REAL COST OF STYROFOAM

Presented to St. Louis Earth Day

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Polystyrene foam products, commonly referred to as Styrofoam, are widely used as single-use consumer goods. Three million tons of polystyrene are produced in the United States each year, predominantly used to make packaging materials and food service items such as foam cups, cartons, and other containers. Several unique qualities of Styrofoam have led to its prevalent use in these applications—its low cost, its lightweight nature and insulation properties, and its durability. However, these same qualities also carry indirect, or hidden costs, associated with using Styrofoam products.

The purpose of this report is to provide a comprehensive analysis of the "real cost of Styrofoam." We have defined the costs associated with Styrofoam as 1) production costs, 2) environmental costs, and 3) human health costs. Our assessment of these costs includes both a qualitative and quantitative perspective.

While Styrofoam is relatively inexpensive to produce, an analysis of the manufacturing process uncovers social costs involving the use of hazardous chemicals, fossil fuels, and the emission of greenhouse gases. Styrofoam's lightweight nature and its use with food products make it difficult and expensive to recycle, thus contributing to its accumulation in landfills (comprising as much as 30% of total landfill volume) and as litter (20% of Styrofoam estimated to end up in waterways). Finally, while Styrofoam itself is inert, or unreactive, the compounds used in its production (benzene and styrene) have been identified as harmful to human health with neurological effects and increased risk of cancers, such as leukemia, from prolonged exposure.

In order to quantify the hidden costs of Styrofoam associated with production, environment, and human health, we have developed a financial model for quantitative analysis.

This model uses statistical data found in the literature for specific costs associated with each category and extrapolates to derive a calculation representative of the comprehensive costs. The model is fluid, and presented in such a way that it may be modified to include updated information over time. Our model estimates the total hidden costs of Styrofoam (for the current production output of 3 million tons) at $7 billion annually. This represents an estimated hidden cost equivalent to 1.2 cents per Styrofoam cup produced.

The results of our analyses suggest that the real cost of Styrofoam outweighs the benefits of its use. The impact of the social costs of production, the effects on the environment, and the risks to human health should be taken into account from both a qualitative and quantitative perspective. The recommendation of our team is that individuals and businesses reduce their use of Styrofoam and take advantage of a growing number of alternative products.

INTRODUCTION

St. Louis Earth Day (SLED) has requested an in-depth analysis of Styrofoam and the "real costs" associated with its use, from production to disposal. Their desired deliverable is a 1-page fact-sheet that can be shared with customers in an effort to drive change among local restaurants, encouraging them to use alternative materials to Styrofoam for serving food.

As we have researched the "Real Cost of Styrofoam", we have found information pertaining to its quantitative costs to be speculative at best. In our meetings with SLED, we have decided that we will focus on both qualitative and quantitative information. In order to come up with the true cost of Styrofoam, we will use a number of assumptions to allocate quantitative costs to Styrofoam.

While Styrofoam may have benefits of being lightweight, insulating, durable, and inexpensive, the product also has many negative and harmful attributes. The production process includes carcinogenic compounds, some of which may be residually present in the Styrofoam product that is used by consumers. Additionally, the same properties that make Styrofoam useful also make it extremely hard to recycle, contributing to its accumulation in landfills and as litter. Upon review of the available research, our team has categorized the costs of Styrofoam in three areas: production, environmental, and human health.

The Green Dining Alliance (GDA) is a program run by SLED, the mission of which is to enhance each diner's experience and support local businesses by engaging restaurants and stakeholders in a process to increase environmental sustainability. One goal of GDA is to get restaurants to stop using Styrofoam containers. However, the problem they face is that Styrofoam is the cheapest solution for a business that operates on razor-thin margins. Because SLED is limited by staffing resources, they have not had the opportunity to comprehensively build a case for the “real cost of Styrofoam.” We hope to provide SLED with an analysis of this important information that they can share with consumers/customers in hopes that they can better educate restaurant owners to change their practices and stop using Styrofoam products.

The purpose of this report is to provide SLED with a detailed assessment of the various “real costs” of Styrofoam, as outlined below. Our assessment will includes both a discussion of the qualitative costs and a financial model for calculation of quantitative costs. In addition to the detailed assessment, we have provided a 1-page fact sheet to highlight data in a simple, easy to read format.

I. Production Costs
  a. Raw materials
  b. Energy required to make
  c. Greenhouse emissions during manufacturing
II. Environmental Costs
  a. Issues with recycling
  b. Landfill costs
  c. Cleanup costs of litter
III. Human Health Costs
  a. Harmful health effects of Styrofoam precursors: benzene, pentane, and styrene
  b. Exposure risks in Styrofoam production process
  c. Exposure risks to consumers

BACKGROUND

What is Styrofoam?

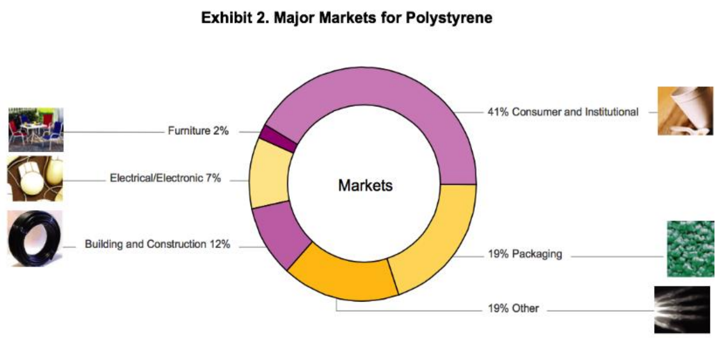
Styrofoam is the name commonly identified with foam consumer products, such as packing peanuts, egg cartons, and coffee cups. More accurately, however, “Styrofoam” is the trademarked name for a specific type of foam product, Dow Chemical’s foam insulation. Dow’s insulation and other foam products are actually a type of plastic known as polystyrene, or plastic #6. Polystyrene (PS) is a petroleum-based material that may exist as a hard plastic, used for products such as CD cases or medical equipment, or that may be made into a foam material known as expanded polystyrene (EPS). It is these foam-like expanded polystyrene products that are commonly referred to as Styrofoam. EPS products include food service containers, home and appliance insulation products, and product packaging for shipping. For the purpose of this report, we use the terms “EPS” and “Styrofoam” interchangeably to refer to all polystyrene foam products.

Common Styrofoam products:

Styrofoam, by nature, has several unique properties which make it seemingly beneficial for consumer use. First, the direct costs of Styrofoam production are relatively inexpensive, making it a low cost option for consumer use. EPS is lightweight and comprised of about 95% air, which makes it a good insulator. Low cost and insulation properties combined make Styrofoam a popular choice as a sanitary single-use food packaging option. Styrofoam is also considered to be unsinkable and capable of maintaining its form. It is an inert compound which does not readily degrade or break down over time, thus making it less likely to leach harmful components to the atmosphere or into groundwater in landfills.

However, the very same properties which provide consumers benefits from Styrofoam products come at costs. In fact, it is estimated that Styrofoam is one of the most environmentally unfriendly types of waste that exist today impacting our planet's ecological system (The Facts on Styrofoam, 2016). Through this report, we explore the indirect, or hidden, costs of Styrofoam from its production to its environmental impact and its human health risks. Polystyrene manufacturing processes use fossil fuels and release greenhouse gas emissions in the atmosphere. Styrofoam products are difficult and expensive to recycle, thus leading to their prevalence in landfills and as litter. The main precursors to polystyrene are benzene and styrene, both of which have been classified as carcinogens, and may present health risks to both producers and consumers of Styrofoam products. A comprehensive analysis of these factors help us derive the "real cost of Styrofoam."

Some Polystyrene Facts:



1) 40% of polystyrene is for consumer (food) use, such as Styrofoam cups (Use and Disposal of Polystyrene in California, 2004)
2) 25-35% (by volume) of landfills are comprised of polystyrene products (about 10 cu ft. of volume taken up for every 10,000 cups in landfill)
3) 18% of total coastal clean-up costs are attributed to polystyrene products, with 2% of total attributed to foam cups (Use and Disposal of Polystyrene in California, 2004)
4) 14 million tons of polystyrene are produced every year around the world (Now and Forever: The Styrofoam Dilemna, 2016)
5) Americans throw away an estimated 25,000,000,000 (25 billion) Styrofoam cups every year, or about 82 cups per person (Now and Forever: The Styrofoam Dilemna, 2016)
6) 80% of Styrofoam ends up in landfills, and much of the remaining 20% in waterways (as per U.S. Environmental Protection Agency: 3 million tons of polystyrene produced in the U.S per year; 2.3 million tons end up in landfills, with much of the remainder finding its way into waterways)
7) Cost of recycling Styrofoam is staggering (due to its light weight), rendering it a loss-making proposition for many recyclers; recycling costs $3000 per ton of polystyrene (Now and Forever: The Styrofoam Dilemna, 2016)
8) It is estimated that it takes 500 years for Styrofoam to decompose
9) Social cost of carbon dioxide (a gas used in Styrofoam production processes) emissions is $220 per ton of CO_2 (Than, 2015)
10) Polystyrene is made from benzene and styrene, both of which have been shown to be carcinogenic compounds; occupational exposure to these compounds carries increased risk of cancer for plant workers
11) Residual styrene is present in low levels in Styrofoam food containers and can leach into food products; leaching is greater at higher temperatures and into foods higher in fat content

QUALITATIVE COST ANALYSIS: PRODUCTION COSTS

Polystyrene manufacturing processes have been shown to pollute the air and create large amounts of liquid and solid waste that end up in streams and landfills. In fact, a 1986 Environmental Protection Agency (EPA) report named the polystyrene manufacturing process the 5^{th} largest creator of hazardous waste. By examining the processes involved in Styrofoam production, we can identify the hidden costs which must be considered when defining the real cost of Styrofoam.

Origin of Styrofoam

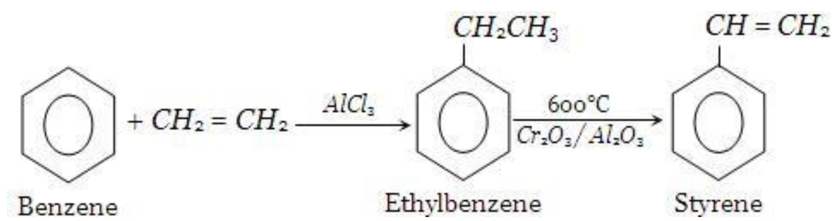
Ray McIntire, a former chemical engineer for the Dow Chemical Co, discovered Styrofoam by accident. Polystyrene, which had already been invented, was a good insulator but too brittle. In the early 1940s, Mr. McIntire was trying to develop a rubberlike polymer to be used as a flexible insulator. He combined styrene with isobutylene, a volatile liquid, under pressure. When the pressure was released, Mr. McIntire discovered that the styrene had formed a polymer but the isobutylene had not. Instead, the isobutylene evaporated and made a foam polystyrene with bubbles in it. It was 30 times lighter and more flexible than the polystyrene that had previously been used. After World War II, Dow Chemical started selling this product for use as building insulation under the trademark “Styrofoam”. Today, the name has become synonymous with all rigid foam products (Who Invented Styrofoam, 2016).

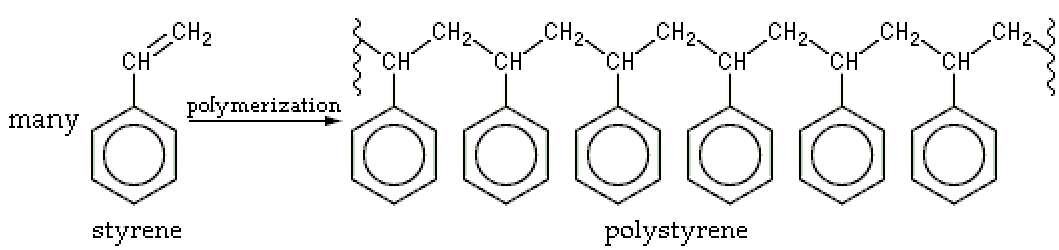
How is Styrofoam Made?

Foamed polystyrene, also known as expanded polystyrene, or EPS, starts as small spherical beads with a typical diameter of 0.5-1.5mm that contain an expanding agent pentane (a hydrocarbon). The polystyrene beads are heated with steam and, as the expanding agent boils, the beads soften and expand up to forty times their original size. The expanded beads are left to cool down before being heated again. However, this time the beads are expanded within a mold. The molds are designed in a variety of shapes depending on the desired end product, such as Styrofoam cups, cartons, wig stands, and more. The beads completely fill the mold and also fuse together. Styrofoam is about 95% air.

Raw Materials

The main component of expanded polystyrene is styrene (C_8H_8), which is derived from petroleum or natural gas and formed by a reaction between ethylene (C_2H_4) and benzene (C_6H_6); benzene is produced from coal or synthesized from petroleum. Styrene is polymerized either by heat or by an initiator such as benzoyl peroxide.





To form the low-density, loosely attached cells EPS is noted for, polystyrene must first be suspended in water to form droplets. A suspension agent is then added to the water. Numerous suspension agents are used commercially. All are similarly viscous and serve to hold up the droplets, preventing them from sticking together. The beads of polystyrene produced by suspension polymerization are tiny and hard. To make them expand, special blowing agents are used, including propane, pentane, methylene chloride, and the chlorofluorocarbons (Expanded Polystyrene Foam, 2016).

Manufacturing Process

To make small-cell EPS, workers melt, add a blowing agent to, and extrude the beads. To produce smooth-skinned EPS, they pre-expand the beads, dramatically reducing their density. Next they heat and expand them before allowing them to sit for 24 hours so that they can cool and harden. The beads are then fed into a mold of the desired shape (Expanded Polystyrene Foam, 2016).

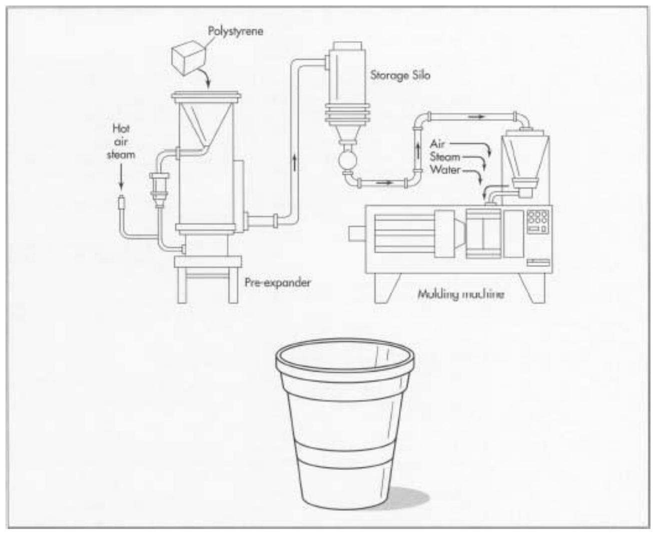
Making expanded polystyrene foam

First, the beads of polystyrene must be expanded to achieve the proper density. This process is known as pre-expansion, and involves heating the polystyrene either with steam (the most common method) or hot air (for high density foam, such as that used for a coffee cup); the heating is carried out in a vessel holding anywhere from 50 to 500 gallons (189 to 1,892 liters). During pre-expansion, an agitator is used to keep the beads from fusing together. Since expanded beads are lighter than unexpanded beads, they are forced to the top of the vessel's cavity and discharged. This process lowers the density of the beads to three percent of their original value and yields a smooth-skinned, closed cell EPS that is excellent for detailed molding. Next, the pre-expanded beads are usually "aged" for at least 24 hours in mesh storage silos. This allows air to diffuse into the beads, cooling them and making them harder (Expanded Polystyrene Foam, 2016).

After aging, the beads are fed into a mold of the desired shape. Low-pressure steam is then injected into and between the beads, expanding them once more and fusing them together.

The mold is then cooled, either by circulating water through it or by spraying water on the outside. EPS is such a good insulator that it is hard to cool the mold down. Using small molds can reduce both the heating and cooling time and thereby speed up the process (Expanded Polystyrene Foam, 2016).

Making extruded, expanded polystyrene foam



This process yields EPS with a small cell size that can be used to manufacture boards used for insulation. The beads are melted, and a blowing agent is added. The molten polystyrene is then extruded into the proper shape under conditions of high temperature and pressure (Expanded Polystyrene Foam, 2016).

Cutting, bonding, and coating

EPS is usually cut with common wood working tools, which must be kept very sharp at all times to cut smoothly. It can also be bonded with adhesives that do not destroy it. Water-based adhesives are good, as are phenolics, epoxies, resorcinols, and ureas. EPS is not resistant to weathering or sunlight, and it is flammable, so generally coatings such as epoxy, different kinds of paint, and nonflammable substances are applied to the surface (Expanded Polystyrene Foam, 2016).

Quality control

The polystyrene melt is tested to determine whether it is sufficiently viscous to produce EPS with the desired properties. Further, the subsequent polystyrene beads must be of uniform size. The standard for perfectly spherical beads is based on those formed in space shuttle experiments under conditions of zero-gravity.

Molded EPS is also tested for strength, flammability, and density. EPS is then tested for porosity which involves determining how many open and closed cells there are. Next is permeability, a simple test involves placing a piece of EPS into a substance and then measuring how much of it is absorbed (Expanded Polystyrene Foam, 2016).

QUALITATIVE COST ANALYSIS: ENVIRONMENTAL COSTS

As previously discussed, expanded polystyrene (EPS), or Styrofoam as it is generically called, actually begins as small pellets of polystyrene. These pellets are steamed and expand to 40 or 50 times their original size. The final product is typically comprised of 95% air and 5% polystyrene. This process gives Styrofoam many benefits of being lightweight, insulating and durable; however, these same qualities also cause Styrofoam to carry a number of environmental costs. To begin, these qualities inherently make Styrofoam difficult to recycle, thus leading to larger amounts (versus other single-use products) in landfills and as litter. Styrofoam does not biodegrade and, without a solvent to break it down, can last for hundreds of years. It is presently estimated that Styrofoam, by volume, takes up as much as 30% of landfills worldwide. Because Styrofoam is so light, it often ends up as litter and easily breaks into tiny pieces presenting problems of clean-up costs and risks to wildlife.

Issues with Styrofoam Recycling

Very few communities recycle Styrofoam, even though it is labeled as a recycling # 6 plastic and is made from polystyrene (Recycling Styrofoam, 2014). In fact, it is estimated that less than 1% of all plastic foam is currently recycled (Lofgren, 2015), thus contributing to its prevalence in landfills and as litter.

A problem that recyclers face is that the very properties that make Styrofoam useful to the consumer, for example its lightweight nature, low cost, and durability, make it hard to recycle. By being very lightweight, the cost of transporting the Styrofoam to a recycling plant makes it undesirable to recycle. The relatively large volume that it takes up in the shipping containers or trucks compared to its weight does not make it conducive to transport. Because

Styrofoam has good insulation properties and is low cost, it is often used in the food service industry. However, this Styrofoam is usually contaminated with food residue and would require cleaning before being processed for recycling. This factor increases the costs and makes it less economically viable to recycle.

While the technology to recycle polystyrene is available, the market is very small and shrinking. The majority of recyclers are not recycling Styrofoam at this time and instead sending it to the landfill because of its difficulty. In our research for this project, we learned that the St. Louis company, Repoly, does not currently recycle Styrofoam, even though it is advertised on their website and in their name. Another local company, EPC in Earth City, does recycle Styrofoam but explained that the commodities market is down right now, thus making the recycling of Styrofoam less lucrative. Dave Beal, Vice President of EPC, explained at a conference in November that the resale price of polystyrene used to be 20 cents a pound and now it is only 6 cents a pound. The reason for the decline in price is that crude oil prices are so low that it is cheaper for companies to produce new Styrofoam products than to clean and reuse post-consumer products. This economic reality discourages other companies from getting into the market of recycling the polystyrene. Even in St. Louis, the county will recycle #6 polystyrene, but the city and its waste haulers will not.

Some organizations have attempted to find ways to deal with the difficulties of Styrofoam recycling. For example the Alliance for Form Packaging Recyclers (AFPR) has a mail-back option that allows individuals with small quantities of expanded polystyrene access to recycling Styrofoam in California. In addition, for commercial organizations with large volumes of Styrofoam, the AFPR has another program that they are trying to develop to recycle reliable high-volume sources of post-commercial expanded polystyrene waste. This EPS is manufactured into other plastic products such as molding trim and plastic lumber. However, the issues remain that the Styrofoam must be viable to transport and can have zero contamination to be effective (Recycling Styrofoam, 2014).

Locally, at EPC, they are trying to defeat the volume issue with a new technology that crushes the foam into logs that reduce the volume by over 100 times, making it more economical to ship. However, they are not able to accept food packaging or packing peanuts (Places to Recycle Polystyrene, 2016). A few other companies are selling similar technology such as the "Styropactor" and other machines of this type that can help to minimize shipping costs by reducing the volume and creating the ability to reuse the Styrofoam. This is great technology, but does not yet have wide reach. The picture (right) shows an example of compacting polystyrene waste down into more manageable sizes. This compacted brick of clean polystyrene waste weighs 40 pounds and is made up of about 8,000 cups.

Even with the best recycling programs available, Styrofoam recycling is not a "closed loop" system and not all types of EPS are recyclable. Foam cups are not actually remanufactured into new foam cups but into other products such as packing filler and cafeteria trays. Any Styrofoam that is contaminated with food (which is basically every Styrofoam cup, plate, package, etc. that is used for food service or delivery) is contaminated and will not be used again. Every new cup manufactured creates more pollution and uses more resources (Polystyrene Foam Report, 2016).

Landfills

Americans throw away 25 billion Styrofoam coffee cups every year, enough to circle the earth 436 times (The Facts on Styrofoam, 2016). And cups are just one of the many different one-time use Styrofoam products that people use on a daily basis. 2.3 million tons of Styrofoam ends up in landfills, accounting for about 30% of landfill space worldwide. Styrofoam does not readily biodegrade and it has been estimated that it takes at least 500 years for plastic foam to break down. That means a foam cup in use today will still be in a landfill in 2516!

There are currently approximately 1,900 landfills in the United States (Municipal Solid Waste Landfills, 2014). A variety of costs are associated with the operation of landfills, including construction costs, maintenance costs for the lifetime of the landfill, and post-closure costs for a mandated period of 30 years post-closing (Eilrich, Doeksen, & and van Fleet, 2003) . Moreover, the social costs of landfills must also be considered as landfill acreage spreads across the U.S. and the world.

Litter

The lightweight nature of Styrofoam makes it a potential litter problem. Even when Styrofoam reaches the landfills it doesn't always stay there. As much as 80% of marine trash comes from urban runoff, littering, and landfills. Plastic foam can easily blow out of a truck or even from the disposal site and small pieces can end up in the storm drains or gutters. Since it has very little weight, it can easily float across land or oceans and may ultimately end up in every major water way and on every coastline around the world. As it breaks apart into tiny pieces, it creates a larger, and more expensive, clean-up problem.

Polystyrene and expanded polystyrene products do not biodegrade, but they do photodegrade to some extent (Styrofoam, 2012). The longer that Styrofoam is exposed to UV

rays from sunlight, the more brittle it becomes, photodegrading into smaller and smaller pieces until it eventually turns into a powder. This process makes it easier to get into the food chain. The picture (left) shows one of the major environmental problems with Styrofoam litter. Birds and other animals can eat the Styrofoam, causing it to clog their digestive system and sometimes resulting in starvation or death.

The costs to deal with Styrofoam litter are high. According to an Earth Resource article in California, the statewide costs of collecting disposable cups and bags is $72 million per year. This adds up to about 520,000 tons of polystyrene landfilled in this one state per year. The beach cleanup is $52.2 million per year and varies depending on the amount of use (Plastics Clean Up Costs, 2016). A 2011 study estimates that plastic products, such as Styrofoam, comprise 90% of all floating marine debris (Facts about Styrofoam Litter, 2011).

QUALITATIVE COST ANALYSIS: HUMAN HEALTH COSTS

With the prevalent use of Styrofoam in food packaging, a natural concern is whether or not Styrofoam poses risks to human health. Because Styrofoam is a relatively inert, or unreactive, compound that does not readily biodegrade or metabolize in humans or animals (Expandable Polystyrene: Product Risk Profile, 2013) it may appear that Styrofoam does not pose health risks. However, while the FDA approves polystyrene for use in food contact, it clearly defines threshold levels for the presence of residual precursor compounds (used in the making of Styrofoam) in the final product that comes into contact with food (CFR - Code of Federal Regulations Title 21, 2016). Examination of those precursors of EPS uncovers a number of potential human health risks that may be associated with Styrofoam. These risks have implications both for those involved in producing EPS, and consumers of EPS products.

EPS is made through a series of chemical reactions beginning with benzene, a natural derivative of petroleum (Toxilogical Profile for Benzene, 2007). First, benzene is reacted with ethylene to form styrene. Styrene is then chemically polymerized to form polystyrene, the basic component of a variety of plastic products, including EPS. EPS foam is created by injection of pentane gas into polystyrene resin. Steam is then used to release the gas, resulting in the airy product commonly referred to as Styrofoam (Polystyrene, 2016).

Several of the precursors of Styrofoam have inherent human health risks. The Department of Health and Human Services, the International Agency for Cancer Research, and the EPA have determined that benzene is carcinogenic to humans, with long-term exposure increasing the risk of leukemia (Toxilogical Profile for Benzene, 2007). Pentane, present residually in low levels in EPS, is a highly flammable gas which may evaporate from EPS during processing and storage thus creating a fire hazard when the product is exposed to ignition sources or high heat (Expandable Polystyrene: Product Risk Profile, 2013). In 2011, the U.S. Department of Health and Human Services determined that styrene is "reasonably anticipated to be a human carcinogen" (Report on Carcinogens, Thirteenth Edition: Styrene, 2014). These three precursors (benzene, pentane, and styrene) impact human health through various means of exposure, both in the production and the use of Styrofoam products.

Styrofoam Precursor #1: Benzene

What is benzene?

Benzene, a chemical compound derived primarily from petroleum, is an early precursor in EPS production. Benzene is one of the top 20 chemicals produced (by volume) in the United States with 55% of its production used in the making of styrene, the building block of polystyrene (Toxilogical Profile for Benzene, 2007). Additionally, benzene may be found in gasoline, cigarette smoke, and the production of other plastics, detergents, and pesticides (Safety and Health Topics: Benzene, 2016)

Benzene is a potentially dangerous chemical, with short-term and long-term health effects resulting from high levels of exposure. Benzene can enter the human body through inhalation, ingestion, or through contact with skin. Once in the bloodstream, benzene travels throughout the body and may be stored in the bone marrow or fat where it is metabolized to compounds that cause potential health risks, depending on amount and length of time of benzene exposure (Toxilogical Profile for Benzene, 2007).

What are the health risks of benzene?

Short-term effects include nervous system reactions such as drowsiness, dizziness, headaches, tremors, confusion, and/or unconsciousness; ingestion of benzene-contaminated products can cause vomiting, stomach irritation, dizziness, sleepiness, convulsions, rapid heart rate, and with extreme exposure, death (Benzene Toxicity, 2000).

The most well-documented and significant long-term health effect from benzene exposure is its effect on bone marrow, the tissue where blood cells are made. Prolonged exposure to benzene can cause anemia (a low blood cell count causing weakness and fatigue) and leukemia (cancer of the blood) (Benzene and Cancer Risk, 2016). Studies have shown that, over as little as 5 years and as long as 30 years, individuals exposed to benzene have developed and died from leukemia (Safety and Health Topics: Benzene, 2016). Additionally, there is evidence that long-term exposure to benzene may have harmful effects on female reproductive organs (Benzene and Cancer Risk, 2016).

Who is at risk of benzene exposure?

Almost all people are exposed to low levels of benzene in their everyday lives, primarily through breathing air contaminated by benzene from tobacco smoke, exhaust from automobiles, and emissions from industrial plants that utilize benzene, such as in styrene production. In a 1989 report, the EPA estimated emissions of benzene from styrene process vents of 135 metric tons/year (Toxilogical Profile for Benzene, 2007). Higher risks of exposure arise for people living near hazardous waste sites, petroleum refining operations, petrochemical manufacturing sites, or gas stations. At greatest risk for exposure are the 238,000 workers employed in industries that make or use benzene, including those involved in EPS production. In the late 1980s, in response to evidence of the toxic effects of benzene to industry workers, OSHA enacted threshold limits for benzene of 1 ppm for a normal 8-hour workday (40 hour work week) and a short-term exposure limit of 5 ppm. The mortality risk from exposure to 1 ppm benzene for a working lifetime has been estimated as 5 excess leukemia deaths per 1,000 employees exposed (Benzene Toxicity, 2000).

Styrofoam Precursor #2: Pentane

What is pentane, what are its health risks, and who is at risk of exposure?

Pentane gas is the "blowing agent" used to expand polystyrene in the production of EPS. Exposure to pentane may result in irritation to eyes, skin, and the respiratory system; the OSHA exposure limits for pentane range is 120 ppm averaged over an 8-hour work day. A principal risk associated with pentane in EPS production, handling, and storage is the risk of fire. Pentane is a highly flammable gas present at a level of 3-8% in polystyrene resin. Pentane evaporates from EPS resin during processing and storage at differing rates (Expandable Polystyrene: Product Risk Profile, 2013), and may even be released from EPS in finished products for a short time after manufacture (Fire and explosion risks from pentane in expandable polystyrene (EPS), 1998).

Pentane vapors may be ignited by low-intensity sources, such as matches, lighters, cigarettes, heaters and stoves, exhaust from forklifts, and static electricity. Buildup of fine EPS dust particles may create an explosive mixture with air (Expandable Polystyrene: Product Risk Profile, 2013). Because pentane is heavier than air, it can collect in low-lying areas or containers and create a persistent flammable atmosphere, which if ignited can cause a flash fire (Fire and explosion risks from pentane in expandable polystyrene (EPS), 1998). Precautions must be taken in the industrial processing of EPS to prevent fire or explosion and the possible risk to human lives. Additional care should be taken in the storage of EPS resin and transportation of freshly manufactured Styrofoam products.

Styrofoam Precursor #3: Styrene

What is styrene?

Styrene is the basic chemical building block of polystyrene. In production of polystyrene, a chemical reaction occurs which links together chains of styrene monomers to form the polystyrene polymer. Once created, polystyrene is relatively chemically inert, meaning that it does not readily degrade back into styrene monomers. However, in the production process of polystyrene, residual amounts of unlinked styrene monomer remain present in the polystyrene product (Expanded Polystyrene Foam (EPS), 2016).

By chemical nature, styrene is a colorless, sweet-smelling liquid that evaporates easily. It is used not only in the production of EPS, but also in a variety of other plastic and rubber products (Toxilogical Profile of Styrene, 2010). Styrene production in the U.S. has increased over the last several decades, with over 13 billion pounds produced in 2006 (Health Effects and Regulation of Styrene, 2016). The largest market for styrene is in the production of polystyrene, primarily for food service products; 65% of styrene is used in polystyrene production (Health Effects and Regulation of Styrene, 2016).

Styrene has been found in a variety of foods and beverages, though whether it is found naturally or as a result of environmental contamination may be debated. Unprocessed cinnamon contains the highest relative levels of styrene, possibly from natural breakdown of cinnamic acid. Styrene may also be found in lower concentrations in agricultural products such as strawberries and some vegetables (Tang W, 2000). Styrene has been detected in the leachate of landfills (Brown KW, 1988), and soil and sediment may become contaminated with styrene from landfill disposal of polystyrene products or through styrene-contaminant water (Health Effects and

Regulation of Styrene, 2016). While risk of exposure through biological organisms is expected to be low, styrene has been detected in fish and other aquatic organisms (Howard, 1989)

Interestingly, the FDA allows the use of styrene as a food additive for flavoring, with maximum allowed levels of 5% by weight (Health Effects and Regulation of Styrene, 2016). When detected in packaged foods, styrene presence is primarily due to leaching of residual styrene monomer present in polystyrene (Toxilogical Profile of Styrene, 2010).

What are the health effects of styrene?

Styrene can enter the human body through inhalation, ingestion, or through contact with the skin (Report on Carcinogens, Thirteenth Edition: Styrene, 2014). High levels of exposure to styrene can cause a number of short-term and long-term health, including risk of cancer. Short-term effects may involve the central nervous system, with symptoms including headache, fatigue, dizziness, confusion, drowsiness, malaise, difficulty in concentrating, and a feeling of intoxication. Styrene exposure can also cause skin, eye, and respiratory irritation, as well as digestive effects (Safety and Health Topics: Styrene, 2016). Additionally, styrene has been shown to cause hearing loss in animal studies (Toxilogical Profile of Styrene, 2010). Long-term exposure has been shown to cause depression, headache, fatigue, weakness, and minor effects on kidney function (Safety and Health Topics: Styrene, 2016).

An important long-term health risk of styrene exposure is risk of cancer. In the 2011 Department of Health and Human Services Report on Carcinogens determined that "styrene is reasonably anticipated to be a human carcinogen based on limited evidence of carcinogenicity from studies in humans, sufficient evidence of carcinogenicity from studies in experimental animals, and supporting data on mechanisms of carcinogenesis" (Report on Carcinogens, Thirteenth Edition: Styrene, 2014).

The most informative studies on the risk of cancer relative to styrene exposure come from research done on workers in reinforced-plastics industry and the styrene rubber industry. Direct studies of styrene exposure in the polystyrene industry have not been as informative, as there were smaller numbers of cancer cases and the results were unclear due to potential for co-exposure with benzene in these workers (Report on Carcinogens, Thirteenth Edition: Styrene, 2014). Two European studies published in the mid-1990s provide evidence of increased risks for leukemia and lymphoma for styrene-exposed workers in both the reinforced-plastics industry and styrene rubber industry. These studies found that the relative risk of developing these cancers was 3.08 for the group with the lowest level exposure (Kolstad HA, 1995). Additionally, studies showed a possible association of styrene exposure and pancreatic and esophageal cancer for workers in the reinforced-plastics industry (Kogevinas M, 1994).

Separate animal studies in mice have shown increased evidence of malignant lung tumors in mice exposed to styrene inhalation. There is no evidence to suggest that these rodent studies would not have direct correlation to human health hazards (Cruzan G, 1997). Further, these studies support evidence that styrene has genotoxic action which creates human cancer risks (Report on Carcinogens, Thirteenth Edition: Styrene, 2014).

Who is at risk of styrene exposure?

The general population is exposed to styrene through a number of factors, primarily through inhalation of contaminated air and ingestion of styrene contaminated food. The estimated exposure from these routes to the general population is between 1µg and >100 µg per day (Health Effects and Regulation of Styrene, 2016). Styrene ingested from contaminated foods is stored in fat tissue in the body. An EPA study in the early 1980s detected styrene in all of an unspecified number of wet adipose (fat) tissue samples (Howard, 1989).

Indoor air may be contaminated with styrene vapors from building materials, cigarette smoke, or copy machines. Outdoor air may also be contaminated with styrene from automobile exhaust and industrial emissions. Persons living near industrial facilities or hazardous waste sites are at increased exposure risk by inhalation (Toxilogical Profile of Styrene, 2010).

The greatest risk of exposure is found in the 90,000 workers in industries that make or use styrene, including the polystyrene, reinforced plastics, and the styrene rubber industries (Safety and Health Topics: Styrene, 2016). The primary exposure risk to industrial workers is through inhalation. OSHA has limited the exposure to workers in these industries to an average of 100 ppm for an 8-hour workday, 40-hour work week (Toxilogical Profile of Styrene, 2010). Styrene-related cancer studies, previously mentioned in this report, have focused on occupational exposure to styrene.

Are consumers exposed to styrene from polystyrene food containers?

Of particular interest to a discussion of the health risks associated with Styrofoam is consumers' exposure to styrene through the contamination of food products. Styrene content in food is primarily due to migration, or leaching, of residual styrene monomer in polystyrene foam containers (Health Effects and Regulation of Styrene, 2016). The FDA has set a limit on the amount of free styrene monomer allowed in polystyrene food containers of 1% by weight of total residual styrene monomer, or 0.5% by weight for certain fatty foods (CFR - Code of Federal Regulations Title 21, 2016). The estimated median exposure to consumers of styrene from migration in food packaging ranges from 1 to 35 µg/day (Vitrac O, 2007). The maximum tolerable daily intake of styrene established by the Joint FAO/WHO Expert Committee on Food Additives is 40 µg/kg body weight/day (Report on Carcinogens, Thirteenth Edition: Styrene, 2014).

The amount of styrene and the rate with which it migrates, or leaches, into food is determined by the lipophilicity (fat content) of the food, surface area of the food container, amount of time the food is in contact with the container, and the food temperature (Report on Carcinogens, Thirteenth Edition: Styrene, 2014). Concentrations of migrated styrene in food products range from <100 to >3,000 ppm (Tang W, 2000).

Migration of styrene from Styrofoam food packaging occurs at a greater rate in fatty foods than in non-fatty foods. For example, 4–6% of the free styrene monomer in polystyrene packaging migrated into corn oil or sunflower oil within 10 days, while only 0.3–0.6% migrated into milk, beef, or water (Report on Carcinogens, Thirteenth Edition: Styrene, 2014). Similarly, the migration of styrene from Styrofoam cups into beverages occurred in concentrations 4 times greater in alcoholic beverages than in water, tea, or coffee (Varner SL, 1981).

Time and temperature also have an effect on the amount of styrene migrated from Styrofoam containers (see table, right). A 1995 study on factors affecting styrene migration show an increase with both increased storage time and the temperature of food products for a variety of different food storage containers (Lickly TD, 1995).

Table 3. Comparison of the increase in styrene migration over time

	Exposure conditions			
Foam article	Time (days)	Temperature (°F)	Mt* (μg/cm^2)	Mt† ratio
Cup	1	120	0.51	
	4	120	0.80	1.6
	10	120	0.99	1.9
	1	150	1.01	
	4	150	1.21	1.2
	10	150	1.39	1.4
Plate	1	120	0.05	
	4	120	0.10	2.0
	10	120	0.15	3.0
	1	150	0.12	
	4	150	0.30	2.5
	10	150	0.54	4.5
Hinged container	1	120	0.12	
	4	120	0.22	1.8
	10	120	0.36	3.0
	1	150	0.23	
	4	150	0.46	2.0
	10	150	0.79	3.4
Meat tray (1)	1	120	0.21	
	4	120	0.35	1.7
	10	120	0.55	2.6
	1	150	0.50	
	4	150	0.80	1.6
	10	150	1.13	2.3
Meat tray (2)	1	120	0.14	
	4	120	0.26	1.9
	10	120	0.41	2.9
	1	150	0.36	
	4	150	0.65	1.8
	10	150	1.03	2.9

*Mt = Amount of styrene migrating (μg styrene/cm^2 foam).
†Ratio of day 1 Mt.

This data creates cause for concern in the use of Styrofoam containers for hot beverages, such as coffee or tea. Additionally, this data suggest that microwaving or otherwise heating food in Styrofoam containers, such as leftovers from restaurants, should be avoided. Consideration should also be made for long-term storage of food and beverage products in Styrofoam containers.

QUANTITATIVE COST ANALYSIS: FINANCIAL MODEL

As was noted earlier in the report, the price the consumer pays for Styrofoam is extremely low, which is the driver for its high usage. However, the up-front cost to the consumer only accounts for the manufacturing cost of Styrofoam and not the issues it creates for the environment or human health. Looking deeper at the impact of Styrofoam, there are three main areas of hidden costs that need to be taken into account. After accounting for all of these items, the annual hidden costs of Styrofoam are approximately $7 billion per year.

Production Costs

Most of the costs of production (raw materials, energy, fixed costs, etc.) are taken into account when pricing Styrofoam for the consumer. Since we are only concerned with the hidden costs of Styrofoam, we have not included those costs in the financial model. However, there are two hidden costs of production that are typically not taken into account. These costs are the social costs of greenhouse gas emissions related to the production of Styrofoam and the social costs of greenhouse gas emissions related to the treatment of water used during the production process. The social cost of the Styrofoam production process is approximately $4.9 billion per year.

Social cost of greenhouse gas emissions from production

Greenhouse gasses are a major contributor to climate change and are released into the atmosphere during the production process of Styrofoam. For every Styrofoam cup that is manufactured, 0.07229 pounds of CO_2 (or the equivalent of CO_2) is released into the atmosphere (Franklin Associates, 2011). A standard cup weighs 4.7 grams (or approximately 0.01 pounds). The United States produces about 3 million tons of Styrofoam every year so approximately 21 million tons of CO_2 equivalent are released into the atmosphere every year. According to the Stanford News, the social cost of carbon (anticipated damages in the form of decreased agricultural yields, harm to human health, and lower worker productivity) is $220 per ton. Therefore, the social cost of greenhouse gas emissions from the production of Styrofoam is estimated at approximately $4.6 billion per year.

Social cost of greenhouse gas emissions from water treatment

Water is a key component in the production process of Styrofoam. While the cost of delivering the water is accounted for in the manufacturing process, the cost of greenhouse gasses emitted during the treatment of the water is not. For every Styrofoam cup that is manufactured, approximately 0.47 gallons of water are used. After the water is used, it is sent to the water treatment plant for cleaning before it is disbursed back into the water supply. When these 0.47 gallons of water are treated, 0.004615 pounds of CO_2 (or CO_2 equivalent) is released into the atmosphere. A standard cup weighs 4.7 grams (or approximately 0.01 pounds). The United States produces about 3 million tons of Styrofoam every year so approximately 1.3 million tons of CO_2 equivalent are released into the atmosphere every year. As noted earlier, the social cost of carbon is $220 per ton. Therefore the social costs of greenhouse gas emissions from the treatment of water used in the production process is approximately $294 million per year.

Environmental Costs

Styrofoam is an environmental hazard for the same reason it is so widely popular-- it’s extremely light weight. While it can be recycled, it is not financially viable for companies to recycle Styrofoam for new uses and therefore is almost exclusively thrown in the trash. While most makes it to the landfill, a large amount ends up as litter which makes its way into our waterways. The three main environmental costs of Styrofoam are the cost to operate a landfill, the cleanup costs of waterways, and the cleanup costs of highways. The annual environmental cost of Styrofoam is approximately $1.96 billion per year.

Coastal cleanup costs

Unfortunately there are not a lot of good metrics kept on cleanup costs for water or land-based trash. According to a study by Earthsource.org, the state of California spends approximately $52.2 million each year on beach cleanup costs. California has approximately 900 miles of beaches which means it costs the state approximately $58,000 per mile per year to keep their beaches clean. If you extrapolate these cleanup costs out to the 95,471 miles of coastline in the entire United States (including ocean coastline, offshore islands, sounds, bays, rivers and the Great Lakes), it costs approximately $5.5 billion. Since 18% of marine debris is Styrofoam, it can be assumed that it costs approximately $997 million to clean up Styrofoam trash from our waterways.

Highway cleanup costs

The same study by Earthsource.org that identified the cost to clean the waterways of California estimated it costs approximately $10,000 to keep 1 highway mile clean for 1 year. According to the DOT, there are approximately 164,000 miles of highways in the United States which means it would cost $1.64 billion dollars to keep our highways clean. There are no good estimates of how much of highway litter is Styrofoam, but assuming it is 18% like it is in our waterways, that means it costs approximately $295 million to clean up Styrofoam trash from our highways.

Landfill costs

The cost to operate a landfill will vary by geography and size, but we do know there are 1,900 landfills in the United States and approximately 30% of the trash in our landfills is Styrofoam. According to an economic analysis performed by Oklahoma State University on a proposed landfill in rural Oklahoma, the estimated cost to develop, construct, operate (for 20 years), close, and monitor after closure is approximately $23 million. Assuming this is a reasonable average of the cost of a landfill, the 1,900 in the U.S. will cost approximately $44.4 billion over their lifetime. Since 30% of a landfill is Styrofoam, we can attribute approximately $13.3 billion of this cost to Styrofoam. Assuming the useful life of a landfill is 20 years, this means the annual cost to operate a landfill related to Styrofoam is $665 million.

Health Costs

The two main inputs to Styrofoam that pose a health risk to humans are benzene and styrene. Both groups are more likely to develop leukemia than the general population and the estimated cost of the exposure-related diseases is approximately $108 million per year.

Benzene health costs

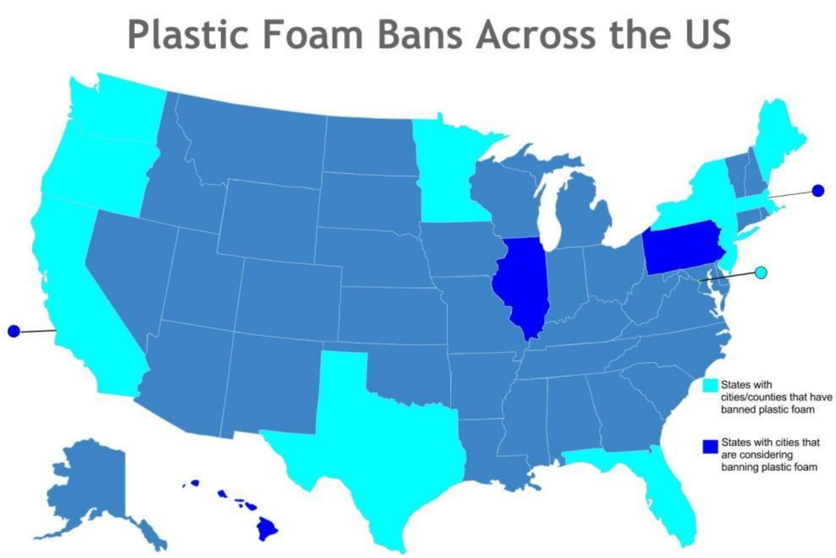
There are approximately 58,000 benzene workers in the United States and 55% of benzene is used to create styrene. Since 65% of styrene is used to make Styrofoam, we can attribute 85,085 of these benzene workers directly to the production of Styrofoam. The leukemia death rate for exposure to benzene is 0.5% for a working lifetime (40 years). This means that annually you can expect 11 Styrofoam-attributed benzene workers (or 0.01%) to die from leukemia. While every human life is invaluable, the U.S. government does put a value on a human life, which is necessary for quantifying the cost-benefit on actions which can result in a loss of life. The U.S. government equates the “value” of a human life at $9.3 million which means the annual “death” cost of benzene related to Styrofoam is approximately $99 million.

Styrene health costs

There are approximately 90,000 styrene workers in the United States and 65% of styrene is used to make Styrofoam so we can attribute 58,500 of these workers specifically to the production of Styrofoam. The average leukemia rate of the general population is 1.48% and styrene workers are 3.08 times more likely to develop leukemia. This means that approximately 1,801 styrene workers will develop leukemia over their lifetime specifically related to their work with styrene. Assuming a 40 year working lifetime, approximately 45 styrene workers will develop leukemia each year. The estimated cost of keeping a leukemia patient alive for one year is $207,000 which means the annual health cost related to styrene exposure is approximately $9.3 million.

RECOMMENDATIONS

The best way to protect the environment and prevent human health risks from the potentially damaging effects of Styrofoam is simply to not use it. When we consider the "3 Rs", we understand that the first "R", reduce, is the most effective, after which is to reuse and recycle. Many companies are now offering environmentally friendly alternatives to Styrofoam in their packaging. They can use air cushion packaging, which is very lightweight, takes up less space before and after its use, and is also recyclable in the same places you can recycle grocery bags. Other alternatives are biodegradable food packaging, cups, forks, spoons and plates that are made of corn starch or paper. These produce less pollution when disposed of and, if clean, can be recycled or composted in most cases.



Many cities and counties across the United States have enacted, or are considering, bans on Styrofoam products (see map, right. June 2015). A majority of these bans are in coastal communities where Styrofoam pollution is prevalent in the waterways and more people are seeing this pollution first-hand on a daily basis.

As of June 30, 2016, San Francisco banned all polystyrene products in the city. They also unanimously banned the sale of polystyrene products by the year 2017. This has been one of the most extensive bans in the U.S. and presents a positive model for other cities to follow (McDonald, 2016). San Francisco is actually taking these steps among others to become a waste-free city by 2020.

With knowledge of the real costs of Styrofoam and its hidden production costs, environmental issues, and human health risks, a natural conclusion is to avoid the use of Styrofoam and seek alternative products. While a city or county-wide ban of Styrofoam may be difficult to achieve in St. Louis, individuals and businesses can take steps on their own to stop using this potentially harmful product.

CONCLUSION

Styrofoam is known as an inexpensive option for single-use consumer goods; however, the hidden costs of its use make Styrofoam a much more expensive choice. In this report, we have assessed those hidden costs from both a qualitative and quantitative perspective. In order to provide a comprehensive analysis of the "real cost of Styrofoam", we have analyzed production costs, environmental costs, and human health costs.

The results of our qualitative analysis provide evidence that the qualities that make Styrofoam so widely used actually carry hidden costs. Though Styrofoam is relatively inexpensive to produce, the social costs of its production involve the use of hazardous chemicals, fossil fuels, and the emission of greenhouse gases. The lightweight yet durable nature of Styrofoam that makes it good for single-use consumer products also yields it not readily recyclable and leads to its accumulation in landfills and as litter in waterways and highways. Finally, though Styrofoam itself is unreactive, the compounds used in its production have been identified as harmful to human health.

The financial model that we have designed provides a quantitative estimation of the hidden costs associated with Styrofoam. The model uses statistical data found in the literature for specific costs associated with the social costs of production, environmental effects, and human health risks. These data are extrapolated with certain assumptions to derive a calculation representative of the comprehensive costs. Our model estimates the total hidden costs of Styrofoam (for production output of 3 million tons) at $7 billion annually. This represents an estimated hidden cost of 1.2 cents per Styrofoam cup produced.

Based upon our analysis, we conclude that it is important to factor both the qualitative and quantitative costs when determining the real cost of Styrofoam. While it may be tempting to base a decision on whether or not to use Styrofoam solely on economics, it is also important to look beyond the numbers. It is impossible to assign a dollar value to every hidden cost associated with the use of Styrofoam; in fact, many categories of costs may be presently unknown. Businesses and individuals should examine the potential harm to the environment and human health that may result from the use of Styrofoam in order to truly assess the benefits versus the costs of its use.

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APPENDIX: FINANCIAL MODEL--EXCEL WORKBOOK

A Financial Model: Excel Workbook has been provided to SLED electronically. Images of each spreadsheet in the workbook are shown below for reference.

Total Costs of Styrofoam

Production Costs		**$$**
Social Cost of Greenhouse Gas Emissions	$	4,604,576,457
Social Cost of Water Treatment	$	293,956,569
Total Production Costs	**$**	**4,898,533,026**
Environmental Costs		
Coastal Cleanup Costs	$	996,717,240
Highway Cleanup Costs	$	295,200,000
Landfill Operating Costs	$	665,278,692
Total Environmental Costs	**$**	**1,957,195,932**
Health Costs		
Benzene Health Costs	$	98,911,313
Styrene Health Costs	$	9,319,471
Total Health Costs	**$**	**108,230,784**
Total Cost of Styrofoam	**$**	**6,963,959,742**

Greenhouse Gas Costs

Description	Amt	Notes	Source
Process	0.0058	Per Cup (4.7 grams)	https://plasticfoodservicefacts.com/life-cycle-inventory-foodservice-products
Fuel	0.0628	Per Cup (4.7 grams)	https://plasticfoodservicefacts.com/life-cycle-inventory-foodservice-products
Combusion Emissions	0.00701	Per Cup (4.7 grams)	https://plasticfoodservicefacts.com/life-cycle-inventory-foodservice-products
Displaced Kwh	-0.00332	Per Cup (4.7 grams)	https://plasticfoodservicefacts.com/life-cycle-inventory-foodservice-products
Methane	0	Per Cup (4.7 grams)	https://plasticfoodservicefacts.com/life-cycle-inventory-foodservice-products
CO2 Equivalent for C seq	0	Per Cup (4.7 grams)	https://plasticfoodservicefacts.com/life-cycle-inventory-foodservice-products
Net Pounds of CO2 Equivalent (LB)	0.07229	Per Cup (4.7 grams)	https://plasticfoodservicefacts.com/life-cycle-inventory-foodservice-products
Total Pounds of Styrofoam Produced	6,000,000,000		
Weight per Cup (LB)	0.010361735		
Net CO2 Factor (Cups to Pounds)	579,053,617,021		
Net CO2 Equivalent Produced (LB)	41,859,785,974		
Net CO2 Equivalent Produced (Tons)	20,929,893		
Social Cost of Greenhouse Emissions (Ton)	$ 220.00		http://news.stanford.edu/2015/01/12/emissions-social-costs-011215/
Social Cost of Greenhouse Emissions (Total)	$ 4,604,576,457		

Water Treatment Costs

Description	Amt	Notes	Source
Net Pounds of CO2 Required to Treat Water	0.004615	10,000 Cups use 4,748 Gallons of Water	
Total Pounds of Styrofoam Produced	6,000,000,000		
Weight per Cup (LB)	0.010361735		
Net CO2 Factor (Cups to Pounds)	579,053,617,021		
Net CO2 Equivalent Produced (LB)	2,672,332,443		
Net CO2 Equivalent Produced (Tons)	1,336,166		
Social Cost of Greenhouse Emissions (Ton)	$ 220.00		http://news.stanford.edu/2015/01/12/emissions-social-costs-011215/
Social Cost of Greenhouse Emissions (Total)	$ 293,956,569		

Coastal Cleanup Costs

Description	Amt	Notes	Source
Beach Cleanup Costs	$ 52,200,000	CA Estimate	http://www.earthresource.org/campaigns/capp/capp-economics.html
Miles of Beaches	900	CA Estimate	
Cleanup Cost per Mile	$ 58,000		
Total Miles of Coastline	95,471	NOAA- shorelines of outer coast, offshore islands, sounds, bays, rivers and creeks (head of tidewater to point where tidal waters narrow to a width of 100 feet) and Great Lakes	http://oceanservice.noaa.gov/facts/shorelength.html
Total Coastal Cleanup Costs	$ 5,537,318,000		
Styrofoam % of Marine Debris	18%		
Coastal Cleanup Cost Related to Styrofoam	**$ 996,717,240**		

Highway Cleanup Costs

Description	Amt	Notes	Source
Highway Cleanup Costs per Mile	$ 10,000	CA Estimate	http://www.earthresource.org/campaigns/capp/capp-economics.html
Miles of Highway in US	164,000	National Estimate	https://www.fhwa.dot.gov/policyinformation/pubs/hf/pl11028/chapter1.cfm
Cleanup Cost per Mile	$ 1,640,000,000		
Styrofoam % of Marine Debris	18%		
Coastal Cleanup Cost Related to Styrofoam	**$ 295,200,000**		

Landfill Costs

Description	Amt	Notes	Source
Site Development Costs	$ 1,490,669		http://ageconsearch.umn.edu/bitstream/35091/1/sp03ei01.pdf
Landfill Construction Costs	$ 5,453,217		
Operating Costs (20 Years)	$ 12,622,754		
Closure Costs	$ 797,778		
Post-Closure Costs	$ 2,978,694		
Cost of Operating Landfill	$ 23,343,112		
# of Landfills in U.S.	$ 1,900		
Total Landfill Cost	$ 44,351,912,800		
% Styrofoam in Landfill	30%		
Total Lifetime Landfill Cost of Styrofoam	$ 13,305,573,840		
Avg Useful Life of Landfill (Years)	20		
Total Annual Landfill Cost of Styrofoam	**$ 665,278,692**		

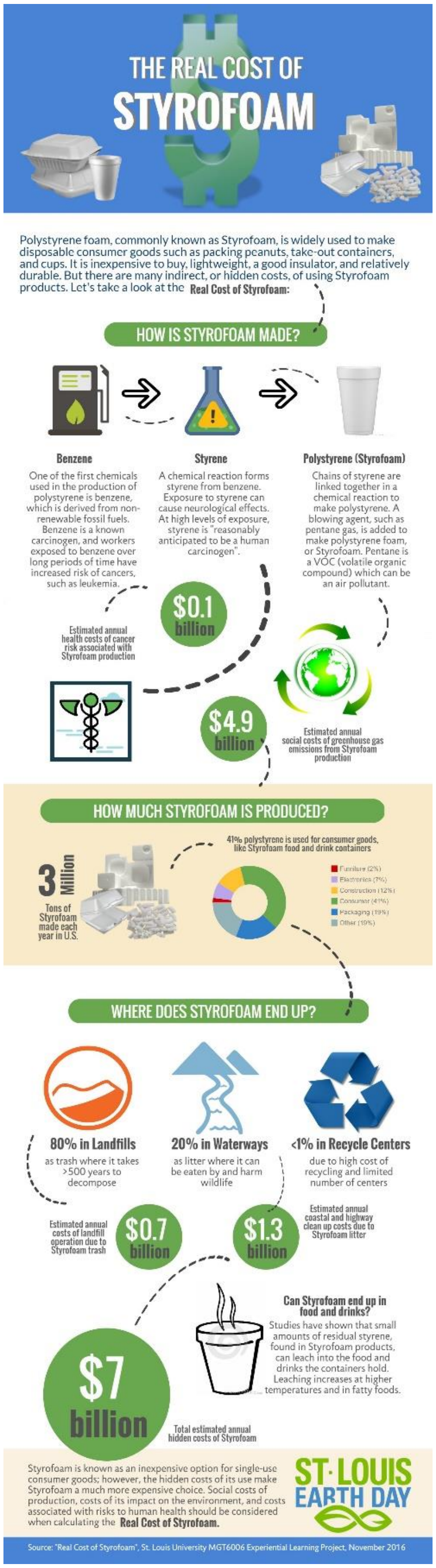
Benzene Health Costs

Description	Amount	Notes	Source
Benzene Workers in US	238,000		http://web.archive.org/web/20100610004540/http://www.atsdr.cdc.gov/csem/benzene/standards_regulations.html
% of Benzene Used for Styrene	55%		https://www.atsdr.cdc.gov/ToxProfiles/tp3.pdf
% of Styrene used for Polystyrene	65%		https://www.atsdr.cdc.gov/toxprofiles/TP.asp?id=421&tid=74
Benzene Workers for Polystyrene	85,085		
Leukemia Death Rate of Benzene	0.01%	Exposure Risk for Working Lifetime (i.e. 40 years)	http://web.archive.org/web/20100610004540/http://www.atsdr.cdc.gov/csem/benzene/standards_regulations.html
Styrofoam Benzene Workers Death	11		
"Value" of Human Life	$ 9,300,000		http://www.wsj.com/articles/why-the-government-puts-a-dollar-value-on-life-1458911310?mg=id-wsj
Benzene "Death" Cost	**$ 98,911,313**		

Styrene Health Costs

Description	Amt	Notes	Source
Styrene Workers in US	90,000		https://www.osha.gov/SLTC/styrene/
% of Styrene used for Polystyrene	65%		https://www.atsdr.cdc.gov/toxprofiles/TP.asp?id=421&tid=74
Sytrene Workers for Polystyrene	58,500		
Leukemia Rate (General Population)	1.48%	Avg of male & female risks	http://m.cancer.org/cancer/cancerbasics/lifetime-probability-of-developing-or-dying-from-cancer
Relative Risk of Leukemia (Styrene Exposure)	3.08	Multinational Study of Reinformed Plastics Industry Workers	http://ntp.niehs.nih.gov/ntp/roc/content/profiles/styrene.pdf
# of Expected Leukemia Cases in Polystyrene Workers	2,667		
Less General Population	(866)		
# of Expected Leukemia Cases in Polystyrene Workers Attributed to Styrene Exposure	1,801		
Annual Leukemia Cases in Polystyrene Workers Attributed to Styrene Exposure	45	Working Lifetime (i.e. 40 years)	
Cost of One Extra Year Life for Cancer Patient	$ 207,000		https://www.drugwatch.com/2015/10/07/cost-of-cancer/
Styrene Health Cost	**$ 9,319,471.20**		

APPENDIX: INFOGRAPHIC/FACT-SHEET



An Infographic/Fact-Sheet has been provided to SLED electronically. An image of the infographic is shown at left, for reference.

APPENDIX: REAL COST OF STYROFOAM--PRESENTATION SLIDES

Real Cost of Styrofoam: Presentation Slides have been provided to SLED electronically.

Slide images are shown in the pages that follow for reference.