Analyzing the Environmental Impacts of Simple Shoes

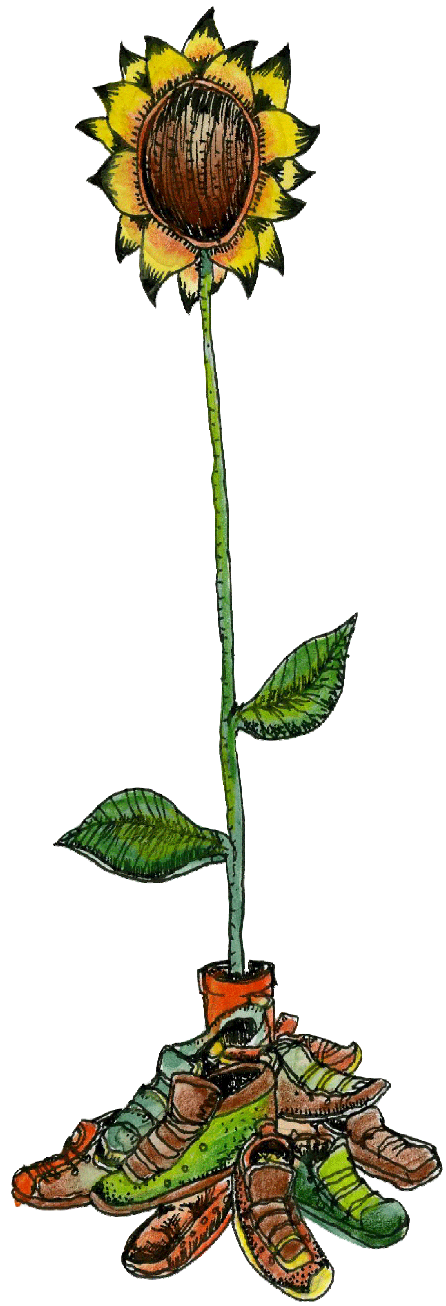
A Life Cycle Assessment of the Supply Chain and Evaluation of End-of-Life Management Options

A Group Project in partial satisfaction of the requirements for the degree of Master of Environmental Science and Management from the Donald Bren School of Environmental Science and Management, University of Santa Barbara, California

Researched and written by:
Kyle Albers
Peter Canepa
Jennifer Miller

Advisors:
Trish Holden
John Melack

Prepared on:
March 21, 2008



DONALD BREN SCHOOL OF ENVIRONMENTAL SCIENCE & MANAGEMENT
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

Simple
a nice little shoe company™
shoes for a happy planet™

Analyzing the Environmental Impacts of Simple Shoes

A Life Cycle Assessment of the Supply Chain and Evaluation of End-of-Life Management Options

March 21, 2008

As authors of this Group Project, we are proud to archive it on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Donald Bren School of Environmental Science & Management.

____

Kyle Albers

____

Peter Canepa

____

Jennifer Miller

The mission of the Donald Bren School of Environmental Science & Management is to produce professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principle of the school is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arrive from scientific or technological decisions.

The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) program. It is a three-quarter activity in which small groups of student conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. The final Group Project report is authored by MESM students and has been reviewed and approved by:

____

Faculty Advisor Patricia Holden, PhD

____

Dean Ernst Ulrich von Weizsäcker, PhD

Abstract

Traditional footwear manufacturing uses environmentally harmful materials such as chromium tanned leather, chemical-based adhesives and synthetic rubbers. The production and disposal of these materials release greenhouse gases, as well as toxic pollutants which can negatively impact human health and natural ecosystems. The magnitude of the footwear industry contributes to environmental problems significantly. The problems associated with footwear production and flux to the waste stream is expected to increase as the footwear industry grows to a projected 20 billion pairs by 2010. Simple Shoes has explored ways to voluntarily reduce the environmental impacts of their products. The goal of this study was to compare the environmental performance of four products. To accomplish this, we performed a comprehensive Life Cycle Assessment (LCA), supply chain analysis and End-of-Life (EOL) evaluation. Simple Shoes can use this analysis to evaluate the effectiveness of steps they have already taken and to focus future environmental initiatives within the firm. The results indicate that traditional footwear materials are the most significant source of environmental impact within the supply chain. Therefore, Simple Shoes should eliminate leather, synthetic plastics and hybrid materials from their shoes, focus their efforts on the material production and assembly phase of their supply chain and redesign their products to be composted, the recommended EoL option.

Acknowledgements

We would like to thank the following people who assisted us by generously sharing their knowledge, time, and energy: Our client, Monica DeVreese (Brand Manager) and Greg Nielson (Marketing Manager) from Simple Shoes, as well as Stephanie Cucurullo and Leah Evert-Burks also from Simple Shoes; Michael Brown, Michael Brown & Associates; Professor Keith Slater, University of Guelph, Canada; Theodoros Staikos, Research Associate, Wolfson School of Mechanical and Manufacturing Engineering Loughborough University; Elissa Loughman; Environmental Analyst, Patagonia; Alan Wheeler, National Liaison Manager, Textile Recycling Association; Nathan Taylor, Director of Technical Services, EcoSynergy Inc.; Marc Binder, Technical Director, PE Americas; Liila Woods, Senior Analyst, PE Americas; Alex Wasbin, Icon and Poster Artist, UCSB.

We would also like to thank the following individuals from the Donald Bren School of Environmental Science and Management at the University of California, Santa Barbara for their continued support and assistance: Mike Best, Financial and Operations Coordinator; Jennifer Purcell Deacon, Assistant Dean of Development; Vered Doctori Blass, PhD student, Corporate Environmental Management; Doris Bleecher, Staff Coordinator; BJ Danetra, Senior Events Manager; Janet Martorana, User Instructor Coordinator; and Former Bren Alumnae Erin Claybaugh (2007) and Alicia De Toro (2004).

We would like to extend a special thanks to our faculty advisors for their invaluable guidance: John Melack, Associate Dean and Professor, Donald Bren School of Environmental Science & Management; Patricia Holden, Professor Environmental Microbiology, Donald Bren School of Environmental Science & Management; Roland Geyer, Assistant Professor Industrial Ecology, Productions and Operations Management, Donald Bren School of Environmental Science & Management.

Finally, we are grateful to our friends and family who were extremely supportive throughout this process.

Definitions

- **Collection:** The process by which EoL shoes are collected from end-users, including storage and transportation of the shoes from the end user to the processing facility.
- ***De minimis****:* An amount of material, chemical and or pollutant too small to be of concern.
- **Ecological Footprint:** A resources management tool that measures the amount of land and water a firm (or human population) requires to produce its goods (resources) and manage waste, using current technology.
- **Economic Flows:** The creation, transformation, exchange, transfer or extinction of economic value through intermediate and final goods produced along a supply chain.
- **Elementary Flows:** Material or energy entering or leaving a product system with little or no human transformation.
- **End-of-Life (EoL):** Footwear that has reached the end of its use phase as determined by the end user. EoL shoes can still be in functional condition
- **End Users:** Those who purchase, own, and/or wear the footwear.
- **Environmental Impact:** The effect on the environment from the production of footwear at any stage along its supply chain. Environmental impacts can occur to the land, water and air and be a result of byproducts, waste and or intense resource consumption.
- **Environmental Impact Category:** A class of environmental issues for which life cycle inventory analysis results may be assigned.
- **Extended Producer Responsibility:** A legislation mechanism that places all financial and/or physical responsibility, on the manufacturer for the collection, transportation and disposal or EoL management of the footwear.
- **Extended Supply Chain:** All the agents that contribute to the production of a product. Each agent in the extended supply chain could have a significant impact on the product quality or on other agents within the chain.
- **Disassembly:** Breaking or taking apart of the shoe into its separate material components and can be performed either by hand or by machinery.
- **Displacement:** The use of either recycled or reused materials to take the place of the primary material used for the shoe. (i.e. recycled PET can be used to replace then need to create primary PET) Displacement can reduce the environmental burden associated with primary production.
- **Functional Unit:** Quantified performance of a product system for uses as a reference unit in a Life Cycle Assessment study.
- **Finished Good:** A good that is completed, in terms of manufacturing, but not yet sold or distributed to the end-user.
- **Green:** Tending to preserve environmental quality (as by being recyclable, biodegradable or non polluting).
- **Grinding:** The process of shredding and reducing the shoe to smaller and finer pieces; commonly performed by machinery.

- **Intermediate Flows:** In Life Cycle Assessment the input to or output from a unit process which requires further transformation.
- **Intermediary Good/Producer Good:** Goods used as inputs to the production process of other goods (partly finished goods or raw materials).
- **Landfilling:** A method of solid waste disposal where the shoes are buried in a low level site with other refuse.
- **Life Cycle:** Consecutive and interlinked stages of a product system, from either raw material acquisition or generation from natural resource to final disposal.
- **Life Cycle Assessment:** A technique that compiles an inventory of relevant inputs and outputs of a product system; evaluates the potential environmental impacts associated with those inputs and outputs; and interprets the results of the inventory and impact phases in relation to the objectives of the study.
- **Life Cycle Inventory Analysis:** Phases of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle.
- **Monomer**: A single molecule that can be combined with others to form a polymer.
- **Polymer:** A natural or synthetic compound of usually high molecular weight consisting of repeating and linked units (monomers).
- **Organic:** The term organic is based on ecological production management system that promotes and enhances biodiversity, biological cycles and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain and enhance ecological harmony.
- **Recycling:** To treat or process, used or waste materials, so as to make suitable for reuse.
- **Reference flow:** Measure of the outputs from processes in a product system required to fulfill the function expressed by the functional unit in Life Cycle Assessment.
- **Reprocessing:** The application of additional manufacturing or technical processes to a product, in preparation for reuse.
- **Reuse of Product (as is):** To directly reuse a product beyond its primary functional life with no major reprocessing and maintenance.
- **Supply Chain:** A system of organizations, people, activities, information and resources involved in moving shoes from suppliers to end users. The supply chain activities transform raw materials and components into a finished product that is transported and delivered to the end user for use and then disposal.
- **Sustainable**: Of, relating to, or being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged.
- **Take-back:** The return of products from end-users to interested parties or the manufacturer. Take-back programs can involve monetary compensation or future discounts.

Acronym Guide

BOD: Biochemical Oxygen Demand
CARB: California Air Resources Board
COD: Chemical Oxygen Demand
EVA: Ethylene vinyl acetate
GWP: Global Warming Potential
HAP: Hazardous Air Pollutants
HTP Human Toxicity Potential
LCA: Life Cycle Assessment
LCI: Life Cycle Inventory
LCIA: Life Cycle Inventory Analysis
EoL: End-of-Life
EPR: Extended Producer Responsibility
ISO 14040-14044: International Organization for Standardization – Environmental Management for Life Cycle Assessment Standards
MEK: Methyl ethyl ketone
ODP: Ozone Depletion Potential
PET: Polyethylene terephthalate
PU: Polyurethane
POCP: Photochemical Ozone Creation Potential
PVC: Polyvinyl chloride
TCA: Trichlorethane
TDI: Toluene di-isocynate
VOC: Volatile Organic Compound

Table of Contents

List of Figures

List of Tables

Section 1 - Executive Summary

Although footwear has not been typically considered to be a commodity or industry that is particularly harmful to the environment, the sheer volume of shoes produced and consumed by humans creates the potential to generate significantly harmful environmental impacts on a grand scale. In 2004, the footwear industry produced 12 billion pairs of shoes worldwide. The United States is a key player in this global market, as the average American owns 10 pairs of shoes. Long before these shoes complete their product life cycle and inevitably become waste, their environmental impacts can be felt during the traditional footwear manufacturing process, which utilizes both natural and synthetic materials. The petroleum-based synthetic materials contain toxic substances and the process of extracting and processing natural materials is often no better in terms of environmental performance. For example, leather and cotton production require significant inputs of water, land, fertilizer, and pesticides while leather tanning releases chromium and other harmful chemicals into the environment. In addition to an environmentally harmful production process, many footwear companies have worldwide supply chains in which products are transported across the globe while burning fossil fuels, thus contributing to global warming.

One shoe company looking to reduce their environmental impacts and redefine traditional paradigms of footwear manufacturing is Santa Barbara, California's Simple Shoes. Simple Shoes began making footwear in 1991 and, in 2005, set out to reduce their environmental impacts by creating a new line of shoes made from materials which were presumed to have a lesser environmental impact. Utilizing materials often referred to as Green, this line of shoes by Simple is called Green Toe and features shoes composed of natural materials such as hemp, jute, organic cotton, bamboo, natural latex, and crepe rubber. In addition, Simple Shoes has incorporated recycled PET and recycled car tires into the Green Toe manufacturing process. Thus far, the Green Toe line has been commercially successful and Simple Shoes is considering expanding the use of Green materials into all of their products.

The decisions and choices made by Simple Shoes regarding the steps necessary to improve the environmental performance of their company have been thus far made using an internal sustainability framework. In accordance with this framework, Simple Shoes sought to systematically analyze the effectiveness of their products to determine what effect Green materials have had on the overall environmental impacts of their supply chain. Furthermore, Simple Shoes sought to find additional methods and strategies to improve the environmental performance of their supply chain and to evaluate the opportunity to incorporate End-of-Life (EoL) management into their supply chain. To answer these questions, this project was conducted with the following objectives:

- Quantify and compare the environmental impacts of four shoes, two of which are from the Green Toe line, one from the EcoSneaks line and one considered a conventional Simple shoe
- Assess Simple Shoes' supply chain using Life Cycle Assessment(LCA) to identify opportunities to improve environmental performance and increase efficiency
- Generate EoL Management options that are feasible and environmentally beneficial
- Present a final recommendation to Simple Shoes, based on LCA and EoL evaluation

To quantitatively measure the impacts of material substitution for Simple Shoes this project compared two of Simple's Green Toe shoes and one EcoSneaks shoe to one of their conventional shoes. The two Green Toe shoes and EcoSneak shoe (Shoe 1, Shoe 2, and Shoe 3) are composed primarily of Green materials, while the conventional shoe (Shoe 4) is made almost entirely of leather and synthetics. The total impact of each pair of shoes was calculated using LCA. The software used for the LCA was created by PE International and is called GaBi 4.0. LCA allowed us to measure the impacts from materials production, shoe manufacturing, transportation, and disposal. From this analysis, it was possible to determine which shoe had the highest overall impact and in what life cycle phase the majority of these impacts were occurring. The GaBi software calculates the emissions of a product lifecycle and separates them into different contributions to environmental problems called "impact categories." Ten impact categories were considered: Global Warming Potential (GWP), Human, Marine, Terrestrial and Freshwater Toxicity Potentials, (HTP, MAETP, TETP, FAETP), Photochemical Ozone Create Potential (POCP), Ozone Depletion Potential (ODP), Acidification Potential (AP), Eutrophication Potential (EP) and Radioactive Radiation (RAD). The impact categories were chosen based on client interests, as well as a literature review that related the environmental impacts of footwear production and the widely accepted nature of these categories in the LCA community. The emissions to each impact category are normalized to total world emissions so that they can be compared to each other.

The major result of the LCA was that the product lifecycle of the four shoes studied contributed the most to various toxicity impact categories (HTP, MAETP, TETP, and FAETP). RAD, AP, and GWP were the next most impactful categories and a majority of these emissions occurred during the production phase. Of the four shoes analyzed, shoe 4 (conventional shoe) had significantly higher emissions in eight of the ten impact categories, including HTP and GWP. Further analysis of the materials utilized in the different footwear products explained the varying emission results (e.g. the traditional materials in shoe 4). To determine which materials caused the greatest impact, the impacts of each material were compared on a kilogram for kilogram basis. This analysis revealed that leather had significantly greater impacts than all the other materials. The other materials, based on their GWP, were ranked from highest to lowest impacts: Nylon 6, Silicone rubber, PU foam, EVA, latex rubber, PET, conventional cotton, crepe rubber, recycled PET, organic cotton, and hemp. This analysis reveals that synthetic materials can be expected to more negatively impact the environment in comparison to natural materials.

The LCA results suggest that Simple Shoes' Green Toe and EcoSneaks shoes do have significantly lower environmental impacts than their conventional shoes and that the Green materials initially chosen by Simple Shoes are the primary reason for the Green Toe products' superior environmental performance.

A supply chain analysis was performed to determine where Simple Shoes could modify its operations to decrease environmental impacts. Three points within the supply chain were identified that exhibited high environmental impacts and for which Simple Shoes had at least a moderate amount of control: material composition of the shoes, manufacturing processes, and EoL management.

For the final portion of the study, EoL management options were delineated and evaluated for Simple Shoes. Through literature review and discussions with Simple, four alternatives to landfilling were identified: Reuse, Recycle, Grinding, and Composting. Two possible EoL collection mechanisms were also factored into the analysis: Drop-Off Boxes and Mail-In. The four EoL options were compared based on their Greenhouse Gas (GHG) emissions and feasibility. GHG emissions were calculated using GaBi 4.0 and feasibility of implementation was estimated based on the additional supply chain steps that Simple Shoes would be responsible for, estimated additional shipping distances, and whether the EoL option required the implementation of a take-back program. Similar to the EoL options, the two collection mechanisms associated with a take-back program were also calculated for GHG emissions and feasibility.

EoL management analysis results were as follows: the current EoL practice for shoes--landfilling--emits 0.27 kg CO_2 eq. per pair resulting from emissions of methane during anaerobic decomposition of organic matter in landfills. Reuse, i.e. donating EoL shoes to charity, would emit 0.17 kg CO_2 eq. per pair during transportation. Recycling, including disassembling EoL shoes and recycling each material would have a net emission of 0.94 kg CO_2 eq. per pair after accounting for the avoidance of landfill and primary production. Grinding, i.e. sending EoL shoes to Nike's Reuse-A-Shoe program to be ground up and used in athletic surfaces, would have a net emission of -1.48 kg CO_2 eq. per pair after accounting for the avoidance of landfill and primary production. Composting, done by customers at home, would have no emissions and would avoid 0.27 kg CO_2 eq. per pair by keeping shoes out of landfills.

Based on the EoL analysis, it was concluded that composting would be the best EoL management option for Simple Shoes. Composting is the most feasible alternative to landfilling because it does not require the implementation of a reverse logistics network and Simple Shoes would not be required to add any supply chain steps or pay for additional shipping. In order for the composting option to be successful, Simple Shoes would have to redesign their shoes to be 100% biodegradable, this means removing all leather and synthetics and replacing them with natural materials. This redesign would allow customers to safely incorporate their Simple shoes into their home compost pile where the product would break down over time.

The overall analysis shows that the changes Simple Shoes has already made to their Green Toe line have improved the products' environmental performance. The best way for Simple Shoes to further increase environmental performance is to incorporate natural materials into their entire product line. Simple Shoes should replace leather and synthetics with Green materials in all of their shoes. This will significantly decrease the emissions of GHGs and toxins emitted during shoe production and will allow for the shoes to be composted, thus facilitating a more environmentally-friendly product life cycle from start-to-finish

Section 2 - Background

2.1 Introduction to Shoe Manufacturing History and Trends

In 2004, 12 billion pairs of shoes were produced world-wide and this figure is expected to increase to 20 billion by 2010 as consumers continue to demand shoes of varied form and function (Staikos 2006). With growing rates of production comes a rise in the concern of the environmental impacts created throughout the different stages of the supply chain (Foreman 2004). In order to effectively reduce environmental impacts, shoe manufacturers should critically analyze their supply chain which includes research and development, manufacturing, storage, transportation and disposal (Zhu 2004). The supply chain is most commonly defined as a network of suppliers, distributors and consumers and includes the transport that occurs between the groups (Zhu 2004). It is within the supply chain that, according to Seuring (2004) decisions can be implemented and either proactive or reactive strategies can be developed for improving environmental performance.

The footwear industry is well-established and steeped in a rich history of well-developed management approaches. During the 18th century, shoe production in Europe and the United States was performed by farmers who manually produced shoes to be traded along with their other goods. The farmers then became craftsman and opened up shops followed by small factories to produce shoes (Buck 1998). Throughout the mid to late 1800's, technological developments within the shoe industry replaced manual labor to increase product output and decrease labor costs (Miranda 2004). By the early 1900's the United States began to gain competitive advantage in the international footwear market due to technological advancement and the production of a comfortable shoe targeted at the middle class (Miranda 2004).

2.2 Introduction to Simple Shoes

Simple Shoes is a small footwear company located in Santa Barbara, California. Simple Shoes was founded in 1991 and acquired by Deckers Outdoor Corporations in 1993. After the success of the Old School Sneaker and other traditional sneaker styles, Simple Shoes in 2005, introduced the Green Toe product line. Shoes within this product line are composed of natural and recycled materials. Overall, the Green Toe concept serves as an internal benchmarking system for Simple Shoes to qualitatively evaluate the environmental performance of all their footwear products (Simple Shoes 2007). Simple Shoes expanded on the Green Toe concept and introduced sustainable sneakers, ecoSNEAKS in 2007.

Simple Shoes, like other companies in their industry such as Nike, Timberland, Adidas, Chaco and Keen are becoming sensitive to the ecological impacts of disposal and are interested in alternative options for End-of-Life management (Doppelt 2001). Companies across a wide variety of industrial sectors, including several footwear manufacturers, have implemented product take-back programs. The main drivers to implement a take-back program, according to Bette Fishbein (2000), are the potential for profits from the displacement of primary production, marketing demand for recycled content to meet other industry goals, legislation preemption and environmental stewardship. Despite the varied motivations, the actual implementation of a take-back program can result in a competitive advantage, a source of profit and or an enhancement of a company's environmental image (Doppelt 2001).

Collection is one of the most important determinates of a successful EoL management program (Neira 2006) and can be conducted either by product manufacturers, retailers, or third parties. EoL products can be collected via either consumer mail-in or drop-off. Drop-off receptacles can be either permanent or temporary (one-day events) and are typically located at retail stores, schools, organizations or government buildings (Neira 2006). Without the implementation of a collection mechanism, footwear will most likely be disposed of in a landfill. The environmental impacts of shoe degradation in a landfill are inextricably connected to the nature of the materials (Doppelt 2001).

2.3 Materials Analysis – Cotton Products

Simple Shoes has focused on altering the material components of their shoes to reduce this environmental burden (personal communication Simple Shoes) The following section is a detailed description of the materials used in the four Simple shoes studied (Shoes 1-4). Each description contains basic background on the material, methods of processing and the associated environmental impacts of growing, extracting and processing.

Cottons

Simple Shoes uses various combinations of conventional and organic cottons and cotton blends in their footwear. The following section examines the methods and impacts of producing these cotton textiles.

Conventional Cotton

Conventional cotton has been used through out the world as a textile for nearly 6,000 years; it is referenced in the Bible, eastern religions, and has a contentious history in the United States with its connection to slavery (UNCTAD, 2007). It is used across many industry sectors including apparel, home furnishing, and to a lesser extent, in industrial settings (NCCA, 2007). Cotton is a pesticide-heavy crop, accounting for approximately 25% of the world's insecticide use and 10% of the world's pesticide use (Allen Woodburn Associates). In addition, cotton is the dominant fiber used in apparel and makes up approximately 66% of this market (NCCA, 2007).

The cotton bolls (Fig. 1) are ginned to remove any seeds or other impurities and then spun into fine yarn. This yarn can subsequently be woven into a myriad of cotton products.

Figure 1. Cotton Bolls Prior to Harvest (Helevetas, 2008)

Organic Cotton

Organic cotton is processed identically to its conventionally grown counterpart (Organic Trade Association, 2007). However, the cotton is grown and harvested using neither fertilizers nor pesticides. According to Brown, (2006) the lack of applied fertilizers and pesticides may result in lower organic yields compared to conventional cotton yields, but believe that this gap could be closed with more effective weed control techniques.

The principal goal of organic agriculture is to "optimize the health and productivity of interdependent communities of soil life, plants, animals and people" (Organic Trade Association, 2007). However, the National Organic Standards Board cautions that the implementation of organic agriculture practices does not definitively indicate that a product is completely free of residues especially from rogue air, soil and water pollution sources.

Cotton Nylon Thread

Cotton nylon thread is created by blending equal volumes of the respective fibers to create a 50/50 mix of cotton and Nylon 6. Blended fibers can be created in two ways. The first method requires the fibers to be mixed within a closed container which often leads to an uneven distribution of fibers. The second method is to create a blended fiber by passing the fibers through machinery which will differentiate and order the two (or more) fibers mechanically (Slater, 2003).

The environmental impacts associated with the production of a cotton nylon blended fiber include dust production and excess waste, as the fibers are damaged through the mechanical processes of mixing (Slater, 2003). The impacts of both growing conventional cotton and synthesizing Nylon 6 must be considered when using a cotton nylon blend.

Twill Cloth (100%) Cotton

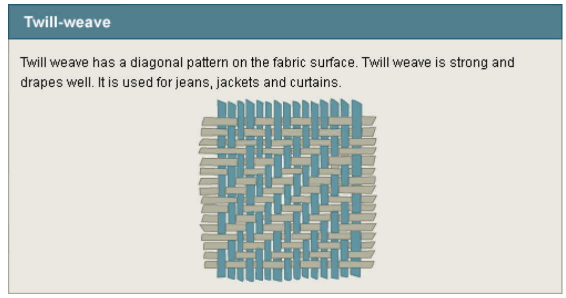


Figure 2. 2/2 Twill Weave (BBC, 2008)

As demonstrated in Figure 2, twill is any type of woven fabric that is easily identified by its marked diagonal pattern. Some common examples of fabrics woven using a twill pattern are chino, denim, gabardine, tweed, drapes, and serge. Because twill cloth can be woven using any number of textile yarns, there are no explicit environmental impacts associated with weaving twill. If the twill cloth is woven using a mechanical loom, then some energy will be required (BBC 2008).

2.4 Material Analysis - Natural Materials

Hemp

Figure 3. Bast or Stem of Hemp Plant (Hemp, 2007)

Hemp is widely used "alternative" fiber. Historically, hemp fell just behind flax as the most widely used textile fiber "from the Middle Ages to the end of the nineteenth century (Bonneville, 1994)." Hemp is a fiber that is derived from the stem, or bast of the plant, as opposed to seed fibers like cotton (Slater, 2003). A major benefit of hemp is that it can be harvested by hand to greatly reduce the environmental impact (Slater, 2003).

The method of processing the hemp plant to create a useable textile is as follows. First, usable fibers are removed from the woody stalks of the stems of the plant (Fig.3). This removal is accomplished through a process called retting which is a chemical decomposition of the stems of the plant (Fig. 4). Retting can also be done via a biological process with little environmental impact. This involves placing the plants in pools/ditches and letting the natural acidity of the surface water decompose the bast of the plant, releasing the hemp fibers. Modern retting techniques aided by technology can take as little as two hours, while, traditional retting can take weeks (Slater, 2003). Once the hemp fibers are separated from the woody debris of the stem, they can be spun into yarn and subsequently woven into any number of hemp -based textiles. Hemp is an extremely durable fabric with almost eight times the tensile strength of cotton. (Lela Designs, 2007).

Bamboo

Bamboo is a renewable resource with a rapid regeneration rate, with plants growing between 24-36 inches in approximately 24 hours (World Bamboo Association, 2003-2007). Bamboo is lauded as an excellent substitute for conventional textile fibers because it is biologically resistant to many pests and can be easily without the use of chemical pesticides. Bamboo is extremely soft, anti-microbial, hypoallergenic, and anti-bacterial. One study found that, "after multiple washings, over 70% of the bacteria cultured on bamboo textiles are destroyed by the fiber (Lela Designs, 2007)."

Figure 4. Retted and Teased Hemp Fiber (Hemp, 2007)

Figure 5. Textile-Grade Bamboo Fiber (Wisegeek, 2007)

Bamboo, similar to that of hemp, uses the process of retting to separate fibers from the woody plant material, but requires extensive chemical bleaching processes to turn bamboo fiber white if desired. The waste water associated with bleaching could produce environmental harms to waterways if not treated properly (Wisegeek, 2007).

Cork

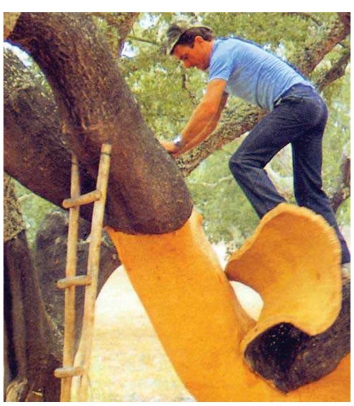


Figure 6. Harvesting Cork (Fletcher, 2002)

Cork is an excellent natural cushioning material, anti-microbial and virtually impermeable to liquid. (Amorim, 2006). This material is considered a renewable material, but can typically only be harvested every 6-9 years (Amorim, 2006). The harvesting process is relatively straightforward and requires the bark to be stripped from the tree using hand tools and the suberin material removed (Fig. 6). The demand for cork is high in other industries, specifically used as bottle closures/stoppers. Cork stoppers represent about 60% of all cork-based production.

Jute

According to the International Jute Study Group (IJSG), jute has many beneficial characteristics as a textile fiber. The IJSG states that "jute is the second most important textile fiber, with cotton being the first." Jute is a renewable material, extremely durable and the fibers tend to be finer than other natural alternatives, such as hemp. The current growing regions for jute include China, India, Thailand, Myanmar, Bangladesh, and Nepal (IJSG, 2007). The availability of jute in these regions makes a likely textile fiber choice for Simple Shoes whose manufacturing facilities are located in China. According to the IJSG, jute's ability to rapidly assimilate and metabolize carbon dioxide quicker than trees increases its role in carbon sequestration. It is believed that within one growing season (100 days) one hectare of jute plants can consume about 15 tons of carbon dioxide from the atmosphere and convert this into approximately 11 tons of oxygen (IJSG, 2007).

Figure 7. Dried and Retted Jute Fiber (IJSG, 2007)

The processing of jute for fiber is tantamount to the processing of hemp or bamboo. The plant stalks are harvested (Fig.7) and defoliated, then retted to chemically remove the fibrous material from the woody stalk. The fibers are then woven into a yarn and eventually made into a textile. As mentioned previously, it is often desirable to blend these fibers with softer counterparts for apparel or footwear, thus again the environmental impacts associated with all the component fibers would need to be considered.

Cow Suede

Suede is a soft, napped, hide of an animal (specifically cow) that goes through a tanning process to render it useable for footwear (Hankcocks, 2007). Tanned animal hides have been used in armor, clothing, blankets, and footwear for thousands of years. Suede tends to be less durable, but softer than standard leather due to the napped texture of the skin hairs, which can be brushed to stand out.

The process of tanning leather is detailed below:

- First, the hides are prepared for tanning (Fig. 8) by removing hairs and applying salts to cure the hides, as well as a treatment to prevent bacterial growth.

- The second stage is tanning, which uses vegetable tannins and/or mineral tannins (chromium). In their raw state, chrome-tanned skins are blue and therefore referred to as "wet blue". Chrome tanning is faster than vegetable tanning (less than a day) and produces a stretchable leather suitable for handbags and garments.

- Lastly, the tanned leather or suede is finished. In this step the hides achieve the desired softness and texture. The suede is finished by elevating the nap, or small hairs, of the leather by scuffing them with a rough surface (O'Flaherty, 1978).

Figure 8. Soaked Hides prepared for Tanning (Simple Shoes, 2008)

Suede, as well as other leathers that require tanning, are associated with large environmental and health effects. These effects are primarily due to the use of chromium, a heavy metal (Cal EPA, 2007). The most common tanning agents used in the US include trivalent chromium (which accounts for 90% of production), vegetable tannins, aluminum, syntans, formaldehyde, glutaraldehyde, and heavy oils (Cal EPA, 2007). Hexavalent chromium, the form (valence state) used in the tanning of leather/suede, was identified as a toxic air pollutant by the California Air Resources Board in 1986. CARB warns that hexavalent chromium should be considered a carcinogen *with no safe threshold level of exposure* (Scorecard.org, 2007). The emission of hexavalent chromium, a known human carcinogen can be released as a by-product of tanning (Cal EPA, 2007). Depending on different processes and chemicals used, tanning can release harmful pollutants to the air including: VOC's, sulfides, and particulates (Cal EPA, 2007). Wastewater from tanning operations typically consists of high concentrations of acidic and alkaline liquors, chromium, sulfide, nitrogen, biochemical oxygen demand (BOD), chemical oxygen demand (COD) and chloride.

It is also important to acknowledge the environmental impacts associated with the farming practices that are required to sustain herds of cattle in order to eventually harvest them for their skins. The main impacts of cattle production are the enormous quantities of food, water and land that cows require, the methane (a greenhouse gas that is 21 times as potent as CO_2 at trapping heat) that cows produce and the pollution that comes from feedlot operations. The average US cow requires six barrels of oil over its life cycle (Leggett 2006). Most of this energy goes into grain production, water, and transportation. In 2003, methane from cows generated 115 Tg CO_2 equivalent (EPA 2006). Cattle feedlots pollute nearby waterways with high concentrations of nutrients which lead to eutrophication, as well as hormones and antibiotics with can be harmful to humans and natural ecosystems (WWF 2005). Not all of these impacts can be allocated to leather production however, because leather is a by-product of beef production.

Many of the materials and textiles listed above are dyed. Supplemental information regarding dying practices, environmental impacts of dyeing and associated best management practices can be found in Appendix I.

2.5 Material Analysis - Rubber Products

Rubber is naturally produced in trees and can be synthesized using chemical polymers. Traditionally, footwear has used rubber for cushioning, as well as a durable outsole material.

Latex

Latex rubber, is a naturally occurring emulsion of various proteins, sugars, starches, and tannins found in plants. Latex can also be synthesized in a laboratory via the polymerization of component chemicals (Bower, 1990).

Figure 9. Rubber Exuding from Tree (Australian, 1999)

Latex rubber can be sustainably harvested from the rubber tree (*Hevea brasiliensis*) by scoring the bark of the tree and allowing the latex to exude from the damaged bark (Fig.9). This raw latex, often referred to as liquid sap, can easily be collected, as the tree tends to release the latex for a few hours after the bark is cut (Bower, 1990). .

The World Wildlife Foundation recently examined the environmental effects of growing, harvesting, producing and using rubber. The results of this study showed that some of the most detrimental impacts are associated with the conversion of the liquid sap into the useable forms of latex which results in "considerable amounts of effluent (WWF, 2005)." The general composition of the liquid sap is about 60% water, 35% rubber particles and 5% various resins, ash, sugars, and proteins. To prevent bacterial contamination, harvested sap must be solidified within 24 hours of being exuded (SMTL, 1996).

Figure 10. Solidified Crepe Rubber (Blick, 2008)

Crepe Rubber

Crepe rubber (Fig. 10) is a wrinkled and hardened form of natural rubber, but otherwise chemically similar to latex and harvested in a similar manner. Thus, the environmental impacts (discussed in the latex rubber section) are the same for crepe.

Virgin Synthetic Rubber

Synthetic rubber can be made from a wide array of monomers. The polymerization of hydrocarbon monomers, such as isoprene, butadiene, chloroprene, and isobutylene (methylpropene), leads to the creation of varieties of rubber with different properties. Synthetic rubber has a range of uses today, but historically the rise in the production of synthetic rubber coincided with a rising demand for tire rubber (Britannica, 2007).

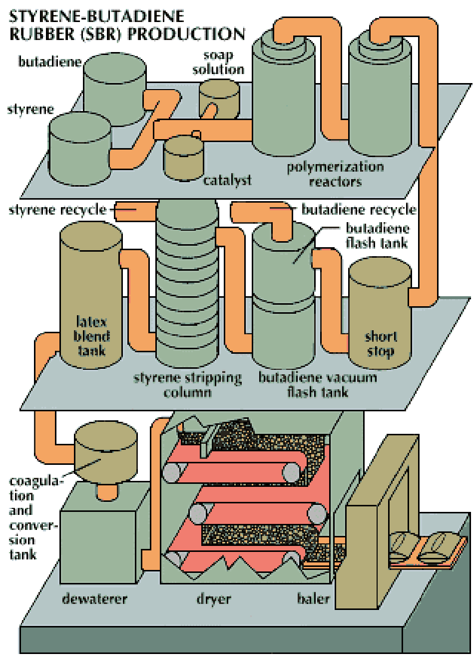


Figure 11. Flow Chart, Polymerization of Rubber (Britannica, 2007)

The polymerization process of rubber (Fig. 11) generate environmental impacts including the fugitive emissions of VOC's and Carbon dioxide. According to the WWF, "the volume of effluent from rubber processing is 25 to 40 times greater than the volume of rubber that is produced (WWF, 2005)."

Tire Rubber

Polybutadiene is the most common polymer used in the production of tire rubber due to its high resistance to wear (UMiss, 2005) (Fig. 12). The environmental impacts associated with the production, use and disposal of tire rubber are the same as those for synthetic rubber. The addition of other chemicals, wire, carbon or even fabrics in car tires can generate additional environmental burdens during the use phase.

Figure 12. Car Tire Rubber (2carpros.com, 2007)

The US EPA estimates that 250 million scrap tires are generated each year. When tires are disposed in landfills they can potentially present environmental hazards because they can leach pollutants into groundwater and can create fires that are difficult to extinguish and are highly polluting (ODNR, 2005).

2.6 Material Analysis - Synthetic Fibers

Synthetic fibers are any large group of man-made materials created through a process of extrusion. Generally, as the polymer is pressed through a shower head-like device, referred to as a spinneret, it extrudes the polymer in the form of a fiber thread. This fiber can then be woven into fabric. The production of many petroleum-based products used in shoe manufacturing including PU, EVA, PVC and solvent-based adhesives release VOC's into the air (EPA 2001). VOC's contribute to the formation of tropospheric ozone, which is harmful to humans and plant life (Staikos *et. al*. 2006).

Polyethylene Terephthalate (PET)

PET is used in two major industries: synthetic fibers and bottle/vessel production. Interestingly, the PET used to make bottles is virtually identical to the PET used for the production of polyester fabric, and thus PET can commonly be referred to as polyester. The production of PET derivatives accounts for as much as 60 million tons of the synthetic polymers created annual around the world (American Chemistry, 2007).

The environmental impacts associated with the production of PET, as with any synthetic material, involves energy, chemicals, and water inputs coupled with chemicals, water, and waste outputs. Furthermore, PET is derived from hydrocarbons and is, therefore, non-renewable (American Chemistry, 2007).

Recycled PET

Simple Shoes has incorporated the use of recycled PET (Fig. 13) from bottles into their supply chain. The benefits associated with the use of a recycled product can be examined in two ways: displace primary production and create energy savings. Estimates suggest that the recycling of PET represents an energy savings of approximately 84% over the energy requirements for primary production (EcoRecycle Victoria, 1999).

Figure 13. Recycled PET Flakes (Ecplaza, 2008)

Polyurethane Foam (PU Foam)

According to the Polyurethane Foam Association the manufacturing process for PU foam (Fig. 14) is rapid and requires the reaction of two raw materials: diisocyanate and polyol, as well as the additive methyl chloride. The reaction of these materials generates bubbles, which cause the solid polymer to rise, creating foam. PU foam can either be manufactured in slab form and cut to fit a specific use, or poured directly into molds shaped towards a specific use (PFA, 2007).

Figure 14. Polyurethane Foam (Deccofelt, 2008)

This material can easily be recycled, and the PU industry has teamed up with carpet manufacturers to turn recycled PU foam into 80% of bonded carpet cushion sold in the U.S. In response to tougher EPA National Emissions Standards for Hazardous Air Pollutants, the industry was able to nearly eliminate the use of methyl chloride in the manufacturing process. In addition, the manufacturers of PU foam have nearly eliminated all Polybrominated Diphenyl Ethers and CFC-causing pollutants (PFA, 2007).

The main environmental concern associated with Polyurethane (PU) foam production is the use of toluene di-isocyante (TDI). TDI is used as a chemical intermediate in the production of PU and is extremely toxic to humans. Acute exposure to TDI harms the skin, eyes, respiratory system, gastrointestinal system, and central nervous system and chronic exposure to TDI is possibly carcinogenic according to the International Agency for Research on Cancer.

Ethylene Vinyl Acetate (EVA)

EVA (Fig. 15) is a copolymer created via an amalgamation of the two polymers: ethylene and vinyl acetate. According to DuPont (2007), EVA has a multitude of applications including adhesives, photovoltaic encapsulates, packaging and obviously in footwear. When used in footwear, EVA is either glued into the lower portion of the shoe or the midsole or it is applied as a foam to improve cushioning and elasticity. To form and mold EVA, the material can either be blow-molded or cast as a film (Raff, 2000).

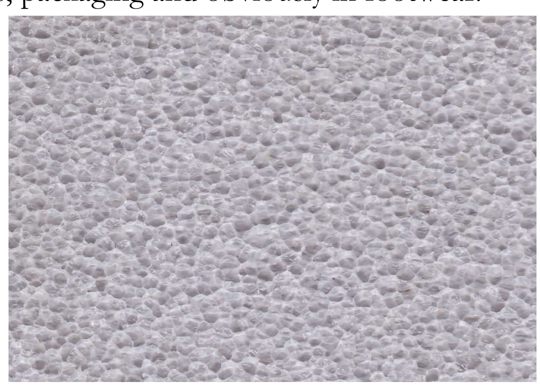


Figure 15. Ethylene Vinyl Acetate (EVA, 2008)

Fugitive emissions to air, water and intense energy consumption are the main environmental impacts associated with the production, use, and disposal of EVA. The largest impact associated with the production of a plastic like EVA is the improper disposal of plastic goods by consumers (ELC, 2007).

Nylon

Nylon is a synthetic material that is derived from hydrocarbons; and is often referred to as a thermoplastic or polyamide. Nylon is produced in many forms and can be applied for different purposes; Simple Shoes uses nylon 6 (Fig. 16) in the production of their shoes (NPG-6, 2006).

Figure 16. Various Forms of Nylon 6 (Acentech, 2003)

Nylon is inherently unsustainable because it is derived from synthesized petrochemicals, a non-renewable resource. Furthermore, the production of nylon leads to the emission of nitrous oxide, an EPA-regulated greenhouse gas with a climate warming potential almost 300 times that of carbon dioxide (UNEP, 2001). Another negative impact of the use of nylon is the associated use of formaldehyde, a toxic chemical with documented carcinogenicity, reproductive and developmental toxicity, neurotoxicity, and acute toxicity. (Pesticideinfo.org, 2000).

2.7 Material Analysis - Adhesives

In addition to alternative materials, Green Toe shoes also substitute solvent-based adhesives with water-based adhesives. Solvent-based adhesives typically use the VOC's: toluene, methyl ethyl ketone (MEK), and trichloroethane (TCA), as carrier fluids. Toluene, MEK, and TCA are considered Hazardous Air Pollutants (HAPs) under the 1990 Clean Air Act Amendments, and are suspected to cause cancer, birth defects, and nervous system damage. TCA also depletes the stratospheric ozone layer. Water-based adhesives use water as the carrier fluid. They are formulated from rubber compounds with various additives such as synthetic hydrocarbon resins or pine sap and may contain some VOC's (PPRC, 1999).

2.8 Description of Simple Shoes 1-4

The materials described above are utilized in the four shoes studied in this report. Depending on the style of the shoe studied the material composition for the various parts of the shoe will be different. A Simple shoe can be delineated into seven major categories: toe cap, upper/vamp, sock liner, heel, outsole, midsole and insole (Fig. 17).

Shoe 1 and Shoe 2 are part of Simple Shoes' Green Toe product line and therefore all of the seven parts delineated in figure 17 are composed of natural materials (organic cotton, hemp, jute, bamboo, cork), natural rubbers (crepe and natural latex), as well as recycled PET and recycled car tire.

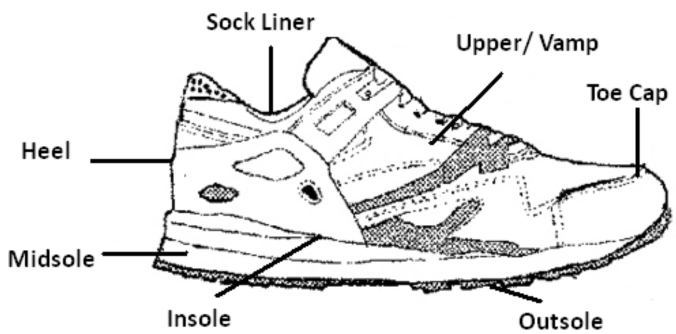


Figure 17. Shoe Components

Though Shoe 3 is considered part of the ecoSNEAKS product line, it also is composed of more conventional materials including synthetic virgin rubber and cow suede. Natural materials such as organic cotton as well as cow suede (leather) is used for the upper/vamp and heel; while virgin rubber is used for the toe cap and midsole and recycled car tire for the outsole.

Shoe 4 is made solely out of conventional shoe materials. The upper/vamp and heel are composed of cow suede (leather); the outsole, midsole and toe cap are composed of virgin rubber. This shoe has an EVA insole and nylon laces.

2.9 Production and Assembly of Simple Shoes 1 - 4

In addition to material production previously discussed, the production and assembly of a Simple shoe also generates negative environmental impacts. An evaluation of the processes and machines used throughout the production and assembly process can reveal opportunities to increase efficiency and reduce overall environmental burden by phasing out older or inefficient equipment, finding alternative resource inputs and implementing pollution control devices.

Simple Shoes manufactures their shoes in China, specifically in the city of Guangzhou. After the textiles, adhesives, rubber and plastic products have been received from sources located approximately 50 miles away; the materials begin a process of modification. Despite differences in material choices between the four shoes analyzed in this study (Shoe 1, Shoe 2, Shoe 3, Shoe 4), the materials and shoes are manufactured in a similar manner. The process of shoe manufacturing can be divided up into discreet phases: cutting, stitching, gluing, finishing and packaging.

General Process of Shoe Assembly

The cutting phase, commonly referred to as die-cutting, involves using a dye-cutting machine to cut upper and outsole materials to various dimensions based on the size of the shoe being produced (Fig. 18). Following the cutting phase, the uppers are sewed together and can be stitched to liners and outsoles with the use of industrial sewing machines (Fig. 19). The gluing phase involves the direct application of adhesives to the shoe outsole and midsole; while the finishing process involves a lasting machine to give the shoe its final shape as well as input foot beds and laces. In addition, each of these processes use other machines, including conveyor belts, mold pressing machines, rubber rollers, vulcanizing ovens (Fig. 20) and EDI machines.

Figure 18. Die Cutting Process (Simple Shoes, 2008)

Figure 19. Stitching Uppers (Simple Shoes, 2008)

Figure 20. Vulcanizing Ovens (Simple Shoes, 2008)

Shoe 1

Figure 21. Crepe Slab (Simple Shoes, 2007)

Shoe 1 is a part of the Green Toe line and is a designed for low impact use and hanging out with friends. The shoe contains jute uppers, a bamboo lining, removable natural latex and cork pedbed with a cotton canvas cover, bamboo linings, layered natural crepe outsole and uses water-based cements. The assembly process of the Shoe 1 involves dye cutting the jute uppers and stitching them to the felt lasting board. Attached to the felt lasting board is the crepe outsole and water based cement is applied to the crepe outsole to increase shoe durability (Fig. 21). After the adhesive has dried, the latex/cork pedbed is placed in the shoe (Fig. 22).

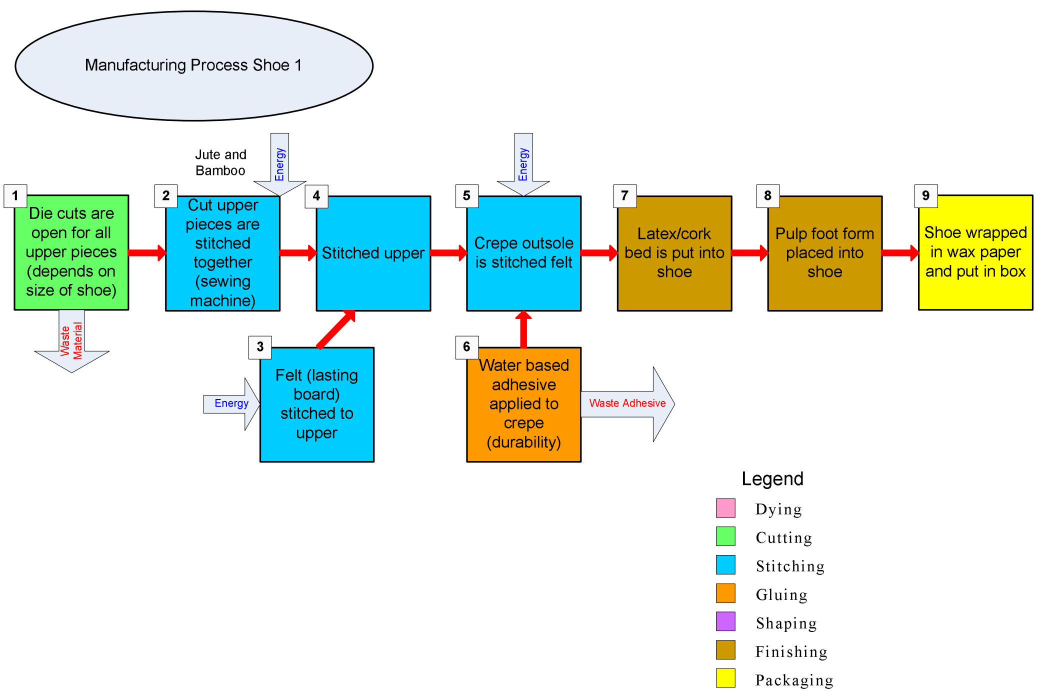


Figure 22. Manufacturing Flow Chart for Shoe 1

Shoe 2

Similar to the materials used in Shoe 1, Shoe 2 is also composed of natural materials including cotton uppers, bamboo and hemp lining, a removable natural latex and cork pedbed with a cotton canvas cover, crepe midsole and water based cements. The main difference is the use of recycled car tires for the shoes outsole. The production of this shoe involves die cutting cotton uppers and stitching them to the felt/crepe lasting board and the hemp and bamboo liners. The car tire is scuffed to increase its adhesion capabilities, die cut and imprinted with tread (Fig. 23). The car tire is attached to the crepe with water based cement. Following adhesion and drying the latex/cork pedbed is placed into the shoe (Fig. 24).

Figure 23. Car Tire Scuffing (Simple Shoes, 2008)

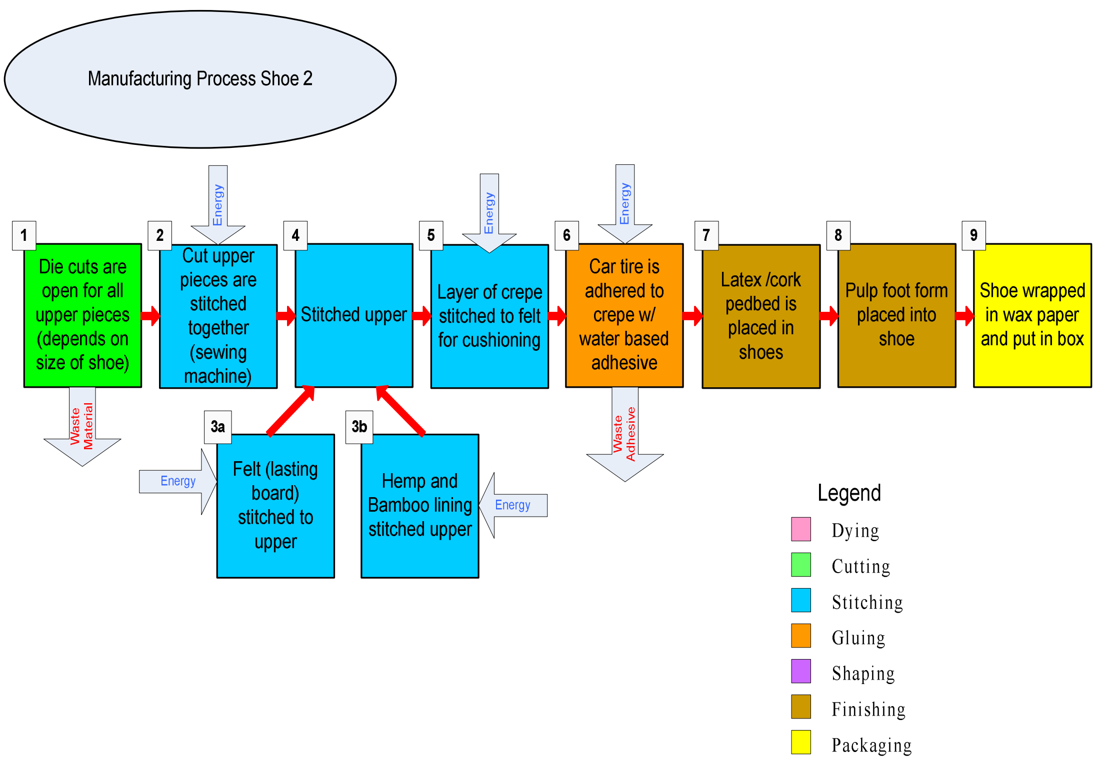


Figure 24. Manufacturing Flow Chart for the Shoe 2

Shoe 3

Shoe 3 is Simple Shoes newest product, which is part of the ecoSNEAKS collection and was launched in the fall of 2007. This manufactured good utilizes both natural and conventional materials to produce a product that is more compatible (design and function) with conventional sneakers (e.g. Converse, Adidas, Pumas). The assembly of this shoe involves die cutting and sewing washed leather, organic cotton canvas uppers and organic cotton linings. The car tire is scuffed, die cut and adhered with water based cement to the upper. Unlike the other shoes explored in this study, Shoe 3 wraps uncured rubber around the sidewall, toecap and heelcap of the sneaker to provide durability and an increase in design appeal. The shoes then run through a vulcanizing oven to bond and dry the rubber (Fig. 25). Subsequent to bonding, the PET pedbed is inserted and the shoe is laced with PET laces.

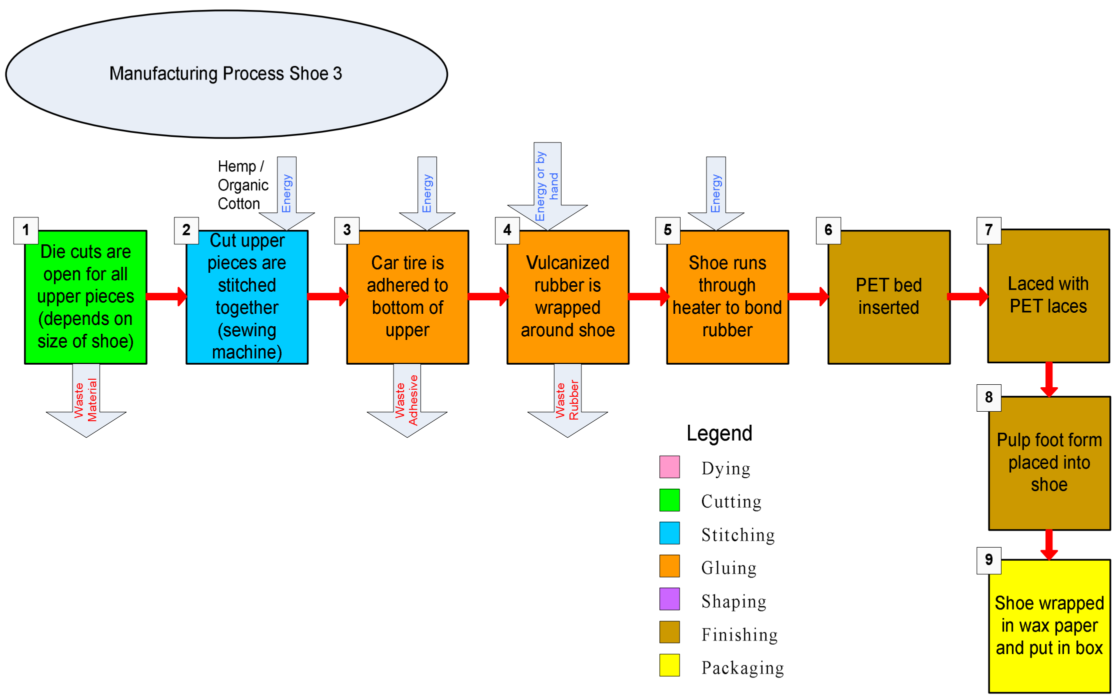


Figure 25. Manufacturing Flow Chart of Shoe 3

Shoe 4

This shoe is Simple Shoes seminal product and designed to compete with other popular skate and surf sneakers. Similar to the other shoes, the suede upper is die cut and stitched together to form the upper. The outer sole is generated by virgin rubber poured into a mold to produce the outsole and sidewall and this molded rubber is stitched to the cow suede upper. An EVA foam sock liner is glued into the shoe to form a spongy insole and the shoe is then laced with nylon laces (Fig. 26).

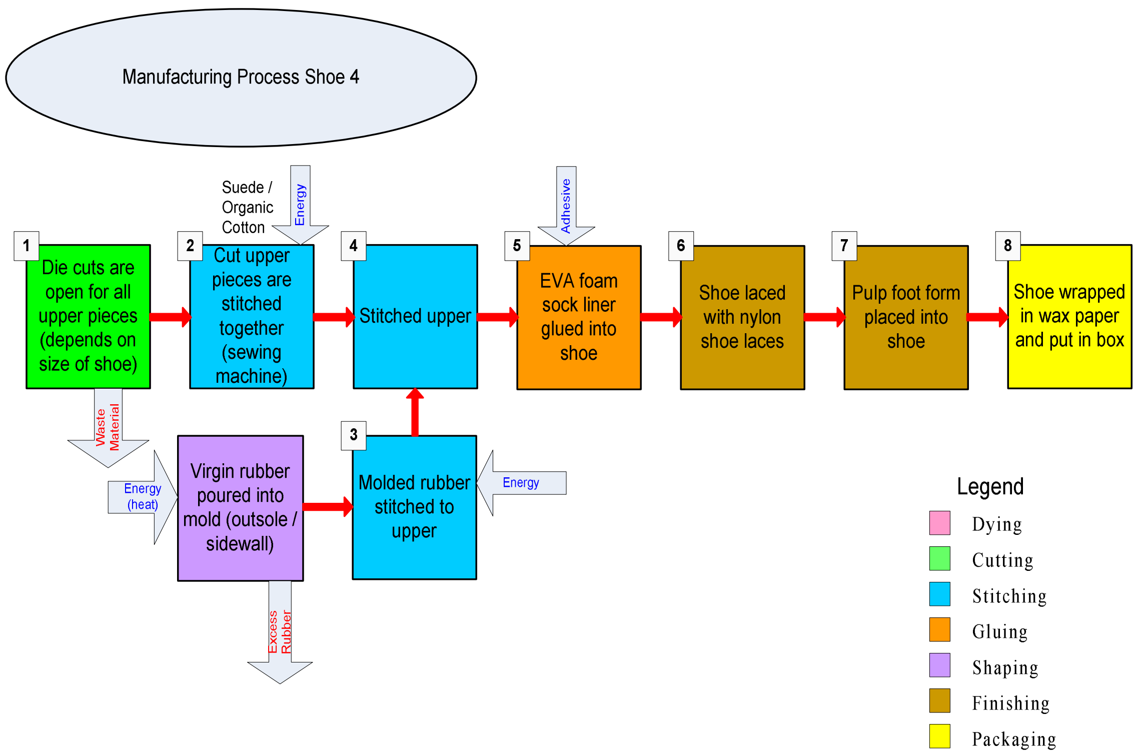


Figure 26. Manufacturing Flow Chart of Shoe 4

Shoe Packaging

After the shoes are assembled they are shipped to Simple Shoes warehouse in Ventura, CA. Simple Shoes has focused on developing innovative ways to change packaging composition and reduce packaging waste. As of July 2006, all packaging (boxes and pulp foot forms) are composed of 100% post-consumer waste. Further, the pulp foot forms used to maintain the shoe shape during shipping are dried outdoors using the most natural form of energy, pure sunlight. In addition, the company also began uses biodegradable bags (January 2007) for shipping its sandals (Simple Shoes, 2007).

Section 3 - Project Approach

The main goal of this project was to analyze the environmental performance of footwear in Simple Shoes product line. To do this, a general framework has been developed which involves assessing the products performance through the lens of the traditional supply chain, as well an expanded life cycle perspective of the supply chain. To examine the environmental product performance in this manner, the types of materials used in the products must be understood in addition to how those materials are extracted and their associated environmental burdens. It is necessary to recognize the production system, the elementary and economic inputs and outputs of that system and the assembly methods required to transform raw materials to intermediate goods and into finished goods. Further, a life cycle approach to supply chain management includes an evaluation of the use phase, as well as disposal and End of Life Management considerations. The approach has been divided into 4 sections and each of these parts contributes to the overall framework for analyzing and thinking about the environmental performance of footwear and options for End-of-Life Management**.**

1) *Quantify and compare the environmental impacts of the four shoes selected: Shoe 1, Shoe 2, Shoe 3, Shoe 4*

A qualitative and quantitative in-depth analysis of the material composition was performed for the four shoes pertinent to this study. This involved a comprehensive literature review and conducting informational interviews with Simple Shoes, as well as other experts in material science and the textile and footwear industry. The data gathered from these methods was visually represented in pie and process flow charts. These process flow charts then served as a baseline model for developing a complete LCA using the GaBi 4.0 software. The GaBi 4.0 software produced by PE America is one of the most widely used, user friendly and functional tools on the market that provide environmental quantitative data related to environmental and economic inputs and outputs of a product system. An LCA evaluates the environmental impacts of the materials and production system in the context of the environmental impact categories chosen. For this project, impact categories were selected based on both the research of environmental impacts caused by the textile and footwear industry and the needs of our client. The ten categories selected include acidification potential, eutrophication potential, freshwater aquatic ecotoxicity potential, global warming potential, photochemical ozone creation potential, human toxicity potential, ozone layer depletion potential, radioactive radiation, terrestrial ecotoxicity potential and marine aquatic ecotoxicity potential. Overall, the LCA provides a system which compiles and evaluates the inputs, outputs and environmental impacts of the products. LCA makes it possible to identify opportunities to improve environmental performance through interpretation of the LCA results. In addition, the knowledge acquired from the LCA can be used to facilitate strategic planning, priority setting and product design. For data that was not accessible, reasonable assumptions were used or data processes were left out. The LCA report includes full documentation of clearly stated assumptions and data limitations.

2) Assess Simple Shoes supply chain for these selected shoes by analyzing via the life cycle approach (raw production to disposal) opportunities within their extended supply chain for efficiency and environmental improvements.

The assessment Simple Shoes supply chain first involved learning about the stages and suppliers currently involved in production of their shoes from raw materials to finished goods, as well as the distribution channels. The ability to obtain only limited knowledge of the 1st, 2nd, and 3rd tier suppliers of the client was augmented with an in-depth literature review and informational interviews conducted with other businesses to learn about supply chain management strategies. The combination of these approaches was necessary to accurately assess Simple Shoes current supply chain and provide industry benchmarks for considering approaches for further enhancing their Simple Shoes supply chain.

***3) Generate End-of-Life management options, including a take-back framework, for Simple Shoes based on the feasibility, environmental benefits, and economic costs of the options*.**

An environmental and economic analysis of potential EoL Management strategies was performed. This included evaluating both qualitatively and quantitatively the advantages, drawbacks and costs of the collection and processing strategies for EoL products in general and more specifically for footwear. The evaluation of these strategies was based on literature review and informational interviews (phone and email) with individuals in the waste management sector, companies who are reprocessing footwear and recycling textiles and non-profit programs involved in charitable donations. Based on the degree of feasibility, environmental impact and economic costs, a range of possible take-back programs for Simple Shoes has been devised. For information that was not able to be obtained, conservative and educated estimates were used.

4) Present scenarios and recommendations to Simple Shoes based on LCA and environmental and economic analysis.

A combination of in depth literature review, informational interviews and the results of the LCA and the environmental and economic analyses were used to generate take-back scenarios, a recommended end of life strategy and more general environmental management recommendations. The prioritization of the various take-back programs is two-fold: those scenarios which require minimal effort on the part of the client and those scenarios that will alleviate the greatest environmental burden. Recommendations provided to the client were based on the LCA, supply chain and EoL results.

Section 4 - Life Cycle Assessment: Product System Modeling Using GaBi

4.1 SCOPE OF LCA

Scope

This LCA examines the product systems of the four shoe styles pertinent to this study (Shoe 1, Shoe 2, Shoe 3 and Shoe 4) to evaluate the individual environmental performance of the product system and how it compares to other product systems being analyzed. Each of the systems is evaluated based on the functional unit and consistent methodology allows for the environmental impacts of the four product systems to be compared equally.

Data used in this LCA has been obtained from industry and academic literature, confidential client information, a mix of measured and calculated raw data, as well data inherently in the GaBi 4.0 software. Further, this study is limited primarily by data availability and software processes and these limitations have been taken into consideration during critical review of the LCA.

Functional Unit

The amount of material required to cover and protect two sample sized feet (pair of shoes)

- Men = US 9
- Women = US 7

Reference Flow

Amount of actual material required to fulfill the functional unit. (Source: Simple Shoes, 2007)

- (Men's 9) Shoe 1: 345 grams of material
- (Men's 9) Shoe 2: 424 grams of material
- (Women's 7) Shoe 3: 278 grams of material
- (Men's 9) Shoe 4: 396 grams of material

System Boundaries

The inputs and outputs of this system range from the production of raw materials to the disposal of the shoes to landfill. Within this system, the process of shoe assembly includes only energy information and there are no processes for the use phase due to lack of data availability. Further, this LCA does not include the disposal of process wastes or the manufacturing of ancillary materials. In addition, the inputs and outputs from production lifecycles associated with the building of the machines, the manufacturing facilities and transportation vehicles, as well as additional operations (lighting, heating of building and production of fuels and electricity) are not being considered due the lack of available raw data to support a credible assessment.

Data Collection, Calculation, Quality and Verifiability for Study

Data quality indicators (DQI) are used to evaluate the completeness of the data, its origins and the data's overall representation of the process, plans and balance of the systems. The quality of data, from both a regional and temporal aspect, as well as the system boundaries is consistent among each of the four product systems. The data processes used were selected from either the PE-G or Buwal databases available in the software and the databases are dated January 11, 2006. Depending on the data processes, the country of origin associated with that process has been chosen as China or U.S. where appropriate. For those processes, where neither China nor the U.S. was available, RER (Europe) has been used.

Environmental Impact Categories, Category Indicators and Selection Rationale

The environmental impact categories and associated category indicators for this LCIA, and LCA have been selected based on the research of both the environmental impacts caused by the textile and footwear industry and the needs of our client. The ten categories selected are listed below.

All of the impact categories are derived from the characterization model CML2001 that is provided in the GaBi 4.0 software. This model was created by the Leiden University and was chosen because it provides the most pertinent, comprehensive, peer reviewed and recent list of impact categories. The results of the Life Cycle Inventory are assigned to the impact categories listed below, creating category indicator results. The results of the LCIA and LCA have been presented in either absolute terms or normalized to world values. The process of normalization involves dividing the absolute emissions by the total world emissions to provide a fraction of the product systems contribution to world emissions.

- **Acidification Potential** (AP), [kg SO_2-equivalent] - AP is the measure of a compound's contribution to acidification, the process whereby specific air pollutants are converted into acid rain. Acid rain damages forests, lakes, freshwater and coastal ecosystems, man-made structures, and leaches heavy metals from soils into groundwater. The primary air pollutants which cause acidification, sulfur dioxide SO_2, ammonia NH_3, and nitrogen oxides NO_x, are mainly emitted by burning fossil fuels (European Environmental Agency, 2008).

- **Eutrophication Potential** (EP), [kg Phosphate-equivalent] - EP is the measure of a chemical compound's contribution to eutrophication, the process in which excess nutrients are added to an aquatic ecosystem. Eutrophication occurs when the addition of a limiting plant nutrient, usually nitrogen or phosphorus, causes increased algal growth. The algal growth and decay decreases dissolved oxygen in the water causing aquatic life to die (Cloern, 2007).

- **Freshwater Aquatic Ecotoxicity Potential** (FAETP), [kg DCB-equivalent]
  Terrestrial Ecotoxicity Potential (TETP inf.), [kg DCB-equivalent]
  Marine Aquatic Ecotoxicity Potential (MAETP inf), [kg DCB-equivalent]
  Human Toxicity Potential (HTP inf.), [kg DCB-equivalent]
  The toxicity potential of all of the above environmental impact categories are measured in 1,4- Dichlorobenzene (DCB) equivalent. DCB ($C_6H_4Cl_2$) is an organic compound primarily used as a pesticide or disinfectant. The toxicity of each category (freshwater, terrestrial, marine and human) is determined by the chemical and toxicological properties of chemical based on the model CalTox. This generic fate and exposure model determines the numerous exposure routes. These routes include the inhalation of gases and particles, ingestion or direct cutaneous absorption (Hertwich et. al. 2006) resulting in skin, eye or throat irritation, damage to the liver and central nervous system and even death in flora and fauna (EPA, 2008).

- **Global Warming Potential** (GWP 100 years), [kg CO_2-equivalent] - GWP measures the radiative forcing (W/m^2) of greenhouse gas emissions relative to CO_2 over the course of 100 years (EPA, 2006). .Climate change is a growing concern for the textile and footwear manufacturing industry. In light of proposed carbon regulations it is important for companies to be aware of their greenhouse gas emissions.

- **Ozone Layer Depletion Potential** (OLDP), [kg R-11-equivalent] - OLDP is the measure of a chemical's potential to destroy stratospheric ozone molecules relative to trichlorofluoromethane (or R-11, CFC-11.Freon-11) (EPA 2007). Despite the Montreal Protocol banning the production of CFCs, ozone depletion remains a significant environmental concern. Continued ozone layer depletion causes severe health impacts (cancer, cataracts), as well as damage to aquatic ecosystems.

- **Photochemical Ozone Creation Potential** (POCP), [kg ethane-equivalent] - Combustion processes emit volatile organic compounds (VOC's) which react with nitrogen oxides in the presence of sunlight to produce ozone. Ozone in the troposphere (ground-level ozone) causes human health problems and ecological damage (EPA, 2004). Ozone-forming emissions are subject to regulation under the Clean Air Act. Ethane (IUPAC name ethylene) is used as the category indicator because it is one of the most important ozone-forming VOC species and its chemical degradation pathways are well-defined (Derwent et al., 1996).

- **Radioactive Radiation (RAD), [DALY]**
  RAD refers to the release of materials capable of emitting ionizing radiation as

waves or particles. The natural environment possesses varying degrees of background radiation caused by solar energy or terrestrial sources (potassium and uranium), but human contributions of radioactive materials can lead to radiation levels which can cause biological harm, including damage to DNA and cells. RAD is measured in disability-adjusted life year (DALY) which counts years of 'healthy' life lost due to poor health. One DALY is equivalent to one lost year of 'healthy' life. (Australian Government, 2006)

Life Cycle Inventory Analysis & Life Cycle Impact Assessment Assumptions

Due to the limited data available for this study, assumptions regarding the footwear production and distribution system were made. It is important to note, that the use of assumptions have the potential to influence the output of the LCA, as well as impose limitations. Therefore, it is critical that all assumptions made during this study were consistent across all four shoes. This consistency diminishes any inaccuracies that would affect the relative impacts of each shoe. The assumptions fall into five categories: general, material, transportation, packaging, and EoL.

General Assumption

- The use phase has minimal environmental impact and is not used in this system.
- The lifetimes (primary use phases) for the four shoes pertinent to this study are similar and therefore do not affect the analyses.

Material Assumptions

- All of the natural fiber materials (hemp, jute, organic cotton and bamboo) go through a production process to convert raw fibers into a fabric that is similar to cotton production process. For this reason the cotton production process is assumed as representative and the ratios of inputs and outputs remain constant.
- The process of polyethylene terephalate granulate was chosen as it most closely resembles the PET used by Simple Shoes.
- The production of styrene-butadiene (car tire) is not included and only the weight of the material is accounted for in transportation and the energy applied during assembly. This assumption is based on the fact that car tire production would occur regardless of the presence of Simple Shoes.

Transportation Assumptions

- After evaluating the distance traveled and researching common transportation vehicle used in both China and the US to carry various loads of commodities, it was assumed that the following vehicles are utilized in this supply chain (table 1).

Table 1. Vehicle and associated capacities

Vehicle Type	Capacity
Truck(local fleet)	9.3 ton payload
Truck-trailer	22 ton payload
Ocean Container Ship	27500 dead weight ton

- The utilization ratio, the percentage of the payload that is actually used, is 85%.
- The average distance from Simple Shoes' Ventura, CA warehouse to retail stores (3,504 stores) where their product is sold is 1,801 miles. This distance has been calculated by grouping the retailers by their zip codes (first two digits).

Packaging Assumptions

- The weight of the master shipping carton has been allocated to account for one shoe box. The packaging materials used in the LCA were chosen as they most closely resemble the materials utilized by Simple Shoes.
- Simple Shoes' packaging processes requires minimal energy input. Based on literature review a energy value of .261MJ has been used (Patagonia, 2007)
- The benefit of using recycled packaging materials has only been incorporated into the model once, at the materials initial use.
- It is assumed that a percentage of the packaging materials (paper and cardboard) will be recycled and not sent to landfill.

End of Life Assumptions

- The disposal of municipal solid waste to landfills in the United States is handled on a per county basis. The jurisdictional nature of this process suggests that the distance between consumer and landfill is minimal. In addition, the impacts associated with the transfer of the commodity itself are aggregated with other products also destined for landfill disposal.
- The output of power generated from landfill gas energy capture is considered a net benefit in this LCA. However, this net benefit of power is not incorporated into the system to offset primary production.
- Recycling processes for the various materials utilized by Simple Shoes are excluded in this LCA. Without fully identifying recycling centers capable of reprocessing the materials pertinent to this study and calculating their associated distances, there is an inadequate basis for performing this assessment.

Life Cycle Inventory Analysis & Life Cycle Impact Assessment Limitations

General Limitations

- Little process information is available based on China and US standards, making this LCA heavily based on European standards. Although this is a limitation, the shoes are being compared to each other making the assumptions and consequently errors consistent throughout all of the LCA's.
- There are limitations due to the nature of the software and the data availability. Certain data processes were unavailable and some processes used in the product system do not contain a complete set of reportable emissions. This results in a data gap that decreases the robustness of the results.
- The energy used to manufacture each shoe was aggregated into a single value, provided Simple Shoes and this value were used consistently in each of the LCA's. Differences in shoe production techniques and assembly locations may create differences in actual energy usage. Examining the differences in energy consumption or a more thorough analysis of the shoe assembly system for the different shoes would have made the results more robust.
- By not having more information related to the use phase (consumer behavior, durability of shoes and environmental impacts of wear) the results of the analyses may be underestimated.
- The assumption that the lifetime of the four shoes studied is the same, may not be accurate in real life. The durability of the shoes, consumer behavior and fashion trends will effect the lifetime of the shoes.
- The study was potentially limited by not performing a sensitivity analysis. Due to time constraints, failure to perform this analysis limits the ability to examine the effects of variations within the process data, the system boundaries, allocation and modeling choices. Overall, the reliability and robustness of the LCI and LCIA results is potentially decreased.

Material Limitations

- Due to the limitations of the software system, the material production processes of cork, jute and bamboo are unaccounted. The weights of these materials, as well as other minor materials have been aggregated and are accounted for in transportation.

Transportation Limitations

- The diesel used for trucks in China is based on industry standards for EU diesel. The chemical makeup of these diesels may be different.
- By calculating the distance from the retail stores to the Ventura warehouse only using the first two digits of the zip code, the process potentially loses a level of detail and accuracy. The LCA does not consider the distance from the Warehouse to consumers who purchased the shoes on-line and is therefore an incomplete representation.

End of Life Management Limitations

- Recycling rates of cardboard may differ based on region and would affect the allocation of cardboard to recycling center vs. landfill.
- Failure to include the recycling processes for materials capable of being recycled limits the robustness of our LCA.

4.2 LIFE CYCLE INVENTORY ANALYSIS (LCIA)

Data Collection for LCIA

As discussed in Section 4.1, the data used for the assessment came from a variety of sources. A majority of the information used in this LCIA has been collected from Simple Shoes. If data was unavailable (e.g. related to the use phase, details about shoe assembly process, recycling processes) a place holder process (box to represent data or phase) was created and inserted into the plan. In addition, the weights of certain shoe materials (nylon thread, eyelets and adhesives) are considered negligible.

Description of Unit Processes and the Four Product Systems

The four product systems differ only in the materials and the material quantities (reference flows) necessary to achieve the functional unit. The table in appendix II describes the system process (material or product phase) the basic primary inputs required and the general outputs. The reference flow and individual quantities related to the functional unit are not disclosed to protect client confidentiality (Appendix II, Exhibit A).

4.3 Life Cycle Impact Assessment (LCIA)

Presentation of LCIA Results

Shoe 1

Toxicity potentials (TETP, MAETP and HTP) have the greatest impacts (Table 1). HTP is nearly 4.5 times greater in magnitude than global warming potential and the environmental impacts associated with ODP demonstrate the least impact. The environmental impacts associated with the main phases of the supply chain indicate that materials production and manufacturing is the most impactful phase, followed by EoL, transportation and packaging (Table 2). (Appendix II-A, B)

Table 2. Normalized values of emissions for each impact category, Shoe 1

Environmental Impact Category	Normalized Indicator Results
Acidification Potential	5.70E-14
Eutrophication Potential	2.56E-14
Freshwater Aquatic Ecotoxicity Potential	1.98E-14
Global Warming Potential	3.76E-14
Human Toxicity Potential	1.70E-13
Ozone Depletion Potential	2.87E-15
Photochemical Ozone Creation Potential	8.78E-14
Radioactive Radiation	1.05E-13
Terrestrial Ecotoxicity Potential	1.47E-10
Marine Aquatic Ecotoxicity Potential	2.74E-13

Table 3. Percentage contribution of emissions at each life cycle phase to selected environmental impact categories, Shoe 1

Major Lifecycle Phases	% Contribution of emissions per phase (Absolute Value)				
	AP	EP	FAETP	GWP	HTP
End-of-Life	0.7	15.78	0.12	15.39	0.01
Transportation	18.97	10.81	0.97	11.84	0.08
Materials Production and Manufacturing	78.42	71.5	98.07	68.25	99.86
Packaging	1.91	1.92	0.84	4.53	0.05
Major Lifecycle Phases	**ODP**	**POCP**	**RAD**	**TETP**	**MAETP**
End-of-Life	0.03	1.59	0.08	0	1.43
Transportation	0.02	4.98	0.07	0	2.53
Materials Production and Manufacturing	99.12	92.45	99.85	100	90.7
Packaging	0.83	0.99	0	0	5.34

Shoe 2

Similar to shoe 1, the environmental impacts of shoe 2 are greatest for MAETP and HTP (Table 3). Shoe 2 also exhibits relatively high impacts for POCP and AP. The magnitude of impacts associated with POCP is 1.5 times greater than the products' GWP, and the impact of GWP is 1.7 times greater than ODP. The phase of materials production and manufacturing, similar to Shoe 1 is the most impactful phase, followed by transportation, EoL and packaging (Table 4). (Appendix II-C, D)

Table 4. Normalized values of emissions for each impact category, Shoe 2

Environmental Impact Category	Normalized Indicator Results
Acidification Potential	4.78E-14
Eutrophication Potential	2.16E-14
Freshwater Aquatic Ecotoxicity Potential	1.66E-14
Global Warming Potential	3.78E-14
Human Toxicity Potential	1.44E-13
Ozone Depletion Potential	2.23E-15
Photochemical Ozone Creation Potential	6.18E-14
Radioactive Radiation	1.05E-14
Terrestrial Ecotoxicity Potential	1.25E-14
Marine Aquatic Ecotoxicity Potential	2.57E-13

Table 5. Percentage contribution of emissions at each life cycle phase to selected environmental impact categories, Shoe 2

Major Lifecycle Phases	% Contribution of emissions per phase (Absolute Value)				
	AP	EP	FAETP	GWP	HTP
End-of-Life	1	22.47	0.17	18.43	0.01
Transportation	26.35	14.91	1.35	13.74	0.12
Materials Production and Manufacturing	70.37	60.35	97.48	63.32	99.81
Packaging	2.28	2.27	1.01	4.5	0.06
Major Lifecycle Phases	**ODP**	**POCP**	**RAD**	**TETP**	**MAETP**
End-of-Life	0.05	2.72	0.1	0	1.84
Transportation	0.04	8.25	0.08	0	3.15
Materials Production and Manufacturing	98.85	87.64	99.82	100	89.3
Packaging	1.06	1.4	0	0	5.7

Shoe 3

The environmental impacts of TETP, MAET and HTP generate the greatest impacts of the product system. The impacts of HTP are nearly 6 times the magnitude of GWP and GWP is almost 3 times the magnitude of ODP (Table 5). The phase of materials production and manufacturing is the most impactful phase, followed by transportation, EoL and packaging. (Table 6) (Appendix II-E,F)

Table 6. Normalized values of emissions for each impact category, Shoe 3

Environmental Impact Category	Normalized Indicator Results
Acidification Potential	3.06E-14
Eutrophication Potential	1.16E-14
Freshwater Aquatic Ecotoxicity Potential	2.04E-14
Global Warming Potential	4.06E-14
Human Toxicity Potential	2.10E-13
Ozone Depletion Potential	1.38E-15
Photochemical Ozone Creation Potential	2.45E-14
Radioactive Radiation	1.15E-13
Terrestrial Ecotoxicity Potential	1.81E-10
Marine Aquatic Ecotoxicity Potential	5.21E-13

Table 7. Percentage contribution of emissions at each life cycle phase to selected environmental impact categories, Shoe 3

Major Lifecycle Phases	% Contribution of emissions per phase (Absolute Value)				
	AP	EP	FAETP	GWP	HTP
End-of-Life	1.08	28.4	0.09	11.77	0
Transportation	30.33	20.21	0.81	9.4	0.06
Materials Production and Manufacturing	65.04	47.22	98.82	74.64	99.89
Packaging	3.56	4.17	0.82	4.19	0.04
Major Lifecycle Phases	**ODP**	**POCP**	**RAD**	**TETP**	**MAETP**
End-of-Life	0	4.71	0.06	0	0.62
Transportation	0.04	15.31	0.05	0	1.14
Materials Production and Manufacturing	98.19	76.45	99.89	100	95.43
Packaging	1.72	3.53	0	0	2.81

Shoe 4

The environmental impact categories of TETP and RAD are significantly greater than the other eight environmental impact categories evaluated. The impact of RAD is over 8 times the magnitude of GWP (Table 7). Similar to the other products evaluated, the environmental impacts vary across the four major phases of the shoe life and the phase of materials production and manufacturing by far is the most impactful phase, followed by transportation, EoL and packaging. (Table 8) (Appendix II-G,H)

Table 8. Normalized values of emissions for each impact category, Shoe 4

Environmental Impact Category	Normalized Indicator Results
Acidification Potential	2.32E-13
Eutrophication Potential	1.39E-13
Freshwater Aquatic Ecotoxicity Potential	7.99E-14
Global Warming Potential	1.69E-13
Human Toxicity Potential	8.24E-13
Ozone Depletion Potential	1.47E-15
Photochemical Ozone Creation Potential	3.69E-14
Radioactive Radiation	1.45E-13
Terrestrial Ecotoxicity Potential	7.13E-10
Marine Aquatic Ecotoxicity Potential	1.56E-12

Table 9. Percentage contribution of emissions at each life cycle phase to selected environmental impact categories, Shoe 4

Major Lifecycle Phases	% Contribution of emissions per phase (Absolute Value)				
	AP	EP	FAETP	GWP	HTP
End-of-Life	0.2	3.43	0.03	3.99	0
Transportation	5.16	2.24	0.27	2.92	0.02
Materials Production and Manufacturing	94.17	93.97	99.49	92.08	99.97
Packaging	0.47	0.36	0.21	1.01	0.01
Major Lifecycle Phases	**ODP**	**POCP**	**RAD**	**TETP**	**MAETP**
End-of-Life	0.07	4.41	0.07	0	0.29
Transportation	0.05	13.12	0.05	0	0.49
Materials Production and Manufacturing	98.27	80.13	99.88	100	98.27
Packaging	1.61	2.35	0	0	0.94

Comparison of Shoes within Impact Categories

Table 9 illustrates how each shoe style performs across the different environmental impact categories. Shoe 4 generates the highest potential impacts in eight of the ten categories examined. Shoe 1 produced the highest potential impacts in the remaining two categories of ODP and POCP. The environmental performance of Shoe 2 and Shoe 3 consistently lies between the poor performance of shoe 4 (highest environmental impact) and the best performing product, shoe1 (lowest environmental impact). Numbers highlighted in red represent the largest values.

Table 10. Comparison of shoe styles across impact categories (absolute value)

Shoe Styles	AP [kg SO2-Equiv.]	EP [kg P-Equiv]	FAETP [kg DCB-Equiv.]	GWP [kg CO2-Equiv.]	HTP [kg DCB-Equiv.]
Shoe 1	0.0171	0.0033	0.0402	1.672	8.482
Shoe 2	0.0143	0.0028	0.0338	1.681	7.189
Shoe 3	0.0092	0.0015	0.0414	1.808	10.469
Shoe 4	0.0695	0.0179	0.1623	7.51	41.03

Shoe Styles	ODP [kg R11-Equiv.]	POCP [kg Ethene-Equiv.]	RAD [DALY]	TEPT [kg DCB-Equiv.]	MAETP [kg DCB-Equiv.]
Shoe 1	1.48E-06	3.99E-03	1.40E-08	39.42	140.25
Shoe 2	1.15E-06	2.81E-03	1.41E-08	33.35	131.28
Shoe 3	7.10E-07	1.12E-03	1.54E-08	48.51	266.61
Shoe 4	7.59E-07	1.68E-03	1.95E-08	190.96	796.12

4.4 Life Cycle Interpretation

Across all shoe styles, using normalized values, TEPT generated the greatest impact. A primary reason for this may be due to the nature of the materials used by Simple Shoes. The production of all the raw materials (natural or synthetic) requires the consumption of natural resources. The next largest impact categories are MAETP and HTP. The high impacts associated with HTP may be directly related to the degree of interaction between the workforce and the materials used in the shoes. The alternative materials (conventional cotton, organic cotton, hemp, crepe rubber, natural latex) must be harvested from the natural environment and transformed into a usable fabric or intermediate product. This action requires individuals to directly handle or be exposed to the raw materials, ancillary chemicals, as well as the fertilizers and pesticides used in the fields.

There currently exists no international consensus on toxicity characterization methods, so it is important when evaluating or weighting the importance of toxicity impacts that the elementary flows also be considered.

Of the environmental impact categories evaluated GWP ranks sixth, followed by POCP and EP. The least environmental impact of the four product cycles occurs in the form of ODP (Table 10).

Table 11. Average normalized values for each selected environmental impact categories

Environmental Impact Category	Normalized value
TEPT [kg DCB-Equiv.]	2.93E-10
MAETP [kg DCB-Equiv.]	6.53E-13
HTP [kg DCB-Equiv.]	3.38E-13
RAD [DALY]	1.18E-13
AP [kg SO2-Equiv.]	9.18E-14
GWP [kg CO2-Equiv.]	7.13E-14
POCP [kg Ethene-Equiv.]	5.28E-14
EP [kg P-Equiv]	4.93E-14
FAETP [kg DCB-Equiv.]	3.43E-14
ODP [kg R11-Equiv.]	1.99E-15

As Table 9 indicates, the GWP for shoes 3 and 4 are higher than for the other shoe styles studied. These high GWP values may be attributed to the fact the components of Shoe 3 and 4 are more aligned with conventional footwear materials that traditionally require more energy intensive processes resulting in higher CO_2 emissions. Reasons for the high POCP impact in shoes 1 and 2 may also be related to the material composition. These shoes are composed of materials which are primarily plant based and release ethane which is a VOC and capable of creating smog.

The results indicate that across all of the shoes studied the greatest impact across all environmental impact categories occurs in the materials production and manufacturing phase. Though, it would be helpful to understand the exact processes involved in materials production and shoe manufacturing that are responsible for these impacts, the results are still beneficial as they indicate where efforts by Simple Shoes should be focused. The next most impactful phases are transportation and EoL. The physical nature of Simple Shoes' supply chain necessitates that the shoes travel a great distance from raw material procurement to distribution in retail stores, it may be valuable for Simple Shoes to manage the impacts associated with transportation by adjusting vehicle mode, sourcing distances and increasing the amount of product shipped at one time.

The EoL option utilized in this study was landfill. Increased knowledge on the environmental impacts and space scarcity issues associated with landfills serve as primary reasons to avoid disposal to landfill. Our study found that even if the shoe were disposed of to landfill, it was still nearly 90% less impactful across all environmental impact categories compared to materials production and manufacturing. The packaging is the least impactful of the four phases and the reasons for this may be attributed to the use of post consumer packaging materials.

Recommendations and results of study can be found in Section 7

Section 5 - Supply Chain Management Options

5.1 Introduction

This section explores opportunities to improve efficiency and environmental performance of Simple Shoes extended supply chain (defined below) for a pair shoes through materials substitution and environmental management standards for first and second tier suppliers, resulting in recommendations for the creation of a new supply chain. To demonstrate how this process can be applied across one's product line, the existing supply chain is considered for a pair of Shoe 4 shoes against the additional, newly created supply chain associated with the Green Toe and ecoSNEAKS lines to qualitatively and quantitatively assess the impacts of the proposed supply chain management changes. This section will first look at the existing extended supply chain processes and agents, and then detail the investigated supply chain management changes that result in the creation of a new supply chain. Next, the recommended changes in terms of environmental and economic impacts will be compared for trade-offs between the two factors.

5.2 Existing Extended Supply Chain

The extended supply chain can be defined simply as the collection of agents that have an impact on a given product line across the product's life cycle. This differs from the conceptualization of the traditional supply chain because it includes end-of-life management. Tracing the extended supply chain of any product can be difficult due to the completely disintegrated nature of today's global marketplace. If one adds in the fact that most corporations are hesitant to divulge proprietary information, this task becomes even more complicated. This sections attempts to accurately represent the extended supply chain for a pair of Shoe 4 shoes. As with any manufactured goods, the traditional supply chain encompasses all the life cycle stages of the product from raw material extraction to product sale and/or delivery (Fig. 27).

Source: Geyer – ESM 289 – Green Supply Chain Management, Spring '07

Figure 27. Traditional Supply Chain

A supply chain is generally defined as "a network of facilities that procure raw materials, transform them into intermediary goods and then final products, and deliver the products to customers through a distribution system" (Billington, 1995).

5.3 Description of Investigated Supply Chain Management Changes

According to Monica DeVreese and Greg Nielson, "HOW we make our shoes is just as important as WHY we make," and they are committed to making products that our 100% sustainable. This statement and commitment are the main components of the Simple Shoe mission. For this reason, Simple Shoes began to replace traditional materials with substitutes that would reduce environmental impacts and attempt to increase economic value-added through every process in the supply chain. The materials substitutions were suggested in this section are the result of a detailed life-cycle inventory analysis (LCIA) and qualitative review of the environmental impacts of the materials. This allowed selecting materials based on their toxicity, contribution to global climate change, ability to be recycled or even downcycled, and overall ability to meet the requirements of shoe consumers. Another key element for consideration is the avoidance of blended materials, defined by Bill McDonough as "monstrous hybrids", because these materials cannot be separated into their useful technical and biological parts and are thus lost into landfills after their useful life (McDonough and Braungart, 2002). Based on the results of the analysis described above, Simple Shoes should eliminate "technical nutrients" in the production of footwear, unless technology can be developed to completely remove these nutrients from the spent shoes. "Technical nutrients" are defined as a material or product that is designed to return to the technical cycle, examples might be synthetic chemicals and fabrics. We believe that shoes made completely of biodegradable materials could be discarded on the ground and left to decompose and release their nutrients to the soil, however further research into the fate and transport of pollutants from spent, discarded footwear would be required to prove/disprove this theory. If Simple Shoes finds it impossible to completely remove technical nutrients from their footwear, than a concerted effort to design the footwear to be recycled must be undertaken at the start. This is often referred to as design-for-disassembly (Dowie-Bhamra, 2003).

It should be noted that Simple Shoes has already incorporated many of these changes into the materials inventories for their shoes but has done so somewhat opportunistically, as seen with the Green Toe product line. Detailed below are the material substitutions we have identified between Shoe 4 and footwear from the Green Toe line (Table 12).

Table 12. Materials Inventory

Material Type	Percentage
Bamboo	4.06%
Cotton	3.77%
Crepe	37.68%
Hemp	17.10%
Latex	33.62%
PET (Combined)	3.77%

Shoe 4 – Original Materials

- Laces, Threads - Cotton
- Outsole – Rubber
- Midsole - EVA
- Upper - Suede

- Adhesives – Chemical Based (Phenol/Urea)
- Packaging - Primary Cardboard

Green Toe Shoes and ecoSNEAKS – Alternative Materials

- Laces, Threads – Organic Cotton, Jute, PET
- Outsole – Crepe, Recycled and Retreaded Car Tires
- Midsole/Insole – Wool Felt, Cork, Recycled PET
- Insole/Liner – Bamboo, Organic Cotton
- Upper – Hemp, Jute, Wool Felt
- Adhesives – Water-Based Glue
- Packaging - Post-Consumer Recycled Cardboard

5.4 Environmental Evaluation of the Investigated Supply Chain Management Changes

The alternative materials that Simple Shoes uses in its Green Toe and ecoSNEAKS lines also have environmental impacts. These impacts are related to agricultural production which consumes land, water, and energy; pollutes water with excess nutrients; and can use harmful pesticides/herbicides. The fiber-crops that Simple Shoes uses for its Green Toe line were selected because they minimize these impacts compared to other crops. Another environmental benefit of plant-based materials is that they are biodegradable at the shoe's end-of-life disposal, e.g. biological nutrients.

Analyzing the Environmental Performance and Energy Use of Materials

The results of the LCA provided information related to the environmental performance of the shoes across their life cycle and obviated the fact that most of these impacts occurred during the production and manufacturing stages, but further investigation was needed to provide information about the individual contributions of materials to environmental impact. To determine if the materials used in the Green Toe line released fewer harmful pollutants into the air and water during their production and disposal, the materials were further evaluated on a kg-to-kg basis, using data from the LCA software to calculate the environmental performance of the materials and compare them to each other. Using the environmental indicator of kg of CO_2 equivalent, the relative Global Warming Potential (GWP) of producing 1 kg of these materials was compared

Generally the results showed that 1 kg of leather had a GWP approximately five times greater than any other material. Synthetic rubber and plastic, such as PET, EVA, Nylon 6, and PU Foam, had a GWP score between 5-10 kg CO_2 equivalent. The results for the GWP can be found in Appendix III-C.

Table 13. Primary Production Energy (Net Caloric Value) - In/Out Aggregation

Material	Amount (MJ)
Crepe Rubber	0.30
Hemp	2.44
Organic Cotton	16.18
Ethylene Vinyl Acetate (EVA)	16.57
Cotton	18.77
Polyethylene Terephthalate (PET)	22.77
Polyurethane (PU) Foam	27.63
Silicone Rubber	47.25
Nylon 6	55.59
Leather	56.95

Source: PE International (GaBi 4.0) Extended DB

Another objective was to calculate the energy required to produce one kg of the materials used in Shoes 1-4. Using the system processes within the LCA it was shown that the materials used in the Green Toe and ecoSNEAKS lines require less energy than those from the traditional line (Table 13). In/Out Aggregation refers to the net caloric energy (energy out – energy in = in/out aggregation) for each material.

To identify Simple Shoes relative control over processes in their existing supply chain against the environmental impacts associated with these processes, a matrix was generated (Appendix III-D). The matrix also allows Simple Shoes to determine hot spots within their supply chain where their relative control over an actor/process is high and the potential environmental payoff for adjusting their practices is also high. According to this qualitative analysis, the highest environmental impacts occur during the extraction and production phases of the materials, yet the only real control Simple has over this processes is in the quality of the finished material they purchase. The matrix also demonstrates that EoL management options have moderate environmental impact, yet currently Simple has little control over them. Based on this analysis, it would seem that Simple has made a step in towards addressing the materials/production impacts by shifting towards alternative materials, which have less of an impact.

5.5 Economic Evaluation of the Investigated Supply Chain Management Changes

According to a recent article in Industry Week, the supply chain of a company accounts for 75% of its direct costs (Moroski, 2007). Any changes to the structure of a companies' chain can therefore have a direct impact on the flow of monetary resources between players along the supply chain. After making a commitment to sustainability both in product and practice, Simple Shoes developed an additional supply chain to fulfill that commitment. The development of an additional supply chain to meet

Simple's goal of 100% sustainability could potentially increase short-term costs on raw materials, research and development, and manufacturing, while leading to decreased costs associated with manufacturing through closed-loop systems (e.g. recycling and take-back).

In addition to changes in direct costs, the success of the extended supply chain is dependent on the ability for Simple Shoes to develop strong business relationships with their upstream suppliers and downstream consumers, as well as supply chain coordinators, facility managers and logistical planners. According to discussions with Jill Dumain and Elissa Loughman of Patagonia, the success of their Green supply chain efforts were a result of strong relationships with their suppliers and the ability to work directly with these suppliers to meet Patagonia's product demands. These good business relationships have and will continue to promote flexibility both in processing, transporting and fair pricing. The implementation of the additional supply chain and the management of both international and domestic business relationships though initially costly, have greatly contributed to the success of the Green Toe shoe line within the market and generated overall economic growth. Another crucial aspect of improving the environmental performance of Simple Shoes supply chain requires coordination with suppliers to ensure that some standard of environmental management is attained, by both the first-tier supplier and potentially the second-tier supplier. The recommendations section contains more detailed information on standards and suggestions on how to work with suppliers to accomplish these standards.

Table 14 - Footwear materials and their associated cost (These prices are retail prices within the last two years gathered from a wide range of national and international distributors and do not represent actual prices paid by Simple Shoes)

Green Toe Materials				
Material	**Component**	**Price**	**Unit**	**Source**
Organic Cotton	upper	1.5	lb	Davis, 2005
Laminated Slabs for Crepe Outsole	outsole	3.55	lb	Simple Shoes, 2007
Car Tires	outsole	0.05	lb	Scrap Tire Council, 2007
Post Consumer Recycled Cardboard	packaging	30	ton	Joint Service Pollution, 2003
Cork Cushioning	insole	2.46	sole	Timpson, Inc., 2005
PET Post Consumer Pellets (cushioning)	midsole	0.73	lb	Plastics Technology, 2005
PET Post Consumer Flake (cushioning)	midsole	0.6	lb	Plastics Technology, 2005
Bamboo	inside liner	38	yrd	Fabric Store, 2007
Wool Felt	upper	11.8	yrd	Navy & Marine, 2007
Water-Based Adhesives	adhesive	3.73	kg	Country Specific, 2007
100% Jute Natural Fabirc Soft Open Weave	upper	3.27	yrd	Natural Jute, 2007
Hemp	upper	2.48	lb	Hayo, 2005
Traditional Materials				
Material	**Component**	**Price**	**Unit**	**Source**
Conventional Cotton	upper	0.62	lb	Davis, 2005
Rubber	outsole	0.69	lb	Chemical Market, 2002
Primary Cardboard	packaging	0.7	p/box	University of Ohio, 2007
Nylon Thread	thread	0.15	yrd	Everestgear, 2005
Chemical/Solvent-Based Adhesives	adhesive	4.85	kg	Country Specific, 2007
EVA	midsole	9.62	lb	Simple Shoes, 2007
PU Foam	inside liner	7.55	lb	Simple Shoes, 2007
Suede	upper	19.47	lb	Hancocks, 2007

To achieve economic growth and meet sales goals while attempting to create a Green supply chain, Simple Shoes must invest more than just capital. The development of their additional supply chain will require extensive research on alternative materials, sustainable manufacturing processes, as well as market and consumer research. The time spent on background and market research is a prime example of an opportunity cost faced by the company. If the Green Toe and ecoSNEAKS lines failed to generate revenue, the company would take a loss on the time, energy and cost associated with the research phase. The results of the research indicated a significant increase in capital costs associated with the production of this additional line primarily due to the nature of the materials chosen. The materials required to assemble a Green Toe and ecoSNEAKS shoes are significantly higher in cost than traditional shoe materials like those used in their Shoe 4. And while this may change in time, as consumers demand sustainable products, this meant that additional funds would need to be allocated to upstream suppliers and compensated for either by a reduced profit margin or an increase in retail price for downstream consumers.

The difference in overall costs of materials (Appendix III-B) is primarily due to the increased costs of certain materials such as organic textiles and adhesives. Moreover, environmentally preferred products, such as organic cotton are often more expensive than their traditional counterparts (Appendix III-B). World-wide, conventional cotton composes 50% of the textile market and of that percentage organic cotton is responsible for less than 1% (Wearing green, 2007). Organic cotton growing techniques, unlike conventional cotton, requires significantly less fertilizers and pesticides. However, this decrease in cost to the organic farmer has yet to translate into cheaper retail and wholesale prices. One of the main reasons for this is that organic cotton due to the lack of fertilizers does not produce yields great enough to grant high government subsidies to lower the purchase price (Wearing green, 2007). Additionally, organic cotton farmers must find alternative methods to protect plants from weeds and pests, as well as employ less invasive harvesting techniques which often result higher labor costs. These reasons in combination with more expensive ginning and cleaning processes continue to make organic cotton the more expensive option for producers (Fig 28). This same story holds true for other organic products such as hemp, bamboo, jute and wool (Wearing green, 2007).

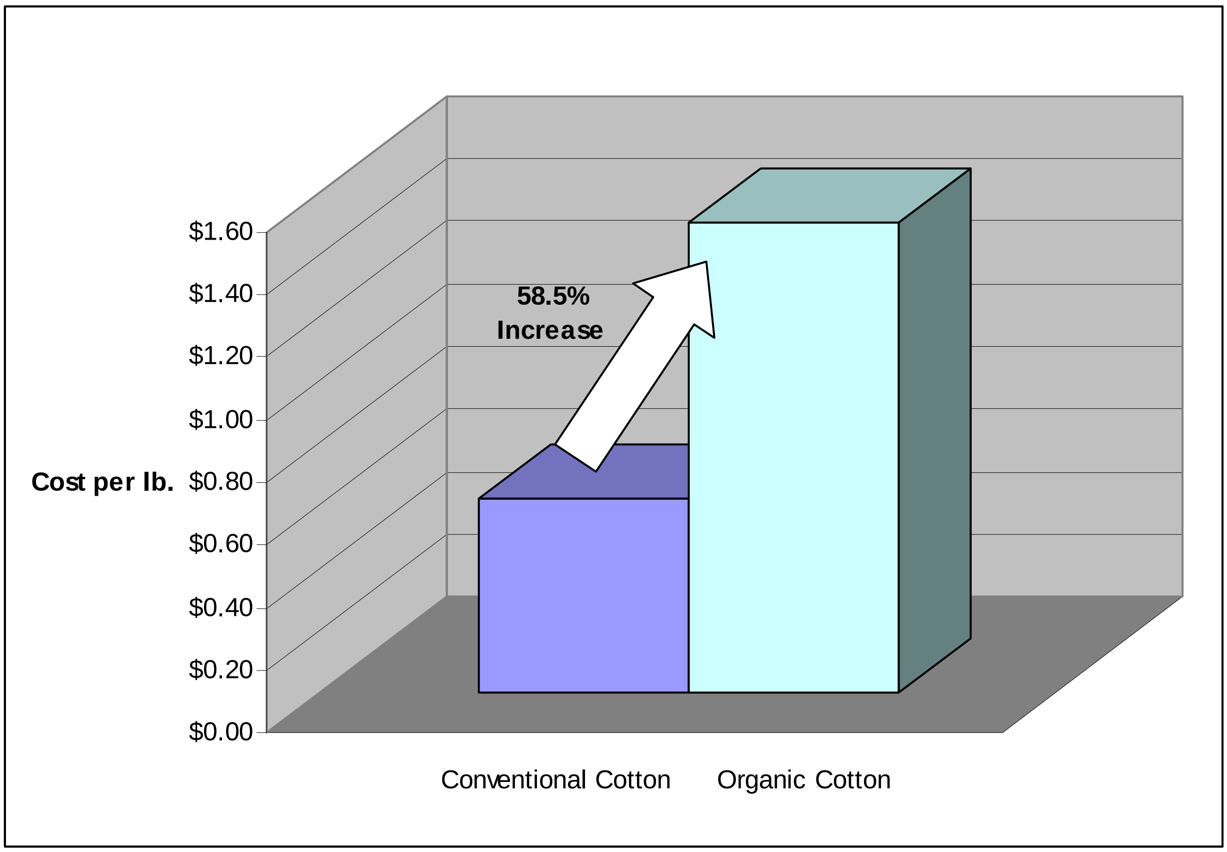


Figure 28. Comparison of Cotton Textile Fabric Options

Though organic textiles seem to be more expensive, not all environmentally preferred products require the expenditure of additional monetary resources. Some materials, such as water-based adhesives can serve as a source of cost savings. According the Pacific

Northwest Pollution Prevention Resource Center, water-based adhesives are found to be 15-20% less than solvent-based adhesives (PPRC, 1999) (Fig. 29). The use of adhesives in many industrial sectors greatly contributes to environmental degradation, specifically air pollution from increase emissions of VOCs. Switching from solvent-based adhesives to water-based can serve as a significant cost savings for companies as application costs as well as occupational risk decreases (Chinese, 2006). Further, water-based adhesives have the same solid content so transportation costs remain the same, while there is a reduction in the investment of emissions controls and regulatory costs (Chinese, 2006).

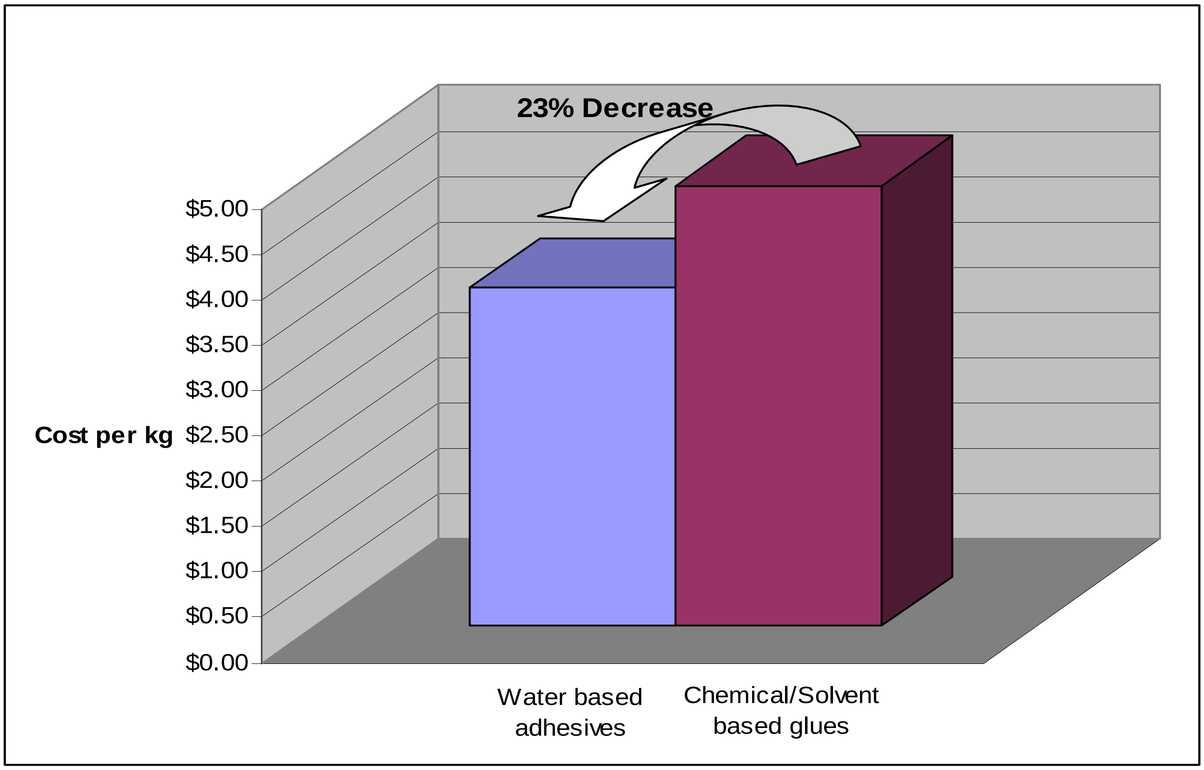


Figure 29. Comparison of Footwear Adhesives

In addition, to the savings associated with switching adhesives, using scrap rubber as opposed to primary rubber for the outsole of a shoe can achieve significant cost reductions. The outsole of a conventional shoe is commonly composed of primary styrene butadiene rubber sheets. From this sheet, outsoles are cut and tread is stamped onto the sole. Using a scrap tire not only diverts waste from land fills but also requires less processing due to its inherent physical features (i.e. tread). As seen in Figure 30, a comparison of the purchase price of scrap tire compared to rubber sheet on a per pound basis results in a cost savings of 93%.

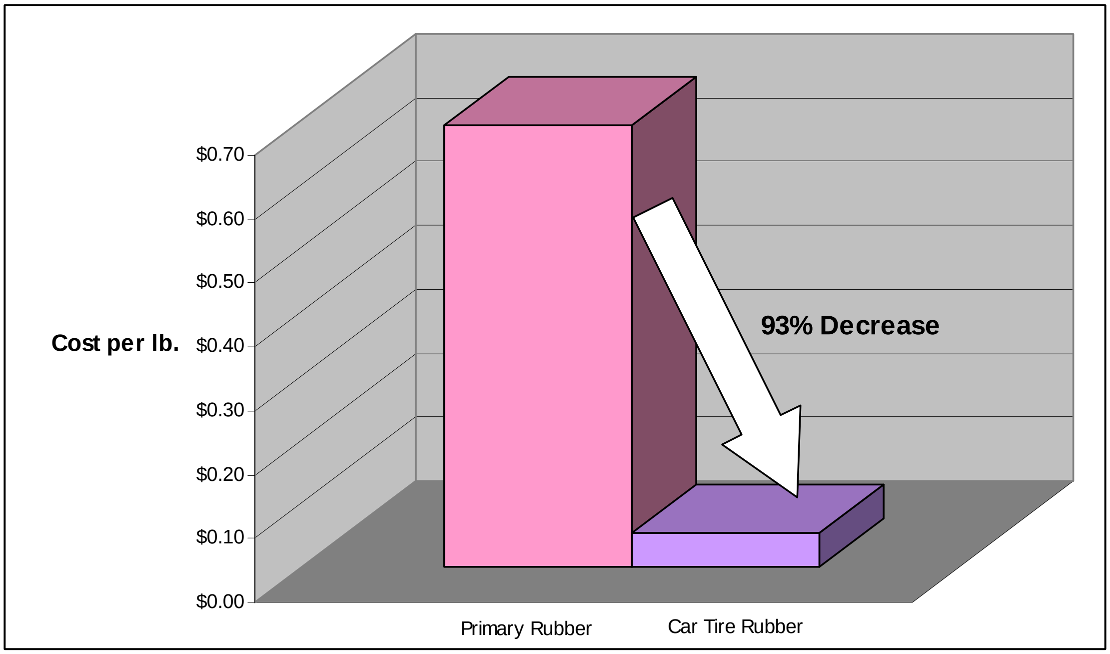


Figure 30. Cost Comparison of Rubber Outsole Options

It is critical to remember that the development of Simple Shoes additional supply chain is primarily occurring in the international arena, which means higher costs associated with transportation, but lower costs associated with labor and less stringent environmental regulations.

A supply chain that crosses international borders is not a new concept as many companies not only within the textile industry, but also in electronics and other industrial sectors outsource work to many developing countries such as China. For Simple Shoes, the reduction of costs from manufacturing in China and changing their purchasing behavior as previously mentioned may not be enough to compensate for the increase in lag time that is often a consequence of outsourcing (BCG, 2006). Increases in transportation time and delays of product signaling can be economically disastrous for companies like Simple Shoes whose purchasing and manufacturing expenditures are completely dependent upon current fashion trends and fickle consumer buying behavior.

The high costs of developing an additional supply chain particularly if involving the purchase of more expensive raw materials must be examined in the context of tradeoffs. Though the production of a Green Toe and ecoSNEAKS shoe is more expensive than Shoe 4 there are significant environmental benefits, as well as an increase in the value of company image and public relation credits. The Life Cycle Assessment section of this report provides one piece necessary to critically analyze the tradeoffs of economic and environmental performance.

While it likely to cost Simple Shoes a lot of money to research and develop alternative materials, it is possible that most of the materials will not be significantly more expensive to use in the long-term, as the demand for these alternative materials results in a decreased price. Whether or not these changes will be economical for Simple Shoes will depend more on the reaction of consumers than the cost of the materials.

5.6 Relationship between Environmental and Economic Supply Chain Performance

The proposed materials substitutions within the supply chain above demonstrate how materials substitution can reduce the environmental impacts of a supply chain. The LCA demonstrated the relative benefits, in terms of environmental impact categories, of the alternative materials. Appendix III-A qualitatively compares the environmental and economic performance of the material substitutions to the supply chain. It should be noted that to determine the price/weight of textiles a price/yard price basis was converted using textile weights based on thread size (A&E, 1997). The average price of a shoe box was used to derive the cost of primary cardboard per unit weight,

Appendix III-B demonstrates where the largest cost savings by component part for shoes occur. Some of the largest economic savings are found in the replacement of poly suede/leather with organic cotton, switching from chemical-based adhesives to water-based adhesives, and displacing the use of primary rubber with re-treaded car tire rubber. The greatest environmental benefits from the supply chain changes above can be found in the reduction in hazardous air pollutants and volatile organic compounds in the shift from chemical to water-based adhesives. Hemp also has demonstrated decrease energy and fertilizer requirements, while being substantially cheaper than poly suede.

A full scale LCA coupled with the matrix co-evaluating economic cost and environmental benefit will allow Simple Shoes to identify the so-called "low hanging fruit" in order to make the best changes to their supply chain, leading to the greatest environmental benefit at the least economic cost to their firm. After determining the component makeup of the materials in the four shoes, the environmental performance of the shoe was evaluated against the economic cost. The analysis in determines if these substitutions were a positive or negative step towards the development of a sustainable product.

5.7 Constraints and Challenges

The economic viability of the additional supply chain developed by Simple Shoes depends greatly on the price of the new materials. Fortunately for Simple Shoes, certain alternative materials can actually serve as a significant cost savings. Recycled car tire outsoles cost less than primary rubber outsoles; water-based adhesives cost less than solvent-based adhesives; the price of upper materials such as jute is less than leather. Other alternative materials like bamboo costs more than nylon, but this material is a small component of the shoe. Simple Shoes has had to invest a lot of money into the research of alternative materials, but now that both capital and opportunity costs have been paid, the purchase of alternative materials should serve as a source of overall cost savings.

The preferences of supply chain agents, mainly customers and retailers, will be a major determinant of the success of the Green Toe line. Simple Shoes is counting on the fact that their customers will prefer shoes that have less environmental impact than those associated with the manufacturing of conventional shoes. The desire to modify the preferences of consumers is evident in their marketing campaign which focuses on the environmental benefits of the Green Toe shoes. Green Toe shoes cost $5 to $30 more per pair than Simple Shoes conventional shoes, but customers seem to be willing to pay the price premium for the piece of mind of supporting a product that has decreased environmental impacts. The Green Toe shoes' more "natural" look, featuring more "earthy" colors such as brown, tan, and green, draws attention to the shoes' natural and recycled materials. This marketing strategy may or may not increase consumers' demand for these shoes. It is likely that this look will create a niche market which will attract environmentally conscientious consumers who want more natural-looking shoes. More difficult to predict is the preferences of retailers. While retailers want to stock shoes that customers will buy; their preferences do not always overlap perfectly. Some retailers such as athletic shoe stores may not want to sell Green Toe shoes because they do not fit in with the theme of the rest of the store; a focus on sports rather than environmental issues. Some retailers may not want to stock the more expensive Green Toe shoes because they do not think that their customers care enough about the environment to pay more.

Supply chain agents may be resistant to the changes imposed by Simple Shoes. In order for Simple Shoes to use new materials they were required to find new suppliers and develop innovative manufacturing methods. More specifically, this involved overcoming resistance to modifying existing manufacturing infrastructure, such as acquiring machines capable of efficiently handling the new materials and supporting programs to train employees to properly work with the new materials and machines. Other challenges associated with the supply chain agents arose due to changes in the business relationships between Simple Shoes and there suppliers. Long standing suppliers who provide leather and EVA may not appreciate the decrease in purchase volume of materials. Overall, it is important that Simple Shoes continue to foster relationships with all of their suppliers so that optimal pricing can be achieved.

Simple Shoes may have difficulty coordinating the Green Toe supply chain, while continuing to coordinate their conventional supply chain. The implementation of an additional supply chain requires Simple Shoes to increase the number of material suppliers and possibly new manufactures. This increase in logistical coordination is evident by the increased costs incurred from transportation, as well as the communication and priorities barrier inherent in outsourcing production. The communication barrier and the mere physical distance between parent company, manufacturers and multiple suppliers all over the world makes the flow of information between these parties extremely difficult. Furthermore, in an effort to purchase materials in close proximity to the manufacturing facility to promote sustainability and local economic growth, Simple Shoes is faced with the challenge of finding the required materials (organic cotton, recycled PET, jute, and crepe) in sufficient supply.

Simple Shoes has already been able to test consumer reactions to the comfort and style of Green Toe shoes, but it is difficult to predict their long-term function. Natural materials may break down and be less durable over time than synthetic materials and leather. Water-based adhesives have been shown to be less robust than solvent-based adhesives. (PPRC, 1999) However, it is possible that decreased durability will not become an issue due to customers growing tired of shoe styles long before the actual product wears out.

Recommendations and results of study can be found in Section 7.

Section 6 - End-of-Life Management

6.1 End of Life Options

Traditionally, after a product has been produced and sold to consumer, the producer's responsibility for that product ends. The environmental impacts of many products do not, however, only occur during production. Many significant impacts occur during a product's use and disposal. The extended supply chain includes the traditional supply chain (raw materials extraction, manufacturing, transportation) as well as the use and disposal phases. End-of-Life (EoL) management is the system by which producers take responsibility for their products after they have reached the end of their useful lives. Proper EoL management can limit the release of toxic substances contained in products and recover valuable materials for reuse. EoL management can include collecting used products for recycling, leasing products as a service, or simply redesigning so that hazardous materials do not leach out in the landfill. Simple wants to include EoL management in their supply chain in order to decrease their products' environmental impacts.

We have identified five End-of-Life options for Simple Shoes: landfilling, reuse, recycling, grinding, and composting. In order to recommend one of these options to Simple Shoes, we compared the option's feasibility with its environmental impact. Feasibility, in the context of this study, is the additional money and effort required for Simple Shoes to implement each EoL option. We estimated feasibility by counting the additional supply chain steps required (e.g. collection, disassembly), the additional shipping distance that Simple Shoes would be responsible for, as well as the necessity of a take-back program (reverse logistics network). This analysis does not include exact calculations of implementation costs, but rather the relative costs of each option. It is assumed that for each additional supply chain step Simple Shoes would be responsible for costs associated with labor and utilities. In addition to increased costs, an EoL option with lower feasibility has a decreased chance of success. Each of the EoL options examined emits air and water pollution, generates solid waste, and consumes resources. However, for the sake of simplicity and because we had limited data, we evaluated the environmental impact of each EoL option on only its greenhouse gas (GHG) emissions measured in 100 years Global Warming Potential (GWP) kg CO_2 equivalent per pair of shoes (averaged for all four shoe styles). The net GWP is the difference between the additional GHG emissions produced and the GHG emissions avoided relative to landfilling (see Appendix IV-A for sources of data for calculations).

Landfilling (Business as Usual)

The current End-of-Life option for a pair of Simple shoes is disposal into landfill. When customers are done with their shoes, we assume that they are too disposed of into the trash. The shoes as well as other waste is picked up by municipal trash trucks and sent to landfills. This option requires no monetary input from Simple Shoes and society bears both the financial and environmental costs.

Greenhouse Gas Emissions

The anaerobic conditions that exist in landfills result in the release of biogas, mostly methane (CH_4), as organic waste decomposes. Methane is a greenhouse gas with a radiative forcing (GWP) 21 times greater than CO_2. As of the year 2000, 14% of landfills in the U.S. burn off, or "flare," the biogas which emits less harmful CO_2 to the atmosphere (Climate 2000). We used the GaBi LCA software to estimate the GWP of a pair of shoes in landfill. We inputted the weights of the 4 shoes into the "Municipal Solid Waste (RER)" process that calculated the GWP of each shoe in landfill. The output is not specific to the materials used in each shoe. Table 1 shows the estimated contribution to GWP of each shoe in landfill (see appendix IV-B).

Table 15. GWP of each shoe in landfill.

	Shoe 1	Shoe 2	Shoe 3	Shoe 4	average
Global Warming Potential (GWP 100 years) [kg CO_2 -Equiv.]	0.26	0.31	0.21	0.30	**0.27**

Note – The average GWP of the four shoes in landfill, ***0.27 kg CO_2 eq.****, will represent the avoided GHG emissions of not sending a pair of shoe to landfill, serving as a baseline for comparison to the other EoL options considered.*

Reuse

Simple Shoes could donate EoL shoes to charity so that these products could be reused. There are various charities that accept shoes and distribute them to needy individuals throughout the world or sell them at second hand stores. We chose to evaluate Soles4Souls primarily because of their established relationship with Simple Shoes and their ability to handle large quantity of shoes. Sole4Souls is a 501(c) (3) charity that accepts used shoes and donates them to third-world countries and disaster victims. This organization has "distributed shoes to over 40 countries, including the U.S., Honduras, Guatemala, Haiti, Dominican Republic, Swaziland, Sudan, Uganda, Romania, Iraq, Peru, Thailand, and Nepal" (Soles4souls.org 2008).

Avoided Greenhouse Gas Emissions

The recipients of reused shoes would be people who would otherwise not have access to new shoes. In addition, when the secondary users of the shoes are through with them, the reused shoes will still end up in a landfill. Thus, reuse would not avoid any GHG emissions because the reused shoes would neither displace primary production nor avoid landfilling. The donation of EoL shoes would serve as a form of corporate social responsibility with social but no environmental benefits.

Additional Greenhouse Gas Emissions

Transporting EoL shoes from Simple Shoes warehouse to the Soles4Souls organization and then to the final recipient would emit GHG's. After Simple Shoes has collected and sorted the EoL shoes, they would mail them to the Soles4Souls warehouse facility in Las Vegas, Nevada. From there, Soles4Souls would send the shoes to their primary warehouse in Roanoke, Alabama. Once the recipient destination has been determined, the shoes would be sent to a port in Mobile, Alabama and put onto a container ship. We calculated an average distance to final recipient of 8000 km (see Appendix IV-C). Table 2 shows the distances and transportation method for each leg of the shoe's journey. Table 3 shows the GWP associated with the transport of a pair of shoes to its final recipient. The GWP calculations are based on weight, and thus the heaviest shoe, Shoe 2, has the highest GWP.

Table 16. Transportation from Simple to recipient

Locations	distance (km)	method	fuel
Ventura to Las Vegas	426	truck	diesel
Las Vegas to Roanoke	2735	truck	diesel
Roanoke to Mobile	268	truck	diesel
Mobile to Recipient	8000	ship	heavy fuel oil
Total Distance	**11429**		

Table 17. GWP (kg CO_2 eq.) for transporting each shoe to reuse recipient

	Shoe weight (kg)	Distance traveled (km)	Fuel consumption (kg)	GWP
Shoe 1	0.345	11429	0.05	0.16
Shoe 2	0.424	11429	0.06	0.19
Shoe 3	0.278	11429	0.04	0.14
Shoe 4	0.396	11429	0.05	0.18
average	**0.361**	**11429**	**0.051**	**0.17**

Feasibility

In order for Simple Shoes to reuse its shoes they would have to implement a take-back program. This would require an additional supply chain step: collecting the EoL shoes from their take back program. Simple would then be required to pay for any labor associated with collection procedures at their warehouse facility in Ventura. Simple would also have to pay for the shipping of the shoes from Ventura to Las Vegas (426 km).

Recycling

In this option, Simple Shoes would disassemble the EoL shoes and send the different materials to recycling facilities. The recyclers would reprocess the materials into usable textiles and other materials so that they could be used again in new products. Simple would collect, sort, and disassemble the EoL shoes at its Ventura facility. Simple Shoes would then send the materials to a recycler and the recycled materials would be shipped to Simple's factory in China to be used in new shoes.

Avoided Greenhouse Gas Emissions

Recycling would keep EoL shoes out of landfill and would displace primary production of virgin materials. By not landfilling the shoe, recycling will avoids 0.27 kg CO_2 eq. per pair. Assuming that all of the materials are recycled back into new shoes, recycling would avoid an additional 1.62 kg CO_2 eq. per pair (see Appendix IV-D). Table 4 shows the GWP for the production of materials in each shoe that would be displaced by recycling. For natural materials this is GHG emissions from agricultural production, for synthetic materials this is the GHG emissions from petroleum production. The estimated avoided GHG emissions from displaced primary production are most likely high because there would be some materials loss of during the recycling process that we did not account for.

Note – Car Tire Rubber and Recycled PET are not included in this analysis because they are already recycled and we did not want to "double count" them. Cork and Bamboo are not included because we did not have data on their primary production.

Table 18. Avoided GWP (kg CO_2 equiv.) of Recycling the Materials in a Pair of Shoes

Material	GWP per gram	grams of each material in each shoe				GWP of material in shoe				average
		shoe 1	shoe 2	shoe 3	shoe 4	shoe 1	shoe 2	shoe 3	shoe 4	
Conventional Cotton	0.0013	2	0	7	63	0.00	0.00	0.01	0.08	0.02
Hemp/jute	0.0005	59	66	38	6	0.03	0.03	0.02	0.00	0.02
Latex Rubber	0.0027	61	55	14	0	0.17	0.15	0.04	0.00	0.09
Leather (Suede)	0.0565	0	0	0	60	0.00	0.00	0.00	3.39	0.85
Synthetic Rubber	0.0070	0	0	79	220	0.00	0.00	0.56	1.55	0.53
PET	0.0024	3	3	12	0	0.01	0.01	0.03	0.00	0.01
PU Foam	0.0042	0	0	0	6	0.00	0.00	0.00	0.03	0.01
Crepe Rubber	0.0012	130	65	0	0	0.16	0.08	0.00	0.00	0.06
Organic Cotton	0.0006	11	11	11	0	0.01	0.01	0.01	0.00	0.01
EVA	0.0032	0	0	14	20	0.00	0.00	0.04	0.06	0.03
other	******	79	224	104	21					
Total		**266**	**200**	**175**	**375**	**0.37**	**0.28**	**0.70**	**5.12**	**1.62**

Additional Greenhouse Gas Emissions

The recycling option would emit GHG's during disassembly, transportation, and recycling. According to Simple Shoes assembling one pair of Simple shoes requires 10.7 MJ of electricity. We assumed that disassembly would require the same amount of electricity as assembly. Generating 10.7 MJ of electricity using the average US power mix (Energy Information Administration 2006) emits 2.21 kg CO_2 eq. Traveling by diesel truck an average distance of 3000 km to the recycling center will emit 0.11 kg CO_2 equivalent (Table 5) (see Appendix IV-D).

Table 19. Transportation of shoes from Simple facility in Ventura to recycler

	Ventura Warehouse to Recycler			
	shoe w/ packing (kg)	distance (km)	diesel (kg)	GWP
shoe 1	0.449	3000	0.031	0.10
shoe 2	0.528	3000	0.037	0.12
shoe 3	0.382	3000	0.027	0.09
shoe 4	0.500	3000	0.035	0.12
average	**0.465**	**3000**	**0.033**	**0.11**

At the recycling facility, the fabric, foam, plastics, and rubber, would be recycled into new usable materials. In order to estimate the GHG emissions from this process we used the GHG emissions from processing virgin material. Due to limited data availability, we are only able to use processing data for the production of cotton fabric and recycled PET. The production data for the other materials, listed above, is based on virgin production (e.g. synthetic rubber production includes extraction and refining of petroleum). We inputted the weights of the fabrics: conventional cotton, organic cotton, hemp, jute, and bamboo, into the fabric process; and the weights of the plastics: recycled PET and virgin PET into the recycled PET process. We did not include the emissions of the other materials due to the high levels of uncertainty associated with the calculation. We calculated an average GWP for recycling the PET and fabric in each shoe to be 0.44 kg CO_2 equivalent (Table 6).

Table 20. GHG emissions from recycling PET and fabric

	total kg	kg PET	kg fabric	GWP
Shoe 1	0.345	0.013	0.086	0.50
Shoe 2	0.424	0.013	0.091	0.53
Shoe 3	0.278	0.03	0.056	0.34
Shoe 4	0.396	0	0.069	0.39
Average				**0.44**

Transporting one pair's worth of recycled materials 13,000 km via container ship from the recycling center to Simple's manufacturers in Guangzhou, China will emit 0.07 kg CO_2 equivalent (table 7) (see Appendix IV-D).

Table 21. GHG emissions from transportation from recycler to Guangzhou, China.

	Recycler to China			
	shoe w/ packing (kg)	distance (km)	diesel (kg)	GWP
shoe 1	0.449	13000	0.022	0.07
shoe 2	0.528	13000	0.025	0.08
shoe 3	0.382	13000	0.018	0.06
shoe 4	0.500	13000	0.024	0.08
Average	**0.465**	**13000**	**0.022**	**0.07**

The total gross GHG emissions resulting from recycling one pair of shoes is 2.83 kg CO_2 equivalent. The net GHG emissions of recycling one pair (gross emissions – avoided emissions) would be 0.94 kg CO_2 equivalent (table 8).

Table 22. Net GHG emissions from recycling

	Phases for recycling	GWP (kg CO_2 equiv.)
Gross Emissions	Disassembly	2.21
	Transport Simple to Recycler	0.11
	Recycling	0.44
	Transport Recycler to China	0.07
Avoided Emissions	Avoided Landfill	-0.27
	Avoided Production	-1.62
Net Emissions		**0.94**

Even with avoiding landfill and primary production, recycling still has a net positive GWP. The additional GHG emissions from disassembling, recycling, and transporting the EoL shoes are greater than the GHG's saved by recycling according to our calculations. We had to make several assumptions in order to estimate the GHG emissions of each step, due to incomplete information. The net emissions should be seen as a rough approximation rather than an exact figure. The important conclusion is that recycling shoes may not have environmental benefits because it requires so much additional energy.

Feasibility

Recycling would be the least feasible of all of the EoL options. This option necessitates the implementation of a take-back program and Simple Shoes would have to add two additional steps to its supply chain: collection and disassembly. Simple Shoes would be required to pay for labor and utilities to collect its EoL shoes and disassemble them into each individual material. Clearly separating these materials presents a significant challenge as there are 19 different materials in the four Simple shoes analyzed in this study. In addition, Simple Shoes would be responsible for shipping costs, including shipping the materials to recycling facilities and then shipping the recycled materials to its manufacturing facility in China.

If Simple were to pursue this option, we recommend redesigning their shoes to possess fewer materials and increasing the ease of disassembly. Simple Shoes may be able to decrease the cost of recycling a material below the cost of buying virgin material by developing partnerships with recycling facilities (e.g. Patagonia and their PET Capilene recycler Teijin).

Grinding

Nike's "Reuse a Shoe" program takes used athletic shoes of any brand and grinds them up to form a material they call "Nike Grind." Nike separates the shoes into three parts: fabric upper, foam midsole, and rubber outsoles, for different material applications. Nike partners with four surfacing companies in the US that incorporate 10% – 20% "Nike Grind" by weight into new athletic surfaces such as running tracks or basketball courts (Nike, Inc. 2008). Simple could send its EoL shoes to Nike to become "Nike Grind."

Avoided Greenhouse Gas Emissions

By sending their EoL shoes to Nike's Reuse-a-Shoe program, Simple would avoid landfill and displace primary production of virgin materials using in athletic field surfacing. By not landfilling, grinding would avoid 0.27 kg CO_2 eq. per pair. Assuming that "Nike Grind" displaces virgin materials in the production of athletic surfaces, Grinding would avoid 1.25 kg CO_2 eq. per pair (Table 9) (see Appendix IV-E).

Table 23. Avoided GHGs from Grinding

Nike Grind Material	Primary Production GWP per gram	Grams of each material in each shoe				GWP of material in shoes				
		shoe 1	shoe 2	shoe 3	shoe 4	shoe 1	shoe 2	shoe 3	shoe 4	average
Fabric	0.0013	72	77	56	129	0.10	0.10	0.07	0.17	0.11
Foam	0.0042	0	0	14	26	0.00	0.00	0.06	0.11	0.04
Rubber	0.0070	191	120	93	220	1.35	0.85	0.66	1.55	1.10
Total		**263**	**197**	**163**	**375**	**1.44**	**0.95**	**0.79**	**1.83**	**1.25**

Additional Greenhouse Gas Emissions

Grinding would emit GHG's during transportation. Energy use associated with grinding machines has not been included due to unavailable data. The GHG emissions from transporting the EoL shoes from Simple's collection facility in Ventura to Nike's Reuse-a-Shoe collection facility in Wilsonville, OR are 0.04 kg CO_2 eq. (Table 10).

Table 24. GHG emissions from Grinding Transportation

	weight (kg)	distance (km)	diesel use (kg)	GWP (kg CO_2 eq.)
shoe 1	0.345	1535	0.012	0.04
shoe 2	0.424	1535	0.015	0.05
shoe 3	0.278	1535	0.010	0.03
shoe 4	0.396	1535	0.014	0.05
Average	**0.361**	**1535**	**0.013**	**0.04**

The net GWP for Grinding equals the GHG emissions from transportation (0.04 kg CO_2 eq.) minus GHG emissions savings from avoided landfilling (0.27 kg CO_2 eq.) and avoided primary production (1.25 kg CO_2 eq.). Grinding has a negative GWP, saving an average of 1.48 kg CO_2 eq. per pair (Table 11).

Table 25. GWP of Grinding

	GWP
Transportation	0.04
Avoided Landfilling	-0.27
Avoided Production	-1.25
Net	**-1.48**

Feasibility

Grinding would require that Simple Shoes implement a take-back program and add one additional supply chain step: collection. Simple Shoes would also have to pay for shipping the commodity from Ventura, CA to Wilsonville, OR (1535 km).

Composting

Composting is the decomposition of organic matter by aerobic bacteria and microorganisms (US Green Living 2008). Simple's shoes could be composted if they were redesigned to be 100% biodegradable. Biodegradable shoes would mean that they "break down into carbon dioxide, water, inorganic compounds, and biomass, at a rate consistent with known compostable materials and leaves no toxic residue" (American

Society for Testing & Materials. 2008). Some of the materials in Simple shoes are already biodegradable and some are not. The biodegradable materials included in the four Simple shoes we analyzed are: cotton, hemp, jute, bamboo, cork, crepe rubber, natural latex. The non-biodegradable materials include: synthetic rubber, PET, PU, EVA, and leather. Although leather is a natural material it is not included as biodegradable because it requires 25 -40 years to decompose and releases toxic chemicals such as chromium (from tanning) when it breaks down (Worldwise 2008).

Composting shoes would keep them out of the landfill and would produce a soil amendment that could be used for gardening (EPA 2007). Aerobic decomposition of organic matter in a compost pile avoids the anaerobic decomposition which occurs in landfills and produces methane, a GHG with a GWP 21 times greater than CO_2.

Composting would be performed by the customer rather than by Simple Shoes. Customers would either dispose of the shoes in Greenwaste recycling bins or place them in their home compost pile. Not all municipalities have Greenwaste collection programs, and customers would have to check if their city's Greenwaste collection system would accept biodegradable shoes (City of Santa Barbara Environmental Services 2008). If customers have a home compost pile, the shoes could be put in to become compost. In order to ensure that customers are composing their shoes properly, Simple shoe boxes could include a compost guide with tips such as cutting up shoes for faster decomposition, making sure that the compost pile has the correct C:N ratio, and providing adequate water and oxygen. If the compost pile is properly taken care of compost waste can decompose aerobically and not produce methane. Proper care of a compost pile ensures that that the compost is decomposed quickly by achieving the correct temperature to facilitate bacterial decomposition of organic matter (NRCS 2008).

Avoided Greenhouse Gas Emissions

The primary environmental benefit of composting is that it would keep the shoe out of the landfill which would avoid 0.27 kg CO_2 eq. per pair of shoes.

Additional Greenhouse Gas Emissions

Aerobic decomposition of organic matter in compost emits CO_2. The amount of CO_2 emitted, however, is equal to the CO_2 taken out of the atmosphere while the plant that the material was harvested from was growing. Thus, the EoL option of composting has a GWP of zero.

Feasibility

Once the shoes are redesigned composting would require no effort or additional cost on the behalf of Simple Shoes. In addition, composting would not require a take-back program and Simple Shoes would not need to add any supply chain steps or incur additional shipping charges. Simple Shoes could print composting tips and instructions on their shoeboxes to encourage their customers, as well as use their website as a forum to providing compost guidance including the contact information for composting coordinators in each state. The only feasibility issue is that the shoes would need to be redesigned to be 100% compostable.

6.2 Take-Back Collection Options

For the EoL options of Reuse, Recycling and Grinding, Simple Shoes would need to collect the EoL shoes from their customers and ship them to their warehouse in Ventura, CA. Our group came up with two main methods of collection. We used a distance of 2900 km to represent the distance that the shoes would travel from both the retail store to Simple and from the customer to Simple. This distance is the average distance from a retail store to Ventura, CA and we assumed that the distribution of customers would be geographically similar.

Drop-Off Box in Retail Stores

Simple Shoes does not have its own retail stores but it could possibly place drop-off boxes in the retail stores in which sell its shoes. Customers would bring their shoes back to the store when they are no longer wanted. Our client would then pay for the retailer to mail the shoes to the Simple collection facility.

Additional Greenhouse Gas Emissions

The GHG emissions of Drop-Off would result from both the 10 km* distance that the average customer would have to drive to the retail store and the 2900 km distance stated above. Transportation from customer to retail store would emit 2.68 kg CO_2 eq. per pair and transportation from retail store to Simple would emit 0.08 kg CO_2 eq. per pair. The total GHG emissions for Drop-Off would be 2.76 kg CO_2 eq. per pair.

**Note – GHG emissions for Drop-Off are extremely sensitive to the distance driven by customer to retail store. The GHG emissions per km of a 19mpg automobile are 0.27 kg* CO_2 *eq. We did not have data on the average distance of Simple's customers to the nearest retail store, nor do we know if the customer would be making a separate trip to drop off their EoL shoes. Given this uncertainty and the weight it has on the overall calculation we chose a distance that was relatively small.*

Feasibility

In order for the mechanism of a Drop-Off box to be successful, Simple's retailers would have to allow Simple Shoes to occupy retail floor space (drop-off box). Simple's retailers would also have to mail the shoes in the drop-off boxes to Simple's warehouse. Simple Shoes would need to provide postage or reimbursement to the retail store for mailing the shoes. Simple Shoes may encounter difficulties in implementing this take-back mechanism as it would require additional work on behalf of the retailer. The benefit to retailers is that customers who return to the store to drop off their shoes may peruse the shop and purchase another item. Customer participation might also be low for this take-back option because it would require an extra trip to be made to a retail store with a Simple Drop-Off Box. Simple Shoes could offer customers an incentive to drop off their EoL shoes, but this would create an additional expense associated with the Drop-Off mechanism.

Mail-In

In this take-back program, customers could mail their EoL shoes directly back to Simple Shoes in the original shoe box. Simple could include postage on the shoe box or provide pre-paid postage through their website.

Additional Greenhouse Gas Emissions

Transporting the EoL shoes by mail from the customer and average distance of 2900 km to Simple's collection facility in Ventura would emit 0.08 kg CO_2 eq. per pair.

Feasibility

We believe that the Mail-In option would be more feasible than that of the Drop-Off box for Simple Shoes because it would not require the participation of retail stores. In addition, customer participation would probably be higher because it would require no more than placing their EoL shoes in the mailbox. Simple would have to pay for postage and possibly an additional customer incentive to ensure customer participation. Postage to ship a pair of shoes (average weight including box: 0.465 kg) 2900km USPS Priority mail would be $4.60.

Recommendations and results of study can be found in Section 7.

Section 7 - Project Recommendations

7.1 Life Cycle Assessment Recommendations

- The results of the LCI and LCIA indicate that the production of leathers, synthetic materials and plastics have the highest environmental impact across multiple environmental impact categories. To reduce this impact, Simple Shoes should remove these components from their products or develop more environmentally friendly practices for extracting and processing the materials.
- A majority of the environmental impacts associated with shoe production were associated with toxicity potential (freshwater, terrestrial, marine and human). The robustness of the environmental impact category of toxicity is still in debate among international experts, so while this category was high for the four shoes analyzed, efforts to reduce toxicity potential should be balanced with efforts to reduce AP, GWP, POCP. These efforts may include reducing energy consumption, investing in renewable energy and implementing pollution control devices.
- The LCIA demonstrated that of the main supply chain phases (materials production and assembly, transportation, EoL and packaging), the former process was responsible for nearly 90% of the environmental impacts. A majority of the impacts being associated within one phase serves as an opportunity for Simple Shoes to develop targeted efforts and programs to reduce overall environmental impact.
- We recommend that further LCA's being conducted on other shoes within our clients product line. Further, that within the framework of the software future LCA's delve deeper into phases of footwear manufacturing, consumer use and EoL.

7.2 Supply Chain Recommendations

The Supply Chain Management Assessment resulted in recommendations for three key aspects of the supply chain:

1. **Materials** - Compared the environmental performance of individual materials on a kg-to-kg basis.
    - In terms of GWP and Energy-Use, leather (suede) had the greatest impact, thus we recommend replacing leather.
    - Synthetic rubber and plastics (PU, EVA, Silicon, Nylon) were the next most impactful, in terms of GWP and Energy Use, and thus should considered for replacement.
    - Hemp, Organic Cotton, and Crepe Rubber had the least GWP and used the least amount of energy of all the materials we examined.

2. **Phases** - Identified "hot spots" along the supply chain based on increased environmental performance and supply chain control.
    - The impacts of footwear were found to predominantly result from the production of materials. We recommend targeting and replacing those materials with the worst environmental performance on a kg-to-kg basis.
    - Simple Shoes has the greatest control over their manufacturing process, which contributes somewhat to the overall environmental impact of the shoes (as shown by the LCA results). Therefore, we recommend that Simple Shoes examine ways to improve the energy demands and efficiency of their faculties and manufacturing processes.

3. **Cost and Environmental Performance** - Co-evaluated the environmental performance of materials and their relative economic cost on a kg-to-kg basis.
    - Generally, conventional cotton, when replaced by materials with lower environmental impact, such as organic cotton or jute, leads to increased financial costs. Thus, Simple Shoes must decide if it is worth the increased cost of materials for the enhanced environmental benefit.
    - Conversely, replacing suede with materials that have a lower environmental impact, also results in a net decrease in financial costs. Therefore, the least cost method to gain the greatest environmental benefit would be to replace suede.

General Supply Chain Recommendations

- Work with suppliers to learn more about their current practices and develop supplier guidelines to assist suppliers in understanding the environmental performance and standards for specific materials. Due to the limited nature of control over suppliers, Simple Shoes should conduct a survey of key suppliers to obtain information related production output, energy consumption, energy sources as well as waste streams (water, scrap, hazardous waste) and treatment of those streams. This information in combination with Simple Shoes environmental goals can be used develop guidelines and potential training programs for suppliers.
- A main benefit of material substitution and using similar materials in multiple shoe styles is that it streamlines the amount of suppliers involved in the supply chain. A reduction in overall suppliers increases Simple Shoes ability to focus efforts on a smaller subset of suppliers to ensure that they are meeting environmental performance standards and generally increases Simple's control over their supply chain.
- The success of Simple Shoes sustainability and stewardship efforts is inextricably linked to all of its suppliers and the products that they provide. For this reason, we recommend that Simple Shoes work beyond its 1st tier suppliers to interact with its 2nd and 3rd tier suppliers in order to effectively address issues and

implement changes that will reduce the overall environmental impact of the supply chain and their footwear.

7.3 Recommended End-of-Life Scenario

- Based on the tradeoffs of greenhouse gas emissions and feasibility, composting is the best EoL option for Simple Shoes. Reuse and recycling are inferior options because they have a positive net GWP and low feasibility. Grinding has higher avoided GHG emissions than composting, but composting is more feasible. Unlike grinding, composting would not necessitate a take-back program, collection at Simple Shoes warehouse, or additional shipping expenses. If Simple Shoes chooses the grinding option they would incur an additional and unnecessary step in the shoe's End-of-Life management.
- Composting will require that Simple Shoes redesign their shoes to be 100% biodegradable and this will be an extra expense for Simple Shoes, but it is consistent with the recommendation from the LCA to replace leather and synthetics with natural materials in order to decrease GHG emissions and human toxicity.

Section 8 - References

2carpros.com, Image of car tire, [Accessed: February 27, 2007], <2carpors.com>

A&E Thread Selection Chart, 1997, [Accessed: June 1, 2007], <http://www.amefird.com/fabric_weights_thread_size_chart.htm>

Acentech Corporation, (2003), Image of Nylon 6 products, [Accessed: February 27, 2008], <www.acencorp.com/.../product.asp?product_id=306>.

Allen Woodburn Associates Ltd./Managing Resources Ltd., (1995)"Cotton: The Crop and its Agrochemicals Market."

American Chemistry Council, Glossary of Terms , "Plastic," (2001), [Accessed on November 28, 2007].<http://www.americanchemistry.com/s_plastics/sec_learning.asp?CID=1185&DID=4422#P>

American Society for Testing Materials (2008), "Standard Specification for Compostable Plastics," [Accessed: February 20, 2008], http://www.astm.org/cgi-bin/SoftCart.exe/DATABASE.CART/REDLINE_PAGES/D6400.htm?L+mystore+umbs6938

Amorim, 2006, "Natural Cork Production." [Accessed: December 10, 2007], <http://www.corkfacts.com/natlcrk11.htm>

fAntique Rugs of the Future, "Azerbaijan Rugs."(2004). [Accessed November 8, 2007]. <http://www.presentltd.com/rugs/arof-_natural_dyes_mordants.htm.>

Australian Government, (2006), Department of Health and Ageing Factbook, "DALY," [Accessed: February 19, 2008], <http://www.health.gov.au/internet/wcms/publishing.nsf/Content/Factbook2006-1~factbook2006-glossary>.

Australian National University, (1999), Image of tapping latex from Hevea tree, [Accessed: February 27, 2008], <http://images.google.com/imgres?imgurl=http://sres-associated.anu.edu.au/fpt/nwfp/naturalrubber>.

BBC, "Design, Textiles, Woven Fabrics." [Accessed: January 23, 2008]. <http://www.bbc.co.uk/schools/gcsebitesize/design/textiles/fabricsrev2.shtml>

Barbara, Blue Line Transfer Co. South San Francisco. (Oct. 2007) Phone Correspondence.

Billington, C., (1995), "The evolution of supply-chain management models and practice at Hewlett-Packard", *Interfaces* **25** (5), pp 42-63.

Blick Art Materials, (1999-2008), Image of solidified crepe rubber, [Accessed: February 27, 2008], <www.dickblick.com/zz249/08/>.

Bonneville, Françoise de. "The Book of Fine Linen," 1994. Flammarion, Paris, France. p.70

Boston Consulting Group), (BCG), (May 2006), "Supply chain delays disruption makes china sourcing a potential strategic trap, new BCG report warns." *PR Newswire United Business Media*,
[Accessed: May 20, 2007],
<http://www.prnewswire.com/cgibin/stories.pl?ACCT=109&STORY=/www/story 05-09- 2007/0004584045&EDATE>

Bowers, J.E. (1990). *Natural Rubber-Producing Plants for the United States.* Beltsville, MD: National Agricultural Library.

Brown, Martha,(2006)"Study comparing the yield and quantity potential of organic cotton," Center for Agroecology & Sustainable Food Systems. [Accessed: December 10, 2007], <http://www.sustainablecotton.org/html/resources/articles06.html>

Buck, R.., "Railroads and capital: money, credit, and the industrialization of Shoemaking." *The American Journal of Economics and Sociology*, **57**(4), (1998): 513-.

Cal EPA CARB hexavalent chromium fact sheet, (2007) "Hexavalent chromium can be a by-product of leather tanning," [Accessed: May 31, 2007]. <http://www.arb.ca.gov/coatings/thermal/factsheets/factsheethexchrome.pdf>

"Chinese economy soars so does the use of adhesives", (Nov 2006), *Power at Work,*
[Accessed: May 20, 2007],
<http://www.rohmhaas.com/AdhesivesSealants/PW_e_magazine_nov06/articles/chineseecconomy.html,As>

City of Santa Barbara Environmental Services, (2008), "Recycling and Trash Information" <http://www.santabarbaraca.gov/Recycling-Trash/single_family_green.htm#placed>

Climate Change Technologies, Landfill methane recovers, (Jan. 2000), [Accessed Feb 15. 2008], http://yosemite.epa.gov/oar/GlobalWarming.nsf/UniqueKeyLookup/SHSU5BUR8R/$Fil e/landfillmethanerecovery.pdf

Cloern, J., (Dec. 2007), Encyclopedia of the Earth, "Eutrophication", [Accessed: February 16, 2008]<http://www.eoearth.org/article/Eutrophication>.

Council for Textile Recycling, (1997). [Accessed: November 8, 2007] and phone correspondence, <http://www.textilerecycle.org/>

Country specific parameters used in RAINS VOC module, UK, [Accessed: May 20, 2007] <http://www.iiasa.ac.at/rains/voc_review_cafe/uk_voc.xls>

Davis, K., (November 12, 2005)"Bad chemistry worries infuse textile revolution." West Coast Homes, *The Vancouver.*, [Accessed: May 20, 2007], <http://www.dreamdesigns.ca/VanSun_Nov05.pdf>

Deccofelt Corporation, (2008), Image of PU Foam, [Accessed: February 27, 2008], <http://images.google.com/imgres?imgurl=http://www.deccofelt.com/images/circles/big/polyurethane_foam-big.jpg&imgrefurl>.

Derwent, R. G.; Jenkin, M. E.; Saunders, S. M. (2006). Photochemical ozone creation potentials for a large number of reactive hydrocarbons under European conditions, [Accessed: January 26,2008], <.http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VH33TGNG13M&_user=112642&_coverDate=08%2F31%2F1998&_fmt=summary&_orig=search&_cdi=6055&view=c&_acct=C000059608&_version=1&_urlVersion=0&_userid=112642&md5=ac42ee02df506de914ba158eb6fb63aa&ref=full.>

Doppelt and Nelson., "Case studies of voluntary US corporate take-back programs" (2001).

Dowie-Bhamra, Tracy., "Green Design - Design for Disassembly." University of Manchester, UK [Accessed: January 10, 2008], <http://www.co-design.co.uk/design.htm>

DuPont. "Types and Uses of EVA." (2007), [Accessed on November 28, 2007], <http://www2.dupont.com/Elvax/en_US/uses_apps/index.html>

EC Plaza, (1996) Image of PET flakes, [Accessed: February 17, 2008], http://images.google.com/imgres?imgurl=http://earthtec.en.ecplaza.net/1s.gif.

EcoRecycle Victory. "Is Recycling Worth It?" (2007), [Accessed on November 28, 2007], <http://209.85.173.104/search?q=cache:X159MM3iiLYJ:www.dcp.ufl.edu/ckibert/Poland/MiscMaterials/RecyclingLCAAustralia.pdf+environmental+impacts+of+recycling+PET&hl=en&ct=clnk&cd=7&gl=us&client=firefox-a>

Energy Information Administration, (2006), "Official Energy Statistics from the U.S. Government, [Accessed: February 20, 2008], <http://www.eia.doe.gov/cneaf/electricity/epa/epat1p1.html>

Engineering Department, University of Dayton, Ohio, "Cardboard," [Accessed: May 20, 2007], <http://www.engr.udayton.edu/udiac/Documents/Cardboard.doc>

Environment Canada, " International Affairs, Glossary," (2001), [Accessed: February 18, 2008] <http://www.ec.gc.ca/international/refs/gloss_e.htm>.

EPA (2007), "Composting," [Accessed: February 20, 2008], <http://www.epa.gov/epaoswer/non-hw/composting/basic.htm#todo>

EPA (2001), "Photochemical Smog – What it Means for Us." [Accessed: January 26, 2008], <http://epa.sa.gov.au/pdfs/info_photosmog.pdf >

EPA (2006), "Life Cycle Assessment Principles and Practice," [Accessed: January 26, 2008], <http://www.epa.gov/nrmrl/lcaccess/pdfs/chapter4lca101.pdf>

EPA (2004, 2007) Ozone Depletion Glossary. [Accessed: January 26, 2008], <http://www.epa.gov/Ozone/defns.html#odp.>

EPA (2008). 1,4-Dichlorobenzene (para-Dichlorobenzene), [Accessed: January 26, 2008], <http://www.epa.gov/ttn/atw/hlthef/dich-ben.html#ref1.>

Ecotextiles, "Concern over textile dye price rises" *EcoTextile News,* February (2007). [Accessed: November 9, 2007], <http://www.ecotextile.com/headline_details.php?id=629>

Encyclopedia Britannica Online, (2007) "*Rubber, natural and synthetic*." [Accessed: December 10, 2007], <http://www.britannica.com/eb/art-53930>.

Energy Systems Research Unit, University of Strathclyde, UK. "Carbon Dioxide". [Accessed: January 31, 2008], <http://www.esru.strath.ac.uk/EandE/Web_sites/01-02/RE_info/C02.htm>

European Environmental Agency, (2008) "Acidification Introduction," [Accessed: February 16, 2008], <http://www.eea.europa.eu/themes/acidification>.

Everestgear.com, (2005) "Nylon thread fine," [Accessed: May 20, 2007], <http://search.store.yahoo.com/cgi-bin/nsearch?catalog=yhst-3786489705811&query=nylon+thread>

Fabric Store, (2007) "Bamboo woven.," [Accessed: May 20, 2007] <http://www.bamboofabricstore.com.au/woven-fabrics/bamboo-woven.html>

FabricUK, "Natural jute hessian fabric," [Accessed: May 20, 2007], <http://www.fabricuk.com/fabrics.php?fabric_type=210>

Fishbein, Bette K. "Carpet take-back: EPR American style." *Environmental Quality Management*, **10**(1), (2000): 25-36.

Fletcher, Scott (2002), Image of cork extrusions, Green Building Magazines, [Accessed: February 27, 2008], <www.buildingforafuture.co.uk/autumn02/focus_o....>.

Foreman, Marianne., "Organizing environmental supply chain management: experience from a section with frequent product shifts and complex product chains: the case of the Danish textile sector," *Greener Management International*, (2004).

Geyer, Roland – ESM 289 – Green Supply Chain Management, Spring 2007, Donald Bren School of Environmental Science and Management, University of California, Santa Barbara

Hankcocks of Paducah, (2007), "Poly Suede," [Accessed: December 10, 2007] <http://www.hancocks-paducah.com/ItemList--search-poly-suede.html.>

Helvetas, (2008), Image of organic cotton boll, [Accessed: February 27, 2008], <www.helvetas.ch/.../welcome_page.asp>

Hertwich, Edgar G.; Mateles, Sarah F.; Pease, William S.; McKone, Thomas E. (2006). "An Update of the Human Toxicity Potential with Special Consideration of Conventional Air Pollutants."

Hultquist, N. "Soles4Souls: changing the world, one pair of shoes at a time." *Shoe Retailing Today*, Jan-Feb. (2007).

Icis pricing – Ethylene Vinyl Acetate (2006), [Accessed: May 6, 2007], <http://www.icispricing.com/il_shared/Samples/SubPage10100041.asp>

Institute of Environmental Sciences (CML), (2008) "General Information About CML," Universiteit Leiden, [Accessed: January 25, 2008], <http://www.leidenuniv.nl/cml/>

International Cotton Advisory Committee (2007), [Accessed: November 23, 2007], <http://www.icac.org/>

International Jute Study Group (2003). "Jute & the Environment," [Accessed: December 10, 2007], <http://www.jute.org/environment.htm>

ISO 14040: Environmental management — life cycle assessment — principles and framework. (2006).

ISO 14044. Environmental management Systems —life Cycle Assessment – requirements and

Klausner, M., "Reverse-logistics strategy for product take-back." *Interfaces*. **30**(3), (2000): 156-165.

Leggett, Jeremy., "What they don't want you to know about the coming oil crisis.," *The Independent* (UK). January 20, 2006.

Lela Designs, 2008, "Fabric FAQS" [Accessed: December 10, 2007], <http://www.leladesigns.ca/fabric-faqs.php>.

Llorenç Milà i Canals; Xavier Domènech; Joan Rieradevall; Pere Fullana i Palmer; Rita, Puig. "Application of life cycle assessment to footwear." *The International Journal of Life Cycle Assessment*, **3**(4) (1998): 203-208.

Loughman, Elissa, Patagonia. (Nov. 7, 2007). Conference Call Communication.

McDonough, W., Braungart, M. Cradle to cradle, remaking the way we make things. (2002):13-14.

Miranda, J. "American machinery and European footwear: technology transfer and international trade, 1860--1939." *Business History*, **46**(2), (2004). 195-.

Mississippi, University of, Polymer Science Learning Center – Department of Polymer Science. (2005). "Polybutadiene", [Accessed December 10, 2007], <http://pslc.ws/macrog/pb.htm>

Moroski, R., "Supply chain management: are there kinks in your links," *Industry Week*, May 9, 2007, [Accessed: May 20, 2007], <http://www.industryweek.com/ReadArticle.aspx?ArticleID=14109>

National Cotton Council of America (NCCA), "Sharing a Common Thread", (2007), [Accessed: December 10, 2007], <http://www.cotton.org/econ/textiles/cotton-and-textiles.cfm>

National Resource Conservation Services, (2008), "Composting," [Accessed: February 20, 2008], <http://www.nrcs.usda.gov/FEATURE/backyard/compost.html>

Navnet, Downey Area Recycling and Transfer, Downey, CA. (Oct. 2007) Phone Correspondence.

Nieminen, E, Linke, M, Tobler, M, et al. "EU COST Action 628: life cycle assessment (LCA) of textile products, eco-efficiency and definition of best available technology (BAT) of textile processing." *Journal of Cleaner Production*, **15**(13/14), (2007): 1259-.

Neira, Favret, Fuji, Miller, Mahdavi, Blass. "End-of-life management of cell phones in the united states." Donald Bren School of Environmental Science and Management Group Project (2006).

Nike. "Environment Reuse-A-Shoe." (2000). [Accessed: May 3, 2007]. <http://www.nike.com/nikebiz/nikebiz.jhtml?page=27&cat=reuseashoe>

NPG-6 – Nylon-6 Promotional Group. "About Nylon-6." (2006). [Accessed: February 29, 2008]. <http://www.npg-6.com/internet/en/html/algemeen/aboutnylon6/aboutnpg6.pshe>

O'Flaherty, Fred; Roddy Lollar (1956). The Chemistry and Technology of Leather. American Chemical Society, ACS Monograph 134, Krieger Publishing Co., 1956, reprint 1978.

Organic Trade Association, (2007), "The National Organic Standards Board Definition of Organic", [Accessed: December 10, 2007], <http://www.ota.com/definition/nosb.html>

Pacific Northwest Pollution Prevention Resource Center, PPRC, (1999), "Water-based adhesives economics," [Accessed: May 20, 2007], <http://www.pprc.org/pubs/techreviews/waterbsd/wbecon.html>

Patagonia. (2007). "Patagonia's common threads garment recycling program: a detailed analysis." [Accessed: May 6, 2007] <http://www.patagonia.com/pdf/en_US/common_threads_whitepaper.pdf>

Pesticideinfo.org, (2007) "Pesticides Database – Chemicals," [Accessed on November 27, 2007],

<http://www.pesticideinfo.org/Detail_Chemical.jsp?Rec_Id=PC40254>

Plastics Technology, (December 2005), "2006 May bring back more stable prices for recycled resins," [Accessed: May 20, 2007], <http://www.ptonline.com/articles/200512recprice.html>

Polyurethene Foam Association (PFA), (2007),"Flexible Polyurethene Foam – Industry at a Glance," [Accessed on November 29, 2007], <http://www.pfa.org/Library/IAG_no_logo.pdf,>

Polyurethene Foam Association, (PFA) (2007), "Adapting to Environmental Change,"[Accessed on November 29, 2007], <http://www.pfa.org/Library/AEP_no_logo.pdf>

Recycled PET, Image, [Accessed on November 28, 2007], <http://www.openrussia.ru/imgs/products/logos/28387.jpg>

Raff, Gretchen. (2000), "Ethylene Vinyl Acetate Copolymers." [Accessed on November 28, 2007]<http://www.mbhs.edu/departments/magnet/coursesandlife/RandE/matsci/2000-pd2/raff.html>

Robert, West Valley, Fontana, CA. (Oct. 2007) Phone Correspondence.

Salvation Army Trading Company Ltd. (February 2002),"Streamlined lifecycles assessment of textile recycling." *Environmental Resource Management.* [Accessed: April 10, 2006], <http://www.satradingco.org/Reports/LCA.pdf>

Surgical Materials Testing Laboratory. (1996), "What is Latex?" [Accessed on November 15, 2007], <http://www.smtl.co.uk/MDRC/Gloves/jowcpaper96/jowc-glove-paper-what-is-latex.html>

Seuring, S. "Emerging issues in life-cycle management." *Greener Management International*, (45), (2004): 3-.

Simple Shoes, (2007), "Green Toe-ology." [Accessed: April 2007-April 2008] <http://www.simpleshoes.com/greentoe/>

Slater, Keith., Environmental impact of Textiles: Production, Processes and Protection, CRC Publishing. 2003.

Slater, Keith, Professor Emeritus, University of Guelph, Ontario CN. (Oct. 2007). Email Correspondance.

Sneakerhead.com, (2001), "Sneaker Technology," [Accessed: May 20, 2007], <http://www.sneakerhead.com/nike-brand-technology.html>

Soles4Souls.org, (2008), "Changing the World One Pair at a Time," [Accessed: January 20, 2008] <http://www.soles4souls.org/>

Staikos, Theodoros, et al. "End-of-life management of shoes and the role of biodegradable materials." Centre for Sustainable Manufacturing and Reuse/Recycling Technologies (SMART), Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University, UK, (2006).

Staikos, Theodoros, Research Associate, Centre for Sustainable Manufacturing and Reuse/Recycling Technologies (SMART), Wolfson School of Mechanical and Manufacturing Engineering Loughborough University, (Nov. 2007) Email Correspondance.

Taylor, Nathan, Director of Technical Services, EcoSynergy, Inc. (Dec. 2007) Email Correspondence.

The Navy and Marine Living History Association, "Sample colors of wool fabrics available to NHMLA membership," [Accessed: May 20, 2007] <http://www.navyandmarine.org/woolrichsamples/index.htm>

The Lazy Environmentalist, (2006). "Eco-glossary: textiles and production." [Accessed: November 27, 2007], <https://www.lazye.co.uk/eco-textiles.php>

UNCTAD – "Market Information in the Commodities Area – Cotton," [Accessed on December 1, 2007], <http://r0.unctad.org/infocomm/anglais/cotton/sitemap.htm>

UNEP - Intergovernmental Panel on Climate Change. "Climate Change 2001," [Accessed on November 27, 2007], <http://www.grida.no/climate/ipcc_tar/wg1/248.htm>

United Nations Food and Agriculture Organization. (2006), "How to Tap a Rubber Tree" [Accessed on November 15, 2007], <http://www.fao.org/DOCREP/006/AD221E/AD221E06.htm>

United States – Asia Environmental Partnership (US-AEP), "Clean technologies in US industries focus on textile production," [Accessed: November 8, 2007], <http://www.p2pays.org/ref%5C06/05656.htm>

USA Hemp Museum, (2007), "Hemp Textile Room," [Accessed: November 6, 2007], <http://hempmuseum.org/SUBROOMS/HEMP%20TEXTILE%20HISTORY.htm>

US EPA., (1997), "Profile of the textile industry" EPA Office of Enforcement and Compliance Assurance.

US EPA., (2001). National Emission Standards for Hazardous Air Pollutants: Flexible Polyurethane Foam Fabrication Operations." Federal Register Environmental Documents. [Accessed: May 8, 2007], <http://www.epa.gov/fedrgstr/EPA-AIR/2001/August/Day-08/a19603.htm>

US EPA., (2000). "2,4-Toluene diisocyanate," Technology Transfer Network Air Toxics. [Accessed: May 8, 2007], <http://www.epa.gov/ttnatw01/hlthef/toluene2.html>

US Textile Recycling Directory, "US used footwear recycling directory-California," (2007) [Accessed: January 10, 2008], <http://www.wipingrag.net/usa/footwear/index-california.html>

US Green Living, (2008), "Composting and Biological Disposal," [Accessed: February 20, 2008] <http://www.usgreenliving.com/green_living/composters.html>

"Wearing green: the cotton conundrum," (March 2007), Mindful mommas adventures in living green [Accessed: May 20, 2007], <http://mindfulmomma.typepad.com/mindful_momma/2007/03/ecofabrics.html>

Wheeler, Alan, National Liason Manager of Textile Recycling Association, (Nov. 2007) Email Correspondence.

Wikipedia, "Dye" (2007). [Accessed: November 11, 2007], <http://en.wikipedia.org/wiki/Dye>

Wikipedia, "Image and Background of EVA," [Accessed: May 27, 2007], <http://en.wikipedia.org/wiki/Ethylene-vinyl_acetate>

Wikipedia, "Polybutadiene," (2007). [Accessed: December 10, 2007], <http://en.wikipedia.org/wiki/Polybutadiene>

Wikipedia, "Synthetic Rubber," (2007), [Accessed: December 10, 2007] <http://en.wikipedia.org/wiki/Synthetic_rubber>

WiseGeek, (2007), "What is Bamboo Fabric, [Accessed: December 10, 2007] <http://www.wisegeek.com/what-is-bamboo-fabric.htm>

Woolridge, AC, Ward, GD, Phillips, PS, et al. "Life cycle assessment for reuse/recycling of donated waste textiles compared to use of virgin material: an UK energy saving perspective." *Resources, Conservation, and Recycling*, **46**(1), (2006): 94-.

World Bamboo Organization, (2003-2007), "Archives" [Accessed: December 10, 2007] <http://www.world-bamboo.org/>

World Centric, "Compostable, biodegradable bioplastics," (2004), [Accessed January 10, 2008] <http://www.worldcentric.org/store/bioplastics.htm>

World Wildlife Fund, (2005) "Environmental Impacts of Rubber: Pollution from Processing Rubber," [Accessed on November 15, 2007], <http://www.panda.org/about_wwf/what_we_do/policy/agriculture_environment/commodities/rubber/environmental_impacts/pollution/index.cfm>

World Wildlife Fund, (2005). "Agriculture and Environment: Beef." [Accessed on November 15, 2007], <http://www.panda.org/about_wwf/what_we_do/policy/agriculture_environment/commodities/beef/environmental_impacts/cattle_feedlots/index.cfm>

World Wise, “Biodegradable”, (2007), [Accessed: January 10, 2008], <http://www.worldwise.com/biodegradable.html>

Zhu, Q, & Sarkis, J. “Relationships between operational practices and performance among early adopters of green supply chain management practices in Chinese manufacturing enterprises.” *Journal of Operations Management*, **22**(3), (2004): 2

Appendix I – Dyeing Practices

History and Purpose of Textile Dyeing

The earliest records indicate that dyeing has occurred in China since 2600 BC and in the Middle East and India for the past 5000 years (EPA, 1997). Until the 19th century dyes (dye stuff) were derived from plants. In 1856 William Henry Perkin invented the first synthetic organic dye (EPA, 1997). Since that time, synthetic dyes have been massed produced for commercial use and have displaced the use of natural dyes in most markets primarily due to increases in color range, higher fixation rates and decreased costs. In the 1950's, reactive dyes were created and now serve as the largest class of dyes used throughout the world. Today the textile industry is composed of a group of diverse and fragmented establishments with thousands of dyes being manufactured throughout the world (EPA, 1997). The dye house serves as a crucial step in the supply chain and transforms dull and plain materials into dramatic and colorful fabrics.

Process of Textile Dyeing

The dyeing process can take place at several stages along the manufacturing process of textiles (fibers, yarn, and piece dyeing). Currently, the two major methods of dyeing textiles used by Simple Shoes are continuous (long vehicle) and batch (reel dye vat). The latter process involves placing the fabric into a vat and adding dyestuff and water. Depending on the type of fabric the vat runs for 3-6 hours and the fabric is continually checked for color quality. The wastewater is removed and the vat is refilled with more water in order to clean the fabric (10 times). The product is then retrieved from the dye vat and put into a drying oven. This process generates fabric that in general is less wrinkled and overall requires less material (30-400 yards) to run the process. However, vat batch dyeing does yield more color variation (EPA 1997, Personal Communication Simple Shoes).

Unlike batch dyeing, continuous dyeing involves placing raw fabrics into a dyeing machine and using water to wash out impurities. Dyestuff and water are added to a dye trough and the fabric is passed through the trough at 100-150 meters per minute. The fabric is then washed with cold water and dried in an oven. Throughout this process the quality of color is continually checked and this method of dyeing provides less differentiation in color, but requires a minimum of 3,000 meters of fabric to run the process (EPA. 1997, Personal Communication Simple Shoes). Overall, the continuous dyeing process has a greater rate of dyeing fixation and accounts for over 60% of total volume output from the textile industry (EPA, 1997). In addition to these processes, pad batch dyeing is quickly becoming an acceptable dyeing alternative due to its lower environmental impacts. Pad batch or cold dyeing involves immersing the fabric into a cold liquor solution (water, chemicals, and dye), squeezing out excess solution, and then letting the fabric dry for 2-12 hours covered in a plastic film to prevent CO_2 absorption (EPA, 1997). Cold dyeing required no additional salts or chemicals and is seen as a cost-effective and environmental friendly technique to apply reactive dyes to cotton. Each of these dyeing processes require various amounts of dye per unit of fabric and any excess dyes in addition to salts, mordants, and auxiliary chemicals often end up in the waste stream.

Dye attributes and cost

Textiles are dyed using a wide variety of chemicals and dye stuff. Worldwide, a total of 70,000 tons of dye are produced annually and, of this amount, synthetic dyes are used far more commonly than natural dyes as they are safer, more reliable and cost effective (EPA , 1997). Natural dye application requires mordants that are commonly composed of salts from aluminum, chromium, copper, and iron and there is a movement across the industry to develop new methods for fixation that does not use metal based mordants (Council for Textile Recycling, 1997).

APPENDIX I – Dyeing Practices

There are multiple classes of dyes on the market each with varying environmental impacts and dyeing fixation rates ranging from 60-80%.

The different classes of dyes vary in price from approximately $.80 to $3.50 per ½ ounce (Appendix I-A). In general, the overall cost of dyes has been increasing over the last few years due to a multitude of outside factors including a decrease in raw and intermediate material supply, facility closures, environmental clean-up from dye houses, and higher costs related to oil, energy and transportation (Ecotextiles, 2007). Some of the major dye manufactures such as CIBA, Dystar and Huntsman, have increased their prices from 10-30% for various dyes (Ecotextiles, 2007). This increase in price is likely to continue to rise during the coming years due to the factors listed above.

Simple Shoes currently uses 22 different "CIBA" colors on the four products analyzed in this study (Shoe 1, Shoe 2, Shoe 3, Shoe 4). The colors vary from shades of brown, greens and yellows and the most commonly used dye colors are Tan and Chocolate.

Environmental Impacts of Textile Dyeing

It requires nearly 200 liters of water to produce 1 kg of finished cloth which creates 53 billion gallons per year of polluted wastewater requiring treatment prior to release from textile manufacturing mills (US-AEP, 2007). Wastewater is by far the largest waste stream and includes cleaning water, process water, non-contact cooling water, and storm water (EPA, 1997). Process water or water from the dyeing and rinsing phases result in an odorous and colored effluent with high salinity content. More specifically, the dye can leave a solution residue with a high load of suspended solids in the water (by-products and auxiliary chemicals), as well as detergents from washing machines. The wastewater pumped from a dye house or manufacturing facility can have a high pH and be saturated with oils, grease, sulfate and other toxic materials (US-AEP, 2007). This wastewater effluent commonly has high BOD and COD levels, two indicators of water quality, and often contains measurable amounts of heavy metals.

In addition to the impacts associated with water, the application of dyes to fabric requires a high consumption of energy and chemicals. The dyeing processes generate hazardous and non-hazardous solid waste (cotton combings, material scrap, sodium sulfite bags), contaminates the land and produces atmospheric emissions and noise (US-AEP, 2007). Atmospheric emissions include: carbon dioxide, nitrogen and sulfur oxides from transportation and boilers, steam from drying and heating, oil and mist associated with finishing and proofing and VOC solvents from dry cleaning and washing. In addition to these, NH_3 and Formaldehyde are also released from dyeing and coating (EPA, 1997).

Best Management Practices to be utilized in Dyeing Process

In light of increased environmental awareness, the textile industry is working to implement Best Management Practices (BMP) to achieve compliance with federal and state regulations as well as also decrease energy and water usage as a means of increasing overall productivity and economic efficiency (Appendix I-C). The successful execution of BMP's requires a commitment on the part of management for not only initial implementation, but also monitoring. The well known environmental impacts of dyeing in juxtaposition with the plethora of opportunities to Green this process serve as a valid prospect for Simple Shoes to improve the environmental management of their value chain by working with suppliers.

APPENDIX I – Dyeing Practices

Dye Class	Acid	Basic	Direct	Disperse	Reactive	Sulfur	Vat	Natural
Description	Water-soluble anionic compounds	Water-soluble, applied in weakly acidic dyebaths, is a very bright dye	Water-soluble cationic compounds, directily applied to fibers without mordants (metals like chromium or copper)	Water-insoluble applied in the form of powder or paste and have a large surface area	Water-soluble anionic compounds, largest dye class, most permanent	Organic compounds containing sulfur or sodium sulfide	Oldest dyes, more chemically complex, water-insoluble	Oldest dyes, requires mordant to achieve color, water-soluble
Method	Exhaust/ Beck/ Continuous	Exhast/ Beck	Exhaust/ Beck/ Continuous	High temperatures required, Exhaust/ Continuous	Exhuast/ Beck/ Cold pad batch/ Continous	Continuous	Exhaust/ Package/ Continuous	Batch
Fibres Typically Applied to	Silk, Wool, Nylon	Acrylic and some Polyester Fibers	Cotton, Rayon, Paper, Leather, Wool, Silk	Nylon, Polyester, Acrylic other Synthetics	Cotton, Wool and other Cellulosics	Cotton and other Cellulosics	Cotton and other Cellulosics	Silk, Hemp, Cotton
Typlical Fixation %	80-93	97-98	70-95	80-92	60-90	60-70	80-95	Approx. 70
Associated toxicity impacts	H_2SO_4, HCL, HNO_3, and other metals	N/A	Unfixed dye, Cationic fixing agents, Surfactants, Defoamers, Leveling and reaterding agents, Finsh, Dilutents, Acids, Metals, Phosphorous and Organics	H2SO4, HCL, HNO3,Carriers, Leveliing agents, Phosphates, Defomaers, Lubricants, Despersants, Delustrants, Dilutents	Alkali, Unfixed dye, Surfactants, Defoamers, Dilutents, Finish	Alkali, Oxidizing agents, Reducing agents, Unfixed dye	Alkali, Oxidizing gents, Reducing agents	Metal mordents, potential increase in water and energy usage from re-dying
Cost (0.5 ounce)	$3.49	$3.12	$1.52	$1.77	$1.32	$0.82	$2.59	$1.30

Exhibit A
Source: EPA 1997

APPENDIX I – Dyeing Practices

Exhibit B. List of Dyes used by Simple Shoes

Dyes	Material Dyed					Shoe
	Bamboo	Cotton	Hemp	Jute	Leather	
Adriatic Blue 17-4320TPX		x			x	SHOE 3
Birch 13-0905TPX	x	x		x	x	SHOE 2, SHOE 3
Black Coffee 19-111TPX	x	x	x			SHOE 2
Blanc de Blanc 11-4800TPX		x			x	SHOE 3
Brick 18-1531TPX		x			x	SHOE 3
Buckthorn Brown 18-0935TPX					x	SHOE 4
Burnt Brick 18-1350TPX					x	SHOE 4
Chestnut 16-1432TPX					x	SHOE 4
Chocolate 19-0912TPX	x	x	x	x	x	SHOE 1, SHOE 2, SHOE 4
Crème Brulee 13-0908TPX		x			x	SHOE 3
Cub 18-1015TPX		x			x	SHOE 2, SHOE 3
Meadow Green 16-0233TPX		x			x	SHOE 3
Mineral Yellow 15-1045TPX		x			x	SHOE 2, SHOE 3
Moss 16-0532TPX		x			x	SHOE 3
Oil Green 17-0115TPX	x	x	x			SHOE 2
Oyster Grey 14-1107 TPX		x			x	SHOE 2, SHOE 3
Phantom 19-4205TPX	x	x	x			SHOE 2
Rabbit 19-3905TPX		x			x	SHOE 3
Sand 17-113TPX	x			x		SHOE 1
Silver Cloud 15-4502TPX	x	x	x			SHOE 2
Tan 17-1022TPX	x	x	x		x	SHOE 2, SHOE 3, SHOE 4
Whitecap Gray 12-0304TPX		x			x	SHOE 3

(Source: Simple Shoes, 2007)

APPENDIX I – Dyeing Practices

Exhibit C. Dyeing Best Management Practices

Best Management Plan	Avoid Environmental Burden	Components of Plan
Waste Management Plan	Decrease the quantity and impact of solid and liquid waste streams	- Ensuring water is turned off when equipment is not operating - Identifying all gaseous, liquid, solid waste s Streams - Quantify and characterize all waste streams - Conduct waste audit and - Increase staff awareness of waste minimization principles and practices
Air Quality and Emissions Plan	Reduce the quantity of fugitive air emissions and increase indoor air quality for employees	- Examine and review all coatings for concentration, volatility, odor potential and toxicity - Implement the use of reduced toxic coatings and coating concentration in production - Turn power off for machines not in use - Optimize drying oven performance - Warm up incoming gases - Use pressure dyeing machines where practical - Apply coatings at optimum level - Implement air pollution control devices (fabric – filter, bag houses, wet scrubbers)
Water Quality Management Plan	Decrease and or eliminate residual dye stuff, Halogenated Organic Compounds, heavy metals, BOD, COD, TOS and elevated water temperatures	- Implement low liquor ratio dyeing machines - Utilize pad batch dyeing techniques for cotton - Minimize machine cleaning through regular Maintenance - Reduce the number of rinses and cycles to the optimum amount - Combine rinses with scours - Recycle clean rinses - Choose biodegradable surfactants - Reduce salt usage - Ensure dye fixing is maximized - Recycle light shade dye baths into darker shades - Avoid chlorinated bleaches - Implement waste water treatment before water is expelled to environment

Exhibit C. Dyeing Best Management Practices (continued)

Best Management Plan	Avoid Environmental Burden	Components of Plan
Energy Use Management Plan	Decrease the use of energy and reduce dependence on fossil fuels to cut green house gas emissions and save money	- Identify most energy intensive equipment and concentrate on improving efficiency in order to produce larges energy savings - Evaluate the cost of energy dyeing methods (Steam, Gas, RF) - Recover cooling water and use it as heated water Input - Install motion sensors - Eliminate all leaks in equipment - Set dryer and vulcanizing oven to optimum temperature and operating time - Identify and implement alternative energy and fuel sources (combustible waste, solar, wind)
Solid Waste Management Plan	Reduce the impact and quantity of solid waste and potential land contamination from toxic material scraps, salt bags and packaging	- Recycle waste fibers and sludge as feedstock for cleaning, dye adsorption, external uses: insulation, geotextiles, non-woven's - Implement bulk chemical delivery - Utilize a returnable container system - Segregate containers into recycling areas - Re-use non hazardous containers

(Source: EPA, 1997)

Appendix II – LCA Results

Exhibit A. Unit Process Descriptions for Shoes 1-4

Shoe	Processes	Primary Inputs	Outputs
Materials			
1,2,3	Hemp	solar and wind energy, water, land, air and soil nutrients, cooling water, hydropower, coal	radioactive and inorganic emissions to air and water
1, 4	Cotton		
1, 2.3	Organic cotton		
1, 2.3	Latex		
1, 2	Crepe		
4	Cow Suede	solar, wind and hydropower, CO_2, feed, surface water, phosphate, sodium, chromium ore, limestone, calf hide	waste for recovery
1, 2,3	PET	crude oil, natural gas, coal, hydropower	air and water emissions
2,3	Recycled PET	surface and ground water, inert rock, unspecified plastic, cooling water, lignite, hard coal, power	secondary PET, low lever radioactive and consumer waste
1, 2	Recycled paper and cardboard	energy, natural gas, waste paper, manure	inorganic and organic emissions to air and water
3,4	EVA	ground, surface and cooling water, crude oil, natural gas, energy, quartz sand, gold, silver and copper ore	consumer and hazardous waste
3, 4	Synthetic Virgin Rubber	ground, surface and cooling water, crude oil, natural gas, energy	consumer and hazardous waste
4	PU Foam	river and sea water, nuclear energy, sodium chloride, natural gas, crude oil, hard coal	hazardous waste
Phases			
1,2,3,4	Transportation	diesel, heavy fuel	inorganic emissions to air
1,2,3,4	Assembly	Electric power	emissions to air
1,2,3,4	Packaging	Electric power	emissions to air
1,2,3,4	Landfill	air, surface water, clay, soil	emissions to air, water, soil

(Source: LCA Software GaBi 4.0)

APPENDIX II – LCA Results

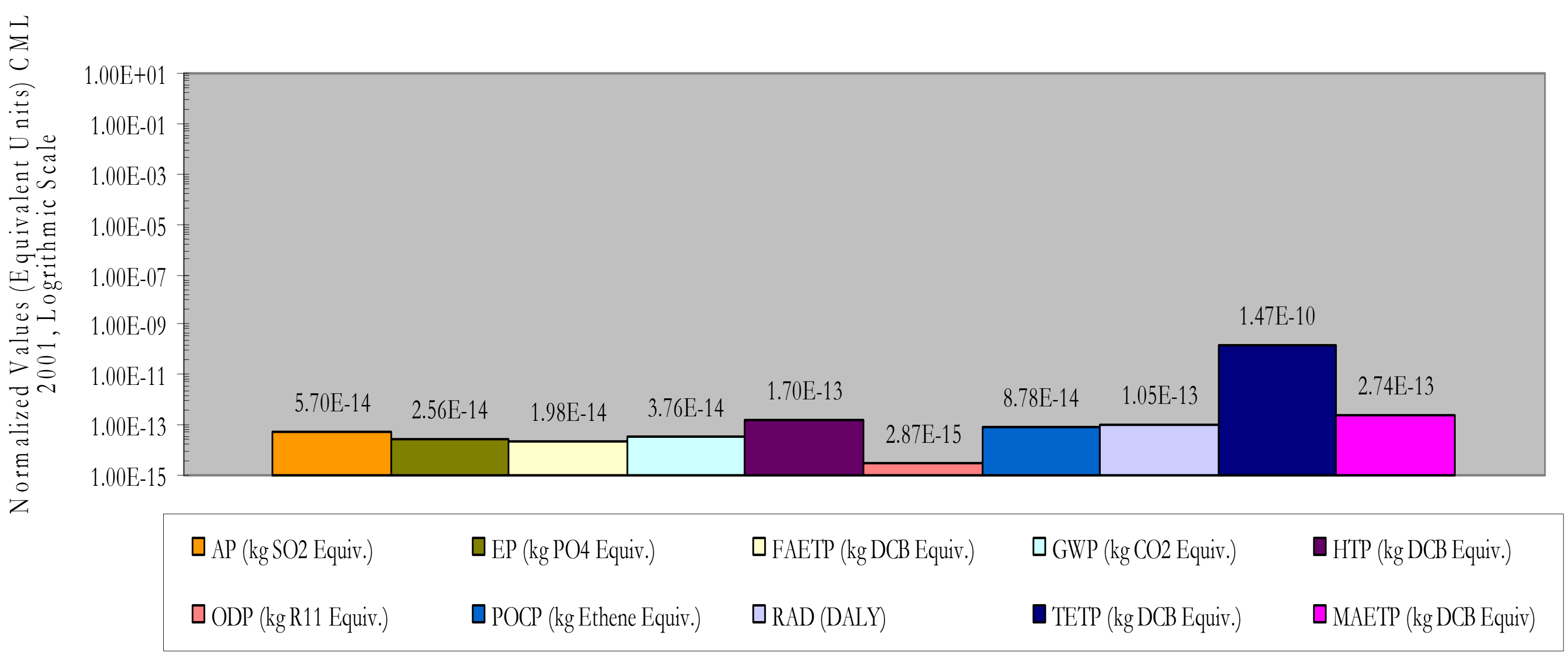


Exhibit B. Environmental Impact Categories, Normalized Results - Shoe 1

(Source: LCA Software GaBi 4.0)

APPENDIX II – LCA Results

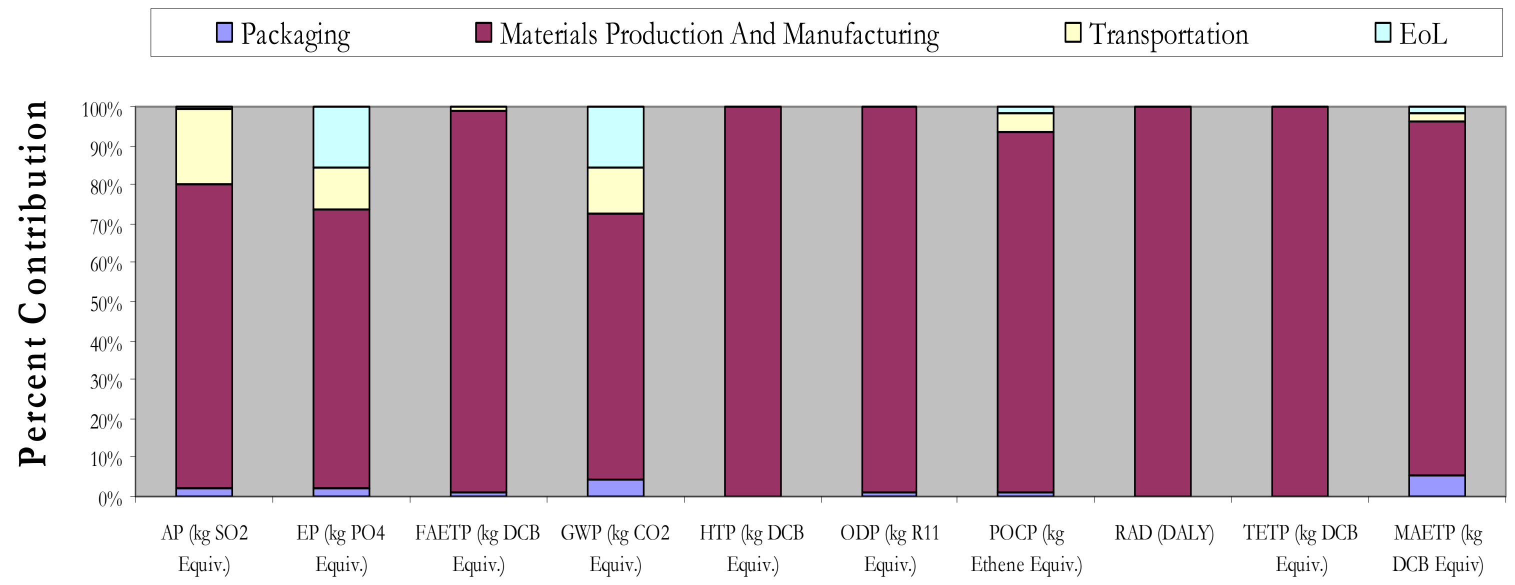


Exhibit C. Relative Contribution of System Processes Across Environmental Impact Categories, Actual Data - Shoe 1

(Source: LCA Software GaBi 4.0)

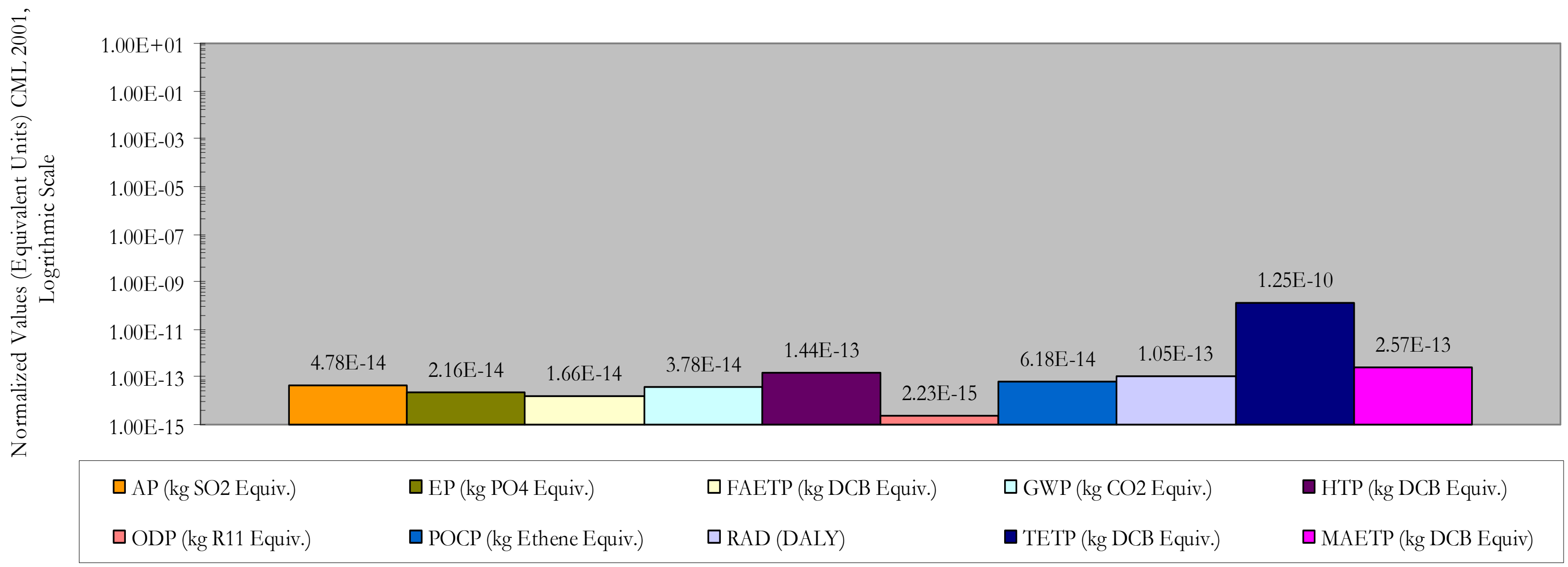


Exhibit D. Environmental Impact Categories, Normalized Results - Shoe 2

(Source: LCA Software GaBi 4.0)

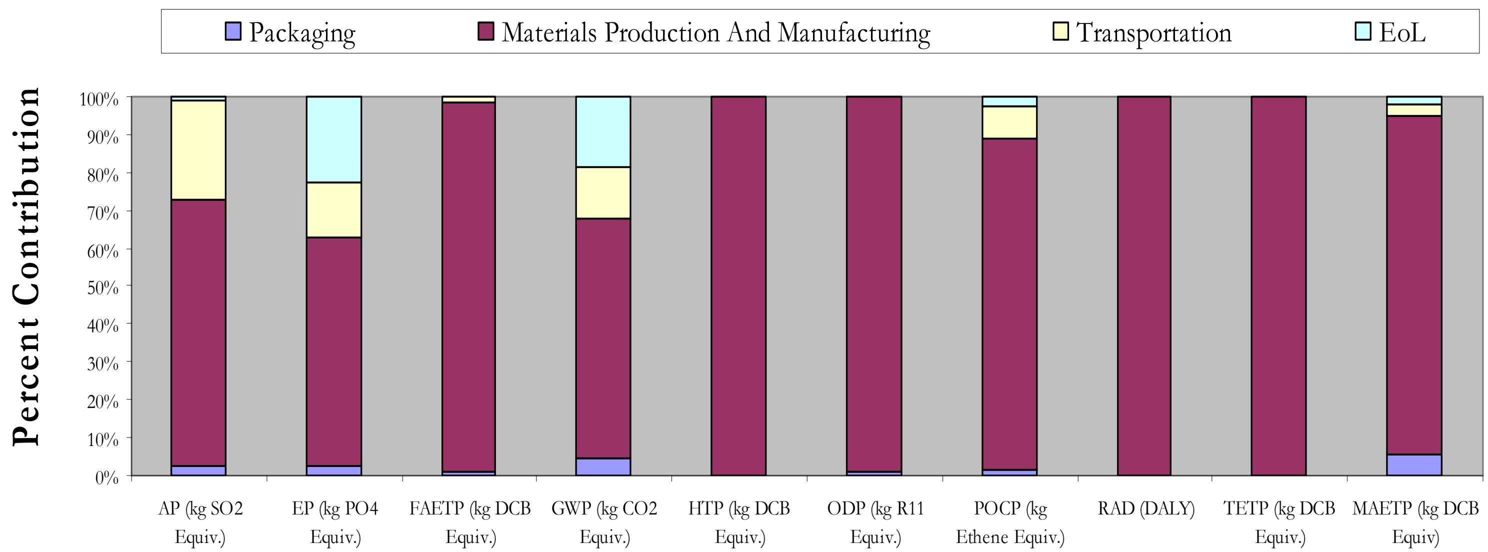


Exhibit E. Relative Contribution of System Processes Across Environmental Impact Categories, Actual Data - Shoe 2

(Source: LCA Software GaBi 4.0)

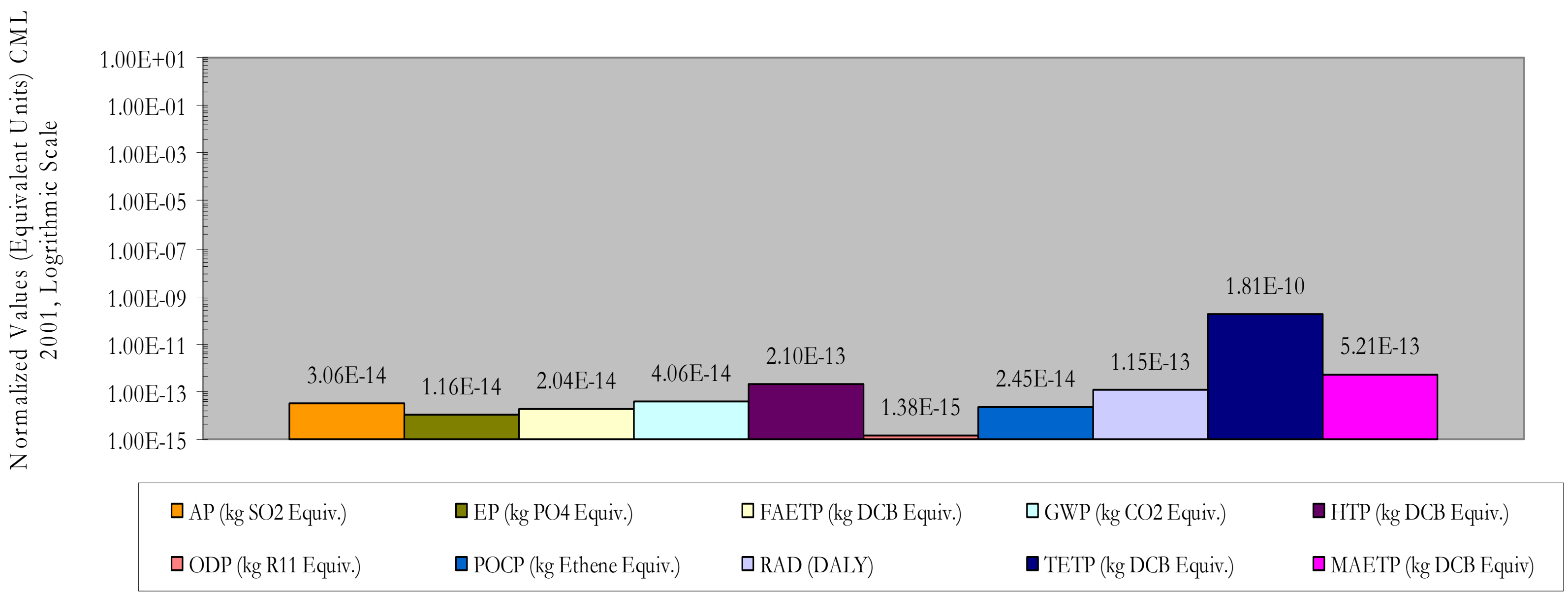


Exhibit F. Environmental Impact Categories, Normalized Results - Shoe 3

(Source: LCA Software GaBi 4.0)

APPENDIX II – LCA Results

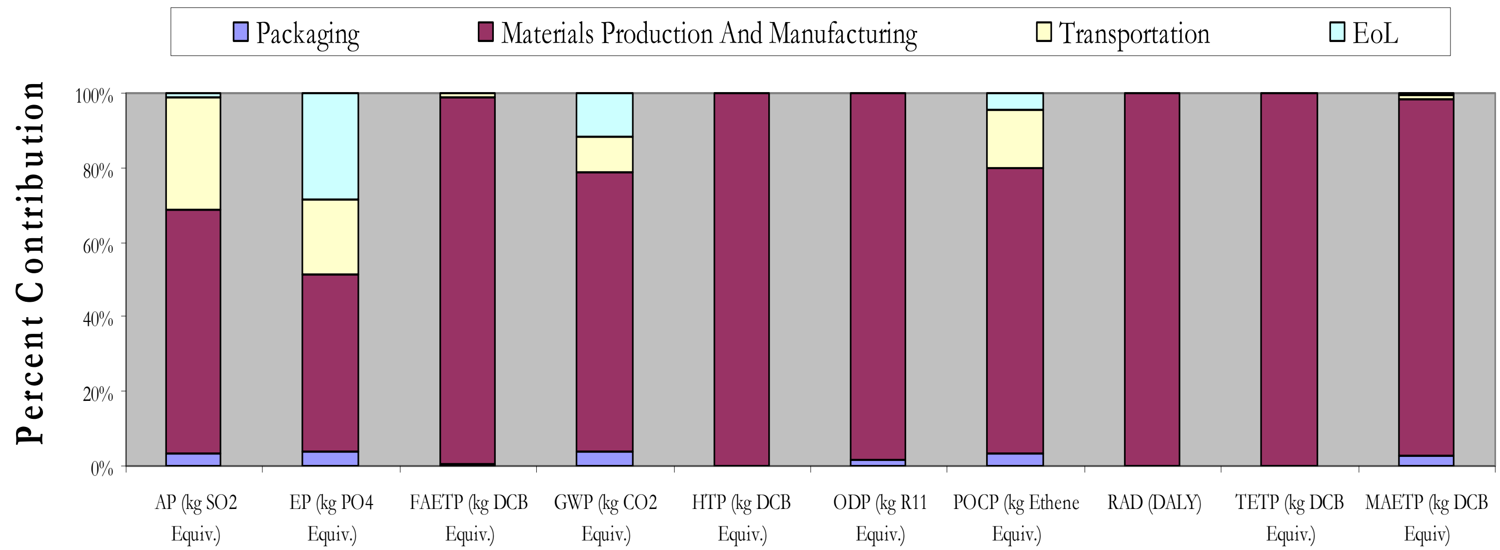


Exhibit G. Relative Contribution of System Processes Across Environmental Impact Categories, Actual Data - Shoe 3

(Source: LCA Software GaBi 4.0)

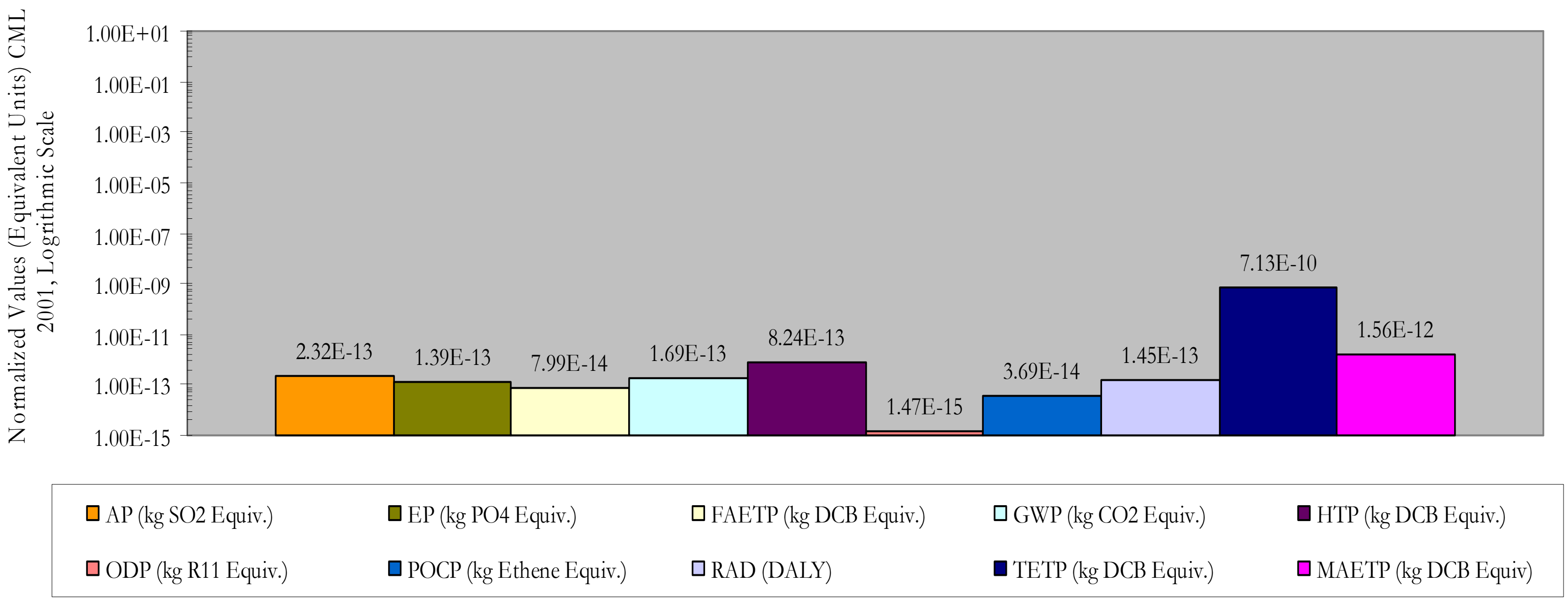
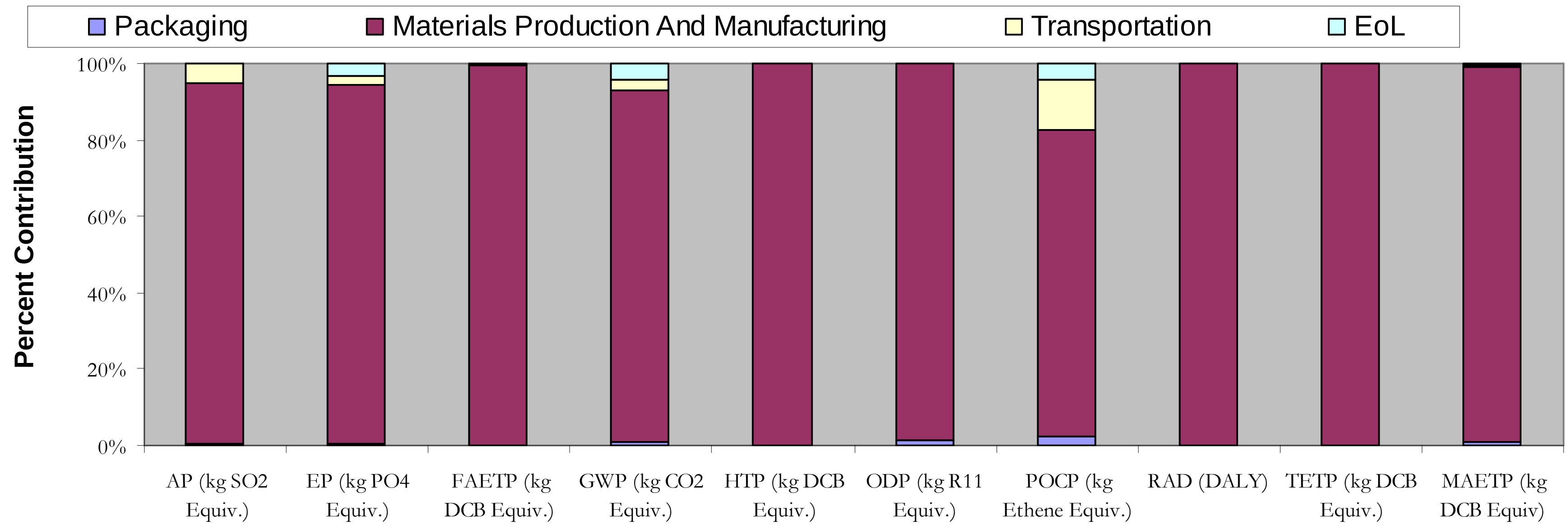


Exhibit H. Environmental Impact Categories, Normalized Results - Shoe 4

(Source: LCA Software GaBi 4.0)



Exhbit I. Relative Contribution of System Processes Across Environmental Impact Categories, Actual Data - Shoe 4

(Source: LCA Software GaBi 4.0)

Appendix III – Supply Chain Assessment

Exhibit A

Assessment of the Economic and Environmental Benefits of Materials Subsistution for Simple's Supply Chain

	Original Material - OS Sneaker	Alternative Material - Loaf	Environmental Impactt[1]	Economic Cost[2]
Laces	Cotton	Organic Cotton	↘	↗
		Jute	↘	↗
Outsole	Rubber	Crepe Rubber	↘	↗
		Retreaded Car Tires	↘	↘
Midsole	EVA	Wool Felt	→	→
		Cork	No Data	↘
		Recycled PET	→	↘
Insole/Liner	Cotton	Bamboo	↘	↗
Upper	Suede	Hemp	↘	↘
		Jute	↘	↘
		Wool Felt	↘	→
Adhesives	Chemical-Based Adhesives (Phenol/Urea)	Water-Based Adhesives	↘	↘

[1] *Source: PE International (GaBi 4.0) Extended DB*

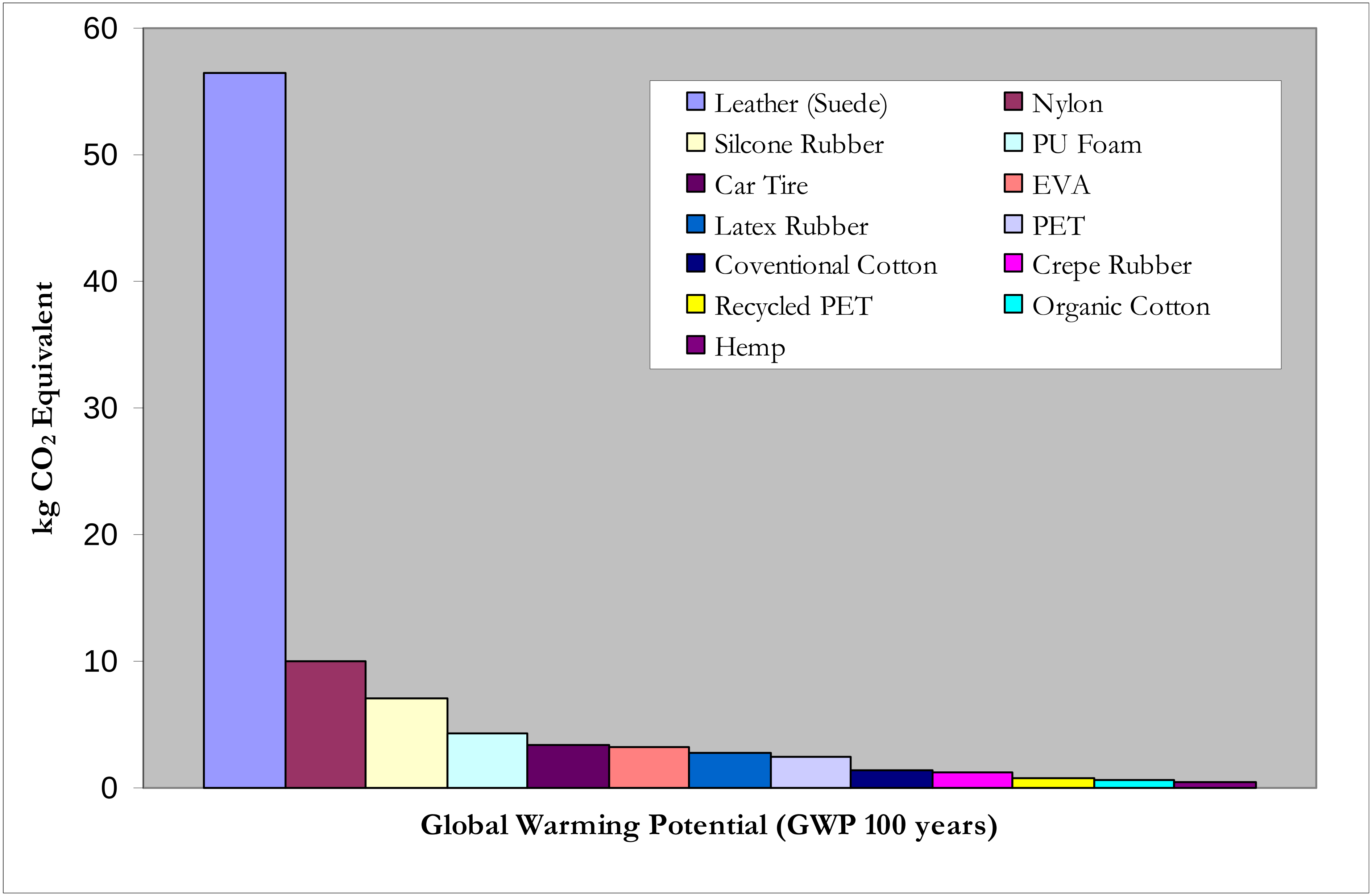
[2] *Source: See Table 4, of Supply Chain Section*

Exhibit B

Relationship between Environmental and Economic Supply Chain Performance

Part of Shoe	Traditional Material	Traditional Cost/lb	Alternative Material	Alternative Cost/lb	Net Change	Environmental Benefits
Upper	Cotton	$0.62	Organic Cotton	$1.50	**$0.88**	Decreased Pesticides & Herbicide Use
			Hemp	$2.48	**$1.86**	Decreased Energy & Fertilizer use for Production, Decrease GWP and Acidifcation compared to Wheat/Sugar.
			Jute	$8.72	**$8.10**	Fast Growing, High Pest Resistance, High CO2 Assimilation, High Biomass Yield/ Unit Area
			Wool	$11.80	**$11.18**	Grazed on pastuerland avoiding feedlots. No chromium but can use organophosphate compounds to control parasites.
	Poly Suede	$11.98	Organic Cotton	$1.50	**($10.48)**	Decreased Pesticides & Herbicide Use
			Hemp	$2.48	**($9.50)**	Decreased Energy & Fertilizer use for Production, Decrease GWP and Acidifcation compared to Wheat/Sugar.
			Jute	$8.72	**($3.26)**	Fast Growing, High Pest Resistance, High CO2 Assimilation, High Biomass Yield/ Unit Area
			Wool	$11.80	**($0.18)**	Grazed on pastuerland avoiding feedlots. No chromium but can use organophosphate compounds to control parasites.
Midsole/Inner	EVA	$0.64	Cork	$1.23	**$0.59**	Renewable natural resource. Harvested without felling tree. Carbon sequestration.
			Recycled PET Flake	$0.60	**($0.04)**	Displacement of primary PET production and associated waste/emissions, diversion of PET waste from Landills
			Recycled PET Pellet	$0.73	**$0.09**	Displacement of primary PET production and associated waste/emissions, diversion of PET waste from Landills
			Bamboo	$19.00	**$18.36**	Fast Growing, Little/No input of water/fertilizers
Outsole	Rubber	$0.69	Used Car Tires	$0.05	**($0.64)**	Displacement of primary rubber production and associated wastes/emissions.
Adhesive	Chemical-Based	$10.69	Water-Based	$8.22	**($2.47)**	Reduction of Hazardous Air Pollutants, harmful VOCs that can affect human health and lead to stratospheric ozone depletion.
Packaging	Primary Cardboard	$1.40	Post-Consumer Cardboard	$0.02	**($1.38)**	Displacement of primary cardboard production and its associated wastes/emissions

Exhibit C. Comparison of GWP per KG of Material



APPENDIX III – Supply Chain

Exhibit D. Relationship between the Degree of Control and Environmental Impact across Supply Chain Phases

	Processes	Degree of Control	Potential Environmental Impact
Textiles	Growing Harvesting Finishing	None None Moderate	High Moderate Moderate
Natural Rubber	Growing Harvesting Finishing	None None Moderate	Moderate Low Low
Synthetic Plastics/Rubber	Extraction Synthesis Shaping	None None Moderate	High High Moderate
Leather	Cattle Production Tanning	None Moderate	Extreme High
Logistics	Transportation Warehouse	Absolute Absolute	Low Low
Manufacturing and Sales	Footwear Manufacturing Retail	Absolute Absolute	Low Low
Use Phase	Consumption	Low	Low
End of Life	Landfill Take-back Composting	None Moderate Low	Moderate Moderate None

Appendix IV – End-of-Life Assumptions

A – General

- All weights provided and verified by Simple Shoes.
- All distances calculated using Google Earth software
- All GWP calculations come from GaBi 4 LCA software
- Diesel fuel consumption of a 9.3 ton payload truck at 85% capacity is 2.34 E-05 kg/km/kg of load (from GaBi)
- GWP of diesel fuel combustion is 3.3 kg CO_2 eq./kg (from GaBi)
- Diesel fuel consumption of a container ship is 3.7E-06 kg/km/kg of load (from GaBi)

B – Landfilling

- We assumed that the impact from transportation of waste from household to landfill is negligible because waste is collected by municipality and therefore travels a short distance. Also, the weight of the shoe makes up a small fraction of the trash truck's payload.

C – Reuse

- Because Soles4Souls has so many recipient countries, we choose to average the distance from Alabama to the 12 destination countries listed on their website (soles4souls.org). We calculated a distance of 8000 km as the distance that the container ship would travel.

S4S recipient country	Distance from Alabama (km)
Honduras	1700
Guatemala	1700
Haiti	2000
Dominican Republic	2200
Swaziland	14000
Sudan	12000
Uganda	13000
Romania	9000
Iraq	11000
Peru	5000
Thailand	15000
Nepal	14000
average	**8000**

D – Recycling

- We assumed that all of the materials would be completely recycled and that each gram of recycled material would displace primary production of a virgin material.
- To calculate avoided primary production we inputted the weight of each material into the corresponding production process in GaBi. The avoided production for each shoe is the sum of the production GWP for each of the shoe's materials. We took the average production GWP of all four shoes as the average Avoided Primary Production.

- Shoes 1 and 2 have cork and bamboo which GaBi did not have data for. These materials, along with Car Tire and Recycled PET, are included in the "other" category

Appendix IV - End-of-Life Assumptions

-

- The additional transportation steps required for Simple to recycle their shoes are from Simple Collection Facility in Ventura, CA to the recycling facility and from the recycling facility to Simple's Manufacturing Facility in Guangzhou, China. We found several recyclers for each material around the country. Since Simple does not currently recycle their shoes we had to estimate a location for the recycler. To do this we took the average distance from Ventura to all of the recyclers we found. The average distance was 3000 km. We picked St. Louis, MI as the location of the recycler because it is approximately 3000 km from Ventura. The distance from St. Louis to Guangzhou is 13000 km.

E – Grinding

- To calculate the avoided primary production of surfacing materials we grouped the materials of each shoe into fabric, foam, and rubber because Nike Grind is separated into these 3 components. We assumed that the fabric materials would be displacing cotton production, the foam materials would be displacing PU foam production, and that the rubber materials would be displacing synthetic rubber production. We did include PET, cork, and bamboo because they did not fit into any of the 3 categories. We did not include car tire rubber because we did not want to double count it.