WASTE REDUCTION AS A METHOD TO MEET CONSERVATION GOALS; A COMPARATIVE ANALYSIS OF PLASTIC WASTE MANAGEMENT

by

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DEDICATION

This is dedicated to my family and friends that believe in my ideals, even if they don't always agree with me, especially my son Dylan who provided emotional and moral support, as well as a sense of humor during the past two years of my graduate work.

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ABSTRACT

WASTE REDUCTION AS A METHOD TO MEET CONSERVATION GOALS; A COMPARATIVE ANALYSIS OF PLASTIC WASTE MANAGEMENT

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Plastics have become a staple of the urbanized human environment. Production and distribution of plastic resins became widespread during World War II. Nations at that time were not aware of the consequences of the use of plastics would impose on the environment. In the 1960s it was determined that plastics and had become a threat to wildlife and that their design for durability had also caused them to become a persistent pollution problem. By the 1980s, it was recognized that plastics had also become a threat to human health. In the past two decades it has been determined that plastics contribute to many more environmental threats and have also been recognized as a contributor to greenhouse gas emissions, attributed to global climate change.

While efforts have continued in the United States to recover plastic materials for recycling, a large percentage of waste that is disposed of is composed of plastic material. Federal legislation in regards to plastics is soft law that is aimed at encouraging use of the

three “Rs”: Reduce, Reuse, and Recycle. There are no specific regulations regarding their reduction, reuse, or recycling. The Environmental Protection Agency (EPA), however, has introduced through their Resource Conservation Challenge (RCC), a goal to increase the national recycling rate to 35 percent. Local efforts at the municipal, county, or state level have been attempted through various types of legislation to address increasing the recovery of plastics only, as well.

This study examined the threats that plastics pose to the natural and human environment, the effectiveness of policy to address those issues, and the contribution of plastic production, use, and disposal in the United States to the emission of greenhouse gases. This study focused on polyethylene, the plastic that is most widely produced, used, and disposed of plastic material in the United States. Waste management strategies applied to polyethylene plastics that are currently in place and their overall contribution to carbon dioxide (CO_2) emissions have been examined, as well. Source reduction as a policy instrument was compared to the nation reaching the EPA’s 35 percent recycling goal to determine which would be more effective at addressing the cumulative threats of plastics.

In examining these aspects in regards to polyethylene plastics this study has determined that a 25 percent source reduction of virgin plastic material as a policy instrument will more effectively reduce the amount of plastics bound for release in the environment and that are available to create hazards to human health, and will also reduce greenhouse gas emissions attributed to the production, use, and disposal of plastics more effectively than meeting the national recycling goal of 35 percent.

CHAPTER 1

Introduction

1.1 Problem Description

Plastics have become a staple of the urbanized human environment. While recycling and other policy initiatives have assisted in the recovery of plastics, problems persist. It is well understood that alternative waste management of plastics is required to address the problems associated with their production and use. This study will focus on polyethylene, the most widely produced, used and disposed of plastic and its contribution to the overall negative impacts and to the emission of greenhouse gases attributed to global climate change.

This study will examine the background of plastics in order to understand their proliferation, the myriad of problems that have surfaced from their widespread uses, policy mechanisms currently in place to address these problems, and the waste management practices that are currently employed to deal with their end of life disposal. While many of the issues attributed to plastics will only be briefly addressed by this study, it is not the intention of this study to undermine their significance and the need for further study. The goal of this study is to determine if source reduction or an increased recycling rate of polyethylene will be best to reduce the amount available for introduction into the environment and the emissions of carbon dioxide (CO_2).

1.1.1 Background

World War II brought about many changes in human consumption. Plastic polymers were refined and their production became widespread during this time due to their low cost and durability (Conner and O'Dell, 1988). By 1960, nearly 6 billion pounds of plastic had been produced and consumed in the United States alone and by 1990 the amount had increased to 50 billion. Many nations' governments had a *laissez faire* attitude toward business during this time and concern of the environmental impact of this consumption had not developed, so it was not an issue of environmental policy (Kubasek and Silverman, 2008). Catastrophic events detrimental to the environment that occurred in the late 1960s and early 1970s, combined with widespread media allowed evidence to surface publicly about the negative effects of human activities on the environment, including the consumption and disposal of plastics (Kubasek and Silverman, 2008).

Because plastic polymers are designed to be durable and long lasting their disposal meant continued persistence in the environment. By the 1970s the persistence of plastics in the environment became recognized as a pollution problem, causing new concerns and challenges for waste disposal management. The implications of the persistence of plastics in the environment have become more apparent in the past few decades with studies focused on plastic debris removed from inland and coastal shorelines. Studies conducted by the Ocean Conservancy (1993) have estimated the decomposition rates of common plastic materials found discarded along coastal shores during their annual International Coastal Cleanup (ICC). These estimates are shown in Table 1.

Table 1: Estimated Decomposition Rates of Common Plastic Materials

Item	Decomposition Period
Plastic Grocery Bag	1-20 years
Foamed Plastic Cup	50 years
Plastic Beverage Holder	400 years
Plastic Bottle	450 years
Fishing Line	600 years

As more areas have become urbanized, there has been an increase in the amount of plastic waste, as increased urbanization has been found to be positively correlated with dependence on plastic products (Leous and Parry, 2005). According to the Environmental Protection Agency (EPA) (2009c), the waste generation of plastics in 2008 at $\approx$30 million tons (27.2 billion kg), exceeded the combined total of glass, aluminum, rubber, and leather the same year at $\approx$23 million tons (20.9 billion kg). Of the 30 million tons of generated plastic waste, only two tons were recovered, representing a mere 7.1 percent of the total plastic waste generation. This is the lowest recovery rate of recyclable materials in the U.S. waste stream estimated at solid waste management facilities. The amount of plastics that have ended up in the environment are unknown, but could exceed billions of tons, as the International Coastal Cleanup has removed millions of pounds each year from the banks of rivers and inland and coastal shorelines since 1986 (Ocean Conservancy, 2010).

Plastics become loose and enter the environment at all life cycle stages. At the preproduction stage as resin pellets, the raw material of plastics, they are often inadvertently introduced through spills during production or transportation and then distributed throughout the environment by surface runoff (Mato et al., 2001). During the postproduction stage, manufactured plastics can enter the environment accidentally through freight incidents and during violent storms and surges. For example, Hurricanes Katrina and Rita deposited debris throughout the Gulf region, including plastics (Gulf of Mexico, 2007). Post consumer plastics are introduced directly through litter and illegal dumping and incidentally through mishandled solid waste.

The lightweight characteristic of plastic permits it to be carried throughout the environment by freshwater streams and storm water drains. It can be deposited onto stream banks or carried to rivers where it may end up in the marine environment. Its existence in the environment has caused a myriad of problems. Plastics and the problems associated with them have been widely studied and it has been found they negatively impact the environment and human health.

1.1.2 Environmental Aspects

Environmental concerns regarding plastic debris include the ingestion by and entanglement of wildlife, transport of toxic chemicals and invasive species, changes in geology in coastal regions, and emissions of greenhouse gases during production, transport, and waste disposal. There have been many deaths of several species of birds, whales, turtles, and other marine species that have been attributed to the consumption of plastic materials. Biologists have reported that at least 50 species of birds have consumed plastics, mistaking them for prey (Day et al., 1985; Pierce et al., 2004). The plastic is incapable of being digested, which can lead to false satiation and ultimately to starvation. The same false satiation has been reported as the cause of death of a beaked whale found dead in Brazil (Secchi and Zarzur, 1999). Filter feeders such as bowhead whales are also at risk of oral entanglement of plastics in the baleen racks (Lambertsen et al., 2005). In addition, leatherback turtles have died as a result of consuming plastic grocery bags (Mrosovsky et al., 2009). It is believed that they mistook them for jellyfish, their principal food source, as they are similar in appearance when suspended in the marine environment

Many deaths of marine species have also been attributed to entanglement in plastic materials at sea. In the Pacific, deaths of monk seals, green sea turtles, and humpback whales were caused by entanglement (Bamford et al., 2008.). Fur seals in the Pribilof Islands were observed entangled in fishing nets, packing bands, monofilament fishing lines, beverage rings, and plastic lawn chair material (Kozloff, 1985; Scordino, 1985). A major concern is that reproductive success can be affected by less than a one percent mortality rate from entanglement, which compounds difficulties in the population growth of endangered species (Boren et al., 2006).

A study of four Japanese coastal areas determined that polypropylene (PP) plastic resin pellets either contain or are capable of absorbing polychlorinated biphenyls (PCBs) and dichlorodiphenylethylene (DDE) (Mato et al., 2001). It is believed that this occurs through the attraction of the hydrophobic chemicals to the non-polar surfaces of the thermoplastic resin pellets. Persistent Organic Pollutants (POPs) such as Polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs) also are hydrophobic and can attach to plastic particles (Saloranta et al., 2006). It is hypothesized that the POPs will be distributed throughout food webs in the future by the consumption of plastic pellets by wildlife, as 60 to 72 percent of floating particulate matter in the Pacific Ocean was found to be plastic (Leous and Parry, 2005).

Plastic ingestion begins at the most basal of marine food webs. Crustaceans, worms, and barnacles have all been examined ingesting microscopic plastic particles (Beam, 2004). Persistent Organic Pollutants (POPs) attached to these plastic pellets can be passed up to species that ingest these prey. For example, POPs have been both bio-magnified and bio-accumulated in the blubber of marine mammals. They have been detected in the blubber of gray whales, killer whales, Risso's dolphin, and Dall's porpoise (Jarman et al., 1996). These POPs include the organchlorine compounds polychlorinated dibenzo-*p*-dioxins (PCDD) and dichlorodiphenylethylenes (DDE). POPs have been attributed to reproductive impairment in marine mammals, lowering fecundity rates and creating challenges in the conservation of endangered species.

The transport of invasive species by floating plastic material is another threat that plastic causes. It was recently discovered that plastics can serve as a vector for invasive species such as fungi and barnacles (Barnes and Milner, 2004). The lightweight and durable characteristics of plastic that have contributed to its commercial success have also created a medium for organisms to raft to alternate ecosystems. Once colonized by fungi or barnacles, the buoyancy of plastic materials allow the species to travel thousands of miles where they could potentially be invasive and disrupt ecosystem processes.

The geology and physical composition of many areas have been altered by the presence of plastics. A study of 18 beaches in the United Kingdom revealed that one-third of sediment at these beaches were comprised of microscopic plastic polymers and the concentration had increased over time (Beam, 2004). The Pacific Ocean, north of the Hawaiian Islands now has an artificial island from the accumulation of approximately three million tons (2.7 billion kg) of plastic debris (Leous and Parry, 2005). A study in the Bristol Channel has concluded that the Channel may actually be a sink for plastics that are washed downstream from litter and illegal dumping (Williams and Simmons, 1996). The researchers believe that a build-up of plastics could continue into the future, possibly creating a plastic dam.

The production, consumption, and disposal of plastic materials have also been found to contribute to the emission of CO_2, a chief greenhouse gas. Globally, the production of plastics utilizes 297.6 million tons (269.98 billion kg) of fossil fuels contributing to the emission of greenhouse gases (Kurdikar et al., 2001). The International Organization for Standardization (ISO) developed a life-cycle assessment in order to determine the environmental impact of a product from its production to its disposal (ISO, 2006). A life cycle assessment of the impacts plastics have on the environment from their production to waste disposal gives a more complete picture of their total contribution of CO_2 emissions (O'Neill, 2003). There have been many attempts to account for this, including the Environmental Protection Agency's (EPA, 2009a) WaRM model in its assessment of plastic waste management, which accounts for the life cycle of three commonly disposed types of polyethylene plastics from the point of production to their disposal.

1.1.3 Human Health Aspects

Human health is also threatened by plastics at all stages of its life cycles. During pre-production stabilizers, activators, and fillers can cause harm (Eckardt, 1976). Liver cancer and destruction of fingers through the loss of bone tissue have been attributed to exposure to plastic compounds in the pre-production and post-production stages. Nitric acid used in plastic manufacture is extremely flammable and can cause injury or death. Phenol, carbon disulfide, and formaldehyde are also used in plastic manufacture and are all toxic to humans. During the production of polyethylene, a controlled explosion is used to complete the process which can threaten the lives of those involved in its manufacture. Catalysts used in the production of polyurethanes have led to cases of bronchial asthma in workers, as well.

Post-production plastics have been found to create unique health hazards, as well. A study in Stockholm showed increases of polybromo diphenyl ethers (PBDEs) in women's breast milk from 1972 to 2000 (Schubert, 2001). Soon after researchers in North America, Japan, Israel, and Spain found that PBDEs were also present in human tissue and fat. The source of PBDEs is believed to be from flame retardant additives in plastics. Animal studies conducted to assess the threats that PBDEs pose on humans found negative effects on nervous system functioning that was found to increase with age.

Phenolic stabilization additives used in the production of plastics cause a number of problems in humans and have been found to migrate easily from plastics to food (Yamamoto, et al., 2000). A study in 2001 determined that a number of these additives used in plastics have estrogen activity *in vitro*, suggesting that these additives can serve as an endocrine disruptor (Miller et al., 2001). Later, it was determined that these same additives could cause cancer, as well (Jenkins, et al., 2009). In addition, quaternary ammonium compounds used in plastic manufacturing as anti-static agents or biocides have been found to leach from plastic into biological media (McDonald et al., 2009). These ammonium compounds were found to bind to DNA and proteins and were also attributed to infertility in mice.

1.1.4 Policy Implications

Plastics have been widely studied and the negative impacts on the environment and human health are well documented. The success of plastic has created long term environmental and waste management policy issues because it accumulates in the environment and produces considerable amounts of greenhouse gas (GHG) emissions, as well (Rosen, 1990). Many local and state jurisdictions began looking at various bills designed to address plastics and their subsequent negative effects on the environment and human health. Legislation that has been implemented include: recycling laws, deposit laws, landfill bans, charging for waste disposal through “pay as you throw” programs, and source reduction.

Research has been conducted into degradable plastics. However, the term of bio-degradability in regards to plastic is inconsistent as loss of physical integrity is often mistaken for bio-degradation (Palmisano and Pettigrew, 1992). It is vital to be able to make the distinction between deterioration and bio-degradation as deterioration will not allow plastic to be recycled in the environment and can lead to larger issues as smaller fragment size can distribute plastics more widely. In addition, partial bio-degradation can also lead to the release and accumulation of toxic stabilizer chemicals in the environment. Problems have resulted in the processing of plastics that manufacturers claim are bio-degradable and compostable. According to Will Bakx (2009), co-owner and Soil Scientist at Sonoma Compost, problems include the inability to distinguish compostable plastic from others, the rate of decomposition is much higher than residence time for compost, and many compostable plastics are not permitted for organic compost under the National Organics Program.

According to the American Chemistry Council (2009) the amount of plastic resins, the raw material of consumer plastics, produced in 2004 was 86 billion tons (78 trillion kg) of dry weight. Packaging and consumer and institutional markets, including the polyethylene plastic resins used in the production of plastics this study is focused on, constitute more than 50 percent of all plastic markets combined at over 44 billion tons (39.9 trillion kg). The total amount of plastic resins sold had only decreased to 74 billion tons (67.1 trillion kg) as a result of the economic downturn in 2008 and the packaging and consumer and institutional markets still stood at more than 39 million tons (35.4 billion kg), reflecting the dependence the United States has on the plastics industry.

1.2 Study Organization

1.2.1 Study Purpose

This study is an attempt to determine if source reduction or meeting a higher recycling rate is the most effective means to reduce the amount of plastics available for introduction into the environment and to reduce their negative impacts. This study hopes to provide valuable information in order to make informed policy recommendations by evaluating the effectiveness and economic costs of current policy choices and how they relate specifically to polyethylene plastics. In addition, the cumulative GHG emissions of polyethylene plastics from use to: landfill disposal, waste to energy, and recycling will be calculated in three scenarios: status quo with the current recycling rate and no policy change, attainment of 35 percent plastic recycling, and a 25 percent source reduction. The results will be compared to determine the best policy choice.

The EPA (2009a) has developed the Waste Reduction Model (WaRM) to evaluate the impact of certain waste management activities on GHG emissions. The WaRM model was chosen for this study to calculate the CO_2 emission produced by polyethylene plastics during their life cycle in each of the waste management activities currently in place. WaRM applies a life-cycle analysis of CO_2 emissions in the processes of: raw material acquisition, manufacturing, and waste disposal (EPA, 2006b). The waste management activities currently in use for plastics include: recycling, waste to energy (combustion), and landfill disposal. Additional GHG emission inventories calculated by the EPA based on the transportation sector involved in raw material extraction, commercial product distribution, and waste distribution have also been included in the GHG emission calculations.

The plastic composition of municipal solid waste, as reported by the EPA from 1995 until 2008, were used as a basis to determine the types and amount of polyethylene plastic waste that were generated and the figures were applied to future municipal waste projections. The results have been used in a comparative analysis of the GHG emissions of these waste management strategies in order to determine the best alternative.

Because greater quantities of paper (55.5 percent), glass (23.1 percent) and aluminum (38.3 percent) are recovered for recycling than plastic (7.1 percent), alternative waste management measures are required (Arsova, et al. 2008). This study has attempted to quantify both the economic costs and cumulative global warming impacts of policies concerning the waste management of polyethylene plastics. It has also compared the CO_2 emission impacts of source reduction and an increased recycling rate. The results will benefit the policy making process in waste management by allowing the policy makers to make more informed decisions. It may also serve as an education tool in communicating the importance of legislation in regards to plastics.

1.2.2 Justification

There have been some previous attempts to characterize the contribution of waste management to the reduction of greenhouse gas emissions (Calabro, 2009; Xiaoli, et al. 2009; Diaz, 2008). However, limited research has been conducted that combines multiple environmental impacts of waste management policies regarding polyethylene plastics specifically. A large majority of research on plastics and waste management has focused primarily on the need for waste management strategies, the proliferation of plastics in the marine environment, and how the problem will worsen in this century (Marine Debris, 2008). The information collected during this study will be combined with the results from previous research on waste management activities to enhance our knowledge of how waste management policies can contribute to conservation.

1.2.3 Methods and Analysis

This study will focus on the composition of polyethylene plastic waste including high density polyethylene (HDPE), low density polyethylene (LDPE), and polyethylene terephthalate (PET), the three most common types of plastics present in municipal solid waste. The figures used for the purpose of analysis are from the annual EPA municipal solid waste reports. Total waste will be examined from 1960 through 2008 in order to project waste growth in the future. The percentage of plastics in municipal solid waste will be examined from 1995 through 2008, as plastics were not accounted for by individual material in municipal solid waste prior to 1995. Using trend analysis, the total amount of waste and composition of plastic waste will be projected into the year 2040. These steps will be taken because the amount of and composition of solid waste changes with time and it has been found that plastics disposal is increasing (LaRiviere, 2007). The calculated composition of plastic waste will be listed in a table located in Appendix I.

It is well known that municipal solid waste is a primary concern in regards to population growth and increased urbanization (Leous and Parry, 2005). In addition to the cumulative environmental impacts of plastics, the analysis in this study is intended to determine if GHG emission reductions could be realized while also preventing its introduction into the environment. By estimating the greenhouse gasses that are produced in the life cycle of plastics from production to disposal and evaluating policies that result in GHG emission reductions will allow policy makers to make more informed decisions about the management of municipal solid waste. The goals of this study are to propose a policy to ensure there is a reduced amount of polyethylene plastic material to manage, fewer incidents of its release into the environment, lowered emissions of CO_2, and eased efforts of municipalities in the management of solid waste.

1.3 Study Limitations

While broad in scope, this study does have limitations that include: incomplete impact assessment, waste composition, and the CO_2 emission model. Some details regarding the impacts of plastics may be incomplete in this study, as new details surface regularly. Research should continue in their impacts. In addition, the EPA's waste data are not based on actual count data. The percentages of polyethylene plastics that are represented may be higher or lower, depending on the nature of the waste and the area it is located it. Localities would have to conduct individual waste composition studies to determine if the figures used in this study apply to their waste stream. Finally, while the EPA's WaRM model does apply a life-cycle assessment of the waste management of waste and recyclable materials, it may not be capable of properly projecting increases in emissions over time. It was designed for municipal waste management assessment at the local level.

CHAPTER 2

Municipal Solid Waste: Plastics

2.1 Plastic Types

Not all plastics fall into the polyethylene category chosen for this study. However, polyethylene, the resin used to produce high density polyethylene (HDPE), low density polyethylene (LDPE) and polyethylene terephthalate (PET) represent the largest percentage of plastic raw materials that are consumed and disposed of in the United States in 2008. At 36.3 billion pounds in 2008 sales, they make up over 50 percent of the plastic resin industry (American Chemistry Council, 2009a). The polyethylene resins are used in the production of the most widely consumed and disposed of plastics. Common uses of polyethylene resins are shown in Table 2.

Table 2: Common uses of Polyethylene Resins

Type	Common Uses
PET (recycling code number 1)	Drink bottles, peanut butter containers, salad dressing and oil containers
HDPE (recycling code number 2)	Milk and juice bottles, bleach and detergent bottles, small percentage of plastic bags, cereal box liners
LDPE (recycling code number 4)	Squeeze bottles, most plastic bags (bread, freezer, dry cleaning, trash, and shopping bags), plastic plates and cups

2.2 Generation and Recovery

According to the United States Environmental Agency (EPA) (2009c) Americans generated approximately 250 million tons (226.8 billion kg) of waste, a 64.64 percent increase since 1980. The per capita waste generation has also increased from 3.66 to 4.50 pounds (1.66 to 2.04 kg) per day since that time. The national recycling rate, including composting, has increased less than 10 percent to approximately 33.2 percent, as well. An increase in both the recycling rate and per capita waste generation reflect that the nation has become an increasingly disposable society.

Eighty three million tons (75.3 billion kg) or 33.2 percent of the municipal waste stream in 2008 was recycled or composted. Plastics represented approximately 30 million tons (27.2 billion kg) or 12 percent of the waste. Only 2.12 million tons (1.9 billion kg) were recovered, a rate of 7.1 percent. In 2008, 23.53 million tons (21.3 billion kg) of plastic waste was categorized as non-durable goods and containers and packaging, the categories primarily composed of polyethylene. The recovery rate of non-durable plastics was the lowest at 3.7 percent and containers and packaging was at 12.2 percent. Estimated amounts of polyethylene products in the MSW stream in 2008 are shown in Table 3.

Table 3: Polyethylene Products in Municipal Solid Waste (in thousands of tons)

Type	Generated	Recovered	Recovery Rate
PET	3,740	730	19.52%
HDPE	5,350	570	10.65%
LDPE	5,880	330	5.61%

The purpose of the data provided by the EPA is to characterize municipal solid waste in the United States in order to provide a picture of waste generation, recovery, and disposal (EPA, 2006a). A materials flow methodology is used by collecting data from industry associations and other industry sources. Waste characterization studies are used only to supplement the data gathered. Estimates are made and adjusted by imports, exports, and average life-spans of products consumed. The results are useful to determine nationwide trends in generation and recovery and as a benchmark for local waste management.

2.3 Waste Composition Projections

The waste composition estimated in the EPA's semi-annual publications entitled *Municipal Solid Waste Generation, Recycling, and Disposal in the United States* were used from 1960 until 2008 to project the growth of municipal solid waste to the year 2040, the results are illustrated in Figure 1. The annual increase of municipal solid waste for the purpose of this study is estimated at 3.13 percent.

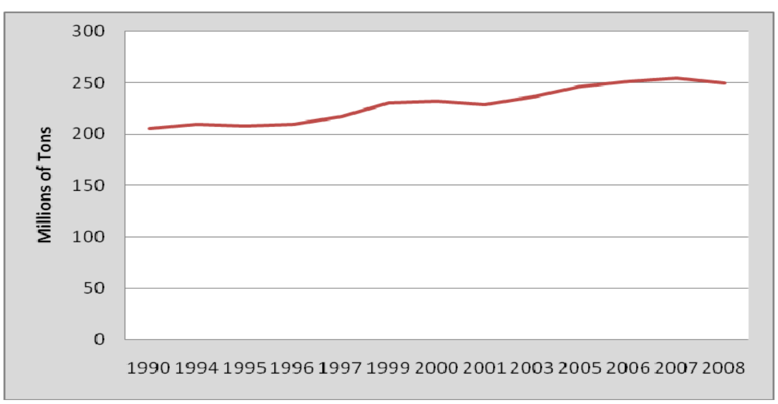

Figure 1: Municipal Solid Waste Generation from 1990 to 2008 in millions of tons

Changes in the composition of plastics in the waste stream is as important as changes in the total amount of waste, as each type of plastic has a unique impact on the production of greenhouse gases. Changes in the composition of polyethylene non-durable and containers and packaging plastics were determined from EPA reports from 1995 until 2008. Trend analysis was used to determine the annual changes in the composition of polyethylene plastics in those categories and those changes were projected into the future and applied to the projected waste stream. The annual increases in the percent of polyethylene materials is estimated at; PET: .06 percent, HDPE: .04 percent, and LDPE: .02 percent. The plastic waste figures estimated for the purpose of this study are shown in Table 4.

Table 4: Projected Plastic Waste in Millions of Tons (907.18kg)

Year	Total Waste	PET	HDPE	LDPE	Percent of Total
2010	265.89	3.33	4.87	5.31	**5.08**
2015	310.20	3.89	5.69	6.26	**5.11**
2020	361.88	4.56	6.65	7.38	**5.14**
2025	422.17	5.33	7.78	8.69	**5.16**
2030	492.50	6.24	9.09	10.23	**5.19**
2035	574.56	7.30	10.63	12.07	**5.22**
2040	670.29	8.54	12.42	14.22	**5.25**

2.4 Environmental Impacts: Plastic Production

The 18.2 million tons (16.5 billion kg) of polyethylene resins that were produced in 2008 utilized 34.77 percent of the fossil fuels involved in plastic production in the United States. The U.S. Energy Information Administration (2009) reported that in 2006, the

United States utilized 2 million barrels of liquid petroleum gasses (LPG) and 324 billion cubic feet of natural gas for energy in the production of plastic resins. In 2008, polyethylene resins sales were 10.3 percent lower than in 2006, as a result of the economic downturn. The lowered production consumed approximately 623,782 barrels of LPG and 101 billion cubic feet of natural gas. According to the U.S. Department of the Interior (2006), the equivalent British Thermal Units (BTUs) for this energy use is 106.4 trillion, which is equal to 31.2 billion kilowatt hours. The CO_2 metric ton equivalent of energy used in polyethylene resin production is 22.4 million metric tons. Recovery from the present economic downturn would lead to the increase in both polyethylene production and in the emission of CO_2. The projected growth of CO_2 emissions from polyethylene plastic production, which is estimated to be identical to the growth rate of municipal solid waste, is illustrated in Figure 2.

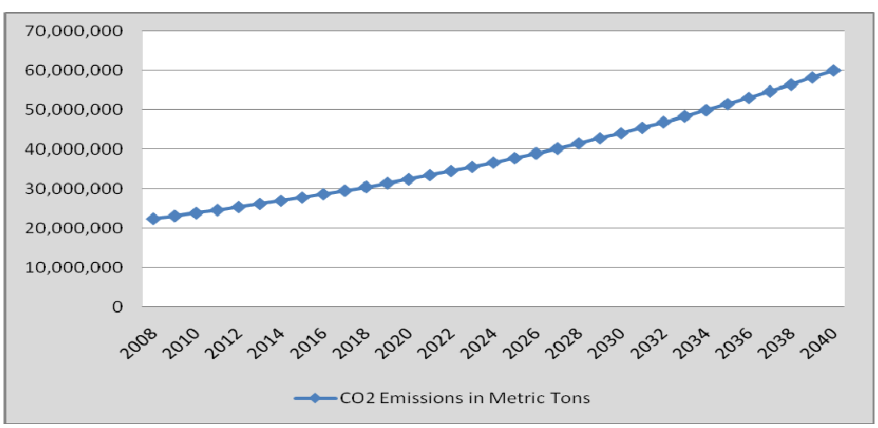

Figure 2: Projected Growth of CO_2 Emissions: Plastic Production

The emissions involved in the production of polyethylene products will be combined with the metric ton CO_2 figures calculated in waste management scenarios in later chapters in order to illustrate the cumulative emissions that are incurred from the production to the disposal of plastic products.

CHAPTER 3

Existing Waste Management Policy Choices

3.1 National Level Legislation

National legislation pertaining to waste is primarily soft-law in the form of goals and guidelines, rather than hard-law regulations. There are several attempts at the federal level to reduce waste that began in 1976. The Resource Conservation and Recovery Act of 1976 (RCRA) sought to reduce waste in active and future solid waste facilities through comprehensive waste management, including recycling (42 *USC*, Sec. 6901). This hard law established no mandates to require recycling or waste reduction at the federal level, but does suggest that states and municipal governments are responsible for setting their own guidelines, goals, and laws. RCRA does not specifically address plastics in any of its references.

The Resource Conservation Challenge (RCC) was launched in 2002 as an effort to encourage citizens, industry, and government agencies to conserve resources and energy by recycling 35 percent of its waste, the current national recycling goal, but no goals were included for waste reduction (EPA, 2009e). The initiative offers several resources for those wishing to meet the “challenge.” The resources include partnerships in the challenge, conservation tools, and tips to reduce, reuse, and recycle. However, the challenge does not address plastics directly. The Comprehensive Procurement Guideline (CPG) is an effort of the EPA to promote the use of recycled materials and promotes a market for their use (EPA, 2009f). Plastics are indirectly addressed through the CPG categories and designated items in the non-paper office products and landscaping products

The proposed Waxman Markey Bill, the American Clean Energy and Security Act of 2009 (ACESA) indirectly addresses recycling and waste reduction as means to address global climate change by reducing the emission of greenhouse gases (U.S. House of Representatives, 2009). Recycling and waste reduction have been shown to reduce greenhouse gas emissions and Title III, sections 311, 312, and 321 all address the reduction of global warming pollution. There are no other federal efforts to reduce the amount of plastic waste produced, or to increase the amount that is recovered. Those efforts have been limited to state and local governments.

3.2 State and Local Legislation

3.2.1 Bottle Bills

Packaging materials are the most widely produced type of plastic and have the lowest rate of recovery. They also are a large component of litter in the environment because of ineffective waste management or carelessness (Florida Center for Solid Waste and Hazardous Waste Management, 1996; Beck, 2006). In 1972, the state of Oregon introduced a revolutionary law known as the Oregon Bottle Bill in order to address the problem of litter (Guerts and Wheeler, 1980). The bill's goal was to roll the cost of litter removal into the cost of the container by charging a refundable deposit. The deposit then gives value to the container, increasing the rate of return and lowering the chances of its improper disposal.

Many other states have followed the example of Oregon, by passing similar container deposit laws on plastic materials such as PET and HDPE. California passed the Beverage Container Recycling and Litter Reduction Act of 1987 to address such issues (Bottle Bill Resource Guide, 2009). As a result, California's recycling rates of all beverage containers have increased including PET and HDPE plastics. The exact amount of increase and relationship to the law's implementation is difficult to assess because recycling data does not include specific items recovered, only materials. Vermont, Oregon, New York, Michigan, Massachusetts, Iowa, and Hawaii have all passed similar laws and claim redemption rates of 6 percent or higher of plastic beverage containers, lower than the national recycling rate of 19.52% of PET. California also requires that beverage manufacturers pay fees to offset costs of recyclers when their costs exceed the value of the material being recycled.

Bottle bills have several economic benefits. First, they avoid the cost of removing plastic containers that end up in the environment. It also places no economic burden on the recycler, as they receive the deposit back once the bottle is returned for redemption. In addition, it places a monetary value on a disposable good so that if one person does not value the deposit and discards the bottle, another person that does value the deposit will come along and pick the bottle up. However, there is a perception that bottle bills do impose a cost of freedom on consumers. It is believed by some that consumers have to give up personal freedom with bottle bills because they have to pay a deposit and it is their responsibility to return the bottle to get it back (Wiener, 1993).

3.2.2 Mandatory Recycling

There have been very few attempts at passing statewide mandatory recycling laws, most laws that require recycling of some type of goods occur at the municipal or local government level. Most recycling laws implemented at the state level mandate diversion rates and require that local governments implement programs to meet those diversion rates. States that have attempted this type of state law are: California, Minnesota, Wisconsin, Michigan, and Illinois. There are, however, some states with more comprehensive recycling laws in place that require recycling, but do not specifically include plastic materials in the guidelines. These states are: Connecticut, Delaware, Maine, New Hampshire, New York, and Vermont (Northeast Recycling Council, 2005). States with mandated recycling of HDPE, LDPE, and PET include: New Jersey, Pennsylvania, and Rhode Island.

Most mandatory recycling legislation is at the city, local, or municipal level. Honolulu, HI requires businesses of a certain size and all government agencies to recycle, but only city government agencies are required to recycle plastic materials (City and County of

Honolulu's Department of Environmental Services, 2005). The city of San Francisco implemented a mandatory recycling and composting law, requiring the diversion of materials from landfills that are capable of being recycled, including plastics (San Francisco Environment, 2009). Fort Myers, Florida has also implemented an ordinance that requires commercial, non-profit organizations, and those conducting special events separate and collect recyclables, including plastics (City of Fort Myers, 2010).

There are several advantages and disadvantages of mandatory recycling. Advantages include that it lowers the demand of raw materials by increasing rates of recycling and decreases the costs associated with disposal through revenues generated by the recycled commodities (Massachusetts Department of Environmental Protection, 2009a). Mandatory programs have been found to collect more materials than voluntary programs and are more successful with increased collection frequency (Everett, 1993). Disadvantages could result through higher costs imposed on municipal entities in providing curbside collection and processing recycled goods, as well as the additional responsibility of finding markets for the recycled materials (Northeast Recycling Council, 1999). In addition, problems may arise from the lack of measurement and enforcement capabilities of municipalities (Roberts, 1995).

3.2.3 Pay as You Throw

Pay as you throw programs (PAYT) have been implemented in approximately 2,000 jurisdictions in order to extend landfill capacity and deal with rising costs of collection and disposal (EPA, 2009g). PAYT programs are also known as unit or variable rate pricing for waste disposal. Boulder, CO instituted a volume based PAYT program in 2001 (Ruzzin, 2001). As of July, 2009, 129 towns in Massachusetts had implemented PAYT programs (Massachusetts Department of Environmental Protection, 2009b). 213 municipalities in Pennsylvania utilize PAYT programs, as well (Pennsylvania Department of Environmental Protection, 2009a). The state of Connecticut Department of Environmental Protection (2009) offers guidance to local waste management planners through their SMART unit based pricing system currently in place in several locations.

There are several advantages and disadvantages of PAYT programs. Advantages are that they offer an economic incentive to residents to reduce the amount of waste they generate and because they provide revenue to the municipality (EPA, 2009g). In addition, they have been shown to increase recycling, conserving natural resources and energy (North Carolina Division of Pollution Prevention and Environmental Assistance, 1998). Problems arise in their implementation because trash service financing has traditionally been hidden from consumers and based on tax money. As a result, residents have had the perception that the collection was free so switching to a fee based service often meets resistance (Canterbury and Newill, 2003). Illegal dumping is the primary disadvantage, as it is feared that residents and businesses would prefer to dump their waste illegally than pay for collection. However, it was discovered that comprehensive education directed to the general public of the rationale behind PAYT programs have helped municipalities to reduce this threat (North Carolina Division of Pollution Prevention and Environmental Assistance, 1998).

3.2.4 Landfill Bans

Landfill bans have been implemented as a policy choice to recover recyclable materials and preserve natural resources, as well as extending the life of landfill facilities (Tennessee Department of Environment and Conservation, 2009). Most landfill bans have been used as a means to prevent hazardous items from being disposed of improperly. Landfill bans used to reduce the disposal of recyclable materials are often implemented in tandem with mandatory recycling legislation. For example, the county of Santa Cruz banned the disposal of recyclable goods and implemented a mandatory recycling law in 2005 (Santa Cruz County Recycles, 2009). The ban includes non-durable polyethylene plastic materials that are required to be recycled but excludes some durable plastics, packaging, and plastic bags that are currently recyclable. The state of Massachusetts has banned all plastic containers from landfills, combustion facilities, and generators (Northeast Recycling Council, 2005). Pennsylvania has banned plastics from combustion facilities only.

As with other waste diversion policy measures, there are advantages and disadvantages of implementing landfill bans on plastic materials. Advantages are that they increase recycling rates if the municipality has the infrastructure to provide locations and opportunities to recycle goods (Skumatz et al., 2008). Landfill bans of yard waste have decreased the amount of yard waste disposed of in landfills in several states, so landfill bans of polyethylene plastic materials could extend the life local landfills, as well (Fickes, 2002). Disadvantages include the inability to monitor compliance and to measure the effectiveness.

3.2.5 Extended Producer Responsibility (EPR) Laws

EPR laws involve making the producer responsible for the products they manufacture through their life cycle from production to their disposal (Institute for Local Reliance, 2006). Policies built on EPR concepts internalize the environmental externalities and shift the burden of the economic costs associated with environmental costs to the consumer through the higher costs of products. Most EPR laws currently in place in the United States were implemented at the state level and require that the producer take back or provide recycling options for their products. This type of legislation is considered a “cradle to grave” policy and involves economic costs to the producer and increased prices for the consumer. States that have introduced this type of policy include: Minnesota, California, Oregon, Washington, Rhode Island, and California (Product Policy Institute, 2010). EPR framework policies have been adopted as law in only Rhode Island and California.

The California Integrated Waste Management Board adopted their policy, referred to the California EPR Framework Policy on January 23, 2008 (California Product Stewardship Council, 2010). During the 2009 state legislative session, the framework was adopted as state law, entitled The California Product Stewardship Act, AB 283 (Product Policy Institute, 2010). The goals of this law are to address all materials in the waste stream and their life cycle impacts, provide improved environmental performance of products including reducing solid waste, the advancement of the design of green products, the design and promotion of product stewardship programs, and to place the economic costs on producers and consumers of certain of commercial products (California Product Stewardship Council, 2010).

The principles guiding the implementation of the EPR policy of California state that producers assume responsibility of the products' end of life environmental impacts both physically and financially. They also require that producers either develop or participate in a product stewardship program. These requirements involve provisions that are complex and include: goals, fees, specified administration of the process, reporting procedures, collection, and sustainable use. They recommend that the plans include an environmental component such as source reduction and product design. While comprehensive in other waste reduction methods, it only applies to products produced in California. Producers who do not wish to participate can move manufacturing facilities to another state.

Advantages of EPR laws are that producers are compelled to consider the environment when designing their products and it prevents certain products from entering the waste stream. When a producer must design products that allow for take back or recycling, the use of materials that are harmful to the environment are less attractive because the producer must handle the item at the end of the products life cycle. This indirectly compels producers to consider the environment when choosing materials they will use. In addition, the producer would be responsible for disposing the materials that are incapable of reuse or recycling.

Disadvantages are that they do result in higher market costs and require regulatory measures to monitor and measure effectiveness. Producers would expect higher operating costs if they are expected to handle items at the end of their life cycle. Higher operating costs are then built into their business model, which results in higher market prices which passes their costs to consumers. In addition, without government regulatory measures to monitor the compliance of producers, items returned by consumers to producers may continue to enter the waste stream, rather than being reused or recycled.

3.3 Source Reduction

Source reduction is a type of extended producer responsibility law that achieves waste reduction by reducing waste before a product's purchase through producer or consumer choices. The most effective source reduction strategy is to reduce the waste generated before products enter the marketplace. Source reduction directed at producers as a policy choice is currently not in use in the United States. The RCC program of the EPA includes reduction, but through consumer choices only. Source reduction offers many advantages with fewer disadvantages than traditional EPR laws that are in place.

Because source reduction is achieved at the production stage of a product's life cycle it offers advantages to producers, the environment, and consumers. Advantages include reduced use of resources and energy to produce and distribute products, as well as lowered disposal demand and negative environmental impacts. In addition future lowered production costs to producers for raw materials would result in lower costs to consumers for products. The primary disadvantage of source reduction is negligible economic costs to producers. The economic costs include, but are not limited to: research and development (R&D), design, and the possibility of higher costs associated with alternative raw materials.

3.4 Summary

The goal of the legislation summarized in this chapter is to reduce waste entering the municipal solid waste stream, not to prevent its generation. Recycling has been the traditional strategy to reduce the amount of waste bound for disposal and has allowed the recovery of materials that may otherwise be disposed of in landfills or waste to energy facilities. The recycling of materials such as glass, paper, and aluminum leads to the production of similar items that can also be used and recycled repeatedly, so a reduced use of raw materials and energy results from recycling of those products. With plastics, however, there is often only a single reuse and does not involve the production of similar items. For example, PET may become carpet and HDPE may become toys or trash cans (Lotfi, 2009).

The legislation currently in place has assisted in increasing the recycling rate of certain materials, but little has been accomplished in increasing the recycling rate of polyethylene plastics and preventing its introduction into the environment. In addition, there is no consistency among states in the types of legislation chosen to reduce waste. Challenges still remain with the legislation currently used including: gaining compliance, monitoring and measurement, and building the necessary infrastructure. Without a federal level mandate, little progress in the recovery of polyethylene plastics can be expected.

Extended Producer Responsibility (EPR) laws and source reduction are legislative choices that have been implemented in other nations, but are under used in regards to plastics and in the United States. In regards to packaging and non-durable containers, the European Union has implemented an EPR law known as the Packaging Directive 2004/12/EC which addresses packaging waste only, including plastics (EPA, 2009). In response to the Directive, England passed the 1998 Essential Packaging Requirements Regulations in order to meet the EU's Packaging Directive (DTI, 2007). The law requires the minimization of packaging volume, weight, and design as well as use that permits reuse and recovery. The regulations have enforcement provisions that include a requirement that manufacturers submit design plans for approval from government officials.

CHAPTER 4

Waste Management: Landfills

4.1 Capacity and Demand

The United States' landfill disposal capacity has remained comparatively constant with many states reporting that there is 19-20 years worth of waste disposal remaining total in existing landfills (American Society for Civil Engineers, 2003). Total available landfill capacity in 2008 was reported at 6.5 billion tons (5,896 billion kg) (Waste Business Journal, 2009). The projected capacity for 2013 is 5 billion tons (4, 536 kg), a decrease of approximately 17.87 percent.

The Northeast Region had 11 percent of the total capacity in 2008 and its projected capacity represents a decline of approximately 29 percent from existing capacity. The Pacific Region had 17 percent of the total and its projected capacity represents a decline of approximately 16 percent. The Midwest Region had 18 percent of the total and its projected capacity represents a decline of approximately 28 percent. The Western Region had 23 percent of the total and its projected capacity represents a decline of approximately 11 percent. Finally, the Southeast Region had 31 percent of the total and its projected capacity represents a decline of approximately 13 percent. The projected decrease in landfill capacity from 2008 to 2013 is illustrated by region in Figure 3.

Figure 3: Projected Landfill Capacity in Millions of Tons (907.18 kg)

There are several states, however, that reported in 2003 less than 10 years of capacity remaining (American Society for Civil Engineers, 2003). Many landfill closures and the construction of fewer mega landfills have increased interstate waste disposal, adding to the economic and environmental costs of waste management through waste distribution. New York, one of the states with the lowest remaining capacity is located in the region with the lowest remaining capacity and is the largest exporter of waste, which adds to the cumulative emission of greenhouse gases from transportation.

With few alternative disposal options, landfill demand has steadily increased during the last two decades. Growth of landfill demand since 1991 is illustrated in Figure 4. It is important to note that landfill demand remained static during the recession in the early 1990s, but rebounded quickly with economic recovery. It can be expected to do the same once the current recession ends and economic recovery begins.

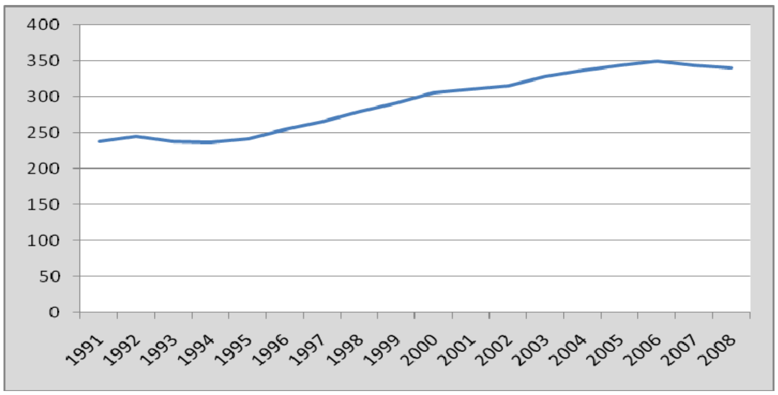

Figure 4: Landfill Demand in Millions of Tons (907.18 kg)

Population growth of the United States in the 1990s was remarkable compared to other industrialized nations, with more areas becoming more densely populated (Hobbs and Stoops, 2002). The continued increase in population and waste disposal per capita will present challenges for landfills to meet the demand. Plastics are also more voluminous than mixed municipal waste and contribute to landfill capacity declines. Each ton of plastic is equal to approximately 55.55 cubic yards while mixed municipal waste is only 8.88 cubic yards (EPA, 1997). Landfill demand versus capacity is illustrated in Figure 5. It is important to note that the graph below represents the capacity and the demand for each year independently and that each variable can fluctuate from one year to the next.

For example capacity will continue to decline unless new landfill sites are opened, while demand increases over time, with short periods where it remains stable.

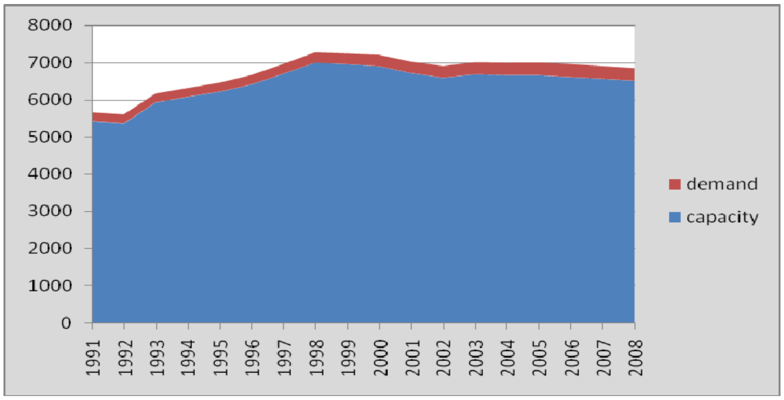

Figure 5: Landfill Demand versus Capacity in Millions of Tons (907.18 kg)

Increasing capacity at landfills often requires expansion or new site development which meets with the resistance of local residents. The resistance, known as "Not in My BackYard" (NIMBY), has often grown into large networks composed of known public figures and environmental groups. These networks often cause the cancellation of site expansion and development, or delay it considerably. Extending the life of present landfills can avoid the political issues of expansion and site development in the near term.

4.2 Environmental Impacts: Landfill Disposal

Landfills were found to create negative environmental impacts from the leachate of unlined landfills discharging into local water systems (Kuajara, 1997; Harper et al., 1996). Treatment systems have been designed to combat this problem, but the problem persists in closed or unmonitored landfills (Keenan et al., 1984). The EPA has implemented requirements to combat leachate problems and other environmental issues created by landfills. Cumulative environmental impacts associated with landfills are beyond the scope of this study, but do merit further study.

Studies in recent years have shown the contribution of landfill operations to the emission of GHGs, specifically CO_2, as well. Sources of CO_2 in municipal waste processing include the use of fossil fuels in the transportation and processing of waste, as well as decomposition of the waste itself (EPA, 2010). After being placed in a landfill waste is partially decomposed by aerobic bacteria. Once the oxygen is depleted, anaerobic bacteria begin further decomposition and through fermentation create the substrate that supports methanogenic bacteria which convert the products of fermentation into organic materials and biogas which includes methane (CH_4) and CO_2.

Emissions from the production of polyethylene plastic resins discussed in Chapter 2 have been calculated and combined with the emissions from landfill waste management of the plastic waste stream calculated in Chapter 2 and illustrated in Appendix I. The plastic waste stream at five year intervals was entered into the Excel version of the EPA's WaRM model showing that 100 percent of the materials are to be disposed of by landfill to demonstrate the emissions of landfill activities relative to the disposal of polyethylene plastics. The cumulative emissions of CO_2 attributed to polyethylene plastics in metric tons (1000 kg) from production to landfill disposal are illustrated by material in Table 5.

Table 5: Production and Landfill Disposal: CO_2 Emissions in Metric Tons (1000kg)

Year	Production	PET	HDPE	LDPE	Total
2010	23,824,185	137,094	200,626	218,866	24,380,771
2015	27,793,494	160,416	234,520	257,894	28,446,324
2020	32,424,122	187,705	274,141	303,882	35,189,850
2025	37,826,253	219,636	320,456	358,070	38,724,415
2030	44,128,423	256,998	374,594	421,922	45,181,937
2035	51,480,588	300,717	437,880	497,160	52,716,345
2040	60,057,685	351.873	511,857	585,814	61,507,229

4.3 Total Projected CO_2 Emissions Savings

Current efforts to increase recycling have lowered the emissions of GHGs attributed to landfill disposal of plastics. Savings are realized from the assumption that there is less virgin material entering the production phase (EPA, 2009a). Savings, which are negligible, from the current recycling rate of 11.03 percent and total GHGs from landfill disposal of polyethylene plastics have been projected and are illustrated in Figure 6.

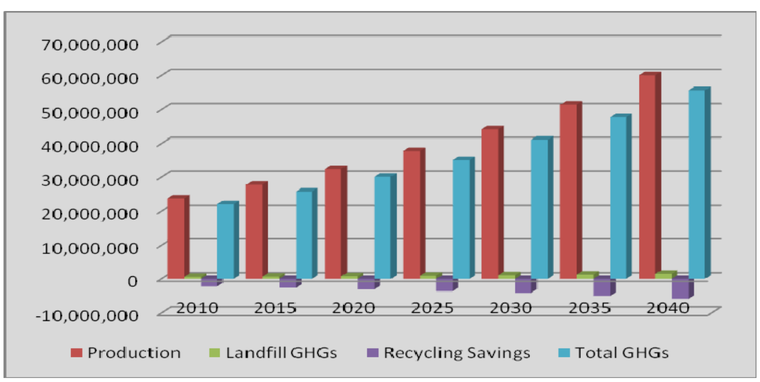

Figure 6: Projected Landfill CO_2 Emissions in Metric Tons: Recycling Savings

CHAPTER 5

Waste Management: Waste to Energy

5.1 Waste to Energy: Capacity and Demand

Waste to energy (WTE) capacity in the United States is much lower than landfill capacity, but is a method that is widely used for disposal of municipal solid wastes, including plastics. Unlike landfills, there is no total limit on the amount of waste that can be disposed of through WTE. There are limits on the quantities per day that can be accepted and limits on the expected number of service years of a given unit. In 2008, the total annual capacity at WTE facilities in the United States was 32,403,400 tons (29.4 billion kg), representing 12.9 percent of the waste stream (Waste Business Journal, 2009).

The northeast region had a capacity of 14,729,000 tons (13.3 billion kg) which represented approximately 45.5 percent of the total WTE capacity in 2008. The southeast region had a capacity of 7,089,000 tons (6.4 billion kg) which represented approximately 21.9 percent of the total. The mid-west region had a capacity of 3,890,400 (3.5 billion kg) tons which represented approximately 12 percent of the total. The western region had a capacity of 507,000 tons (459.9 million kg) which represented approximately 1.6 percent of the total. Finally, the pacific region had a capacity of 6,188,000 tons (5.6 billion kg) which represented approximately 19.1 percent of the total. With jurisdictions facing landfill capacity shortages and renewable energy requirements, the WTE capacity is expected to increase in the future. The total WTE capacity in 2008 is illustrated by region in Figure 7.

Figure 7: Waste to Energy Capacity in Tons

There are conflicting policies regarding WTE in the United States. Some states define solid waste as a renewable resource, while others have incinerator bans in place. The differences between policies reflect the changing attitudes toward WTE. States that have defined solid waste as a renewable resource allows solid waste authorities to implement and operate waste to energy facilities as a method to manage solid waste and produce energy. The Energy Recovery Council (ERC, 2006) reports the states that have instituted this type of waste management policy. These states are listed in Table 6.

Table 6: States and Equivalents: Waste to Energy Defined as Renewable Energy

Alaska	Florida	Maryland	Nevada	Pennsylvania
Arkansas	Hawaii	Massachusetts	New Hampshire	South Dakota
California	Indiana	Michigan	New Jersey	Virginia
Connecticut	Iowa	Minnesota	New York	Washington
D.C.	Maine	Montana	Oregon	Wisconsin

5.2 Environmental Impacts: Waste to Energy

The emissions of waste to energy facilities have been of concern since it was discovered that WTE plants were a source of toxins and heavy metals identified in the environment (Eddings, 2005). The Clean Air Act (CAA) 1990 amendments addressed the emissions that were the source of the contaminants with new source performance standards (42 *USC*, Sec. 7429). The cumulative environmental effects of the emission of these toxins are beyond the scope of this study, but do merit further research.

Recent studies have demonstrated the contribution of WTE operations to the emission of GHGs, specifically CO_2. Emissions from the production of polyethylene plastic resins from chapter 2 are shown with the emissions from waste to energy waste management of the plastic waste stream also from Chapter 2. The plastic waste stream at five year intervals was entered into the Excel version of the EPA's WaRM model. The cumulative emissions in metric tons (1000 kg) of CO_2 produced from production to the incineration of plastics through the year 2040 are illustrated by material in Table 7.

Table 7: Production and WTE Incineration: CO_2 Emissions in Metric Tons (1000kg)

Year	Production	PET	HDPE	LDPE	Total
2010	23,824,185	3,806,368	5,089,771	5,552,516	38,272,840
2015	27,793,494	4,453,878	5,949,675	6,542,648	44,739,695
2020	32,424,122	5,211,528	6,954,834	7,709,341	53,299,825
2025	37,826,253	6,098,086	8,129,808	9,084,079	61,138,226
2030	44,128,423	7,135,445	9,503,285	10,703,964	71,471,117
2035	51,480,588	8,349,273	11,108,804	12,612,708	83,551,373
2040	60,057,685	9,769,588	12,985,563	14,861,821	97,674,657

5.3 Total Projected CO_2 Emissions Savings

The overall emissions of GHGS attributed to the WTE disposal of polyethylene plastics are very high from the combustion process. There are negligible emission offsets realized from the production of energy and from the current recycling efforts, however. The WaRM model calculates the energy savings from energy production in BTUs which were converted to kilowatt hours (kWh) and then to metric tons of CO_2. The high emissions associated with the incineration of polyethylene warrant a reduction in their use as feedstock. The emissions of WTE operations and savings from energy production and recycling are illustrated in Figure 8.

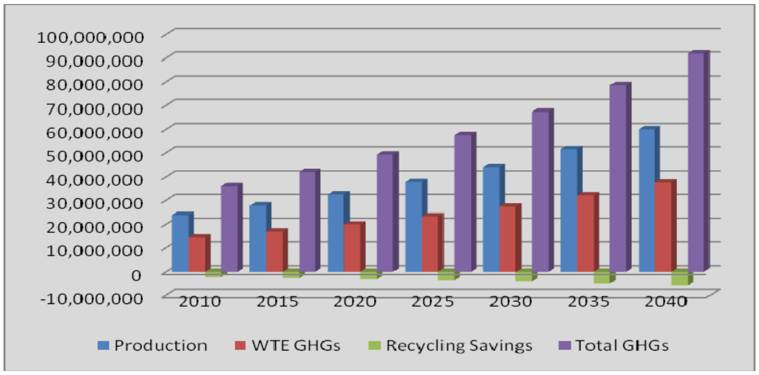

Figure 8: Projected WTE CO_2 Emissions in Metric Tons: Recycling Savings

CHAPTER 6

Analysis: Plastic Waste Reduction Strategies

6.1 Waste Management Scenarios

Waste projections through 2040 calculated in Chapter 2 were used in three scenarios. Scenario one represents status quo waste management operations with plastics recovery at; PET: 19.5 percent, HDPE: 10.7 percent, LDPE: 5.6 percent, landfill disposal at: 81.14 percent, and incineration at: 18.86 percent. Scenario two added a 25 percent source reduction of polyethylene plastic materials with the current recovery and disposal rates. Scenario three added instead the EPA's (2009e) 35 percent recovery goal with the current WTE and landfill disposal rates.

6.2 Landfill Capacity and Incineration

Landfill capacity, illustrated in Figure 9, would be reached less quickly than with status quo waste management with both a 25 percent source reduction and with a 35 percent recycling rate of polyethylene plastics. However, source reduction would allow the capacity to be extended three percent longer than with a 35 percent recycling rate. Fewer polyethylene plastics would be bound for incineration, illustrated in Figure 10, with both a 25 percent source reduction and with a 35 percent recycling rate. However, source reduction would prevent three percent more plastics from being used as WTE feedstock than with a 35 percent recycling rate being reached, as well.

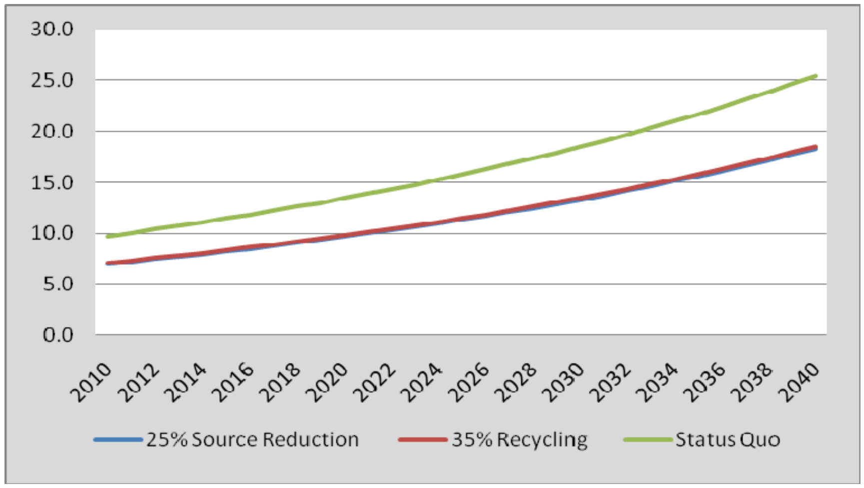

Figure 9: Landfill Tons to Capacity in Millions of Tons (907.18 kg)

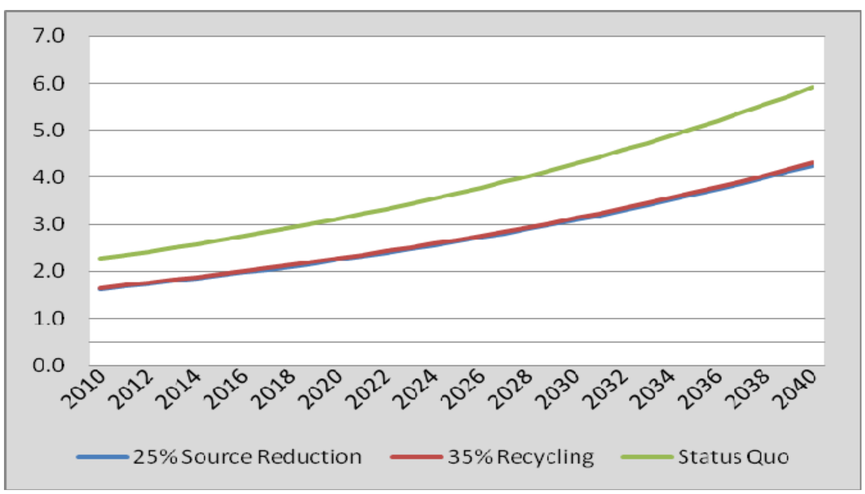

Figure 10: Plastics Bound for Incineration in Millions of Tons (907.18 kg)

Consideration must be given to the voluminous nature of the polyethylene plastics waste examined in Chapter 2. Landfill capacity in cubic yards, as illustrated in Figure 9, would be greatly reduced by polyethylene plastics because they are more voluminous than average mixed municipal waste. A metric ton of polyethylene plastics occupies 6.23 times the space in cubic yards as mixed municipal waste (EPA, 1997). A 25 percent source reduction results in a 4 percent greater extension of landfill capacity over time that a 35 percent recycling goal when applied to polyethylene plastics in cubic yards.

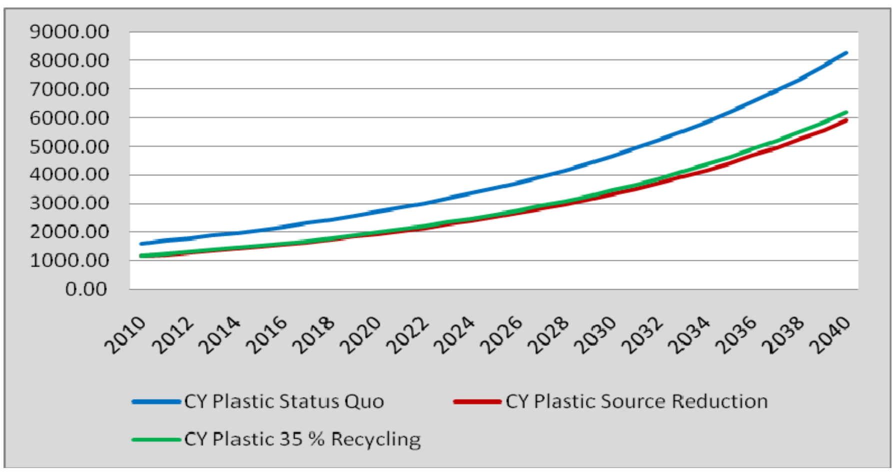

Figure 11: Landfill to Capacity in Cubic Yards

6.3 Plastics Recycling Market

Currently plastics have the lowest recovery rate of any other recyclable material and according to the Waste Business Journal (2009); the infrastructure of plastic recycling is still in the development process. In addition, the polyethylene plastics recycling market has fluctuated widely since 2005 (Waste & Recycling News, 2010). The saturation of the polyethylene plastics market that would result with increased recycling associated with the United States reaching the 35 percent recycling goal could cause the market to crash. This could create conditions necessary for private recycling companies to abandon their business, leaving the responsibility of recycling to municipal governments. The result would be further economic costs to government if the market price of polyethylene reaches zero. Plastics pricing per ton (907.2 kg) from 1995 through 2010 is illustrated in Figure 12.

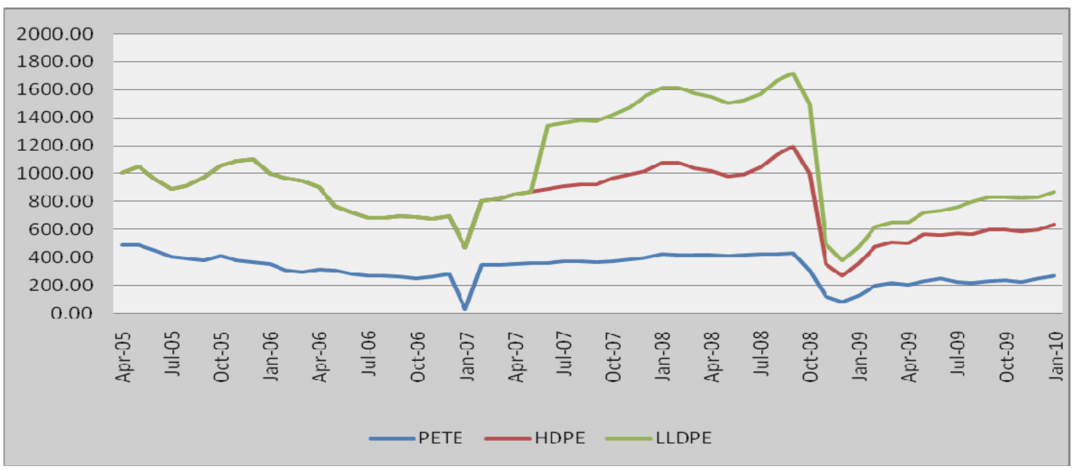

Figure 12: Polyethylene Plastics Commodity Pricing per ton (907.18 kg)

6.4 Total Projected CO_2 Emissions Savings

The three scenarios for polyethylene plastic waste management including: status quo waste management and recycling rate of polyethylene plastics, status quo waste management and recycling rate with a 25 percent source reduction, and status quo waste management with the EPA's (2009e) 35 percent recycling goal were all entered into the

EPA's WaRM model to determine the CO_2 emissions in metric tons. The results have been projected through the year 2040 and are illustrated in figure 13. The figure illustrates that status quo waste management of polyethylene plastics results in a steady increase of CO_2 emissions. Both a 25 percent source reduction and a 35 percent recycling rate of polyethylene reduces the emissions considerably. However, a 25 percent source reduction of polyethylene plastics reduces CO_2 emissions attributed to their life cycle greater than a 35 percent recycling goal being reached.

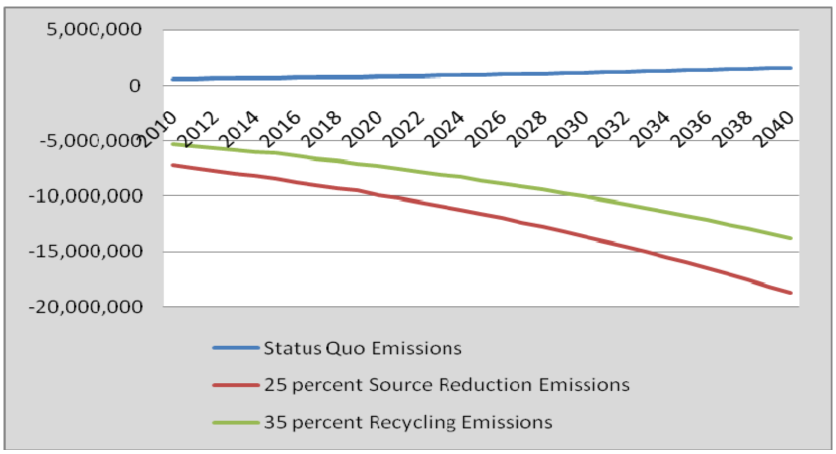

Figure 13: Waste Management CO_2 Emissions in Metric Tons (1000kg)

6.5 Descriptive Statistics

The hypothesis formulated for the purpose of this study is: there is a significant difference between a 25 percent source reduction of plastics and the EPA's (2009a) 35 percent recycling goal in reducing the amounts of plastic available for introduction to the environment, available to create hazards to human health, and in the production of CO_2

emissions. The null hypothesis is that there would be no difference. The figures (N=31) used to illustrate the changes that were derived from use of the WaRM model are listed in a table located in Appendix II. Descriptive Statistics of the data are displayed in Table 8.

Table 8: Descriptive Statistics: CO_2 Emissions in Metric Tons (1000kg)

Variable	Sum	Mean	Standard Deviation	Minimum	Maximum
Status Quo	58,600,000	1,900,000	165,000	1,403,000	2,100,000
Source Reduction	-1,706,600,000	-56,800,000	28,800,000	-22,000,000	-119,200,000
35% Recycling	-1,222,600,000	-39,400,000	19,100,000	-16,100,000	-80,500,000

The statistics above demonstrate that the total, average, minimum, and maximum CO_2 emissions related to both source reduction and 35% recycling of polyethylene plastics is much lower than the total production of CO_2 emissions of current waste management of polyethylene plastics. The reductions, however, are 39.6 percent greater with a 25 percent source reduction than a 35 percent recycling rate. In addition, the amount of dispersion attributed to the negative emissions associated with source reduction of plastics is more than 30 times that of emissions attributed to current waste management of plastics, enough to compensate for the emissions associated with waste management of all waste.

The results demonstrate that the United States establishing a 25 percent source reduction and reaching a 35 percent recycling goal both reduce waste bound for disposal by landfill and waste to energy. In regards to landfill capacity and the volume of polyethylene plastics, the difference between source reduction and increasing the recycling rate capacity is extended greater over time with source reduction. The CO_2 emissions attributed to the life-cycle are also reduced much greater with source reduction than with the 35 percent recycling goal. The difference is attributed to the lowered use of LPG and natural gas, as both feedstock and energy for production of polyethylene plastics. We can reject the null hypothesis with confidence.

CHAPTER 7

Conclusion

7.1 Discussion

Waste reduction means to reduce waste bound for disposal and recycling is the traditional method used to achieve it. Legislation has been implemented at the state and local level in the United States as a waste reduction strategy to increase the recovery rate. However, polyethylene plastic materials still remain the lowest recovered recyclable material. The nation achieving a 35 percent recycling goal was compared to a 25 percent source reduction of polyethylene plastic materials and found advantages for both strategies including a reduced demand for raw materials and energy, extended landfill life, and reduced plastics bound for incineration in WTE operations.

There were significant differences to consider in the two strategies including costs in implementation and reduced negative impacts to the environment. Achieving the EPA's 35 percent recycling goal would result substantial costs for municipal entities that don't engage in collection of LDPE for recycling, as it would require significant capital investment to incorporate its collection and recycling. However, little cost would be associated with mandated source reduction because issues from the use of less plastic material in containers and packaging can often be resolved with design rather than replacement materials. In situations where replacement materials are required, materials such as cellulosic plastic or recycled plastic materials would be inexpensive substitutes.

There are also differences in the environmental impacts between a 35 percent recycling goal and a 25 percent source reduction, as well. A mandated 35 percent recovery rate of polyethylene does not prevent the initial production of plastics, so preproduction plastic resin pellets would still be available for introduction to the environment. It also only results in a minimally lowered demand for raw materials and energy as plastics recycling involves only a single reuse. Finally, source reduction results in CO_2 emissions being lowered 39.6 percent more than 35 percent recycling.

7.2 Conclusion

The evidence of detrimental effects created by plastics support that there is a need to address the abundance of polyethylene plastics. Source reduction of their production will reduce the negative impacts identified in this paper more comprehensively than a 35 percent recycling rate. Local implementation at the municipal or state level will not accomplish this task, as the implementation of other policies designed to increase their recovery, polyethylene plastics remain the lowest recovered of any other recyclable material.

Legislation at the federal level of source reduction should be considered. The benefits to United States in the implementation of this type of national legislation covering plastics involved in the production of polyethylene packaging and containers would include: reduction of negative impacts associated with disposable plastic materials, prevention of manufacturers avoiding local legislation by moving production to another jurisdiction, and allowing the United States to be an example to other nations that produce and utilize polyethylene plastics.

APPENDIX I

Projected Polyethylene Plastic Waste by Type in Metric Tons (1000 kg.)

Year	PET	LDPE	HDPE	Total
2010	3,327,676	5,291,309	4,869,771	13,488,756
2011	3,433,892	5,467,841	5,024,203	13,925,936
2012	3,543,497	5,650,262	5,183,533	14,377,293
2013	3,656,601	5,838,770	5,347,916	14,843,287
2014	3,773,315	6,033,566	5,517,512	15,324,394
2015	3,893,755	6,234,862	5,692,486	15,821,103
2016	4,018,039	6,442,873	5,873,010	16,333,921
2017	4,146,290	6,657,824	6,059,257	16,863,371
2018	4,278,634	6,879,946	6,251,412	17,409,992
2019	4,415,203	7,109,479	6,449,660	17,974,342
2020	4,556,131	7,346,670	6,654,195	18,556,996
2021	4,701,557	7,591,774	6,865,216	19,158,547
2022	4,851,625	7,845,055	7,082,929	19,779,610
2023	5,006,483	8,106,786	7,307,547	20,420,817
2024	5,166,284	8,377,250	7,539,288	21,082,822
2025	5,331,186	8,656,737	7,778,377	21,766,300
2026	5,501,350	8,945,548	8,025,049	22,471,948
2027	5,676,947	9,243,995	8,279,544	23,200,486
2028	5,858,148	9,552,398	8,542,109	23,952,656
2029	6,045,133	9,871,091	8,813,001	24,729,225
2030	6,238,086	10,200,417	9,092,483	25,530,986
2031	6,437,198	10,540,729	9,380,829	26,358,756
2032	6,642,666	10,892,395	9,678,319	27,213,380
2033	6,854,692	11,255,794	9,985,243	28,095,728
2034	7,073,485	11,631,316	10,301,900	29,006,701
2035	7,299,262	12,019,367	10,628,599	29,947,228
2036	7,532,246	12,420,365	10,965,659	30,918,269
2037	7,772,666	12,834,740	11,313,407	31,920,813
2038	8,020,760	13,262,940	11,672,184	32,955,884
2039	8,276,773	13,705,427	12,042,338	34,024,538
2040	8,540,957	14,162,675	12,424,231	35,127,864

APPENDIX II

Projected Carbon Dioxide Emissions and Savings

Year	Status Quo	35% Recycling	Overall Savings	Source Reduction	Overall Savings
2010	582,274	-5,286,459	**4,704,185**	-7,200,359	**6,618,085**
2011	601,735	-5,458,264	**4,856,529**	-7,433,613	**6.831,878**
2012	621,848	-5,635,666	**5,013,818**	-7,674,427	**7,052,579**
2013	642,635	-5,818,828	**5,176,193**	-7,923,043	**7,280,408**
2014	664,113	-6,007,948	**5,343,835**	-8,179,727	**7,515,614**
2015	686,313	-5,839,821	**5,153,508**	-8,444,720	**7,758,407**
2016	709,235	-6,404,845	**5,695,610**	-8,718,308	**8,009,073**
2017	732,959	-6,624,940	**6,613,023**	-9,000,762	**8,267,803**
2018	757,459	-6,827,979	**6,070,520**	-9,292,379	**8,534,920**
2019	782,777	-7,049,919	**6,267,142**	-10,376,220	**9,593,443**
2020	808,942	-7,292,224	**7,279,076**	-9,904,265	**9,095,323**
2021	835,983	-7,515,693	**6,679,710**	-10,225,160	**9,389,177**
2022	863,926	-7,760,000	**6,896,074**	-10,556,463	**9,692,537**
2023	892,803	-8,012,252	**7,119,449**	-10,898,511	**10,005,708**
2024	922,645	-8,272,714	**7,350,069**	-11,251,638	**10,328,993**
2025	953,488	-8,541,647	**7,588,159**	-11,616,214	**10,662,726**
2026	985,357	-8,819,327	**7,833,970**	-11,992,618	**11,007,261**
2027	1,018,293	-9,106,034	**8,087,741**	-12,381,224	**11,362,931**
2028	1,052,331	-9,402,073	**8,349,742**	-12,782,422	**11,730,091**
2029	1,087,508	-9,707,741	**8,620,233**	-13,196,627	**12,109,119**
2030	1,123,857	-10,023,352	**8,899,495**	-13,624,271	**12,500,414**
2031	1,161,423	-10,349,227	**9,187,804**	-14,065,773	**12,904,350**
2032	1,200,246	-10,685,707	**9,485,461**	-14,521,592	**13,321,346**
2033	1,240,368	-11,033,131	**9,792,763**	-14,992,187	**13,751,819**
2034	1,281,826	-11,391,860	**10,110,034**	-15,501,709	**14,219,883**
2035	1,324,675	-11,762,256	**10,437,581**	-15,979,659	**14,654,984**
2036	1,368,955	-12,144,704	**10,775,749**	-16,497,528	**15,128,573**
2037	1,414,713	-12,539,590	**11,124,877**	-17,032,198	**15,617,485**
2038	1,462,002	-12,947,324	**11,485,322**	-17,584,204	**16,122,202**
2039	1,510,873	-13,368,324	**11,857,451**	-18,154,111	**16,643,238**
2040	1,561,376	-13,803,025	**12,241,649**	-18,742,497	**17,181,121**

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CURRICULUM VITAE

Dana M. Griffith graduated from Chantilly High School, Chantilly Virginia, in 1982. She received her Associate of Applied Science in Computer Information Systems from Northern Virginia Community College in 1986. After 20 years as an international travel specialist and industry instructor decided to explore more meaningful work. In 2005 she received her Associate of Science in Business Administration from Northern Virginia Community College and then transferred to George Mason University. She received her Bachelor of Science in Management with a minor in Biology from George Mason University in 2008. The same year, wanting to contribute to innovative solutions for environmental issues, she began graduate work in George Mason University's Environmental Science and Policy department and will graduate in May 2010.