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A Comparative Life Cycle Assessment of Protective Mailers in the Postal Industry

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A Comparative Life Cycle Assessment of Protective Mailers in the Postal Industry

by

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Abstract

In 2010, Purolator and Canada Post were seeking an alternative to low density polyethylene (LDPE) parcel packaging due to its inability to be recycled. A study was required to determine if the disposal stage was in fact the most detrimental. A comparative Life Cycle Assessment was conducted evaluating a generic 8” x 12” LDPE bubble mailer, versus a product marketed as environmentally-friendly, a generic 8” x 12” Kraft paper and newsprint filled padded mailer. General Life Cycle Inventory data from U.S. LCI and ecoinvent were customized with primary data from Associated Bag Company and product measurements. SimaPro software calculated the Life Cycle Impact Assessment. Results showed the *upstream stages* and the *use stages* as significant for both products. Based on the results of this study, it is recommended that both products are eventually replaced with lighter, rapidly renewable materials.

Preface

In 2008, I picked up a courier envelope that I had just thrown into the garbage in my office in Vancouver. I asked myself “why do we do this?” This tiny question has lead to an unpredicted journey.

Acknowledgements

I would like to acknowledge and thank my supervisor, Professor Getachew Assefa Wondimagegnehu at the University of Calgary and Roland Hischier at Empa in Switzerland for introducing me to Life Cycle Assessments. Thank you both for sharing your knowledge and patience. I would also like to thank Dr. Mike Quinn, Professor Jim O`Grady, Mr. Barry Wylant, Dr. Tom Harper, Dr. Larissa Muller and Dr. Stan Stein for their guidance and for teaching me to think critically over the past four years. MEDes registrants from September 2009: Jason Archibald, Colleen Arnison, Mary Benjamin, Tomasz Budny, Cheryl Clieff, Derek Coonan, Matt Currie, Kate Cawthorn, Sarah Freigang, Susana Garcia San Roman, Jessica Guinto, Alex Harmer, Adam Kinney, Dani Koleyak, Cynthia Nemeth, Shirin Radmehr, Farzana Rahman and Katie Rasmussen, I am grateful for meeting each one of you. It has been a great journey of learning with you and from you all.

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Epigraph

"We have lived by the assumption that what was good for us would be good for the world. We have been wrong. We must change our lives, so that it will be possible to live by the contrary assumption that what is good for the world will be good for us."

~ Wendell Berry, American philosopher, poet, essayist, farmer, novelist and social activist

CHAPTER 1: INTRODUCTION

1.1 Environmental Design

Design is the base process for optimizing the function and form of products and services and can influence short and long-term technological, cultural, and ecological systems. The current life cycle of many products is myopic by design, focusing only on short-term economic benefits. Designing products for short-term consumption without prioritizing long-term consequences can lead to unsustainable practices. For example, planned obsolescence of products was introduced in North America post World War II to stimulate economic growth through rapid consumption (Packard, 1960, Slade, 2006). As a result, planned obsolescence and similar economic theories have lead to a rate of consumption that is unsustainable, as approximately one and a half planets worth of natural resources are currently required to meet global consumption needs, with an estimated three planets needed by 2050 (Borucke et al., 2013). Bridging the gap between short-term economic benefits and long-term environmental impact lies within design thinking, and a more holistic approach is required.

Environmental design is a systems approach bound by the context of design choices. A core principle of environmental design is that every action has a consequence; even the choice not to act. Application of environmental design principles can vary from architecture to ecology, urban planning and industrial design. Design thinking applied to the environment provides greater awareness of the interconnectivity between technological, cultural, and ecological systems. As such, environmental design requires carefully selected boundaries and variables to approach complex real world environmental issues that produce multiple rational solutions. The goal is to apply systems thinking through design solutions.

1.2 Problem Context

The design of manufactured products frequently focuses on the product separate from its system. Yet, the system may include processes that are environmentally degrading. A side effect of the rapid consumption of manufactured products is the mass utilization of single-use packages. Culturally, packaging only houses the product of interest and has less perceived value in comparison to the product. Its relevance is short-lived and seemingly harmless, yet it can produce long-term ecological consequences and deplete natural resources.

1.2.1 Design Implications

Product packaging contributed one third of the municipal solid waste found in landfills in North America in 2011 (U.S. EPA, 2013). Reducing the volume of solid waste by establishing recycling and composting programs has become a recent focus for many communities in Canada (Statistics Canada, 2008). Though this focus is worthwhile, significant reductions to the solid waste stream can also occur through the proper design of products, including packaging, by considering each stage of a product`s life cycle. Product design that includes variables of function, time and context can prevent toxins or pollutants from entering a product in the first place {{281 Boylston, Scott 2009}}.

1.2.2 Brief History of Packaging Design

Some of the oldest recorded packaging dates to 12,000 years ago when baskets were made out of interlaced twigs to gather food and carry goods, and provide decoration (Twede and Selke, 2005). The materials used for packaging evolved over the centuries. In 1809, chef and chemist Nicolas Appert invented sealed containers for the French military, to can and preserve food (Tewari, 2005). By the late 19th century, packaging utilized a variety of materials and progressed to satisfy three purposes: 1) to protect products in shipment, 2) to increase salability among competing products, and 3) to individualize portions (Boylston, 2009, Slade, 2006). At the turn of the 20th century packaging itself became a sellable product, designed and manufactured for the purpose of sale and profit (Leonard, 2011), and discarded as waste after achieving this purpose (Pongrácz and Pohjola, 2004).

After the Great Depression in the 1930s in North America, a trend of mass production of products was designed to stimulate the economy. Over production of goods created jobs and excess materials in inventory. Advertisers were tasked to stimulate sales and annual profits between 1930 and 1950. As Victor Lebow, a Marketing Consultant stated in 1955:

> Our enormously productive economy demands that we make consumption our way of life, that we convert the buying and use of goods into rituals, that we seek our spiritual satisfactions, our ego satisfactions, in consumption…We need things consumed, burned up, worn out, replaced and discarded at an ever increasing pace. (Lebow, 1955)

Advertisers marketed goods to stimulate the economy through repetitive consumption, and single-use disposable items became a culturally accepted standard (Packard, 1960). The packaging design industry became part of this trend as packaging protected, advertized and individualized the majority of these items before reaching the consumer. As new goods were sold, more packaging was required. As a result, profits increased and packaging became the source of a range of negative environmental impacts including toxicity, energy consumption and natural resource depletion.

Sustainable design of products and services has recently become a concern for many companies. In the 1980s, packaging design improvements followed the waste hierarchy principles, focusing on diverting waste or utilizing input materials derived from post-consumer content (Gertsakis and Lewis, 2003). In the early 2000s, sustainable packaging became a new trend in packaging design, as the Sustainable Packaging Coalition was established in 2004 (Sustainable Packaging, 2013). Design departments now consider the whole life cycle of a product in context to environmental, social and economic impacts, otherwise known as the *triple bottom line* (Boylston, 2009).

Forward thinking companies in the packaging industry embrace the principle of the triple bottom line. Currently, one of these protective packaging companies is Ecovative in New York, USA: “in addition to generating profits, [Ecovative] strive[s] to create products which are good for our planet, and benefit the people who use them and make them” (Ecovative Design, 2013). The triple bottom line adds progressive values and criteria for measuring organizational and societal success in the 21st century (Boylston, 2009). Other trends such as Product Stewardship, Extended Producer Responsibility and Manufacturer Responsibility are also becoming popular tools to use to reduce landfill waste {{281 Boylston, Scott 2009}}. This is conducted by designing products with fewer toxins, making products that are more durable, reusable, and recyclable, and constructed with post-consumer content (Boylston, 2009).

1.2.3 Postal & Courier Services Packaging

Two valuable business sectors that depend on packaging are the postal and courier services industry. Packaging protects customer goods and documents during transport, forming a critical part of the service. Postal and courier services are an important component for the global communications infrastructure and crucial for business-to-business interactions and online shopping. In 2012, Canadian companies Purolator and Canada Post delivered and picked up approximately 10.3 billion parcels or pieces of mail across Canada (Purolator Inc, 2013; Canada Post Corporation, 2012). Postal and courier services are concerned about their environmental impact, and are taking steps to reduce their footprint. For example, in 2005, Purolator became the first Canadian logistics company to start the transition to hybrid electric vehicles for transportation and deliveries (Purolator, 2010). However, the packaging used by Canadian courier and postal organizations has not been assessed environmentally to determine if, or how, it can be improved.

Packaging used for postal and courier services are disposed after a single use, as the materials have not been designed to be easily reused or recycled. Many courier packaging options are composite products. Most of this packaging ends up in landfills after a single use except for the portion of separated materials that relies on recycling processes. Materials have four general options in Canada for disposal: landfill, incineration, recycling or composting (Statistics Canada, 2011). Packaging components can emit toxic chemicals into the air, ground and water after disposal in a landfill or incineration. Recycling of components often degrades the product into its base materials and consumes large amounts of additional resources in the process (Gertsakis and Lewis, 2003, McDonough and Braungart, 2002). Implementing a systems approach for postal and courier packaging would account for the reuse or end of life of a package and could change the types of materials used, how the materials are assembled and how the materials could later be disassembled and reused. Perhaps courier packaging designed to be made of regional, renewable components, with the ability to be disposed, recycled, landfilled, or composted regionally, could lower environmental impacts for postal and courier packaging.

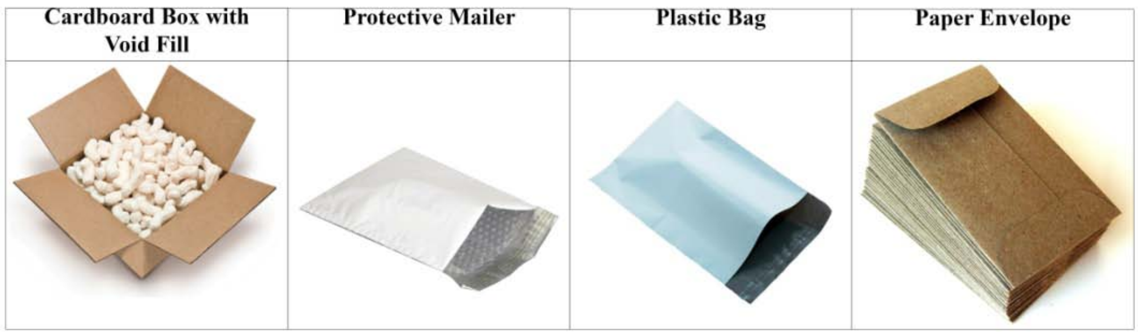

Image sources: www.mhpn.com, www.sealedairprotects.com, www.polypostalpackaging.co.uk, www.etsy.com

Figure 1: Common Packaging Used to Ship Small Parcels

Courier and postal packaging today includes the use of cardboard boxes combined with void-fill (or cushioning materials to protect the interior contents in transit), protective mailers, plastic bags and paper envelopes. Cardboard boxes can be reused and easily recycled in Canada. Void-fill is frequently made of Styrofoam peanuts or dunnage bags that cannot be recycled but have the potential to be reused before disposal. Protective mailers are cushioned envelopes with an adhesive closure, which are commonly made of paper, plastic or a combination of the two materials. Once materials are combined, it is challenging to separate them for recycling. Courier bags used in express shipments are usually provided by postal and courier companies and often made of low density polyethylene (LDPE). This material is not accepted for recycling at many municipal facilities across Canada. Paper envelopes are often certified by the Forestry Stewardship Council of Canada (FSC) but then covered with waybill stickers or lined with plastics that restrict the ability to easily recycle the envelope.

Recent studies and changes to design criteria for postal and courier packaging have been isolated to the United States. In April 2004, a peer-reviewed report was conducted by Franklin and Associates to analyze the environmental impact of packaging options for shipment, mainly soft order goods (Franklin Associates, 2004). In September

2010, McDonough Braungart Design Chemistry (MBDC) collaborated with the United States Postal Service (USPS). MBDC worked with 20 suppliers to assess the packaging materials and 250 additional suppliers to identify the environmental impacts of postal and courier packaging in order to recommend design solutions. MBDC has also recently worked with FedEx Express to provide the same style of assessment and certification. In Canada, progress has been limited.

1.3 Thesis Overview

In 2008, I was working as the Marketing Manager of a software reseller in Vancouver. Purolator picked up and dropped off goods and mail on a daily basis from our locations across Canada. I found myself thinking about the amount of fuel it required to transport these items and questioned if the service was necessary. Based on the business practices of our society today, I realized postal and courier services are crucial to the Canadian economy. I then questioned the amount of courier packaging that I struggled to recycle, and tried to convince my coworkers to recycle. My biggest question was “why”? Why do we throw these materials in the landfill? Why are we using single use disposable packaging? What are the alternatives? What is most sustainable? Are we doing the best that we can? I then applied for the Master of Environmental Design program at the University of Calgary to pursue these questions in the context of the courier and postal services.

In November 2009, I was introduced to Dr. Getachew Assefa Wondimagegenehu at the University of Calgary during an Environmental Design faculty lecture on Life Cycle Assessments (LCA) of buildings. The LCA methodology of quantifying environmental impacts of products from extraction to disposal fascinated me. After taking a course in LCA taught by Professor Assefa in 2010, I pursued an international internship with ecoinvent, the world-renowned Life Cycle Inventory (LCI) database. During the internship at ecoinvent, Dr. Rainer Zah, an LCA expert, mentioned that a comparative LCA of two protective mailers would provide a more interesting and valuable study for the LCA community.

In 2010, a request was made to Purolator Canada and Canada Post to share courier packaging data to analyze the environmental impacts of a PuroLetter™ envelope for this research project. During an interview with two executives from Purolator Canada, it was mentioned that the company was satisfied with the PuroLetter™ envelope as it is made of FSC approved paper (Appendix A: Purolator Correspondence). However, it was stated that Purolator Canada and Canada Post would like to change the use of soft plastic packaging, particularly LDPE, as this material is not commonly recyclable in Canada. Unfortunately after a few proposals and discussions, both Purolator and Canada Post were unable to provide data for this study due to proprietary reasons.

Based on the interview with Purolator Canada, it was determined that the design criteria of courier packaging is selected by the packaging manufacturer, not the postal or courier companies. Packaging manufacturers Crownhill Packaging Ltd. and Sealed Air of Canada Ltd. were also approached to share product data but refused. Associated Bag Company, a distributor of packaging supplied products details and shipment dimensions for this study. As limited data was available, I chose to analyze a generic type of packaging that is commonly used in the postal services. A product that I purchase frequently for mailing small items is a protective mailer. These mailers can be purchased at any office supply store or post office.

Figure 2: Kraft Paper and Newsprint Filled Padded Mailer and a LDPE Bubble Mailer

For this thesis I compared a commonly purchased generic LDPE bubble mailer, with a product that is marketed as an environmentally-friendly alternative, a Kraft paper and newsprint filled mailer. The Kraft padded mailer is marketed at a customer segment that values purchasing products with minimal environmental impacts. The logos have earthy colours and pictures of leaves or the planet and the descriptors mention recycled paper in the first sentence. Employing LCA methodology, I completed a comparative assessment to determine the environmental impacts of these two generic protective mailers. Generic data from ecoinvent and US LCI databases were modified with transportation data, based on the assumption that the products were made at the largest and most common manufacturing facilities in various locations across Canada. The goal was to provide recommendations for product improvement for a future industrial designer to design the next prototype for sustainable packaging for parcels shipped in the Canadian postal service. The results have identified areas for product improvement that can be implemented at various stages of the product life cycle.

CHAPTER 2: LIFE CYCLE ASSESSMENT METHODOLOGY

2.1 Introduction to Life Cycle Assessment (LCA)

A Life Cycle Assessment (LCA) is a method to evaluate the entire life cycle of a product, process or service, from raw material extraction to waste treatment (Baumann and Tillman, 2004, Ekvall et al., 2007). LCA's include a systems approach of principles and assumptions for modelling a product life cycle (Baumann and Tillman, 2004). The LCA model of a product or service describes the material flows between the processes such as raw materials extraction stage, manufacturing stage, use stage, and disposal stage (Baumann and Tillman, 2004). The Cradle-to-Grave LCA model includes the entire product life cycle, all steps from raw material extraction to waste disposal, compared to the Cradle-to-Gate LCA model that only includes the environmental impacts that occur between extraction and point of sale (Baumann and Tillman, 2004).

Among the numerous strategies that aim to address the issue of sustainable development, a LCA is a benchmarking and analytical tool that quantifies environmental impacts of products and services for decision making processes (Guinée, 2002). LCA provides a standardized method for product analysis based on the International Organization for Standardization (ISO), and is one of the most extensive methods for assessing the environmental impact of products and services (Azapagic and Clift, 1999, Baumann and Tillman, 2004). This methodology assesses the entire system of a product or service with the goal of isolating processes that could be improved and support these recommendations with quantified data. The intended application of a LCA could be for product development, product improvement, strategic planning, marketing, or public decision making. LCA typically does not address the economic or social aspects of a product (International Organization for Standardization, 2006a). However, Life Cycle Costing (LCC) and socio-economic Social Life Cycle Assessment (S-LCA) are options to expand the scope of the potential impacts of production and consumption on the workers, communities, citizens and the value chains.

2.2 History of LCA Studies

In the 1960s, Coca-Cola was the first company to conduct a LCA, to explore packaging alternatives (Hunt and Franklin, 1996). The emphasis was primarily solid waste reduction, rather than environmental emissions or energy use. In the 1970s, the basis for the modern LCA was introduced in response to concerns about energy supply through Resources & Environmental Profile Analysis (Hunt and Franklin, 1996). In the 1980s, green politics prioritized emissions and the need to recycle. In the 1990s, impact assessment methods such as greenhouse gas emissions, acid rain and habitat loss were developed. In 1996, the ISO 14040 LCA framework was introduced. From 1996 until today, background Life Cycle Inventory (LCI) databases have been built to provide transparent and consistent data for analysis. Methods are continually being refined as calculation software also evolves. The current standards for LCA follow ISO (International Organization for Standardization) 14040:2006 and 14044:2006 (International Organization for Standardization, 2006a, International Organization for Standardization, 2006b).

2.3 LCA Procedures

A LCA is a step-by-step process that consists of four procedures: goal and scope definition, inventory analysis, impact assessment, and interpretation of results (Figure 3). Interpretation is ongoing throughout the assessment and occurs during the other three procedures. Results are built from measured weight of materials and processes (extraction, production, transportation, distribution, use and disposal). These weights are multiplied by emission and resource factors from the libraries of life cycle inventory (LCI) processes and result in the total emission and resource values (Bare, 2003). This product is then input into a selected mid-point or end-point tool and multiplied by characterization factors for each of the selected impact categories, for example global warming, acidification, carcinogenics, non-carcinogenics, respiratory effects, eutrophication, ozone depletion, ecotoxicity and smog. A standardized metric is used for simple comparison. This metric is selected as the most common impact for that characterization category, for example benzene equivalents for carcinogenic impacts, or carbon dioxide equivalent for global warming impacts. Selected LCA software then calculates the results that can be displayed as a comparative graph of outputs.

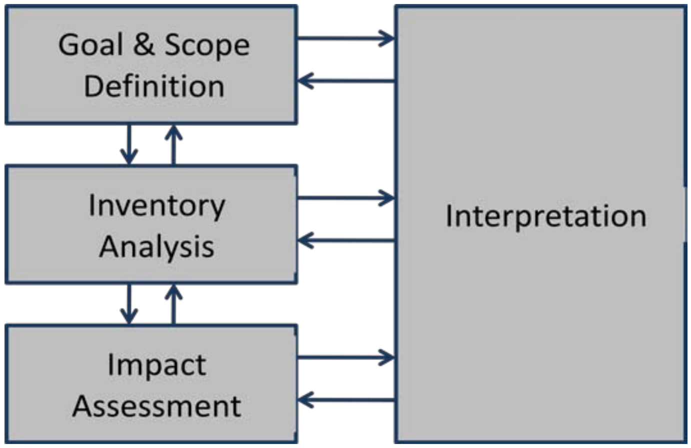

Figure 3: Life Cycle Assessment Procedures.

(Boxes indicate the procedural steps and the arrows indicate the sequence these steps are performed.) Source: ISO 14040:2006 and 14044:2006

2.4 Goal and Scope

The goal and scope phase is the foundation for a LCA as it defines the purpose of the LCA study, model, procedure specifications and boundaries of the study. Criteria include defining the target audience, level of detail, basis of comparison (functional unit), and procedures for data collection. This phase is usually established by the commissioner and the practitioner of the study (Baumann and Tillman, 2004). Other stakeholders include the target audience, steering and supervising committee and an expert reviewer.

2.5 Life Cycle Inventory (LCI)

The life cycle inventory (LCI) analysis phase is built on the specifications determined in the goal and scope definition. In this phase quantitative data are collected to calculate the environmental load of a product and determine the inputs and outputs, to and from the system (Baumann and Tillman, 2004). This data creates an inventory table of material and energy requirements, products, co-products, waste and emissions.

This phase also includes a flow diagram to illustrate the processes involved within the system boundaries, which determines the cut-off criteria for the study. Allocation may also be part of this phase if certain processes are shared with other industrial process. The system boundary defines the included and excluded processes in the study.

Primary and secondary data sources are used for building the LCI data table. Primary data include measurements, interviews, annual reports, data from manufacturers of goods or operators of processes and services, and industry associations (European Commission Joint Research Center and Institute for Environment and Sustainability, 2010). Secondary data include information from generic resources such as LCA databases, previous LCA studies and Input-Output Analysis data, consultants, and research groups (European Commission Joint Research Center and Institute for Environment and Sustainability, 2010).

There are two methods for collecting data in this phase: collecting general background data from LCI databases, and customizing it with assumptions and data from other sources to the scope of the study, or collecting foreground data that is complex, specific data that is available from detailed production processes. Beyond the criteria recommended by ISO, no standardized method exists to judge the overall quality of a LCA. Data quality depends on precision, completeness of LCI data, representativeness of data including temporal, geographical, technical nature, as well as consistency and reproducibility. Errors introduced can include measurements, data entry, units, prefixes, and nomenclature.

General LCI data are collected in various national databases around the world and include processes based on the countries practices such as electricity mix, or disposal methods, such as incineration or landfill.

There are private and public databases available:

Canada:

- *CIRAIG* (Interuniversity Research Centre for the Life Cycle of Products, Processes and Services) in Quebec partnered with Swiss-based ecoinvent LCI database, to provide Canadian context

United States:

- *U.S. LCI Database* (United States Life Cycle Inventory); managed by the National Renewable Energy Lab, data sources include Franklin Associates, Athena Institute

Switzerland:

- *ecoinvent Database v2.1 (2007)* - Swiss energy production, transport, and materials, 2,500 users in more than 40 countries
- *Buwal 250* - Packaging materials from the Swiss Packaging Institute
- *ETH-ESU* - Swiss and Eastern European production of energy, resource extraction, raw material production, semi-manufactures, auxiliary materials, supply of transport and waste treatment services, and infrastructure construction

Both ecoinvent and U.S. LCI are data centres that provide important roles for LCI analysis in a LCA.

2.5.1 ecoinvent

The ecoinvent Centre, or Swiss Centre for Life Cycle Inventories, is a not-for-profit organization that advances environmental research. Ecoinvent was formed by various Swiss research institutions as an Integration Center of Expertise performing methodical integration of LCA data for Agroscope Reckenholz-Tänikon Research Station, École Polytechnique Fédérale de Lausanne, Empa - Swiss Federal Laboratories for Materials Science and Technology, Paul Scherrer Institute and Swiss Federal Institute of Technology Zurich. Ecoinvent is the world's leading supplier of the most relevant, consistent, transparent LCI data in both academia and industry. The core product at ecoinvent is the ecoinvent Database that provides globally accessible, science-based, international LCA and life cycle management data.

As an organization, ecoinvent provides high quality, generic, background data for LCA research in areas including agriculture, biofuels, biomaterials, chemicals, both bulk and specialty, construction materials, detergents, electronics, energy supply, information and communication technology, mechanical engineering, metals processing, basic metals, precious metals, packaging materials, paper, plastics, textiles, transport and waste treatment. Data from ecoinvent is used within academia and industry to model and assess the environmental performance of products and processes. It is also used to base decisions on reliable, transparent and up-to-date environmental data, report on the sustainability of a company and to calculate the carbon footprint of products or services.

Most ecoinvent Datasets serve primarily as background data in specific LCA studies. Therefore, LCI of ecoinvent datasets cannot directly be compared with the aim to identify environmentally preferable products or services. For comparative assessments, problem-specific and case-specific data is required by a researcher. Company or problem-specific data can be combined with general data for background processes from the ecoinvent database. Once data are collected, LCA software can compute and analyze results.

Data available in the ecoinvent Datasets are supplied by interdisciplinary research scientists and industry experts from all over the world. Researchers provide the data and ecoinvent compiles it, creates an expert review and makes it globally accessible for further environmental research. Contributing data to the ecoinvent database allows thousands of other researchers to build on this data. Contributions to ecoinvent are as equally respected in the LCA research community as having data published in a distinguished journal.

Currently, the ecoinvent Database has 2,500 users in more than 40 countries. Ecoinvent assists in everyday research related to the environmental and socio-economic impacts of decisions in Integrated Product Policy, LCA, Environmental Product Declaration, Product Stewardship, Design for Environment, Environmental Management Systems and Carbon Footprint analyses (ecoinvent Centre, 2010).

2.5.2 United States Life Cycle Inventory Database (U.S. LCI)

The U.S. LCI Database was created by the American National Renewable Energy Laboratory and its partners to help LCA practitioners answer questions about environmental impacts. This database provides individual gate-to-gate, cradle-to-gate and cradle-to-grave accounting of the energy and material flows into and out of the environment that are associated with producing a material, component, or assembly in the U.S. (National Renewable Energy Laboratory, 2013).

The mission of the U.S. LCI Database project is to maintain data quality and transparency while including commonly used American materials, products, and processes with up-to-date, critically reviewed LCI data. Its goal is to maintain compatibility with international LCI databases by providing excellent data accessibility that supports U.S. industry competitiveness (National Renewable Energy Laboratory, 2013). There are currently 639 published datasets in the LCI database, of which 200 were published in 2010 (National Renewable Energy Laboratory, 2013). Data were provided by users of the database, or purchased by U.S. LCI from undisclosed sources, then adapted to the U.S. LCI Database data format (National Renewable Energy Laboratory, 2013).

2.6 Life Cycle Impact Assessment (LCIA)

Similar to the LCI phase, the Life Cycle Impact Assessment (LCIA) phase depends on the goal and scope of the study. The LCIA phase analyzes and evaluates the list of environmental impacts from the inventory analysis and categorizes the impacts by the mediums affected, such as soil, air, land-use, or sound pollution to determine the overall significance in the study. The LCIA consists of several steps that include classification, characterization and weighting (Baumann and Tillman, 2004).

Characterization refers to the scientific, quantitative calculations of impact category indicator results defined by the ISO 14044 standard for LCA (ISO 2006). Characterization models address separate impact categories determined through classification to complete the LCIA method (Hauschild et al., 2013). There are different scientific methods and models used for developing characterization indicators that sort the inventory results according to the type of the environmental impact that is contributed. Within the LCIA, characterization factors are multiplied with inventory data, and the outcomes are category indicator results, expressed in a unit common to all contributions within the category. Examples and reporting methods are listed in Table 1: Characterization – Sample Impact Categories. Classification is different from characterization as it sorts inventory results qualitatively based on the type of impact on the environment, such as global warming and human health impacts.

Weighting indicates the environmental harm of pollutants or resources relative to other pollutants and resources (Baumann and Tillman, 2004). Weighting methods evaluate environmental loads or problems on a single scale and can be used to express the overall environmental impact as a single number (Baumann and Tillman, 2004). According to ISO standards, weighting is only permitted for internal decision making and not for comparison of products that are to be marketed to the general public. Four main weighting principles are available, including distance-to-target methods, monetary-based methods, panel-based methods and damage-oriented methods. Distance-to-target methods include a relationship between current impact and future target and can be modelled with the Ecoscarcity Method (Switzerland) or EDIP Method (Environmental Design of Industrial Products; Denmark). Monetary-based methods provide an estimate of society's or individual's willingness to pay to avoid a specific impact or effect and can be modelled with the EPS Method (Environmental Priority Strategies; Sweden) or Tellus (USA). Panel-based methods use a team of representatives from different interest groups that value different impacts and can be modelled using Environmental Theme (The Netherlands). Finally, damage-oriented methods are based on environmental mechanisms of endpoint damages and can be modelled using Eco-Indicator 95 (The Netherlands), Eco-Indicator 99 (The Netherlands) or ReCiPe (The Netherlands) (Baumann and Tillman, 2004). Damage-oriented methods are composed of midpoint or endpoint methods.

Table 1: Characterization – Sample Impact Categories (unit shows common metric for comparison between studies)

Impact Category	Unit (per kg of emission)	Explanation	End Result
Acidification	H^+ mol-eq	Hydrogen ion concentration of water and soil systems creating atmospheric emissions (NO_x and SO_x)	Reduced alkalinity of lakes
Ecotoxicity	2,4-D-eq	Potential of toxic industrial and agricultural chemicals to be released into an evaluative environment to cause ecological harm (2,4-D: Dichlorophenoxyacetic acid; common systemic herbicide)	Plant, animal, and ecosystem effects
Eutrophication	N-eq	Fertilization of surface waters by previously scarce nutrients, phosphorus (P) and nitrogen (N) releases, leading to proliferation of aquatic photosynthetic plant life	Plant, animal and ecosystem effects, odors, recreational effects, and human health impacts
Greenhouse Gases	CO_2-eq	Potential change in the earth's climate caused by the buildup of chemicals; atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)	Malaria, coastal area damage, agricultural effects, forest damage, plant and animal effects
Carcinogenics	kg benzene-eq	Concentrations of particulate matter; potential of a chemical released into an evaluative environment to cause human cancer effects	Variety of specific human cancer effects
Non-carcinogenics	toluene-eq	Potential of a chemical released into an evaluative environment to cause human non-cancer effects	Variety of specific human toxicological non-cancer effects
Ozone Depletion	CFC-11-eq	Emissions of chlorofluorocarbons (CFCs), halons, and other ozone-depleting substances believed to cause acceleration of destructive chemical reactions, resulting in lower ozone levels and ozone "holes" in certain locations	Skin cancer, cataracts, material damage, immune system suppression, crop damage, other plant and animal effects
Respiratory Effects	$PM_{2.5}$-eq	Particulate matter (PM) less than 2.5 µm in diameter by emissions of SO_2 and NO_x, which lead to the formation of secondary particulates sulfate and nitrate	Chronic and acute respiratory symptoms, as well as mortality rates
Smog	NO_x-eq	Potential to cause photochemical smog; NO and NO_2 (nitric oxide and nitrogen dioxide) in Tropospheric Ozone	Human mortality, asthma effects, plant effects

Source: (Bare, 2003)

2.6.1 Midpoint versus Endpoint Method

Midpoint methods refer to quantitative relationships while endpoint methods are qualitative classifications of factors developed to reflect the relative importance of emissions or extractions (Table 2). Midpoint methods tend to be more certain than endpoint methods. Midpoint methods refer to characterization impacts such as global warming, acidification, carcinogenics, non-carcinogenics, respiratory effects, eutrophication, ozone depletion, ecotoxicity and smog. Impacts can be calculated using impact assessment methods such as CML 2002 (Guinée, 2002), IMPACT 2002+ (Jolliet et al., 2003), LUCAS (Toffoletto et al., 2007), ReCiPe (Goedkoop et al., 2009), and TRACI (Bare, 2003). Endpoint methods refer to classification of impacts such as human health, natural environment or natural resources and can be calculated using the following impact assessment methods: Ecological Scarcity, Eco-indicator 99 (Goedkoop M.J. and Spriensma R., 2000), EDIP, EPS, or Impact 2002+. Midpoint and endpoint assessments can be combined using ReCiPe and IMPACT2002+ (Hauschild et al., 2013). Midpoint, endpoint, or combined methods, are selected based on the goal and scope of the study.

Similar to LCI databases, many of the LCIA methods are representative of the geographic location of where data are collected. However, different LCIA methods analyze different collections of impact categories. Two methods that are local to North America are TRACI and LUCAS. TRACI (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) is a midpoint method produced by the Environmental Protection Agency in the United States (Bare, 2003). LUCAS (LCIA method Used for a CAnadian-Specific context) is a Canadian tool, also a midpoint method, created by CIRAIG in Montréal, Québec (Toffoletto et al., 2007). Selecting a method depends on the goal and scope of the project as well as the geographic location of the majority of the LCI data. Geographical differentiation in LCIA is complicated as most emissions and resource consumption inventory databases are unable to be fully isolated in detail (Toffoletto et al., 2007).

Table 2: Midpoint versus Endpoint Methods (cause-effect chain from left to right)

Inventory Results	**Midpoint Method** (Characterization)	**Endpoint Method** (Classification)
Elementary Flows →	Climate change →	Human Health
	Ozone depletion →	
	Human toxicity, cancer →	
	Human toxicity, non-cancer →	
	Respiratory inorganics →	
	Ionising radiation, humans →	
	Ionising radiation, ecosystems →	
	Photochemical ozone formation →	Natural Environment
	Acidification →	
	Eutrophication, terrestrial →	
	Eutrophication, aquatic →	
	Ecotoxicity →	
	Land use →	Natural Resources
	Resource depletion, water →	
	Resource depletion, mineral, fossil and renewable →	

Source: EC-JRC (2010b) Framework and requirements for LCIA models and indicators. ILCD Handbook—International Reference Life Cycle Data System, European Union EUR24586EN. ISBN 978-92-79-17539-8. (http://lct.jrc.ec.europa.eu/assessment; Accessed March 2013)

2.6.2 LCIA Software Tools

Software tools are commonly used to conduct the LCIA. These tools allow users to collect, manage and interpret emissions from life cycles for product and services. Software tools include SimaPro, GaBi and Athena. SimaPro is commonly used as it accesses global LCI inventory databases such as U.S. LCI and ecoinvent, which have current and peer reviewed data. GaBi is also commonly used for LCAs and can also assess Life Cycle Costing, Life Cycle Reporting, and Life Cycle Working Environment (PE International, 2013). Athena is a Canadian tool that specializes in building materials.

2.7 Interpretation

The interpretation phase of a LCA examines the validity of the results against the goal and scope definition. This phase summarizes and discusses the results from the inventory analysis and the impact assessment to form conclusions or recommendations for decision making (International Organization for Standardization, 2006a; Baumann and Tillman, 2004). The outcome of the results of this phase could be a proposal for material substitution for a product, a change of production method, or a change in the operation and use of products.

The interpretation phase may include a consistency analysis, contribution analysis, sensitivity analysis, uncertainty analysis, data quality analysis, and a critical review by independent experts. Data quality is tested using an uncertainty analysis of the data and methodology for a LCA. A consistency analysis confirms the reliability of the study. A contribution analysis expresses the contribution of life cycle stages, or groups of processes, as a percent of the total contribution (International Organization for Standardization, 2006b). Sensitivity analyses test alternative outcomes or isolate variables within the study to determine importance.

LCA results can be difficult to interpret as context is important in understanding the environmental impact categories and results compared to other products or processes (Hamilton and Ayer, 2013). Given this complexity, transparency and precision are important when conducting or peer reviewing a LCA.

2.8 Comparative LCA

In contrast to a stand-alone LCA where a single product, process or service is studied, a comparative LCA study evaluates two or more alternative products, processes or services (Baumann and Tillman, 2004). Comparative studies use Accounting LCA or Change-oriented LCA methodology, with restricted terms to allow for fair comparisons (Baumann and Tillman, 2004). Accounting LCA describes the environmental impacts that can be associated with the product, process or service (Baumann and Tillman, 2004). Change-oriented LCA compares environmental consequences of alternative courses of action, such as an opportunity cost analysis (Baumann and Tillman, 2004). A data quality analysis is a mandatory test for comparative assertions to ensure equality between compared products.

2.9 Strengths and Weaknesses of Life Cycle Assessment

The benefits of using LCA are to provide quantifiable data that can be used as a marketing tool, or for internal operations or management to decide areas to invest in for improvements. The downfalls of using LCA are the same as the limitations in all science including: data availability and quality, uncertainty, boundary selection criteria, alternative scenario considerations, and correctly determining the comparative unit.

2.10 Scope and Objectives

This study compares the LCA of two generic protective packaging alternatives used for mailing parcels in Canada: (1) low-density polyethylene and inflated cushioning bubble mailer and (2) Kraft paper and shredded newsprint padded mailer. The study is intended to be of sufficient detail and quality to inform the public of the comparative impacts of these two choices but it does not provide a comparative assertion to be used in marketing applications of LCA, or to denote an environmental claim regarding the superiority of equivalence of one product over the other product. This study is only a start and will require more data and information as it becomes available.

The objective of this study is to collect and analyze data to quantify the environmental impacts of a Kraft paper and newsprint filled padded mailer compared to a LDPE bubble mailer, with a cradle-to-grave comparative LCA. The comparative LCA will examine the inputs and outputs for each stage of the products, identifying areas for product improvement. The final goal of this research is to propose packaging recommendations that reduce the environmental impacts of the protective mailers. The results of this study could: 1) act as a blueprint for a future industrial designer to build the next prototype, or 2) improve production processes by providing data to be utilized in future managerial decisions. Generic data has been collected using U.S. LCI database and ecoinvent, and tailored to fit this study. The LCIA was calculated using TRACI through SimaPro.

CHAPTER 3: COMPARATIVE LIFE CYCLE ASSESSMENT OF A BUBBLE MAILER VS. A PADDED MAILER

3.1 Introduction

Human activities result in different levels of environmental impacts. Many decisions made at the design stage determine the impacts of products, processes and services during production, use and disposal. Today, package design is a human activity that is rapidly changing in response to environmental concerns. Wasteful secondary packaging (packaging within packaging) ideas are shifting, essential packaging is being designed with fewer toxins, delivery systems are improving and recovery systems are becoming more efficient (Boylston, 2009). Protective packaging is usually involved in moving raw material to a manufacturer, bulk products to a distributor or the final product to the end-user. Protective packaging is a necessity for postal and courier companies to protect contents during shipment from one location to another. There may be potential to improve the packaging used in the postal industry. A Life Cycle Assessment (LCA) can quantify these impacts to support informed decision-making that avoids problem-shifting between life cycle stages and sub-optimization.

Within the field of LCA, packaging is frequently examined (Hischier, 2007) yet there has not been a LCA published for courier packaging in Canada. Current examples of packaging LCA's include the comparative analyses of milk packaging (Xie et al., 2011), single-use versus reusable cups (Garrido and Alvarez del Castillo, M. Dolors, 2007) and baby food packaging (Humbert et al., 2009). One study by Franklin Associates in 2004, prepared for Oregon Department of Environmental Quality and the U.S. EPA Environmentally Preferable Purchasing Program, examined the Life Cycle Inventory (LCI) of different packaging options for shipping small items such as clothing (Franklin Associates, 2004). The U.S. Postal service had a Cradle to Cradle certification completed for its packaging in 2010. The study took two years to complete as it involved the cooperation of 200 suppliers, and found 1,400 individual ingredients. Canadian courier and postal services have received limited attention in the LCA research community.

In 2012, Canadian companies Purolator and Canada Post delivered and picked up approximately 10.3 billion parcels or pieces of mail across Canada (Purolator Inc, 2013), (Canada Post Corporation, 2012). Purolator provides complementary packaging to customers while Canada Post sells parcel packaging at various post office outlets across Canada. Commonly used packaging for small items shipped in the Canadian postal system include boxes, envelopes, bags and protective mailers. A protective mailer is a cushioned envelope with an adhesive closure that protects contents during shipment without additional void fill or sealant materials. Protective mailers are small and convenient to use compared to boxes and are lighter and less expensive to ship (McEvoy, 2013). Protective mailers do not require assembly and can reduce labour cost for bulk shipments (McEvoy, 2013). Due to the smaller size, inventory space is saved using protective mailers and less solid waste is generated (Freedonia Group Inc., 2012).

Protective mailers are generally constructed using type four low-density polyethylene (LDPE), for both the interior and exterior components, and called *bubble mailers*. The physical properties of LDPE allow bubble mailers to be lightweight, flexible, water resistant, with high impact strength (Mark, 2009). The inflated cushioning interior of a bubble mailer provides product protection that is marketed as a competitive advantage over cardboard boxes that require tape, void fill, additional postage, and more storage space to be kept in inventory (McEvoy, 2013). Aside from the convenience of using bubble mailers, LDPE material degradation is limited after disposal, causing environmental pollution with possible ecosystem level effects (Bastioli, 2005). In Canada type four LDPE can be recycled, technically and legislatively, in some municipalities. According to the Canadian Plastics Association 28,000 metric tonnes of polyethylene film were recycled in Canada in 2010 (Appendix F), which is approximately 10% of the total plastic material collected for recycling in Canada (Moore Recycling Associates, 2012). However, bubble mailers tend to be single-use disposal items. If the LDPE in bubble mailers were completely separated from any other plastics, the product could technically be recycled. The bubble mailer, along with the majority of plastic goods, are made of a combination of plastics or combined with other materials that cannot be disassembled for recycling.

As an alternative to the LDPE bubble mailer, a Kraft paper and newsprint filled padded mailer provides the same general functionality, but is not water resistant, and has a different disposal scenario. This mailer utilizes post-consumer paper fibres as the exterior shell is made of Kraft paper and the interior padding is 100% shredded recycled newspaper. The Kraft paper and newsprint filled padded mailer, named *padded mailer* in this study, has approximately 50% post-consumer content overall and no colour additives. The padded mailer has a double-fold and double-glued bottom flap construction for added strength, self-seal closure and a tear-strip for easy opening. Padded mailers can either be recycled with mixed paper in municipalities that offer such programs, or composted in a common municipal anaerobic digester.

3.1.1 Market Demand

A third-party industry market research group, The Freedonia Group, conducts high-level marketing studies based on secondary data from trade publications, government source books, privately owned databases, product literature, and annual industry reports. The Freedonia Group has conducted bi-annual studies on the protective packaging industry in the United States. These packaging trends are assumed to be applicable in Canada due to cultural similarities and comparable consumer spending habits. Freedonia’s research conclusions are verified through primary research interviews with Fortune 500 companies.

The Freedonia Group`s study from 2012 showed that the protective packaging industry is highly competitive with product choice dependent on price, packaging requirements and performance capabilities (Freedonia Group Inc., 2012). Flexible protective packaging demand has been projected to reach $2.7 billion in 2016 in the United States alone. Protective mailers are expected to continue to generate the largest share of the protective packaging segment demand, reaching 45% in 2016 (Freedonia Group Inc., 2012). It was interpreted that demand for protective packaging is correlated to the growth of online shopping and will drive requirements for economical, lightweight, pre-constructed protective packaging to ship small products (Freedonia Group Inc., 2012). Consumer demands have been progressing toward purchasing protective packaging that is perceived to be environmentally-friendly: ecologically harmless, recyclable, reusable, compostable, or fabricated from recycled materials (Freedonia Group Inc., 2010). The Freedonia Group predicts that environmental factors, such a source reduction, recyclability and compostability, are expected to continue strengthening the demand for protective packaging types that reduce waste volume and are made from recyclable or biodegradable materials (Freedonia Group Inc., 2012).

Paper-based protective packaging is frequently marketed as a more environmentally-friendly option as it is considered recyclable and compostable (Freedonia Group Inc., 2012). For this study, Kraft paper and newsprint filled padded mailers are perceived to be an environmentally-friendly protective packaging option, although the environmental impacts have not been advertized or publicly quantified. LDPE bubble mailers are not marketed as an environmentally-friendly packaging option, although many plastic products are recycled to some degree. Recycled materials are a common perception for environmentally-friendly packaging (Freedonia Group Inc., 2012).

3.2 Methods

3.2.1 Goal and Scope

The functional units for this study were two North American standard No.2, 21.6 cm x 30.5 cm (8½” x 12”) self-sealing protective mailers designed to protect 1 kg of parcel contents during one way shipment (Figure 4). This particular dimension of No.2 protective mailers was selected for three reasons: 1) it represented one of four identically sized Kraft paper and newsprint filled padded mailer and LDPE bubble mailer options (Table 3); 2) it was a top seller for many packaging companies (Top Mailers, 2013) and 3) it was priced identically for purchasing a box of 100 mailers (Table 3).

The reference flow was a padded mailer made of Kraft paper with macerated newsprint padding, weighing 70.62 grams, and the other was a bubble mailer with a LDPE exterior, cushioned with a LDPE bubble lined interior, weighing 15.47 grams. The function of these protective mailers was to protect parcel contents in transit in the Canadian postal service from one Canadian location to another.

Figure 4: Padded Mailer (left) versus Bubble Mailer (right)

The base scenario for this study was modelled using the weight of a protective mailer filled with parcel contents to capacity during the *use stage* (1 kg). It was assumed that the TransCanada Highway was used for all longer distance ground shipments. Three sensitivity analyses were conducted, including: Sensitivity Analysis A: analyzing empty protective mailers during the *use stage*, Sensitivity Analysis B: a LCA to test the differences in transportation emissions for long-haul transportation using air freight at major airports instead of a tractor-trailer, and Sensitivity Analysis C: a LCA based on 1 kg of each mailer type (weight equalized).

The system boundaries for both protective mailers were cradle-to-grave. The systems were bound by resource extraction, production, assembly, use, disposal, and transportation between stages (Figure 5). The average life cycle of a protective mailer used in the Canadian postal service consisted of three groups of life cycle stages: *upstream*, *use*, and *downstream*. *Upstream* stages consisted of extraction, production, assembly, and transportation between stages. *Use* stages consisted of transportation between Customer A, sending parcel, to Customer B, receiving parcel. *Downstream* stages only included disposal. The results of this study are specific to the studied protective mailers and are not to be generalized for other comparative studies or to determine a generalized outcome, such as paper being better than plastic overall.

3.2.2 Cut-off Criteria

Cut-off criteria were identical for both packages (Figure 5). Extraction stages for both protective mailers involved collecting sourced materials. Production stages included manufacturing of components for both protective mailers. Assembly stages required input materials into a single machine that produced the final protective mailer. Both types of protective mailers were then packaged into secondary packaging in boxes and crates and shipped to distribution centres across Canada. The use stages were exactly the same between the mailers as it was assumed that a consumer purchased a protective mailer at the point of sale, then filled it with desired contents and shipped it through the Canadian postal system to the receiver. The disposal stage included the end of life for both types of protective mailers. Production, construction and maintenance of postal industry infrastructure and transportation vehicles were outside of the scope of this study.

Table 3: Available Protective Mailer Sizes (standard size No. 2 were used for this study)

LDPE Bubble Mailer						Kraft Padded Mailer					
Standard Bag #	**Industry Dimensions W x L (cm)**	**Usable Dimensions W x L (cm)**	**# per Carton**	**Approx kg per Carton**	**Price/ Mailer**	**Standard Bag #**	**Industry Dimensions W x L (cm)**	**Usable Dimensions W x L (cm)**	**# per Carton**	**Approx kg per Carton**	**Price/ Mailer**
000	10.2 x 20.3	10.2 x 17.1	500	3.2	$0.29	000	N/A	N/A	N/A	N/A	N/A
00	12.7 x 25.4	12.7 x 22.2	250	2.7	$0.32	00	N/A	N/A	N/A	N/A	N/A
0	**15.2 x 25.4**	**15.2 x 22.2**	**250**	**2.9**	**$0.34**	**0**	**15.2 x 25.4**	**14.9 x 22.2**	**250**	**10.9**	**$0.33**
CD	18.4 x 20.3	18.4 x 17.1	200	2.5	$0.36	CD	N/A	N/A	N/A	N/A	N/A
1	18.4 x 30.5	18.4 x 27.3	100	1.8	$0.42	1	N/A	N/A	N/A	N/A	N/A
2	**21.6 x 30.5**	**21.6 x 26.7**	**100**	**2.3**	**$0.47**	**2**	**21.6 x 30.5**	**21.3 x 27.3**	**100**	**7.3**	**$0.47**
4	**24.1 x 36.8**	**24.1 x 34.3**	**100**	**2.7**	**$0.54**	**4**	**24.1 x 36.8**	**23.8 x 33.7**	**100**	**9.8**	**$0.59**
5	**26.7 x 40.6**	**26.7 x 38.1**	**100**	**3.2**	**$0.65**	**5**	**26.7 x 40.6**	**26.4 x 37.5**	**100**	**12.2**	**$0.67**
6	31.8 x 48.3	31.8 x 45.1	50	2.3	$1.05	6	N/A	N/A	N/A	N/A	N/A
7	36.2 x 50.8	35.6 x 48.3	50	2.7	$1.19	7	36.2 x 50.8	35.9 x 47.6	50	10.4	$0.62

Source: Associated Bag Catalogue 2012, V.1, p. 117 - 118

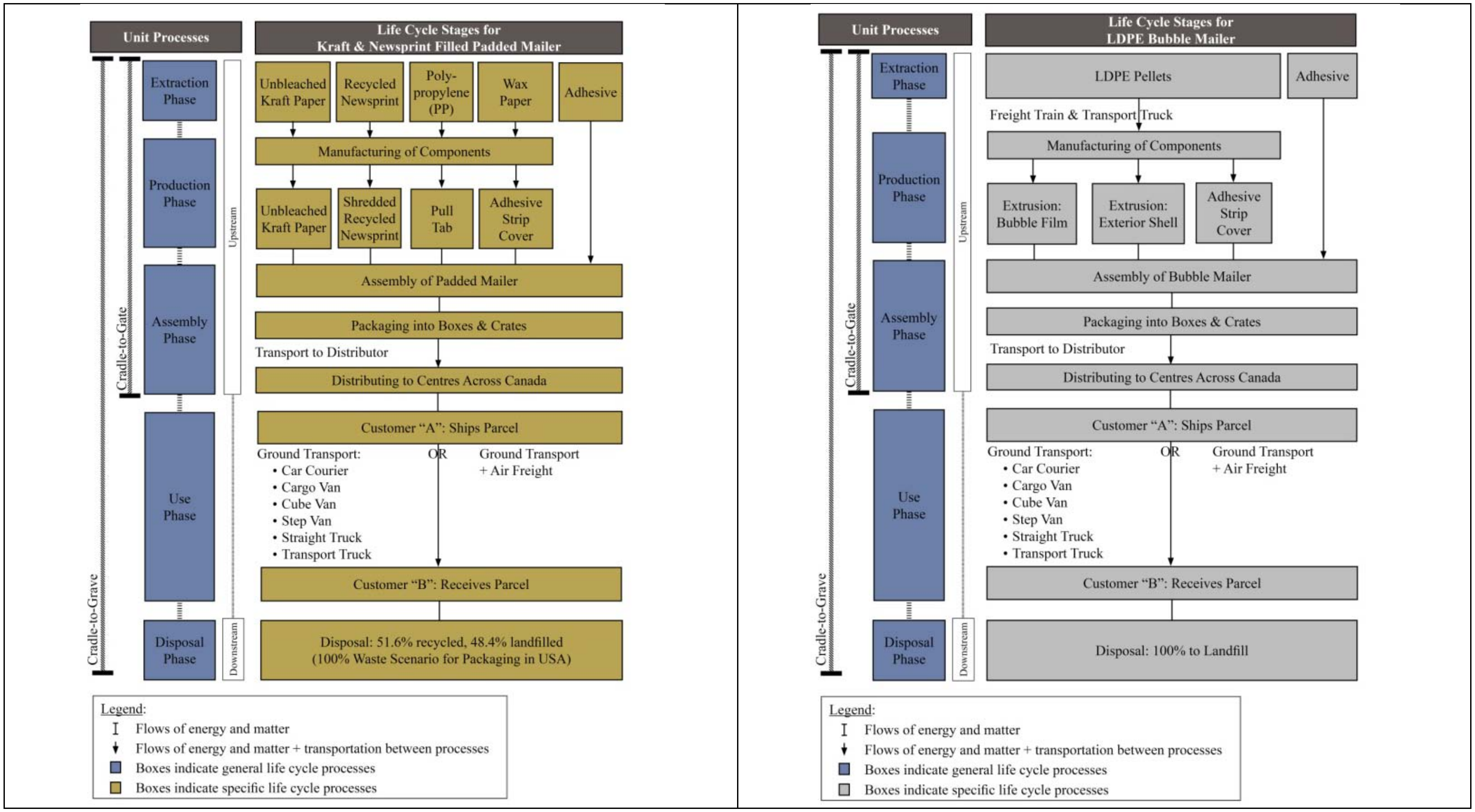

Figure 5: Life Cycle Stages and Unit Processes for Both Protective Mailers

3.2.3 Life Cycle Impact Assessment (LCIA)

The LCIA results describe the environmental life cycle burdens of the production of a single LDPE bubble mailer and a single Kraft paper and newsprint filled padded mailer. SimaPro v7.3.2 (PRé Consultants, The Netherlands) software was used to provide the Life Cycle Impact Assessment (LCIA) for this comparative LCA. The LCIA was performed using TRACI 2, v3.03, which provides a North American perspective for mid-point results (Bare and Gloria, 2006). TRACI (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) includes a set of nine impact categories including: global warming (CO_2-eq), acidification (H^+ mol-eq), carcinogens (kg benzene-eq), non-carcinogens (toluene-eq), respiratory effects ($PM_{2.5}$-eq), eutrophication (N-eq), ozone depletion (CFC-11-eq), ecotoxicity (2,4-D-eq) and smog (NO_x-eq). When possible, this study adheres to the latest LCA standards within the International Standards Organization, ISO 14040 and ISO 14044, and therefore only partially adheres to the standards due to the limited availability of industry data for production processes (International Organization for Standardization, 2006a, International Organization for Standardization, 2006b).

3.2.3.1 Life Cycle Inventory Data

Select secondary resources were utilized to determine the production and assembly processes of protective mailers components including: Environmental Product Declarations of the European Plastics Manufacturers for LDPE (PlasticsEurope, 2008), Air Cushion Film Laminate and Method of Making Same (Wetsch, 2002), and the production of Kraft paper (Kasser, 1983, Landqvist et al., 1988).

Publically provided information or confirmation of data was inadequately available for this study as the majority of organizations refused to provide assistance. Purolator was approached for data but no agreement was reached (Appendix A: Purolator Correspondence). Numerous attempts were made over a twelve month period but no data were available from courier companies or packaging manufacturers to determine current production, output, transportation methods or previous environmental assessments on packaging. Sealed Air was contacted a dozen times without response. Staples, Grand & Toy, Scotch, and Crownhill Packaging Ltd. were also contacted for data without success. Generic mailers used in this study were purchased from a packaging distributor, Associated Bag Company. Associated Bag provided the weight and composition of the secondary packaging, the carton, containing 100 mailers for bulk orders over the phone while dimensions of protective mailers were provided in the company`s annual sales catalogue (Appendix D: Associated Bag Company Correspondence- LDPE Bubble Mailer; Appendix E: Associated Bag Company Correspondence- Kraft Paper and Newsprint Filled Padded Mailer). For this study two boxes were purchased containing 100 bubble mailers and 100 padded mailers. These boxes were weighed with a scale and dimensions were measured with measuring tape, and then the mailers were dissected into individual components and weighed and measured.

The majority of general LCI data for this study was from ecoinvent (ecoinvent Centre, 2010), while the U.S. LCI database (USLCI Database, 2012) and primary data were used to help model the life cycle. The bubble mailer and padded mailer contain five main components: 1) protective exterior of the mailer; 2) interior padding material; 3) hot-melt adhesive for the closure and sealed areas; 4) strip cover to protect the adhesive until the use stage; and 5) generic ink for branding (Figure 6).

Figure 6: Self-sealing Protective Mailer Components: Kraft padded mailer (left) made from 50% post- consumer paper and LDPE bubble mailer (right) made from co-extruded LDPE

Ink and hot melt adhesives were assumed equal between the bubble mailer and padded mailer by weight (Table 9: Weight of Mailer Components – Kraft Paper and Newsprint Filled Padded Mailer). These components could technically have been excluded from the study, as it is common among comparative LCA's to exclude comparable ingredients, or processes that could cancel each other out. However, the protective mailers were not the same weight, even though the ink and hot melt adhesives were, and resulted in different proportional weights. Additionally, ink composed less than 1% of the weight of the mailers, while hot melt adhesives composed more than 1% of the weight of the LDPE bubble mailer. A 1% composition is a standard cut-off for inclusion in LCAs. As limited inventory processes were available for adhesives in ecoinvent, a glue stand-in, or dummy weight, was included for both mailers in this comparative LCA. Ink was estimated to be less than 0.01% weight composition of both protective mailers and was not included in the study.

Both protective mailers were assumed to be manufactured at the same industrial plant located in Mississauga, Ontario. Manufacturing plants and locations throughout this thesis reflect the largest and most common facility in Canada. Mississauga is the location of Sealed Air (Canada) headquarters, the first manufacturer of protective mailers and the largest packaging manufacturer in the world with $7.65B in sales in 2012, $16M of which were sales in protective packaging (Sealed Air Inc., 2013). To account for infrastructure for the manufacturing process, the ecoinvent unit process for the extrusion of plastic film was used with five areas of modification to specialize the process to the context of this study, (as detailed in upcoming sections):

1) Power based on the province of Ontario's 2010 electricity production mix (53% nuclear, 20% hydropower, 13% natural gas, 8% hard coal, 5% other; Table 4)
2) Mailer manufacturing machine power requirement and production capacity
3) Cardboard box production to reflect bulk shipping method of product
4) Disposal scenario for manufacturing waste products to match Canadian standards
5) Transportation from manufacturer to retailer for each product

The extrusion process of LDPE in ecoinvent calculated 2.4% material loss during manufacturing and therefore the processes were assumed to be 97.6% efficient for both mailers. The mass of raw component materials were increased to account for the 2.4% of material lost in the manufacturing process. Upstream processes included any processes that were necessary for the production of the protective mailers. Downstream processes included any waste.

Table 4: SimaPro Data Calculations - Electricity: Ontario Production Mix 2010 (ecoinvent process modified with data from Ontario government)

Materials/Fuels	%	Amount	Unit	Details
Electricity, nuclear, at power plant/US U	53%	0.53280	kWh	National and international statistics
Electricity, hydropower, at power plant/SE U	20%	0.19483	kWh	National and international statistics; no US-specific dataset available
Electricity, natural gas, at power plant/US U	13%	0.13096	kWh	National and international statistics
Electricity, hard coal, at power plant/US U	8%	0.08151	kWh	National and international statistics
Electricity, oil, at power plant/UCTE U	2%	0.02311	kWh	National and international statistics; no US-specific dataset available
Electricity, at wind power plant/RER U	2%	0.02088	kWh	National and international statistics; no US-specific dataset available
Electricity, at cogen 6400kWth, wood, allocation exergy/CH U	1%	0.00994	kWh	National and international statistics; no US-specific dataset available
Electricity, production mix photovoltaic, at plant/US U	0%	0.00005	kWh	National and international statistics
Electricity, lignite, at power plant/UCTE U	0%	0.00000	kWh	National and international statistics; no US-specific dataset available
Electricity, hydropower, at pumped storage power plant/US U	0%	0.00000	kWh	National and international statistics; no US-specific dataset available
Electricity, at cogen with biogas engine, allocation exergy/CH U	0%	0.00000	kWh	National and international statistics; no US-specific dataset available
Electricity, industrial gas, at power plant/UCTE U	0%	0.00000	kWh	National and international statistics; no US-specific dataset available
TOTAL	100%	0.99408	kWh	N/A

Source: (Government of Ontario, 2010); SimaPro v7.3.2 *Process datasets are identified by the name, location, unit and a marker for infrastructure processes. *Unit processes* are further identified by a U, or *system processes* (results) are identified by an S.

3.2.4 Upstream Processes for LDPE Bubble Mailer

3.2.4.1 History of Plastic

Plastic was introduced to the packaging industry in the 1950`s to replace heavy containers made of metal, tin and wood. Polyethylene was introduced just before World

War II when Du Pont, Dow Chemical, and Union Carbide convinced the military of the value of plastics. Rigid plastics were used to ship medicine, ammunition and spare parts used in the war. The result created a supply and demand for inexpensive, strong and theft-proof packaging, while straining natural and non-renewable resources.

3.2.4.2 Plastic Production Process

Today, plastic packaging houses the majority of the products consumed in daily human life. Approximately 80% of plastics in use are thermoplastics that become soft when heated and regain original properties when cooled (Hischier, 2007). Thermoplastics are made from crude oil with a life cycle that began millions of years ago. Fossil fuels are made from anaerobic decomposition of plants and organisms that died millions of years ago that were buried and folded into the earth, heated and compressed to be transformed into either coal or deposits of fluid hydrocarbons. Fossil fuels are considered to be one of Earth's non-renewable resources. To make plastic such as low density polyethylene, crude oil is refined to create the product naptha, and combined with natural gas through the process of steam cracking. This process creates ethylene and propylene and various other products are separated after the cracking furnaces by distillation, compression and cooling. The material is then extruded into plastic pellets and mixed with dyes or fillers. These pellets are then extruded again or molded to become the intended final product.

3.2.4.3 Plastic Recycling Process

In 1988 the Society of Plastics developed the resin code system to help manufacturers and recyclers categorize the different types of plastics using a whole number (Table 5). The resin numbers strictly identifies the input material for future recycling rather than what is socially perceived, that the numbers infer that products marked with arrows can be recycled in general (Boylston, 2009). Recycling of plastic can only occur if both 1) the specific resin is accepted at a recycling facility, and 2) the material is not cross-contaminated with food or other pollutants.

Table 5: Plastic Resin Codes (Type 4, LDPE is used the most in this study)

Symbol	Resin Codes	Common Applications
PET	Type 1: Polyethylene Terephthalate	Pop bottles, water bottles and some packaging intended for single use
HDPE	Type 2: High Density Polyethylene	Milk jugs, detergent containers, reusable and recyclable containers
PVC	Type 3: Polyvinyl Chloride	Pipes, electrical cables, vinyl
LDPE	Type 4: Low Density Polyethylene	Plastic bags, plastic wrap, six-pack beverage can rings
PP	Type 5: Polypropylene	Bottle tops, automotive parts (bumpers, dashboards, etc), margarine and yogurt containers
PS	Type 6: Polystyrene	Food take-out clamshell containers, egg cartons peanuts for void fill
OTHER	Type 7: Other	Biphenol-A

Source: (Boylston, 2009)

Plastic is currently perceived as a source of environmental stress based on petroleum-based extraction, toxicity, and ecological persistence (Boylston, 2009). Plastic is dependent on the extraction of crude oil, and as noted by Imhoff and Carra, 2005:

> The most serious external costs of packaging lie in the extraction of natural resources, energy consumption and the emission of air and water pollution throughout the manufacturing process.

Additionally, plastics cannot be recycled infinitely and must be downcycled into blended forms of less functional plastic (Boylston, 2009, McDonough and Braungart, 2002). Recent developments have improved the percentage of reuse for recycled plastics, but cannot compare with other materials such as metals and glass that can be recycled and reused indefinitely.

Despite negative attributes of plastic during extraction and disposal stages, plastics are significantly lighter than other comparable materials. Lighter materials used in packaging can contribute to decreased fuel consumption and lower transportation costs compared to heavier materials (Boylston, 2009). Additionally, even if plastic is downcycled during the recycling process, recycling plastics reduces the need for extracting new raw materials and encourages the reclamation of existing waste plastic (Boylston, 2009).

3.2.4.4 Low Density Polyethylene (LDPE)

Polyethylene is a thermoplastic and can be either low density polyethylene (LDPE) or high density polyethylene (HDPE). LDPE is manufactured in a high-pressure process while HDPE is manufactured in a low-pressure process. LDPE is used primarily to make plastic films while HDPE is used to make containers, such as ice cream containers.

An application of LDPE in the packaging industry is Sealed Air`s Bubble Wrap®. This material was invented in 1957 in New Jersey by engineers Alfred Fielding and Marc Chavannes. The idea for Bubble Wrap® began with the invention of paper-lined plastic wallpaper using two shower curtains sealed together. The product was repositioned as greenhouse insulation before being marketed to IBM to protect the shipment of mass-produced business computers. Bubble Wrap® competed and still competes with balled newspaper, an essentially free material, repurposed as void fill for protective packaging.

Low density polyethylene (LDPE) is flexible, tough and has high impact strength, which are important characteristics for protective packaging (Mark, 2009). Similar to other plastics, the degradation of LDPE is limited after disposal, which causes pollution to the environment with possible ecosystem level effects (Bastioli, 2005). Current methods for addressing this problem include recycling, chemical recovery, and incineration with energy recovery (Hamid, 2000). The cost and pollution of these procedures have increased the demand for research on the biodegradation of LDPE waste

(Zahra et al., 2010). However, a major obstacle to biodegradation is LDPE`s resistance to water and high molecular weight (Hamid, 2000).

3.2.4.5 LDPE Production Process

Steamcracking is used to polymerize LDPE at approximately 230 megapascal (MPa) and 300 degrees Celsius (Baumann and Tillman, 2004). This high pressure is maintained by electrically powered pumps. The resulting polyethylene base resin is transferred to an extruder where the material is modified with additives and made into pellets using pelletizing equipment (Baumann and Tillman, 2004). The polyethylene granulates, or pellets, are transported from the plastics manufacturer to various packaging manufacturers for the production of bubble mailers. The pellets are converted into LDPE film and other types of end products that result in waste, all of which can be recycled while at the production facility. This extruded waste flow it termed *floss*, as it resembles cotton candy floss, and is approximately 12% of the waste flow, based on the output of the machine used (The Dow Chemical Company, 2002); (Baumann and Tillman, 2004).

3.2.4.6 LDPE Bubble Mailer Production Process

The bubble mailer is made from a machine that heats polyethylene pellets to approximately 340 degrees Celsius and creates a long, thin tube of plastic. The inner bubble film of the mailer is wrapped around a drum with holes machined in it. Suction forms the film into bubbles and air is trapped in the bubbles as another layer of film is laminated to it. The bubble film is then laminated to a strong three-layered outside film. Sides of the protective mailer are sealed with heat. Hot melt adhesive is added and topped with an adhesive strip cover for future customer use. Cutting, printing and packaging the bags requires additional time, labour and energy. Used energy includes process, transportation and material resource energy, 10,000 LDPE bubble mailers equals about 52.8 GJ (Franklin Associates, 2004). In addition, 10,000 LDPE bubble mailers equal approximately 2,268 kg (5,000 lbs) of CO_2 during its life cycle (Wetsch, 2002), (Franklin Associates, 2004).

The waste floss from this process is collected and ground in a mill at the recycling plant, washed, dried, extruded and re-granulated. Most of the recycled floss varies in colour so this material is usually downcycled into producing materials that are dark in colour, such as garbage bags. Any additional waste is usually disposed of at landfill sites (Baumann and Tillman, 2004).

3.2.4.7 Functional Unit Characteristics – LDPE Bubble Mailer

The LDPE bubble mailer is a multi-layer co-extruded LDPE film and a single mailer weighs 15.47 grams. The exterior shell, inflated cushioning, and adhesive strip cover are assumed to be made of 100% LDPE (Table 6). The extraction and production of LDPE pellets were based on the cradle-to-gate U.S. LCI dataset for the production of LDPE resin at the manufacturing facility, which includes pipeline transport of raw petroleum (Table 7). For this study, LDPE pellets were assumed to be manufactured at the Dow Chemical plant in Fort Saskatchewan, Alberta. The transportation of LDPE pellets to manufacturer was calculated as the distance between Fort Saskatchewan, Alberta to Mississauga, Ontario using the ecoinvent unit process for the operation of a diesel freight train (SimaPro v7.3.2 European unit process). According to SimaPro this inventory data refers to average goods transport conditions in Europe and includes the diesel consumption and diesel engine emissions for an average European diesel traction goods train (1000 Gt). It also accounts for diesel consumption and emissions of shunting processes and the variation in the geography of different countries by classifying 15 European countries into three regions (flat, hilly, mountainous), which is representative of Canada’s diverse landscape.

Power for the manufacturing process was calculated using the average wattage and production output of bubble film extrusion machines currently on the market (nineteen machines) and are assumed to be produced in China (Table 8). The cardboard box used to ship 100 LDPE bubble mailers was made of 175# Test, C-Flute corrugated carton based on specifications provided by Associated Bag Company. Designation for corrugated board flute grades refers to the order the style of packaging was introduced, not the size (Twede and Selke, 2005). The carton, or box, was measured using a scale and measuring tape: 464.0 grams and measured 56.0 cm tall, 28.9 cm long, 24.8 cm deep and 0.3 cm thick.

Manufacturing waste was modeled using the ecoinvent disposal scenario for plastics to a landfill without recycling (Baumann and Tillman, 2004). Transportation of mailers was assumed to be on pallets of standard size (122 cm x 102 cm), shrink-wrapped in plastic, and stacked according to capacity. The average shipment load was provided by Associated Bag Company as 864 cartons of 100 mailers (86,400 LDPE bubble mailers) per 16 metre tractor-trailer, and this study assumed the whole shipment was LDPE bubble mailers. Distance from manufacture to point-of-sale was determined as a weighted average based on population sizes of Canadian cities (Appendix G: Sample Calculations).

Table 6: Weight of Mailer Components - LDPE Bubble Mailer (measured and estimated weights)

Composition of LDPE Bubble Mailer (No.2: 21.6 cm x 30.5 cm)		
Component	**Material**	**Weight (grams)**
Exterior Shell	Low-Density Polyethylene	9.67 (measured)
Padding	LDPE Inflated Cushioning	4.78 (measured)
Padding	Air Sealed inside Inflated Cushioning	0.22 (estimated)
Adhesive	Hot Melt Adhesive	0.50 (estimated)
Adhesive Strip Cover	Low-Density Polyethylene	0.30 (estimated)
Ink	Industry Standard Printing Ink	0.001 (estimated)
TOTAL	**LDPE Bubble Mailer**	**15.47 grams**

Table 7: SimaPro Data Calculations - Materials & Assembly Process for LDPE Bubble Mailer (measured and estimated weights)

Materials/Assemblies	Amount	Unit	Comment
Low density polyethylene resin, at plant/RNA	0.01584	kg	Package weight including estimated loss of material in assembly process
Dummy Glue-adhesive, at plant/US	0.0005	kg	Adhesive strip for sealing mailer
Processes	**Amount**	**Unit**	**Comment**
Extrusion, bubble plastic film/US U	0.01547	kg	Mailer 100% LDPE
Operation, freight train, diesel/RER U	0.055862	tkm*	Fort Saskatchewan Dow Chemical Plant
Transport, lorry 16-32t, EURO3/RER U	0.0003043	tkm*	Vareness, Quebec Dow Chemical

*tkm: tonne·kilometers, a unit of measure representing the transport of a payload over a given distance. See Appendix G: Sample Calculations

Table 8: LDPE Bubble Mailer Assembly Machines - Average Power and Production Specifications (assumed to be made in China, used in Canada)

#	Machine Function	Model No.	Manufacturer	Total Power (kWh)	Maximum Output (kg/h)	Power (kW/kg LDPE Extruded)	Data Source
1	Compound Polyethylene Bubble Film Making Machine	FPE-1500	Wenzhou Wanqun Plastic Machinery Co.	122	90	1.3556	www.alibaba.com
2	Compound Polyethylene Bubble Film Making Machine	FPE-2000	Wenzhou Wanqun Plastic Machinery Co.	200	110	1.8182	www.alibaba.com
3	Compound Polyethylene Bubble Film Making Machine	FPE-2500	Wenzhou Wanqun Plastic Machinery Co.	243	150	1.6200	www.alibaba.com
4	Compound Polyethylene Bubble Film Making Machine	FPE-3000	Wenzhou Wanqun Plastic Machinery Co.	263	200	1.3150	www.alibaba.com
5	PE Air Bubble Film Blowing Machine/Extruder	QPE-1250	Ruian Huarui Plastic Machinery Co.	58	62	0.9355	hrsljx.en.made-in-china.com
6	PE Air Bubble Film Blowing Machine/Extruder	QPE-1000	Ruian Huarui Plastic Machinery Co.	48	50	0.9600	hrsljx.en.made-in-china.com
7	PE Air Bubble Film Blowing Machine/Extruder	QPE-1500	Ruian Huarui Plastic Machinery Co.	68	70	0.9714	hrsljx.en.made-in-china.com
8	PE Air Bubble Film Blowing Machine/Extruder	QPE-1200	Ruian Huarui Plastic Machinery Co.	55	30 - 60	1.8333	hrsljx.en.made-in-china.com
9	Polyethylene Air Bubble Extruder Machine	PCM-2768	Plastemart	30-90	25 - 80	1.2000	www.plastemart.com

#	Machine Function	Model No.	Manufacturer	Total Power (kWh)	Maximum Output (kg/h)	Power (kW/kg LDPE Extruded)	Data Source
10	Polyethylene Bubble Film Extrusion Machine	BLPE-1000	Billy Machine	50	60	0.8333	www.plasticmachine-cn.com
11	Polyethylene Bubble Film Extrusion Machine	BLPE-1200	Billy Machine	58	70	0.8286	www.plasticmachine-cn.com
12	Polyethylene Bubble Film Extrusion Machine	BLPE-1500	Billy Machine	70	90	0.7778	www.plasticmachine-cn.com
13	Polyethylene Bubble Film Extrusion Machine	BLPE-1800	Billy Machine	86	120	0.7167	www.plasticmachine-cn.com
14	Polyethylene Bubble Film Extrusion Machine	BLPE-2000	Billy Machine	95	150	0.6333	www.plasticmachine-cn.com
15	Three-Five Layer Polyethylene Bubble Film Making Machine	BLPEG-1000	Billy Machine	86	80	1.0750	www.plasticmachine-cn.com
16	Three-Five Layer Polyethylene Bubble Film Making Machine	BLPEG-1200	Billy Machine	95	100	0.9500	www.plasticmachine-cn.com
17	Three-Five Layer Polyethylene Bubble Film Making Machine	BLPEG-1500	Billy Machine	112	150	0.7467	www.plasticmachine-cn.com
18	Three-Five Layer Polyethylene Bubble Film Making Machine	BLPEG-1800	Billy Machine	141	180	0.7833	www.plasticmachine-cn.com
19	Three-Five Layer Polyethylene Bubble Film Making Machine	BLPEG-2000	Billy Machine	158	220	0.7182	www.plasticmachine-cn.com

3.2.5 Upstream Processes for Kraft Paper and Newsprint Filled Padded

3.2.5.1 History of Papermaking

Paper was invented in China more than two thousand years ago (Twede and Selke, 2005). The definition of paper is a product with changed properties due to maceration or disintegration (Tsien, 1985). The origin of the word paper (*chih* in Chinese) came from the Chinese words *hsü i chan yeh*, which translates to “a mat of refuse fibres” (Tsien, 1985). Paper is created from a sheet of fibres formed on a screen in a suspension of water (Tsien, 1985). The material is then drained and the screen is removed. The material is then dried and paper is the result (Tsien, 1985).

Wood fibers have been used to make paper since the 1850s (Twede and Selke, 2005). Today, softwood and hardwood trees are used for papermaking (Twede and Selke, 2005). Trees are a composite of cellulose fibres bonded with lignin, sugars and other organic compounds (Broten and Ritchlin, 1999). The cellulose fibres are the valuable component for making paper (Broten and Ritchlin, 1999). Nearly half of the weight of the tree consists of cellulose that can be used for papermaking (Broten and Ritchlin, 1999). Cellulose is separated from the lignin and other materials through pulping to create wood pulp.

3.2.5.2 Paper Production Process

The entire papermaking process, from seedling to final product, takes decades in Canada. Trees begin as seedlings and require approximately twenty years before reaching maturity. Trees are eventually cut, topped, and lifted by a machine called a *fellerbuncher* (Broten and Ritchlin, 1999). The logs are transported from the forest to a mill and stored for three years to dry before use (Franklin Associates, 2004). The logs are then stripped of bark and chipped into two centimeter cubes (Broten and Ritchlin, 1999). Mechanical pulping and chemical pulping are two primary methods for making wood pulp.

Chemical pulping uses chemicals, heat, and pressure to dissolve the lignin in the wood to expose the cellulose fibres (Broten and Ritchlin, 1999). Cubes of wood, or wood chips, are cooked with intense heat and pressure and digested with limestone and sulphuric acid until the wood becomes pulp (Broten and Ritchlin, 1999). The pulp is washed with massive amounts of water and bleach, and then pressed into finished paper (Twede and Selke, 2005). The waste from the digester is known as *black liquor*, and often burned at the paper mill as an energy source (Broten and Ritchlin, 1999). Black liquor is composed of lignin residues, hemicellulose, and the chemicals used in the process (Broten and Ritchlin, 1999). Another by-product created is called *tall oil* which is an oily liquid particularly from pine wood that is composed of a mixture of rosins, fatty acids, and other substances (Broten and Ritchlin, 1999).

For mechanical pulping, wood is chopped and ground to separate cellulose fibres (Broten and Ritchlin, 1999). Resulting pulp still contains lignin, which causes the final product to appear yellow or brown when exposed to the sun (Broten and Ritchlin, 1999). This process creates fibres that are short and stiff, which makes flimsy paper. Examples of products made from mechanical pulping include newsprint and paper packaging for low-strength applications (Broten and Ritchlin, 1999).

3.2.5.3 Kraft Paper Production Process

The word *kraft* translates to *strongly* in the German language and Kraft paper fibres are strong and durable (Broten and Ritchlin, 1999). Kraft paper is usually made from softwood using a specialized sulfate pulping chemical process (Twede and Selke, 2005). Kraft paper has high strength properties when blended into two or more layers in the production process (Twede and Selke, 2005). Unbleached natural Kraft paper is the strongest type of paper (Twede and Selke, 2005).

During the Kraft paper process, once the wood pulp has been prepared, it is heavily diluted with water and the mixture is sprayed onto a moving mesh screen in layers to make a mat (Broten and Ritchlin, 1999). It then goes through several mechanical and vacuum processes to drain, compact, and dry. This mat is then sent through heated rollers to remove remaining moisture and compress it into paper. Mechanical dryers may be used to speed up the process or to help achieve a more consistent product. Once the paper has the proper thickness and moisture content it may be coated with synthetic binders (to increase strength and water resistance), or coloured, or given a light plastic coating (to give it a glossy texture and remove any paper odour) (Broten and Ritchlin, 1999). The mat can be as wide as 9 meters and often wrapped as a continuous roll (Broten and Ritchlin, 1999). The paper rolls are then cut to size and packaged for shipping to another facility for secondary processing.

3.2.5.4 Paper Recycling Process

Recycled paper begins with a large vessel of water filled with chopped paper to be recycled. The washing process creates a paste that can be separated into solids and liquids and includes cellulose fibres, inks, colours, coatings and other contaminants. This slurry goes through several cleansing cycles to remove contaminants while the handling process shortens the cellulose fibres, limiting the number of times it can be recycled. Recycled material that is lost must be replaced with virgin material (Baumann and Tillman, 2004).

The process of restructuring recycled paper into pulp has negative impacts on the environment as it uses additional water and energy. Fibres can only be recycled 5-7 times before losing adequate fibre strength and becoming too short for recycling (Boylston, 2009). The process also creates secondary effluents that are challenging to dispose. While current recycling program provide good results, focusing improvements on overall product design and production processes may produce better results in terms of minimizing environmental impacts.

3.2.5.5 Kraft Paper and Newsprint Filled Padded Mailer Production Process

A generic Kraft paper and newsprint filled padded mailer is mainly composed of Kraft paper and macerated recycled newsprint. For this study it was assumed that the Kraft paper exterior was made with the sulfate pulping chemical process. In order to produce a Kraft paper and newsprint padded mailer, it was assumed that rolls of Kraft paper, shredded recycled newspaper and adhesive were supplied into a Model Pocket Envelope Making Machine. It was assumed that this machine cut the Kraft into the correct dimensions, embedded a plastic tear-strip, double-folded the exterior, filled the two cavities with shredded newsprint and sealed the bottom edge of the mailer with a double-glued bottom flap construction with hot-melt adhesive. It was assumed that this same adhesive was sealed into the mailer, and applied to the remaining end and topped with a wax adhesive strip cover for the end-user to remove during the use stage. The finished product was a Kraft paper and newsprint padded mailer.

Power and production specifications of Kraft paper and newsprint filled padded mailer manufacturing machines were collected from online sources. It was assumed these machines were built in China for Canadian manufacturers.

3.2.5.6 Functional Unit Characteristics – Kraft Paper and Newsprint Padded Mailer

Figure 7: Extraction of Interior of Padded Mailer

The generic No.2 size Kraft paper and newsprint filled padded mailer weighed a total 70.62 grams. According to the exterior packing labels, the Kraft paper and newsprint filled padded mailer was a product made of 50% post-consumer content. The interior newsprint contents were extracted and weighed, and compared with the exterior Kraft paper shell (Table 9). Based on 100 samples, the Kraft paper exterior shell weighed 34.87 grams and the shredded recycled newsprint interior weighed 34.80 grams (Table 9). As the measured ratio of newsprint to Kraft paper per mailer was nearly 50/50, it was assumed the post-consumer content was all newsprint. The Kraft paper used in this process was assumed to be a virgin product as it was a thick paper that would require long fibres for overall strength.

The extraction and production of Kraft paper was based on the ecoinvent cradle-to-gate unit process for Kraft unbleached paper at the plant. The shredded newsprint process was based on the ecoinvent waste paper collection process without further treatment. The pull-tab was assumed to be made from 100% polypropylene as it was a tougher, thicker plastic than LDPE and is commonly used in packaging. The extraction and production processes were based on the ecoinvent LCI for polypropylene granulate. The adhesive cover strip had a texture that felt like wax paper and was assumed to have the production properties of generic wax paper: made of 80% super-calendered paper, 15% paraffin, and 5% LDPE with extraction and production processes based on ecoinvent LCI data. Manufacturing plants and locations throughout this thesis reflect the largest and most common facility in Canada. The largest Kraft paper manufacturing plant in Canada is Domtar, which is located in Kamploops, BC. The transportation of Kraft paper to the manufacturer was calculated as the distance between Kamloops, BC and Mississauga, Ontario. This calculation used the ecoinvent unit process for the operation of a diesel freight train, based on the same data provided by SimaPro v7.3.2 for the LDPE bubble mailer mentioned earlier.

Table 9: Weight of Mailer Components – Kraft Paper and Newsprint Filled Padded Mailer (measured and estimated weights)

Composition of Kraft Paper and Newsprint Filled Padded Mailer (No.2: 21.6 cm x 30.5 cm)		
Component	**Material**	**Weight (grams)**
Exterior Shell	Kraft Paper	34.87 (measured)
Padding	Recycled Newsprint, Shredded	34.80 (measured)
Adhesive	Hot Melt Adhesive	0.50 (estimated)
Adhesive Strip Cover	Wax Paper	0.30 (estimated)
Pull-Tab to Open Package	Polypropylene Strip Embedded Paper Tape	0.15 (estimated)
Ink	Industry Standard Printing Ink	0.001 (estimated)
TOTAL	**Kraft Paper and Newsprint Filled Padded Mailer**	**70.62 grams**

Power for the manufacturing process was calculated using the average wattage and production output from the only two envelope making machines that had available data (Table 10). The cardboard box used to ship Kraft paper and newsprint filled padded mailers was made of 175# Test, C-Flute corrugated carton, as provided by specifications from Associated Bag Company. The carton, or cardboard box, the mailers were shipped in weighed 481.0 grams and measured 29.5 cm tall, 45.0 cm long, 32.0 cm deep and 0.3

cm thick. Waste from the manufacturing processes was modeled using the ecoinvent disposal scenario for packaging waste.

Table 10: Kraft Paper and Newsprint Filled Padded Mailer Assembly Machines - Average Power and Production Specifications (assumed to be made in China, used in Canada)

#	**Machine Function**	**Model No.**	**Manufacturer**	**Total Power** (kWh)	**Maximum Output** (kg/h)	**Power** (kW/kg Kraft Paper)	**Data Source**
1	Model Pocket Envelope Making Machine	WF240	China Fangda Envelope Making Machine Co., Ltd. Design	9.2	8,000 pcs/hour	0.0163	www.wz-xinfengji.cn
2	Envelope Paper Bag Machine	WF-53	China Fangda Envelope Making Machine Co., Ltd. Design	8.5	10,000 pcs/hour	0.0120	www.wz-xinfengji.cn

Transportation of Kraft paper and newsprint filled padded mailers was assumed to be on pallets of standard size (122 cm x 102 cm), shrink-wrapped in plastic, and stacked according to capacity. It was determined that volume capacity for these boxes was 1,052 cartons of 100 mailers (105,200 Kraft paper and newsprint filled padded mailers) per 16 metre tractor-trailer, assuming the whole shipment was Kraft paper and newsprint filled padded mailers (Appendix G: Sample Calculations). Distance from manufacture to point-of-sale was determined as a weighted average based on population sizes of Canadian cities (Appendix G: Sample Calculations).

Table 11: SimaPro Data Calculations - Materials and Assembly Process for Kraft Paper and Newsprint Filled Padded Mailer (input manually to calculate results)

Materials/Assemblies	Amount	Unit	Comment
Kraft paper, unbleached, at plant/RER U	0.03487	kg	Weight measurements include 2.4% loss in manufacturing process (Table 9)
Waste paper, mixed, from public collection, for further treatment/RER U	0.03480	kg	Weight measurements include 2.4% loss in manufacturing process (Table 9)
Dummy_Glue-adhesive, at plant/US	0.00050	kg	Adhesive strip (Table 9)
Polypropylene, granulate, at plant/RER U	0.00015	kg	Pull Tab Component. (Table 9)
Paraffin, at plant/RER U	0.000045	kg	Assuming Adhesive Strip Cover is 80% super-calendered paper - pressed to make shiny, then topped with combination of paraffin and LDPE to make it a wax paper. Assuming 15% of weight is paraffin.
Low density polyethylene resin, at plant/RNA	0.000015	kg	Assuming Adhesive Strip Cover is 80% super-calendered paper - pressed to make shiny, then topped with combination of paraffin and LDPE to make it a wax paper. Assuming 5% of weight is LDPE
Paper, wood-containing, super-calendered (SC), at regional storage/RER U	0.00024	kg	Assuming Adhesive Strip Cover is 80% super-calendered paper - pressed to make shiny, then topped with combination of paraffin and LDPE to make it a wax paper
Processes	**Amount**	**Unit**	**Comment**
Kraft Padded Mailer Assembly US / U	0.07062	kg	New Process created.
Operation, freight train, diesel/RER U	0.1437480	tkm*	Travel from Kraft manufacturer Domtar Plant in Kamloops BC. 4020 km. Recycled newsprint assumed to be local collection, without additional transport. Second largest Kraft producer in North America, largest in Canada
Transport, lorry 16-32t, EURO3/RER U	0.0003043	tkm*	Vareness, Quebec - Dow Chemical for emulsion polymers; adhesive. 594 km to Mississauga. Dow is biggest manufacturer of chemicals in world. Assumed Dow is involved in this process. Assuming shipped via Tractor-Trailer.

*tkm: tonne·kilometers, a unit of measure representing the transport of a payload over a given distance. See Appendix G: Sample Calculations

3.2.6 Use Stage

The *use stage* for both types of mailers began when a mailer became a parcel, filled with the intended contents for delivery by the postal service. A *trip* was defined as the time a parcel was picked-up until it was delivered, and it was assumed that the mailer was purchased in the same location it was mailed. In the year 2000, a total of 24,700 vehicles were estimated to be involved in the pick-up and delivery of courier shipments in Canada (Breininger, 2001) and these numbers were assumed to be similar for the Canadian postal industry.

Figure 8: Process of Shipping a Parcel for Both Mailers

Automobiles used for the transportation stages for both types of mailers included cars, cargo vans, cube vans, straight trucks, step vans, and tractor-trailers. Step vans made up the majority (52%) of the Canadian service fleet, followed by cargo vans (20%), while the remaining fleet was comprised of cars, cube vans, straight trucks and tractor-trailers (Breininger, 2001). Tonne·kilometers per trip were calculated for each transportation type and mailer using the following:

$$tkm_{i,j} = [(W + M_i)/1000](d_j)(p_j)$$

where i is the mailer type (LDPE bubble mailer or Kraft padded mailer), j is vehicle type (e.g. cargo van), W is the content weight of the parcel (1 kg), M is the weight of the mailer (kg), d_j is the average distance of each trip (km/trip).

The probability p_j of a mailer being transported in a given vehicle type j was calculated as:

$$p_j = \frac{n_j t_j c_j u_j}{\sum n_j t_j c_j u_j}$$

Where n_j is the number of fleet vehicles, t_j is the number of trips per year, c_j is the vehicle capacity (kg), and u_j is the estimated utilization of the capacity (Table 13). To estimate the impact of the use stage, ecoinvent LCI data were employed to model each vehicle type separately.

Tonne·kilometers were calculated for the base scenario and three sensitivity scenarios during the *use stage* (Table 14). The base scenario assumed that the mailer was filled to capacity (1 kg) with parcel contents. *Sensitivity Analysis A* tested the effect of the assumed weight of the parcel contents in the *use stage* by assessing mailers with no parcel contents (0 kg). *Sensitivity Analysis B* modeled air freight transport instead of long-haul shipping using tractor-trailers during the *use stage*. *Sensitivity Analysis C* focused on the materials used in the study by normalizing both products as per kilogram of mailer.

Table 12: Automobiles Used for Transportation Stage

Automobile Name	Automobile Icon
Car	
Cargo Van	
Cube Van	
Straight Truck	
Step Van	
Tractor-Trailer	

Table 13: Calculation of Tonne·kilometers (tkm) for Mailer Type for Each Type of Automobile (component to calculate results)

Vehicle Type (*j*)	**# of Each Vehicle Type*** (*n*)	**Distance Vehicle Type Travel Per Year (km)***	**Trips Per Day**	**Trips Per Year **** (*t*)	**Distance Per Trip (km)** (*d*)	**Total Distance Travelled Per Year (km)**	**Vehicle Weight Capacity (kg)** (*c*)	**Ave. Capacity Utilization (%)** (*u*)	**Probability of Trip Type** (*p*)	(*n*)*(*t*)*(*c*)*(*u*)	**Tonne Kilometer Probability of Vehicle Type, Full Mailer; 1 kg. (tkm)*****	
											Kraft Padded Mailer (tkm)	LDPE Bubble Mailer (tkm)
Cars[1]	2,841	61,424	6.0	1,500	40.9	174,505,584	500	33.5%	0.0642	713,801,250	0.00281	0.00267
Cargo Vans[1]	5,014	61,503	1.0	250	246.0	308,376,042	1,000	71.1%	0.0802	891,238,500	0.02111	0.02003
Cube Vans[1]	1,778	42,972	1.0	250	171.9	76,404,216	2,500	70.1%	0.0701	778,986,250	0.01289	0.01223
Step Vans[1]	12,943	36,598	1.0	250	146.4	473,687,914	2,500	74.1%	0.5391	5,994,226,875	0.08450	0.08015
Straight Trucks[2]	1,161	48,200	1.0	250	192.8	55,960,200	5,000	75.0%	0.0979	1,088,437,500	0.02021	0.01917
Tractor-Trailers[3]	963	185,878	0.2	73	2,546.3	179,000,514	30,000	78.3%	0.1485	1,651,323,510	0.40490	0.38404
Each mailer is assumed to take one trip; therefore the *tkm* is the relative probability of a trip in a particular vehicle type.									Total: 1	Total: 11,118,013,885		

[1]Transport, van <3.5t/RER U, [2]Transport, lorry 3.5-7.5t, EURO3/RER U, [3]Transport, lorry 16-32t, EURO3/RER U

*Based on Infobase Marketing Report, Total Vehicles = 24,700, obtained from undisclosed surveyed courier companies

**Assuming cars made 6 trips/day, 5 days/week, 50 weeks/year; cargo vans, cube vans, step vans & straight trucks made 1 trip/day, 5 days/week, 50 weeks/year; tractor-trailers made 1 trip every 5 days, year round

***Shipment includes maximum weight (1 kg) parcel inside mailer

Table 14: Calculation of Tonne·kilometers (tkm) of Each Transportation Type during Use Stage and Adjusted by Scenario (summary table of transportation results)

Transportation Type	Processes	Tonne·kilometers (tkm)							
		Base Scenario		Sensitivity A		Sensitivity B		Sensitivity C	
		LDPE	Kraft	LDPE	Kraft	LDPE	Kraft	LDPE	Kraft
Car courier (500 kg)	Transport, van <3.5t/RER U	0.00267	0.00281	0.00004	0.00019	0.00267	0.00281	0.00263	0.00263
Cargo van (1000 kg)	Transport, van <3.5t/RER U	0.02003	0.02111	0.00031	0.00139	0.02003	0.02111	0.01972	0.01972
Cube van (2500 kg)	Transport, van <3.5t/RER U	0.01223	0.01289	0.00019	0.00085	0.01223	0.01289	0.01204	0.01204
Step van (2500 kg)	Transport, van <3.5t/RER U	0.08015	0.0845	0.00122	0.00557	0.08015	0.0845	0.07893	0.07893
Straight truck (5000 kg)	Transport, lorry 3.5-7.5t, EURO3/RER U	0.01917	0.02021	0.00029	0.00133	0.01917	0.02021	0.01887	0.01887
53' Transport truck (30,000 kg)	Transport, lorry 16-32t, EURO3/RER U	0.38404	0.40490	0.00585	0.02671	----	----	0.37819	0.37819
Freight airplane, long haul	Transport, aircraft, freight/RER U	----	----	----	----	0.38404	0.40490	----	-----

3.2.7 Downstream Processes

According to the telephone conversation with Purolator, none of the LDPE PuroPaks could be recycled in Canada. For this study it is assumed that 100% of the LDPE bubble mailers were landfilled. In comparison, Kraft paper and newsprint filled padded mailers could be recycled, landfilled or composted based on the majority of its components, except the polypropylene strip and the wax adhesive cover. Both the LDPE bubble mailer and Kraft padded mailer disposal were based on the ecoinvent unit process for packaging waste to account for the available disposal options for packaging component materials (51.6% recycled, 48.4% landfilled according to the 100% Waste Scenario for Packaging in USA) as Canadian data was not available. Transportation was not included for this process as it is assumed to be minimal based on local commercial and residential waste management pick-up programs in Canada.

3.3 Comparative LCIA Results – Base Scenario

Based on the assessment of the impact categories, the LDPE bubble mailer had lower environmental impacts compared to the Kraft paper and newsprint filled padded mailer in every category except for acidification and respiratory effects (Figure 9). The carcinogenics, non-carcinogenics and ecotoxicity impact categories had the largest difference between the LDPE bubble mailer and the Kraft padded mailer, driven by the downstream portion of the life cycle (Figure 10). For both mailers the impact categories and the largest chemical contributors were as follows: global warming impact category was carbon dioxide, acidification impact category was nitrogen oxides and sulfur dioxide, carcinogenics impact category was arsenic and lead, non-carcinogenics impact category was lead, respiratory effects category was particulates (less than 2.5 micrometers) and sulfur dioxide, eutrophication impact category was phosphate, ozone depletion was methane, bromotrifluoro-, halon 1301, ecotoxicity impact category was aluminum and copper ion, and finally the smog impact category was nitrogen oxides (Table 15). Lead was thirteen times higher in the Kraft mailer downstream disposal processes, resulting in high carcinogenic, non-carcinogenic and ecotoxicity impacts (Table 15). The *use stage* had the largest impact for the remaining six impact categories (Figure 9). Overall this comparison proves that the *use stage* (transportation) is a major component of the product life cycle and must be considered in future designs.

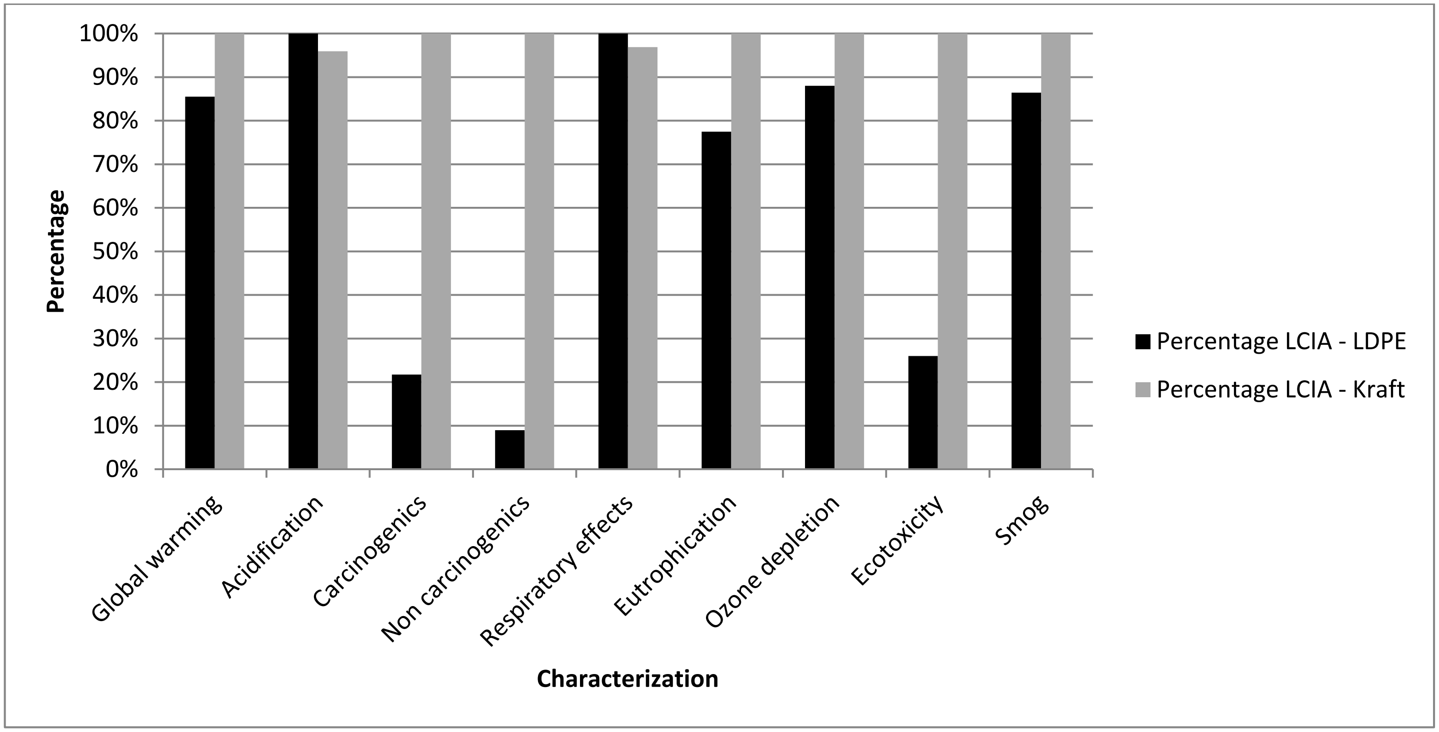

Figure 9: LCIA for Bubble Mailer versus Padded Mailer – Base Analysis (1 kg Parcel Weight; Maximum Capacity)

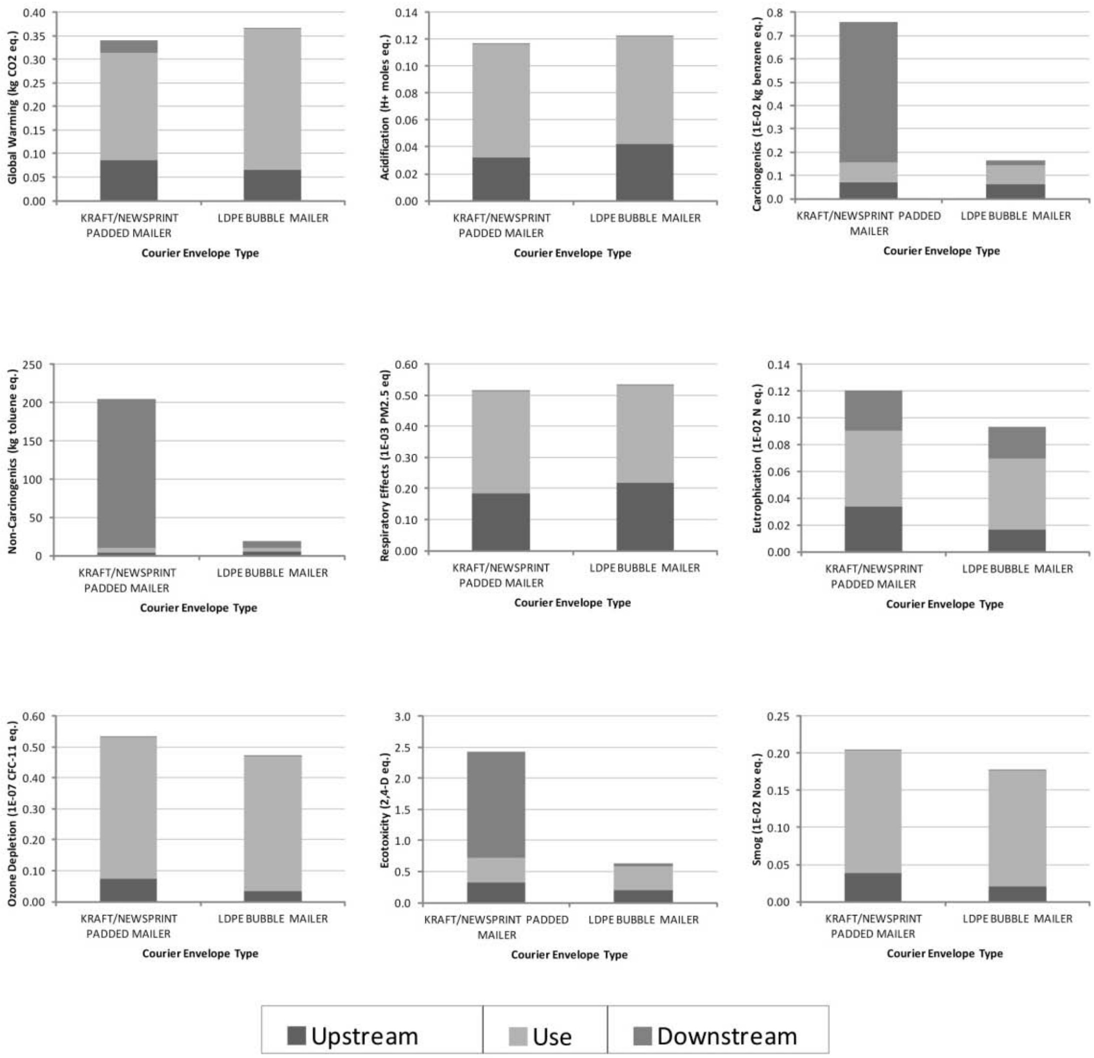

Figure 10: Impact Categories Characterized by Upstream, Use and Downstream Processes – Base Analysis

Table 15: Substance Inventory Analysis – Base Analysis (summary of impact results for largest contributor in each characterization category, for each product, measured using standardized metrics)

Substance (largest contributor for each mailer per impact category)	**Compartment**	**KRAFT Mailer**			**LDPE Mailer**		
		Life Cycle	% of Total	Major Contributing Phase	Life Cycle	% of Total	Major Contributing Phase
Global Warming (kg CO2 eq)							
Total		4.29E-01	100%		3.67E-01	100%	
Carbon dioxide, fossil	Air	3.84E-01	90%	Use	3.41E-01	93%	Use
Acidification (H+ moles eq)							
Total		1.17E-01	100%		1.22E-01	100%	
Nitrogen oxides	Air	7.78E-02	67%	Use	6.65E-02	55%	Use
Sulfur dioxide	Air	3.30E-02	28%	Upstream	4.91E-02	40%	Upstream
Carcinogenics (kg benzene eq)							
Total		7.57E-03	100%		1.64E-03	100%	
Arsenic	Air	7.41E-04	10%	Upstream	6.68E-04	41%	Downstream
Lead	Water	6.22E-03	82%	Downstream	4.66E-04	28%	Downstream
Non-Carcinogenics (kg toluene eq)							
Total		2.04E+02	100%		1.83E+01	100%	
Lead	Water	2.01E+02	98%	Downstream	1.51E+01	82%	Downstream

Substance (largest contributor for each mailer per impact category)	**Compartment**	**KRAFT Mailer**			**LDPE Mailer**		
		Life Cycle	% of Total	Major Contributing Phase	Life Cycle	% of Total	Major Contributing Phase
Respiratory Effects (kg PM2.5 eq)							
Total		5.17E-04			5.33E-04		
Particulates, < 2.5 um	Air	1.87E-04	36%	Use/Upstream	1.52E-04	29%	Use/Upstream
Sulfur dioxide	Air	1.56E-04	30%	Upstream	2.33E-04	44%	Upstream
Eutrophication (kg N eq)							
Total		1.20E-03			9.32E-04		
Phosphate	Water	6.62E-04	55%	Downstream	5.08E-04	54%	Downstream
Ozone Depletion (kg CFC-11 eq)							
Total		5.35E-08			4.71E-08		
Methane, bromotrifluoro-, Halon 1301	Air	4.82E-08	90%	Use	4.28E-08	91%	Use
Ecotoxicity (kg 2,4-D eq)							
Total		2.42E+00			6.30E-01		
Aluminium	Water	1.51E+00	62%	Downstream	3.17E-01	50%	Upstream
Copper, ion	Water	5.58E-01	23%	Downstream/ Upstream	6.06E-02	10%	Upstream
Smog (g NOx eq)							
Total		2.05E-03			1.77E-03		
Nitrogen oxides	Air	1.94E-03	95%	Use	1.66E-03	94%	Use

3.4 Sensitivity Analyses

ISO has recommended that LCA model results have a sensitivity analysis conducted when contributing to decision-making (International Organization for Standardization, 2006a). Conducting sensitivity analyses allows decision makers to understand the risks and conditions associated with the given results, which can increase its application (Mattila et al., 2011). Three sensitivity analyses were conducted in this study to address transportation assumptions in the *use stage*. *Sensitivity Analysis A* tested the effect of the assumed weight of the parcel contents in the *use stage* by assessing mailers with no parcel contents (0 kg). This change in weight mainly affected tonne·kilometers (Table 17). *Sensitivity Analysis B* modeled air freight transport instead of long-haul shipping using tractor-trailers during the *use stage*. *Sensitivity Analysis C* focused on the materials used in the study by normalizing both products as per kilogram of mailer.

3.4.1 Sensitivity Analysis A: Change of Parcel Weight – Empty Mailers

The results for *Sensitivity Analysis A* were similar to the base analysis. The LDPE bubble mailer had lower environmental impacts compared to the Kraft paper and newsprint filled padded mailer in every impact category except for acidification and respiratory effects (Figure 11). As the proportional difference in mailer weight is larger between the two packages when empty (empty = 4.56:1 vs. full = 1.05:1), the proportional differences in impact category were also greater (Figure 11). Although the total impact was reduced when the parcel contents were removed, the relative difference between the LDPE bubble mailer and the Kraft padded mailer increased. The reduction in parcel weight during the *use stage* resulted in the upstream and downstream stages dominating the impact categories (Figure 12).

The carcinogenics, non-carcinogenics and ecotoxicity impact categories had the largest difference between the LDPE bubble mailer and the Kraft padded mailer, and were continued to be driven by the downstream portion of the life cycle (Figure 11). For *Sensitivity Analysis A* the largest contributors in the impact categories for both mailers were the same except for the non-carcinogenics as lead became the largest contributor for both mailers (Table 16). Lead was nearly eighteen times higher for the padded mailer compared to the bubble mailer, which resulted in high carcinogenic, non-carcinogenic and ecotoxicity impacts (Table 16). The *upstream stage* continued to be the largest impact for the remaining six impact categories (Figure 12).

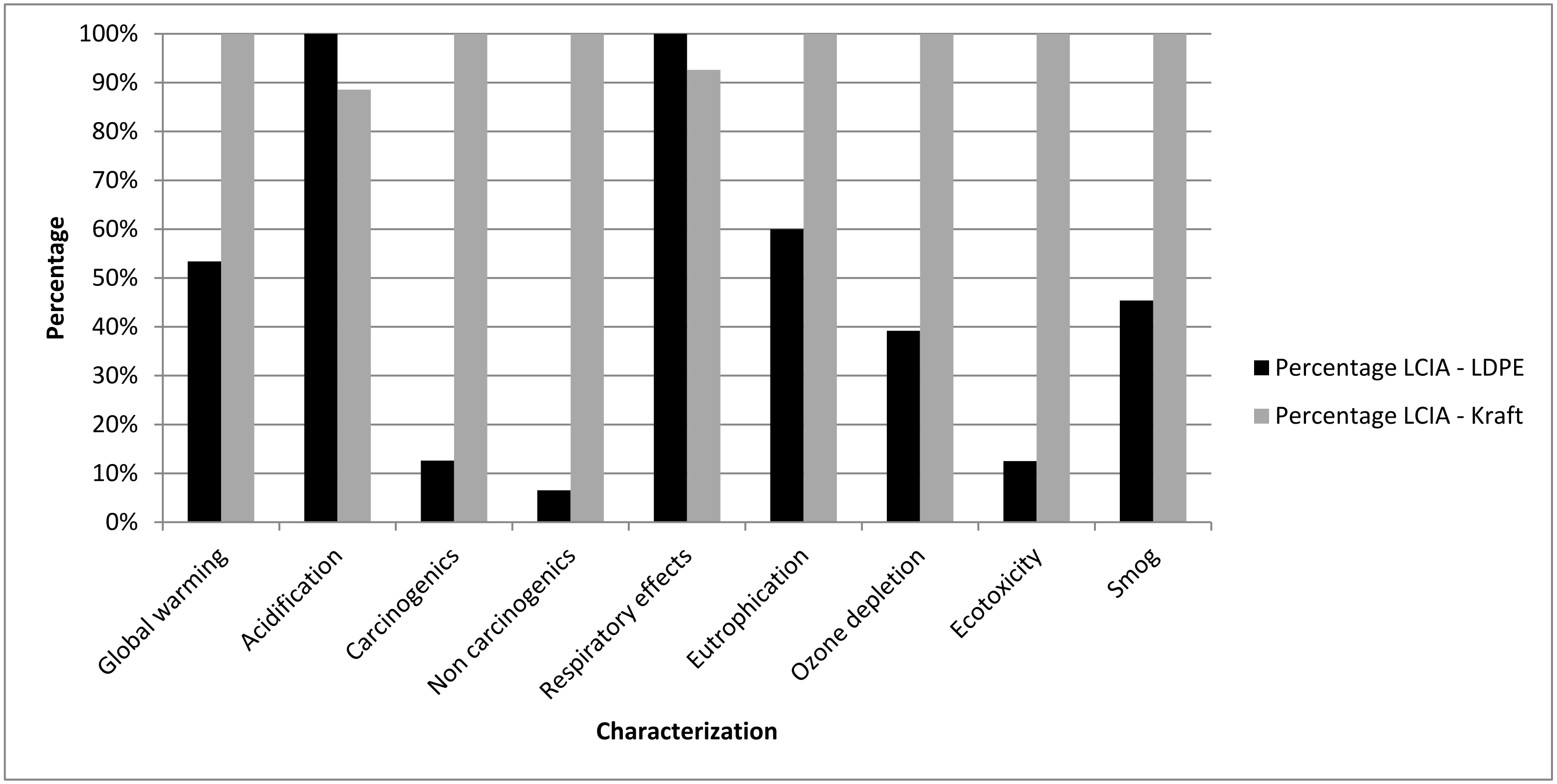

Figure 11: LCIA Results for LDPE Bubble Mailer versus Kraft Paper and Newsprint Filled Padded Mailer; Parcel Weight = 0 kg. (Sensitivity Analysis A)

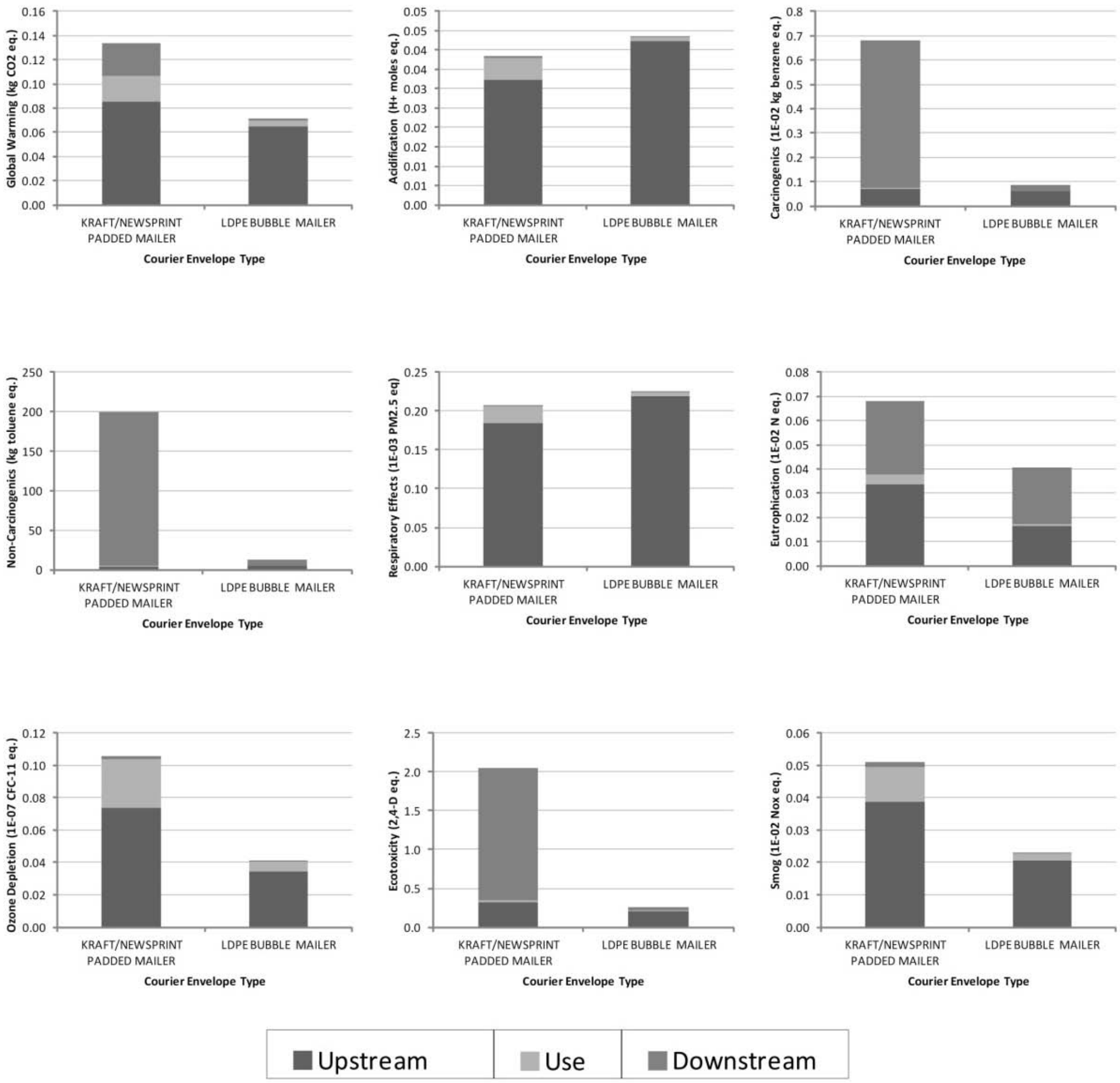

Figure 12: Characterization Phases – Empty Mailers (Sensitivity Analysis A)

Table 16: Substance Inventory Analysis - Empty Mailers (Sensitivity Analysis A) (summary of impact results for largest contributor in each characterization category, for each product, measured using standardized metrics)

Substance (largest contributor for each mailer per impact category)	**Compartment**	**KRAFT Mailer**		**LDPE Mailer**	
		Life Cycle	**% of Total**	**Life Cycle**	**% of Total**
Global Warming (kg CO2 eq)					
Total		1.34E-01	100%	7.13E-02	100%
Carbon dioxide, fossil	Air	1.04E-01	78%	6.00E-02	84%
Acidification (H+ moles eq)					
Total		3.85E-02	100%	4.35E-02	100%
Nitrogen oxides	Air	1.95E-02	51%	8.19E-03	19%
Sulfur dioxide	Air	1.36E-02	35%	2.97E-02	68%
Carcinogenics (kg benzene eq)					
Total		6.78E-03	100%	8.56E-04	100%
Lead	Water	6.10E-03	90%	3.42E-04	40%
Non-Carcinogenics (kg toluene eq)					
Total		1.99E+02	100%	1.30E+01	100%
Lead	Water	1.97E+02	99%	1.11E+01	85%
Respiratory Effects (kg PM2.5 eq)					
Total		2.08E-04	100%	2.25E-04	100%
Particulates, < 2.5 um	Air	7.70E-05	37%	4.23E-05	19%
Sulfur dioxide	Air	6.46E-05	31%	1.41E-04	63%

Substance (largest contributor for each mailer per impact category)	**Compartment**	**KRAFT Mailer**		**LDPE Mailer**	
		Life Cycle	**% of Total**	**Life Cycle**	**% of Total**
Eutrophication (kg N eq)					
Total		6.78E-04	100%	4.07E-04	100%
COD, Chemical Oxygen Demand	Water	1.94E-04	29%	1.97E-04	48%
Phosphate	Water	2.88E-04	42%	1.34E-04	33%
Ozone Depletion (kg CFC-11 eq)					
Total		1.06E-08	100%	4.14E-09	100%
Methane, bromotrifluoro-, Halon 1301	Air	7.59E-09	72%	2.26E-09	54%
Ecotoxicity (kg 2,4-D eq)					
Total		2.05+00	100%	2.56E-01	100%
Aluminium	Water	1.32E+00	65%	1.31E-01	51%
Copper, ion	Water	5.28E-01	26%	3.10E-02	12%
Smog (g NOx eq)					
Total		5.09E-04	100%	2.31E-04	100%
Nitrogen oxides	Air	4.88E-04	96%	2.05E-04	89%

3.4.2 Sensitivity Analysis B: Change of Method of Transportation - Long-Haul Distance

Sensitivity Analysis B changed transportation methods from long-haul tractor trailer to air freight, as postal services use air transport for premium overnight service. The LDPE bubble mailer had lower environmental impacts compared to the Kraft paper and newsprint filled padded mailer in every category, similar to the base analysis, except for the marginal differences in acidification and respiratory effects impact categories (Figure 13). Similar to the base analysis, the carcinogenics, non-carcinogenics and ecotoxicity impact categories had the largest difference between the bubble mailer and the padded mailer, driven by the downstream portion of the life cycle (Figure 14). For both mailers the largest contributors in the impact categories were the same as the base analysis except for the respiratory effects category was mainly sulfur dioxide without particulates, ecotoxicity impact category was mainly aluminum without copper ion (Table 17). The CO_2 equivalents in the global warming impact were twice as high using air transportation instead of ground transportation. Carbon dioxide was the major contributor at 94% of impacts for the padded mailer and 96% for the bubble mailer (Table 17). Similar to the base analysis, the *use stage* had the largest impact for the remaining six impact categories (Figure 14). Overall this sensitivity analysis continued to prove that the *use stage*, either air or ground transportation, was a major component of the product life cycle and must be considered in future designs.

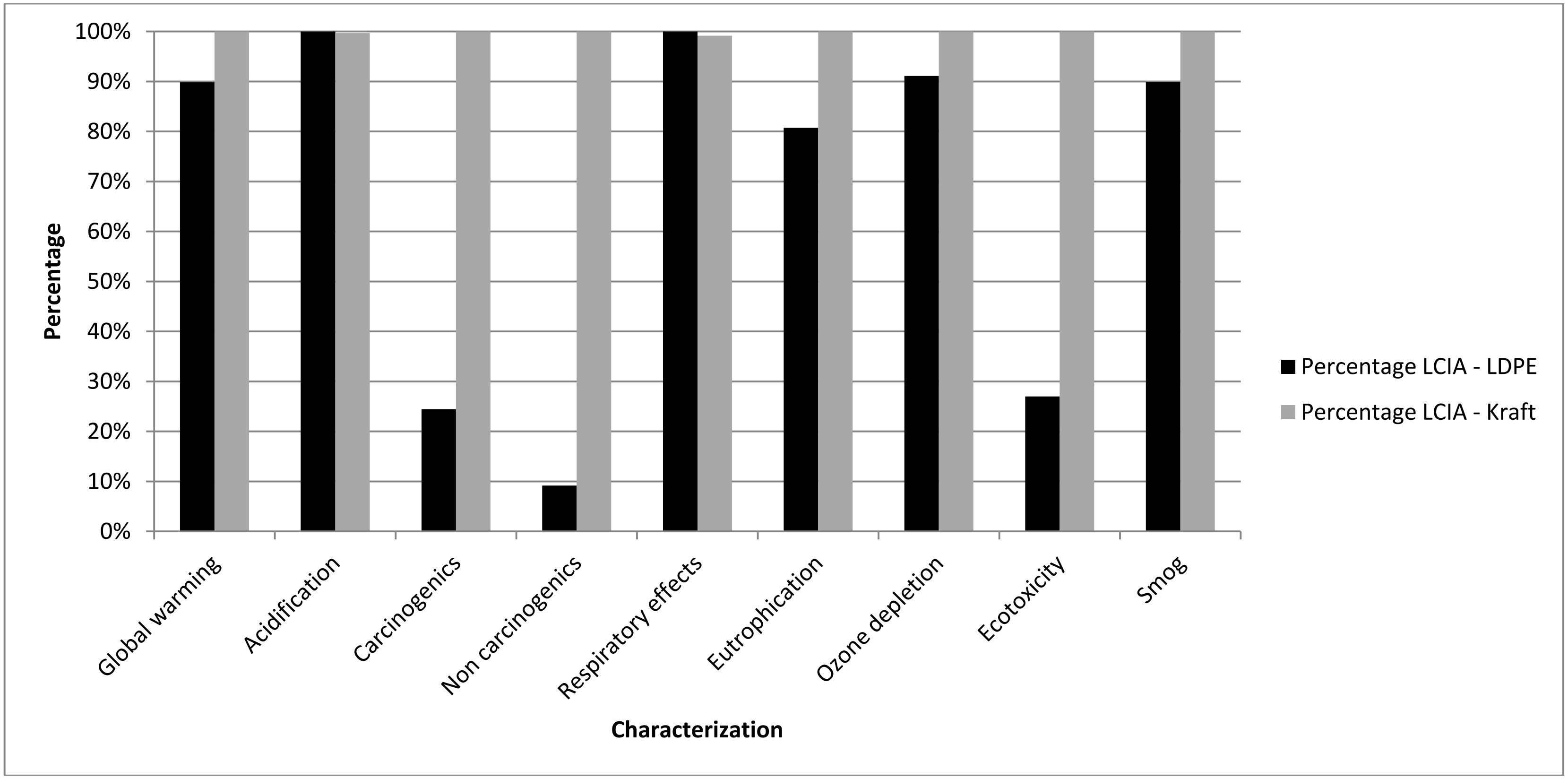

Figure 13: LCIA of Bubble Mailer versus Padded Mailer – Air Freight for Long Haul Transportation Instead of Tractor-Trailer (Sensitivity Analysis B)

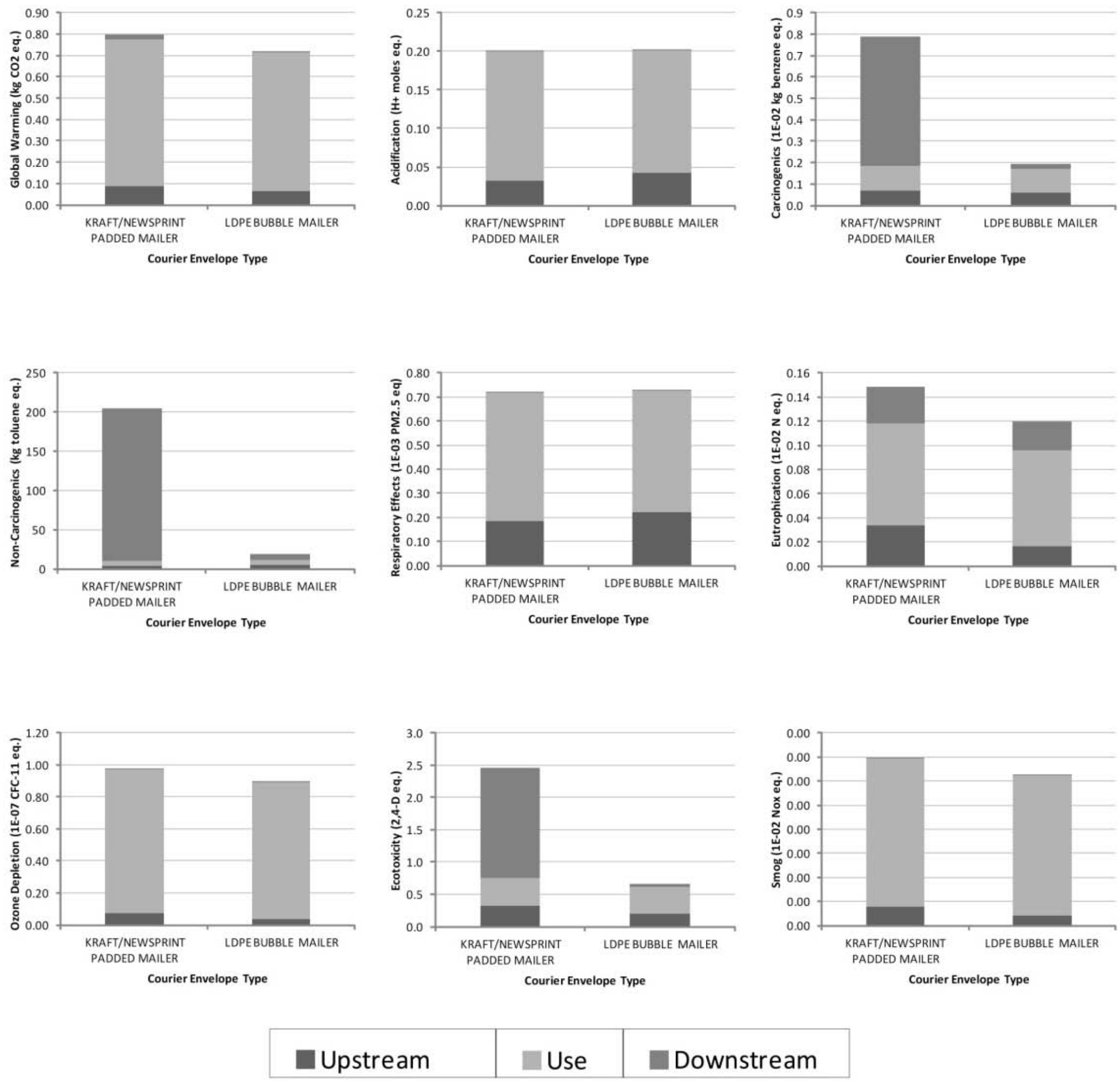

Figure 14: Characterization Phases – Air Freight for Long Haul Transportation Instead of Tractor-Trailer (Sensitivity Analysis B)

Table 17: Substance Inventory Analysis – Air Freight for Long Haul Transportation Instead of Tractor-Trailer (Sensitivity Analysis B) (summary of impact results for largest contributor in each characterization category, for each product, measured using standardized metrics)

Substance (largest contributor for each mailer per impact category)	**Compartment**	**KRAFT Mailer**		**LDPE Mailer**	
		Life Cycle	**% of Total**	**Life Cycle**	**% of Total**
Global Warming (kg CO2 eq)					
Total		8.00E-01	100%	7.18E-01	100%
Carbon dioxide, fossil	Air	7.50E-01	94%	6.88E-01	96%
Acidification (H+ moles eq)					
Total		2.01E-01	100%	2.01E-01	100%
Nitrogen oxides	Air	1.33E-01	66%	1.18E-01	59%
Carcinogenics (kg benzene eq)					
Total		7.87E-03	100%	1.92E-03	100%
Arsenic	Air	7.58E-04	10%	6.84E-04	36%
Lead	Water	6.23E-03	79%	4.80E-04	25%
Non-Carcinogenics (kg toluene eq)					
Total		2.05E+02	100%	1.88E+01	100%
Lead	Water	2.01E+02	98%	1.55E+01	83%
Respiratory Effects (kg PM2.5 eq)					
Total		7.20E-04	100%	7.26E-04	100%
Sulfur dioxide	Air	2.93E-04	41%	3.63E-04	50%

Substance (largest contributor for each mailer per impact category)	**Compartment**	**KRAFT Mailer**		**LDPE Mailer**	
		Life Cycle	**% of Total**	**Life Cycle**	**% of Total**
Eutrophication (kg N eq)					
Total		1.48E-03	100%	1.20E-03	100%
Phosphate	Water	7.09E-04	48%	5.53E-04	46%
Ozone Depletion (kg CFC-11 eq)					
Total		9.76E-08		8.89E-08	
Methane, bromotrifluoro-, Halon 1301	Air	9.16E-08	94%	8.40E-08	95%
Ecotoxicity (kg 2,4-D eq)					
Total		2.46E+00		6.65E-01	
Aluminum	Water	1.54E+00	62%	3.42E-01	51%
Smog (g NOx eq)					
Total		3.47E-03		3.12E-03	
Nitrogen oxides	Air	3.31E-03	95%	2.96E-03	95%

3.4.3 Sensitivity Analysis C: Normalization of Materials – Per Kilogram of Mailer

Sensitivity Analysis C normalized the materials used by analyzing per kilogram of mailer. Based on the assessment of the impact categories, the results are largely opposite of the base analysis. Similar to the base analysis, the Kraft paper and newsprint filled padded mailer had higher environmental impacts for carcinogenics, non-carcinogenics and ecotoxicity (Figure 15). However, in all other categorizations, the impacts were reversed. LDPE bubble mailer had higher environmental impacts for global warming, acidification, respiratory effects, ozone depletion, eutrophication and smog (Figure 15). In contrast to the base analysis, the *upstream stage* for both mailers had the greatest environmental impact among stages (Figure 16). The largest contributors in the impact categories were similar to the base analysis except for the carcinogenics impact category was primarily lead, without arsenic, and eutrophication impact category also had chemical oxygen demand in addition to phosphate as the largest contributors (Table 18). Lead was fourteen times higher for the Kraft padded mailer in Sensitivity Analysis C. The global warming category was four times higher for the base analysis of the Kraft padded mailer compared to Sensitivity Analysis C. This sensitivity analysis suggests that on a kilogram per mailer basis, the Kraft mailer has a smaller environmental impact compared to the LDPE bubble mailer (Figure 15, Figure 16, Table 18). Overall this analysis demonstrates that production processes and weight of materials must be considered in future designs.

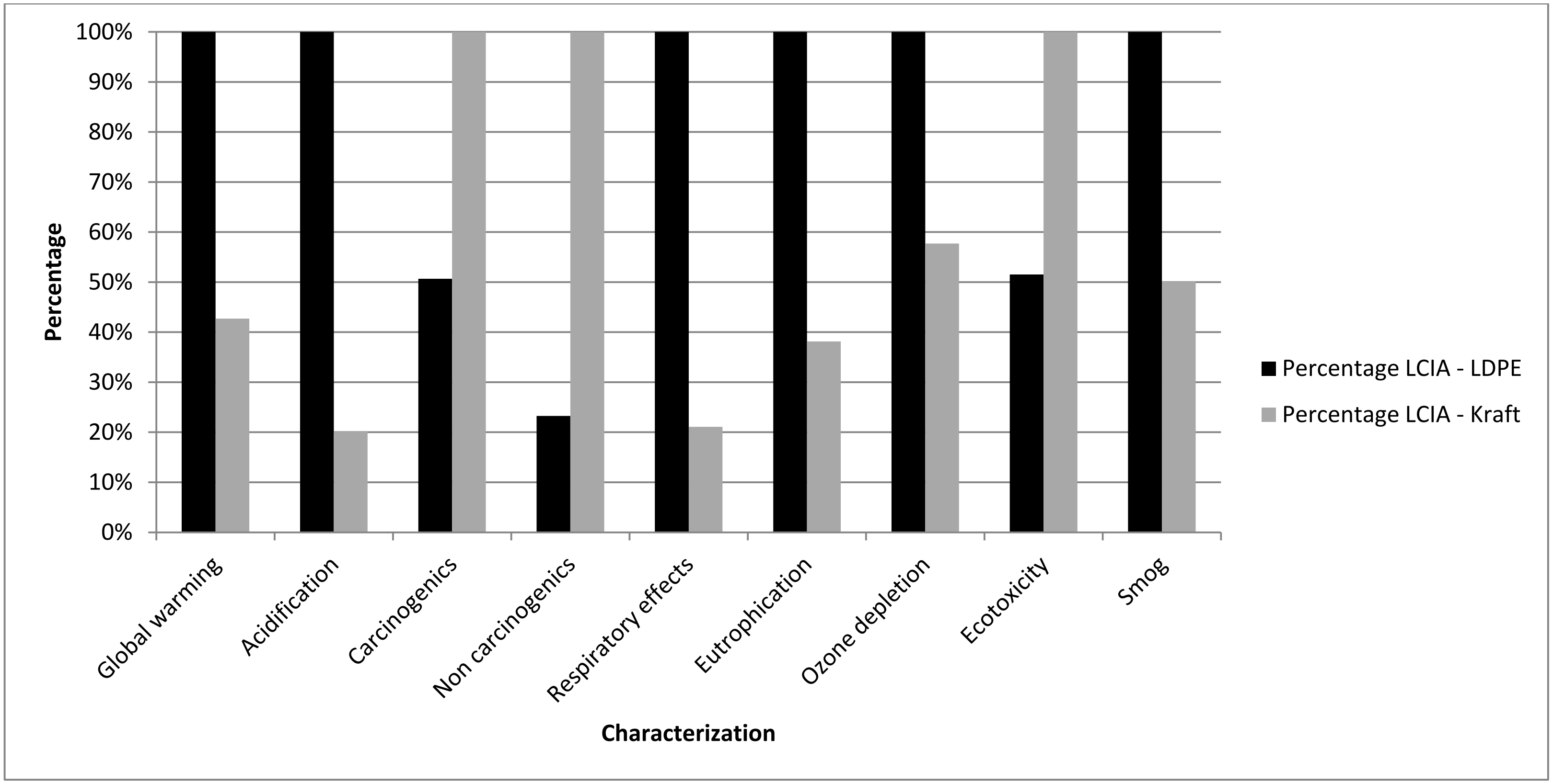

Figure 15: LCIA Results – Normalized Weight (Sensitivity Analysis C)

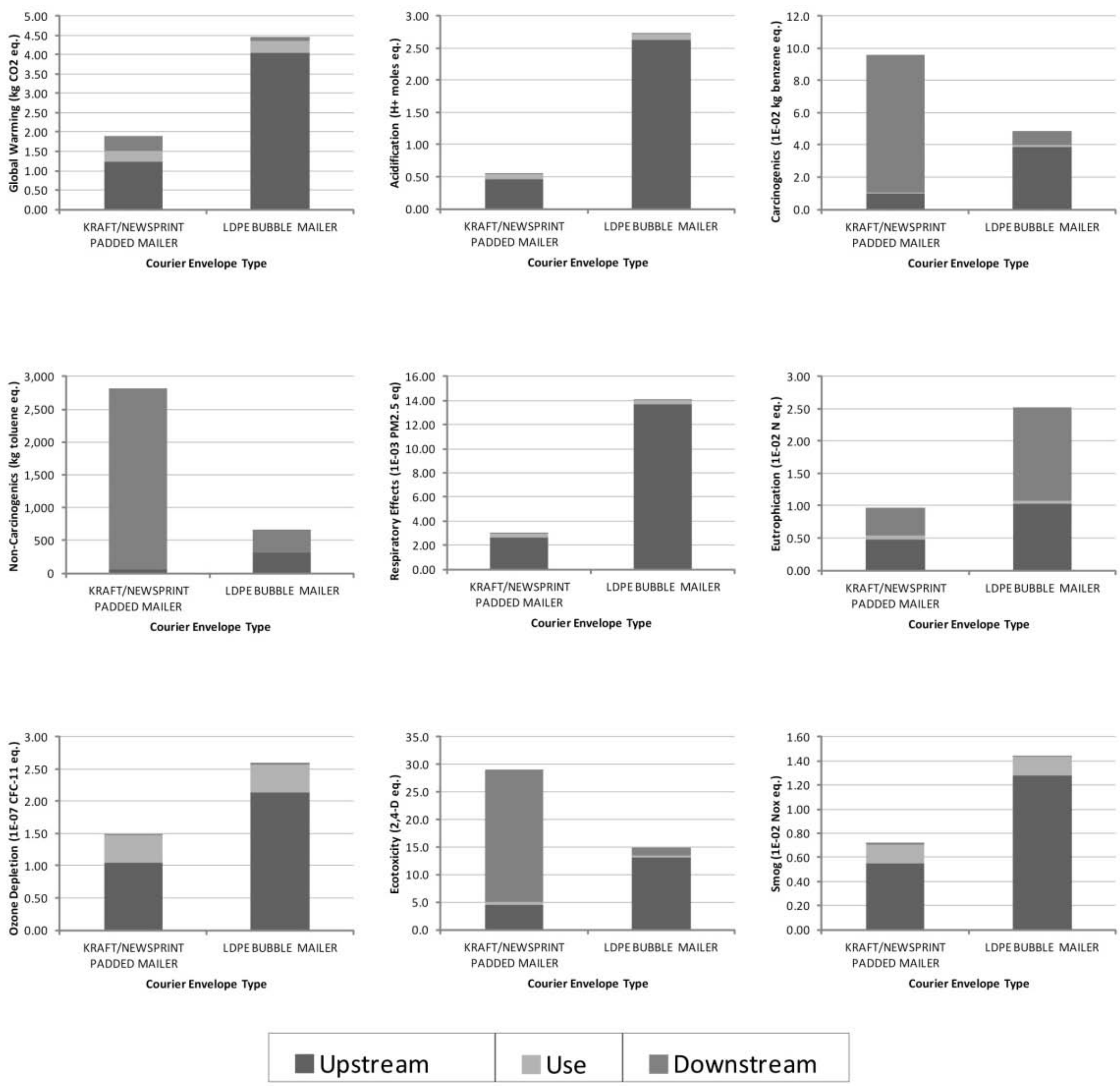

Figure 16: Characterization Phases – Normalized Weight (Sensitivity Analysis C)

Table 18: Substance Inventory Analysis – Normalized Weight (Sensitivity Analysis C) (summary of impact results for largest contributor in each characterization category, for each product, measured using standardized metrics)

Substance (largest contributor for each mailer per impact category)	**Compartment**	**KRAFT Mailer**		**LDPE Mailer**	
		Life Cycle	**% of Total**	**Life Cycle**	**% of Total**
Global Warming (kg CO2 eq)					
Total		1.90E+00	100%	4.45E+00	100%
Carbon dioxide, fossil	Air	1.48E+00	78%	3.76E+00	84%
Acidification (H+ moles eq)					
Total		5.50E-01	100%	2.72E+00	100%
Nitrogen oxides	Air	2.78E-01	50%	5.12E-01	19%
Sulfur dioxide	Air	1.96E-01	36%	1.86E+00	68%
Carcinogenics (kg benzene eq)					
Total		9.60E-02	100%	4.86E-02	100%
Lead	Water	8.62E-02	90%	1.65E-02	34%
Non-Carcinogenics (kg toluene eq)					
Total		2.82E+03	100%	6.56E+02	100%
Lead	Water	2.79E+03	99%	5.33E+02	81%
Respiratory Effects (kg PM2.5 eq)					
Total		2.96E-03	100%	1.40E-02	100%
Particulates, < 2.5 um	Air	1.09E-03	37%	2.65E-03	19%
Sulfur dioxide	Air	9.30E-04	31%	8.81E-03	63%

Substance (largest contributor for each mailer per impact category)	Compartment	KRAFT Mailer		LDPE Mailer	
		Life Cycle	% of Total	Life Cycle	% of Total
Eutrophication (kg N eq)					
Total		9.64E-03	100%	2.53E-02	100%
COD, Chemical Oxygen Demand	Water	2.78E-03	29%	1.22E-02	48%
Phosphate	Water	4.08E-03	42%	8.39E-03	33%
Ozone Depletion (kg CFC-11 eq)					
Total		1.50E-07	100%	2.60E-07	100%
Methane, bromotrifluoro-, Halon 1301	Air	1.08E-07	72%	1.42E-07	55%
Ecotoxicity (kg 2,4-D eq)					
Total		2.90E+01	100%	1.50E+01	100%
Aluminum	Water	1.87E+01	65%	7.53E+00	50%
Copper, ion	Water	7.47E+00	26%	1.55E+00	10%
Smog (g NOx eq)					
Total		7.23E-03	100%	1.44E-02	100%
Nitrogen oxides	Air	6.93E-03	96%	1.28E-02	89%

CHAPTER 4: DISCUSSION & CONCLUSION

4.1 Comparative Life Cycle Assessment Results

The primary goal of this study was to compare the environmental impacts for the life cycles of two generic protective mailers used for mailing parcels in Canada, including a (1) low-density polyethylene and inflated cushioning bubble mailer and a (2) Kraft paper and shredded newsprint padded mailer. The comparative LCA quantified the environmental impacts of the products by examining the inputs and outputs of each stage. The comparative LCA used in this study compared the impact of two protective mailers segmented into three product life cycle stages. The base analysis, which included the mailer filled to capacity (1 kg), indicated that the *use stage* (transportation) was a major component of the product life cycle. Additionally, when the long haul transportation was changed to air freight (*Sensitivity Analysis B*), the *use stage* was again the major contributor to the impact of both mailers. However, when the mailers had no parcel contents (*Sensitivity Analysis A*), and when the weight of the mailers was normalized (*Sensitivity Analysis C*), the *upstream stage* had the highest impact for six out of nine impact categories. Results suggest that the *upstream* and *use stages* were the significant contributors to the overall environmental impact for both protective mailers.

In the base scenario, the LCA suggested that the Kraft padded mailer had a higher overall environmental impact compared to the LDPE bubble mailer. In particular, the Kraft padded mailer had higher impacts in the carcinogenic, non-carcinogenic and ecotoxicity categories. The *downstream stage* dominated these categories, and lead was the major chemical contributor. Kraft paper is known to have higher lead content than other paper sources (Castle et al., 1997), although the specific origin is unknown. Heavy metals such as lead can be difficult to manage. Once Kraft paper is disposed of in a landfill, lead can become mobile with paper degradation and leach, as it does with electronic waste (Jang and Townsend, 2003). Additionally, Kraft pulp and paper mill effluent is known to have high levels of heavy metals (Reyes et al., 2009), some of which can be difficult to remove with traditional wastewater treatment (Achoka, 2002).

The *use stage* was the primary contributor to the impact categories of global warming, acidification, respiratory effects, eutrophication, ozone depletion and smog in the base scenario. Given that Canada is the second largest country in the world by total land area, distances between major cities can be considerably larger than in other developed countries. For Canadian postal and courier companies, the mass of the overall package makes a significant difference to its overall environmental impact. Comparing the base scenario (1 kg parcel) with the *Sensitivity Analysis A* (no parcel) revealed that the *use stage* was highly dependent on the mass of the mailer. For example, the global warming impact was 3-5 times higher when the mailer was full versus empty. In addition, smog and ozone depletion were 4-5 times higher when the mailer was full versus empty.

The *use stage* was also sensitive to changes in the transportation type for long-haul shipments. When the long-haul transportation was changed from transport truck to airplane (*Sensitivity Analysis B*), the magnitude of the impact of global warming, acidification and ozone depletion each doubled. Global warming has been shown to be about thirty times more sensitive to aircraft emission as compared to ground emissions (Johnson et al., 1992). Additionally, aircraft can also emit black carbon soot directly into the lower stratosphere, which can react with ozone resulting in its depletion (Bekki, 1997).

When the weight of the mailers was normalized (*Sensitivity Analysis C*), the LCA results suggested that the LDPE bubble mailer had a higher overall environmental impact compared to the Kraft padded mailer. Global warming, acidification, respiratory effects and smog impacts were between two to six times higher for the LDPE bubble mailer in the *upstream stage*. These normalized results suggest that on a per unit basis, the materials extracted for the LDPE bubble mailer have a higher environmental impact. The process of extracting crude oil to make plastic compounds used in the bubble mailer is an energy intensive process known to have detrimental environmental impacts (Kelly et al, 2009).

4.2 Design Recommendations

The second goal of this research was to propose recommendations to reduce environmental impact of the protective mailers used in Canada. The comparative LCA results indicate two areas for product improvement for future designs of courier packaging in the Canadian postal industry: 1) weight of component materials and 2) source of materials. Designing lighter courier packaging, or *lightweighting*, could be achieved by using less material, or substituting with a lighter material, as long as the new material does not have higher environmental impacts in *upstream* or *downstream processes* (Boylston, 2009). Using *rightsized* materials could also minimize weight and volume for sustainable courier packaging (Boylston, 2009). For production processes, rapidly renewable materials, that are locally sourced, could minimize the environmental impact of protective mailers in Canada. An example of an ultra-rapid renewable resource is mycelium, which is a natural self-assembling organism that feeds on regional agricultural waste and can be grown into a cast shape in one week (Ecovative Design, 2013). Based on the results of this study, it is recommended that future courier packaging is made lighter, to parcel size, sourced locally, and with renewable materials that require minimal upstream resources and processes.

This study showed that design decisions influence every stage of a product's life cycle. This study also showed that system thinking, or environmental design thinking, is required to design environmentally-friendly courier and postal packaging. As listed above, there are numerous ways to provide innovation to the courier and postal packaging industry based on these principles. In the end, what is best for nature`s web of systems, is best for us all.

4.3 Assumptions and Limitations

Based on the results of this study, the system boundaries were well selected as the boundaries were not too simple to explore consistent results, nor too complicated to be used practically (Hondo et al., 2007). The bias for this LCA, as for all LCA's, was based on the viewpoint of the practitioner. The assumptions were subjective and influenced the overall outcome of the study. Significance levels of uncertainty could not be determined for this study. This study was intended to be of sufficient detail and quality to inform the public of the comparative impacts of a Kraft padded mailer and a LDPE bubble mailer. This study is only a start and will require more data and information as it becomes available.

Future studies may benefit from the cooperation of primary industry data provided from packaging manufacturers to confirm or deny the assumptions and measurements calculated in this study. Limitations of this study are apparent as generic data from life cycle inventory databases were modified with primary research data. Generic data requires many assumptions and is not as accurate as primary data from manufacturer`s processes. Primary data collection was the biggest challenge for this study. Courier companies, postal organizations and packaging companies would not provide information or confirm any production or environmental impact data.

The next application for this study requires an industrial design perspective and a market feasibility study. An industrial designer is required to determine the type of materials that could meet the design criteria and design a prototype. Future research could determine whether the packaging criterion results in this study can produce an attractive, cost-effective form that still provides the same functionality as a padded mailer or bubble mailer. Bridging the gap between short-term economic benefits and long-term environmental impact lies within design thinking, and a holistic approach is required.

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APPENDIX A: PUROLATOR CORRESPONDENCE

Initial Email to Purolator

Subject:	Purolator Express Envelope: Life Cycle Assessment
From:	"Kathleen Pilfold" <kmpilfol@ucalgary.ca>
Date:	Tue, May 18, 2010 12:51 pm

Dear <Name>:

My name is Kathleen Pilfold and I am a graduate student from the University of Calgary in the faculty of Environmental Design. I am doing research on courier packaging and I am interested in using Purolator as my focus for my research. I was wondering if I could speak with you if this would be a viable opportunity.

I am interested in using the Purolator Express™ Envelope as the focus of my study and to carry out a quantitative analysis of a Life Cycle Assessment which examines the inputs and outputs of this system based on ISO 14040, determining the characterization of greenhouse gases, resource depletion and energy consumption. I am looking to compare this analysis with a simulated closed-loop system of re-tripper packaging.

I would also interested in conducting a social science portion of research that will carrying out questionnaires of Purolator employees and clients to determine the values and perceptions towards change for Purolator's Express™ Envelope packaging.

I decided on this project from using this product as a client in the past and would greatly appreciate your feedback on Purolator's interest to be a part of such research.

Kind regards,

Kathleen Pilfold

Master of Environmental Design Candidate
Faculty of Environmental Design
University of Calgary

Follow up Emails

From:	Kathleen Pilfold <kmpilfol@ucalgary.ca>
To:	Director, Environment, Health and Safety
Date:	Tue, May 18, 2010 12:51 pm
Subject:	Purolator Express Envelope: Life Cycle Assessment

Dear <Name>:

I am emailing to follow-up with the voicemail that I left last Tuesday. I am a master's student from the University of Calgary in the Faculty of Environmental Design. I am proposing to conduct research on courier packaging using a Life Cycle Assessment methodology. As Purolator has a proud tradition of promoting environmental innovations under the context of the ISO 9001:2000 standard, I am inquiring about Purolator's interest in this research.

I am proposing a Life Cycle Assessment of the Purolator Express™ Envelope. As approximately 80 million Express™ Envelopes are used annually, a small improvement in the core packaging system could produce a large environmental benefit. This quantitative analysis would examine the inputs and outputs of the product with the final goal of reducing environmental impacts while minimizing cost and maximizing efficiency. As this may be a beneficial study for Purolator, in line with the ISO 9001:2000 standards, I am eager to speak with you about this opportunity.

If you are available for a brief 15 minute phone call please let me know when it would be a good time to speak with you.

Kind regards,

Kathleen Pilfold, B.Comm

Master of Environmental Design Candidate
Faculty of Environmental Design
University of Calgary

From:	Kathleen Pilfold <kmpilfol@ucalgary.ca>
To:	Director, Environment, Health and Safety
Date:	Tue, May 18, 2010 2:20 pm
Subject:	RE: Purolator Express Envelope: Life Cycle Assessment

Hi Kathleen

I would be interested in talking to you about this. Please call me next Tuesday in the morning to discuss.

<Name>
Director, Environment, Health and Safety
Purolator Courier Ltd.
5995 Avebury Road
Mississauga, Ontario
L5R 3T8

Questions for Purolator

1. How many employees at Purolator are there currently working on environmental standards?
2. What method does Purolator use for environmental assessments?
3. Has there been an analysis on how much “waste” is created in Purolator’s current packaging system, in looking at pollution prevention (this word used in one of the presentations I found online), specifically with Purolator Express™ Envelopes?
4. For example, the amount of greenhouse gases emitted, resource depletion, or how much energy is consumed throughout the entire system?
5. Does Purolator manufacture its own packaging? If not, who manufactures it for Purolator?
6. How does Purolator choose a packaging manufacturer?
7. What are the criteria for designing this packaging?
8. Is it the packaging manufacturer or Purolator that determines this criteria or a combination of both?
9. Has there been a previous analysis in Purolator on a “re-tripper” system for shipping documents?
    a. If yes, when? What was included in this analysis and why wasn't it used?
    b. If not, why not?
10. Does each stage of operations get consulted when there is a change to packaging?
11. What were the criteria in the decision making process to provide “free” packaging shipped to regular customers for frequent use?
12. What are the top 5 values from your perspective for getting a package from point A to point B?
13. The research I am proposing focuses on the end-of-life treatment of these packages and I interested in analyzing the greenhouse gases, resource depletion and energy consumption in:
14. Distribution Stage– Transportation to clients
    a. Use
    b. Disposal – Mass of components sent to landfill each year
    c. Recycling process – How much energy does it take to recycle one envelope?
    d. Total emissions for one Purolator Express™ Envelope package
15. Would this information be beneficial to Purolator at this time?

Transcribed Interview

Purolator Courier Ltd. Contacts:	
Director, Environment, Health and Safety	National Manager Environmental Affairs

Phone call: Tuesday, May 25th, 2010

- For this study they are willing to share data on:
    - The number of PuroLetters (Purolator's own letter packaging)and PuroPaks (Purolator's sealable "polybag") produced in each province
    - Corporate communications and advertising
- The "use of more sustainable packaging" is their goal
- The PuroLetter has a baseline of recyclable materials, made with recycled content and Forest Stewardship Council (FSC) certified materials
- Changing the PuroLetter that is made out of cardboard/ boxboard is not an economical change for them because there are so many options for paper recycling in the office or curbside recycling (blue bins)
- However, Puropaks, low density polyethylene has limited options for disposal
- Purolator is looking for a "closed-loop system" – to their definition this means re-using Puropak containers for Purolator Express and Canada Post Express packaging
- They can (and will) provide data by province where these packages are used *(Note: this did not happen)*
- Their vision: institutional users of these packages. Packages will be picked up in a provincial location and he hopes for an agreement with waste management companies and a secondary beneficial use for the mailers. Believed that downcycling the product into a lower grade product was the best option
- I mentioned and explained the definitions of Cradle-to-Cradle and upcycling as defined in the McDonough and Braungart book "Cradle to Cradle: Remaking the Way We Make Things"
- Response: "We don't want a dirty Purolator pack being used at home"
- There was still a misunderstanding
- Puropaks are made of Type 4, low density polyethylene plastic
    - LDPE has a high strength to weight ratio
    - LDPE is good for re-packing in transit and is durable
- **Suppliers came up with the performance criteria for the product and give limited options for disposal by using polyethylene. My contact wants this changed.**
- Purolator agreed to provide the product specifications
- Purolator wants publically available emission factors for the Puropak product
- They think this is a great project
- Asked how they could be of help besides information, a request for a financial stipend was made
- They responded that this could not be done in 2010, but possible for the new fiscal year in January 2011

After this phone call, Purolator ended correspondence for this project without providing data or voicing the reason. I contacted them again in September 2012 while interning with ecoinvent and had no response.

Email Correspondence

From:	Kathleen Pilfold <kmpilfol@ucalgary.ca>
To:	Director, Environment, Health and Safety
Date:	Tue, June 15, 2010 1:09 pm
Subject:	Proposal: LCA of the Purolator Express™ Pack

Hi <Name>,

In follow-up to the conversation with <Name> National Manager, Environmental Affairs, and yourself on May 25th, 2010, please find the attached letter from my supervisor, Dr. Wondimagegnehu, as well as my research proposal for a Life Cycle Assessment of the Purolator Express™ Pack.

Thank you for your interest in this research opportunity. I look forward to answering any questions that you may have about my proposal.

Regards,

Kathleen

Kathleen Pilfold, Bachelor of Commerce,
Master of Environmental Design (Candidate)
Faculty of Environmental Design
University of Calgary

Research Proposal

UNIVERSITY OF CALGARY

FACULTY OF ENVIRONMENTAL DESIGN
GETACHEW ASSEFA WONDIMAGEGNEHU
Associate Professor and Athena Chair in Life Cycle Assessment in Design
Professional Faculties Bldg., Room 3191
Telephone: +1(403) 220-6961
Fax: +1(403) 284-4399
Email: gassefa@ucalgary.ca

June 14, 2010

[redacted]
Director, Environment, Health and Safety
Purolator Courier Ltd.
5995 Avebury Road
Mississauga, Ontario
L5R 3T8
[redacted]

Dear [redacted]

I am writing this on behalf of Kathleen Pilfold who is my thesis student here at our Faculty of Environmental Design, University of Calgary. In follow-up to the conversation with [redacted] National Manager, Environmental Affairs, and yourself on May 25th, 2010, following is her research proposal for a life cycle assessment of the Purolator Express™ Pack.

As millions of these packages are used annually, an improvement in the core packaging system of Purolator could produce a large environmental benefit. The proposed quantitative analysis of an accounting Life Cycle Assessment will examine the inputs and outputs of this product with the objectives of reducing environmental impacts, minimizing costs and maximizing efficiency.

Thank you for your interest in this research opportunity. Kathleen looks forward to answering any questions that you may have about her proposal.

Sincerely,

Getachew Assefa Wondimagegnehu, Ph.D.
University of Calgary, Canada

APPENDIX B: CANADA POST CORRESPONDENCE INITIAL EMAIL

From:	Kathleen Pilfold
To:	Manager Media & Community Affairs
Date:	Thu, Sep 16, 2010 at 4:10 PM
Subject:	Request for Information

Hi <Name>,

I'm the friend of <Name> that's looking for data for my master's thesis project in Environmental Design at the University of Calgary. Please see the attached PDF for details on my proposed research and where this information will be published. Ideally, I'm looking for data regarding Canada Post's "bubble mailer envelopes", the bubble-wrap type ExpressPost packages.

More specifically I'm looking for data regarding:

1. Emissions and energy used in *resource extraction* to create these packages
2. Emissions and energy used for *manufacturing* these packages
3. Emissions and energy used for *transportation* in delivering packages from the manufacturer to Canada Post, assuming this is the case
4. Emissions and energy used for *transportation* from Canada Post headquarters to postal outlets across Canada
5. Annual usage of these packages per location – such as per province and city if available
6. Disposal data – the amount of waste created annually by these packages in Canadian landfills

I really appreciate your help and look forward to answering any further questions you may have. Even if a portion of this data is available it would be a great start. I am willing to sign a confidentiality agreement if necessary.

Kind regards,

Kathleen Pilfold, B. Comm.
Master of Environmental Design Candidate
Faculty of Environmental Design
University of Calgary

Data Request, p. 1 of 6

Thesis Proposal:

Life Cycle Assessment of Courier Packaging;
A Bubble Mailer Envelope

Prepared by Kathleen Pilfold, Bachelor of Commerce,
Master of Environmental Design (Candidate)

September 16th, 2010

UNIVERSITY OF CALGARY

Project Summary

My proposed research involves a life cycle assessment (LCA) of courier packaging – a bubble mailer envelope used by Canada Post. The goal of this research is to propose alternative recommendations to reduce the environmental impact of courier packaging, while minimizing cost, maximizing efficiency and maintaining the integrity of the product. Currently this bubble mailer envelope is constructed with type four, low density polyethylene (LDPE) plastic. It is sealable, tear-free, water resistant, and non- recyclable. I propose to collect and analyze data to quantify the environmental impact of this type of packaging through measuring greenhouse gases and energy consumption at different stages of product implementation. The LCA will examine the inputs and outputs for each stage of the product, identifying areas for product improvement. The results of this study will provide valuable data that could be utilized in future managerial decisions of Canada Post and may act as a blueprint or building block for designing future packaging in the industry.

Three publications are proposed from this research:

1) Project report for Canada Post
2) Research thesis for the University of Calgary
3) Peer-reviewed article to be published in the International Journal of Life Cycle Assessments

These publications will be based upon the data from this research and will be produced in different formats to achieve the objectives of each party.

Problem Statement

Last year Canada's primary postal operator, Canada Post, delivered approximately 11 billion pieces of mail while Purolator, a Canadian courier company that is ninety-one percent owned by Canada Post, distributed approximately 275 million pieces of mail (Purolator 2010; Canada Post 2010). Many of these were delivered in bubble mailer envelopes, composed of type four, low density polyethylene which has limited recycling capabilities. This material is currently used because it is flexible, tough and has high impact strength (Mark 2009). However, degradation of this material is limited after disposal, causing pollution to the environment with possible ecosystem level effects (Bastioli 2005). Waste management assumes that disposal methods of LDPE consist of 80% incineration and 20% landfilling (Bastioli 2005). Current methods for addressing this problem include recycling, chemical recovery, pyrolysis and hydrolysis, incineration with energy recovery and biodegradation (Hamid 2000). The cost and pollution of these procedures have increased the demand for research on the biodegradation of LDPE waste (Zahra et al. 2010). However, a major obstacle to biodegradation is LDPE`s resistance to water and high molecular weight (Hamid 2000). With the high-volumes of mail delivered through Canada Post and Purolator, an integrated assessment is required for understanding the environmental impacts of this linear packaging system. This will ensure that future courier packaging in Canada is designed with the most current materials as well as an eco-friendly focus.

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Life Cycle Assessment

The International Organization for Standardization (ISO 14040) defines a life cycle assessment as a collection and evaluation of the inputs and outputs of a product's system throughout its life cycle (Guinee 2002). A life cycle assessment is a benchmarking and analytical tool that explains the environmental impact of a product or service's existence (Guinee 2002). It defines potential environmental impacts to highlight the most detrimental effects in order to avoid problem shifting, where pollutants may be transferred from one stage in a life cycle to another (Guinee 2002).

Courier Packaging – A Bubble Mailer Envelope

In this research a life cycle assessment will analyze the environmental impact related to one bubble mailer envelope in order to provide product improvement recommendations. The choice of one-way packaging will be examined in a similar context to the European Union's Packaging Directive which allows a linear system as long as it can be proved that it creates less of an impact than reusable packaging materials (Guinee 2002). The current *system* will be bound by resource extraction, manufacturing, distribution, use, disposal and emissions. However, production of the manufacturing equipment, infrastructure and maintenance of the shipping facilities and the development and maintenance of transportation vehicles, including cars, trucks and airplanes, will not be included in this study. The *core system* will be bound by the manufacturing and transportation of the bubble mailer envelope; delivery of the packaged item and finally disassembly for disposal.

Inventory Table

The inventory table is made up of the impact categories of greenhouse gases and energy consumption:

Impact Category	Measurement Unit
Greenhouse Gases	
• Carbon Dioxide (CO2)	Kilograms/ Tons
• Methane (CH4)	Kilograms/ Tons
• Nitrous Oxide (N20)	Kilograms/ Tons
Energy Consumption	
• Total energy consumed	kWh

Table 1: Inventory Table - Bubble Mailer Envelope

This table outlines the inputs and outputs of one bubble mailer envelope. Greenhouse gases are measured by the emission of carbon dioxide, methane and nitrous oxide. Energy consumption is measured by kilowatts per hour.

Data will be collected using Microsoft Excel and confirmed with SimaPro if funding allows. SimaPro is the industry standard, commercial LCA software used to collect, analyze and monitor the environmental performance of products and services. The research will be modelled to analyze complex life cycles in a systematic and transparent way, following the ISO 14040 series recommendations.

Recommendations

Recommendations will be made based on the results of the LCA. Potential recommendations may precipitate from addressing the following issues:

Potential Recommendations
A. Improving production, operation and recycling programs for the current packaging
B. Improving transportation and distribution methods for the current packaging
C. Changing the disposal system of the current product through exploring the research of microbes that can break down plastic (Shah et al. 2008)
D. Re-designing the product into a product that fits within the Canadian recycling requirements currently in place
E. Re-designing the product so that it has a peak life span where it self-destructs purposefully as a nutrient to the earth
F. Re-designing the product and the system by creating a closed-loop system for a new product that never breaks down and can be continually reused

Table 2: Potential Areas for Recommendations

Evaluation Plan

The information collected will be for the purpose of Canada Post's decision-making team and it will be recommended that this information is not distributed to the public unless through a peer-reviewed article which explains the source of this analysis. This project will be evaluated based on methodology and precision of the data collected in order for the research to be reproduced. The project will be documented through progress reports and meeting minutes with my Steering Committee. Files will be kept on my personal laptop and backed-up weekly onto a digital video discs (DVD).

A project report will be presented to Canada Post with the following deliverables:

a) Collection and analysis of data
b) Life Cycle Assessment of a bubble mailer envelope
c) Recommendations for improvements

Dissemination Plan

My thesis will be bound and available in the Faculty of Environmental Design at the University of Calgary, as well as digitally through the new Taylor Family Digital Library at the University of Calgary. This information will also be publically available through AMICUS, a free national catalogue listing the holdings of libraries across Canada. The AMICUS collections site covers all public opinion research reports that are deposited with Library and Archives Canada under the provisions of the Federal Accountability Act.

The information provided in these reports may be published in the International Journal of Life Cycle Assessments and posted in the international LCA discussion forum.

Timeline

The proposed time for completion of this research project is May 2011. Exploratory research will be implemented through a systematic review to document and quantify the inputs and outputs of the bubble mailer envelope between September 2010 and December 2010. The data will be gathered in Microsoft Excel and SimaPro software until January 2011. Upon final collection of this data the thesis and project report is anticipated to be written and complete by April 2011 for presentation in May 2011.

Research Timeline	Sep 2010	Oct 2010	Nov 2010	Dec 2010	Jan 2011	Feb 2011	Mar 2011	Apr 2011	May 2011
Conduct LCA Research of Bubble Mailer	■	■	■						
Attend LCA conference in Portland, Oregon			■						
Gather Data and Results	■	■	■	■					
International Experience - Los Angeles, CA				■	■				
Write Thesis and Recommendations					■	■	■	■	
Defence									■

Table 3: Research Schedule

Budget

SimaPro software normally costs $12,000 but a student version is available through my supervisor, Getachew Assefa Wondimagegnehu at the University of Calgary, costing approximately $6,000 for a one year license. An international experience is required before defence and will be acquired through a distance education research project between September and December 2010, followed by a site visit to Los Angeles, California in late December 2010. A potential meeting with Canada Post has also been factored into the budget. Miscellaneous costs include printing, binding, and other unforeseen costs. The final cost of this research is $13,500.

Item	Cost
LCA Conference Attendance: Portland, Oregon	$2,500
International Experience: 12 days - Los Angeles	$1,000
SimaPro Software	$6,000
Potential Travel for Meetings with Canada Post	$2,000
Miscellaneous Expenses	$2,000
TOTAL	$13,500

Table 4: Research Expenses

References

Bastioli, C., *Handbook of Biodegradable Polymers*, Rapra Technology, Italy, 2005

Canada Post Corporation, '2009 Annual Report', <http://www.canadapost.ca/cpo/mr/assets/pdf/aboutus/annualreport/2009_Annual_Report.pdf>, Canada Post Corporation, accessed 14 Jun. 2010

Guinee, Jeroen B., (Editor) *Handbook of Life Cycle Assessment: Operation Guide to ISO Standards,* USA: Kluwer Academic Publishers, Secaucus, NJ, 2002

Hamid, S.H., *Handbook of Polymer Degradation*, Marcel Dekker Inc., New York, USA, 2000

Mark, J.E., *Polymer Data Handbook*, 2nd Ed., Oxford University Press Inc., New York, USA, 2009

Purolator Courier Ltd., 'Purolator Media Centre', <http://www.purolator.com/media/corporate/faq.html>, Purolator Courier Ltd., accessed 10 Jun. 2010

Shah, A.A., Hasan, F., Hameed, A., Ahmed, S., 'Biological degradation of plastics: a comprehensive review', *Biotechnology Advances*, vol. 26, 2008, pp. 246–265.

Zahra, S., et al. 'Biodegradation of low-density polyethylene (LDPE) by isolated fungi in solid waste medium', *Waste Management*, vol. 30, no. 3, March 2010, pp. 396-401.

Follow Up Emails

From:	Kathleen Pilfold
To:	Manager Media & Community Affairs
Date:	Mon, Sep 27, 2010 at 3:18 PM
Subject:	Request for Information

Hi <Name>,

In follow-up to my email regarding potential research data for the bubble mailer envelope, is it possible for Canada Post to share this information?

Kind regards,

Kathleen Pilfold

From:	Manager Media & Community Affairs
To:	Kathleen Pilfold
Date:	Mon, Sep 27, 2010 at 4:12 PM
Subject:	Request for Information

Hi Kathleen,

I'm still waiting to hear back from my communications contact in Ottawa as to who the subject matter is regarding your request. We're looking into whether we can accommodate your request and I hope to provide you with an answer shortly. Thank you for your patience.

Regards,

<Name>
Manager Media & Community Affairs
Pacific Region, Canada Post

From:	Manager Media & Community Affairs
To:	Kathleen Pilfold
Date:	Tue, Sep 28, 2010 at 12:00 PM
Subject:	Request for Information

Hello Kathleen,

Unfortunately, we are unable to release the information you requested for proprietary reasons. I am sorry we cannot assist you with your research paper. I wish you best of luck in your studies and I thank you for your interest in Canada Post.

Kind regards,

<Name>
Manager Media & Community Affairs
Pacific Region, Canada Post

APPENDIX C: CROWNHILL PACKAGING CORRESPONDENCE

From:	Kathleen Pilfold <kmpilfol@ucalgary.ca>
To:	info@crownhillpackaging.com
Date:	Tue, Jan 25, 2011 at 4:34 PM
Subject:	Life Cycle Assessment of Air Jacket Bubble Mailer: #740340

Hi there,

I am looking to conduct a "Life Cycle Assessment" for a research project on packaging at school. I am looking to analyze a generic low density polyethylene (LDPE) bubble mailer, through an anonymous company, in order to analyze the environmental impact of this product, with the research goal to provide recommendations for future designs within the industry.

Would it be possible to share the product information for the air jacket bubble mailers, I believe Part #: 740340? (According to the help desk at Grand and Toy) I am mostly looking for the chemical composition, size and weight in order to conduct a few analyses. As much data that you are willing to share would be wonderful. The more detailed, the better.

Kind regards,

Kathleen Pilfold, B.Comm
Master of Environmental Design Candidate
Faculty of Environmental Design
University of Calgary

APPENDIX D: ASSOCIATED BAG COMPANY CORRESPONDENCE- LDPE BUBBLE MAILER

Product and Packaging Specifications for LDPE Bubble Mailer

Associated Bag Company

Associated Sales & Bag Company - Manufacturing Specification

Item: 534-3-110
Desc: 8-1/2X12 JIFFY SELF-SEAL TUFFGARD MAILER #2
Group: 534C00 - MAILERS - JIFFY TUFFGARD

Group Common Description:
Co-extruded polyolefin material; white inside, and outside; permanent hot melt adhesive across a 1-3/4" lip with paper release liner; 5/16" Bubble Wrap laminated to inside; tolerances: +/- 1/8" on width, +/- 1/4" on pocket length, and +/- 1/4" on lip.

Item Specific Information:
Usable space is approximately 8-1/2x10-1/2.

Packaging:
Packed 100 per minimum 175# test c-flute corrugated carton.

Date: 16-FEB-2012

550 Lillard Dr. Sparks, NV 89434 4039 Rock Quarry Rd. Dallas, TX 75211
400 W. Boden St. Milwaukee, WI 53207 14 E. Main St. New Kingstown, PA 17072
PHONE 800-926-6100 FAX 800-926-4610 www.associatedbag.com

APPENDIX E: ASSOCIATED BAG COMPANY CORRESPONDENCE- KRAFT PAPER AND NEWSPRINT FILLED PADDED MAILER

Product and Packaging Specifications for Kraft Padded Mailer

Associated Bag Company

Associated Sales & Bag Company - Manufacturing Specification

Item: 534-1-310
Desc: 8-1/2X12 YESTERDAYS NEWS SELF-SEAL PADDED
Group: 534A01 - MAILERS - JIFFY PADDED - YESTERDAYS NEWS

Group Common Description:
Outer layer is kraft paper with 100% recycled/55% post-consumer content overall content; inner layer made of 100% recycled kraft paper; 1-1/4" top flap pre-scored; double glued bottom flap tolerances: +/- 1/8" on width; +/- 1/4" on length.

Item Specific Information:
Flap has 1/2" adhesive strip across flap and 3/8" from ends; 3/4" release paper over adhesive strip; back has built-in tear tape for opening. Usable space is approximately 8-3/8x10-3/4.

Packaging:
Packed 100 per minimum 32ECT or 175# test c-flute corrugated carton.

Date: 16-FEB-2012

550 Lillard Dr. Sparks, NV 89434 | 4039 Rock Quarry Rd. Dallas, TX 75211
400 W. Boden St. Milwaukee, WI 53207 | 14 E. Main St. New Kingstown, PA 17072

PHONE 800-926-6100 FAX 800-926-4610 www.associatedbag.com

APPENDIX F: CANADIAN PLASTICS ASSOCIATION CORRESPONDENCE

From:	<Name>
To:	Kathleen Pilfold
Date:	Thu, Jan 19, 2012 at 7:40 AM
Subject:	RE: CPIA - Contact Us Form

Hi Kathleen,

Thank you for your inquiry. There were 28 million kg of PE film recycled in Canada in 2010.

There is a wealth of documentation on our web site that may also be useful for your project: http://www.plastics.ca/Recycling/index.php

Kind regards,

<Name>
Canadian Plastics Industry Association

APPENDIX G: SAMPLE CALCULATIONS

1. Calculation of Tonne·kilometers (tkm) for material transport by train:

   tkm = (Material Weight kg / 1000)*Distance Travelled km

   e.g. LDPE pellets travelling from Dow Chemical in Fort Saskatchewan, Alberta to the mailer manufacturing plant in Mississauga, Ontario for the construction of a single bubble mailer.

   - Material Weight = 0.01623 kg
   - Distance Travelled = 3,442 km
   - tkm = (0.01623 / 1000) * 3442
   - tkm = 0.05586

2. Calculation of number of boxes of Kraft padded mailers for a standard 16-meter tractor trailer on pallets 1.22 m x 1.02 m in size.

LDPE Mailers		Kraft Mailers	
Cartons per Truck *(Provided by Associated Bag Company over the phone)*	864 cartons x 100 mailer per carton	Cartons per Truck	
Pallets	(*x*)		
Total		Total	

   (*x*) must be an whole number, available divisors are: 864, 432, 288, 216, 144, 108, 96, 72, 54, 48, **36**, 32, 27, 24, 18, 16, 12, 9, 8, 6, 4, 3, 2

Pallet	Wood (48" x 40"; Standard Pallet Size according to ISO Standards)	1.22m x 1.02m	metres
Boxes per Pallet	Depends on calculation	36	pallets/truck load
Truck Load (t)	Boxes of 100 Mailers per Truck Load	**864**	**cartons**
100 Mailers per Box	Mailers per Truck Load	**86,400**	**mailers/ truck load**

3. Calculation of average distance travelled from supplier based in Mississauga, Ontario to retail locations across Canada. Trips were assumed to occur more frequently to destinations with larger populations due to larger product demand.

All cities with populations over 100,000 and all capitals were used (table below). A weighted average was calculated as follows:

- Weighted Average = $(d_1p_1 + d_2p_2 + \ldots + d_ip_i) / (\sum p_i)$
- d_i = road distance from Mississauga
- p_i = population

4. Manufacturer Transportation - List of Municipalities in Canada with Population Greater Than 100,000, or Canadian Capital Cities:

City *(*Provincial/ *Territorial or **National Capital)*	**Province**	**Population** (2011)	**Distance from Mississauga, ON by Car*** (km)	**Weight**
Calgary	AB	988,193	3,408	9.88
Edmonton*	AB	812,201	3,389	8.12
Abbotsford	BC	133,497	4,367	1.33
Burnaby	BC	223,218	4,424	2.23
Coquitlam	BC	126,456	4,437	1.26
Kelowna	BC	117,312	4,071	1.17
Langley	BC	104,177	4,394	1.04
Richmond	BC	190,473	4,441	1.90
Saanich	BC	109,752	4,538	1.10
Surrey	BC	468,251	4,411	4.68
Vancouver	BC	603,502	4,434	6.04
Victoria*	BC	80,017	4,539	0.80
Winnipeg*	MB	663,617	2,070	6.64
Fredericton*	NB	56,224	1,379	0.56
St. John's*	NL	106,172	3,097	1.06
Halifax*	NS	390,096	1,804	3.90
Yellowknife*	NT	19,234	4,935	0.19

City *(*Provincial/ *Territorial or **National Capital)*	**Province**	**Population** (2011)	**Distance from Mississauga, ON by Car*** (km)	**Weight**
Iqaluit*	NU	6,699	N/A	0.07
Ajax	ON	109,600	70	1.10
Barrie	ON	135,711	99	1.36
Brampton	ON	523,911	16	5.24
Burlington	ON	175,779	40	1.76
Cambridge	ON	126,748	72	1.27
Chatham-Kent	ON	103,671	273	1.04
Guelph	ON	121,688	66	1.22
Hamilton	ON	519,949	49	5.20
Kingston	ON	123,363	283	1.23
Kitchener	ON	219,153	80	2.19
London	ON	366,151	171	3.66
Markham	ON	301,709	58	3.02
Oshawa	ON	149,607	82	1.50
Ottawa*	ON	883,391	471	8.83
Richmond Hill	ON	185,541	47	1.86
St. Catharines	ON	131,400	92	1.31
Sudbury	ON	160,274	392	1.60
Thunder Bay	ON	108,359	1,385	1.08
Toronto*	ON	2,615,060	28	26.15
Vaughn	ON	288,301	39	2.88
Whitby	ON	122,022	78	1.22
Windsor	ON	210,891	344	2.11
Charlottetown*	PE	34,562	1,710	0.35
Gatineau	QC	265,349	443	2.65
Laval	QC	401,533	572	4.02
Lévis	QC	138,769	818	1.39
Longueuil	QC	231,409	584	2.31
Montreal	QC	1,649,519	566	16.50
Quebec City*	QC	516,622	815	5.17
Saguenay	QC	144,746	1,022	1.45
Sherbrooke	QC	154,601	712	1.55

City *(*Provincial/ *Territorial or **National Capital)*	**Province**	**Population** (2011)	**Distance from Mississauga, ON by Car*** (km)	**Weight**
Terrebonne	QC	106,322	591	1.06
Trois-Rivières	QC	131,338	696	1.31
Regina*	SK	193,100	2,713	1.93
Saskatoon	SK	222,189	2,926	2.22
Whitehorse*	YT	23,276	5,593	0.23

* Found on Google Maps (May 24, 2012) using TransCanada Hwy. or routes through Canada only.

Weighted average journey from manufacturer to point of sale = **1332.05 km**.