomp
Caps & Closures	3.11	2.44	2.09	0.8	0.7	-0.67	-1.01
Beverage Containers	13.4	21.8	20.7	1.6	1.5	8.40	7.31
Stretch & Shrink	2.50	11.8	9.30	4.7	3.7	9.31	6.79
Carrier Bags	4.19	10.9	8.11	2.6	1.9	6.75	3.93
Other Flexible	15.1	40.4	20.2	2.7	1.3	25.3	5.10
Other Rigid	19.4	37.4	36.8	1.9	1.9	18.0	17.4
TOTAL	**57.6**	**125**	**97.1**	**2.2**	**1.7**	**67.1**	**39.5**
Substitutes % Higher than Plastics		117%	69%				
Plastic Results as % of Substitutes		46%	59%				
Savings Equivalencies							
Million passenger vehicles per year						14	8.5
Thousand tanker trucks of gasoline						889	523

Table 4-15. GWP Results for Canadian Plastic and Substitute Packaging (million metric tonnes CO_2 eq)

	Plastic Packaging	Substitutes, Max Decomp	Substitutes, No Decomp	Ratio, Max Decomp	Ratio, No Decomp	Savings, Max Decomp	Savings, No Decomp
Caps & Closures	0.16	0.15	0.13	0.9	0.8	-0.0087	-0.036
Beverage Containers	0.85	1.74	1.62	2.0	1.9	0.89	0.77
Stretch & Shrink	0.21	1.10	0.69	5.3	3.4	0.89	0.49
Carrier Bags	0.31	0.63	0.15	2.1	0.5	0.33	-0.16
Other Flex	1.37	6.15	2.29	4.5	1.7	4.78	0.92
Other Rigid	1.40	3.18	3.07	2.3	2.2	1.79	1.68
TOTAL	**4.29**	**13.0**	**7.94**	**3.0**	**1.9**	**8.66**	**3.65**
Substitutes % Higher than Plastics		202%	85%				
Plastic Results as % of Substitutes		33%	54%				
Savings Equivalencies							
Million passenger vehicles per year						1.9	0.8
Thousand tanker trucks of gasoline						115	48

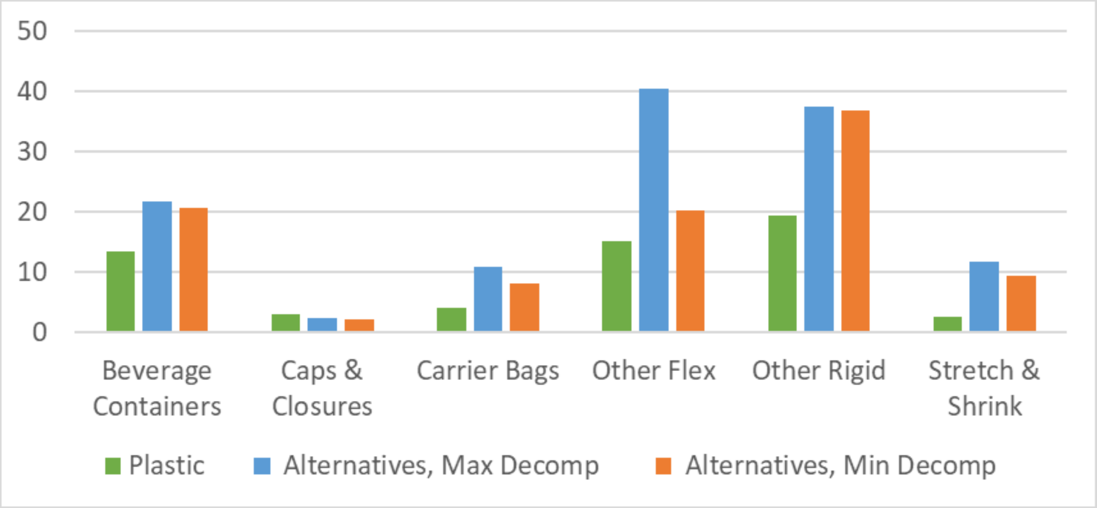

Figure 4-15. GWP Results by Category for US Plastic Packaging and Substitutes (million metric tonnes CO_2 eq)

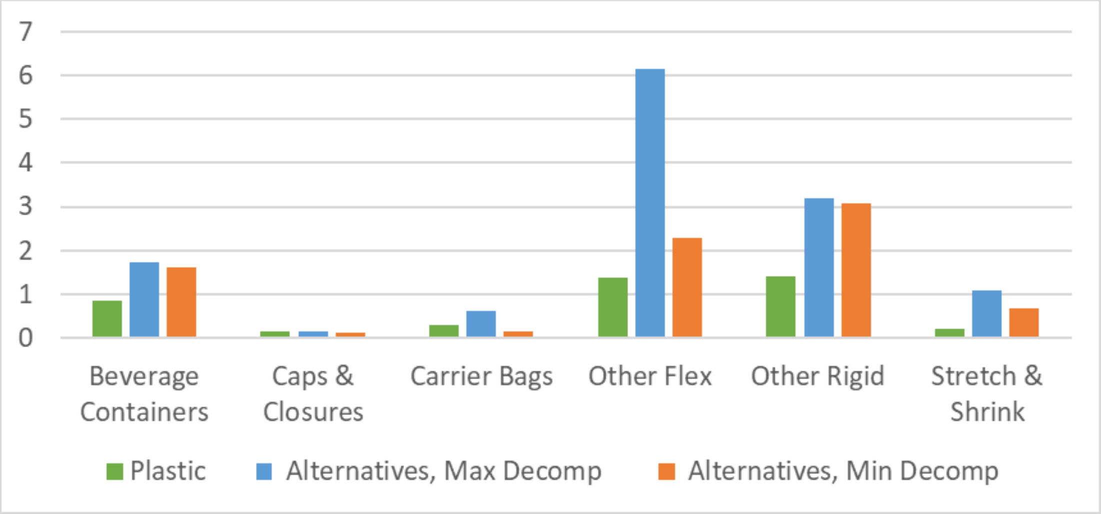

Figure 4-16. GWP Results by Category for Canadian Plastic Packaging and Substitutes (million metric tonnes CO_2 eq)

4.8. ACIDIFICATION POTENTIAL RESULTS

Acidification potential results are based on the accumulation of acids and acidifying substances (SO_2, NO_x) in the water particles suspended in the atmosphere or deposited onto the ground by rains. These acidifying pollutants have a wide variety of adverse impact on soil, organisms, ecosystems and materials (buildings).

Acidification impacts are typically dominated by emissions associated with fuel combustion, particularly SO_x and NO_x. Coal combustion in utility boilers is the largest contributor to acidification for both US and Canadian packaging, followed by combustion of other fossil fuels for process and transportation energy. Similar trends in acidification results are seen for the US and Canada, although Canadian results are proportionately lower due to a less fossil fuel-intensive electricity grid.

The overall acidification ratio for plastic packaging compared to substitute packaging is 3.3 for the US and 4.3 for Canada. The savings in acidification is expressed as the emissions from combustion of the equivalent number of railcars full of coal. Acidification savings for US plastic packaging compared to substitutes are equivalent to the acidification from burning over 290,000 railcars of coal, and Canadian savings are equivalent to 29,000 railcars of coal.[176]

Table 4-16. Acidification Potential for US Plastic Packaging and Substitutes (thousand metric tonnes SO_2 eq)

	Plastic Packaging	Substitutes, Max Decomp	Substitutes, No Decomp	Ratio, Max Decomp	Ratio, No Decomp	Savings, Max Decomp	Savings, No Decomp
Caps & Closures	11.9	16.3	16.4	1.4	1.4	4.35	4.49
Beverage Containers	55.5	143	144	2.6	2.6	87.8	88.9
Stretch & Shrink	8.17	64.9	66.8	7.9	8.2	56.7	58.6
Carrier Bags	15.8	80.4	81.5	5.1	5.2	64.6	65.7
Other Flexible	54.3	220	230	4.1	4.2	166	176
Other Rigid	79.7	226	227	2.8	2.8	147	147
TOTAL	**225**	**752**	**766**	**3.3**	**3.4**	**526**	**541**
Substitutes % Higher than Plastics		233%	240%				
Plastic Results as % of Substitutes		30%	29%				
Savings Equivalency							
Thousands of rail cars of coal burned						292	301

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[176] Based on tons of coal per railcar from https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator and emissions per kg of coal burned from US LCI Database.

Table 4-17. Acidification Potential for Canadian Plastic Packaging and Substitutes (thousand metric tonnes SO_2 eq)

	Plastic Packaging	Substitutes, Max Decomp	Substitutes, No Decomp	Ratio, Max Decomp	Ratio, No Decomp	Savings, Max Decomp	Savings, No Decomp
Caps & Closures	0.58	0.96	0.96	1.7	1.7	0.38	0.38
Beverage Containers	3.06	10.9	10.9	3.6	3.6	7.82	7.85
Stretch & Shrink	0.70	5.59	5.66	8.0	8.1	4.89	4.96
Carrier Bags	1.20	4.35	4.37	3.6	3.7	3.15	3.18
Other Flex	4.88	26.8	27.1	5.5	5.5	21.9	22.2
Other Rigid	5.20	19.3	19.3	3.7	3.7	14.1	14.1
TOTAL	**15.6**	**67.9**	**68.3**	**4.3**	**4.4**	**52.3**	**52.7**
Substitutes % Higher than Plastics		335%	338%				
Plastic Results as % of Substitutes		23%	23%				
Savings Equivalency							
Thousands of rail cars of coal burned						29	29

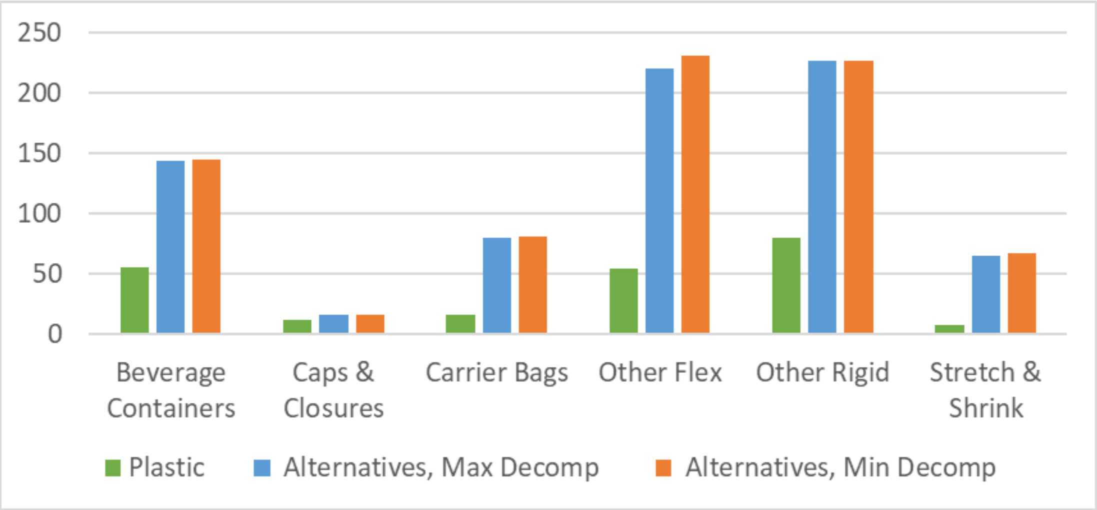

Figure 4-17. Acidification Potential by Category for US Plastic Packaging and Substitutes (thousand metric tonnes SO_2 eq)

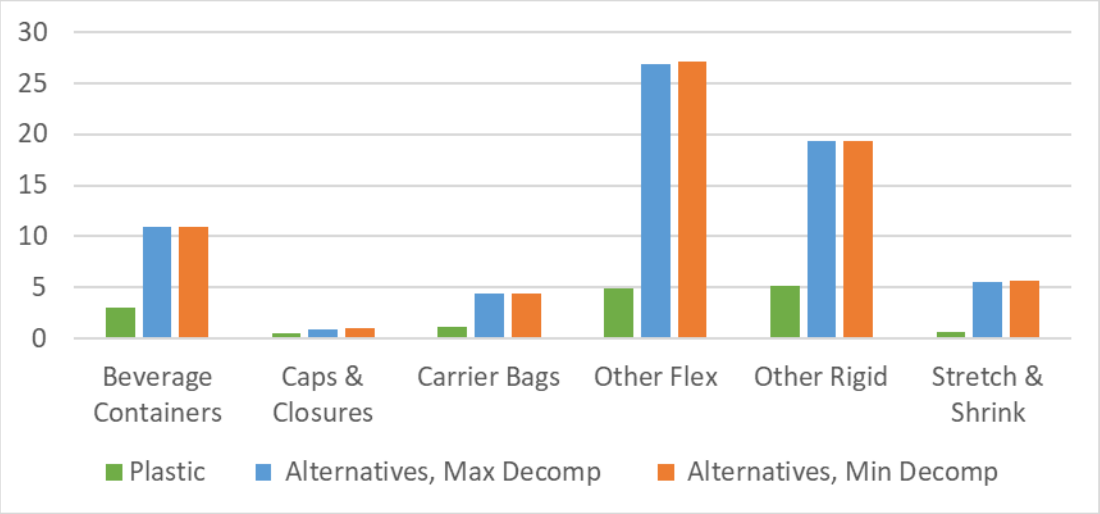

Figure 4-18. Acidification Potential by Category for Canadian Plastic Packaging and Substitutes (thousand metric tonnes SO_2 eq)

4.9. EUTROPHICATION POTENTIAL RESULTS

Eutrophication potential is based on releases of nutrients (phosphorus, nitrogen, BOD) to the aquatic and the terrestrial environment which can lead to a decrease in the oxygen content. This in turn can lead to ecosystem disturbances such as algal blooms and fish kills.

Atmospheric emissions of nitrogen oxides (NO_x) as well as waterborne emissions of nitrogen, phosphorus, ammonia, biochemical oxygen demand (BOD), and chemical oxygen demand (COD) are the main contributors to eutrophication impacts. The largest share of eutrophication for plastic packaging systems is fossil fuel combustion emissions. While fuel-related emissions are also significant contributors to eutrophication for substitute packaging, some process emissions have large eutrophication impacts (e.g., waterborne emissions from aluminum can manufacturing, BOD and COD from paper and paperboard manufacturing processes). As a result, overall plastic packaging eutrophication results are only 2% of the total eutrophication for substitute packaging, and the overall eutrophication ratio for substitutes compared to plastic packaging is very high, 54 times as much eutrophication for US packaging, and 66 times as high for Canadian packaging. (Note that the high results for some substitute packaging categories prevent smaller magnitude results, e.g., for caps and closures and for plastic packaging in most categories, from showing up on Figure 4-19 and Figure 4-20.)

Table 4-18. Eutrophication Potential for US Plastic Packaging and Substitutes (thousand metric tonnes N eq)

	Plastic Packaging	Substitutes, Max Decomp	Substitutes, No Decomp	Ratio, Max Decomp	Ratio, No Decomp	Savings, Max Decomp	Savings, No Decomp
Caps & Closures	0.30	0.35	0.36	1.2	1.2	0.053	0.055
Beverage Containers	1.86	278	278	149	149	276	276
Stretch & Shrink	0.24	4.28	4.31	18	18	4.04	4.07
Carrier Bags	0.41	10.9	10.9	27	27	10.5	10.5
Other Flexible	1.57	14.6	14.8	9.3	9.4	13.0	13.2
Other Rigid	2.09	38.9	38.9	19	19	36.8	36.8
TOTAL	**6.47**	**347**	**347**	**54**	**54**	**340**	**341**
Substitutes % Higher than Plastics		5263%	5266%				
Plastic Results as % of Substitutes		2%	2%				

Table 4-19. Eutrophication Potential for Canadian Plastic Packaging and Substitutes (thousand metric tonnes N eq)

	Plastic Packaging	Substitutes, Max Decomp	Substitutes, No Decomp	Ratio, Max Decomp	Ratio, No Decomp	Savings, Max Decomp	Savings, No Decomp
Caps & Closures	0.018	0.020	0.020	1.1	1.1	0.0012	0.0012
Beverage Containers	0.16	30.5	30.5	196	196	30.4	30.4
Stretch & Shrink	0.024	0.45	0.45	19	19	0.43	0.43
Carrier Bags	0.036	1.11	1.11	31	31	1.07	1.08
Other Flex	0.17	1.71	1.71	10	10	1.54	1.54
Other Rigid	0.18	4.19	4.19	24	24	4.01	4.01
TOTAL	**0.58**	**38.0**	**38.0**	**66**	**66**	**37.4**	**37.4**
Substitutes % Higher than Plastics		6463%	6465%				
Plastic Results as % of Substitutes		2%	2%				

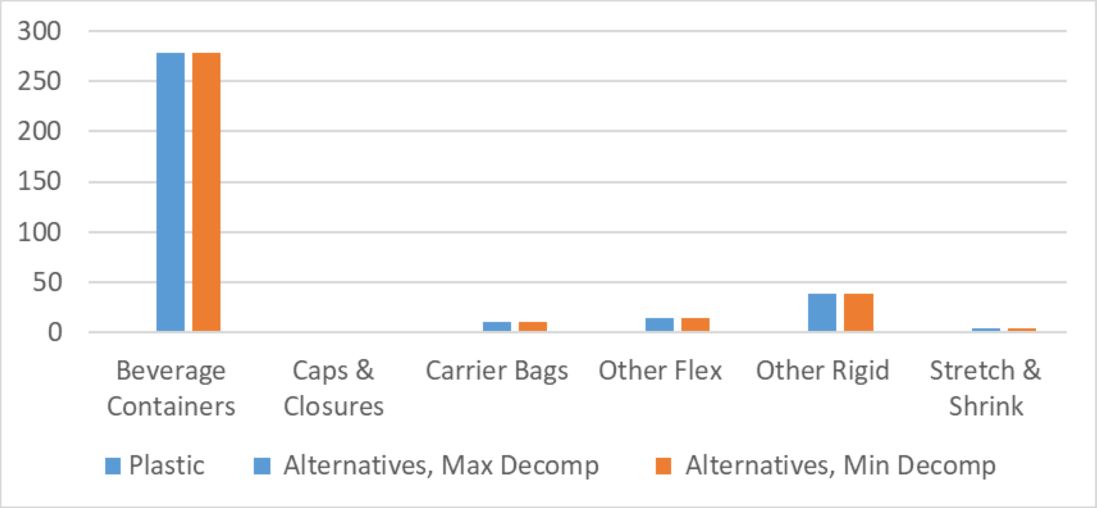

Figure 4-19. Eutrophication Potential by Category for US Plastic Packaging and Substitutes (thousand metric tonnes N eq)

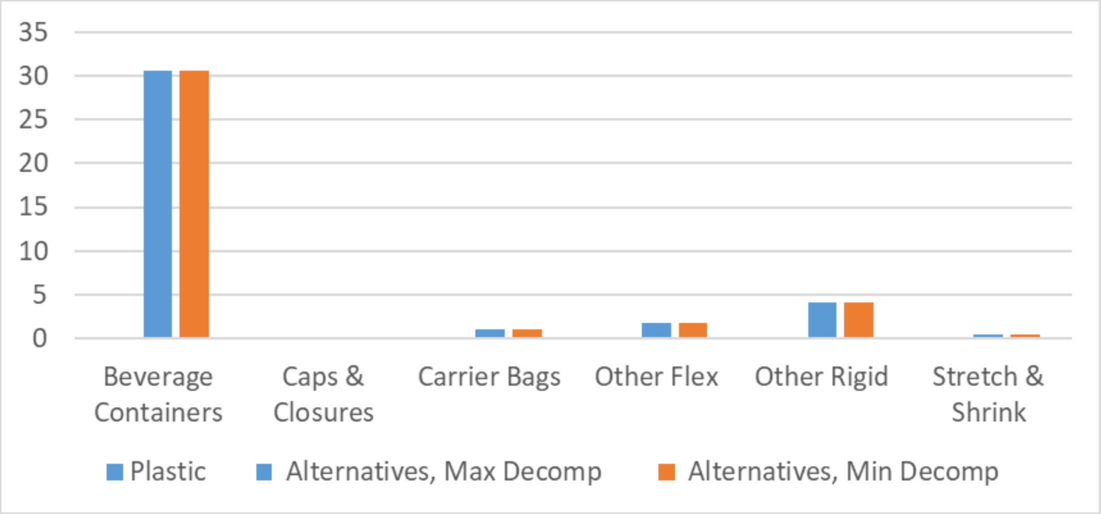

Figure 4-20. Eutrophication Potential by Category for Canadian Plastic Packaging and Substitutes (thousand metric tonnes N eq)

4.10. SMOG FORMATION POTENTIAL

Smog formation potential reflects the photochemical creation of reactive substances (mainly ozone) in the lower atmosphere which affect human health and ecosystems. This ground-level ozone is formed in the atmosphere by nitrogen oxides (NOx) and volatile organic compounds (VOCs) in the presence of sunlight.

Smog formation impacts, like other atmospheric impact indicators included in this study, are generally dominated by emissions associated with fuel combustion, so that impacts are higher for life cycle stages and components that have higher process fuel and transportation fuel requirements. As shown in the expended energy results section, substitute packaging requires more expended energy (primarily derived from fossil fuels) than plastic packaging. As a result, fuel combustion-related smog impacts are also notably higher for substitute packaging compared to plastic packaging. Trends by packaging category are very similar for the US and Canada. For the US, total smog impacts for plastic packaging are only about a third of smog impacts for substitute packaging. For Canada, overall plastic packaging smog impacts are 28% of substitute packaging impacts.

Table 4-20. Smog Formation Potential for US Plastic Packaging and Substitutes (thousand metric tonnes O_3 eq)

	Plastic Packaging	Substitutes, Max Decomp	Substitutes, No Decomp	Ratio, Max Decomp	Ratio, No Decomp	Savings, Max Decomp	Savings, No Decomp
Caps & Closures	150	137	138	0.9	0.9	-13.2	-11.9
Beverage Containers	747	2,247	2,257	3.0	3.0	1,499	1,509
Stretch & Shrink	132	777	794	5.9	6.0	645	662
Carrier Bags	225	950	960	4.2	4.3	726	736
Other Flexible	844	2,432	2,524	2.9	3.0	1,588	1,680
Other Rigid	971	3,074	3,078	3.2	3.2	2,103	2,107
TOTAL	**3,068**	**9,617**	**9,750**	**3.1**	**3.2**	**6,549**	**6,682**
Substitutes % Higher than Plastics		213%	218%				
Plastic Results as % of Substitutes		32%	31%				

Table 4-21. Smog Formation Potential for Canadian Plastic Packaging and Substitutes (thousand metric tonnes O_3 eq)

	Plastic Packaging	Substitutes, Max Decomp	Substitutes, No Decomp	Ratio, Max Decomp	Ratio, No Decomp	Savings, Max Decomp	Savings, No Decomp
Caps & Closures	8.82	7.69	7.69	0.9	0.9	-1.13	-1.13
Beverage Containers	51.8	206	206	4.0	4.0	154	154
Stretch & Shrink	13.0	73.6	74.3	5.7	5.7	60.6	61.3
Carrier Bags	19.8	64.0	64.3	3.2	3.2	44.2	44.5
Other Flex	90.6	288	291	3.2	3.2	198	200
Other Rigid	75.7	286	286	3.8	3.8	210	210
TOTAL	**260**	**926**	**929**	**3.6**	**3.6**	**666**	**670**
Substitutes % Higher than Plastics		256%	258%				
Plastic Results as % of Substitutes		28%	28%				

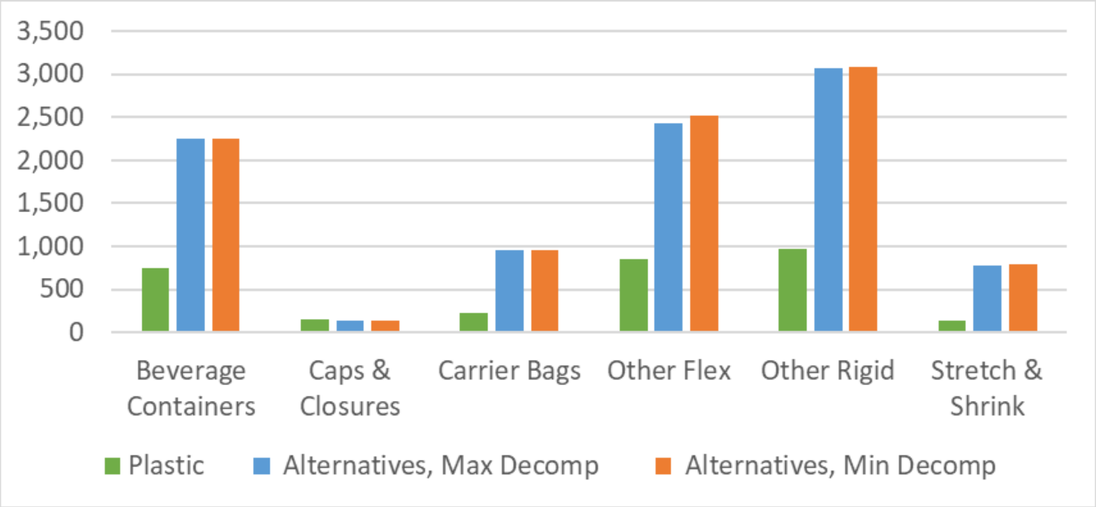

Figure 4-21. Smog Formation Potential by Category for US Plastic Packaging and Substitutes (thousand metric tonnes O_3 eq)

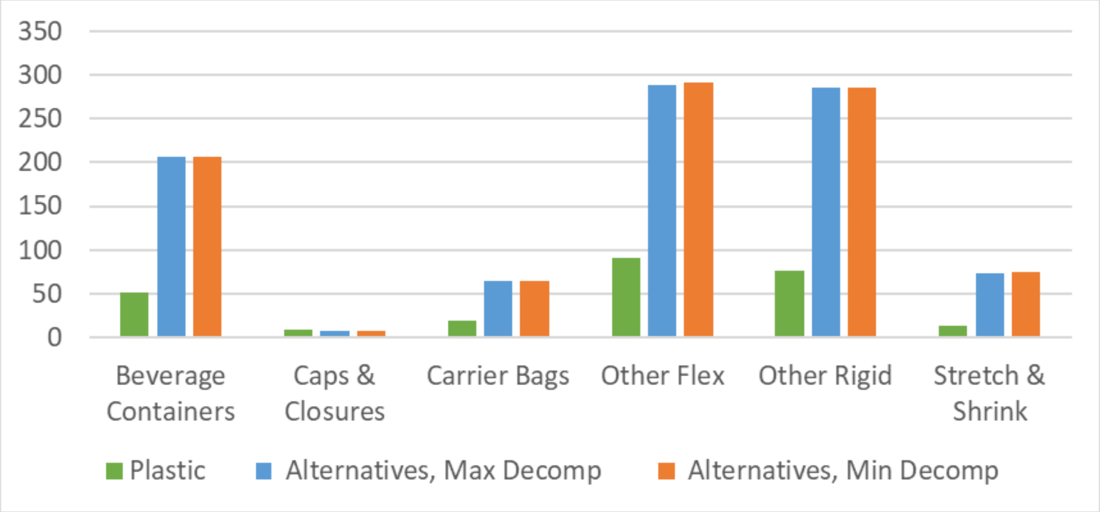

Figure 4-22. Smog Formation Potential by Category for Canadian Plastic Packaging and Substitutes (thousand metric tonnes O_3 eq)

4.11. OZONE DEPLETION POTENTIAL

Depletion of stratospheric ozone increases exposure to radiation, which can lead to increased frequency of human health issues such as skin cancers and cataracts as well as detrimental effects on crops, other plants, and marine life. For plastic packaging, the main substances that contribute to ozone depletion are chlorofluorocarbons (CFCs) and halogenated chlorofluorocarbons (HCFCs) associated with petroleum refining for fuel use and for use as feedstock material for plastic resins. Ozone depleting emissions from petroleum refining also drive the impacts associated with transportation energy use. For paper and paperboard packaging, emissions released from combustion of wood fuel in boilers at paper mills also make significant contribution to ozone depletion results.

Table 4-22 and Table 4-23 show that ozone depletion results are not significantly affected by decomposition assumptions for substitute packaging. Trends in ozone depletion results are very similar for the US and Canada, as shown in
Figure 4-23 and
Figure 4-24.

Table 4-22. Ozone Depletion Potential for US Plastic Packaging and Substitutes (metric tonnes CFC-11 eq)

	Plastic Packaging	Substitutes, Max Decomp	Substitutes, No Decomp	Ratio, Max Decomp	Ratio, No Decomp	Savings, Max Decomp	Savings, No Decomp
Caps & Closures	0.024	0.0071	0.0071	0.3	0.3	-0.017	-0.017
Beverage Containers	0.055	0.36	0.36	6.6	6.6	0.31	0.31
Stretch & Shrink	0.041	0.14	0.14	3.4	3.4	0.097	0.097
Carrier Bags	0.024	0.17	0.17	7.4	7.4	0.15	0.15
Other Flexible	0.18	0.77	0.77	4.2	4.2	0.58	0.58
Other Rigid	0.083	0.11	0.11	1.4	1.4	0.032	0.032
TOTAL	**0.41**	**1.56**	**1.56**	**3.8**	**3.8**	**1.15**	**1.15**
Substitutes % Higher than Plastics		282%	282%				
Plastic Results as % of Substitutes		26%	26%				

Table 4-23. Ozone Depletion Potential for Canadian Plastic Packaging and Substitutes (metric tonnes CFC-11 eq)

	Plastic Packaging	Substitutes, Max Decomp	Substitutes, No Decomp	Ratio, Max Decomp	Ratio, No Decomp	Savings, Max Decomp	Savings, No Decomp
Caps & Closures	0.0019	4.0E-04	4.0E-04	0.2	0.2	-0.0015	-0.0015
Beverage Containers	0.0047	0.035	0.035	7.5	7.5	0.031	0.031
Stretch & Shrink	0.0051	0.016	0.016	3.1	3.1	0.011	0.011
Carrier Bags	0.0020	0.018	0.018	8.8	8.8	0.016	0.016
Other Flex	0.024	0.092	0.092	3.9	3.9	0.069	0.069
Other Rigid	0.0090	0.0098	0.0098	1.1	1.1	8.1E-04	8.1E-04
TOTAL	**0.046**	**0.17**	**0.17**	**3.7**	**3.7**	**0.13**	**0.13**
Substitutes % Higher than Plastics		270%	271%				
Plastic Results as % of Substitutes		27%	27%				

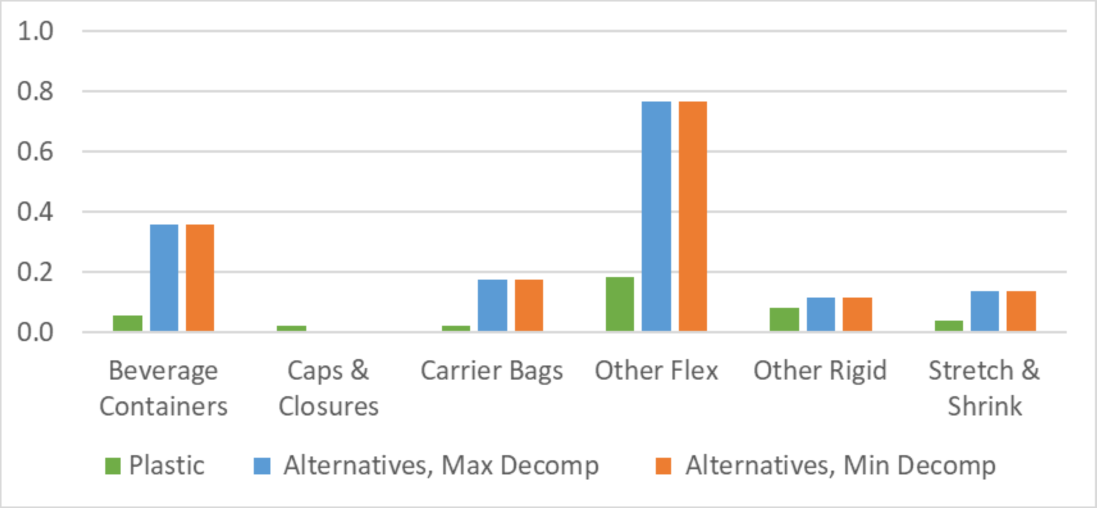

Figure 4-23. Ozone Depletion Potential by Category for US Plastic Packaging and Substitutes (metric tonnes CFC-11 eq)

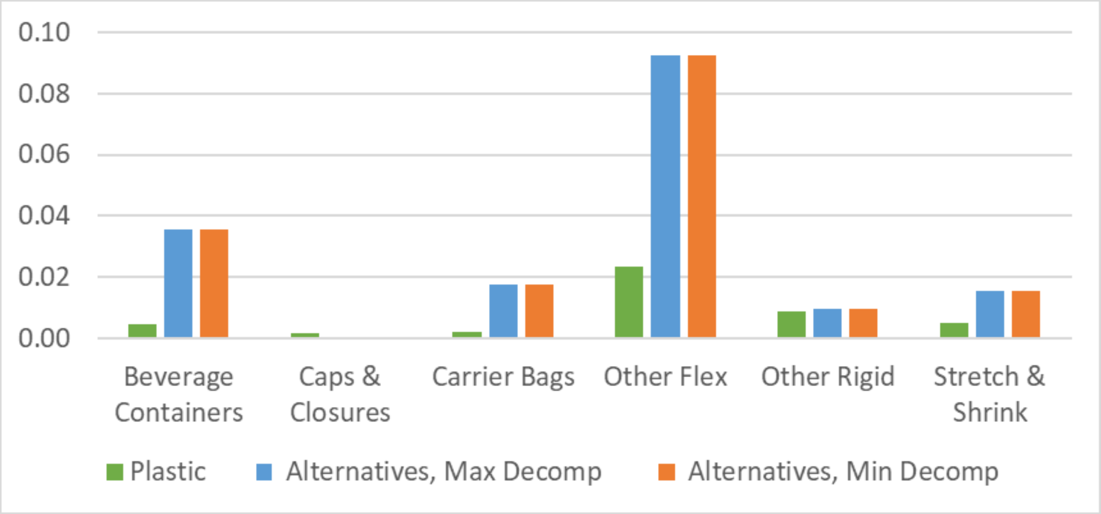

Figure 4-24. Ozone Depletion Potential by Category for Canadian Plastic Packaging and Substitutes (metric tonnes CFC-11 eq)

4.12. EQUIVALENTS

Equivalents used to provide perspective on overall savings in results for plastic packaging compared to substitute packaging in the US and Canada were provided in the individual results sections. Table 4-24 summarizes the savings equivalents across the various results categories.

Table 4-24. Savings Equivalents for Plastic Packaging Compared to Substitutes

		US Savings		Canadian Savings	
Results Category	**Equivalence Factor**	Plastics compared to Substitutes with Max Decomp	Plastics compared to Substitutes with No Decomp	Plastics compared to Substitutes with Max Decomp	Plastics compared to Substitutes with No Decomp
Total Energy	Million passenger vehicles per year	18	18	1.8	1.8
	Thousand tanker trucks of gasoline	1,073	1,108	108	110
Global Warming Potential	Million passenger vehicles per year	14	8.5	1.9	0.8
	Thousand tanker trucks of gasoline	889	523	115	48
Water Consumption	Thousand Olympic swimming pools	461	467	54	55
Solid Waste by Weight	Thousand 747 airplanes	290	291	22	22
Solid Waste by Volume	U.S. Capitol Rotundas	1,496	1,505	101	102
Acidification	Thousand railcars of coal	292	301	29	29

4.13. SUMMARY

The results of this substitution analysis provide a snapshot of the environmental impacts of the current overall mix of plastic packaging in several categories, and the environmental impacts of the overall mix of alternative types of packaging that might be used as substitutes. Results are presented for broad categories of packaging and do not make comparative assertions as defined by ISO 14040 regarding individual competing plastic and alternative packages. The analysis is intended to provide information regarding the overall potential impacts of a theoretical plastic packaging substitution scenario and is not intended to be used as the basis for comparative environmental claims or purchasing decisions regarding specific packaging products.

Plastic packaging has many properties that are vitally important for packaging applications, including light weight, flexibility, durability, cushioning, and barrier properties, to name a few. This substitution analysis demonstrates that plastic packaging is also an efficient choice in terms of environmental impacts.

For the six packaging categories analyzed – caps and closures, beverage containers, stretch and shrink film, carrier bags, other rigid packaging, and other flexible packaging –14.4 million metric tonnes of plastic packaging were used in the US in 2010. If other types of packaging were used to substitute US plastic packaging, more than 64 million metric tonnes of packaging would be required. The substitute packaging would result in significantly higher impacts for all results categories evaluated: total energy demand, expended energy, water consumption, solid waste by weight and by volume, global warming potential, acidification, eutrophication, smog formation, and ozone depletion, as shown previously in Figure 4-1.

Canadian plastic packaging use was approximately 1.6 million metric tonnes in the same time frame. To provide the same service as this amount of plastic packaging, more than 7.1 million metric tonnes of other packaging materials would be needed. As was shown in Figure 4-2, plastic packaging in Canada has notably lower results than substitute packaging for all 10 results categories evaluated.