Plastics: Establishing The Path To Zero Waste

A pragmatic approach to sustainable management of plastic materials

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Abstract:

Plastic items are a critical part of modern society and they are used in almost every aspect of our lives. One of the values of plastics for packaging and manufacturing articles is the strength and durability of the material, however, after use this durability means that the plastics remain after use and continue to accumulate in the environment indefinitely. This means that as we use more and more plastic, we will also discard an ever growing amount of plastic that will last for centuries.

Today, plastics are disposed of in several ways including recycling, landfilling, incineration, composting and littering. In the US, recycling captures approximately 9% of plastics, we incinerate (burn) nearly 1% and we litter or compost less than a fraction of a percent. This leaves nearly 90% of plastic being discarded into landfills. Sustainability managers must be able to identify the most sustainable method for handling plastics after use.

To be truly sustainable, we must understand what is the most environmentally and economically beneficial thing to do with plastic and embrace methods that will address the 90+ percent of plastic discarded in the landfill each year. Only by addressing these issues can we maximize our success in reducing plastic waste by creating value in the process; a system known as “Zero Waste”.

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Introduction

Plastic is a versatile, inexpensive, durable and easily processed organic material that is used in an enormous range of products. While plastic has in one form or another been used since the early 1900's, the use of and different types of plastics in the past 30 years has skyrocketed. Today, plastics have replaced many traditional materials such as glass, metals, stone, ceramic, bone, wood and leather. This transition to plastic has provided the means to preserve and protect food from spoilage, manufacture items that are affordable to the majority, reduce product breakage, improve medical care and innumerous other benefits. While the use and production of plastic articles continues to increase, the disposal of plastic is becoming a critical issue.

Modern societies utilize several methods for managing the huge quantities of used plastic, including landfilling, recycling, composting and incineration. While each of these options is used in varying degrees, it is seldom that each of these methods is evaluated strategically from an economic and environmental approach. Current infrastructure, social behavior and statistics of waste disposal should also be a consideration when determining optimal ways to deal with waste. Understanding the whole picture and taking each impact into consideration will provide a clear path to sustainable plastics management.

The information contained in this paper will provide a clear picture of plastic disposal today and the environmental, economic and social impact of landfilling, recycling, composting and incineration. The information covered is beyond what one will find in most media reports and may at times seem negative. This is not because there are not positive aspects to each subject; the information provided is to be used in conjunction with the information provided regularly in media to create a balanced perspective. It is expected that this common information will already be understood by the reader.

This paper then expands beyond the current methods of managing our waste and explores how waste is processed within nature. Nature has been managing waste for millions of years in a very effective and sustainable way. The closer we can replicate and integrate into the processes of nature, the more we can truly become sustainable. Sustainability managers who incorporate the concepts presented in this paper have the tools to implement solutions for their products and packaging that integrate effectively and sustainably in the environment where their product is disposed.

Important note: This document is written in sections and it is not necessary to read each section in order. If the reader has limited time and simply is looking for direction on how to design products for sustainability, they may choose to simply read Part 7 which summarizes all the preceding information and provides instructions for sustainable plastic management.

Part 1: The Current State of Plastics

We are a society that requires plastic to maintain our standard of living; we use plastic in almost every aspect of our lives. With 7.2 billion people on this planet, we use a LOT of plastic. World-wide the annual production of plastic in 2012 was in excess of 600 billion lbs., or to put into perspective; enough plastic to circle the earth one foot wide and one foot deep over 450 times![1] And the use of plastics is continuing to increase, with consumption estimated to reach over 650 billion lbs. by the end of 2015. (PRWEB, 2015).

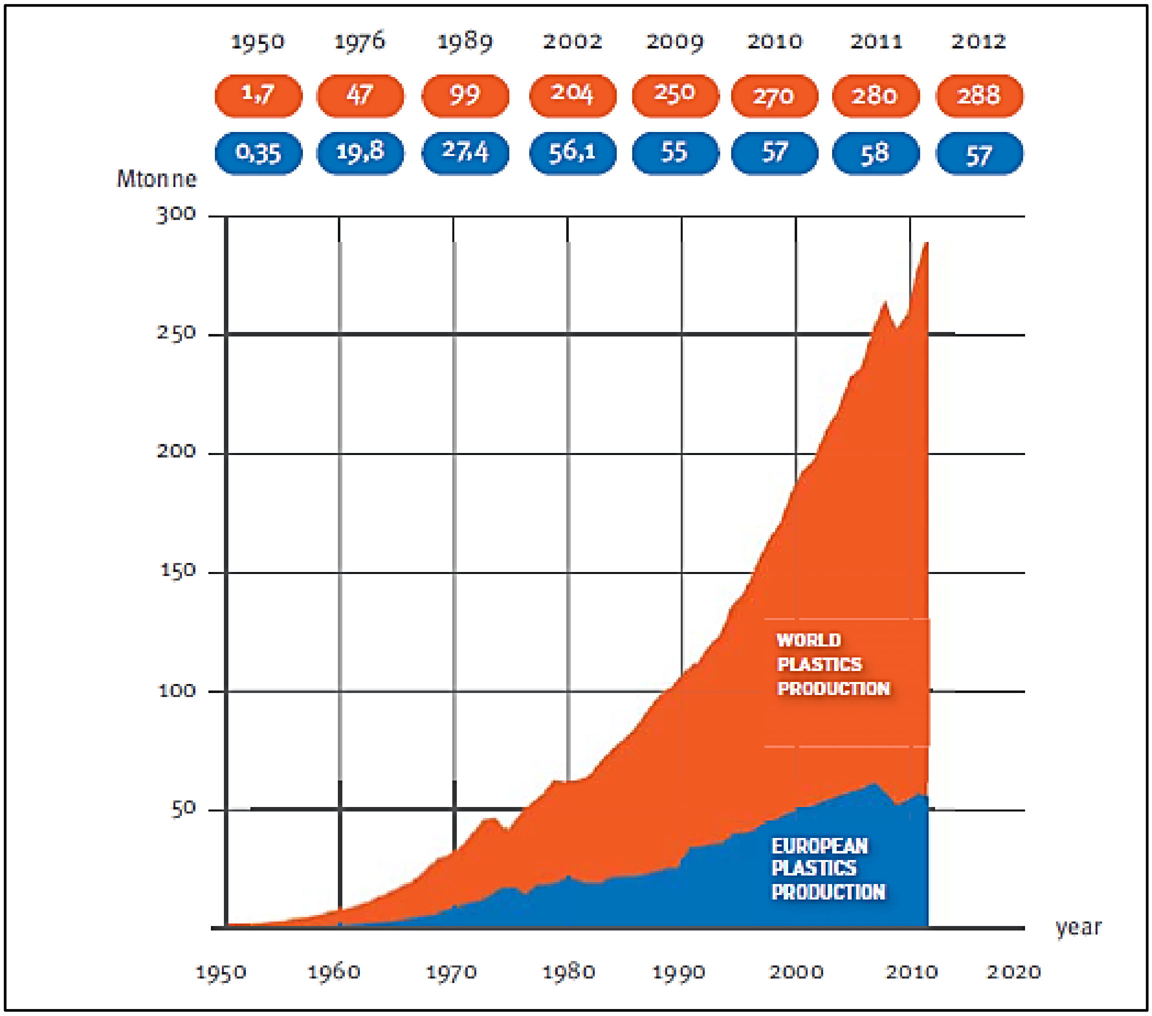

Figure 1: Worldwide plastic production 1950-2012. Includes thermoplastics, polyurethanes, thermosets, adhesives, coatings, sealants and PP-fibers. Not included PTE-, PA-, and polyacryl-fibers. Source PlasticsEurope (PEMRG) / Consultic

[1] The average weight for unbaled scrap plastic is 10lbs per cubic foot. 600 billion lbs would equal 60 billion cubic feet. The circumference of the earth is 133 million ft. circling the earth with plastic one foot wide and one foot deep would take 133 million cubic feet, we could circle the earth over 451 times with the production of plastic in 2012 alone.

It is clear that the use of plastic is not going to decline anytime in the foreseeable future, and we will continue to dispose of this plastic after use. As the production of plastic increases, so does the disposal. We are producing plastics that will last nearly forever. Forty percent of the overall plastic made, although extremely durable, is used for packaging, meaning it will most likely only be used for a few months before it is disposed of. So, while some plastics may only be used for a few days or months and others will be used for several years, there is no disputing that every ounce of plastic produced will at some point become plastic waste that may last for centuries.

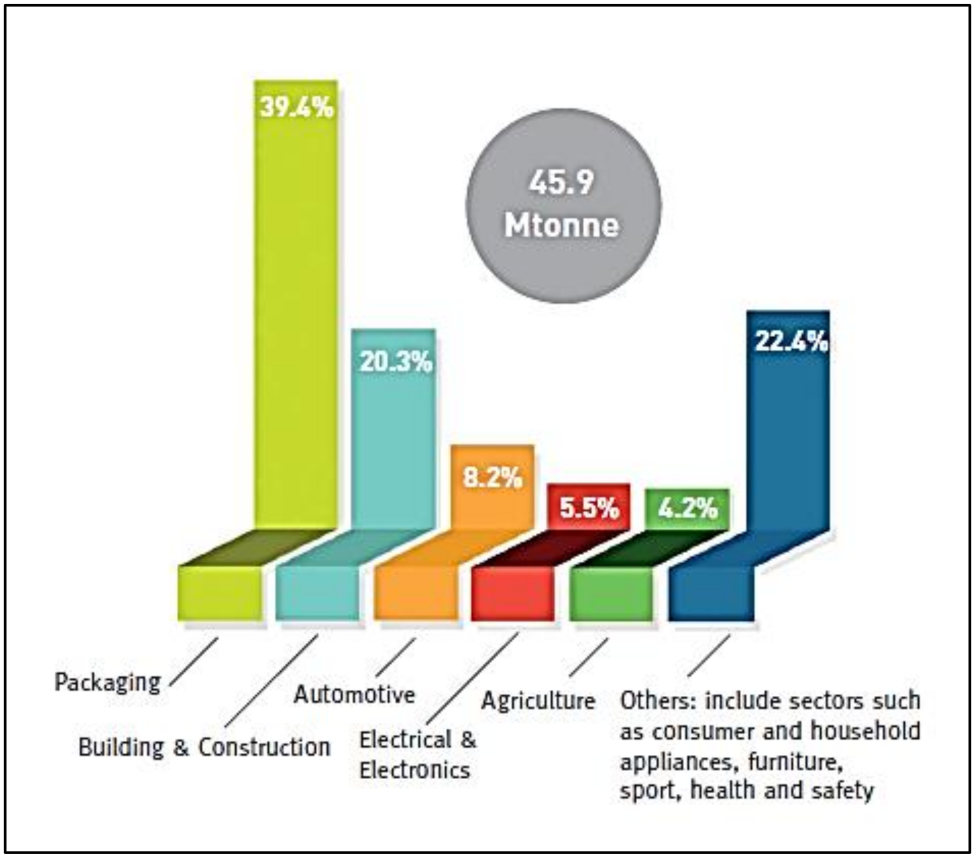

Figure 2: European plastics demand by segment 2012. Source: PlasticsEurope (PEMRG)/ Consultic/ ECEBD

With this immense amount of plastic becoming waste, how can sustainability managers ensure it is disposed of in the most sustainable way? The first step in addressing the issue of plastic waste is to understand where plastic is currently being disposed of after use.

When plastics first commercialized the only disposal of plastics was landfilling. The now infamous "Garbage Barge" fiasco of 1987 in which a garbage barge left Long Island, NY carrying nearly thirty-two hundred tons of garbage and was turned away at every port, created a panic. People began to believe that landfills were running out of space and that we soon would have nowhere to dispose of our trash. Fear of garbage piling up in streets and cities because there was nowhere else to put trash resulted in a new focus – diversion of waste from landfills.

Recycling was one of the initial methods utilized to divert valuable materials from landfills. As the concept of recycling gained popularity, media and industry organizations began to demonize landfills. Landfills were presented as wasteful, polluting and unsanitary – and this perception was justified because the landfills at that time had significant environmental issues.

As the perception of landfills continued to decline, more methods were introduced to divert waste; we began to burn our waste (incineration) and the idea of commercially composting plastics and organics was born. The primary focus became finding every way possible of preventing any materials from entering the landfill.

The idea of diverting from landfills has continued, and today we have become a society that loves to hate landfills while adoring any method of diverting materials from a landfill. This approach would lead one to assume that recycling, incineration and composting should by now be the primary disposal methods for plastic. As is seen in Figure 3 below, after nearly 40 years of spending billions of dollars to increase recycling, incineration and composting, we continue to landfill almost every pound of plastic produced.

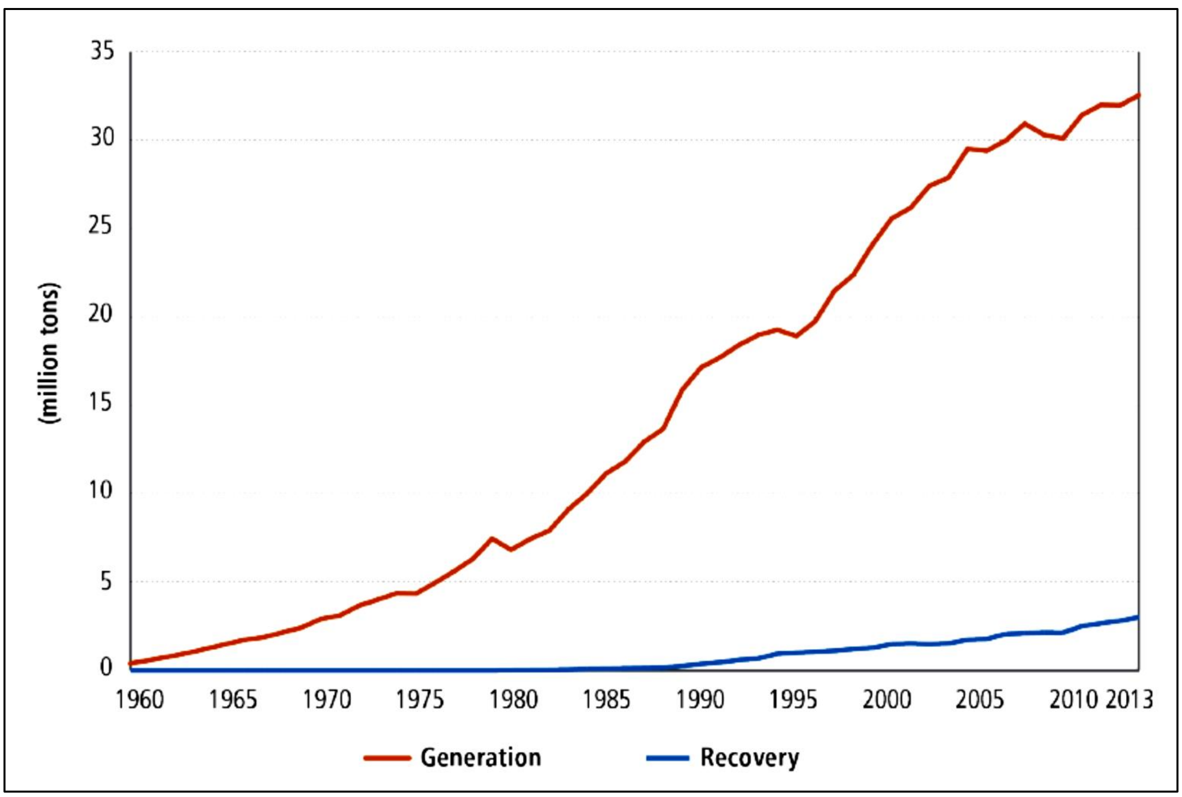

Figure 3: Plastics Generation & Recovery - US EPA

As sustainability managers look for new strategies to decrease their organizations environmental footprint, it is imperative to understand that while recycling, incineration and composting are an important part of an overall sustainability strategy, our society still landfills over 90% of all plastics. Most companies' products and packaging will have nearly 100% disposal into landfills. This means that to address a company's products and packaging that will leave their facility, landfilling must be a focus or the majority of waste will be overlooked. What this means is that a company must understand where their products and packaging will be disposed of after use and build strategies around that environment. Ultimately, multiple methods of disposal will be necessary to provide the most environmentally sustainable and economically viable options for different types and forms of plastic. (Caraban, 2008)

Rather than attempting to create a 'one size fits all' program, which does not work, each material and product must be evaluated separately; regional variations will come into play as well as social behavior. Ultimately, an effective sustainability strategy will have to embrace solutions that include landfilling, recycling, incineration, and composting in varying degrees. While this may sound daunting or complex, it is fairly simple in practice once the details are understood.

Determining the optimal disposal method for a specific product, will include understanding the regional waste management infrastructure and common method of plastic disposal. In the US, the primary method of disposal is landfilling, with the remaining portions sent for recycling, incineration and composting. The infrastructure is already in place to support landfilling as the largest repository for waste; this is reflected not only by the number of facilities in the US, but also the total volume being deposited in landfills each year.

Note: Litter is an aspect of overall waste, as plastics do end up littered in the environment through both deliberate and unintentional littering. However, as visible as litter is, litter equates to less than 1% of all plastics. Therefore, littering is not included in this assessment. If a specific product has a high chance of being littered (i.e. shot gun wads, cigarette butt, single use plastic bags, etc.) companies taking responsibility for those products should develop product solutions that address littering which would include biodegradability of the littered product in the open environment.

In the US there are approximately 1908 operating landfills, 633 material reclamation facilities (recycling) and 86 incineration sites. (EPA, Municipal Solid Waste Generation, Recycling, and Disposal in the United States, Tables and Figures for 2012) We have three times more landfills than we do facilities to accept materials for recycling and 22 times more landfills than incineration sites. Sustainable strategies for plastic must include landfill disposal.

In countries outside of the US, the number of landfills, recycling facilities and incineration sites will vary. In Europe there are more incineration sites and recycling facilities, yet landfills are still the primary location for disposal of waste. Recycling in Europe is typically limited to select plastics, metals, organics and paper and does not significantly impact the landfilling of the non-bottle plastics, resulting in the disposal of most plastic waste in landfills. There are a few countries within Europe that incinerate nearly

50% of their waste, in these countries landfills are still used but to a lesser degree. Less developed countries typically utilize landfills as the primary method of disposal for all wastes including plastics, at a rate higher than the US.

The reality of where we dispose of our waste is often overlooked when sustainability initiatives focus on reducing waste. The focus is most often on trendy subjects such as “zero waste”, “zero landfill”, “compostable” or “recyclable”, which leaves sustainability managers misunderstanding the true picture and how to create actual solutions. We will have little to no impact on overall waste unless we come to terms with the fact that globally most all trash is put into landfills and we incorporate solutions that involve landfilling.

To achieve the maximum value, both economically and environmentally, we must take a scientific approach as opposed to an emotional response to our methods of waste management. This can mean stepping back from what “feels good” to determine what is actually more environmentally beneficial. Often our feelings about specific methods of disposal are influenced by the media, industry organizations and regulators that may have specific agendas, don’t understand the full spectrum of our waste systems or have commercial interests. The only way organizations will reach sustainability with plastics is to step back look at the entire picture and evaluate the facts.

So let’s start with taking a look at how plastics are disposed of and what we can do to increase the sustainability of these disposal methods.

Part 2: Disposal Environments and Management of Plastic Waste

When our global approach to trash is to avoid discussing the truth of where our waste is going or developing solutions based on those disposal environments, our global method of waste management is at best ineffective. To achieve a sustainable mindset, we must accept the facts regarding our waste and identify where plastic is currently being disposed and the impact of plastic in that disposal method. This includes evaluating the resources required to transport, separate and process waste as well as the efficiencies of these processes from an economic, environmental and social perspective.

Only once we understand and accept the facts of where and how our waste is disposed can we develop solutions that are effective and impactful.

This part of the document will review in detail the methods society currently uses to discard plastics; landfilling, recycling, incineration and composting. The part is organized into chapters that each focus on a specific disposal environment. The chapters are ordered by the prevalence of the method; the majority of plastics are disposed of in landfills so it is addressed first and very few plastics are composted so this is covered last.

Each chapter is further divided into sections to focus on areas of concern such as how to correctly interpret publicly reported rates of material, economic concerns, negative environmental impacts and challenges specific to the disposal environment. Concluding each chapter is a section on sustainability with information on how sustainability managers can design products to integrate most effectively in the disposal environment being discussed.

Chapter 1: Landfilling of Plastic

Landfilling is the oldest form of waste management; it involves the disposal of waste products by burial. Worldwide, landfills continue to be the primary method to dispose of human waste. In regards to plastics, landfills remain the most common method of disposal worldwide. In developing sustainable strategies for plastics, we must include landfilling because most plastic is disposed of in the landfill. As with recycling, incineration and composting, determining the sustainability options of landfilling requires understanding the details of landfills and landfill operations.

Typically, landfills are controlled to avoid toxic waste, confined to as small an area as possible, compacted to reduce their volume and covered (usually daily) with layers of soil. To accomplish this, waste collection vehicles are inspected for any toxic waste upon arrival to the landfill. Once they are cleared, they proceed to deposit the waste and compactors and bulldozers are used to spread and compact the waste. There are many loads delivered each day to a landfill. At the end of each day, the compacted waste is covered with soil or another alternative material such as crushed glass, compost, or plastic film. This continues until the space is full.

This is a very simplistic overview of landfills and there are many details about landfills that are important to sustainability and how we dispose of our waste. The economic and environmental sustainability of putting plastic in landfills is affected by how the plastic is collected, what plastics are put into landfills and the design and management of the landfills themselves.

This section is to provide a basic understanding of landfill design and management. It also covers landfill gas, an energy rich gas that is produced as materials biodegrade in the landfill. Finally, we will see how landfills fit within an overall sustainability profile and how to design products that will provide an environmental and economic benefit in the landfill.

Section 1: Understanding Landfilling Rates

Most would expect that the reporting of how much waste we send to the landfill would be pretty straightforward, that it would mean how much material total is going into the landfill. Landfill statistics are typically based on municipal solid waste only. Municipal solid waste is the trash that comes from residential homes, apartment homes and some office buildings. What is not reported is industrial waste; this is the waste from manufacturing, construction waste, demolition debris, and other industrial processes.

Surprisingly, also not included in solid waste statistics is waste from recycling processes and the waste/ash from incineration facilities. The process of recycling can produce a large amount of waste both from materials that are baled but not wanted as well as from the recycling process itself, this waste is sent to landfills but not reported as municipal waste. Similarly, after incineration the remaining ash is nearly 25% of the original material weight and this ash is sent to landfills but not reported as municipal waste.

The actual amount of material disposed of in a landfill is much higher than reported in statistics. This means that more of our discarded material goes into landfills than is ever shown or reported.

Section 2: Economics of Landfilling

Not only does most all waste worldwide go into landfills, they are also the most cost-efficient way to dispose of waste. Recycling, incineration and composting all cost significantly more than landfilling. This is because they require extensive investments in infrastructure, additional transportation vehicles, and recycling also requires extensive manpower to maintain, whereas landfills have fewer fixed—or ongoing—costs. In addition, landfill gas is a revenue stream opportunity for landfills that can offset or even cover the costs of landfilling.

To compare the costs of landfilling to other methods of plastics disposal consider the following: A sanitary landfill, which is one that is managed to avoid groundwater air pollution, is the most common type of landfill in developed nations and it costs municipalities/waste management organizations on average $62.50/ton of waste material deposited. Recycling costs an average of $108.50/ton, composting costs an average of $115.00/ton and incineration is the most expensive at $175/ton. (Cointreau, 2008)

Disposal Method	Average Cost Per Ton
Landfilling	$ 62.50
Recycling	$ 108.50
Composting	$ 115.00
Incineration	$ 175.00

Figure 4: Average cost of landfilling is a fraction of the cost to recycle, compost or incinerate (Cointreau, 2008)

The above landfill costs reflect the expense to collect waste and deposit it in the landfill, manage the landfill and control the environmental impact of the landfill such as leachate, and air emissions. What is not considered is the revenue that is generated when the landfill gas is collected and used as a fuel or energy source. The revenue from landfill gas utilization can cover the entire costs of the landfill. Ideally, this will provide a way to manage waste and generate clean energy in an economically sustainable way. (Cointreau, 2008) Landfill gas is considered the most economical form of green energy available today, even when considering the costs of hydro, solar and wind energy.

Section 3: Environmental Impact of Landfills

More than 1.8 billion tons of waste is landfilled across the globe each year with most of this waste being deposited in municipal solid waste landfills. (EPA, A Landfill Gas To Energy Project Development Handbook). While landfills are the most inexpensive way to manage our waste, we must also consider the environmental impacts. The common opinion is that landfills are wasteful and damaging to the environment, however to make an accurate determination we must look at the facts and understand the true impacts.

The negative image of landfills came from the way we designed and operated landfills decades ago. These older landfills were often poorly managed which resulted in many environmental problems such as;

1. Emissions to atmosphere such as noise, dust, odor, and bio-aerosols and landfill gas
2. Emissions to water which could include contaminated surface water run-off to local streams and rivers as well as leachate seeping into groundwater below the landfill
3. Litter from wind blowing waste from uncovered landfills and animals getting into uncovered landfills.
4. Fires that would erupt within the landfill, causing safety hazards and air pollution.

These issues were very problematic and lead to the development of modern landfills that control these environmental impacts as well as develop ways to extract valuable resources from the landfill. These landfills are called “modern landfills” and the management, design and environmental footprint is completely different than the landfills of the 70’s and 80’s.

Today, U.S. landfills are regulated by each state's environmental agency, which establishes minimum guidelines; however, none of these standards may fall below those set by the United States Environmental Protection Agency (EPA). Understanding the design and operation of modern landfill can overcome the misconceptions about landfills and provide a way to evaluate the value of modern landfills.

We will focus only on modern landfills as they are the type of landfills where waste will be disposed of today and in the future. Understanding the design and processes in modern landfills will provide a guide to determining the impact and performance of discarded products in these environments. It will also help in understanding what types of materials provide maximum value in the unique environment of a modern landfill.

Section 3.1: Modern Landfill Design

For most, the term “landfill” conjures images of garbage, pollution and excessive waste. We imagine landfills filling at an enormous rate and the eventuality of the world becoming one large garbage dump. Remember Disney's 2008 movie "Wall-E" where the robot was tasked with cleaning up the abandoned, waste-covered Earth? When we think of landfills, we envision billions of tons of trash mummified in tombs that will never go away. What we don't envision, however, is that through proper management of these sites and management of our waste, landfills can be a source for clean inexpensive energy, a process for detoxifying materials and a resource recovery facility.

It used to be that landfills were simply a location to store trash, but with increasing amounts of waste generation and greater awareness of environmental issues, there has been a change in how we design and manage landfills. This new approach includes landfills that are designed from the start to reduce the environmental impacts seen in older landfills; they are lined to prevent groundwater contamination, piping is installed to remove leachate and collect landfill gas, the landfill is covered daily to prevent animals and wind from creating litter and the disposal of toxic waste is prohibited.

Modern landfills accelerate biodegradation to enhance gas generation, improve leachate quality, and reduce leachate treatment costs. The enhanced gas generation refers to landfill gas or methane which is generated during the biodegradation of materials within the landfill. This landfill gas is captured to prevent atmospheric pollution, and is used as a valuable source of clean-burning alternative energy (Wisconsin-Madison, 2011). Ultimately, the use of biodegradation within landfills has proven an effective method to detoxify waste and create value. So how are landfills encouraging biodegradation?

Conventional sanitary landfills as practiced in North America in the 1970s and 1980s are generally referred to as "dry tombs" because the approach taken in designing them was to minimize water contacting the waste, primarily to try and reduce biodegradation and leachate formation. (Associates) Modern research and technology has created a transition in the landfill industry from dry tomb landfills to the bioreactor landfill and hybrid landfill energy site, where biodegradation is a primary objective.

The most widely used approach to increase the biodegradation within modern landfills is to increase the moisture content through recirculation of leachate or addition of supplemental liquids (e.g., sewage or industrial wastewater). (Wisconsin-Madison, 2011) The aim of operating landfills in this way provides several benefits; the accelerated biodegradation of waste increases the methane production so landfill energy projects can effectively capture the methane and convert it to a valuable resource – energy, fuel and heat.

The modern process of capturing and utilizing landfill gas reduces the total methane released into the atmosphere in comparison to the gas released into the atmosphere with older landfill designs. The increased moisture/temperature conditions also induce the waste to settle creating more space in the landfill and the ability to put more materials in the same space. Finally, the leachate is naturally detoxified through biodegradation each time it is recirculated so groundwater and soil will not be contaminated.

Designing landfills for biodegradation is an economic benefit to landfill operators. By producing more methane in a shorter period of time, say less than 50 years, landfill energy projects can become profitable and often cover the costs of landfill operations. If the methane is produced more slowly over longer periods of time, there is not enough methane produced on a regular basis to support the expense or operation of energy conversion. Older landfills can take hundreds of years before they stop producing methane, whereas modern landfills produce the majority of their methane within 50 years. (Associates)

The designs of modern landfills utilize the understanding of the biological processes occurring within the landfill. These modern landfills focus on biodegradation for the purpose of generating methane, the primary component in landfill gas, and the value of converting the resulting methane to energy. While some of these landfills are built more recently and designed from inception for maximum capture of landfill gas, increasing biodegradation and converting the methane to energy is so effective that conventional landfills are also being retrofitted in a similar manner.

Landfills that are capturing the methane production and converting it to energy/fuel are called landfill gas energy projects (LFG energy projects). Many landfills across the globe are currently using their methane as a resource. Some of these LFG energy projects are part of the Global Methane Initiative program. A program designed to promote the beneficial use of methane.

While many LFG energy projects are not registered with the Global Methane Initiative, we can look at the number of ones that are registered to see the worldwide presence of these projects. Internationally there are 1937 LFG energy projects registered with the Global Methane Initiative program. In the US there are 967 projects producing 1044 million cubic feet per day of LFG that is actively converted to energy (Initiative, 2015).

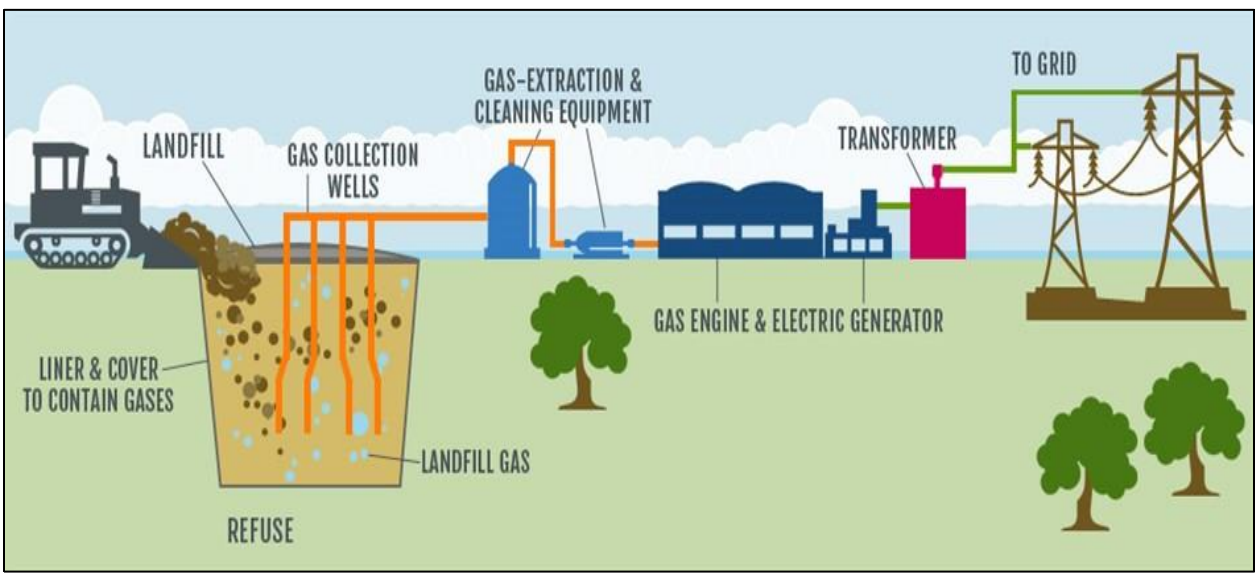

Figure 5: Modern landfill design integrates gas collection to create value from biodegrading landfilled waste

The U.S. Environmental Protection Agency (EPA) estimates that more waste is placed in landfills that capture methane to energy than landfills that allow the methane to escape into the atmosphere. In 2011, 35 percent of municipal solid waste went into landfills that capture methane for energy use, since that time an additional 133 landfills are now converting methane to energy, over 80% of all municipal solid waste goes into landfills that manage their methane. (Shipman, 2011)

Landfill design and operation have definitely evolved over the past few decades, providing a new perception of landfills and changing the environmental impacts of those landfills. We no longer simply bury the trash; today, landfills are highly managed resource centers where discarded material is converted into energy through the natural process of biodegradation. While outside of the waste management industry we don't hear much about it, there are still advancements taking place that will change the face of landfills completely.

Section 3.2: Biodegradation Process in Modern Landfills

There are different designs of landfills, conventional, modern and bioreactor, and while the design and operation of these landfills differ; the biodegradation process remains the same. The primary change is in the rate of biodegradation – does it take years, decades or centuries. Biodegradation in landfills takes a different path than biodegradation in soil and compost. Primarily this is due to the lack of oxygen (called anaerobic) in the landfill.

So, let's talk biodegradation.

Biodegradation is the process by which organic substances (meaning carbon based) are broken down into smaller compounds using the enzymes produced by living microbial organisms. The microbial organism transforms the substance through metabolic or enzymatic processes. Although biodegradation processes vary greatly, the final product is most often carbon dioxide and/or methane, soil, and water.

Biodegradable matter is generally organic material such as plant and animal matter and other substances originating from living organisms, or man-made materials that are similar enough to plant and animal matter to be put to use by microbes. Microorganisms have the astonishing ability to biodegrade many different types of organic materials, including most all natural and many man-made organic materials.

Organic material can be biodegraded aerobically (with oxygen) or anaerobically (without oxygen). Biodegradable waste in landfill degrades in the absence of oxygen through the process of anaerobic digestion. Anaerobic digestion is a series of processes in which microbes break down biodegradable material in the absence of oxygen. It is widely used to treat wastewater sludge and biodegradable waste because it provides volume and mass reduction of the input material. Anaerobic digestion also produces biogas, an energy rich blend of methane and carbon dioxide.

There are a number of bacteria that are involved in the process of anaerobic digestion including acetic acid-forming bacteria and methane-forming bacteria. These bacteria feed upon the initial feedstock, which undergoes a number of different processes converting it to intermediate molecules including sugars, hydrogen & acetic acid before finally being converted to biogas.

The process begins when microorganisms break down insoluble organic polymers such as carbohydrates into sugars and amino acids. Acidogenic bacteria then convert the sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acid. Acetogenic bacteria then convert these resulting organic acids into acetic acid, along with additional ammonia, hydrogen, and carbon dioxide. Methanogenic bacteria finally are able to convert these products into methane and carbon dioxide.

To put the above in more simplistic terms; biodegradation is the breakdown of a material from a complex form to a much simpler and natural form. This breakdown is done by microscopic organisms that produce extra-cellular enzymes that break apart the complex material and move around the atoms to create simpler materials such as carbon dioxide, methane, water and soil.

Biodegradation can be a complex process that requires many different types of microorganisms and different enzymes, but the final result is the same, complex materials are converted into the basic building blocks of life, air, soil and water.

Landfill Decomposition Cycle

When the biodegradation process that occurs within landfills is looked at from a general standpoint, it is clear that there are four primary stages. As a landfill ages, the conditions change and this requires a change in the way material is biodegraded. At first there is some oxygen available and biodegradation is aerobic, as the oxygen depletes the process transitions from aerobic to anaerobic. Here is a brief description of the four primary stages:

> Aerobic Phase – A very short period, often limited to just a few days, when aerobic microbes are becoming established and moisture is building up in the refuse. Aerobic decomposition is at its maximum and the oxygen is replaced with carbon dioxide (CO_2) as the waste biodegrades. During the final stages of this phase the anaerobic microbial populations increase by a factor of 100. (Barlaz, Microbiology of Solid Waste, 1996)
>
> Anaerobic Acid Phase - After oxygen concentrations have declined sufficiently, the anaerobic processes begin. During the initial stage (hydrolysis), the microbe colonies consume the particulates, and through an enzymatic process, solubilize large polymers down into simpler monomers. A rapid accumulation of carboxylic acids and organic intermediaries as well as a decrease in pH occurs during this stage. CO_2 production occurs rapidly at this stage and then progresses to methane (CH_4) toward the final stages. (Barlaz, Microbiology of Solid Waste, 1996)

Accelerated Methane Production Phase – During this phase there is a rapid increase in methane production to maximum concentrations of 70% CH_4. During this phase, carboxylic acids and organic intermediaries are consumed faster than they are produced. This results in an increase in the pH and decrease in the carboxylic acid content. Microbial populations remain steady during this phase. (Barlaz, Microbiology of Solid Waste, 1996)

Decelerated Methane Production Phase - The final stage of decomposition involves a decrease in the CH_4 production, although the CH_4 and CO_2 ratios remain steady at 60/40 relative. This decrease results from a decrease in carboxylic acids. Polymer hydrolysis is maximized during this phase; however the resulting carboxylic acids are decomposed at a similar rate to their production due to a balance of microbial population. Humic material (soil) is produced during this stage, similar to the humic matter produced during composting. (Barlaz, Microbiology of Solid Waste, 1996)

In summary, the conditions in a landfill change over time, partially due to the reduction of oxygen and partially due to the by-products of biodegradation. The decomposition process in landfills demonstrated above is a process that requires a coordinated effort between several groups of micro-organisms. The decomposition products from one group of bacteria become the food source for another group of bacteria until the complete decomposition is finalized. While the process may change during the four stages of the landfill, biodegradation continues until all the organic material is decomposed completely.

Microbial Biodegradation of Materials in Landfills

When a material biodegrades it does not typically convert directly from a complex material into air, soil and water. Biodegradation is a process where one type of microorganism will take the complex material and break it down into a simpler material. That simpler material is then used by a different type of microorganism that breaks it down even further. This process continues until the material is completely biodegraded. This is what is meant by the "phases of biodegradation".

In a landfill, the primary method of biodegradation is anaerobic. There is some oxygen in the initial days of a landfill but this oxygen is quickly used up and the environment becomes anaerobic. Anaerobic biodegradation occurs when the anaerobic microbes are dominant over the aerobic microbes (because there is not much oxygen for the microbes to use).

The anaerobic biodegradation process begins with bacterial hydrolysis and fermentation of complex organic structures to smaller low-molecular-weight insoluble organic acids, such as carbohydrates (e.g. acetate). These smaller compounds can be used by some bacteria to be directly mineralized to CO_2. Acetogenic bacteria then convert the low-molecular-weight organic acids (sugars and amino acids) into carbon dioxide, hydrogen, ammonia, and acetic acids. Methanogenic bacteria finally are able to convert these products to methane and utilize hydrogen as an energy source.

There are four key biological and chemical stages of anaerobic digestion; hydrolysis, acidogenesis, acetogenesis and methanogenesis. In most cases waste in the landfill is made up of large organic polymers, both natural and synthetic. In order for the bacteria to access the energy potential of the material, these chains must first be broken down into their smaller constituent parts. These constituent parts or monomers such as sugars are readily available by other bacteria.

The process of breaking down these complex chains and dissolving into smaller molecules is called hydrolysis. Therefore hydrolysis of these complex materials is the necessary first step in anaerobic digestion. Through hydrolysis the complex organic molecules are broken down into monomers; simple sugars, amino acids, and fatty acids.

The biological process of acidogenesis is where there is further breakdown of the remaining components by acidogenic fermentative bacteria. Here VFAs are created along with ammonia, carbon dioxide and hydrogen sulfide as well as other by-products. The process of acidogenesis is similar to the way that milk sours.

The third stage anaerobic digestion is acetogenesis. Here simple molecules created through the acidogenesis phase are further digested by acetogens to produce largely acetic acid as well as carbon dioxide and hydrogen.

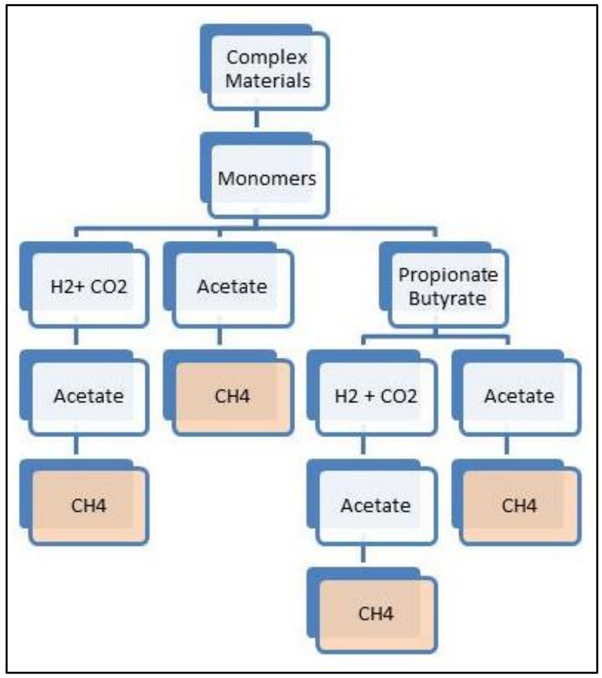

Figure 6: Conversion of complex materials to methane by microbial enzymes in municipal landfills

Acetate and hydrogen produced in the first stages can be used directly by methanogens (a type of microorganism). Other molecules such as volatile fatty acids (VFA's) with a chain length greater than acetate must first be catabolized into compounds that can be directly utilized by methanogens.

The terminal stage of anaerobic digestion is the biological process of methanogenesis. Here methanogens utilize the intermediate products of the preceding stages and convert them into methane, carbon dioxide and water. The majority of the biogas emitted from landfills is methane and carbon dioxide; there may also be other trace gases depending on the material being biodegraded.

Anaerobic biodegradation ultimately produces methane as the final biogas.

Biodegradation in landfills is a complex process that involves hydrolysis, fermentation, acetogenesis and methanogenesis. It requires the concentric effort of various methanogenic bacteria, acetogens, protozoa and flagellate. The complexity of the process does not mean that it is not effective or efficient. Landfills are a thriving ecosystem of biological diversity and modern landfills optimize this process for biodegradation.

Section 3.3: Landfill gas

Landfill gas (LFG) is created as organic waste in a landfill biodegrades anaerobically, as demonstrated in the previous sections. This is a similar process as is seen in other anaerobic environments that produce methane, such as swamps, animal intestines and anaerobic digesters. All of these are natural processes that produce methane as microorganisms reorganize the hydrogen and carbon from complex materials into simpler structures such as methane –CH_4 (one carbon atom and four hydrogen atoms) and carbon dioxide – CO_2 (one carbon atom and two oxygen atoms). This gas consists of about 50-70 percent methane (the primary component of natural gas) and about 30-50 percent carbon dioxide.

In the past, landfill gas was a problem because it was not controlled and collected. Today, both European and US EPA law requires that landfill gas be collected and utilized. This prevents negative environmental impacts that the gas could otherwise cause, such as global warming effect. Utilizing the gas is also a sustainable way to manage our resources by producing energy and fuel.

The Value of Landfill Gas

Modern landfills collect landfill gas and convert it to energy or use it as fuel for vehicles. Using landfill gas for energy is both environmentally and economically valuable. Landfill gas is a consistent, reliable and proven renewable energy source, and when converted to energy, reduces a community's carbon footprint. From an economic viewpoint, when the energy is sold, landfill gas provides a revenue stream that can often cover the entire expense of the landfill.

In 2014, the US had 636 operational LFG energy projects in 49 states/territories that supplied approximately: 16 billion kilowatt hours of electricity, and 100 billion cubic feet of LFG to end users. Annually, LFG energy projects produce enough energy to power nearly 1.2 million homes for a year and heat more than 731,000 homes. (EPA, Green Power from Landfill Gas, 2015)

LFG energy projects help to curtail global climate change, because they reduce emissions of methane, a greenhouse gas more potent than CO_2. Reducing LFG emissions by converting them to energy reduces local ozone levels and smog formation, diminishes explosion threats, avoids unpleasant odors created by the landfill, and improves overall landfill management. The United Nations Development Program recognizes the use of methane from anaerobic biodegradation as one of the most useful decentralized sources of energy supply.

Landfill gas is used in a variety of ways, as liquid fuel, gaseous fuel and direct conversion to electricity.

One option is for utilities and power providers to purchase the electricity generated from the recovered LFG. Purchasing electricity from LFG enables utilities and power providers to add a renewable energy component to their energy portfolios. LFG can also be piped directly to a nearby facility for use as either a boiler or industrial process fuel. Direct use of LFG is reliable and requires minimal processing and modifications to existing combustion equipment. Landfill gas is also used as a replacement to natural gas to fuel vehicles.

Waste Management is the largest waste management company in North America, not only do they operate many landfill gas projects, but they also use landfill gas to fuel some of their collection vehicles. The 300 collection trucks in Livermore, California are fueled by compressed landfill gas from the same landfill they service. This landfill produces up to 13,000 gallons of liquefied natural gas each day. (Lozanova, 2008)

From the commercial waste management perspective, their position is; “the greatest danger to landfills is contaminating the air, so we suck the gas out and use it for energy recovery. It’s green energy. Gas from an average-sized landfill in the United States could provide a consistent energy supply for up to 4,000 homes. People have this mindset that we’re only waste companies, but we’re also recycling and energy supply companies. We need to change people’s perception.” (Kudialis, 2015)

The benefits of LFG energy in terms of greenhouse gas emission reductions are substantial. For example, a 3 megawatt LFG energy facility requires approximately 1,075 standard cubic feet per minute (scfm) of LFG to operate. Not only does the combustion of this quantity of methane in an LFG energy facility result in direct methane emission reductions, but also in indirect CO2 emission reductions of about 11,950 metric tons per year (depending on the type of fuel that was used to generate the displaced electricity). The indirect environmental benefits of fossil fuel displacement through LFG energy can amount to nearly 10 percent of the direct greenhouse gas emission reduction benefits from methane combustion.

The direct and indirect CO2 equivalent (CO2e) emission reductions from a direct–use project utilizing 1,000 scfm of LFG are approximately 126,000 and 12,440 metric tons per year, respectively. Twenty-two states and the District of Columbia have renewable portfolio standards (RPS), requiring that electricity producers obtain a certain amount of their power from renewable sources. In most of these states, waste-to-energy facilities and landfill gas are considered renewable energy sources. (EPA, Solid Waste Management and Greenhouse Gases, 2006)

The annual environmental benefits from current landfill gas-to-energy projects are equivalent to; planting over 20.5 million acres of forest per year, preventing the use of over 177 million barrels of oil, removing the carbon dioxide emission equivalents of over 14.5 million cars, or offsetting the use of 370,000 railcars of coal. Silicon Valley is also utilizing energy from landfill gas to meet its obligations under the California Renewable Portfolio Standard which requires 33 percent of total energy come from renewable sources. (Defreitas, 2011)

LFG energy projects provide significant cost savings and long-term sustainable energy to LFG end users.

Some recent examples include: (Source list from US EPA) (EPA, Green Power from Landfill Gas, 2015)

- Coca-Cola's Atlanta Syrup Branch facility gets nearly all of its energy in the form of electricity, steam and chilled water from green power generated at a nearby landfill, providing Coca-Cola with real energy savings. The landfill annually generates 48 million kilowatt-hours of on-site green power.
- The U.S. Navy saves approximately $1.1 million annually in utility costs at the Marine Corps Logistics Base located in Albany, Georgia, since its first LFG cogeneration plant was completed in 2011. This facility is made up of a dual-engine generator, a heat recovery steam generator and two dual-fuel boilers.
- In 2012, Gundersen Health System's Onalaska Campus became the first energy-independent medical campus in the United States by using LFG piped from the local landfill in La Crosse County, Wisconsin. The LFG is used to power a generator that supplies 100 percent of campus energy needs.
- The U.S. Department of Justice obtains 80 percent of its Federal Bureau of Prisons' Allenwood Correctional Complex's electricity from the combustion of LFG at the nearby landfill in Lycoming County, Pennsylvania.

The benefits of LFG energy are also well recognized and include: (Source list from US EPA) (EPA, A Landfill Gas To Energy Project Development Handbook):

- LFG is recognized by energy certification programs as a renewable energy resource.
- LFG serves as the "baseload renewable" for many green power programs, providing online availability exceeding 90 percent.
- Most states have landfills that can support LFG projects.
- Energy produced from LFG is least expensive form of renewable energy.
- Landfill gas comes from local sources, and it usually costs less than conventional fuels.
- Landfill gas energy recovery is a proven technology.
- Landfill gas recovery projects provide a net environmental benefit by reducing methane and volatile organic compounds emissions, conserving fossil fuels, reducing explosive hazards, and reducing odor.
- Landfill gas projects can serve on-site electrical loads at dispersed locations, thus reducing the need for new generating plants and transmission facilities.
- Landfill gas projects offer a way for utilities to attain Climate Challenge voluntary greenhouse gas emission reduction targets.
- Title IV of the Clean Air Act (Acid Rain Program) creates a quantifiable value for avoided SO2 emissions.

Landfill gas is used worldwide as a proven and reliable source of renewable energy; it is used for many purposes such as in conversion to electricity, heat and fuel for vehicles. Landfill gas energy is providing a way for communities to reduce their carbon footprint and comply with rigorous renewable energy requirements. Landfill gas is an important part of overall sustainability not only for how we dispose of materials but also how we create energy.

Section 3.4: Importance of Biodegradation Rates

The capture and use of landfill gas is critical in the overall sustainability profile of a landfill. One of the most important factors in capturing landfill gas is making sure the systems are in place to collect the gas when that gas is produced. This will mean balancing the time frame between when biodegradation produces the gas and when the landfill can collect that gas. If a material biodegrades too quickly in the landfill, the landfill gas collection system will not yet be installed and the gas will escape to the atmosphere. Similarly, if a material biodegrades too slowly in the landfill, the collection system will have been removed and the landfill gas will again escape into the atmosphere. For optimal environmental value a material should biodegrade during the time that the landfill gas is being collected.

Landfill and LFG collection operations in the United States are well established and more than 90 percent recovery can be achieved at cells with final cover and an efficient gas extraction system. (EPA, LFG Energy Projects) This means that less than 10% of the methane is not converted to energy. However this efficiency is dependent on the design of the landfill as well as the length of time the waste has been within the waste environment. So how can we not only manage landfills but also design products for maximum value in the landfill?

Most landfill gas collection systems are installed within two years at a landfill site. Once the collection system is in place, it will continue to collect the landfill gas until the material in the landfill is biodegraded and the gas production stops or becomes minimal. The period of time where the gas is actively collected is considered the “managed life” of a landfill and it will start once the gas collection system is in place and continue for up to 50 years after the landfill stops accepting waste.

As you may recall, a landfill has four primary phases of biodegradation. The first two phases, aerobic and anaerobic acid phases, produce primarily carbon dioxide and smaller amounts of methane. It is not until the third and fourth phases, the accelerated methane production and decelerated methane production phases, when the majority of methane is generated; between 40 and 70 percent of total volume. (Associates) The third and fourth phases are the most critical time to have the landfill gas collection system in place.

Typically, the waste in most landfill sites will reach the stable methanogenic phase within less than 2 years after the waste has been placed into the landfill. Depending on the depth of the waste, the type of waste and the moisture content of the waste; the methanogenic phase might be reached as early as six months after placement.

It may initially appear that rapid movement into the fourth phase and the resulting methane production would be most beneficial. However, studies show that more rapid biodegradation may actually be environmentally harmful. During the first two years there is often no collection system in place for the gas. If materials break down and release methane quickly, much of that methane will likely be emitted before the collection technology is installed. This means less potential fuel for energy use, and more greenhouse gas emissions. (Shipman, 2011)

As a result, a slower rate of biodegradation is actually more environmentally friendly, because the bulk of the methane production will occur after the methane collection system is in place. (Shipman, 2011) Ideally, the majority of biodegradation, and the resulting methane, should take place after the collection system is in place and biodegradation should complete during actively managed post closure (50 years). In this scenario, the collection of methane is most likely to reach the 90% efficiency.

There has been some confusion as to what time frame a material should biodegrade to be considered “biodegradable”. In the US there has been talk of a one year limitation. For composting there is a 6 month limitation, however in landfills the optimal time frame is much different. Biodegradation in landfills should occur during the managed life of the landfill, specifically 2-50 years. This should clarify the confusion regarding the definition of biodegradable, products labeled as biodegradable should biodegrade in the optimal time frame for the relevant disposal environment.

This problem may be exacerbated by the US Federal Trade Commission (FTC) guidelines call for products marked as “biodegradable” to decompose within “a reasonably short period of time” after disposal[2]. However, if a material is to biodegrade in less than one year in the landfill, all of the landfill gas would go directly into the atmosphere because there is no collection system in place. This means less potential fuel for energy use, and more greenhouse gas emissions. (Shipman, 2011)

We must design the products to integrate into the most optimal process time of the landfill, this means biodegradation that occurs primarily during the managed life of the landfill. As was stated by Morton Barlaz of NC State; “If we want to maximize the environmental benefit of biodegradable products in landfills, we need to both expand methane collection at landfills and design these products to degrade more slowly – in contrast to FTC guidance.” (Shipman, 2011)

Recently an FTC judge upheld this position by ruling that biodegradation is an inherent feature of a material and that the one year limitation previously identified by the FTC was not applicable. Regardless of the popular view of biodegradable time frames, from an environmental perspective the most beneficial time frame for biodegradation within the landfill is from 2-50 years.

Most food and garden waste is expected to biodegrade within 1-3 years, whereas paper, yard waste and slower degrading materials would biodegrade in 10-50 years. (Associates). This indicates there may be a

[2] *Note: The US FTC regulations do not require biodegradation within one year, the guidelines state that products that biodegrade in greater than a year must be marketed with a qualification statement that includes the rate, environment and extent of biodegradation validated. More clarification is provided in the section “Marketing of Sustainability in Plastics”.*

benefit to diversion of food waste from landfills as the methane production from these materials would most likely be released directly into the atmosphere.

When considering the environmental impact of plastic in the landfill, how fast it biodegrades is the most important factor. We must move away from the notion that faster biodegradation is better and look at the facts. If a plastic biodegrades in less than 2 years you could be causing environmental harm, similarly, if it biodegrades too slowly, more than 50 years, you have the same negative environmental harm. Both can cause harm because of the landfill gas that will go directly into the atmosphere and contribute to global warming.

So, although over 75% of all MSW is placed in landfills managing biogas (Dr Morton Barlaz, NC State), the management is less effective when the waste biodegrades too quickly or too slowly. Thus it is important from an environmental perspective plastics should be designed to biodegrade within the managed life of a landfill which is 2-50 years. Controlling the rate of biodegradation to the managed life of the landfill will ensure that the landfill gas is captured and converted to a resource that increases our green/renewable energy profile, reduce the energy needs from coal, reduce the carbon footprint of both the plastic and the landfill, and provide the most economic value as the energy/fuel is sold.

Section 3.5: Advancements in Landfill Design

The most recent development in landfill design is called a bioreactor landfill. Bioreactor landfills are focused solely on accelerating biodegradation as quickly as possible. Not only is moisture used to increase biodegradation, but often the temperature, oxygen levels, microbial colonies and pH levels are monitored and controlled.

Some bioreactor landfills are designed to not only biodegrade material quickly, but are also designed to be reused. This means that the waste goes into the bioreactor landfill, it decomposes and then the resulting soil is dug up, used as a soil amendment and the landfill space is reused for more waste.

> *Note: This may sound similar to industrial composting, but it is significantly different. Bioreactor landfills accelerate the rate of biodegradation in comparison to other landfill designs; however it is still slower than would be seen in industrial composting. Bioreactor landfills are designed to take mixed waste (everything that goes into the garbage can) while composting uses sorted organic waste. Also, bioreactors produce both methane and carbon dioxide through anaerobic biodegradation, whereas composting is aerobic and produces primarily carbon dioxide.*

The design of bioreactors accelerates the biodegradation so effectively that the bioreactor can hold up to 30% more waste in the space of a modern landfill. As materials biodegrade they reduce in size and the overall mass of the landfill declines, creating more space for placing more waste. With increasing amounts of waste produced every year, bioreactor landfills provide a significant way of maximizing landfill space. This is not just cost effective, but since less land is needed for the landfills, this is also better for the environment.

Furthermore, once a landfill is closed it must be monitored for at minimum 30 to 40 years to ensure leachate or landfill gases are no longer an environmental impact. With bioreactor landfills, the accelerated biodegradation can reduce the time of monitoring down to less than 10 years. Biodegradation is the key to detoxification. Once a material has biodegraded, there is no additional methane production and toxicities have been removed. Accelerating the biodegradation stabilizes the landfill and removes toxins much faster. This allows the land to be used much more quickly and safely for other purposes such as community parks and reforestation without risk of contamination or danger.

Using the landfill space multiple times is another potential benefit of bioreactors. While not currently practiced, some bioreactor landfill designs provide a way for the soil to be dug up once biodegradation is complete. By reusing the space, it would not be necessary to build new landfills. Once the landfill is done biodegrading, it would be dug up, the metals and non-biodegradable materials sorted out and the remaining soil would be similar to compost and used as a soil amendment. This is a very sustainable method of landfilling.

Today, there are only a handful of bioreactor landfills in operation as the design is fairly new. However the environmental and economic value these offer will pave the way for the complete conversion of all landfills to this design. Ultimately, bioreactor landfills are not landfills at all; they are more similar to anaerobic digesters where the organic material biodegrades into soil, air, water and methane, the methane is captured and converted to energy and then the resulting non-biodegradable material can be sorted out for recycling or reuse.

Section 4: Challenges of Landfilling

The prevalence of landfilling has made landfills the most mature infrastructure available for management of waste materials. The primary challenge with the landfilling of plastics not in the design of landfills as they are well designed and well maintained, the challenge is in the engineering of plastics. Plastics should be engineered to biodegrade during the managed life of the landfill so the methane can be captured and utilized for energy.

Today over 90% of plastics are disposed of within landfills where they will slowly biodegrade over centuries. For many companies products and packaging closer to 100% of the plastic will be landfilled. During the biodegradation of plastics methane is produced. Because the methane is produced over such a long period of time, it is not captured but instead it is released into the atmosphere.

Technology is currently available that accelerates the biodegradation of plastics in the landfill so that the plastics will biodegrade during the managed life of the landfill. This allows the energy value to be utilized, and reduce volume in the landfill.

Another challenge is the public perception of landfills. There is a general negative impression regarding landfills and sustainability, a belief that nothing should ever go into a landfill. This view inhibits the adoption of technologies that improve the sustainability of landfills because some are slow to accept the truth that plastics are and continue to be disposed of in the landfill. The result is that many companies continue producing traditional plastics that will be disposed of in landfills where there is no environmental value rather than incorporating technologies that accelerate the biodegradation of landfilled plastics for optimal environmental value.

The challenges of plastics in the landfill can easily be overcome through education. The technologies for sustainability manager to incorporate landfill biodegradable plastics are available today and the landfill infrastructure is already in use, now it is a matter of implementing the technology.

Section 5: Sustainability with Landfilling

When considering landfills from a sustainability perspective, often the most difficult thing is to step back from the negative notions of landfills. Too often, sustainability managers get caught in the trend of "zero landfill" because it is great marketing and it sounds like it would be more environmental. We must overcome the negative perception of landfills so we can evaluate them objectively.

The truth is always in the facts. Landfills are an important part of any sustainability strategy. Most all of the waste worldwide goes into landfills. Landfills can be the most environmentally and economically beneficial disposal options for certain items. Technology has completely changed landfills; they are not the same as they were prior to the 1980's. And landfills are an important part of many municipal green energy initiatives.

Landfill design and operation has completely changed over the past few decades. Landfills are now actively managed to avoid leachate absorption into the surrounding soil, to avoid air emissions and they are a valuable and consistent source of renewable energy. Modern landfills are by far the most inexpensive method to dispose of materials and they allow a means to provide economic and environmental value through the conversion of landfill gas to energy.

There is no doubt that most all plastics are disposed of in landfills. Even after 40 years of efforts to divert plastics from landfills, we still landfill over 90% of plastics. Many companies' products and packaging will have closer to 100% landfill disposal. History has shown that we will continue to landfill plastics for a very long time and attempts to divert plastics from landfills usually causes more damage to the environment and economy than any benefit it may provide. Because of this, we must understand how to create sustainability with landfilling of plastics.

Plastics in the landfill should biodegrade during the managed life of the landfill, 2-50 years. When compostable plastics enter a landfill many will biodegrade too rapidly and the methane is released into the atmosphere and most traditional plastics biodegrade over hundreds of years meaning, again, the methane goes into the atmosphere. We must use plastics that biodegrade during the 2-50 year managed time of a landfill so the methane can be managed, collected and converted to clean energy. Once collected, the methane provides energy, fuel, and reduces the methane's global warming effects.

Ultimately, we cannot disregard landfilling because plastics are, and will continue to be, discarded into landfills. Instead, we must design plastics that provide value in the landfill. In this way, we can create a sustainability platform that is realistic and beneficial.

From a sustainability perspective, traditional plastics should never be disposed of in a landfill. Companies producing products that will most likely be disposed of in a landfill should not use traditional plastics alone; they should use landfill biodegradable plastics to provide the maximum environmental benefit upon disposal.

Chapter 2: Recycling of Plastic

In any conversation related to plastics and sustainability, recycling is an inevitable topic. Remember the garbage barge fiasco of 1987? As a result in 1988, Winston Porter of the US EPA first set national recycling goals as a more effective way to manage certain waste. This was a simple message of removing valuable materials from the waste stream so they could be reused for another purpose, and it has become a very valuable part of sustainability.

The idea of keeping valuable materials out of the landfill has evolved into the modern message of "recycle everything, regardless of the costs". From a recycling perspective, there is the notion of a world without landfills, where all plastic products are kept in a continual cycle of use, collection and reuse. There are some in the industry that go as far as to claim 'any process other than recycling of plastic is a waste of the molecule'.

The thought here is that we have put resources into creating a molecule of plastic and that by sending it to a landfill we are wasting the energy and resources we used to create it. But what if recycling that molecule takes more resources and causes more harm to the environment and economy than other methods of disposal? To evaluate this further we should also consider the resources needed to replace the molecule that was not recycled. In essence, to know if recycling a specific material is beneficial we must know which requires the least amount of resources; recycling the material or disposing of it in a sustainable way and creating new molecules?

This idea has become so extreme and entrenched that some feel recycling is a moral obligation that should be done at any cost. There is also the idea that regardless of the resources required recycling is always more environmental. It is seldom that the details of recycling, including the true costs and impacts are discussed openly. We have to start critiquing recycling with the same scrutiny as with any other waste management process to ensure the result is both economically and environmentally beneficial. Studies show that while recycling of some materials can be environmentally beneficial, attempting to recycle other materials can be both environmentally and economically costly.

There is no doubt that certain plastics can and should be recycled. PET beverage bottles and HDPE bottles are a prime example of ideal plastics to recycle. These two products have proven success in current recycling processes, providing they are not colored, blended with other plastics or combined with other materials. They are available in large quantities, easy to identify, relatively uncontaminated, simple to process and have resale value. But what about the other types of plastic?

Instead of aiming for specific recycling rates, cities should aim for making an environmental difference, says J. Winston Porter, who, as former assistant administrator for America's Environmental Protection Agency, was the first to establish nationwide recycling targets in the United States in the 1980s. His target then was 25%, and it's a number he largely sticks by. Diverting 35% of waste into recycling is about as a high as any city can justify, he says.

Trying to recycle more can be wasteful, if not harmful, he says, even though many major cities are setting targets at 70% or higher. "People say you can't recycle too much. It turns out you can," says Mr. Porter, president of the environmental consulting firm, the Waste Policy Center, near Washington, D.C. "If you spend enough money, you can recycle anything. That doesn't mean you should." (Libin, 2009)

In a recent Perspective article, Bill Sheehan and David Kirkpatrick asked, “Is zero waste, which means recycling nearly everything, achievable?” The answer is provided by Winston Porter, the originating father of the US EPA recycling directive:

> *“No. Not only is 100 percent recycling not reachable, but it is not even good for the environment. Georgia and the nation are recycling more than 25 percent of their trash, thus meeting the national goal I set in 1988 while an assistant administrator at the U.S. Environmental Protection Agency. However, most areas are not going much higher than 30 percent to 35 percent recycling for several reasons. First, at least one-fourth of trash—including such items as kitty litter, paper towels, dirt and broken toys—is virtually non-recyclable because it is hard to collect and has almost no value. So to reach even 50 percent recycling, about two-thirds of every “recyclable” item would need to be recovered. Second, only a few of the 50 or so identifiable items in garbage are present in significant percentages: cardboard boxes (13 percent of trash) and newspapers (6 percent), to name two. Those items are already recycled at high rates. To increase overall recycling dramatically, we would have to go after dozens of “one-percenters,” at great cost and inconvenience to consumer. How about 15-20 recycling bins at your curb?*
>
> *There’s more. It is often difficult and expensive to recycle in rural areas. And much of our recycling is voluntary—we can’t force everyone to do it. Finally, we have to sell our recyclables, which is not easy when prices for these commodities soften, as they do periodically. The zero-waste notion begins with the false assumption that reuse or recycling is always best for the environment. In March 1996, I conducted a study of reusable vs. disposable food service packaging, analyzing more than 30 European and American environmental investigations. The basic result was that a disposable package or container (e.g., a foam coffee cup) is preferable to a reusable one (e.g., a porcelain cup) from the standpoint of water supply and water pollution, since washing the reusable cup creates hot, soapy wastewater. Disposables are also safer from a public health viewpoint. The reusables are better from air and solid waste standpoints, but only if reused several hundred times.*
>
> *It is apparent that the zero-waste advocates are talking about zero solid wastes. But what about air and water pollution or energy usage? Not to mention the negative economic impacts of pursuing such a pie-in-the-sky venture. Also, modern landfills, demonized by Sheehan and Kirkpatrick, have to meet very stringent federal and state*

> *regulations and pose very small environmental risks.*
>
> *Finally, the zero-waste concept ignores the law of diminishing returns. We already recycle the items that make the most environmental and economic sense. As we force ourselves to go after less valuable wastes in more difficult locations—say, hotdog wrappers at ballparks or leftover napkins at the airport—the costs will skyrocket. Recovered items will be trucked greater distances, or more resources will be used to clean and process dirty recyclables.*
>
> *Our goal should be to minimize the overall environmental impact of our products, not simply to shut the door in one area—solid wastes. And every dollar spent on zero waste is a dollar taken away from other environmental problems or from such areas as education, health care, or transportation."* (Porter, Too much recycling can be a waste of resources, 1997)

Recycling is an important part of an overall sustainability strategy, but we must look at the facts. While the media is quick to report on aspects of recycling that appear to be successful, the recycling industry promotes that the increased collection of materials is a success, and society continues to believe that recycling is the key to being sustainable; we have yet to achieve sustainability.

If we want to be a sustainable species, we have to look at the scientific data and not blindly assume that we must recycle <u>all</u> items and that it is <u>always</u> beneficial to recycle. We must understand the economics and environmental impacts of recycling so we can determine when it is beneficial to recycle.

Section 1: Understanding Recycling Rates

In different regions of the world the definition of “recycled” can vary significantly. Some countries define recycling as simply the collection of materials, while others consider burning plastic (incineration) as recycling, and others determine recycling by the material that is actually remanufactured into new products. Without a standardized definition of what recycling means, it can be difficult to interpret the reports of recycling rates. For example, in Europe, incineration of plastic is very common and is included in plastic recycling statistics.

In 2014, Sweden published a recycling rate of 99% - their definition of recycling included incinerating nearly 50% of their trash. (inhabitat.com, 2014) Minister Auken of Denmark, in 2013 stated that Denmark incinerates nearly 80% of household waste, which is again considered as recycling. (ZeroWaste Europe)

Similarly, Europe is often considered the leader in recycling of plastics and reports over 50% recycling of plastics. The details of their report show that only 19% was actually recycled and the remaining 30.3% was incinerated. (Plastemart.com) European countries reporting the highest “recycling” rates incinerate at a minimum 50% of their waste and include the incineration of plastic as part of the total recycling rates. The inclusion of incineration of plastic within recycling rates is causing a rising debate regarding the definition of recycling, because the environmental and financial impacts of recycling and incineration are much different. (Seltenrich, Incineration versus Recycling: In Europe, A Debate Over Trash, 2013)

Note: The following information is presented to provide a clear understanding of current recycling rates; it is not to discount the importance of recycling or to discourage recycling. The information is provided so sustainability managers can interpret recycling rates accurately and assess the current status of recycling, to know if recycling efforts are being successful for their types of products and evaluate if their products and packaging will be recycled.

Some misunderstand how recycling is reported and think that a reported figure for recycling includes all types of plastic. With paper and glass, the recycling rates are reported as a total figure, all the different forms of the material are included in a single number. With plastics, they are not grouped into a single category; instead certain subcategories are separated and then reported. For example, recycling of PET single use beverage bottles is a reported subcategory. Currently single use PET beverage bottles are reported at 32% recycle rates. This means that of the single use PET beverage bottles produced, about 32% of them were collected for recycling. However, this is only related to single use PET beverage bottles and should not be extrapolated to other types of plastic.

PET bottle recycling rates are calculated by taking the how many bottles were produced by manufacturers (production) and comparing it to the amount of PET collected at recycling facilities (collection). The production figures are calculated only using single use PET beverage bottles. The collection numbers are calculated using the entire PET bale that includes many other types of PET bottles such as shampoo bottles, conditioner bottles, ketchup bottles, lotion containers, vitamin and supplement containers, 5 gallon water bottles, 2 liter soda bottles, plastic wine and beer bottles, etc. This makes the reported recycled rates appear much higher than they actually are.

Often reports claiming an increase in recycling are based on an increase in the poundage of collected material not an actual increase in the percent of plastic recycled. A recent report claimed a 4% increase in the recycling of plastic (Johnson J. , 2014), but the report fails to clarify that this is an increase in the pounds collected for recycling – not an increase in the overall percentage of plastic recycled. Nor does it include the fact that plastic consumption has increased at a higher rate than the increased rate of recycling.

When looking at the actual recycling rates, indications are that the overall percentage of plastics being recycled may be decreasing! The actual recycling rate in the US for plastic was only 9% in 2011 and still less than 9% in 2013. (EPA, Municipal Solid Waste Generation, Recycling, and Disposal in the United States, Tables and Figures for 2012) This would seem to indicate that 9% of plastics were remanufactured into valuable products. But recycling numbers are estimated based on bale weight not actual material weight. A bale of PET bottles is not only PET bottles, it also includes paper labels, plastic labels, adhesives, PP and PE caps as well as other incorrectly sorted materials. All of these items are included in the total weight reported as recycled PET.

Many people aren't aware that recycle rates are based on municipal waste and not industrial waste. Why is this important? That PET bale that contained all sorts of other materials is going to be sold to a processor. Once this bale is sold to a processor, the contaminants and other materials will be removed and discarded to a landfill. This waste is not considered "municipal waste" as it is now coming from an industrial site. Industrial waste is not reported in landfill or recycling rates of municipal waste. A processor could determine that an entire bale of PET is too contaminated to use, send it to a landfill and that bale would still be reported as having been recycled!

It can be difficult to get a clear picture of where recycling rates are by simply reading media and industry reports. However, once you understand how the numbers are derived, you can begin to see the true picture of the current recycling rates. We need to push the recycling industry into reporting recycled rates based on actual plastic being remanufactured into a new product. Accurate and easily understood reporting of recycle rates will allow us to determine if our recycling efforts are in fact increasing recycling rate of plastic or if we are falling short in relation to the growth of plastic production.

Section 2: Economics of Recycling

Recycling programs in the United States have become an important aspect of waste management. With the focus on increasing recycling rates it is important to understand that recycling programs can be a costly method of waste disposal. With the time, money, and energy spent collecting and processing recycled goods, educational and marketing costs, and subsidies; the price of recycling is much higher than discarding waste into landfills.

Despite the high costs of recycling, proponents of recycling argue that the environmental and health benefits of recycling outweigh the costs. Recycling advocates believe that recycling is more than just an issue of economics and is essential to caring for human health and environmental sustainability. They argue that recycling is an environmental effort that should be subsidized by the government and taxed to the consumers and manufacturers. Some believe that any cost – no matter how high – should be paid to recycle plastic.

This is a philosophy that is great for the recycling industry, but what about from a broader economic sustainability perspective? To determine the economic sustainability we need to understand the cost of recycling and how it compares to other methods of waste management.

So, why is recycling so expensive, and what are the actual costs?

In general, recycling is a costly method of waste management as it requires recycling centers to add specialized trucks and additional employees to collect, transport, and separate recyclable materials. In New York City, for every ton of recycled goods that a truck delivers to a recycling facility, the city spends $200 more than it would spend to dispose of that waste into a landfill. There is also the cost of purchasing, providing and maintaining a variety of recycling containers to residences. Recycling programs also spend a great deal of resources on continual public relation campaigns explaining to the public which products are recyclable and which are not.

According to author Harvey Black of the Environmental Health Perspectives Journal, in San Jose, California “it costs $28 per ton to landfill waste compared with $147 a ton to recycle”. In Atlantic County, New Jersey, selling recyclable goods brings in $2.45 million. However, the cost of collecting and sorting these recycled materials plus interest payments on the recycling facility costs the county over $3 million – meaning a net loss of over half a million dollars each year.

In June 2015, one of the largest waste processors, Waste Management, admittedly declared that our current method of recycling is a “broken model” that is not sustainable. The system does not work because consumers are demanding more recycling, the processors are bringing in an unburdened amount of raw material and this recycling is leaving companies with an excess of raw materials and limited market for the final product. They cannot continue to sell the output for less than the cost of producing the output - one ton of recycled material can cost anywhere from $65 to $100 to process (compared with $20 to $40 to dispose the same material in a landfill) and then have a product that’s worthless. (Kudialis, 2015).

A case in point, San Francisco's Department of Waste recently calculated it paid $4,000 a ton to recycle plastic bags. Its resale price for the recycled product? $32. Rivanna Solid Waste Authority, which operates recycling locations in Virginia, sell their recycled material for $269,000, but the recycling program cost $634,000 annually, so each year they operate at a loss of $365,000. (Province, 2007) The promise of environmentalists of a "flourishing recycling market" where reused goods would find ready buyers "was already a dream 40 years ago and is, unfortunately, still a dream." (Libin, 2009)

States in the US spend over $322 million annually to subsidize recycling, and these recycling costs are passed to the consumer through trash bills or taxes. One study found that the average cost per household with curbside recycling was $144 annually; without recycling, the cost of trash disposal was $119.90. These costs can consume a considerable amount of a city’s budget. For example, Sanford, Maine, spent $90,990 to recycle waste that it could have safely placed in landfills for $13,365.10. (Logomasini, 2008)

A large percentage of the cost to recycle is related to the labor costs. In 2011 ISRI reported that the recycling industry required 459,140 jobs at an average salary of $66,704. That same year, Tellus Institute projected that to double the recycling rate we would need to add 1.5 million additional jobs. Our current labor cost for recycling is over $30.5 billion every year; to double our recycling rate we will need to quadruple the labor expense to $130.5 billion each year!

If we look at the recycling of plastics only, for every 10,000 tons of plastics recycled the Institutes for Local Self Reliance estimates it will require 103 jobs, whereas it requires only 1 job for the same amount sent to a landfill. Job creation is often considered beneficial; however in an industry that is not economically sustainable and requires governmental subsidies, we are doing no more than increasing the financial burden on society which is not sustainable in the long run.

As we evaluate the economics of recycling, we must compare it to the costs of producing virgin material (material made from original sources not recycled material). Recycling costs are generally more expensive than the manufacturing costs of producing virgin materials. Materials, such as plastics, are more expensive and time consuming to recycle than to produce initially. Thus, it is cost effective to manufacture virgin plastics rather than recycled plastics, which must undergo collection, transportation, and sorting costs. This is seen directly in the price of recycled plastic in comparison to virgin plastic, which is most always less expensive than recycled plastic. This makes the economics even more difficult because recycled plastic is typically lower quality (strength, purity and color) than virgin plastic. Manufacturers, brands and consumers don’t want to pay higher price for lower quality.

Another example of the increased cost, but from a different perspective was seen in Seattle when over a dozen local residents filed suit against the city. The city had hired nine solid waste inspectors to oversee the residents sorting of materials sent for recycling. The inspectors were sorting through recycle bins and writing violations and citing fines for residents who incorrectly sorted materials in their recycle bin.

The residents felt this activity was overly intrusive and filed suit against the city.

Recycling is an expensive venture for any community, primarily because we try to recycle items that have little value. The data shows that continued recycling of materials with little value will not continue without additional government subsidies, increased taxes to the consumer, and additional cost to manufacturers. Any financial burden required to uphold recycling will ultimately be borne by the individual citizen either through direct taxes or increased product costs.

Many feel that this cost is offset by the environmental benefit of recycling. It is often forgotten that recycling is a private industry and private industry needs innovation. However, financially propping up an industry does not spur innovation and economic independence. We must determine the balance between what is financially supported to assist the growth of the recycling industry for environmental purposes, and when to pull back and let the market grow naturally.

To determine if the extra cost of recycling is a price worth paying to benefit the environment, we must look at the environmental impact of recycling.

Section 3: Environmental Impact of Recycling

Recycling can cost a great deal of money, but that cost can often be justified if the environmental value is substantial. As is shown previously, recycling programs require additional vehicles which will emit pollutants, but are there other environmental impacts from the sorting and processing that should be considered? And if there are other environmental impacts, how does the overall environmental profile compare to the increased cost?

Overly aggressive residential recycling programs have shown to a community's environmental goals. Citywide blue box/bin programs typically mean a whole new fleet of trucks: Calgary added 64 more diesel-burning rigs retracing the same tracks its garbage trucks did just a few days before implementing their curbside recycling program, roughly doubling carbon dioxide emissions and other pollutants. The environmental emissions associated with curbside collection includes significant amounts of carbon dioxide, carbon monoxide, sulfur dioxide, and other gasses polluting the atmosphere due to the increased number of trucks on the road. A 2000 study by the London-based environmental group Friends of the Earth found that collecting waste for recycling emitted 264 more pounds of CO2 than burying it in a landfill. In 2002, two of Sweden's leading environmental authorities argued that recycling's benefits were usually undone by the resources required to collect and process it. Other environmental and social costs found during the study included increased road congestion, litter, and noise pollution.

The toxic waste released from recycling activities can create long term environmental problems. For example, recycling plastics creates a waste stream that includes contaminated wastewater and air emissions. Also, many additives are used in processing and manufacturing plastics such as colorants, flame retardants, lubricants, and ultraviolet stabilizers. Recycling facilities that do not properly manage these chemicals may cause health problems for humans, and chemicals that get mixed with rainwater can also damage nearby biomes and percolate into groundwater. Today, thirteen of the fifty worst Superfund Sites (hazardous waste sites) are currently or were at one point recycling facilities. These facilities contain hazardous wastes due to the number of toxic substances utilized and released when recycling materials.

Rather than focus on the problem creating these sites so that future contamination could be prevented, on November 29, 1999, President Clinton signed into law the Superfund Recycling Equity Act (SREA). SREA serves to correct the potential environmental and legal costs of a cleanup that had discouraged recycling. SREA clarifies that recycling is not disposal, and shipping of material to be recycled is not arranging for disposal. SREA no longer holds companies who sell scrap for recycling responsible for the cleanup of contaminated sites when the site's owner or operator has caused the contamination. This point is brought up to show that there is a loop hole in the system that a recycling facility could use to avoid responsibility for environmental contamination. Many believe that regulation is overseeing and controlling possible contaminants and environmental hazards, in this case it is not.

Overall, the environmental impact of recycling is something to take into consideration. By adding additional trucks for collection we increase the air emissions, the processing of plastics produces wastes that may be toxic and uses additional energy. These impacts can be reduced through higher regulation and restructuring of collection techniques, however this will increase the economic cost of recycling.

The most sensible approach for sustainable recycling is to identify the problematic materials, remove them from recycling programs and focus our efforts on the plastics that have the best economic and environmental profile. This will allow the recycling infrastructure an opportunity to maximize the environmental value of recycling.

Section 4: Challenges of Recycling

Recyclers are interested in recycling plastics that make economic sense, this worked well when recycling was limited to PET and HDPE bottles. However with the recent green movement, recycling facilities are being pushed to accept more and more different types of plastics. Many of these plastics are difficult to recycle, will not sort using their machinery and have no resale value. The continual push to include more items in recycling programs is the primary challenge for recycling.

This section will review in detail the challenge with recycling different types of plastics. The information will help sustainability managers understand why many current products and packaging types are not recycled. Sustainability managers can also use this information in designing their products and packaging to more effectively integrate into current recycling infrastructure.

Plastics pose a unique challenge to recycling due to their versatility. If plastics were all one type of material and the same size/shape, recycling would be much more effective. Unfortunately, there are at minimum several dozen different types of plastic in today’s waste stream, we have PET, PETG. PE, HDPE, LDPE, PVC, PS, SAN, nylon, ABS, POM, PLA, EVA, PU and the list continues. Often these plastics look the same but each type of plastic is a completely different chemical and they are not compatible together. This means that you cannot mix them. Recycling these plastics requires first separating and sorting them which can be difficult because they are often visually indistinguishable.

Even a small amount of incorrectly sorted material can be devastating to recycling. For instance; a PET bottle and a PVC bottle look nearly identical. But, even a small amount of PVC mixed into the PET is considered severe contamination and will render the entire batch worthless. Similarly, PET and PLA bottles look the same, but PLA melts at under 200F and PET melts above 400F. In processing PET even a small amount of PLA will cause issue because the PLA melts during processing and clogs up the machinery. Again, the entire batch of PET is typically destroyed.

Sometimes sorting the different materials is nearly impossible because many of the finished articles discarded are created by layering these different types of plastic. This is a growing practice in flexible films, as seen with juice pouches, bags, and most food packaging films. Cartons are another product that utilizes multiple layers; although they are marketed as “recyclable” each of these containers is a complex layering of paper, several types of plastic and metal. None of these materials can be recycled together so a recycler would need to separate each of these materials. Next time you buy a carton, try pulling apart each of the layers and you will understand first-hand the complexity.

Additionally, for each different type of plastic, we have different forms; rigid containers, flexible containers, films, sheets, thermoformed items, injection molded products, roto-molded parts, foamed plastics, beaded plastic and plastic fibers. Not only are the different types of plastic not able to be recycled together, the different forms are made from different grades of plastic that cannot be recycled together either. To create recycled plastic that can be reused, it is required that only the same types and forms of plastic be recycled together.

PET is a great example. PET is a type of plastic, but there are many forms of PET. These forms are called grades. For PET the grade is typically defined by the intrinsic viscosity of the material (the length of the molecule that makes the plastic). Grades with shorter molecules are typically used to make sheet and film products, while longer molecules are used to make bottles and very long molecules are used for monofilament production. Using the wrong grade of PET can result in manufacturing defects and product failure. This means that with recycling, each of these different grades would need to be processed separately.

Another example is PE (polyethylene), which is one of the most versatile and widely used plastics. The polyethylene family of plastics includes; ultra-high molecular weight high-density PE, high-molecular weight high-density PE, high-density PE, general PE, crosslinked PE, low-density PE, and linear low-density PE. Within each of these types of PE, there are different grades that have different melt flows. Melt flow is how easily the plastic will flow when melted and it is critical to have right when manufacturing. If the melt flow is wrong, you will have product failure, machine failure and wasted plastic.

To add to the complexity, recycling processes and systems can only incorporate certain forms and sizes of materials. There are many materials that are not financially or environmentally beneficial to recycle.

1. **Films** are lightweight thin plastics such as stretch wrap, shrink-wrap, labels, bags and packaging. Films are often made from PE, LDPE, HDPE, Nylon, PET or PVC and can include several layers of different types of plastic that cannot be easily separated or recycled together.

   Films and bags cause problems at the reclamation facility as they wrap around sorting equipment and blow around the facility. Additionally, films are very lightweight so it takes a very large amount of plastic film to make a bale, meaning that the recycler will spend more on sorting and processing than they can sell the material for.

2. **Foamed materials** are often made of PS or PE. Some are extruded foams such as meat trays and egg cartons while others are expanded beads as is seen with packaging and disposable cups. These materials are lightweight and brittle causing breakage and difficulty at the sorting facility and during transportation.

   Some foams are chemically modified so they cannot be easily melted and manufactured into new materials – this makes recycling difficult. Additionally, as with film they are very lightweight and so unlikely to be economically viable, but unlike film, foamed plastics are primarily air and take a large amount of space.

3. **Small items** are another sector that is not typically feasible for recycling. Small items include

things such as; straws, table service items, single use coffee pods, lids, candy wrappers and most anything smaller than a beverage bottle. These items are too small for most sorting systems, are too small to hold together as a bale, and as with both films and foams, contribute very little to the weight of a bale so are not economical to collect.

4. **Contaminated materials** are a different type of problem. Contamination can be from the plastic product itself, during use of the plastic or from contaminants collected during disposal. Materials can be contaminated with anything from hazardous chemicals which pose a threat to workers at the facility, to dirt that damages processing equipment, to bacteria/virus risk and even contamination from materials manufactured as part of the plastic article.

   Packaging plastics are usually contaminated from use, think of a bottle that contained bleach and one that contained ammonia. If these two bottles are baled together during recycling, the bleach and ammonia can combine creating toxic chloramine gas and liquid hydrazine (an explosive and toxic liquid). Contamination poses a serious risk to recycling many materials.

5. **Complex materials** are very common in the waste stream. These are products made from layers of different types of materials. The layers can be different types of plastic, or they can include metals, paper and rubber. This is very common seen in cartons for food packaging, electronics, pouches, furniture, automotive materials, batteries and toys. These types of products are some of the most common ones in municipal waste and separating these materials is very energy intensive and can require the use of harsh chemicals, both of which make attempting to recycle these materials ineffective.

6. **Colors** can cause a problem with recycling because it makes it more difficult to distinguish between different types of plastic and lowers the quality of the plastic. Color in plastic becomes a permanent feature and there is no way to remove color when recycling. Take a stroll down the grocery aisle and notice the different colors of plastic. Mixing these colors in recycling is like mixing a pallet of paints – brownish-green-gray plastic.

The challenge in recycling extends beyond the types of plastic, their forms and contaminants. There is a general misconception of closed loop recycling – a belief that plastic can be recycled over and over again indefinitely. This is not the reality of plastics recycling. To recycle plastic it must not only be collected, sorted, decontaminated and ground into flake; it must also be melted and remanufactured into a new product.

Each time plastic is melted it will degrade the polymer chain (meaning the plastic becomes weaker and more brittle), after 3-4 melt cycles the plastic becomes virtually unusable and will be discarded – into a landfill. This is the reason many products contain only a portion of recycled content – they need virgin plastic to overcome the degraded state of the recycled material.

Most plastics however are not remanufactured into the same type of product or a product that has a high chance of being recycled. Most often, recycled plastic is actually down-cycled (made into less valuable products that are not recyclable). This is seen when plastic bottles are recycled into clothing, after the clothing is worn the plastic fibers will not be recycled and will be thrown in the landfill. This prevents the option of closed loop recycling systems and instead simply extends the life span slightly and delays the inevitable disposal into the landfill.

Another challenge for plastics recycling is the current trend of “reducing” plastic use. This is part of the “Reduce, reuse, recycle” mantra. Most often this reduction comes from “light-weighting” packaging and products by making the same item thinner and with less plastic (think of how water bottles have changed over the past 5 years). A water bottle has reduced plastic use by nearly 50% in the past few years, meaning that recyclers must now collect twice the amount of bottles for the same weight. Since recycled material is sold by weight, each bottle is only half as valuable as it was a few years ago.

A more recent trend is changing from rigid packaging to pouches and films. This approach is even more problematic for recycling as pouches and films are most often multi-layer to compensate for the thinner material and multi-layer film is not recyclable because the different types of material used in the multilayer are not compatible and cannot be recycled together or separated. This is another revenue loss for the recycler. Even if the film is a single material, most recycling systems will not accept it, resulting in all of these films and pouches being diverted directly to the landfill.

From a product perspective, many brands claim the desire to produce “recyclable” products. They make changes in their product or packaging in the desire to make it more recyclable without understanding the full dynamics of the collection, sorting and processing inherent in recycling. Brand owners believe they can make their package recyclable by converting to a plastic that is recycled. Not only is this not true, it is misleading to the public when the brand promotes their product as recyclable when it is not going to be recycled.

For example, there is a single use coffee pod made of multi-layer material which has received significant negative exposure in the media because the pods are not recyclable. Recently, the manufacturer of these pods announced they are changing the pod to polypropylene, a “recyclable” plastic as a more environmental option. However, these claims fall short. The reality is that a coffee pod will not be recycled regardless of the resin it is manufactured from – the size of the product is the limiting factor. Recyclers that receive these pods during curbside collection will not process them and the pods will be sent to a landfill. Even if a recycling facility would accept a large shipment of these pods, there is not an economical or environmental means to collect these items separately. Ultimately these coffee pods will be sent to a landfill. This is completely misleading to consumers who do not understand the limitations of recycling.

If a brand is truly interested in making their product recyclable, they need to use materials and forms that are currently recycled. This means changing their packaging to PET or HDPE rigid containers only.

They would not use any colors, processing aids or barrier materials in the plastic. They would avoid the use of labels, caps and other items that will not be recycled and could hinder the recycling of their product. They would not use any films, bags, pouches, foams or any other materials or forms that would limit the recyclability.

Changing packaging to completely integrate with recycling can be very limiting to a brand because the look, feel and quality of their product are often controlled by the packaging. And it may be more expensive, use more plastic and still not ensure it gets recycled – however when brands are willing to do all of these things, they can honestly market their product as recyclable. Any deviation from this and they are simply using the term “recyclable” as a marketing tool. At best, this approach is referred to as “greenwashing”.

The Association of Postconsumer Plastic Recyclers (APR) publishes a technical guide for designing products that will integrate most effectively with current recycling methods. While not completely inclusive as it can overlook new technologies, the APR guide can be a good tool to use when evaluating the design of packaging. Currently the guide provides direction on subjects such as; caps/closures, labels/inks, colorants/additives and material layers as they relate to PET and HDPE bottes. This guide can be found at the APR website: www.plasticsrecycling.org.

There are many challenges to recycling materials in a sustainable way. Plastics come in many different types and forms; each of these requires separation from the other before recycling. Separating these plastics is expensive and sometimes impossible. If brands want to ensure their products are recycled they will need to redesign their products and packaging in ways that may not protect the product effectively and will cost more. While some brand owners claim to have recyclable materials, they do not ensure they are actually recycled or integrate into the existing processes of recycling. Brands should not market their product as “recyclable” until that product will actually be recycled.

Section 5: Sustainability with Recycling

Recycling is an important part of a sustainable waste management system. A system that recognizes some portions of our waste are most efficiently recycled, some are most efficiently placed in landfills, some should be burned in incinerators, and other materials should be composted. The key is finding the mix of options that conserves the most resources, while protecting the environment. Each option represents its costs to society: the value of the water, energy, land, labor, and other resources that the disposal option requires.

Using numbers that are reported by the EPA, less than 9% of all plastics are being recycled. Increasing the recycling rate of plastics to even 20% will require millions of dollars in public funding and a change in the way products are manufactured and packaged. It will also require recyclers to approach their business from an environmental focus rather than an economic one. With these changes, we can increase our plastic recycling rates, but it is naïve to expect that we should recycle all plastics.

When looking specifically at plastics, there are a few materials that are currently recycled effectively; clear PET beverage bottles and HDPE bottles. One reason it's so hard to increase recycle rates is because we're already recycling the most valuable and accessible items: bottles. The rest of the waste is hard to collect, difficult to process, requires greater resources and has almost no value. (Porter, Playing the game to meet the 50% recycling law, 1997)

The diversity of plastics in the waste stream is exasperated by modern requirements for product safety and preservation. As manufacturers and brands design packaging to better preserve and protect products it requires more diverse types of packaging. This creates thousands of items that are not only a challenge to recycle but are available in such small quantities that they are not feasible to recycle.

If brands want to have their products or product packaging recycled, they must first understand the processes and business of recycling so they can design products and packaging that integrate with recycling. This will mean making packaging out of materials that are currently recycled effectively and in a form that will be recycled. Specifically, they will use only clear PET or HDPE bottles. They will avoid adding any labels or caps that are not easily removed and they will not use multi-layering of plastics in their bottles.

For many products packaging with bottles may not be possible and changing a product or packaging based solely on the ability to recycle the item will have unintended consequences. Sustainability managers must balance the cost and performance of their plastic with the disposal environment they intend for their products. Not all packaging performs as needed when it is the type and form of plastic most recycled; for these products, designing for alternative disposal methods is appropriate.

Brands can also assist recycling by using recycled content in their products. This supports the resale value of recycled material and will result in higher demand for the recycling of those specific products. This does not directly impact the recyclability of the finished product but it does support the recycling industry and indirectly will encourage higher percentages of recycling.

Sustainability with recycling will require the recycling industry to step up to the plate and approach recycling from a sustainability perspective rather than only a commercial business perspective. This will involve working with manufacturers and the community to identify which materials are beneficial to recycle and focusing on those materials. This may mean pushing back on the idea of including all plastics in their collections, and it may involve calling out products that incorrectly claim recyclability because they are in a form that is not recyclable.

To have recycling sustainable, we must understand that not all materials should or can be recycled. We must understand that the decision as to what materials are collected for recycling can determine if the program is beneficial. Too often it is assumed that if recycling aluminum, copper, paper and select other materials is beneficial, that same benefit will be realized with all materials. It is also assumed that recycling is limited to the collection, separation and reprocessing of materials into similar products. This limited perspective blinds us to the true impacts of wide spectrum recycling initiatives.

Chapter 3: Incineration of Plastic

The third most common method of waste disposal for plastics is incineration; this is a waste treatment process that involves thermal degradation of waste materials. Incineration is widely used throughout Europe and Japan, as a method to avoid landfilling of materials and to capture the energy value of the waste. In this section several types of incineration technologies are included; combustion, gasification and pyrolysis.

Combustion is the simplest and most common form of incineration as it is simple burning of waste. Combustion can accommodate mixed waste, although for health, safety and environmental purposes hazardous wastes should be removed prior to combustion. Combustion can be used only to reduce the volume of waste, or the resulting heat from combustion can be harnessed as an energy source. From a sustainability perspective, it is always best to capture the energy value during incineration rather than simply burning the materials.

Combustion is the most common form of incineration worldwide. It is popular in Japan, Denmark and Sweden where the combustion facility also captures the energy value of the waste. In Denmark, waste combustion energy accounted for 4.8% of the country's total electric usage and 13.7% of their domestic heat consumption. (Danish Energy Authority, 2007)

Plasma gasification is a new method to thermally treat waste materials that is not yet used in commercial applications. It involves using a plasma torch to heat the waste to temperatures up to 25,000F so that the waste instead of burning is vaporized. Basically, the heat is so high that it breaks the molecular bonds in the materials and the complex molecules are separated into individual atoms. The end goal with plasma gasification is a combustible gas called Syngas which can be used for fuel. (Kalinenko, Kuznetsov, Levitsky, Messerle, & al, 1993)

Pyrolysis is another new technology that is not used often commercially. Pyrolysis uses high heat (not as high as plasma gasification) to transform the waste materials; however it is more often used with pre-separated waste rather than mixed waste. Plastics that have been separated from other waste can be converted to a diesel like fuel through pyrolysis. This technology is expected to work well for plastics such as polyethylene and PS, but other plastics may cause difficulty. PET and PVC are not suitable for pyrolysis. Therefore it will be necessary for plastics being sent for pyrolysis to be separated similar to separation for recycling. (Ricardo - AEA, 2013)

Incineration of waste materials is a common practice in many countries throughout the world. In some countries incineration is comparable to recycling in regards to desirability and the materials incinerated are included in recycling figures. However, there are also those who feel incineration should not be advocated and that the environmental and economic impact of incineration outweighs the value.

Let's consider the details of incineration.

Section 1: Understanding Incineration Rates

The amount of waste sent to incineration varies significantly by region. In certain European countries, incineration rates of waste can be as high as 50%. The US incinerates significantly less, at 10% of municipal solid waste. (EPA, Municipal Solid Waste Generation, Recycling, and Disposal in the United States, Tables and Figures for 2012).

When reporting incineration rates, some countries include the figures as part of their recycling numbers, where other countries separate combustion into a separate category. Some reports do not specify if the combustion also included energy recovery which can be an important factor in evaluating the environmental value of incineration.

Obtaining the incineration rates for different regions can involve parsing data from several sources and possibly separating the incineration with energy recovery from that of incineration without energy recovery. Unfortunately, incineration figures are not readily available and it will require some effort to dig through numbers in order to understand how much of your company's waste is actually being disposed of in an incineration facility.

Section 2: Economics of Incineration

The cost to incinerate waste will be heavily dependent on the incineration technology utilized and the air emission requirements implemented. On average, municipal solid waste (MSW) incineration plants tend to be among the most expensive solid waste management options when environmental emissions are managed, even when the value of the resulting energy is considered. The implementation and operation of incinerators will require public funding or increased costs of waste disposal fees. (The World Bank, 1999)

Waste incineration facilities are expensive because they require highly skilled personnel and careful maintenance. The capital costs to build incineration facilities can be very high and the operation of the facility can also provide difficulty in economic sustainability. Combustion tends to be the least expensive from a capital and operational perspective, whereas gasification and pyrolysis are significantly more expensive.

Incineration through combustion can be less costly than recycling for many materials, including mixed plastics. Primarily this is because the plastic does not require any additional collection trucks, separation or processing prior to combustion. However, from a strictly financial perspective the biodegradation of mixed plastics in landfills is the least costly option.

Gasification and pyrolysis are both promising technologies for the conversion of plastic to fuel; however at this time there is no large scale commercial gasification or pyrolysis facilities due to the high cost, so these technologies are not covered here.

From an economic perspective, incineration of waste can be an expensive option for waste disposal and the costs to implement incineration should be weighed carefully against other waste disposal options.

Section 3: Environmental Impact of Incineration

Incineration of waste materials is a controversial subject from an environmental perspective. There are arguments that incineration is beneficial and other arguments that it is detrimental. Often the arguments from both sides have validity and sometimes they are referring to different technologies of incineration. The environmental impacts of incineration very significantly by the type of incineration and the control measures used at the facility to prevent pollutants from being released into environment.

It is important to note that gasification and pyrolysis both have the potential for a better environmental footprint over combustion incineration. The intense heat used in gasification and pyrolysis removes much of the toxins and results in fewer emissions. Combustion is the only form of incineration used on a commercial scale so the environmental impact discussed here is considered only from combustion incineration perspective.

The environmental effects of combustion are related to the feedstock. Most often combustion involves mixed waste rather than sorted materials. The combustion of mixed waste can create toxic ash that must be disposed of in a controlled hazardous landfill site. (Grundon, 2004) While the ash is an area of concern, the highest environmental risks are due to the emissions during combustion. (The World Bank, 1999)

Combustion produces dioxin and furan emissions that unless controlled pose health risks, most well-constructed and maintained facilities will filter the air to remove these before releasing the gas. Filtering can remove these toxins, but other toxic materials such as vanadium, manganese, chromium, nickel, arsenic, mercury, lead and cadmium can be more difficult to remove through filtering. And even after filtration, ultra-fine particles remain that are released into the atmosphere. (Godfrey, 2009)

These toxins and ultra-fine particles are shown to accumulate in the human body causing cancer, birth defects, asthma, emotional and behavioral problems and death. These health impacts have resulted in the Paris Appeal of 2004, 2006 and 2008 in which hundreds of scientists, 200,000 doctors, 68 international experts, the International Society of Doctors for the Environment and the medical organizations of 25 EU member states representing 2 million doctors, called for a moratorium on the building of any new incinerators in Europe. (Godfrey, 2009)

Often combustion is considered a good option to reduce the volume of waste going into landfills. However reports show that at least 25% of the mass entering a combustion facility comes out as ash volume and is sent to landfills. (Godfrey, 2009)

Overall there are environmental impacts to incineration that must be considered when evaluating the sustainability of incineration and the most common form of incineration is producing significant environmental impacts.

Section 4: Challenges of Incineration

Beyond the environmental and economic impacts of incineration, there are additional challenges to incinerating plastics. Incineration can take mixed waste just as it is provided from a consumer's trash but this mixed waste will produce additional toxins. There also is a social hurdle as some believe that widespread incineration will hinder the progress of recycling.

Another challenge is when combustion facilities take in mixed waste, but some of the waste will be of little energy value and may have high moisture content or may be toxic. Both of these can reduce the effectiveness of the system. Ideally, materials entering the combustion facility would be high energy items such as plastics and paper. These are also the items that if separated from other waste are most often recycled. But, if recycling and incineration both require sorting and processing of the same materials than which is the best option from an environmental and economic perspective? This will create a struggle between increasing recycling and increasing the efficiency of combustion.

There are concerns that using combustion as a method of landfill diversion can decrease the desire to recycle materials. The concern is that if the combustion of mixed plastics is less expensive than recycling mixed plastics there will be more incentive to incinerate the plastic than to recycle it. This concern is increased in areas where combustion incineration is included in the reports of recycled plastics. (Seltenrich, Incineration Versus Recycling: In Europe, A Debate Over Trash, 2013)

There is also social movement to ban the use of combustion incineration due to the potential health hazards. In 2009 the Paris Appeal requested a moratorium on any new incineration facilities (Godfrey, 2009). Some regions have banned the incineration of waste, including gasification and pyrolysis. In 2009 Hidalgo was the 4th Mexican state to ban the use of incinerators for municipal solid waste. (Tamborrell, 2009) That same year, incineration was banned in the Philippines after 9 years of community pressure stating the health and environmental impacts of incineration were too detrimental. (Farmaciaannunziata, 2009) Incineration bans have been proposed in other areas such as Rhode Island, Utah, New Zealand, Maryland, UK, and the greater EU.

Overall, there are challenges that must be addressed if incineration is to be a sustainable method for handling some of our waste materials. These challenges are environmental, health, economic and social.

Section 5: Sustainability with Incineration

Sustainability with incineration is primarily a community agenda, meaning that sustainability managers will have little influence over how incineration is managed. There is little action that a company can take in regards to incineration and the impact of plastics on incineration will not be determined by the product or packaging design.

Primarily, sustainability managers only control the design of their products and packaging. That design should include understanding how the materials will affect the disposal environment. While sustainability managers cannot control if their products and packaging will be landfilled, recycled or incinerated, they can ensure that they use materials that will biodegrade in landfills, are valuable if recycled and have energy value if incinerated.

Chapter 4: Composting of Plastic

Composting is a disposal method primarily for food and yard. With a growing focus in this area, there have been new plastics developed that are specifically designed to be commercially composted alongside food waste. The concept of composting these plastics is to produce a nutrient rich soil amendment that can be used for enriching depleted soil in gardening and farming. Although composting is a general term that relates to aerobic biodegradation, for purposes of this section we are referring to industrial composting only.

Compostable plastics have the potential to be a great part of an overall sustainable plastic strategy. Sustainability managers looking for product solutions that relate to composting may find that compostable plastics provide a beneficial alternative to traditional plastics. So, how can we make compostable plastics more sustainable?

What are Compostable Plastics?

Compostable plastics are not the same as traditional plastics. This may seem obvious to the polymer chemists out there, but for everyone else it is easy to think of plastics as being all the same. Each type of plastic has a very unique molecular structure, meaning they have very different characteristics. They will melt at different temperatures; some are hard and brittle while others are flexible and soft; plastics can be made from fossil fuel or out of plants such as corn, sugar cane and potatoes. Some plastics are made in nature while others are only created synthetically. Even more complex is that some plastics are inherently biodegradable while others are not and their biodegradability does not depend on if they are made from plants or fossil fuels.

> *Note: There is sometimes confusion regarding the differences between compostable, biodegradable, renewable and traditional plastics. To clarify this, traditional plastics are made from fossil based plant resources while bio-based/renewable plastics are made from recently living plant resources. Both of these refer only to what type of resource was used to create the plastic and most types of plastic can be made from either source. Biodegradable and compostable refer to how and where a plastic will biodegrade. Compostable plastics are those that will biodegrade in an industrial compost process within the time required for commercial resale of the final compost. Biodegradable plastics are plastics that will decompose through the action of naturally occurring living organisms, this can occur in many different environments such as; native soil, home compost, industrial compost, landfill, ocean, etc. Both biodegradable and compostable plastics can be manufactured from either renewable or fossil based sources.*

A popular compostable plastic (PLA) is made from corn rather than petroleum. This plastic is not as durable as traditional plastics and melts at very low temperatures (think of your car in the summer kind of heat). PLA doesn't have the same barrier properties, which means that they are not air and water tight as provided from traditional plastic. Additionally, the use of PLA can require more plastic than traditional plastic to make the same item.

However, compostable plastics also provide the opportunity to integrate plastics into composting of food waste which can be beneficial. In doing this, plastics need not be sorted from the food waste and this can make composting a simpler solution for commercial facilities that have large amounts of food waste. In commercial facilities it can be difficult to separate plastic from food waste, and in this scenario compostable plastic can be a good option.

Because compostable plastics are so much different than traditional plastics, they cannot be comingled in the recycle stream and they must be separated. Many of these plastics look and feel the same as traditional plastic so they are put in the recycle bin with traditional plastic. If these plastics are sent to a recycling facility they can damage equipment or make entire batches of recycled plastic worthless from contamination and result in it all being landfilled. In short, compostable plastics are not recyclable with traditional plastics.

Some facilities have the ability to sort out the valuable plastics and prevent the contamination of compostable plastics. Once sorted, these compostable plastics are not sent to a compost facility but are sent to the landfill where they are not designed to biodegrade.

Compostable plastics are different than traditional plastics, they are manufactured differently, they perform differently and they should be disposed of differently. Each of these factors is important to understand the overall sustainability profile of compostable plastics.

The Environmental Impact of Creating Renewable Plastics

Creating any product has an environmental impact; this includes both traditional plastics and compostable plastics. This section is going to specifically focus on renewable based plastics primarily because some feel that plastics made from plants are inherently better for the environment. Renewable plastics have environmental impacts; the key is to know what environmental impacts are involved so they can be assessed against traditional plastics.

Compostable plastics can be made from fossil fuels; however the most utilized compostable plastics are made from corn, potatoes and sugarcane. These plastics are often marketed more environmentally sustainable because they are renewable and compostable. The concept in using plants is that it would give the plastic a better environmental profile than it would have if the plastic were made from petroleum. We can make assumptions as to the environmental value, but to achieve sustainability we must evaluate the data.

First, we will take a look at PHA (Polyhydroxyalkanoate), a compostable polymer produced by bacterial fermentation of sugar or fat. There is widespread belief that PHAs are a sustainable alternative to traditional plastics because they are made from sugar and are biodegradable. However, in considering the full impact of making PHA we find that PHA fermentation process consumes 22% more steam, 19-times more electricity, and 7-times more water than it would to produce the same amount of traditional plastic (specifically polystyrene). Producing PHA consumes significantly more energy, releases more net greenhouse gases than conventional petrochemical polymer production.

Note: Even when some of the data seems similar, it is necessary to evaluate carefully. For instance, with PHA, reports often state that the consumption of fossil fuel is similar to the amount required to produce polystyrene. It takes 2.39 kg of fossil fuel to produce 1 kg of PHAs, and 2.26 kg of fossil fuel to produce an equal amount of polystyrene. This may seem like they are very similar, but what is not disclosed is that PHA production requires the combustion of the entire 2.39 kg for energy production, whereas polystyrene production combusts only 1 kg of the 2.26 kg fossil fuel and the remainder is the actual plastic. (The energy consumption estimates used in the analysis above are very conservative and far below those of other researchers who have assigned energy requirements to PHA fermentation processes that were 57% and 467% greater than those used in the present analysis for electricity and steam, respectively. If their values were used, the net effect would be fairly drastic, resulting in an overall fossil fuel consumption of 3.73 kg per kilogram of PHA). (Gernross, 1999)

When we look at another popular plastic, poly-lactic acid (PLA) which is made from corn (most often referred to as “corn plastic”) the overall sustainability comes into question again. A recent report by NatureWorks, a primary producer of PLA, clearly outlines the resources required and waste created to produce PLA.

To produce one kilogram of PLA plastic it requires 67MJ of energy, the equivalent of 1.0168kg of energy mass. But the resources required to manufacture PLA go far beyond the energy; it also requires 48kg of water and an additional 2.3kg of other raw material such as fertilizers and fossil resources. In evaluating the waste, each kilogram of PLA produces .27kg of solid waste, almost a kilogram of water and air toxins and 1.3kg of CO_2. Add up all these resources and waste and we find that to manufacture 1kg of PLA will require 51kg of resources and produce 2.5kg of waste! A system cannot be sustainable when the inputs are 51 times greater than the product itself and the wastes are over twice. (Erwin Vink, 2010)

Researchers at the University of Pittsburg found that biopolymers are among the most prolific polluters during their production. This is primarily due to the impacts of farming (agricultural fertilizers and pesticides, extensive land use for farming) and the intense chemical processing needed to convert plants into plastic. The cultivation of corn, the primary crop for plant based plastics, uses more nitrogen fertilizer, more herbicides and more insecticides than any other US crop; exhibiting the maximum contribution to water eutrophication (what happens when over fertilized water can no longer support life). It is clear that plant based plastics are not necessarily better than traditional ones. (Kelly, 2010)

Not only are plant based plastics possibly not better than traditional plastics, the environmental harm they create may be far more critical than that caused by traditional plastics. In Brazil, sugar cane is farmed to produce plant based plastics from ethanol. These farmlands are not only destroying vast areas of rain forests, but the burning of sugar cane prior to harvest produces a huge amount of emissions (air pollution). Epidemiological studies suggest that exposure to these emissions results in respiratory disease. The radiative forcing of the emissions may also have significant regional climate impacts. And according to researchers, climate change may be the least of our concerns. (C-C Tsao, 2011)

Earlier this year, a group of nearly two dozen researchers representing countries from around the world (Sweden, Australia, Denmark, Germany, UK, USA, Canada, South Africa, and Kenya) released a study identifying the most critical areas of concern regarding the environment. (Will Steffen, 2015) This study provides a method of prioritizing environmental impacts so that decisions are based on the most important and critical areas.

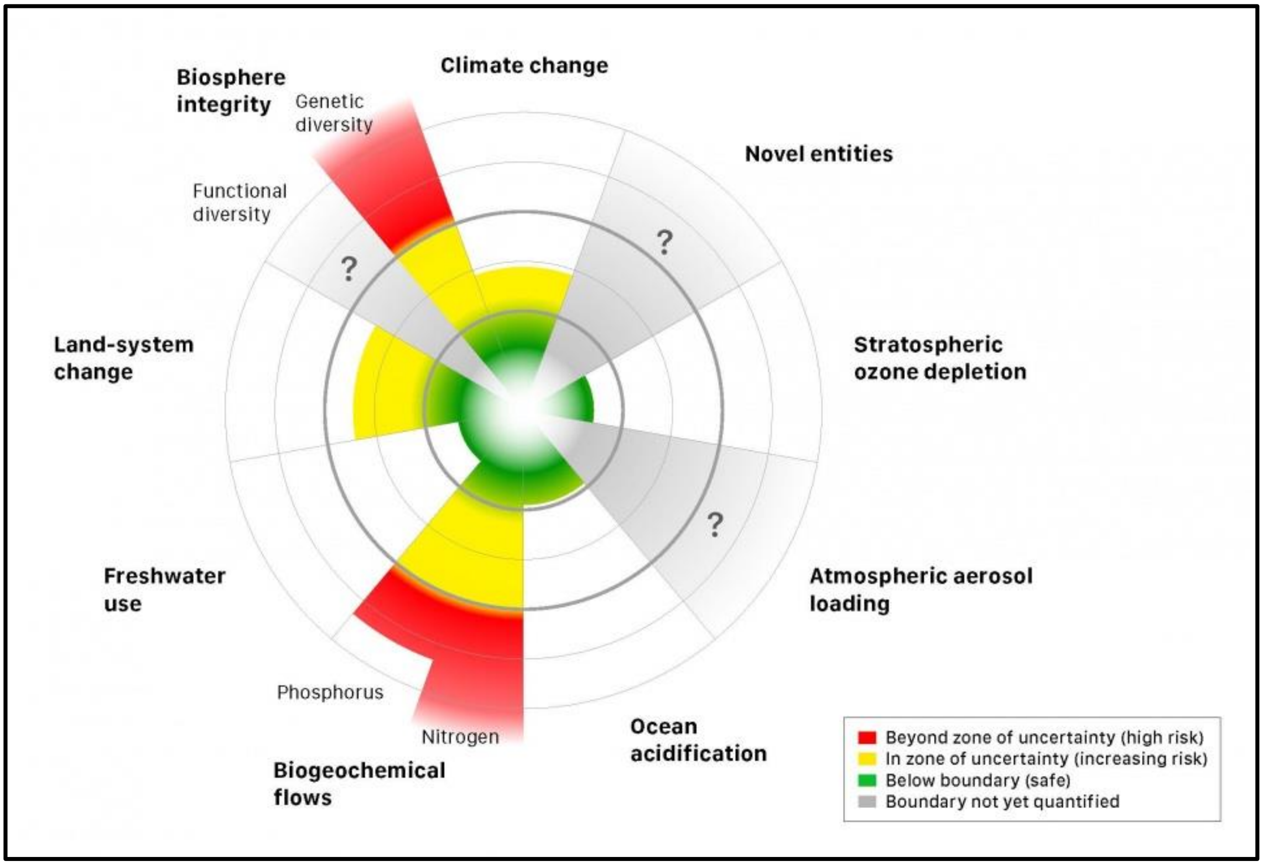

Figure 7: Planetary boundaries showing the highest areas of concern are nitrogen, phosphorous, genetic diversity all of which are in the zone of certain danger. Land system change is nearing the danger zone. All of these criteria are directly related to farming. (Will Stephen, 2015)

This study categorizes areas of environmental impact such as climate change, fresh water usage, biosphere integrity, land-system change, and ozone depletion. The purpose of this study was to assist societies with making decisions that will allow life on this planet to continue by addressing areas that are nearing tipping points of irreversible damage.

The results of this study showed that we are damaging the planet in ways that are worse than climate change. While we all hear about climate change and many sustainability programs are based on carbon footprint to reduce the contribution to climate change, it is seldom we hear about biosphere integrity, land-system change, phosphorous and nitrogen pollution or the importance of genetically unique materials; and yet these were found to be critical areas where we are destroying the resiliency of the earth and its ability to support life.

Genetically unique material means the variances in genetics both between different species of plants and animals as well as genetic diversity within species. This genetic diversity is the information bank that ultimately allows life to adapt and co-evolve with changing conditions. Genetic diversity provides the long-term capacity of the biosphere to persist under and adapt to abrupt and gradual abiotic change.

The importance of diversity is seen first-hand in farming when there are droughts and disease that affects a specific crop and the effect is devastating. Modern farming minimizes the genetic diversity by destroying areas of diversity and replacing it with identical crops. This not only creates a system with very little resilience, but is also destroying the ability of the earth as a whole to adapt.

Farming not only reduces the genetic diversity but also is the primary contributor to nitrogen (N) and phosphorous (P) pollution. These fertilizers add N and P to depleted soil to assist plant growth, but also put excessive nitrogen and phosphorous in the water runoff from irrigating crops. These fertilizers are devastating to our water and ocean systems because nitrogen and phosphorous cause water eutrophication, or the inability of bodies of water to support life.

Another direct impact toward sustainability is land-system change. This is the conversion of the three primary forest biomes (tropical, temperate and boreal), which control land surface-climate coupling (exchange of energy, water and momentum between the land surface and the atmosphere) and genetic diversity, to cropland. Our current rate of forest destruction is unprecedented, especially in tropical regions which have the largest affect to climate change when they are converted to non-forest systems. While land-system change is not yet in the high risk range, it will transgress this barrier shortly should we continue to expand farmland for non-food uses.

While this study clearly identifies risk levels of several categories, it also identified new areas of concern that do not yet have known risk levels. One of these is called “novel entities”. Novel entities are human developed substances and organisms for which we do not yet know the long term effects. Entities of concern are determined by the ability of the entity to persist in the environment, they can spread within the environment and they have a potential impact on the earth processes or life systems. This includes genetically engineered species released into the environment which are not naturally occurring. These global-scale experiments on the genetic codes of life are being performed on this planet through genetically modified crops (corn is a primary one that is used for plastics) and we have no concept of the long term danger.

The genetic diversity and nitrogen/phosphorous levels on this planet are currently beyond the tipping point of irreversible damage and land-use change is close behind. These areas of damage are almost solely due to farming. These are areas that are no longer in a zone of uncertainty as we still see with climate change; the current damage to genetic diversity and the N/P levels are a clear and present danger to life on this planet. Land system change will exceed the high risk zone very shortly. We are also increasing the use of genetically engineered crops that are disrupting the natural genetics of this planet. With this in mind, does it make sense from an environmental sustainability perspective to increase farming to support plastics production at the risk of planetary stability?

The impact of farming for plastics cannot be taken lightly, however this does not mean that using fossil fuel for plastics is the answer. Ideally, there should be a transition away from fossil fuels and toward sustainable sources for materials. Perhaps, farming just isn't the right direction.

With this perspective, there are some compostable plastics made from sources that can avoid excessive farming. One of these is thermoplastic starch based plastics such as ENSO RENEW that are made from potato starch. While potatoes are farmed, and the farming itself has the impacts described above, ENSO RENEW is made from the starch that is leftover after potato processing. In this way, the use of the starch does not increase the impact of farming, and it uses a material that may otherwise become waste.

Another interesting advancement that may prove to be a beneficial solution is in using methane produced in landfills and dairies as a source material for plastics. BASF has plans to open a methane-to-propylene manufacturing plant in 2019. Total Petrochemicals started their methane-to-propylene plant back in 2010 and there are others doing the same, such as UOP and Air Liquid. (Chang, 2014) Using methane to create plastics will be most effective environmentally if that methane is obtained from landfill gas or dairy farms. In this way, the source for the plastic is again a waste material that is being utilized and it has the benefit of reducing greenhouse gases that may otherwise be emitted.

There is also work in progress to make plastics from algae. Algae are unique in that they can use waste water and CO2 from industrial facilities and use these as a food source to grow. Just add sunlight and you have everything needed to grow algae. Some of the processes to grow algae include vertical systems that occupy minimal land space and other systems use open ponds that can integrate into more natural type habitats.

All of the data in this section is not to discourage the movement toward bio-based plastics, it is designed to shed light on the negative impacts that should be considered when selecting the type of plastic to use. Any plastic will have impacts, but we should prioritize which impacts are the highest priorities.

Section 1: Understanding Composting Rates

Compostable plastics have been in existence for some time but the commercialization of compostable plastics is fairly new. There is currently no infrastructure in place that allows for the inclusion of plastics in composting on a broad scale and as such, there are no reporting mechanisms to provide information as to how much, if any, compostable plastics are entering industrial compost facilities.

Over the last handful of years several studies have been performed by industrial compost facilities to evaluate the effectiveness of compostable plastics in industrial compost operations. The results of these studies were mixed and as such the current approach of most industrial compost facilities is not to accept compostable plastics.

At this time we are unable to provide information on how much, if any, plastic is actually being disposed through industrial composting.

Section 2: Economics of Composting

Economic factors must also be considered in a full sustainability profile. Implementing and maintaining a commercial composting program requires capital expenditures due to the collection, storage, processing and post–processing storage of compost. These higher operation costs can be overcome if the final product can be sold at a profit. In some regions the final compost is given for free or even used as daily cover in landfills. Most often commercial compost facilities are not profitable as the overhead is higher than the resale value.

Collecting material for commercial composting is expensive as it requires separate trucks travelling long distances to collect small amounts. The coalition for Resource Recovery found the cost of collecting waste for commercial composting in a city can be as high as $233 per ton. It costs twice as much to transport the material to compost as it does to landfill as there must be a separate truck to collect the material and that truck will travel more miles to collect the same amount of waste, which means increased fuel cost, more vehicle maintenance and more wages paid to collect the same amount of material. (Matt de la Houssaye)

In Pennsylvania, Upper Mt. Bethel Township was considering implementing a commercial compost program for yard trimmings. The assessment found that it would cost the township over $100K each year to operate the compost program – more if they paid the workers anything over minimum wage. (Environmental Resources Associates) This is just operational costs and does not include the extra cost to collect the material for composting. If we include the increased collection cost above, it would add an additional $73K of expense each year, totaling nearly $175K annually to have commercial composting in this township.

Operators of composting systems can overlook critical processes and cost factors. As a result, communities might adopt bad composting systems that produce strong, unpleasant odors, create toxic compost that has limited/no use, or that require much more investment than initially quoted. One of the primary contributions to the failure of organic composting programs is the lack of resell value and demand for the resulting compost. For example, in Virginia the compost program is operated by Environmental Solutions, a contract for that service costs $450,000– and there is no compost revenue. (Province, 2007)

Failure of commercial compost programs is an expensive situation for municipalities. Failure of a large composting system typically involves loss of about $30 million, according to Professor Melvin S. Finstein of Rutgers University. Notable failures include the Agripost facility in Dade County, Florida; the Reidel/Dano facility in Portland, Oregon; the Pembroke Pines facility in Florida; and the Pigeon Point facility in Delaware which operated for almost 10 years but was recently closed because of odors.

Most often, commercial composting is subsidized by the local community as an environmental service and method to obtain federal recycling guidelines rather than as an economically sustainable activity. The profitability of commercial compost facilities is difficult as the overhead is often higher than the resale value.

To make commercial composting economically sustainable markets should be developed or found that will bear the increased cost by purchasing the resulting compost, this is going to be directly tied to the quality of the compost. When not economically viable, residents, businesses and public/private entities will need to bear the burden of commercial composting expenditures.

Section 3: Environmental Impact of Composting

Industrial composting sounds like such a natural process, at first glance one may believe that it is the same process as happens in nature. Material biodegrades into great soil, new plants grow from the soil and the cycle of nature continues. With that perspective it would appear that adding plastics into the system would be a great idea. An evaluation of the effectiveness of composting plastics must include consideration of the economic impact, consumer impact and environmental impact. (Food, 1996) So, what are the environmental impacts of industrial composting?

One of the benefits cited for composting relates to reductions in carbon footprint. The environmental impact of composting from a greenhouse gas (GHG) perspective is most often due to the reduction of methane that would have otherwise been produced if the material was in a landfill. However, if a compost system is not strictly controlled, the decaying material will often still produce methane. Even well maintained compost will produce greenhouse gases.

While methane is typically reduced, the amount of nitric oxide can be higher with composting than with landfilling. Nitric oxide is created in compost due to the intense microbial activity and nitric oxide is 240 times more harmful than carbon dioxide ($CO2$) in contributing to global warming. Nitric oxide is also stable in the environment, meaning it will last for a long time, and contributes to the destruction of the ozone. (Barton & Atwater, 2002) (Food, 1996)

The greenhouse gas impact will depend on the type of waste composted. The end result of biodegradation is primarily $CO2$. Nearly 50% of organic waste will convert fairly rapidly to $CO2$; this is considered a fast to moderate degrading material. The other half will remain as carbon in the soil and slowly complete the biodegradation over several years to decades. This balance of fast and slow degrading portions creates valuable nutritious soil that is carbon rich can retain moisture and support plant growth, while also limiting the carbon emissions.

When comparing emissions from compost and landfilling, studies indicate the net GHG emissions from composting are lower than landfilling for food discards, but the opposite is true for yard trimmings. (EPA, Solid Waste Management and Greenhouse Gases, 2006) This is primarily due to the rapid degradation of food waste in landfills (meaning rapid conversion to methane) and the high percent of yard waste that decomposes slowly in compost - leaving carbon in the soil (humus). Slow degrading material represents approximately 52 percent of carbon in compost (EPA, Solid Waste Management and Greenhouse Gases, 2006). The slower degrading material provides the reduction in carbon footprint as well as the value of nutrients in the soil.

If we consider plastics in the compost environment, with compostable plastics there is no slow degrading portion as compost standards for plastic require a minimum 90% conversion to $CO2$ within 180 days (ASTM D6400), this prevents slower degrading portions of carbon remaining as humus. The value proposition for plastic materials is not the same as it is for food waste because less than 10% of the carbon can remain in the soil and the remaining 90% is required to convert rapidly to greenhouse gas. But, how does composting compare with modern landfilling from an environmental perspective, and which is the most beneficial route for plastic disposal?

There have been a number of studies conducted to compare the environmental impact of professional composting vs. landfill bioreactors. In these studies, the potential environmental impacts associated with aerobic composting vs. bioreactor landfills were assessed using the life cycle inventory (LCI) tool. The results are fairly consistent across the studies performed. These studies concluded that the emissions to air and water that contribute to human toxicity are greater for the composting option than for the landfill option and the landfill option yields greater energy savings due to the conversion of the landfill gas (LFG) to electrical energy.

One such study was conducted at the Michigan State University under the Fulbright Research Grant by Maria Theresa I. Cabaraban, Milind V. Khire and Evangelyn C. Alocilja and was later published in November 2007. Their study looked at the potential environmental impacts associated with aerobic in-vessel composting vs. bioreactor landfilling. The results showed that the estimated energy recovery from bioreactor landfilling was approximately 9.6 MJ per kg of waste.

The air emissions from in-vessel composting contributed to a global warming potential of 0.86 kg of CO2, compared to 1.54 kg of CO2 from the bioreactor landfill, meaning the compost produces less global warming gases. However, emissions to air and water that contribute to human toxicity were greater for the composting option than for the landfill. In addition, costs associated with in-vessel composting were about 6 times greater than that for the landfilling alternative. In conclusion, bioreactor landfill was a favorable option over in-vessel composting in regards to cost, overall energy use, and airborne and waterborne emissions.

Carbon footprint is often the deciding factor with environmental studies; however there are other impacts to the environment that are of more immediate consequence. One such factor is chemical pollutants. Commercial compost facilities produce leachate much like a landfill. This leachate contains soluble minerals, toxic organic chemicals, pesticides, organic colloids, pathogens and toxic metal (Cd, Cr, Cu, Hg, Pb, Ni, and Zn). This leachate is produced during the decomposition process in composting. Commercial compost facilities are required to control the leachate and prevent it from entering surrounding soil and water tables. Even compost runoff from rainwater is not allowed to be discharged without a permit.

Under oxygen-limited conditions, the decomposition process also produces methane, nitrogen oxides, volatile organic compounds, and ammonia. Feedstock high in nitrogen content tends to release considerable amounts of nitrogen oxides and ammonia if anaerobic conditions prevail in the compost pile. (Nirmalya Chatterjee, 2013) Ammonia production is inevitable in composting. Ammonia contributes to acid rain formation, contaminates surrounding areas with excess nitrogen and causes foul odors. (Food, 1996)

Note: The environmental impact of composting in the U.S. may be partially due to poor *regulations. The federal EPA [U.S. Environmental Protection Agency] has no regulations for quality of compost, and no plans for creating any. Under Section 503 of the Clean Water Act, EPA has created regulations for municipal sewage sludge and EPA takes the position that those regulations could apply to compost.*

Unfortunately, EPA used risk assessment to establish its standards for sewage sludge, and the resulting standards are very permissive. For example, EPA defines sewage sludge containing 300 parts per million (ppm) of toxic lead as "high quality" and allows it to be applied to agricultural land. A buildup of toxic lead in soils would almost certainly occur after prolonged use of compost containing 300 ppm of lead. In contrast, present Dutch regulations only allow 65 ppm lead in sludge or compost. Germany only allows 100 ppm of lead in compost. The Canadian guideline for lead in compost is 83 ppm.

The U.S. EPA's permissive standards will allow compost that is toxic to be defined as "clean" or "acceptable" or "high quality." Thus U.S. regulations may encourage production of compost that will poison soils, which will in the long run reduce public confidence in compost (and in government regulations). To succeed with composting, state and local governments will need to pay attention to the quality of compost themselves, and not be seduced by the dangerously permissive regulations of U.S. EPA.

When the full environmental impact of industrial composting is considered, we see that composting can produce greenhouse gases that are 240 times more damaging than carbon dioxide. Toxic leachate is produced that contains pesticides, toxic metals and other chemicals. And compost can produce foul odors.

Overall as was shown by Michigan State University, from an environmental perspective, composting is not always the ideal disposal method and for some materials, there are better options than composting. With industrial composting requiring double the amount of trucks covering the same routes, the infrastructure required to process the materials and the emissions from composting; the environmental impacts of industrial composting should be considered. This is not to imply that composting is always detrimental, as there are certain wastes that should be composted. We must look at the facts so educated decisions can be made regarding composting, and the full impact of composting can be understood.

Section 4: Challenges of Composting

Once we consider the economic and environmental impacts of composting, and provided for the scenario it appears beneficial, we then must look at the specifics of plastic in that compost. Composting of plastic introduces unique challenges beyond the economic and environmental factors inherent with composting organics. To compost plastics, we must only use specific types of plastic that will biodegrade in the compost, we must determine how to effectively sort compostable plastics so they are included in the compost materials, ensure there is not too much plastic in the compost and finally we must increase the availability and number of compost sites as well as the market for purchasing finished compost.

First, let’s look at how the plastics will get into the compost. There are a limited number of compost facilities that accept food waste, and even fewer that accept plastics in the food waste. Plastics are considered a contaminant regardless of their ability to compost. Some compost facilities will accept compostable plastics mixed with food waste as a necessary method to obtain the food waste. Simply put, they do not want plastic. Just try calling your local commercial composting site (if there is one near you) and asking them if you can bring by a truckload of compostable plastics to put in their windrows!

While composters do not want plastic, there are brands who still would like to compost the plastic. So let’s consider the logistics. Certain plastic products are often comingled with food waste, (i.e. utensils, plates and cups) so for these specific items it is fairly simple to just leave them with the food waste. If the food waste is already going to a compost facility it makes the composting of these plastics considerably easier.

It is also fairly simple to compost plastics in situations where there is a controlled environment such as a large facility, stadium or public event. In these places it can be much easier to control the types of plastics discarded at the location. This can allow a sustainability strategy to include only the use of plastics that integrate into composting. Just be sure that the compost facility is within close proximity to the controlled environment, otherwise the transportation could undermine the overall benefit.

Compostable plastics that are comingled with food waste or in a controlled environment account for a negligible percent of the overall plastic waste; for the rest of plastics composting becomes a much more complicated scenario.

For most plastics composting is not an option as they will not biodegrade in the compost. For the few types of plastics that are compostable but not already comingled with food waste, the process of going from a consumer’s possession to finally being composted can be more complex than most realize.

To enter a compost facility, plastics will need to be sorted from other trash, cleaned of any toxicity (soaps, chemicals, etc.) and then mixed with food waste. Then a separate truck will need to collect this waste and transport it to a commercial compost facility (which may be several hundred miles away). If and when the plastics get to the compost facility, they are often sorted out of the organic waste and shipped to the landfill. (Johnson T. , 2010) So, it can be difficult to get plastics into the industrial compost.

Commercial compost facilities are operations designed to rapidly break down organic materials into nutrient rich soil amendment for resale value. Materials entering these facilities should easily decompose, leave maximum humus (soil) and minimal to zero toxicity. Additionally, composting requires a balance of varying materials to create the proper carbon-nitrogen relationship to prevent delayed biodegradation, fermentation or depleted soils.

Getting the compostable plastics to the appropriate composting facility can be challenging, but there are other difficulties that can arise. Compostable plastics are not as durable as traditional plastics; so many times the compostable plastic is blended with traditional plastic. This is fairly common when looking at food-service ware because the compostable plastic melts in hot food and drinks. To overcome this, the manufacturer often blends in some traditional plastic during the manufacturing.

By blending traditional plastic with the compostable plastic, it no longer composts. However, it may be sold and marketed as compostable plastic. Some of these types of products advertise their ability to compost by putting certification logos on the product, but do not perform once put in compost. This was seen several years back with the Sun Chips bag, which received widespread publicity when the bag was shown not to biodegrade in compost as claimed. (Consumer Reports, 2010)

Another issue that can prevent compostable plastics from breaking down is the conditions of the compost itself. ASTM D6400 tests plastics at very high compost temperatures, much higher than many industrial compost facilities normally operate. This causes thermal degradation to plastics that may not occur in real world composting. When plastics thermally degrade, the resulting material can be biodegradable when the original plastic was not inherently biodegradable.

Earlier this year, Ithaca College banned all compostable plastics from their compost collection because the utensils labeled as compostable were not biodegrading in their compost system. Removal of the residual plastic in the compost cost $21,000 in 2014. (Meckley, 2015) In 2014, compostable foodservice plastics were banned from commercial organics collection in Portland, Oregon. (Kittlestone, 2014) And in 2010, the University of Vermont also banned compostable plastics in their organics collection for composting.

These are not isolated incidences, in 2010 a compostable plastics trial was conducted at Miramar Greenery compost facility. The test included 105 different products, plates, cups, bowls and cutlery all marketed as compostable and many certified through BPI. At the conclusion of the test only 37 of the 105 products were completely biodegraded. None of the compostable cutlery showed any signs of biodegradation. (Hailey, 2010)

In 2011, Intervale Compost Products banned biodegradable and compostable cutlery from compost collections, because not only were some of the products not biodegrading but also because the US Department of Agriculture considers plastics (including bioplastics) a synthetic material that cannot be used in organic agriculture. Organic agriculture is one of the larger purchasers of organic compost. Many organic farms use compost as a soil amendment, but compost that has had plastics in it, cannot be used. This reduces the ability of a compost facility selling finished compost at a profit. (Bormage, 2011)

To effectively include plastics in compost processes, several items must be controlled. Any plastic entering the compost system must biodegrade at a similar rate as the other organic material, it must not leave toxic or visually identifiable residue and it must not hinder the biodegradation of the other organics. Ideally, these plastics would biodegrade in the same manner as organic vegetation and leave the same nutrient rich soil. If there is more than a fraction of plastic in compost, even plastic that biodegrades, it can create an imbalance of carbon/nitrogen and inhibit biodegradation of the organics. As such it is important to control the amount of plastics entering commercial compost.

There are however, certain plastic items that could make the most environmental sense to compost – even given the challenges involved with composting plastics. Items such as spoons, forks, cups and plates that are used in an environment where they are very likely to be mixed with food waste and collected for industrial composting, are all good examples of products that should be considered for composting.

Section 5: Sustainability with Composting

Commercial composting can be a valuable part of an overall sustainability program when used for food and yard waste, it can also be beneficial for specific plastic items. However, compostable plastics and composting of plastics is not always the best option from both an economic and an environmental perspective.

First, the environmental impacts to create some compostable plastics can be higher than traditional plastics; and higher in ways that may be more damaging to the environment. Producing compostable plastics from crop plants requires an increase in commercial farming. Commercial farming is the primary contributor to our world's loss of species diversity, water pollution, and destruction of natural ecosystems. These factors are damaging the resiliency of the earth and are identified as more critical than global warming.

The environmental impact of compostable plastic production can be reduced with some of the newly developed processes and types of materials. This includes, plastics made from materials that would otherwise have become waste (such as ENSO RENEW), plastics from methane gas (Such as BASF's methane-to-propylene facility) and plastics from unique sources like algae. These are a good direction toward creating renewable and sustainable plastics.

Secondly, compostable plastics are not the same as traditional plastics. Often they do not have the same strength, may not protect the product as well as traditional plastics and can melt very easily at low temperatures, this can result in requiring more compostable plastic to do the same job as traditional plastics, higher environmental impact, increased risk of product failure and a requirement to keep the plastic in temperature controlled environments.

And, once we produce compostable plastics, they must be disposed of properly. Compostable plastics cannot be recycled together with traditional plastics because they cause damage to recycling equipment and contaminate the recycled plastics. Compostable plastics can be recycled, but require separate processing from other plastics. Most recyclers do not accept or recycle compostable plastics.

The proper disposal of compostable plastics is in an industrial compost facility. With the limited availability of industrial compost facilities it can be difficult for consumers to properly dispose of compostable plastics and as a result most compostable plastics will ultimately be thrown away into a landfill. In a landfill, the compostable plastics may not biodegrade effectively.

Compostable plastics typically do not pose a problem for commercial composting, provided they are in limited quantity. But, compostable plastics are also not of value to compost because the ASTM D6400 compost standard requires 90% or more of the carbon in the plastic to convert to carbon dioxide, there is little to no carbon remaining in the soil. This means little to no nutrient value to the compost or economic value for the compost facility.

This does not imply that we should not compost plastics, but that there are limited situations wherein composting of plastics is economically and environmentally best. Instead of widespread consumer use of compostable plastics, it is more effective, from an end-of-life perspective, to use compostable plastics in specific applications and environments such as restaurants, stadiums and event venues. In these environments it is feasible to comingle the compostable plastics with food waste provided there is an industrial compost facility within close proximity.

Part 3: What Does Nature Do With Waste?

A review of sustainability would be far from complete without discussing the processes of nature. The best sustainability platforms are modeled after nature and integrate into natural processes. This is because sustainability ultimately requires us to work in concert with all of the aspects of nature. Sustainability ultimately is measured by how well a process or product can either work in sync with nature or have no impact on nature.

We have explored the ways that human societies manage their waste products through landfilling, incineration, recycling and composting. But, how is waste handled in nature? There must be a very effective way to handle waste because every living creature and plant produces waste and yet the earth continues without any excessive buildup of this waste.

In nature, there is no waste because everything gets utilized in a system that is fully sustainable from which we should replicate our waste management practices. It is a process performed every day within nature. In nature, the waste products from one organism become the food for others, providing nutrients and energy while breaking down organic waste in a process called biodegradation.

Biodegradation is when materials are broken down from complex molecules into more simple ones. Biodegradation is nature's way of utilizing wastes, or breaking down organic matter into simple materials that can be used as food for other organism.

"Degradation" means decay, and the "bio-" prefix means that the decay is carried out by a huge assortment of bacteria, fungi, insects, worms, and other organisms that eat dead material and convert it into new forms. Some organic materials will biodegrade much faster than others, but all will eventually biodegrade.

The products of this biodegradation become the building blocks for other life processes. This is the same process used in composting. The food scraps and yard waste are broken down by microorganisms into nutrient rich soil, air and water. During composting when organic material is decomposed, it is often referred to as organic recycling, because we are taking the carbon based materials and turning them back into a form that is beneficial and useable in nature.

Microorganisms are by far the most effective and efficient re-processors on this planet. They make virtually all carbon based waste materials re-useable through the process of biodegradation. Biodegradation is the biological breakdown of organic materials by microorganisms into soil, water, and air.

To biodegrade complex and synthetic materials, microorganisms secrete special enzymes that catalyze the degradation and break the material into more simple components such as organic acids. These organic acids are then further degraded by other microorganisms in to the basic building blocks of nature; air, soil and water.

Biodegradation can happen fast or slow and the speed of biodegradation depends on interactions between the environment, the number and type of microorganisms present and the chemical structure of the compound(s) being biodegraded. (Board, 1999) Oxygen, moisture, nutrients and microorganisms are very often the limiting factors in soils.

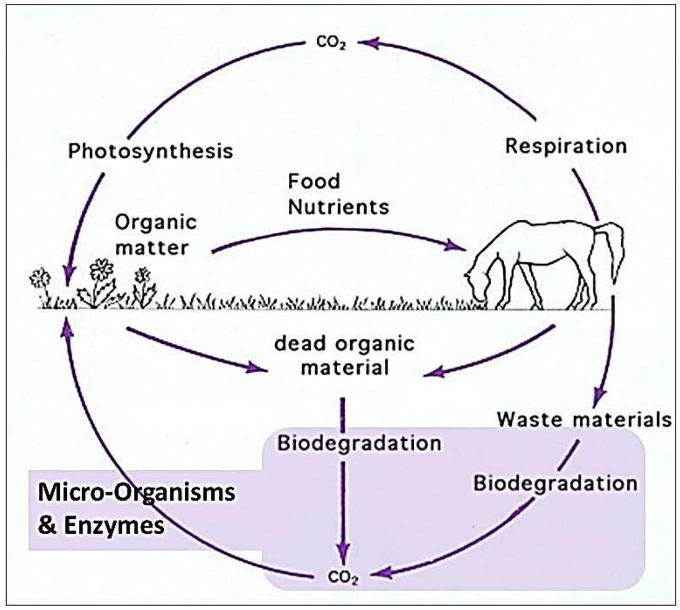

Figure 8: Natural carbon cycle made possible through biodegradation caused by microbial produced enzymes

While microorganisms can degrade most natural compounds, they often don't produce the appropriate enzymes to degrade many synthetics (man-made materials such as chemicals and plastics). Over thousands of years, microorganisms have evolved to produce the correct type of enzymes that will match natural materials and allow for biodegradation. As humans create new materials (these are called synthetic materials), there has not been enough time for microorganisms to evolve and adapt to these new materials, so they do not produce the correct enzymes.

Producing the correct enzyme to biodegrade a material is critical. This is because enzymes are very specific, meaning that an enzyme must match the material it is intended to degrade, if it does not then the enzyme will have no effect. Enzymes are much like a lock and key, the enzyme being the key and the material to be biodegraded is the lock. Only if the key is a correct match, can it can release the lock.

Over time, microorganisms adapt to new materials and learn to produce the correct enzymes. An example of this evolution has been seen in polyethylene contaminated soil at the polyethylene production plant of Carmel Olefins in Israel. Polyethylene is considered non-biodegradable; however after many years of polyethylene contamination in the soil at that factory, it was found that the microorganisms evolved to biodegrade polyethylene. (D. Hadad, 2004)

Biodegradation of waste materials constitute one of the most important processes in water, sediment, soil and other ecosystems. There is significant concern regarding synthetic materials that are not readily biodegradable and not only remain for a very long time but can accumulate over time to dangerous levels. (Board, 1999)

By harnessing these natural forces of biodegradation, it is possible to reduce the environmental contaminants caused by synthetic materials and chemicals. This is a process called bio-remediation, or remediating/detoxifying through natural biological processes. This can be accomplished through enhanced bio-remediation which involves increasing the rate of biodegradation by supplying required nutrients to an indigenous microbial population (bio-stimulation) or by inoculating the site with microorganisms capable of degrading the target pollutant (bio-augmentation). Biodegradation is currently used within waste management for organic waste, sewage, landfills, oil spills and other human produced contaminants.

Biodegradation is the key within nature to convert waste products into a resource. Through biodegradation all organic materials are broken down into forms that are useable for other organisms to complete a full circle of sustainability. Biodegradation is currently used to convert many human wastes into natural materials such as nutrient rich soil, air and water.

Through composting, natural biodegradation is accelerated to convert organic wastes to soil amendments. Wastewater treatment also accelerates natural forces of biodegradation to break down organic matter so that it will not cause pollution problems when the water is released into the environment. Landfills harness biodegradation to convert organic matter into energy and eliminate contaminants that could otherwise leach into groundwater and soil. Micro-organisms are used to clean up oil spills and other types of organic pollution.

Each of these is an example of bio-remediation, which is the use of naturally occurring processes to decrease human pollutants within the environment. Sustainability managers should learn from and replicate how waste is handled within nature. In doing so they would either ensure their products are either recycled after use or fit within natural processes of biodegradation so they will return to a natural form. This is the most effective way to achieve long-term sustainability of product wastes.

Part 4: Mimicking Nature with Biodegradable Plastics

Nature processes all waste through biodegradation. The process of biodegradation takes complex materials and breaks them down to simpler forms which are used by other living organisms. This is a sustainable process that converts waste materials into resources. As humans, we must learn to replicate this process of waste management to be sustainable.

Today we as a society create many synthetic materials by taking natural products and rearranging the molecules in a way to create materials with specific properties. This is beneficial from a use perspective as the new materials are very useful; however once we have used the material it often remains in the synthetic form and does not readily integrate back into nature.

Plastics are a perfect example; they are created from natural materials that are readily biodegradable in nature. After we have rearranged the molecules to create the plastic it is no longer readily biodegradable and once disposed of will remain for hundreds or thousands of years. This prevents the molecules within the plastic from integrating back into nature and becoming useable for other living organisms.

This can be overcome by creating plastics that are readily biodegradable and will biodegrade after use in the disposal environment. Biodegradable plastics can include new forms of plastic, but also includes traditional plastics that utilize technologies that increase the rate of plastic biodegradation.

Ultimately, as a responsible society we need to ensure our waste materials will integrate effectively back into natural processes. This means only create synthetic materials that we know will return to nature in a useable form.

Chapter 1 provides education on different types of plastics that are often confused; degradable, biodegradable and compostable plastics. Chapter 2 reviews methods to biodegrade traditional plastics and also as most plastics are disposed of in landfills this chapter discusses how biodegradable plastics can integrate into landfill operations to provide a steady source of clean energy.

Chapter 1: Defining Degradable, Biodegradable and Compostable

There is often confusion when discussing biodegradable plastics because there are many terms that are confused with the word "biodegradable". These are terms like, oxo-degradable, oxo-biodegradable, compostable, home compostable, industrial compostable, degradable, photo-degradable, thermal-degradable, etc. Each of these terms describes a different type of material and a different type of breakdown. These terms should not be used interchangeably.

It should also be understood that these terms all refer to the way a plastic can break down; it has no relevance on if the plastic is made from renewable or fossil based sources.

In clarifying the meaning of these words, we will start with the broadest category; degradable plastics.

Section 1: Degradable Plastics

Degradable plastics are simply plastics that will lose strength and other physical properties due to exposure to a specific trigger over a designated period of time. This is a very general category that includes all the other terms. The breakdown can be caused by living organisms, exposure to oxygen, light, heat, or water.

To know what causes the degradation, there is often a prefix on the word; **bio**-degradable (degradation caused by living organisms), **photo-**degradable (degradation caused by exposure to light), **oxo-**degradable (degradation caused by oxygen exposure), **hydro-**degradable (degradation caused by exposure to water).

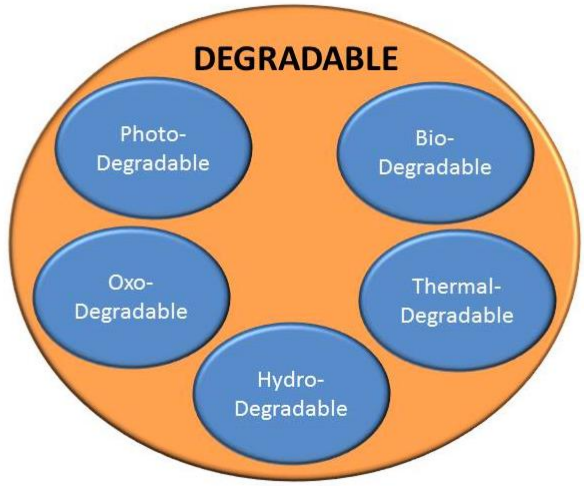

Figure 9: Degradable plastic is a category that encompasses many forms of breakdown.

All plastics will degrade over time as they are exposed to light and heat, but when these terms are used in plastic, it means that the plastic will degrade faster than traditional plastic. Plastics can break down into many forms. They can break down into small plastics fragments or they can break down into non-plastic residue such as soil, air, or water. Often this depends on the cause of the degradation.

Section 1.1: Photo-degradable Plastics

Photo-degradable plastics are plastics that degrade with exposure to light. Most often this is caused by the UV spectrum of sunlight. If you have ever tried to pick up a plastic grocery bag that has been on the side of the road and have it fall apart and crumble in your hands, this is an example to photo-degradation.

There are some plastics such as six-ring holders for soda cans that have additives put into the plastic to accelerate the photo-degradation. This means it will become brittle and fragment into smaller and smaller pieces as it is exposed to UV light. Photo-degradable plastic requires much less UV exposure than traditional plastics do to degrade.

Photo-degradation does not imply that the plastic itself is gone; it simply breaks it into very small fragments.

Section 1.2: Oxo-degradable Plastics

Oxo-degradable plastics are plastics that break down by exposure to oxygen in the air. Plastics are made oxo-degradable through the use of additives in the plastic. The additives are most often metals or salts that create weak links in the plastic molecule. Because the strength of plastics is due to their very long molecule chains, these weak links when exposed to oxygen begin to break and weaken the plastic.

This degradation is very similar to photo-degradation in that both result in a weakening of the plastic molecule and fragmentation of the plastic into smaller and smaller pieces.

There are some plastics marketed as oxo-biodegradable plastics which claim to biodegrade after the fragmentation (oxo-degradation). This may be theoretically possible, but sustainability managers that use these types of plastics should ensure that the plastic will have sufficient exposure to oxygen so that it will fragment prior to disposal. However, they must also be careful that the plastic will not have exposure during storage or use of the plastic. Premature degradation could risk product failure and products contaminated with plastic fragments.

Oxo-degradable plastics do not degrade in landfills. They are strictly intended for plastics that are littered and are designed to reduce the visible impact of litter.

Oxo-degradable plastics can prematurely degrade if recycled. Recycling requires melting the plastic and the heat from melting will trigger the oxo-degradable additive and cause degradation of the plastic.

Oxo-degradable additives should not be used for plastics that will most likely be landfilled or recycled.

Section 1.3: Hydro-degradable Plastics

Hydro-degradable plastics are plastics that degrade in contact with water. These plastics can degrade quickly or over a longer period of time. For hydro-degradable plastics the catalyst for degradation is water. Very often these plastics will eventually biodegrade.

Sometimes biodegradable plastics are misclassified as hydro-degradable plastics. However, biodegradable plastics require living organisms to catalyze the biodegradation whereas hydro-degradable plastics only require water.

Hydro-degradable plastics are not as common as other types of degradable plastics.

Section 1.4: Thermal-degradable Plastics

Thermal degradable polymers are plastics that degrade due to heat. While all plastic will degrade with heat, thermal degradable plastics typically have additives that make the plastic degrade more quickly when exposed to heat.

Some plastics such as PLA, are considered commercially compostable, when they are actually thermally degradable. They can be classified as commercially compostable plastic because the heat of a commercial compost facility is very high and the PLA will thermally degrades into chemicals that will biodegrade. So while PLA is not biodegradable, the products of its thermal degradation are biodegradable.

Thermally degradable plastics are not recyclable with traditional plastics because recycling requires melting of the plastic and the heat from melting will degrade the plastic and make it unusable. These plastics can technically be recycled but it will require separation from traditional plastics and a market for the recycled resin.

Section 2: Biodegradable and Compostable Plastics

Bio-degradable plastics are plastics that degrade through the action of naturally occurring organisms. They break down similar to other organic materials, like leaves and wood.

They will biodegrade at different rates depending on the environment, but they must break down into base materials, such as soil, air and water. Biodegradable plastics do not leave plastic fragments.

There are several categories of biodegradable plastics that identify the environment where the plastics will biodegrade. These include home compostable, industrial compostable and landfill biodegradable plastics. Biodegradable plastics can also degrade in soil, such as when littered, these are covered in the Home Compostable section below.

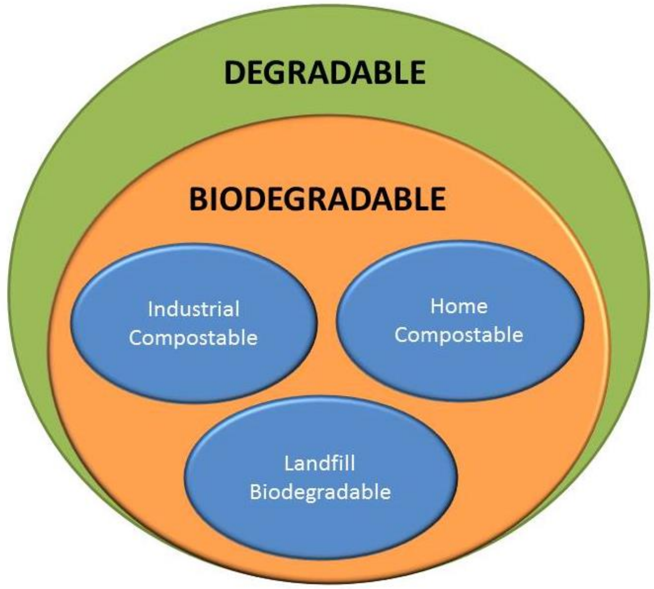

Figure 10: Biodegradable plastics include home compostable, industrial compostable and landfill biodegradable plastics.

Section 2.1: Home Compostable Plastics

Home compostable plastics are biodegradable plastics that will biodegrade in home or backyard compost piles. These plastics will biodegrade in oxygen rich environments where other organic material is breaking down. If leaves and grass will biodegrade in an environment, then home compostable plastics should biodegrade as well.

Plastics that will biodegrade in home compost will also degrade if buried in soil. This would apply to plastics that may be littered in the open environment.

Home compostable plastics should biodegrade in a similar time frame as other organic material. They also require the same conditions as most organic material for biodegradation to occur. A good rule of thumb is, if other organic material is breaking down around it, home compostable plastics will most likely biodegrade as well.

Home compostable plastics should not leave any toxic residue in the soil after biodegradation.

Section 2.2: Industrial Compostable Plastics

Industrial compostable plastics, also known as commercially compostable plastics, are plastics that biodegrade in the controlled conditions of a commercial/industrial compost facility. This is not the same as a home compost and plastics that biodegrade in an industrial compost will not necessarily biodegrade in home compost. Additionally, industrial compostable products may not biodegrade in a landfill.

Industrial compostable plastics often require very high heat to initiate breakdown (see thermal-degradable plastics) and the breakdown is followed by biodegradation. Many compostable plastics are not biodegradable in any environment except industrial compost facilities.

ASTM D6400 is a specification for industrial compostable plastics. It requires that at minimum 90% of the plastic converts to carbon dioxide within 180 days. This means that the plastic must nearly entirely convert to air, which leaves no nutrients in the soil. ASTM D6400 also requires that toxicity tests be performed to ensure that there is no toxic residue in the compost. The primary focus of ASTM D6400 is to make sure the plastic does not interfere with the commercial aspects of industrial compost operations.

Industrial composting is a man-made managed environment; it is not an environment that occurs in nature. In industrial compost, conditions are optimized to maximize the rate of biodegradation so that the compost can be sold as quickly as possible. This means, high heat, controlled moisture, optimal oxygen flow, balanced carbon/nitrogen ratios and a multitude of other conditions that are monitored and controlled.

Because industrial composting is not a natural environment, plastics that biodegrade in this environment may not biodegrade in other environments such as, soil, backyard compost, landfills, oceans and roadsides. Therefore, the biodegradation of industrial compostable plastics are only beneficial when the plastic will be disposed of in an industrial compost facility.

Section 2.3: Landfill Biodegradable Plastics

Landfill biodegradable plastics are plastics that will biodegrade in a landfill environment. Landfills are considered one of the more difficult places to achieve biodegradation; there is little to no oxygen, no light, reduced moisture and the materials are under pressure. Most often a material that will biodegrade in a landfill, will biodegrade in soil, compost and other natural environments (though not always in the time frame needed for industrial business purposes).

Landfill biodegradable plastics should biodegrade within 2-50 years; this is much longer than the time restriction for industrial compostable plastics. This is because a landfill does not need to have material ready to sell in a short period of time like an industrial compost facility would. The primary factor for landfill biodegradable plastics is that they biodegrade in the landfill using the microorganisms that are naturally occurring in the landfill and they biodegrade without need for exposure to light, oxygen or heat.

There are several tests used to verify the biodegradability of plastics in the landfill, ASTM D5511, ASTM D5526 and Biochemical Methane Potential testing. Each of these tests validates biodegradability in landfills by measuring the conversion of the plastic to carbon dioxide and methane. The ASTM D5511 and Biochemical Methane Potential tests show accelerated results in ideal conditions and the ASTM D5526 is meant to more closely replicate the conditions in a landfill to provide more realistic time frames for biodegradation.

Landfill biodegradable plastics are an important part of an overall sustainability strategy because 90% of all plastics end up in landfills and landfill biodegradable plastics provide a means to ensure the positive end-of-life for that plastic.

Chapter 2: Biodegrading traditional plastics

Plastics are a key development for modern society, however, they also have the negative impact of not biodegrading – they last for hundreds to thousands of years. In learning to replicate natural processes, it is apparent that plastics should be biodegradable. It is also clear that they should be biodegradable in the landfill because that is where most plastics will be deposited.

To create biodegradable plastics, there are two primary areas of focus: create new plastics with inherent biodegradability or utilize microorganisms with the ability to biodegrade plastics so traditional plastics will be biodegradable.

There are many new plastics that are biodegradable. Some of these plastics may hold great promise for the future of plastics. There are others that lack the properties we require of plastics; these ones are weaker, more expensive and not as good as traditional plastics. Many of these plastics are considered "compostable plastics". The environmental impact to produce these plastics is reviewed in the section "Creating Compostable Plastics".

Most of the newer inherently biodegradable plastics are still in the development process. There are improvements being developed that will make inherently biodegradable plastics more similar in performance and durability to traditional plastics without affecting the biodegradability. And, increasing production to commercial scale so pricing can be reduced and make the materials more economically feasible. Ultimately, some of these plastics will find success in the market but there is still some work to be done before they can replace traditional plastics on a broad scale.

The most promising area for biodegradable plastics is in making traditional plastics biodegradable utilizing naturally occurring microorganisms in the traditional waste disposal environment. So how can a synthetic fossil fuel based material ever be biodegradable?

There is a common misconception that it is impossible for traditional plastics to biodegrade. This stems from a lack of knowledge regarding polymer chemistry and microbiology; plastics are often considered synthetic materials, yet a look at the atomic composition reveals that the polymer chain is comprised of primarily carbon and hydrogen – the same primary materials in natural organic materials. The difference between natural and synthetic materials is simply the configuration of the atoms. With the correct enzymes, any carbon based material has the opportunity to biodegrade in the same manner as plant matter.

Traditional plastics are made from fossil fuels and most often petroleum. Many people believe that petroleum is a horrible chemical that we extract from the earth. But, petroleum is simply fossilized algae. What this means is that petroleum and fossil fuels are plants, just like the plants that grow today, that have been fossilized. The carbon and hydrogen that make up fossil fuel is the same as the carbon and hydrogen that make up plant matter.

While the carbon and hydrogen atoms are the same, when we make plastics we are rearranging the atoms. We arrange the atoms into molecules like ethylene and propylene. Ethylene and propylene are still biodegradable. However, in the next step we take these molecules and polymerize them.

Polymerization is taking smaller molecules, like ethylene and propylene, and connecting them together into very long chains. This creates polyethylene and polypropylene (-poly means many, so many ethylenes and many propylenes). Once in these very long chains, they are no longer considered inherently biodegradable because the molecule is too big for microorganisms to work with. To biodegrade it, first the microbes will need to produce the right enzymes to release the bonds holding the chain together. But, these are fairly new materials and the microorganisms are not producing the right enzymes to allow biodegradation.

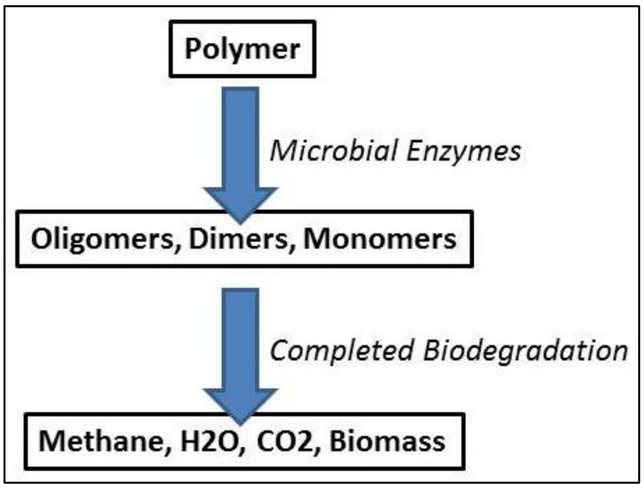

Figure 11: Process of polymer biodegradation

Over the years, there have been concerted efforts to understand microbial plastic biodegradation. It is known that bacteria as well as fungi are capable of biodegrading plastic, but that plastic biodegradation is a slow process. Historically it was believed that the biodegradation of the plastic backbone was initiated by oxidative cleavage and hydrolysis (Sudhakar, 2007) of the carbon bonds (G. N. Onyeagoro, 2012). More recently, isolated strains of bacteria have been identified that are able to secrete extracellular enzymes capable of biodegrading plastic.

Once the microorganisms secrete the correct extra-cellular enzymes, those enzymes begin to shorten the polymer chain. The resulting low molecular weight materials are then further utilized by the microorganism as carbon and energy sources. The ultimate products of this biodegradation are CO_2, CH_4 (in anaerobic conditions), H_2O and biomass.

For the benefit of managing our plastic waste, we must have biodegradation occur within a time period that is beneficial for the specific environment. For example, if plastics are put into a commercial compost facility, the plastic should biodegrade as rapidly as possible and in no more than 180 days. This is because commercial composting is a business activity and they need to sell the compost within 180 days. If there are plastics remaining in the compost, the compost facility will need to filter out the plastics and further process the compost. This increases the cost and time required before the compost can be sold. So, for composting the key driving factor in the rate of biodegradation is the resell value of the compost.

For plastics that are in a landfill, the biodegradation must be slower than compost. If the plastic biodegrades similar to compost, in 180 days, then the gas that is produced during biodegradation will be released into the atmosphere. Ideally, plastics in the landfill should biodegrade within 2-50 years (the time during which a landfill is actively managed and methane is captured). Ideally, the plastic needs to biodegrade in the same manner and time frame as slower degrading organic materials like yard waste would in the landfill environment.

We know that most all plastics are going into a landfill, and that these plastics need to biodegrade within 2-50 years. But, traditional plastics take hundreds of years to biodegrade. To solve this, a technology has been developed that increases the rate of plastic biodegradation in the landfill.

As we discuss this technology, keep in mind that plastics are made of carbon and hydrogen from fossilized plants and the only reason they don't easily biodegrade is because the polymer chain is so long and the microorganisms aren't familiar with producing the right enzymes needed to biodegrade the plastic. So rather than change the plastic, what if we can teach the microorganisms how to produce the right enzymes?

This advancement is unique in that it does exactly that! Older concepts tried to alter the plastic molecule but this caused weak plastics that did not work well and often fell apart before they were ever used. The modern method is to work directly with the naturally occurring microorganisms that are already in the landfill and encourage the production of plastic biodegrading enzymes.

ENSO RESTORE™ is one such method which employs a unique blend of materials designed to not only attract specific naturally occurring microorganisms, but to induce rapid microbial acclimatization to synthetic plastics and resulting biodegradation. In simple terms, this means that by exposing microorganisms to specific types of materials we can alter the types of enzymes they produce. And we can induce the right types of enzymes that will biodegrade the plastic.

The benefit of this method of enhancing biodegradation is in the retention of the plastic properties. We can have the same strength, durability and low cost that we do with traditional plastics. And, the plastic will remain intact throughout its service life and will biodegrade only upon disposal in the landfill or an environment with active microbial diversity.

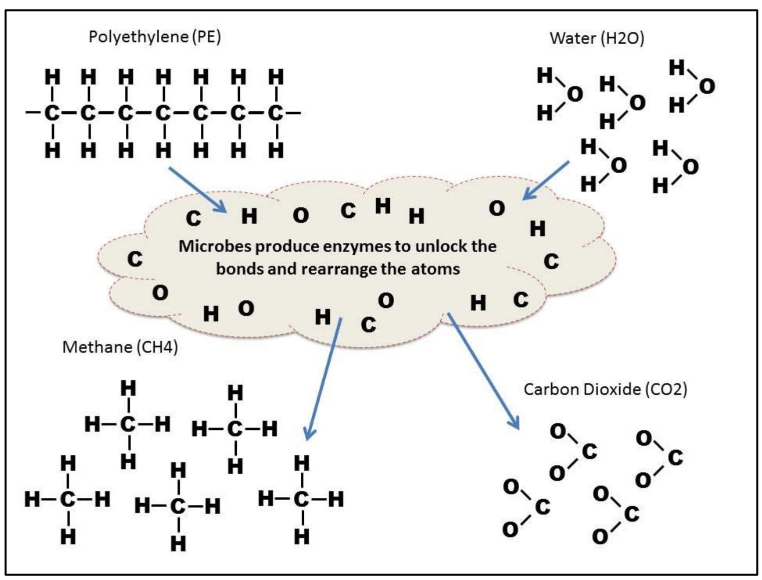

Figure 12: Microbes utilize enzymes to release atomic bonds and rearrange the atomic structure of materials

Once the plastic is deposited in the landfill, the action begins. Naturally occurring microorganisms are attracted to the plastic and the technology induces the production of plastic biodegrading enzymes. These enzymes effectively depolymerize the plastic and allow the conversion of the plastic into natural components - the same end products resulting from the biodegradation of plant matter.

The biodegradation is faster because when microorganisms come in contact with plastic using technologies, such as ENSO RESTORE™, they have a readily available energy source and that energy source causes them to begin producing specific types of enzymes. The enzymes they produce are exactly the ones needed to biodegrade plastic.

This is a method of biodegradation designed to integrate into landfills. The process works very effectively in the conditions of a modern landfill, and allows all the benefits of traditional plastics. By utilizing natural biodegradation within the landfill and doing it in the optimal time, we not only return plastics to a natural form but we also create clean energy.

Let’s discuss what that energy profile would look like.

Section 1: Creating Energy through Biodegradation of Landfilled Plastic

Understanding that billions of pounds of plastics are disposed of within landfills, and also that the current trend worldwide is the capture and use of landfill gas (methane) to produce power, it is a logical conclusion that converting this landfilled plastic to methane is an optimal energy strategy. We can either leave traditional plastics as they are, and they will slowly biodegrade over hundreds of years, releasing methane directly into the atmosphere, or we can use technologies like ENSO RESTORE™ to biodegrade the plastic faster so the methane can be a resource for communities. Either way, the methane will be produced – why not utilize it?

The value of landfill gas is well understood and currently utilized statewide, federally and throughout the world. Landfill gas is part of many renewable energy strategies and it also reduces the overall greenhouse gas emissions of a community. Including plastics in this process is a natural progression that maximizes the value of our energy from landfills and also of the plastics themselves.

How much energy would we produce by using biodegradable plastics in the landfill?

In the US, we landfill 63.6 billion pounds of plastic each year. If this plastic[3] was biodegradable in the landfill and was placed in landfills converting methane to energy, the 63.6 billion pounds landfilled each year would produce **66.2 trillion Btu**.[4]

This is a significant amount of energy, but to many people the term BTU is foreign and hard to understand what impact that really is. If we are to look at the energy value from using biodegradable plastics in the landfill in terms more understandable, we have the following:

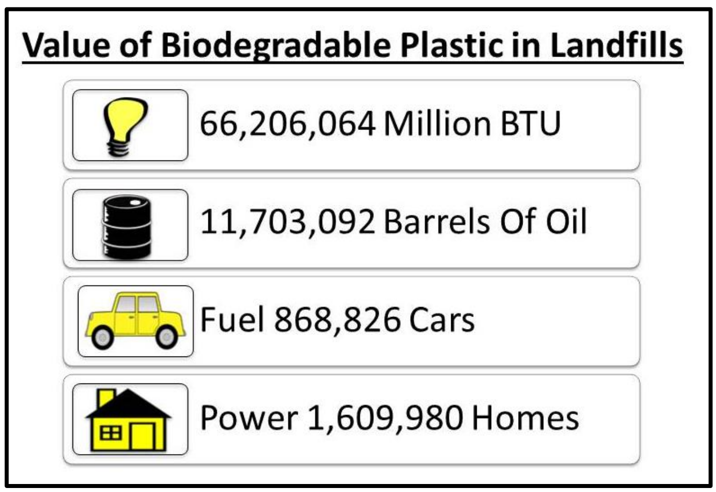

Figure 13: Energy/fuel value of biodegradable plastics in landfill gas energy projects (US only)

[3] To calculate the energy value one must know the actual carbon content and methane conversion ratio of each discarded material, for purposes of this report we will use an average of 86% carbon for synthetic plastics.

[4] To calculate how much energy can be created from the biodegradation of landfilled plastic waste we take the total weight of plastic waste (69,850,000,000lbs), remove the 9% recovered for recycling and we are left with 63,563,500,000lbs landfilled annually. We then multiply it by % carbon (approximately 90%), multiply by 1.33 (molecular weight of CH_4 16 / molecular weight of carbon 12 – this converts the carbon to methane), then multiply by 22.4 (L/g – ideal gas law). This will provide the volume of methane potential, which we then convert to cubic meters (1,704,315,412m3 or 60,187,330,726ft3). Assuming that the gas production is approximately 70% methane and 30% carbon dioxide, we then multiply by .7 to achieve the actual methane potential value. The energy value is calculated using an average of 7 barrels per TOE and the 1TOE energy equivalent of 39.68 million Btu as defined by the US EIA.

Biodegradable plastics in landfills converting methane to energy would save an equivalent to 11,703,092 barrels of oil, be enough energy to fuel the annual usage of 868,826 cars[5] or provide power to 1,609,980 homes each year[6]

This means that by biodegrading our plastics in energy generating landfills, we could power 20% of all the homes in New York, all of the homes in Oregon or power all of the homes in Nevada, North Dakota and South Dakota!

These energy values are only the direct conversion of the methane resulting from landfill biodegradation. Calculating the overall energy/carbon savings considering the offsetting of coal produced energy, the reduced transportation cost by remaining integrated with municipal waste, and the avoided energy of handling/reprocessing in alternative methods, the actual realized benefit would be far greater.

With the current pressure on energy utilities to convert from coal to more “green” energy sources, utilizing biodegradable plastics as a way to increase the energy output of landfills should be a very serious consideration.

[5] 1 barrel of oil = 42 gallons: driving 1400 km (840 miles) in average car, the average vehicle miles traveled in 2011 was 11,318 miles per year, equivalent is 13.47 barrels/vehicle/year - US EPA

[6] Average home electricity use in US (2013) - 12,069Kwh

Part 5: Testing and Validation for Degradable, Biodegradable and Compostable Plastics

Sustainability managers need to make decisions based on factual data, an important part of that data is validating the performance of materials. The validation when referring to degradation and biodegradation will be in the form of laboratory testing. To evaluate data and validation, one must know what test methods are available and which ones will apply to a specific product and disposal environment.

There are several methods employed to study the degradation and biodegradation of plastics. If one is looking to confirm degradability, than tests are used that measure the change in physical characteristics such as; physical weight loss, disintegration, brittleness, fragmentation or molecular weight.

To test biodegradation, the most effective and accurate measurement is that of gas production. This is because the gas production is the result of microbes taking the carbon atoms in the plastic and converting them into carbon dioxide and/or methane. Gas production is not seen when plastic simply fragments, so measuring gas production confirms the microorganisms are breaking the plastic apart, not exposure to other elements such as water, heat, light or oxygen.

The appropriate test for a plastic is determined by where that plastic is most likely to be disposed. To test a plastic for industrial compostability when the plastic will be disposed of in a landfill does absolutely no good, it will not validate the products customary disposal and end-of-life environment. Therefore, for sustainability managers, the first objective is to determine the most likely place your plastic will be sent, and then require testing based on that environment.

It is also important to understand the test reports and what to look for. Some organizations promote that 90-100% of the carbon in the plastic must convert to gas during testing to prove biodegradability. This is a misconception based on the industrial compostable plastic requirements of the ASTM D6400. Remember the key to D6400 is to validate plastics will not impact the commercial value of compost, so the key is to have the plastic “disappear” or convert as completely as possible to air/gases.

When considering biodegradation in general, converting all the carbon is not as important as it is to validate that the microorganisms in the disposal environment have the ability to biodegrade the plastic. This is because the plastic is made up of the same molecules throughout, meaning that a polyethylene molecule in plastic is the same as the

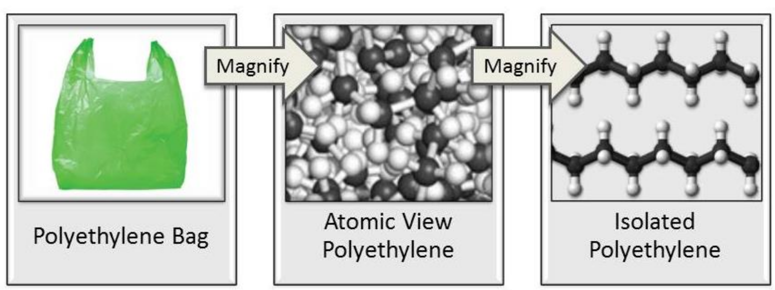

Figure 14: Magnification of a polyethylene bag shows how it is made of millions of identical polyethylene molecules that all have the same properties and the same biodegradability. If one molecule of polyethylene biodegrades, so will the others.

rest of the polyethylene molecules. If the microorganisms can biodegrade one of the polyethylene molecules, then they will also biodegrade the rest.

Note: When looking at the biodegradation percentage of plastic, while there is no need to achieve complete biodegradation or any specific percentage of biodegradation during the test, it is important to exceed the percentage of any additives put into the plastic. This will ensure that the plastic molecule is biodegrading and not just the additives.

Many falsely represent biodegradability testing by stating that the only test for biodegradability is ASTM D6400. However, as we have established the ASTM D6400 relates only to plastics entering into an industrial compost facility; it does not confirm biodegradability in any other environment. Thus, ASTM D6400 should only be used to validate industrial compostability of plastics.

Testing for degradability or biodegradability should be relative to the final disposal environment to ensure performance during real world scenarios. For plastics entering an industrial compost facility, ASTM D6400 is the most appropriate testing. Plastics that will most likely be placed into a landfill should be tested using landfill based conditions as are used in ASTM D5526, ASTM D5511 and Biochemical Methane Potential tests.

The testing should also take into account what you are testing for; are you looking to see degradability /fragmentation or biodegradability? If biodegradability is your goal, then tests that measure conversion of the plastic to gas such as, ASTM D6400, ASTM D5526, ASTM D5511 and Biochemical Methane Potential, should be used. If the desire is to break the plastic into small pieces, then degradable tests such as ASTM D5272, D5208 and D7473 should be used.

Part 5 is organized into 3 chapters, each focusing on testing of a specific category. Chapter 1 will cover what degradable tests measure and ASTM tests specifically related to degradable plastics. In chapter 2 we look at tests that measure the biodegradability of plastic. Chapter 2 also contains a special section relating to the importance of microbial diversity in testing that can assist laboratories and sustainability managers in performing valid biodegradation tests. Chapter 3 will address testing for industrial composting of plastics.

Chapter 1: Degradable Testing

Remember, degradable plastics are those that break into smaller and smaller pieces when exposed to specific triggers such as UV light, heat and oxygen. Testing for degradation of plastic is to determine how a specific condition will deteriorate the strength of the plastic. These tests typically expose the plastic to a condition that would stimulate degradation and then measure the result by weight loss, brittleness, fragmentation or reduced molecular weight (meaning that the plastic molecules have broken into smaller pieces).

Some tests that measure the degradability of plastic include; ASTM D5272, ASTM D5208, ASTM D7473 and ASTM D6954.

ASTM D5272 - Standard Practice for Outdoor Exposure of Photo-degradable Plastics

This is a test for degradation caused by exposure to UV light. In the laboratory the plastic is put under lamps that simulate prolonged exposure to the sun's UV light. Degradation is measured by reduction in molecular weight of the plastic and brittleness of the plastic. This tests if a plastic will degrade/fragment if left in the open environment where it is exposed to natural sunlight for extended period of time.

This is an appropriate test for photo-degradable plastics that are expected to be littered and the desire is to have the plastic become brittle and then break into smaller and smaller pieces as it sits exposed to the sunlight. This test does not measure biodegradability or verify if the plastic will have toxic effects on the surrounding soil and biota.

ASTM D5208- Standard Practice for Fluorescent Ultraviolet (UV) Exposure of Photo-degradable Plastics

This test is designed to measure the degradation of plastic when littered in the open environment or roadside. This test is performed in a laboratory by exposing the plastic to heat, UV light and moisture. After exposure the plastic is measured to see if it has lost strength and become brittle or broken into small pieces.

This is an appropriate test to perform if you have an oxo-degradable, thermal degradable or photo-degradable plastic that will be littered and the desire is to have the plastic become brittle and then break into smaller and smaller pieces as it sits exposed to the sunlight, oxygen and moisture. This test does not measure biodegradability or verify if the plastic will have toxic effects on the surrounding soil and biota.

ASTM D7473 - Standard Test Method for Weight Attrition of Plastic Materials in the Marine Environment by Open System Aquarium Incubations.

This test is used to measure how much weight is lost when a plastic is exposed to sea water. This can include weight loss from small fragments of plastic leaving the plastic product, the plastic dissolving in the water, or biodegradation of the plastic – however it does not determine which is actually happening. This test only determines if the plastic is losing weight.

This is an appropriate test for hydro-degradable plastics that will be littered in the ocean and you want to know if it will remain in one large piece, or if it will get smaller. This test does not determine how the plastic is losing weight (fragmenting, biodegrading, dissolving), it only identifies if the plastic will lose weight.

ASTM D6954 - The ASTM D6954 is the Standard Guide for Exposing and Testing Plastics that Degrade in the Environment by a combination of Oxidation and Biodegradation.

This is a hybrid test that first exposes the plastic to heat, light and oxygen to fragment the plastic into a plastic powder, and then checks the resulting powder for biodegradability in soil, landfill or industrial compost.

This testing is appropriate for plastics that will be littered or exposed to sunlight, heat and oxygen for extended periods of time before biodegradation is expected. This can be used for plastics that are used as soil cover or agricultural films that will be exposed to the elements and is not expected to be removed for disposal.

> *Note: If the plastic will ultimately be disposed of in a landfill or industrial compost, it may be impossible to collect or contain the plastic once it is in a powder form so it is important to ensure there is a collection method that can expose the plastic to sunlight, heat and oxygen for a sufficient time to fragment it into a powder, and then contain it for transportation to the industrial compost or landfill.*

This test does not verify if the plastic will biodegrade if it is landfilled or composted prior to the plastic degrading to a powder. If the plastic will not be exposed to sufficient light, heat and oxygen prior to disposal – this is not an appropriate test.

This is an appropriate test for oxo-degradable plastics that are marketed as oxo-biodegradable that are expected to be littered in the environment.

Chapter 2: Biodegradable Testing

Biodegradable tests are designed to verify the ability of microorganisms to break down plastic into air, soil and water. These tests measure biodegradation by how much of the carbon in the plastic is converted to carbon dioxide or methane.

Biodegradation testing is more robust and more sensitive than degradation testing. This is because there are more variables involved and the tests include living organisms (microorganisms). This means that not only the conditions of the test be monitored but also variables that could affect the behavior or types of microorganisms in the test must be addressed.

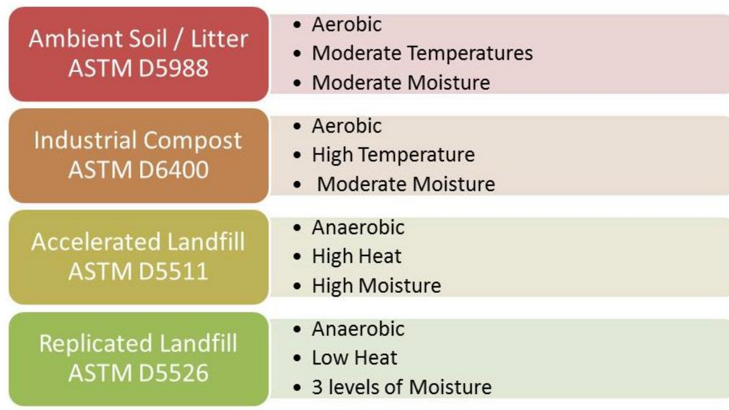

Figure 15: Biodegradation tests attempt to replicate specific environments to ensure biodegradation will occur in real world applications.

When testing with microorganisms it is important to understand microbiology. Sustainability managers don't need to know the details of microbiology; that is the laboratory's responsibility. However it will be beneficial to understand that microorganisms are everywhere. There are more microorganisms in a spoonful of dirt than there are people on this earth. There are also millions of different types of microorganisms; so many that we have yet to identify even a fraction of the microorganisms on this planet.

There are different types of microorganisms in home compost, when compared to industrial compost and different ones still in the landfill. This is because in each of these environments the temperature, moisture and oxygen levels are different. Some microorganisms that thrive in home compost will die if exposed to the high heat of industrial compost conditions. Many of the microorganisms that exist in home compost and industrial compost cannot survive in the landfill where there is limited oxygen.

The microorganisms in each of these environments will also adjust based on the food source available. For instance, if there is a large amount of cellulose in the environment than microorganisms that easily digest cellulose will populate and the microorganisms that do not digest cellulose will die off. If the food source changes the types of microorganisms will adjust based on the food source so the ones that can digest the new food source will be the most prevalent.

This makes the testing of biodegradation very sensitive to what type of food source the soil has been exposed to as well as what environmental conditions it was prepared in. Biodegradation tests are designed to replicate the appropriate environmental conditions and ensure the soil has been exposed to food sources that are expected to be available in the disposal environment replicated.

Note: Some laboratories that do not understand the microbiology details erroneously use incorrect inoculum or inoculum that has not been exposed to the diverse food sources that will be available in the actual disposal environment. This can cause invalid results. See section titled "Importance of Microbial Diversity in Testing" for further understanding on this topic.

The two primary categories for biodegradable plastic tests are aerobic and anaerobic, meaning with oxygen and without oxygen. The biodegradation pathway is different in aerobic vs. anaerobic environments. In general, a material that will biodegrade anaerobically, will also biodegrade aerobically; but the reverse is not true. Biodegradation anaerobically is typically much more difficult, so materials that will biodegrade aerobically do not necessarily biodegrade anaerobically.

Aerobic testing includes ASTM D5988 and ASTM D6400. The ASTM D6400 uses the high heat of industrial composting which biodegrades materials as fast as possible, whereas the ASTM D5988 is ambient temperatures as would be found in natural soil environments which can be slower more natural biodegradation. Therefore the biodegradation results with ASTM D6400 vs. ASTM D5988 are usually much faster.

Anaerobic biodegradation testing includes ASTM D5511, ASTM D5526 and Bio-chemical Methane Potential (BMP) testing. The ASTM D5511 and BMP tests have optimal conditions to biodegrade materials as fast as possible in an anaerobic environment, therefore the biodegradation results with ASTM D5511 and BMP tests are typically much faster than the ASTM D5526.

Section 1: Importance of Microbial Diversity in Testing

It is the microbial processes that govern the biodegradation of materials and the resulting gas generation. (Associates) That means that the biodegradation of plastic is controlled by the microorganisms around it. When testing plastics for biodegradation, the activity and types of microorganisms will often determine the results of the test. For this reason it is important to run tests that not only replicate the disposal environment but that also have maximum microbial diversity. If the correct types or quantities of microorganisms are not in the test inoculum than the test may fail even though the plastic will in fact biodegrade in the actual disposal environment.

For compost testing, both home and industrial, it is fairly simple to create inoculum with similar microbial population as is found in these environments because they are fairly controlled; meaning that the food source is typically limited to organic materials (plant matter) and the conditions are controlled (temperature, moisture, oxygen availability). Because the food source is limited to plant matter in the actual disposal environments, a laboratory can easily create compost from plant waste and have microbial populations very similar to the real world environments.

Testing for landfills requires a more thorough understanding of microbiology for the laboratory. Because all different types of waste is disposed of within landfills (organics, chemicals, metals, plastics, and minerals), the types of microorganisms are much more divers than in composting. This is because the food source is much more diverse. The microorganisms also must be those that can survive in limited oxygen environments.

Within landfills, many types of microorganisms have been identified that contribute to the biodegradation of materials and resulting methane production. It is also well recognized that only a fraction of these microorganisms have been identified and even fewer are cultivable in the laboratory. This means that most of the microorganisms that thrive in the landfill, do not survive in the laboratory. Thus many laboratories struggle with biodegradation testing related to landfill conditions due to a lack of expertise in microbiology.

Though not presented in this paper, it is recognized that laboratories who source inoculum from in-house processes very likely have limited diversity in microorganisms leading to inaccurate test results. This is because of the inability to cultivate a vast majority of microorganisms that dwell in a landfill within a laboratory. This is also due to the problematic nature of attempting to simulate the organic/inorganic matrix within a landfill, the different types of materials in a landfill are so varied that it is difficult to replicate in a laboratory.

Laboratories that do not understand landfill microbiology often mistaken that microbial flora within native soil, compost or anaerobic digesters are adequate for landfill biodegradation testing. Compost and soil contain significant colony forming units and have a wide variety of bacteria and fungi that are optimized within aerobic environments, but not in anaerobic ones. Anaerobic digesters most commonly use plant and vegetation waste so although they do encourage the growth of anaerobic microorganisms, the system lacks the varied food sources that would be available to microorganisms in a landfill and so the resulting microbial flora is limited to those that digest plant matter. To perform landfill tests using this type of inoculum lacks scientific credibility and renders the results of testing invalid.

In these scenarios it is far more common to observe false negatives due to inadequate microbial diversity as opposed to false positives. To avoid false negatives and provide more valid test results, laboratories can utilize landfill leachate as a basis for inoculum used for landfill biodegradation tests. The landfill leachate will provide a better, though not complete, distribution of the types and quantities of microorganisms that occur in actual landfills. Laboratories undertaking biodegradation testing of landfills will find repeatable results by obtaining microbial flora from landfill leachate. It is not recommended that laboratories utilize inoculum produced in-house for landfill testing.

Another limitation to be considered is the use of commercially produced cellulose as a test sample to measure microbial activity. It has been found that commercially produced cellulose can have up to 10X greater activity than the level indicated by the vendor. (Barlaz, Microbiology of Solid Waste, 1996)

Cellulose is used in biodegradation testing to validate that there are viable microorganisms in the inoculum. If the cellulose biodegrades faster than advertised or expected, the laboratory could falsely identify inoculum as viable when in fact the microorganisms are lacking. This can cause false negatives, but is not as common as false negatives due to a lack of microbial diversity in the inoculum.

In short, laboratories performing testing should take great care to ensure that the microorganisms in their test soil are as diverse as possible and reflect the microbial flora that exists in the environment to be tested. Different microorganisms thrive on different types of materials, so if a laboratory creates inoculum using manure or vegetable waste only then the primary microorganisms will be those that thrive on manure and vegetable waste. To try and test for biodegradation of plastic in this environment would very likely provide false negative results simply because there is limited diversity in their inoculum.

For testing of compostable plastics, both home and industrial compost, the inoculum should be created using primarily food and yard waste. This can be done by using compost from an industrial compost facility or by creating the inoculum in-house with the use of food and yard materials.

If a laboratory is testing for a landfill environment, there are many diverse materials including plastics, metals, rubber, food, chemicals, paper, wood, etc., in the landfill and this means that the microorganisms that thrive there will be diverse as well. As such, a laboratory should prepare inoculum either using landfill leachate or in other ways ensure that the inoculum is exposed to this wide variety of materials for a time sufficient to ensure the growth and colonization of a diverse array of microorganisms that would normally be found in a landfill. This will provide the most reliable biodegradation test results for confirmation of real world application.

ASTM D5988 - Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials in Soil

ASTM D5988 is a test that measures the biodegradability of plastic that is littered or buried in soil. The test measures the complete biodegradation of the plastic molecule into carbon dioxide, the endpoint of aerobic biodegradation.

This test is appropriate for plastics that will be buried or littered in the soil and the ultimate biodegradation of the plastic is important. Because the test measures biodegradation by conversion of the carbon in the plastic to carbon dioxide, there is no concern for plastic fragments remaining in the soil. An example of an appropriate application would be agricultural soil covers where the desire is to leave the plastic in the soil and ensure it completely biodegrades.

ASTM D5526 - Standard Test Method for Determining Anaerobic Biodegradation of Plastic Materials under Accelerated Landfill Conditions

ASTM D5526 is the test that measures biodegradability of plastics that are disposed of in the landfill. It measures the conversion of carbon from the plastic into carbon dioxide and methane, the end points of anaerobic microbial biodegradation. This is the most appropriate test for plastics that will ultimately be landfilled.

In landfills, moisture is a critical factor to how fast materials will biodegrade, however in landfills moisture will vary depending on the region and landfill design. For this purpose, the ASTM D5526 test is performed at three different moisture levels representing a very dry landfill (such as would be seen in a desert region), a very wet landfill (as would be seen in tropical region) and a moderately moist landfill (an average of moisture rates across various landfills).

The ASTM D5526 test is performed under pressure, with lower temperatures and without oxygen as would be seen in a landfill. This test is meant to replicate the environment of a landfill as closely as possible and give more realistic biodegradation rates than other landfill tests.

The ASTM D5526 test is the most appropriate test for plastics that will end up in a landfill. With 90 percent of plastics being disposed of in a landfill, the ASTM D5526 is the most appropriate test for the majority of plastic products.

ASTM D5511 - Standard Test Method for Determining Anaerobic Biodegradation of Plastic Materials under High-Solids Anaerobic-Digestion Conditions

The ASTM D5511 test measures the biodegradation of plastic in landfills that have high moisture and optimize biodegradation as well as biodegradation in anaerobic digesters. The ASTM D5511 measures biodegradation by the conversion of carbon in the plastic to carbon dioxide and methane.

The ASTM D551 test uses higher moisture and higher heat than the ASTM D5526, but the test is still anaerobic. Whereas the ASTM D5526 test uses multiple moisture rates to demonstrate how the moisture will change the rate of biodegradation in a landfill, the ASTM D5511 is meant to simply determine biodegradation in an optimal anaerobic environment.

Biodegradation rates in the ASTM D5511 are typically faster than the rates seen in the ASTM D5526 for the same material; this is because the ASTM D5511 is more optimal conditions for biodegradation. So while the determination of landfill biodegradability can be made using the ASTM D5511, the actual rate of biodegradation in the landfill will most likely be much slower than the test results indicate.

The ASTM D5511 test is appropriate for plastics that will be landfilled or disposed of in an anaerobic digester.

Biochemical Methane Potential

Biochemical methane potential (BMP) testing is an anaerobic test used by researchers and academia worldwide to study the biodegradation of materials in landfills. The BMP test is similar to the ASTM D5511 in that it uses optimal conditions to try and biodegrade materials as quickly as possible. The BMP test is meant to determine if materials will biodegrade in the landfill, but not determine how fast.

The BMP test is not a standardized test method, so there is more flexibility in the test protocol to adjust parameters as desired to evaluate different scenarios. The BMP is the test of choice for many researchers and academia due to the flexibility of the test parameters.

The BMP test typically utilizes higher temperature and moisture as is done in the ASTM D5511 and the test is anaerobic like the ASTM D5511. Often the test is run nearly identical to the ASTM D5511 with the exception of the sample size; the plastic sample and amount of inoculum on the test is reduced to minimize the space required in the laboratory. Another adjustment can be to recirculate the leachate during the test period to replicate a bioreactor landfill.

The BMP test is most often used as a litmus test to determine the biodegradability of a material.

Chapter 3: Compostable Testing

Compostability of plastics typically refers to industrial compostability. The conditions in a compost facility are unique because the environment is highly controlled to accelerate biodegradation as quickly as possible. One of the factors that accelerated the biodegradation is very high heat; this heat often thermally degrades plastic which can make it more readily biodegradable.

Industrial compostability testing validates biodegradability in industrial compost facilities only; it does not verify biodegradability in landfills, home compost or ambient soil.

ASTM D6400 - Standard Specification for Compostable Plastics

ASTM D6400 is designed to ensure that plastics intended for an industrial compost facility will biodegrade very rapidly and leave no trace or toxicity in the compost soil. This test uses very high heat and controlled moisture/oxygen levels to replicate a high temperature industrial compost facility.

ASTM D6400 includes testing for fragmentation, biodegradability and verifying that there is no residual toxicity. This is a specification rather than a test because it includes specific performance time frames and parameters to pass the specification. The ASTM D6400 was created to ensure plastics would not compromise the commercial aspects of industrial composting, for this purpose it is important to have specified time frames for biodegradation.

Some plastics that are not inherently biodegradable can pass the ASTM D6400 if after an initial degradation the plastic biodegrades. This is seen with PLA that is not biodegradable until after an initial thermal degradation. The temperatures in an industrial compost facility are hot enough to thermally degrade PLA. After the thermal degradation, PLA will biodegrade and pass the test. This is the primary reason that many plastics that are industrial compostable are not compostable in a back yard. In backyard compost the temperature will almost never reach as high as an industrial compost environment.

ASTM D6400 does not validate biodegradability for any environments outside of industrial composting, including landfilling, littering, marine disposal or home composting. Some companies misrepresent biodegradability testing, stating that the only test for biodegradability is ASTM D6400. However, ASTM D6400 relates to industrial compostability; it does not confirm biodegradability in any other environment.

ASTM D6400 is an appropriate protocol to use for plastics that will be placed into an industrial compost facility after use.

Part 6: Environmental Marketing of Plastics

As sustainability managers move their company into more sustainable materials and practices, there is a desire to communicate this progression to consumers and the market in the form of marketing. A successful company will build a sustainability platform that encompasses many aspects of the company rather than focusing on a specific attribute of one product. In essence, they market a sustainable company rather than a standard company trying to sell a sustainable product. Even with this approach, companies may choose to highlight the features of a product through specific marketing.

Marketing, especially in the sustainability arena, should be accurate, clear and understandable to the consumer. This will involve understanding the information presented in previous chapters, including where the plastic will go after use. Meaning, the marketing should relate to where the plastic will actually be disposed.

Marketing claims should always include the customary disposal environment of the product or packaging. This is not always the same as the optimal disposal. A company may produce a product or packaging that they want to be recycled, but if it is most likely to be disposed of in a landfill than the marketing must reflect the landfill disposal.

For example: a plastic fork is going to be in a stadium where all utensils are collected with food waste and sent to a compost; claims of recyclability should not be made – even when it is made from a plastic that is technically recyclable. Likewise, a fork made from a compostable plastic when sold in an environment where it will be disposed of in a landfill, should not have a claim of compostability.

While the details of how to appropriately market specific aspects of sustainability may vary, the overall theme remains the same; keep your marketing message easily understood and accurate. Validation for specific claims of performance requires reliable scientific evidence. If your marketing claim could easily be misinterpreted, provide enough clarification to avoid misinterpretation of the claim.

This clarification is considered a “qualification” and it makes the difference between a qualified claim and an unqualified claim. Unqualified claims are often scrutinized because they can be confusing and misleading. Qualified claims clearly state enough detail about the claim to specify the specific attribute and benefit you are marketing.

An example of an unqualified claim vs. qualified claim would be:

A plastic trash bag made of plastic that has been tested using ASTM D5526 with results of 61% biodegradation in 205 days during that test.

- An unqualified claim would be to simply label the bag as “**Biodegradable**”.
- A qualified claim would label the bag as “**Landfill Biodegradable***” and include the qualifying

statement “***ASTM D5526 testing showed up to 61% biodegradation within 205 days**”

The qualifying statement provides additional information to clarify the customary disposal environment where the bags will biodegrade and what biodegradation performance could be expected. You will notice that the qualifier does not interpret the test results or make claims beyond the scientific validation.

Additionally, a marketing claim should be applicable to the real world scenario, meaning that a claim should be based on the current processes and technologies used in handling of discarded materials. This will ensure that the benefit claimed in marketing will actually be achieved.

For example: A plastic bag made of HDPE. HDPE is one of the two common recycled plastics. A bag marketed as recyclable would be misleading because most recycling facilities do not regularly accept HDPE in a bag form. So while the bag is made out of a recyclable plastic, it is not a recyclable product because there are no readily available recycling facilities that accept and process HDPE bags. A claim of recyclability would mislead consumers and the public into believing that there is an environmental benefit to the bag in the form of recyclability, when in fact there is not.

The primary focus with marketing is to showcase beneficial attributes of your product. Your marketing should clearly convey what those attributes are without overstating the environmental benefit.

Section 1: General Environmental Claims

General marketing claims of environmental benefit are phrases such as; green, earth friendly or sustainable. These types of claims are very broad and give the impression of a wide scope environmental benefit, and imply that all the aspects of the product are beneficial for the environment.

These types of claims can be used, but should always have a qualifying statement to clarify why your product is more beneficial. The qualifying statement should clearly identify what specific environmental benefit your product provides and that you have the reliable scientific validation to back up the claim.

The US Federal Trade Commission's 2013 Updated Green Guides state, "not to make unqualified general environmental benefit claims because ''it is highly unlikely that marketers can substantiate all reasonable interpretations of these claims.'' The Guides further provide that marketers may be able to qualify general environmental benefit claims to focus consumers on the specific environmental benefits that they can substantiate. In doing so, marketers should use clear and prominent qualifying language to convey that a general environmental claim refers only to a specific and limited environmental benefit(s)." (Register, 2012)

So, it is OK to use general claims as part of your overall marketing, just be sure to provide enough information (qualifiers) to explain what you mean by the general term and why your product applies.

Example: The term ''Eco-friendly'' likely conveys that the product has far reaching environmental benefits and may convey that the product has no negative environmental impact. However, simply adding a qualifying statement such as; ''Eco-friendly: made with recycled materials,'' better clarifies how your product is more environmentally beneficial.

Section 2: Degradable and Biodegradable Claims

Degradable claims refer to the breakdown or decomposition of a material. As with the other types of environmental marketing claims, degradable claims should also be qualified, to clarify what type of degradation, where it will degrade and the performance a consumer should expect. The claim should also be relevant to the actual disposal environment of the product.

Degradable claims cover a fairly wide spectrum of environments and material performances, so degradable claims should indicate what type of degradation is going to occur, and if it is not biodegradation, clarify what it will degrade into.

As with other claims, there must be valid scientific evidence that the plastic degradation will perform as claimed. The evidence must be relevant to the environment where the plastic will be disposed.

The US Federal Trade Commission's Updated Green Guides state, "A marketer should qualify a degradable claim unless it has competent and reliable scientific evidence that the ''entire product or package will completely break down and return to nature, *i.e.,* decompose into elements found in nature within a *reasonably short period of time* after customary disposal.'' (Register, 2012)

> *Note: The US FTC Green Guides state that a "reasonably short period of time" is one year, however more recently an FTC court ruling determined that claims of biodegradability within a landfill do not need to prove complete biodegradability within one year, biodegradable does not mean complete breakdown into elements found in nature within one year after customary disposal, biodegradable refers to a biological process by which microorganisms such as bacterial and fungi use the carbon found in organic materials as a food source and that scientific literature defining biodegradation does not require completion or impose a time frame. Additionally, consumers understand that biodegradation rates vary depending on the materials and environment, and it is not always a rapid process.* (ECM Biofilms Inc, 2015)

Marketing a degradable product is done accurately by simply identifying the type of breakdown, environment in which it will degrade and what rate of degradation can be expected. It is always beneficial to qualify your degradable claim to avoid misinterpretation. And, don't claim degradable or biodegradable if your product will most likely be disposed of in an environment where the degradation will not occur.

Example 1: A marketer advertises its trash bags using a ''degradable'' claim. The marketer relies on soil burial tests to show that the product will decompose in the presence of water and oxygen. Consumers, however, place trash bags into the garbage which goes to landfills or incinerators where they will not degrade. This is a marketing claim that should not be made because the trash bags are expected to go into an environment where the degradation will not take place.

Example 2: A marketer advertises a commercial agricultural plastic mulch film with the claim "photodegradable,'' and qualifies the term with the phrase ''Will break down into small pieces if left uncovered in sunlight.'' The advertiser possesses scientific evidence that product will break down, after being exposed to sunlight, into sufficiently small pieces to become part of the soil. This is a correct claim because it explains what type of degradation, what material is left after the degradation and identifies an environment where the film is expected to be used.

Example 3: A plastic package marketed as landfill biodegradable, has scientific validation that the plastic package will biodegrade in a landfill. The validation includes ASTM D5526 testing in which the plastic biodegrades 61% in 202 days. The claim should be qualified with a statement clarifying the biodegradation performance expected, such as "testing shows 61% biodegradation in 202 days".

Section 3: Recyclable Claims

Marketing claims of recyclability should be limited to products that are reasonably expected to be recycled. A reasonable expectation means that recycling facilities that accept the product are available to a substantial majority of consumers or communities where the product is sold or disposed of. A product or package marketed as recyclable should be one that is collected, separated, or otherwise recovered from the waste stream through an established recycling program for reuse or use in manufacturing or assembling another item.

Manufacturers and brands should not label a product or packaging as recyclable simply because it utilizes a certain resin identification code (plastic numbers 1-6). These marketing claims have no substantiation on the environment the product will be placed in and misleading to the consumers who believe that recyclable claims mean a product will be remanufactured into a new product if it is placed in the recycle stream. Recyclable claims must be based on the fact that the only items recycled at any significant percentage are PET and HDPE bottles.

The recyclability of a package or product will change over time as recycling technologies improve. Today, recycling on a mass scale is limited to PET beverage bottles and HDPE rigid containers. Other products should not be marketed as recyclable unless the community where the product is sold or discarded has programs that recycle that specific application. Qualifications can clarify to the consumer that the recycling may not be available in their area by stating: ‘‘this product [package] may not be recyclable in your area,’’ or ‘‘this product [package] is recyclable only in the few communities that have appropriate recycling facilities.’’

Certain phrases or images can also be a claim of recyclability without directly stating “recyclable”. If a product has labeling that states “Please Recycle” this would imply that the product is recyclable, if it is not a material and in a form that is readily accepted by recycling facilities, the claim would be misleading. The same situation will occur if the product has a prominent marking showing a triangle with chasing arrows, as consumers interpret this as meaning recyclable.

The US Federal Trade Commission’s 2013 Updated Green Guides state, “Marketers can make unqualified recyclable claims for a product or package if the entire product or package, excluding minor incidental components, is recyclable. For items that are partially made of recyclable components, marketers should clearly and prominently qualify the recyclable claim to avoid deception about which portions are recyclable. If any component significantly limits the ability to recycle the item, any recyclable claim would be deceptive. An item that is made from recyclable material, but, because of its shape, size, or some other attribute, is not accepted in recycling programs, should not be marketed as recyclable.” (Register, 2012)

Example 1: A multi-layer carton made of plastic, paper and metal foil is marketed as recyclable. The majority of recycling facilities do not have the means to separate the layers or recycle the carton. This product should not have a claim of recyclability.

Example 2: A frozen food product packaged in an HDPE plastic film. While HDPE is recycled when it is in the form of rigid containers, it is not readily recycled in films as used for this product. This product should not have a claim of recyclability. It is also likely that this plastic film includes layers of other types of plastic to increase the shelf life of the frozen food. Multi-layer film should not be labeled as recyclable.

Example 3: A beverage bottle made of PET and the cap and label made of other materials that are easily separated from the plastic bottle during the recycling process. Even though the majority of the PET bottles are not collected for recycling, the majority of consumers have access to recycling programs that regularly accept PET bottles. This is a product that can be accurately marketed as recyclable.

Section 4: Compostable Claims

Marketing claims of compostability should also be qualified to clarify if it is home compostable, industrial compostable and if there are appropriate composting facilities that will accept the product readily available to the consumer after use. Before you market a product as compostable; make sure you have solid scientific validation that it will in fact compost in the environment where it is likely to be disposed.

For clarification, a plastic product may pass testing criteria for composting, meaning the plastic is technically compostable. If there is rarely the chance that the product will be disposed of in an environment where it will compost, then a claim of compostability is misleading because consumers will believe there is an environmental value with the product when there is not.

The US Federal Trade Commission's 2013 Updated Green Guides state, "that marketers should possess competent and reliable scientific evidence showing that ''all the materials in the product or package will break down into, or otherwise become a part of, usable compost (*e.g.,* soil conditioning material, mulch) ''in approximately the same time as the materials with which it is composted in an appropriate composting program or facility, or in a home compost pile or device.'' (Register, 2012)

Marketing of compostable plastics is fairly easy if the claim includes qualifying statements regarding what type of compost facility is required (home or industrial) and if there are appropriate facilities in the area where it will be disposed. Don't put compostable claims on products that will not reasonably be placed in compost operations.

Example 1: A manufacturer indicates that its unbleached coffee filter is compostable. The unqualified claim is not deceptive, provided the manufacturer has substantiation that the filter can be converted safely to usable compost in a timely manner in a home compost pile or device. If so, the extent of local municipal or institutional composting facilities is irrelevant.

Example 2: A manufacturer makes a claim that its package is compostable. Although municipal or institutional composting facilities exist where the product is sold, the package will not break down into usable compost in a home compost pile or device. To avoid deception, the manufacturer should clearly and prominently disclose that the package is not suitable for home composting.

Example 3: Nationally marketed lawn and leaf bags state ''compostable'' on each bag. The bags also feature text disclosing that the bag is not designed for use in home compost piles. Yard trimmings programs in many communities compost these bags, but such programs are not available to a substantial majority of consumers or communities where the bag is sold. The marketer should clearly and prominently indicate the limited availability of such programs. A marketer could state ''Appropriate facilities may not exist in your area,'' or provide the approximate percentage of communities or consumers for which such programs are available.

Example 4: A trash bag is marketed as “compostable”. Consumers, however, place trash bags into the garbage which goes to landfills or incinerators where they will not compost. This is a marketing claim that should not be made because the trash bags are expected to go into an environment where the composting will not take place.

Part 7: A Sustainable Approach to Plastic Waste

If we are to ever achieve true sustainability as a human race we must change our way of thinking and acting. Albert Einstein once said, "No problem can be solved by the same kind of thinking that created it." Historically sustainability has been driven largely by cost savings, marketability to consumers, media trends and social pressures. In essence, sustainability has not been focused on a company becoming more sustainable, rather sustainability has been a smokescreen to make business as usual appear to have changed when instead the primary objective still remains a commercial one.

A company that is genuinely focused on sustainability will know that it is not about reducing negative impacts, sustainability is about creating positive impacts; environmentally, socially and economically. A sustainable company will make decisions based on what is right rather than what is popular or trendy. They will accept that cost is simply a matter of perception and understand that cost analysis must extend beyond a simple financial assessment so that any increased financial costs can be offset by a reduction of environmental or social costs. A sustainable company will make decisions based on facts and data and use marketing as a method to educate their customers rather than sensationalize promises that hold no merit.

A sustainable society is built by sustainable industries and sustainable industries are built one sustainable company at a time. As more companies admit there is a better way to be in business and integrate sustainability in all their decisions, it will put pressure on their competitors to do the same. These industry leaders will drive innovation and change; they will stand as beacons to their industry and as such will ensure their longevity and growth. Consumers will know who these leaders are, not by their marketing schemes, but by who and what they stand for, how they operate and the integrity apparent through the decisions they make. These companies know that sustainability is not only good for business, sustainability is critical for the survival of business.

Sustainability comes in many forms; financial, environmental and social. This document has touched on each of these aspects as it relates to plastics. Some feel that plastics cannot be part of a sustainable society while they turn a blind eye to the value plastics brings to modern life and the impact of the materials it has replaced. Plastics are a critical part of modern life; they provide protection for products, prevent food spoilage and contamination, are an inexpensive material for the manufacturing of products, are very durable and are extremely versatile.

Even so, plastics can create harm to our environment because they linger for hundreds or thousands of years. When considering the sustainability as it relates to plastic, the primary concern is most often the disposal of plastic after use. This is primarily because the media sensationalizes negative issues regarding the use and disposal of plastics.

There are currently several different ways plastics can be disposed after use; landfilling, recycling, incineration and composting. Which of these options is best for a specific product will depend primarily on the disposal available to the consumer. If there are several options readily available, then a sustainability manager can design products and packaging specific to the disposal option of their choosing. In considering the disposal method, it is important to understand that landfilling is by far the most available and common method of disposal for plastic, so landfilling must always be addressed in product design.

A full evaluation of the disposal options and the varying types of materials brings a solid conclusion: there is not one single option that is the most beneficial for all types of plastics in all regions. However, we can identify a strategy for varied waste management that includes each disposal method and correlates the best materials with that process.

Sustainability managers must first and foremost understand that over 90% of plastics are deposited into landfills. Even plastics with higher recycling rates such as PET beverage bottles and HDPE bottles have a higher percentage entering the landfill than being recycled. This means that every sustainability decision must provide a beneficial aspect regarding the landfilling of that plastic.

The most beneficial option for landfilled plastics is biodegradation and conversion of the resulting methane to energy. Biodegradation will ensure the plastic does not linger for thousands of years by converting the plastic back to natural materials, soil, air (carbon dioxide and methane), and water. When the biodegradation is completed during the managed life of a landfill (2-50 years) the methane produced is captured and used as energy and fuel.

Traditional plastics can biodegrade in landfills through the use of technologies such as ENSO RESTORE. This technology maintains the physical properties of the plastic so that products and packaging remain durable during use and then once the plastic enters the landfill it biodegrades during the managed life of that landfill. This technology is available today and at very little cost.

Using technologies such as ENSO RESTORE allow the continued use of traditional plastics while integrating biodegradability into our current landfill infrastructure so the energy value of the plastic can be captured and the plastic will return to a natural form. In short, the plastic is already going to the landfill and the landfill is already collecting the gas so the only change required is a simple adjustment to the plastic itself. Sustainability managers should implement landfill biodegradability for all their plastic products and packaging that will likely be placed in a landfill after use.

While this approach may seem contrary to the public perception of “zero waste”, it is in fact part of the same directive. By utilizing technologies, such as ENSO RESTORE, to achieve controlled biodegradation it is possible to achieve zero waste through full biodegradation. This complete biodegradation integrates in the natural carbon cycle while also creating clean energy to offset fossil fuel use. Interestingly, the energy consumed in collection is at least 60% less than the energy generated by the recovery and use of the landfill gas (LFG) (Caraban, 2008) indicating that LFG energy can not only offset the energy requirements in waste collection but in single source collection can be a net positive.

LFG is a critical part of the overall energy profile for municipalities as LFG is a local, renewable energy resource. Because landfill gas is generated continuously, it provides a reliable fuel for a range of energy applications, including power generation and direct use. (EPA, A Landfill Gas To Energy Project Development Handbook) Landfill gas is one of the few renewable energy resources that, when used, actually removes pollution from the air.

Once landfilling of plastic is addressed, other disposal options can be considered as well. Depending on the product or packaging involved, recycling may be an important focus. Too often it is assumed that recycling is always beneficial. Studies show that while recycling of some plastics can have a beneficial footprint; the resources required for collecting and processing the majority of mixed plastics for recycling purposes negates any benefit. We also cannot put our heads in the sand and pretend that our products and packaging are sustainable because they are "recyclable" when that plastic has little if any chance to actually be recycled.

Sustainability managers that want to incorporate recycling as part of their overall strategy will design their products and packaging to integrate effectively with current recycling processes. This will entail converting all plastics to clear PET or HDPE bottles. They will avoid adding any labels or caps that are not easily removed and they will not use multi-layering of plastics in their bottles. Products and packaging that are not PET bottles or HDPE bottles do not have readily available recycling facilities and will most likely not be recycled. It is misleading for a company to make any claims of recyclability for products and packaging that are anything other than PET beverage bottles and HDPE bottles.

For many products, packaging in bottles may not be possible and changing a product or packaging based solely on the ability to recycle the item will have unintended consequences. Sustainability managers must balance the cost and performance of their plastic with the disposal environment they intend for their products. Not all packaging performs as needed when it is the type and form of plastic most recycled; for these products, designing for alternative disposal methods is appropriate.

Sustainability managers must avoid misleading the public by claiming a plastic package or product is recyclable when it is in a form that is not recycled. There are many items that may be manufactured out of PET or HDPE but will not be recycled due to their form or intended use (items smaller than a beverage bottle, made out of multiple types of materials, foamed plastic and plastic films). Claiming that these products are recyclable is deceitful and damages public trust in companies.

The current attempt at increasing recycling by adding additional types of plastics into the system is ineffective. The primary focus for recycling should be to increase the collection of both PET and HDPE bottles. Current collection of these two items is less than 40% so there is significant room for doubling these recycle rates with minimal impact to current processes. Other materials should be evaluated carefully for full economic and environmental impact before implementing recycling as an option.

Another option for plastics disposal is through industrial composting. The plastics that will provide the most benefit in industrial compost are more limited than those that benefit through recycling. This is because there is limited availability of industrial compost facilities that will accept plastics, there are few plastics that will break down effectively in industrial compost and it is ineffective to try and sort plastics and then send them to industrial composting facilities.

Sustainability managers that have products and packaging sold and disposed of in regions with generally available industrial compost collection may want to consider compostability for select items such as; food service items and bags used to contain the food waste. Composting these plastics will avoid the energy and resources that would otherwise be required to sort these plastics from the food waste. There is also value in the bags containing the food waste in human health aspects, odor control and insect/animal avoidance. Additionally, the bags can prevent excess water use and water pollution that would otherwise be produced when cleaning re-useable food waste containers.

Compostable plastics should only be used when the product is most likely to be disposed of in an appropriate composting facility. This means that there must be widespread availability of commercial compost collection where the product will be sold and disposed of. The plastic must also be in a form and purpose that would make it commonly comingled with food or yard waste that will be going to an industrial compost facility. Without availability of compost facilities and the expectation that the plastic will most likely be disposed of in industrial compost there is no value in compostable plastics.

> *Note: Cost is sometimes a driving factor even when the primary focus is environmental. Companies can overlook the fact that sustainability will always have a cost, you pay whether you move into sustainability and you pay if you don’t. Ultimately, it is a matter of when and how that cost is paid; we can pay it now by implementing sustainable solutions, or we pay it later by trying to reverse environmental damage and damage to a company’s reputation. Companies that successfully implement sustainable changes understand that the financial cost of a change is offset by the social value and customer loyalty that it provides. They understand that sustainability is a way of ensuring that their company will continue in operation for many years to come.*
>
> *Retailers often push against price increases stating that consumers are unwilling to pay more for environmental products. Studies show that most consumers are willing to pay up to 10% higher costs for green items. Also, prices fluctuate regularly and consumers continue to purchase these items. Most consumers do not recognize small increases in pricing unless the product with the increased cost is sold alongside a product that does not have an increase in price.*

Overall, sustainability with plastics is fairly simple. First, sustainability managers must acknowledge their plastics will most likely be disposed of in a landfill. Armed with this information, sustainability managers can then implement solutions that ensure the plastic in the landfill will biodegrade effectively during the managed life of the landfill. In this way the vast majority of their plastic products and packaging will have a more sustainable end of life. Landfilling is addressed first and foremost because even plastics that can be recycled or composted will most likely be disposed of into landfills.

Landfill biodegradable materials also provide a unique opportunity for brands and manufacturers looking to improve their sustainability profile. Most often once a material leaves the factory there is no method for the producer to control the disposal or end of life scenario of that product. Utilizing landfill biodegradable materials is one of the few methods available that address the sustainability of materials in the customary disposal method; creating a means for companies to implement extended producer responsibility by ensuring that the end of life scenario is beneficial even when the producer no longer has possession of the product.

After a company has made sure their plastic products and packaging are biodegradable within the landfill, then alternative methods of disposal can be evaluated. Recycling and composting can be evaluated to determine any possible benefit of designing products and packaging to integrate into these alternative methods. This evaluation will use facts and data to determine if the plastic will perform as expected during recycling or composting, if the plastic has a high chance of being recycled or composted and if it is more beneficial to recycle or compost the plastic than to have it biodegrade in the landfill.

Using a systematic approach that first addresses the vast majority of the plastics will provide a wider and more immediate impact – basically more bang for the buck. Too often, sustainability managers focus on areas that are sensationalized by the media and have great marketability but prove very little true impact. Rather than implementing solutions for the 90%, the focus of many sustainability managers has in the past wasted time, energy and effort trying to save a small fraction of their plastics.

In conclusion, the message is simple: **Understand where your plastics will be disposed of, implement solutions based on this environment and use your marketing to educate the public.** Don't worry about the 10% of plastic until you have solved the 90% in the landfill. Don't use clever marketing tactics that mislead the public regarding the true end of life scenario for your plastic product and packaging. And don't be afraid to do the right thing, even when it is unpopular because we cannot solve this problem with the same type of thinking that created the problem.

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