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COMPOSTING FOR SUSTAINABLE WASTE MANAGEMENT

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Executive Summary

Puerto Rico is a small, beautiful island known for its picturesque beaches and rich geography. However, behind this surface beauty is a busy economy and dense population that produces a lot of trash, over 11,000 tons per day. Puerto Ricans rely heavily on landfills for disposal of their waste. However, of the existing 29 landfills, 25 are expected to close in the next ten years. This has created a significant waste management problem on the island and has prompted the exploration of other disposal options. McNeil Consumer Healthcare, a large pharmaceutical manufacturing plant in Las Piedras, Puerto Rico, has surfaced as a leader in this search for improved waste management. McNeil has shown that they are a company with concern for the environment and the community by expressing interest in a large-scale composting system for waste reduction.

Composting is the naturally occurring decomposition of biological materials. Today's societal problems of waste management have motivated the enhancement of natural composting into a sophisticated technology. Education and corporate leadership have played an essential role in driving the development of composting technologies. This has resulted in the progression of new machines and methods for more efficient composting. This project has investigated these technologies in order to advance the practice of sustainability and recommend an optimal system to meet the needs of McNeil Consumer Healthcare and spur island wide change.

The essential goal of this project was to help McNeil reduce their volume of landfill waste and raise community awareness by exploring composting options. McNeil is demonstrating leadership through recycling programs and their commitment to a ten percent reduction of waste by 2010. Through composting they would not only help reduce landfilled waste, but they would improve their public image, set an industrial example and help educate the community on methods of waste reduction.

To accomplish these objectives the team assessed McNeil's waste disposal needs, determined resources available and evaluated composting methods. Finally, keeping community interests in mind, we suggested the most feasible solution and designed an implementation plan. The larger, social issue at hand is to present a positive corporate example of alternative waste management to serve as a model for other organizations while concurrently educating the local community. Ideally, this will help encourage widespread composting.

We accomplished the educational goals by reaching out to McNeil's surrounding community of Las Piedras, Puerto Rico. McNeil has an extensive Community Outreach Program and affiliations with four local middle and high schools. We chose to take advantage of the existing school relationships and expand McNeil's educational program to include composting. This was done by developing a compost education curriculum.

To implement this curriculum, we traveled to each of the four schools and spoke to the students. At each school there was a group of students who volunteer to participate in a "Recycling Team" sponsored by McNeil. These students, in addition to science classes, were the chosen audiences because of their pre-established interest in environmental conservation. We developed and presented an interactive lesson to introduce these students to the basics of composting. As a follow-up, we also left three

additional lesson plans with the teachers to encourage the schools to continue our composting education efforts with the community. The lessons included subjects such as the compost process, compostable materials, information on how to create your own compost pile and scientific experiments to explore ideal composting conditions. We were well received at the schools and have already observed the students voluntarily participating in composting activities. Therefore, we feel that our educational initiatives were a successful beginning for compost education in Puerto Rico.

The second major component of this project was to develop a composting system for McNeil's Las Piedras manufacturing plant. We first gathered and analyzed detailed information about the composition and magnitude of McNeil's biodegradable waste. We also researched requirements outlined by the Environmental Protection Agency (EPA) and McNeil's exemplary environmental policy, which aims to exceed regulations in order to function as an environmentally sound company. Factors considered under environmental issues were odor production, leachate and storm water runoff.

Prior to considering any large-scale on-site composting solution, McNeil wanted to initiate a smaller-scale trial system utilizing only yard and food wastes. Wastewater sludge was not used in this trial system in order to avoid additional environmental regulations. The objectives of this trial were to give staff and employees experience with actual composting, provide an immediate reduction in biodegradable waste output and lend credence to proposals for future investment. To complete this trial system we utilized five large, circular bins made of wire and rebar. With help from the maintenance staff, we then proceeded to shred all of McNeil's yard and food wastes for distribution in the bins. Over the course of four weeks, we maintained the piles by turning them and adding water when necessary. We observed the trial compost bins to be rather successful, showing substantial decomposition in relatively little time.

When looking for a long-term compost solution, the major obstacle we faced was the use of McNeil's wastewater treatment sludge. Wastewater sludge is a significant portion of McNeil's waste stream and ideally would be included in the compost process. In order to study the effect this sludge has on the compost process, we developed a series of small-scale experiments to examine different ratios of waste materials. While these experiments did not function as anticipated, we learned some valuable lessons. We realized that the buckets did not contain enough mass to sustain the heat necessary for composting, but more importantly, we discovered that the sludge was too wet and would need to be dewatered prior to treatment. This became a very important consideration in our final recommendations.

The final stage of our work was to research and recommend a long term composting solution. Keeping in mind the criteria we assembled during research and experiments, we investigated specific industrial systems capable of handling McNeil's sludge, yard and food wastes. We focused our recommendations on aerobic, in-vessel systems because of environmental concerns and processing time. Our initial inquiries yielded several systems, however, we narrowed our search to four specific systems for further investigation. The four systems were the Earth Tub™, CompostMan Pro™, Greendrum™ and WEMI Model 600. We contacted the equipment manufacturers as well as organizations currently using the equipment for more detailed information. After accumulating as much information as possible, we compared all the variables and selected the Greendrum by BW Organic systems as our preferred recommendation. The selected process is shown in Figure 1. As part of our recommendation, we compiled all the information McNeil would need to implement the Greendrum system. This included necessary site preparation, shipping details, dewatering requirements and a preliminary economic analysis.

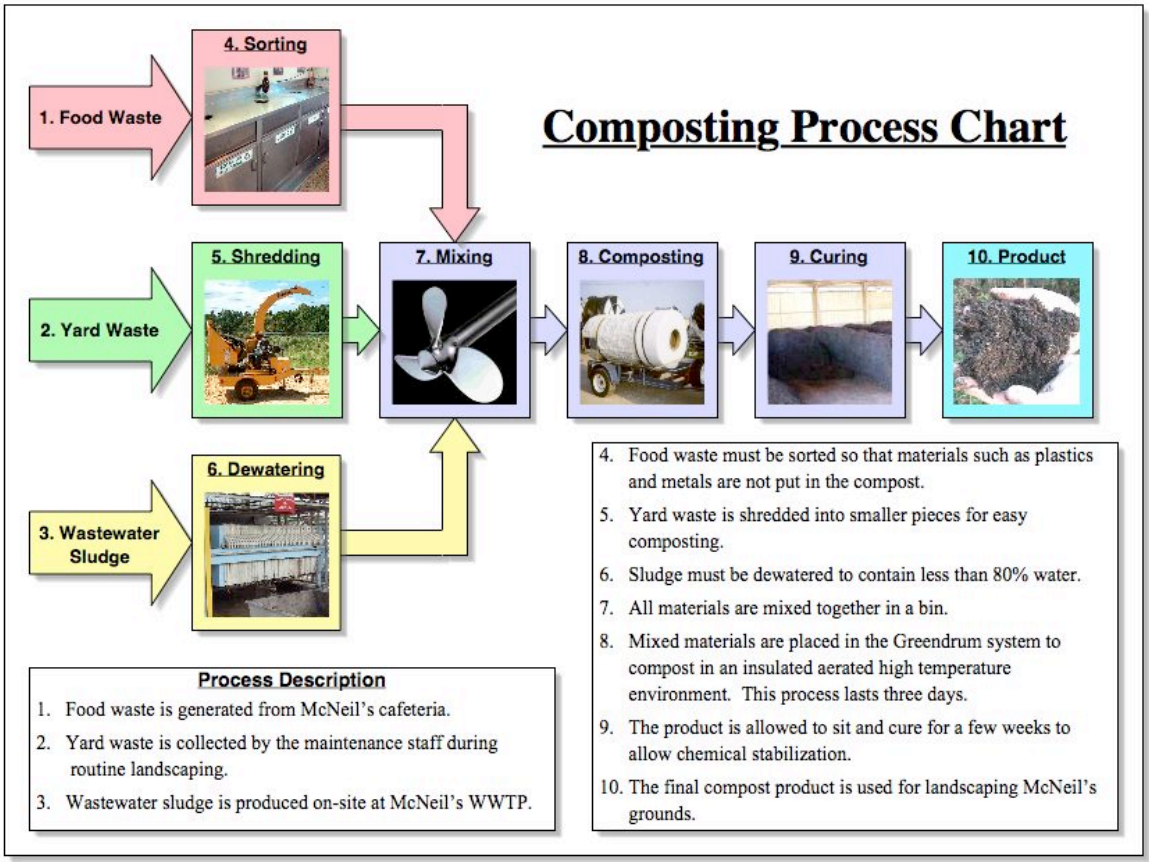

Figure 1: Composting Process Chart

The final products of our work with McNeil are a detailed plan for implementation of a long-term, industrial composting system, and a composting environmental education curriculum. Hopefully, by leaving McNeil with these two deliverables, we have come closer to realizing the educational goals and positive example necessary to promote sustainable waste management in Puerto Rico.

Abstract

This report, prepared for McNeil Consumer Healthcare of Las Piedras, Puerto Rico, explored options to reduce their landfill waste volume and raise community awareness of waste-related environmental concerns through composting. The following document addresses the necessary background, research methods, findings, and recommendations. Through classroom presentations, physical composting, and investigation of composting systems, we initiated community interaction and established the best future options for McNeil. Through education and setting a positive example, this project aims to promote sustainable waste management.

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Chapter 1: Introduction

The population growth and technological advances of the past century have changed and improved the world in many ways. Nevertheless, along with the many beneficial developments, there arises a new set of problems. One of the dominant issues of the present is that of waste management. In the past, people have disposed of their trash in landfills, large areas designated for dumping solid wastes. However, decreasing land availability and growing environmental awareness have recently made the limitations of landfills quite apparent. These deficiencies have motivated the search for alternative waste disposal methods such as recycling and composting. Although promising ideas, these alternatives still have much development and experimentation ahead.

Areas of small land mass and dense population, such as the island of Puerto Rico, have a great sense of urgency regarding the waste management problem due to the lack of available landfill space. Due to capacity and environmental regulations, the majority of Puerto Rico's landfills have closed in the past 20 years; with more expected to close soon. Puerto Rico's situation is further complicated by the fact that a majority of the land on the island is inappropriate for landfilling. The mountainous interior and water-infused coast present considerable difficulties for safe landfill construction. Given these obstacles, it is clear that the lifespan of landfill use in Puerto Rico is in short supply.

The island is only the size of Connecticut, yet contains a population of 3.9 million people who generate approximately 11,100 tons of waste per day (Caribbean Recycling Foundation, 2001). Considering the limited landfill space and large quantity of waste, it is therefore quite apparent that alternative waste disposal options are a necessity for Puerto Rico. An island-wide effort to reduce landfill waste through recycling has been less than successful. An extensive study showed that the island's recycling goal of 35% is far from being met, only reaching a mere 16% (Courtney et al., 2004). Municipal recycling programs, although a possible solution, have demonstrated similar lackluster results.

One option yet to be widely explored is composting biodegradable, organic waste. Composting significantly reduces the volume of waste while simultaneously producing a valuable soil amendment product. It has been a small-scale process in backyards for centuries, however the idea to utilize the technology on a large industrial scale is rather new. Composting is a natural, and potentially economical waste reduction process. A successful case of industrial composting in Puerto Rico could help to propel the process forward as major technique in waste management.

The essential goal of this project is to help McNeil Consumer Healthcare reduce their volume of landfill waste and raise community awareness by exploring composting options. The team will assess McNeil's needs, determine resources available and evaluate composting methods. Finally, keeping community interests in mind, we will suggest the most feasible solution and design an implementation plan. The larger, social issue at hand is to present a positive corporate example of alternative waste management to serve as a model for other organizations while concurrently educating the local community.

Chapter 2: Background Information

Waste management is a worldwide problem that is growing more and more apparent every year. Every area of the world deals with this problem differently, however, areas with limited landfill availability have more reason to worry about their waste. A recent shift away from landfills and towards other options is causing people and businesses to be more aware of their waste. Corporations have begun to take responsibility for their waste production as part of what has been called the Green Industry Movement. In order to better handle and process our waste, we must first understand it. This section will discuss current landfill waste disposal methods and problems in the United States and Puerto Rico; the social implications involving: the Green Industry Movement, motivations for alternative waste disposal methods, and the conditions in Puerto Rico; the processes and technologies of composting options; and the general background of McNeil Consumer Healthcare.

2.1 Waste Management

As the world's population has grown, so has an escalation in resource use and a resultant increase in waste production. It has been common practice both presently and in the past to use landfills such as the one shown in Figure 2 to dispose of the solid portion of this waste stream often called Municipal Solid Waste (MSW). However, this option requires land area – a commodity that in some locations is difficult to acquire. In short, the world is running out of places to put its trash. Even when land can be acquired and even with today's advanced technology, these unsightly landfills are ultimately an expensive, polluting, and unsustainable form of waste management.

Figure 2: Landfill (EPA, 2004)

Some of today's pollution problems can be attributed to crude landfills of the past. Before environmental issues were a consideration, waste was disposed of by being dumped into large holes in the ground. There were no protective liners to prevent the decomposing trash from leaching into the surrounding soil, and many landfills eventually began tainting water supplies (Miranda, 2005). On top of this, many other negative and undesirable aspects of landfills became apparent, such as noise pollution, odors, visual eyesores, and transportation costs (Cheremisinoff, 2004). These aspects have caused significant environmental and social problems in the past and will do so in the future as well if the world's population continues to rely on them. Even with all the drawbacks, landfills are still the number one option for waste disposal today. The United States, which has a better waste management system than Puerto Rico, still disposes 57% of its trash in landfills (EPA, 2003). The main reason this is the case is due to convenience. Currently, landfills remain an easy and cost effective disposal option. In addition, a wide variety of these landfills are now more environmentally suitable than those of the past. Undesirable chemicals and landfill gases are being consumed in a process called flaring, which burns the methane released and converts it into carbon dioxide. Consequently, flaring reduces odor and pollutant emissions. Landfills have also become significantly safer over the years and now fall under strict EPA regulations. They must be lined and equipped to collect and treat leaching fluids. They must also be equipped to control gas emissions and must be monitored for problems such as illegal dumping 24 hours per day. These regulations, in addition to land purchase, construction, maintenance, and emission control make the landfill procedure a much more costly disposal option today than in the past (Miranda, 2005). This increase in cost has brought more environmentally sustainable waste management options into consideration. Nevertheless, landfilling still remains the dominant form of waste management in our world today.

2.1.1 Waste Management in the United States

Waste disposal is a global concern. In recent years, the United States and many other countries have made considerable strides in regulating and managing this growing problem. According to an Environmental Protection Agency (EPA) report in 2003, we as a country have made steady improvements in our waste management system. Over the course of time, we have not only cut down on the number of landfills (over 6000 landfills were eliminated from 1990 to 2001, a massive 75.8% decline), but we have also decreased the amount of MSW actually being landfilled by 12.4 million tons (an 8.9% decline) during same time period. This reduction is a respectable accomplishment considering the total waste generated in the U.S. increased dramatically during the same time period due to the economic growth of the 1990's (EPA, 2003).

One reason landfill disposal has decreased so dramatically in recent years is due to wider use of composting. The trend toward composting began in the late 1980's when more than 20 states banned yard trimmings from landfill disposal (Glenn, 1999). This trend has remained steady throughout the last 20 years. In this year's EPA report (2003) it stated, "Almost half of the waste prevented in 2000 came from organic waste material. This is likely a result of many locally enacted bans on the disposal of yard trimmings from landfills around the country, as well as successful campaigns promoting onsite composting." The endorsement of composting has helped the United States greatly in decreasing landfill usage, but the convenience and low-cost of landfills keeps them abundant. Future work in this area will be required.

2.1.2 Waste Management in Puerto Rico

Waste management in Puerto Rico, (Figure 3) while similar to the U.S. in several ways, also has its own unique set of issues. The small landmass, dense population and island environment make this commonwealth's waste management issues an even more pressing challenge than in the U.S. Even with the limited space available, landfilling is Puerto Rico's primary method of trash disposal. In similar fashion to the U.S., Puerto Rico's early landfills were little more than holes in the ground. As problems with this method became evident, however, several landfills on the island were deemed environmental hazards and closed. In fact, over half of Puerto Rico's landfills have been closed due to environmental mishaps or exceeded capacity since 1980 (Courtney et al., 2004). Of the 29 traditional landfills remaining in Puerto Rico, 25 are projected to exceed capacity within 10 years (Miranda, 2005). This time crunch adds urgency to the problem at hand. The island is only the size of Connecticut, yet contains a population of 3.9 million people who generate approximately 11,100 tons of waste per day (Caribbean Recycling Foundation, 2001). Clearly, something needs to be done to accommodate the growing population and their waste.

Figure 3: Map of Puerto Rico (Owen, 2004)

If Puerto Rico plans to construct more landfills, they will encounter considerable difficulties. Location is one particular problem. Puerto Rico has three main geographical regions: steep mountains, coastal plains, and the karst aquifers. All of these locations are inappropriate for landfill construction. Not only does Puerto Rico lack the type of terrain for new landfills, it also lacks the quantity. Due to the economics of scale, large landfills are cheaper and easier to maintain per unit waste. In Puerto Rico, however, suitable landfill sites available on the island are very limited in size (Miranda, 2005). This translates into poor landfill economics.

With the limited space in mind, it is understandable that authorities have been exploring and promoting alternate waste disposal options. Nevertheless, a recycling program implemented in 1992 has failed to meet its target of 35% waste recycling and remains at just 16% (Courtney et al., 2004). This figure is far behind even the U.S. national average of 31.5% recycling rate (Glenn, 1999). Evidently, the recycling program has not been successful. Part of this problem can be attributed to the cost expenditures associated with recycling equipment, while reluctance to change old habits can also be blamed. Both of these factors must be addressed for any successful sustainable waste program (composting or otherwise) to be effective.

2.1.3 Economics of Waste Management

There are several factors driving waste management efforts: decreasing land availability, health concerns, and environmental interests. Still, there is no denying the reality that money and profitability are the primary forces in the business world and must be considered in any policy decisions. This section will examine the financial motivations and deterrents towards waste management.

The need for cost-efficient waste management has grown over the years along with American prosperity. From 1960 to 1996, the quantity of waste produced in the U.S. per capita increased from 2.7 to 4.3 pounds per day. Porter (2002) observed that people produce more waste as the economy grows. This causes pre-existing waste problems to grow in magnitude and urgency. Although there are many methods of dealing with waste, the most desirable methods in terms of health, space, and the environment aim to reduce and reuse as much as possible. Recycling and composting fit this description, and in an economic view, composting is merely a recycling method (Porter, 2002).

2.1.3.1 Landfill Economics

Until recently, landfills were not an economic concern. They were simply holes in the ground where waste was dumped. There were no costs, profits, or regulations involved. It wasn't until 1976 that legislation was passed governing landfill usage (Porter, 2002). This legislation began to regulate aquatic leaching, odors, and litter from landfills as well as their contents. The move towards "sanitary landfills" also incurred more costs. These costs took the form of linings in order to prevent groundwater contamination, systems to monitor leachate production, heavy equipment to better manage the waste collection, and administration, engineering, and legal expenses. Many small municipal landfills closed due to exceeded capacity or the new sizeable costs and were replaced by large, privately owned sites at this time (Porter, 2002). Landfills thus became businesses and economics became much more of a concern.

One main source of profit for businesses such as Browning-Ferris Industrials (BFI) and Waste Management Incorporated (WMI) is tipping fees – the charges for unloading waste at a landfill (levied by weight). The growing waste management problem and the increased regulation can be seen historically by the increase in tipping fees. In 1985, the average tipping fee was $12/ton. By 2000, the rate had risen to $30/ton. Presently, landfills in densely populated areas such as New York City's Staten Island site charge fees of up to $150/ton. The average income of $30/ton compared with the average large landfill cost of $10/ton clearly demonstrates that landfills can be a profitable business (Porter, 2002).

The problem with landfill economics can be computed by observing the hidden external costs. Marginal external cost (MEC) is defined as the difference between marginal social cost (MSC) and marginal private cost (MPC):

$$MEC = MPC - MSC$$

Private cost is the amount a company expends to produce a product. This would include equipment, employees and operational costs. Social cost is the amount it costs a society to produce a product. This would include factors such as environmental pollution, health risks to the surrounding population, consumption of resources and more. Externalities can be viewed as cost or benefit effects to third parties that are not directly reflected in the price of a product. Therefore MEC is the cost to society that is not a cost to the producer. In the case of landfills, MSC is greater than MPC. This shows that despite the deceiving profitability to waste management firms, there is a negative net effect on society due to the damaging factors outweighing the monetary value of landfills (Porter, 2002).

2.1.3.2 Reduction is Economical

Due to the stiff rise in tipping fees and other costs associated with industrial landfilling, there are incentives to use alternative waste disposal mechanisms. These incentives can drive waste reduction (Institute for Local Self Reliance, 1991). Reduction of waste via recycling methods has several direct effects on waste management economics. According to Ackerman (1997), these effects can be broken into three categories: avoided costs, new costs and new profits.

There are significant monetary savings when companies decrease landfilling and consequently avoid the associated costs. The primary saving is coupled with the expense of waste disposal in a landfill. As previously discussed, landfill sites charge tipping fees based on the weight of waste disposed. Simply put, if a company dumps less waste, they pay less money. Transportation also plays a role as the cost of disposal includes transporting the waste to the landfill site. Again, if there is less waste to be transported, it will cost less.

An additional, probably less obvious, avoided cost associated with waste reduction is the idea of unwanted by-products. Industrially, almost all input materials of a process are purchased. The products created are some variation of these input materials. The same is true for unwanted by-products and waste; they are mostly wasted materials that were paid for. By reducing the amount of unwanted by-products, a company can buy less input material and save money (Porter, 2002).

The extent to which avoided costs can be utilized largely depends on the composition of the waste produced. The amount of waste landfilled can be greatly reduced when waste contains a high percentage of recyclable or compostable materials. For example, a company with large grounds to maintain produces a lot of yard waste, and a company with a large cafeteria produces a lot of food scraps. These materials can be composted, therefore reducing the quantity of waste landfilled (Ackerman, 1997).

The second main economic effect of waste reduction via recycling or composting is the new costs incurred. The most significant new cost is the capital and operational expenses connected with the new process. Depending on the methods chosen, installing and running a recycling or composting site could be a significant and widely variable cost to the producer. Recycling plants and highly mechanical composting facilities have a much higher overall cost than simple, traditional composting piles. This makes high quality sustainable composting a more involved and therefore more expensive process than simple composting systems.

One advantage of industrial waste reduction over municipal programs is that much of the "pre-consumer" waste is easily collected and requires little separation because it is already quite homogeneous. There is also less room for contamination when dealing with industrial waste as opposed to municipal waste because it has not been mixed with other materials (Porter, 2002). This helps to reduce new costs.

The final economical effect of waste management is new profits stemming from the sale of recycled or composted products. Recycling undoubtedly produces valuable, marketable materials. However, their resale revenue has not been stable or predictable (Ackerman, 1997). The state of the overall economy determines productivity of other markets and therefore the demand for recycled products. At the same time, investment into recycling facilities increases the supply available, therefore driving prices down.

Compost has had little resale value until recently. Composting is a natural process, but producing a valuable product requires attention and care. If properly processed and monitored, compost can sell for up to $30 per cubic yard (Porter, 2002). Although the composting movement began as an effort to reduce landfill volume alone, recent developments have given compost an attractive opportunity for profit.

A successful example of waste reduction economics can be seen in the efforts of the New York State Department of Corrections. With a population of 60,000 prisoners, over 30 tons of food waste was generated per day. Transportation and landfill tipping fees alone cost the institution over a million dollars annually. To reduce costs they began a composting program along with yard waste from the Department of Transportation. The initial capital investment for the composting equipment was a mere $20,000. The compost product is used for on-site farming and as community service donations (Porter, 2002).

Financially speaking, initial case studies and cost-benefit analyses of composting programs appear to be profitable. However, the Institute for Local Self Reliance affirmed (1991):

> "Recycling and composting are cost effective in a much larger sense than their role in solving the municipal solid waste crisis. They also play a key role in slowing global warming, reducing ozone depletion and reducing energy consumption and water pollution."

Ackerman (1997) maintains that people do not recycle just for monetary reasons; they do it primarily for environmental reasons and to ensure a better future.

2.2 Social Implications

In recent years, companies, organizations, and even cities have begun moving toward "greener" practices in order to help deal with the increasing waste management problem. This is partly due to economic considerations and the ultimate goal of saving money, but it is also due to new legal developments as well as genuine philanthropic environmental conservation goals. This trend has produced several positive changes in waste and environmental management in addition to shifting attitudes and policies in government and industry. Two specific companies, Ben and Jerry's Ice Cream and Starbucks, have already greatly reduced waste production and increased profits through careful management and product decisions. While this certainly helps create a more sustainable waste management system, it only represents a small step in a big picture.

Puerto Rico alone creates 11,000 tons of waste per day (Miranda, 2005). This is increasing every year and cannot easily be fixed. Puerto Rico is unique, however, in that it has an unusually large pharmaceutical manufacturing sector. These corporations produce a large quantity of similar waste. Therefore, others could easily adapt a large-scale waste management system installed by one. This is McNeil's chance to be the leader in waste reduction and processing. In so doing, they would no only help reduce landfilled waste, they would improve their public image, set an industrial example of waste management, and help educate the community on methods of waste reduction.

2.2.1 Green Industry

The recent trend toward "greener" industry means in essence that companies and corporations now attempt to give consideration to environmental issues when making decisions. This has spawned an entire field of study known as industrial ecology. The broader goal of the "green" industry trend and industrial ecology is to create sustainable development in our society (Allenby, 1999). If current methods of waste management do not change, our own waste will eventually have a detrimental effect on the development of our society, just as it would any biological system. Consequently, industrial ecologists have investigated waste reduction techniques in addition to the problem of inefficient resource use. In doing so, they have discovered not only more efficient ways of producing goods and services, but also the concept of resource management.

Resources are defined by process needs; intelligent resource use cannot only reduce waste production, but it can eliminate it entirely. After all, one person's waste is another person's resource. This is the ultimate goal of industrial ecologists: to create an industrial society where most waste is completely eliminated because it is just fed into other processes (Allenby, 1999). Composting is a specific process that moves society toward this goal. The composting process can produce garden quality, nutrient rich material from industrial waste. Consequently, composting technology is just one example of an important component in sustainable waste development.

2.2.2 History

The origin of the green industry movement and the beginnings of industrial ecology are hard to define. For many centuries, humans have attempted to regulate undesirable pollution. After all, few would want waste dumped in their backyard.

Nevertheless, humans have historically held a very local view of waste disposal and environmental protection. In other words, they felt the best way to eliminate waste was to move it elsewhere. Only in recent years have modern concepts of industrial ecology and environmental management emerged – namely that waste and pollution can no longer merely be relocated. We live on a finite planet, and so moving waste elsewhere in a global society translates into dumping waste on someone else's property. This new attitude toward waste management evolved along with the concept of a global society. This evolution has been gradual over the last century, but the largest single event effecting public attitude was the energy crisis of the 1970s (Allenby, 1999). This energy crisis was caused by an Arab-Israeli war during the 1970's in which oil was withheld as an economic weapon by Arab nations. This cut back world oil supplies and caused crude oil prices to rise dramatically. The crisis changed worldviews by forcing consumer nations to reevaluate their energy resources and consumption. Although not related specifically to waste management, the energy crisis demonstrated the link between societies throughout the world.

Following the energy crisis, much of the U.S. and the world began investigating ways to reduce resource consumption. In the late 1980s, a number of high-profile studies and reports were published relating industrial practices and technology to environmental impact (Allenby, 1999). The World Commission on Environment and Development published one such report, titled "Our Common Future," which introduced the modern concepts and principles of sustainable development and industrial ecology (Allenby, 1999). In spite of these developments, however, the concepts of industrial ecology were still largely ignored in the United States. In Northern Europe, however, "green" industry became very popular in a short time due to the significant resource constraints, limited land area, and greater population density. One country in particular, the Netherlands, set a goal of completely defining all government industrial policy based on sustainable development ideas (Allenby, 1999). This remains a work in progress, but it is a significant goal. In the late 1990s, the United States began accelerating its own efforts toward sustainable industrial development. Unfortunately, the United States and its territories such as Puerto Rico still lag behind European developments in industrial ecology.

2.2.3 Motivating Factors

The "green" industry trend can be attributed to several general motives. These include economics, public demand, government regulations, consumer attitudes, and environmental foresight. Economic motives can include process savings as well as heightened consumer awareness leading to increased sales. Efficiency in production processes and general non-wasteful business practices can also incur large savings. Encouraging employees to reduce their usage of paper, water, and electricity, among many other consumables, can save businesses money and help reduce environmental degradation. New technologies can save resources and create more efficient methods for companies to run their processes. For example, seven times as much electricity can be generated from a ton of coal today as at the start of the century (Cairncross, 1995). Reduction in the use of resources cuts costs of production and has a beneficial effect on the environment.

Consumer attitudes and tastes also create an economic motive for companies to become ecologically sustainable. For example, *The Green Consumers Guide* had a great effect on consumer trends in Britain during the late 1980s when it became a best seller (Cairncross, 1995). This simple book demonstrated that people could protect the environment by paying close attention to the products they buy and the companies they buy from even if they were not willing to reduce consumption. Before green consumerism became important in Britain, northern European industry saw increased product sales by marketing the environmental attributes of their products. One such company was Henkel, a German household goods producer, who created a phosphate free detergent. This detergent used an alternative to phosphate, called zeolite, and encouraged the German government to ban detergents that contained phosphates. Consumers bought the product in droves and Henkel took a large part out of the French detergent market – their greatest competitor. Procter & Gamble also saw success when marketing fabric softener in refillable pouches. They promoted it as a successful way to reduce household packaging waste. The company also benefited from this product by saving in manufacturing costs, packaging and transport costs. Consumers play a role in reducing environmental impact by purchasing greener products and paying attention to the companies they buy from. Still, pressure from consumers is not necessarily sufficient or coherent to ensure that "dirty firms" are driven out of business, and environmentally responsible ones prosper (Cairncross, 1995).

Legal issues, public demand, government regulations, and lawsuits can also motivate businesses to adopt green practices directly or indirectly. Often, businesses know that their own high environmental standards will keep them out of lawsuits and protect them from regulatory pressures. This provides a direct motivation – if the company does not comply with regulations, it will no longer be allowed to continue business. Sometimes a company also knows that a good environmental reputation combined with government regulations can indirectly give them a competitive edge. Strong environmental regulations might improve national competitiveness because there are situations in which government regulations can benefit companies in financial areas (Cairncross, 1995). For example, government regulations or public policy could actually reduce a company's labor costs. A business renting holiday cottages along the south coast of England might pay less to maintain the area if tighter rules on sewage dumping cleaned up the local beach (Cairncross, 1995). Another indirect financial benefit of government and public regulation is a company's product market. For example, Johnson Matthey, a company which mines platinum and palladium for use in catalysts, campaigned to make catalytic converters required in Britain's autos (Cairncross, 1995). This campaign (and its effect on public policy) thus created a larger market for their products and increased their profits.

Unfortunately, regulations do not always help companies. The same changes in government policy that may create a larger market for one company or reduce some resource costs might also drive up the costs of other resources or squeeze other companies out of the market. In addition, the cost of implementing certain environmental regulations may be very large. Consequently, a great deal of time and effort must be expended in order to insure legal requirements and government policy are met at minimum economic cost (Cairncross, 1995).

Yet another motive for sustainable industrial development (and perhaps the most visible factor) is the environmental impact humans currently have on the earth. This environmental impact takes many forms, but often cited are global warming, ozone depletion, aesthetic richness, biodiversity, and chemical degradation of planetary ecosystems. Almost all forms of pollution and waste disposal affect these areas. For example, landfilling creates unsightly and odor-ridden sections of otherwise perfectly good land. At the same time, it releases methane and other greenhouse gasses that in turn warm the planet and alter current temperature-dependent ecosystems. Landfilling also releases toxic chemicals that can integrate with subsurface aquifers, poison water supplies, and destroy life that depends on clean water. In the past, these environmental impacts were often ignored. In recent years, however, scientific study has linked this environmental pollution to negative affects on life. Thus, part of the goal of industrial ecology is to protect the other life on this planet from our actions. Even though this is a significant issue, many don't have a "nature for nature's sake" philosophy. After all, why should a CEO care for a species that will never personally affect their company? Nevertheless, the reasons run deeper. By referring to the negative impact environmental pollution has on the organisms of earth, humans tend to forget that we are also included in this description. Consequently, most humans must still consider the benefits of environmental protection because it will ultimately have an affect their own wellbeing. We depend a great deal on the resources provided by the very same ecosystems we use to dispose of our trash. Dumping waste into one river will just poison our own water later down the road. Therefore, the broader environmental goal of the "green industry" movement is to insure that future generations of humans can survive on earth.

Aside from the more obvious reasons, there are other minor motives that nevertheless influence corporate decisions. One such idea is management morale. According to Green Inc, managers, especially those of the "post-Stockholm generation," often want to have pride in their environmental record. Some also feel it improves the quality of management. Staff morale is also important. In many past cases, pressure to adopt sound environmental policies originated from the workforce. Still another influence on environmental policy is the fear of incurring environmental damage with the associated costs. As regulations have tightened in recent years, the cost of a mistake can be significant. Finally, all companies want good publicity. A good environmental policy, while not sufficient alone, can help in this regard. Together, these incentives help drive corporations and industries to become good environmental stewards.

2.2.4 "Green" Evaluation

When analyzing an industry's attempts to be more environmentally responsible, first impressions may be somewhat deceptive. Becoming more environmentally responsible is a broad concept that can be carried out in countless different ways. Given all these variables, it is often difficult to discern which corporations are truly striving towards reduced emissions and efficient resource use and which companies are simply putting on a show for the public and environmental groups. Previous industrial records of environmental shortcomings make many people skeptical of true industrial motives. For this reason, there are organizations and coalitions that evaluate the efficacy of green industry advancements.

One such organization is the Coalition of Environmentally Responsible Economies (CERES). CERES is a group of environmental, investor, and advocacy groups working together for a sustainable future (Gourlay, 1992). This coalition formed in 1988 when the US Social Investment Forum joined forces with leading environmental organizations. After the Exxon Valdez environmental disaster in 1989, CERES put together a series of principles for firms to endorse called the Valdez Principles. The first four of these principles are: protection of the biosphere, sustainable use of natural resources, reduction and disposal of waste, and wise use of energy. When a company endorses these principles, they agree to publicly disclose meaningful environmental performance data, engage in collaborative dialogue about regulations, and to identify opportunities for constant improvement (CERES, 2005).

The World Environmental Center (WEC) is another organization that credits a corporation's efforts for sustainable industry. The WEC holds an annual Gold Medal award ceremony to recognize preeminent industry leadership initiatives and contributions to worldwide environmental quality and sustainable development (GreenBiz, 2005). An independent jury comprised of international environmental leaders from academia, government, industry and non-governmental organizations awards the medal. The jury examines each nomination for a clearly articulated set of values, a history of proven accomplishment, a global outlook and a commitment to sustainable development (GreenBiz, 2005). Two industry examples, Ben & Jerry's Homemade, Inc. and Starbucks Coffee, show their commitment to environmental responsibility by endorsing the CERES set of principles. Starbucks even received the WEC Gold Medal award of 2005.

2.2.5 Case Studies

There are several companies that have already significantly altered their business in pursuit of more sustainable industrial practices. Starbucks Coffee is one such example. Over the past few years, Starbucks Coffee has made efforts toward environmentally responsibility even as their business grows. A large part of their business includes the purchasing of harvested beans from small coffee farmers in ecologically sensitive rainforest areas. In 1998, Starbucks formed a partnership with Conservation International (CI) to encourage environmentally sound coffee growing practices. Growers who follow "Coffee and Farmer Equity (C.A.F.E.) Practices" guidelines receive incentives such as low cost loans, long-term contracts and guaranteed prices (GreenBiz, 2005). By doing so, Starbucks and CI contribute positively to the livelihood of growers and facilitate environmentally sound practices. As for their efforts in this area, Starbucks received the WEC Gold Medal for International Corporate Achievement in Sustainable Development. Starbucks has also taken its "green" efforts into its stores. In August 1997, the company began a reusable cup pilot test to determine the advantages of having in-store patrons drink beverages with ceramic cups (Figure 4) or glassware instead of plastic polyethylene terephthalate (PET) cups (Starbucks Report, 2000). Displays were used to encourage customers to choose reusable cups instead. In test stores, this change created several environmental benefits, including decreased energy and water use, as well as reduced air, water, and solid pollution. Starbucks also began testing a new unbleached, insulated Saleni cup in 1999. This cup would eliminate chlorine in the production and also reduce the wasteful double cupping practice in which people were given two nested paper cups to hold a single hot coffee. The Starbucks webpage also encourages the use of coffee grounds for home gardens because they are nitrogen rich. These examples show Starbuck's efforts for environmental responsibility and a greener industry.

Figure 4: Green Industry Examples

Ben & Jerry's Ice Cream Company provides another example of trends toward "greener" corporate practices. Their mission statement consists of three interrelated parts: a product mission, an economic mission, and a social mission. This mission statement promotes business practices that respect the Earth and the environment. Two ways Ben & Jerry's has shown its commitment to the environment has been through its contributions toward the development of Thermoacoustic Refrigeration and the Eco-Pint. Thermoacoustic Refrigeration is an environmentally friendly, alternative refrigeration device that cools food with sound waves (Heimert, 2004). Conventional refrigeration uses vapor compression involving gases such as hydrochloroflourocarbons (HCFC's) and hydroflourocarbons (HFC's), which are key contributors to ozone depletion and global warming. Thermoacoustic refrigeration uses sound waves at 173 decibels (many times louder than an average rock concert) instead of these chemicals (Heimert, 2004). In spite of this loud noise, sound levels near the refrigerator remain at safe levels of less than 60 decibels due to a pressurized gas environment.

The Eco-Pint, shown in Figure 4, is another demonstration of Ben & Jerry's environmental commitment. This product is an environmentally friendlier carton made of unbleached paperboard and a printable clay coating. The standard paper-making process uses chlorinated compounds as a bleaching agent. This process creates hazardous carcinogens and toxic dioxin waste that can travel to water sources. According to the EPA, dioxins are highly toxic and exposure has been linked to cancer, genetic and reproductive defects and learning disabilities (Lauzon, 1999). Ben & Jerry's has offered to share this research with other manufacturers in order to help make more of an environmental contribution. Ben & Jerry's continues to create many more social and environmentally conscious products as they grow and become a larger example of "green" business.

2.2.6 Puerto Rico Social Environment

Puerto Rico is in a unique situation both due to its large waste management problem and its social environment. On one hand, Puerto Rico is similar to Europe at the beginning of the 1990s. It has very little geographic area for landfilling but it has a high population density. On the other hand, it is a U.S. territory, and as such has inherited the mainland's lag behind Europe in implementing more environmentally friendly industrial practices. This is in spite of a tax structure that promotes resource intensive business such as manufacturing and pharmaceutical production (Abuyuan et. al. 1999). This is a bad combination, but it is made worse by large unemployment (twice the US average), high crime rate (three times the US average), and mainland economic pressures (Chertow and Deschenes, 2003). These other issues have generated a great deal of public apathy toward greener industry in Puerto Rico. It is difficult, after all, for a person to care about sustainable industrial development while unemployed or barely making a living. Even if Puerto Rico's population was significantly more involved in the development of sustainable industry, change still takes a long time on such a large scale. As Frances Cairncross says in Green Inc, "Think how slow people have been to learn not to drop litter – one of the most basic acts of environmental self-discipline" (Cairncross, 1995). Thus, the general situation in Puerto Rico is not conducive to industry changes toward sustainable waste management systems. A lot of work and a good example will be needed.

An important part of changing the social attitudes in Puerto Rico in regard to the environment is education of the children. Out of the 600,000 children of school age, 58% live under the national poverty. In 1995-1996 Puerto Rico spent $3,771 per student while the U.S. averaged almost double that amount (Countries Quest, 2005). More students attend private schools that are run by the Catholic Church than public schools that are run by the Department of Education of Puerto Rico. In order to change the environmental mind-set of Puerto Ricans it is critical to incorporate environmental awareness into all of the education curriculums.

2.2.7 The Path Towards Green Industry

Over the last 15 years, "green" industry and the concepts of industrial ecology have rapidly evolved and impacted social conscience and industrial development throughout the world. Many companies have embraced sustainable development as a method to reduce costs and help protect the environment. New environmental laws and policies have been created with sustainable development in mind. The world is on the path toward truly "green" industry. Yet Puerto Rico remains largely unaffected in spite of its landfill and more general waste management problems. This is in part due to general social apathy. Consequently, Puerto Rico represents a challenging medium for sustainable waste management introduction. Nevertheless, such a development spearheaded by McNeil would greatly benefit the people, the economy, and environment of Puerto Rico in the long run.

2.3 Composting

The issues of landfilling have resulted in a worldwide search for other waste disposal methods. Composting has come forward as a viable option. Garland (1995) states, "Composting organic matter adds both monetary and environmental value to its raw material." It also cuts down on landfill volume. Substances such as food scraps, yard trimmings and paper can be broken down to yield nutrient-rich compost. Glenn (1999) expresses "The organics portion of the waste stream is underutilized." This points out that portions of everyday waste are exploitable. The benefits of composting are twofold. First, it dramatically reduces the volume of waste landfilled. Second, it creates useful material from the separated and degraded organic waste.

There is a significant portion of everyday waste that can be composted. It has been estimated that yard and food wastes comprise approximately 23% of MSW. If paper is included, this figure jumps to 40 - 50% (Garland et al. 1995). In addition to the reduction in landfill volume, the overall costs are less. In fact, recent research at the University of Maryland has shown that the traditional composting duration of 2-3 months or longer can be reduced to less than three weeks. This gives composting an additional economic advantage (Garland et al. 1995).

The composted product is traditionally used for soil improvement. Not only is the compost nutrient rich, it increases soil water retention and reduces the uses of chemicals such as fertilizers and pesticides (Garland et al. 1995). The benefits of compost have been studied in such detail that scientists can specifically design the product for particular soil properties. In recent years, it has also been discovered that compost can be utilized to fight pollution. For example, it can be used to filter out heavy metals and organic pollutants in water runoff, it can be used to preserve land by preventing silting and erosion, and it can be used industrially to break down Volatile Organic Components (VOC's) and filter out odors (Garland et al. 1995). One particular pollution advantage of composting is the reduction of greenhouse gases. When organic substances are placed in a landfill, their degradation yields methane. When composted, however, organic substances produce carbon dioxide. While both methane and carbon dioxide are associated with global warming, methane is a much more potent greenhouse gas by almost 20 fold (Garland et al. 1995).

Although a composting solution to the waste problem seems ideal as well as beneficial, it is not that easy. In order for composting to make a difference, there are many levels of the social scale that must to be dedicated to the cause. Businesses along with individuals need to make a committed effort to organize their waste for composting. A survey taken in Alameda County, California questioned waste generators such as grocery stores, schools, and restaurants, on how easy it would be for them to separate their waste. Although only one fourth of the participants actually had a physical problem finding space and money, forty percent said the separation of the waste would be extremely difficult. Barriers that tended to deter companies from wanting to separate their waste were: finding space for outside containers, time consumption, and willingness to perform the tedious and unpleasant task (Feinbaum, 1995). Another drawback of composting, foul odor, occurs at the actual facilities. Rynk (2003) described "Masslite," a composting facility in Massachusetts that approached government shut down due to extreme odor problems. Even if composting facilities are originally located in ideal, remote environments in order to minimize odor effects, it is very likely that population growth will eventually engulf the facility. This is exactly what happened to Masslite Compost. In order to keep their company growing in spite of the odor complaints, Masslite had to make a few changes. They reduced the amount of material being distributed on-site, they used odor control chemicals on the surface of their compost piles, and they paid attention to wind direction (Rynk, 2003). Although these tasks seem simple and painless, they are some of the main reasons why composting is not used more widely today.

2.3.1 Process

One of the most unique and defining aspects of composting is the fact that it is almost completely biological in nature and is limited to organic waste treatment (Golueke, 1989). Waste products are used as the primary fuel for an integrated web of organisms (Trautmann, 2002). The lower level microbes break down much of the waste while other organisms higher up on the food chain feed off these lower organisms. Still other organisms eat the wastes of the primary microbes in order to maintain biological and chemical equilibrium. In other words, composting creates an entire ecosystem within the organic waste material. This ecosystem is necessary for complete processing of the waste, and it is what distinguishes composting from many other forms of waste processing including chemical treatment, incineration, pyrolysis (the transformation of a substance purely through heating), and countless others (Golueke, 1989). Because composting is biological in nature, it is affected by all variables that would affect any biological system (Golueke, 1977). Therefore, composting is limited by the environment in which it takes place. Beyond this definition, however, composting can process a wide range of waste products in a variety of different ways. Because there are so many variables and numerous approaches to composting, it is useful to differentiate systems based on variations in operating requirements (Golueke, 1989). The most fundamental of these differences lies in the oxygen required. The most common set of processes is aerobic - that is, it requires oxygen to function. The other set of processes is anaerobic – therefore, it requires no oxygen to function. Both aerobic and anaerobic processes include a diverse set of organisms, but the process of breaking down the material is different.

Aerobic composting is the most commonly used composting method and is sometimes referred to as thermophilic composting. This process makes use of a diverse category of microbes called thermophiles to break down most of the waste material. Thermophiles function efficiently across a broad range of waste environments. This is why the thermophilic process has become the most commonly used method of composting. In fact, it is the process used in most back yard composting piles. While thermophiles are very tolerant of some environmental variety, they function most efficiently in hot (60˚ C) and moist conditions. (Golueke, 1989) Generating adequate temperature is usually not a problem because the composting process is exothermic (producing heat) but moisture must be constantly monitored for optimal results. Effective waste stream management can also greatly improve efficiency. Of particular importance in waste stream management is the carbon and nitrogen content (sometimes referred to as the C/N ratio). Thermophiles require both carbon and nitrogen to survive, and the most habitable environment is created when carbon is 30 times more abundant than nitrogen (Trautmann, 2002). Appendix A lists several common waste materials used in composting along with their associated carbon to nitrogen ratios moisture content, and bulk density. While managing the C:N ratio, the moisture content, and the other environmental parameters may seem complex, a properly maintained thermophilic composting process is capable of completely breaking down waste in as little as one week without producing odors. As an added benefit, the resultant compost from a properly maintained thermophilic process is considered a “Class A” high quality biosolid by EPA standards and may be sold to anyone without further regulatory action for industrial or home use (EPA, 2002). This classification is due to the high heat present in processing, which eliminates most pathogens. The flexible waste considerations, efficient processing, and high quality output make thermophilic composting an attractive candidate for a composting process in Puerto Rico.

While aerobic processes make up the majority of composting systems available, anaerobic composting (sometimes called digestion) is also used in waste management (Golueke, 1977). Anaerobic systems by definition do not require oxygen. Because of this, anaerobic composting is more capable of decomposing waste streams considered unsuitable for aerobic processes due to oxygen limitations such as untreated wastewater (Golueke, 1977). Consequently, anaerobic systems can break down most forms of organic waste without requiring management of moisture content or temperature. In fact, anaerobic composting is so flexible, it can sometimes occur where it is not intended. A poorly managed aerobic composting system is one such example. Anaerobic composting is not desirable in this situation, however, because it is much slower than its oxygenated counterpart. Waste material composted without oxygen can take many months to completely process. In addition, the microbes used in anaerobic composting give off methane, trace amounts of hydrogen sulfide, and ammonia gasses that must be dealt with (Golueke, 1977). These side effects and the long cycle times limit anaerobic composting to those waste streams than cannot easily be processed by other methods.

2.3.2 Systems

Due to the advantages and popularity of thermophilic aerobic composting, numerous technological solutions exist in this category. These solutions can be broken into two primary categories: Windrow systems and In-Vessel systems. Both have advantages as well as disadvantages in the areas of cost, simplicity, and operating requirements. Nevertheless, both methods represent possible composting solutions for both small as well as large scale waste management systems.

2.3.2.1 Windrow Systems

In windrow systems, oxygen is only supplied to the compost through turning, and windrow efficiency depends on the porosity of the mixture. If the mixture is too dense, anaerobic areas can develop near the center of the pile. This slows the composting and can create foul odors (Epstein, 1997). On the other hand, if there is too much porosity, the heat and moisture are lost too rapidly. Due to this, the porosity of the materials used in windrows determines their scale. Typical sizes range from 90 centimeters high for dense materials like manures to 360 centimeters for fluffy materials like leaves. Widths tend to vary from 300 to 610 centimeters (NRAES, 1992).

Figure 5: Typical Windrow Composting System (Remade Scotland, 2003)

Windrows such as those shown in Figure 5 can be managed in a number of ways, but the most common methods involve the use of a front-end or bucket loader on a tractor. The loader mixes the materials simply by lifting them up and spilling them down again into a loose pile. Specialized machines have also been developed recently that reduce the time and labor involved in mixing the materials. Aeration is a critical component of the composting process. Therefore, windrow-mixing schedules are especially important. These schedules depend on the rate of decomposition, the moisture content, the porosity of the materials, and the desired composting time (NRAES, 1992). The rate of turning is greatest at the start of the process and decreases as the piles age. The required composting time in a windrow ranges from 10-14 weeks. This may seem slow for an aerobic process, but it is due to the limited aeration and mixing of the waste in this type of system.

While windrows represent the simplest form of large scale, aerobic thermophilic composting, several problems plague the process. These include leachate production and rodent infestation. Leachates are materials incompatible with the composting process that run off during periods of excess moisture (such as rain) and tend to contaminate groundwater. They include but are not limited to heavy metals and nitrates (Epstein, 1997). Due to the leachate problem, a system to collect and recycle this byproduct is often required in order to comply with regulations. This collection can increase both capital costs and operating costs of windrow systems. In spite of the leachate problems, windrows typically have a lower capital costs in comparison with in-vessel systems. Unfortunately their operating costs tend to be much higher. This is due to the large amount of labor and land necessary for maintaining the composting piles.

There are a few ways to maintain a windrow system. As previously discussed, the compost pile needs air circulation. There is more than one method for this. The first technique is a turned pile; the air is distributed through the pile by manually or mechanically turning the load. The ideal height for these piles is anywhere from 110-220 centimeters. Different ratios and turning times can fluctuate in order to produce the best product. Some disadvantages to this method are a large amount of land usage as well as necessary powerful equipment. Patience is also a factor, for it takes 4-6 months to process. The next option is a passively aerated pile. In this type air is supplied through pipes that run through the middle of the pile. The pipe ends are open so the air passively runs through holes in the pipes. This creates a chimney effect due to the high temperatures and tends to draw air through the windrow. These piles tend to reach 90-120 centimeters high and should be built on straw or moss to absorb the moisture. This method plus the aerated static pile uses the pipes in order to eliminate having to turn the piles. Both of these solutions reduce labor costs by aerating the pile without turning. The aerated static pile method is similar but uses blowers instead of natural convection to supply the air necessary for composting. In both cases, the materials being composted must be mixed with other porous materials in order to help distribute the airflow and maintain biological equilibrium (Rynk, 2003).

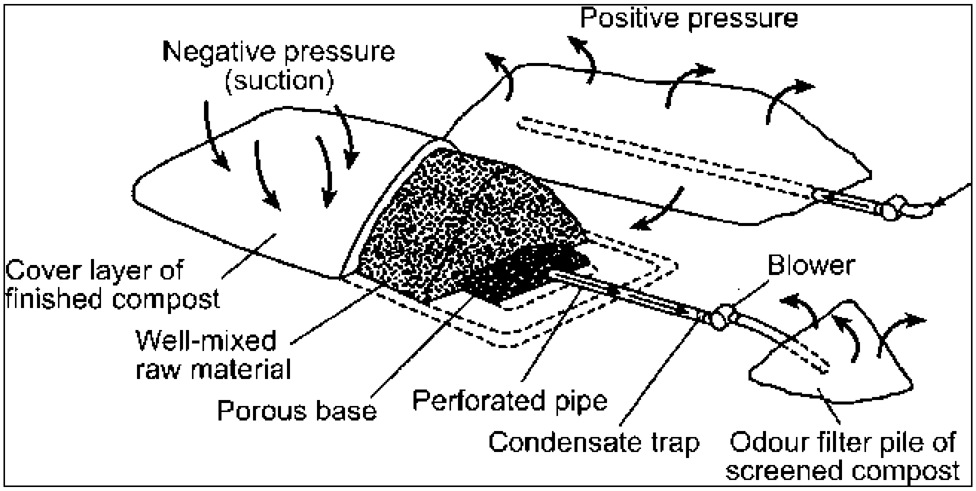


Figure 6: Aerated Static Pile Diagram (Rynk, 1992)

Because the static aerated piles shown in Figure 6 are more productive and less labor intensive, there is equipment that can be bought to turn piles more efficient. For large scale composting, front-end loaders are not always the most effective method. The amount of labor and time required can be higher than desired. Although these machines may be a significant capital investment, they do have the ability to turn the material more thoroughly and mechanically breakdown large pieces in order to produce more uniform compost. These machines also maximize the carbon dioxide to oxygen exchange and have the ability to water each particle of the compost instead of just the outside of the pile. This equipment is primarily split into three main categories. There is the tractor assisted rotary drum with flails, the self-propelled elevating face conveyor, and the straddle type rotary drum with flails. There are variations of these machines depending if a self-propelled or tractor aided mechanism is preferred. Some disadvantages to the drum turners are they compress the lumps in the compost while other methods break it up. Drum turners also can get buried into the pile and have to be dug out (Midwest Bio-Systems, 2005). All of these different methods and mechanisms, if chosen properly will lesson time and labor costs. It is up to the operator what option best suits their needs.

2.3.2.2 In-Vessel Systems

Windrows are the most common composting method, but they are rapidly being displaced in industrial circles by more advanced in-vessel systems (Figure 7).

Figure 7: Typical In-Vessel Composting System (EPTCorp, 2004)

In-vessel composting refers to a group of methods that confine the composting materials within a building, container or vessel (NRAES, 1992). They are automated compost units usually constructed on a concrete pad with a building covering all or part of the unit. Some are very technologically advanced with computerized continuous feed systems and mechanisms to maintain an optimal composting environment. Other in-vessel systems are not as advanced, and simply consist of a motorized augur or other mechanism for turning the composting material. Because in-vessel systems provide greater control over the composting environment, composting times can be reduced from approximately eight weeks to as little as three to eight days in the most advanced systems. This consequently decreases the space required for a composting facility when compared with windrow systems. In addition, rodents are kept away from the composting material, leachate can be collected and processed internally, and order production is minimized. In fact, many in-vessel systems can eliminate odors entirely through the use of bio-filtration devices. These systems are designed to have high durability, with some systems lasting 20 years or more. Unfortunately, for all their advantages, in-vessel systems have one significant drawback: capital cost. The large vessels, automated control systems, and environmental monitoring come at a price. Consequently, any in-vessel composting solution will depend greatly upon financial resources. Table 1 displays the advantages and disadvantages of the two general composting methods while Table 2 compares typical composting time requirements and curing time requirements (time required to chemical equilibrium).

Composting System	Advantages	Disadvantages
Windrow Systems	Simple; Low Capital Cost	High operating cost; Leachate production; Rodent disruption; Labor intensive
In-Vessel Systems	Good control over composting environment; Time reduced to as little as 2-10 days; Eliminate odors; No rodents; Leachate collected; minimal space needed; reduced labor	High Capital Cost: large vessels, automated control systems, and environmental monitoring are all expensive.

Table 1: Composting Technology Comparison

Method	Composting Time	Curing Time
Passive Composting	6 months - 2 years	None
Windrow - infrequent turning	4-8 months	1-2 months
Windrow – frequent turning	1-4 months	1-2 months
Passively Aerated Windrow	10-12 weeks	1-2 months
Aerated Static Pile	3-5 weeks	1-2 months
Rectangular Agitated Bed	2-4 weeks	1-2 months
Rotating Drums	3-8 days	2 months
Vertical Silos	1-2 weeks	2 months

Table 2: Approximate Composting Durations (Rynk, Robert, 1992)

In-Vessel systems can be further classified into two types, vertical and horizontal flow systems. For vertical flow systems two types are common, silo-cage systems and packed bed silo reactors. The silo-cage system is a multi floor aerobic process. The floors consist of a collection of up to 30 stainless steel perforated cages. The cages are put together apart from each other to allow passive aeration thus eliminating the need for turning or force ventilation. The feedstock is screened to eliminate materials unsuitable for compost before being incorporated into the system. The compostable material is loaded onto the upper most floor. Aeration occurs as the material moves downward through the cages. The hottest part of the system is at the top. As material is added it is warmed by the previous waste, this shortens the residence time of the compost in the silo. The process takes between 8 and 21 days dependant on the materials added and the quality of compost desired. The compost must be matured for up to three weeks after removal from the silo. The land required for the silo is minimal but more space is needed for the maturation stage.

Packed bed silo reactors incorporate silo composting into a process for solid and liquid materials. This method can compost feedstock consisting of up to 20% inorganic waste and high in containments. The feedstock is sorted and mixed with waxed cardboard to provide the correct balance of liquid and solid material. The slurry of material is shredded and aerated in the primary thermophilic digestion stage. Secondary digestion is carried out in the silo like containers. The resultant slurry is filtered, dried and formed into pellets. The system is completely automated and has built in bio-filters to remove odors. One acre of land is the minimal requirement for this type of system.

Horizontal flow systems are the other type of in-vessel system and can be more closely categorized into tumbling solids, mobile drum, and agitated bins. The Bedminster co-composting system is an example of the tumbling solids system, which is suitable for municipal solid waste and sewage sludge together. The compost is made by tumbling the waste through rotating drums with the help of scoops to maintain waste movement. Air is pumped from one end to the other opposite the travel of the compost material. Exhaust air is treated to remove odors. The process takes two days at temperatures of 65-71˚C. The maturation time of the compost is 28 days.

Augspurger Engineering Inc. makes a mobile drum composter aimed at small businesses, prisons, or small islands where an industrial composter is too big and a home composter is too small or slow. The system is a batch process with 900 kg of green waste, food scraps, paper, and sewage sludge composted at one time. The drum sections are rotated from the end of the line to the front. The drums are tilted at 10˚ and rotate at 1 rpm. The cycle takes 20 to 30 days to complete.

Agitated bins are another type of horizontal in-vessel, where the material is shredded and blended together. Moisture is added and it is all combined in an agitated container, which mixes the waste to help speed up the process. Temperature, CO_2 and air circulation controls are used to keep the compost running smoothly. Air enters the base and exits the roof via a filter. The compost takes 7 to 14 days to process and has a maturation time of 12 weeks.

2.4 McNeil Consumer Healthcare

McNeil Consumer Healthcare is a subsidiary of Johnson and Johnson, headquartered in Fort Washington, Pennsylvania. They began manufacturing medication in 1879 and currently focus primarily on over-the-counter drugs including Tylenol® and Imodium AD®. McNeil manufactures medication in numerous locations including Las Piedras, Puerto Rico, Round Rock, Texas and Lancaster, Pennsylvania (McNeil Overview 2005). As a manufacturing company, McNeil Consumer Healthcare is required to meet all federal EPA regulations governing solid, liquid and air pollution. In reality, however, McNeil supersedes these standards and implements an Environmental Management System (EMS) that follows stringent ISO 14001 guidelines. In addition, the corporate credo essentially states that McNeil, and more broadly Johnson and Johnson, will strive to embody principles that are socially and environmentally responsible. Because of this philosophy, McNeil spends a great deal of effort working to reduce the environmental impact of its manufacturing facility.

One way in which McNeil reduces their impact is through a well-established recycling program. This program collects both on-site wastes as well as waste brought in by employees for subsequent transportation and processing. By recycling, McNeil helps eliminate manufactured materials such as glass, plastics, paper and aluminum cans from disposal in landfills. Unfortunately, however, McNeil also produces a large amount of yard waste, cafeteria waste and wastewater sludge from an on-site wastewater treatment plant. These materials cannot be recycled and are still currently disposed of in landfills. Luckily, these materials are capable of being composted, and it is for this reason McNeil wishes to initiate an on-site composting program.

While reduced landfill use is a noble goal for McNeil, it not likely their only expectation for this project. By looking at composting in the context of their broader corporate goals, it is apparent they also wish to use this as a vehicle for extending their environmental policy, promoting their company and educating the community. Because of these additional goals, McNeil requires that any composting system be constructed with the strictest attention to environmental concerns and regulations as well as educational potential and opportunities. If done in this manner, a composting system for McNeil can help create and promote sustainable waste management in Puerto Rico.

2.4.1 Environmental Policy

In order to properly grasp McNeil's relationship with the environment, it is important to understand the regulations and standards that govern all corporations. To this end, there are two main bodies of importance: the Environmental Protection Agency (EPA) and the International Organization of Standardization (ISO). The Environmental Protection Agency, as stated on their website, works to develop and enforce regulations that implement environmental laws enacted by Congress. The EPA is responsible for researching and setting national rules for a variety of environmental programs, and it delegates to states and tribes the responsibility for issuing permits and for monitoring and enforcing compliance. The ISO, on the other hand, is an international network of national standards institutes in approximately 140 countries with its headquarters in Geneva, Switzerland (ISO.com, 2005). This organization sets the standards for Environmental Management; compliance is voluntary. The Storm Water Pollution Prevention Plan (SWPPP) required by ISO 14001 standards for the application of a permit is of particular importance to the composting project due to the need for a specific permit allowing the use of wastewater sludge in the compost. ISO 14001 is designed to be the only standard establishing requirements against which companies will be audited for certification (Hemenway, 2005).

The ISO 14000 family of standards is a set of standards designed to deal with environmental management. An organization that adheres to this family of standards minimizes harmful effects on the environment caused by its activities and works to achieve continual improvement of its environmental performance. By setting these standards, an organization can formulate both policy and objectives that take into account legislative requirements and information about significant environmental impacts (ISO, 1996). Detailed explanations of requirements for environmental permits are outlined in ISO 14001. Permits exist for any current activity that could lead to environmental destruction.

McNeil falls under MSGP Sector C – Chemical and Allied Products Manufacturing, Subsector three. MSGP, Sector C requirements include, among other things:

- A Storm Water Pollution Prevention Plan
- A Storm Water Pollution Prevention Team
- Quarterly visual examinations of storm water discharges

- Annual comprehensive site compliance evaluation
- Annual employee training
- Quarterly meeting with the SWPP Team

McNeil and Johnson & Johnson's internal requirements include:

- Annual analysis of storm water run-off
- Storm water program audit, as part of the Environmental Management System Audits for the Wastewater Section.

As required by ISO standards for the application of a manufacturing permit, a Storm Water Pollution Prevention Plan is needed. This plan must address specific issues described by ISO standards. A SWPPP must:

1. Identify potential sources of pollution that may reasonably be expected to affect the quality of storm water discharges from the facility.
2. Describe and ensure implementation of practices the organization will use to reduce the pollutants in storm water discharges from the facility
3. Assure compliance with the terms and conditions of the permit.

The SWPPP covers all applicable aspects of the storm water Multi Sector General Permit (MSGP) regulation, as well as McNeil and Johnson & Johnson's internal practices, guides, and procedures (SWPPP, 2004).

The Storm Water Pollution Prevention Plan at McNeil includes a description of potential pollutant sources. Wastewater spills are listed as a potential source of contamination of storm water. This is particularly relevant to composting work because wastewater sludge can be used in the compost process. Pollutants outlined in the plan originating from the wastewater are pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), and metals. The SWPPP also has a Measures and Controls section in order to comply with all the requirements of the storm water regulation. The control plan incorporates the best management practices such as nonstructural and structural controls, inspections, preventative maintenance, and emergency response procedures. Composting will not eliminate the threat from the wastewater sludge, therefore measures and controls would be needed along with a new permit dealing with larger scale composting. A method of collecting leachate would be necessary so as not to contaminate ground water nearby with pollutants from the wastewater sludge.

2.4.2 Educational Initiatives

McNeil has already begun efforts to educate and interact with their surrounding community (Las Piedras). In 2004, they started an extensive Environmental Community Outreach Program. Due to the fact that McNeil is a manufacturing facility, their relationship with the surrounding towns and communities is very essential. If they maintain a good relationship with the community, they are less likely to have problems in the future. In a message from the General Manager Jorge Ros in 2004,

> "The Community Outreach Program embraces the continuity of these activities and formalizes our commitment and responsibility with this community in which we live and work. One of the most important priorities of this program is the environment and the natural resources."

This existing educational program can be extended in the future to incorporate new areas of environmental management such as composting.

Due to the negative connotations associated with big corporations in general, people can be apprehensive about letting these companies move into their neighborhood. Companies such as McNeil have unsightly buildings and towers, produce increased traffic, and yield hazardous wastes. If the companies explain what goes inside their plant and what they do to prevent accidents, it will be less likely that community members will complain. For McNeil:

> "The Community Outreach Program is a process that brings government, private industry, community groups and private citizens together to discuss and understand activities that have the potential to affect public health, quality of life, or the environment (McNeil, 2004)."

It is beneficial to everyone when companies are concerned about what they do and how it affects citizens.

One portion of this concern extends to issues regarding emissions associated with maintaining McNeil's manufacturing facility, in particular their wastewater treatment plant. Due to this delicate situation, efforts have been taken through the Educational Outreach Program to inform the community of the plant's condition and keep it well under control. These efforts can be easily extended to other areas of problematic emissions including potential odor problems associated with a composting facility.

With this in mind, it is easy to see why McNeil has strict environmental policies that go beyond the necessary requirements. They want to maintain a good relationship with the community. Furthermore, they understand that "open lines of communication foster a sense of mutual trust and enhance the public image of the company" (McNeil, 2004). Ideally this will mean that all avoidable conflicts and misunderstandings will be eliminated both with current programs and with any future systems.

There are other aspects and activities associated with McNeil's educational outreach program. Some of the main environmentally sound outreach programs that McNeil has been a part of and donated money towards include Adopting Schools, Earth and Energy Conservation Week 2005, and the Potable Water Center. On top of those specific activities McNeil has shown willingness to talk with the community about their concerns. McNeil has "adopted" two high schools and two secondary schools. In these schools, they participated along with fifteen interested students in developing a recycling plan. The Environmental Department of McNeil worked with the schools in this regard to teach the students about the benefits of recycling and built a drop off center for recyclable materials. McNeil funded all the necessary items for this project. Additional activities in the schools included contests among the different classrooms that involved bringing in recyclables from home. Students were awarded prizes for being the most productive classroom. A final opportunity for the people to get information about

McNeil is to take tours through the facility where displays and flowcharts notify them about the different processes that go on throughout the plant. All of these programs not only inform the community about environmental awareness but also help open lines of communication in case any problems arise in the future.

2.5 Summary

Clearly, there are a number of technological options and different composting methods available to reduce reliance on landfills in Puerto Rico. Each system and method has advantages and disadvantages such as those outlined in Table 1, but they all have the capability of creating sustainable waste management. Installation of a composting system will work toward McNeil's goal of reducing the cost of their own waste disposal and setting a good educational example for the community.

Chapter 3: Methodology

The essential goal of this project was to help McNeil Consumer Healthcare reduce their volume of disposed biodegradable waste and raise community awareness of alternative waste management methods by exploring composting options. Our team suggested and developed a long term plan for establishing a composting system at McNeil as well as assisted in the fabrication and testing of a smaller-scale composting system on site. In addition, educational outreach was conducted with McNeil's four "adopted" schools in order to both introduce the students to composting as well as establish long-term educational objectives for future composting activities.

In order to fulfill these broad goals, the project was broken down into the following sequential objectives and completed according to the timeline shown in Figure 8**:**

- Assess the waste disposal needs of McNeil Consumer Healthcare.
- Formulate and implement an educational outreach program for local schools.
- Create and assess small-scale static pile composting system.
- Assess the composting potential of McNeil's wastewater sludge.
- Research, compare and contrast large-scale composting solutions.

<table>
<tr><th rowspan="2">TASK</th><th colspan="8">WEEK</th></tr>
<tr><th>prep</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th></tr>
<tr><td>Assess McNeil's needs</td><td colspan="5">Assess McNeil's needs</td><td></td><td></td><td></td></tr>
<tr><td>Formulate Education Outreach Program</td><td></td><td colspan="3">Formulate Education Outreach Program</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Static Pile Compost Experimentation</td><td></td><td></td><td></td><td colspan="5">Static Pile Experiment</td></tr>
<tr><td>Wastewater Sludge Experimentation</td><td></td><td></td><td></td><td colspan="3">Wastewater Sludge Experiment</td><td></td><td></td></tr>
<tr><td>Research Long Term Compost Systems</td><td></td><td></td><td></td><td></td><td></td><td colspan="3">Research Systems</td></tr>
</table>

Figure 8: Methodology Timeline

The overall methodology is outlined in the flowchart shown in Figure 9**.**

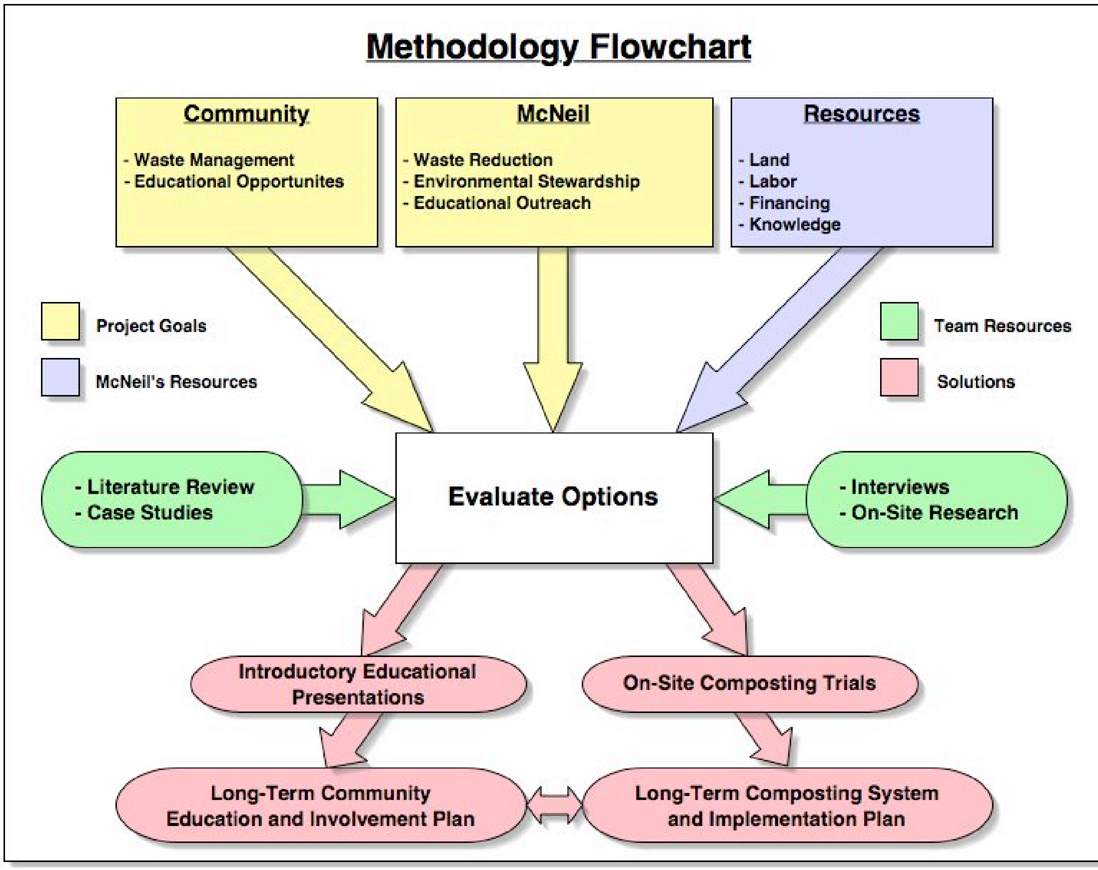


Figure 9: Methodology Flow Chart

3.1 Assess McNeil's Waste Disposal Needs

The first step in designing any system is to thoroughly analyze the exact needs required. Therefore, to best serve McNeil, we first attempted to examine the exact requirements of their waste management problems and goals. Some items we considered are the waste quantity, waste composition, and the environmental standards governing all activities at their facility.

The quantity of waste generated by McNeil was very important in evaluating and comparing different composting systems. Without this information an accurate recommendation could not be made. Therefore, one of the first and most important goals in assessing McNeil's waste disposal needs was determining the quantity of waste generated. In the analysis of the waste quantity the first step was a tour of the wastewater treatment plant. From observation, the wastewater sludge was contained in a 10,000-gallon holding tank onsite before shipment to another Johnson & Johnson plant for further treatment. The total quantity of wastewater sludge on a yearly basis was easily obtained from the Wastewater Treatment personnel. Unfortunately, the food waste and yard waste quantities were more difficult to obtain. Discussions were held with Carlos

Hernández, Maribel López, and Julio López pertaining to these quantities. Records were kept from previous estimates of these waste types. However, these records included extra forms of waste and were thus not very useful for our purposes. For example, the food waste numbers included plastic bags, cardboard, and other miscellaneous waste items mixed in with the food waste. Julio López completed the final separation and computation of food and yard waste quantity estimates. An added food quantity estimate was give to us by Nelson Cruz completed in 2004 over the course of four days to determine an accurate average.

In addition to waste quantity data, detailed analysis of McNeil's waste was necessary in order to predict system efficiency and processing requirements. Further information regarding one particular waste, the wastewater sludge, was obtained from Carlos Hernández. In anticipation of this project, McNeil's Environmental Department ordered a detailed analysis of the wastewater sludge. The laboratory tests were conducted in April and June of 2004 and contained information such as ignitability, total volatile solids and pH. We also took another important analytical step by communicating with the Wastewater Treatment Plant (WWTP) staff in order to determine sludge density and moisture content. Besides wastewater sludge composition, food waste composition was determined by observation of the waste given to us. Initially, many non-compostable materials were found in this waste such as plastics and metal foils. Sifting this waste by hand yielded the ideal composition for composting. After this examination, the cafeteria manager had all subsequent waste separated so that only compostable materials were incorporated into the compost. Yard waste composition was also analyzed both by observation as well with the aid of landscape employees.

While composting systems can provide significant reductions in waste output, they can also emit other forms of air and water pollution such as leachate and noxious gasses. Consequently, any composting system would need to comply with local regulations in addition to McNeil's own environmental management system. This placed constraints on the type of composting system McNeil could implement and the environmental controls required for such a system. Information on the environmental regulations governing McNeil's operations was obtained from Carlos Hernández. A copy of the ISO 14000 standards McNeil abides by and the Storm Water Pollution Prevention Plan were collected. These documents were directly related to the regulations and standards posed on and by McNeil for the act of composting on-site.

3.2 Formulate Educational Outreach Program

McNeil's stated objective for this project is to reduce landfill waste. However, given current trends toward greener industry, they also plan for this composting system to set a good example for the community and provide an educational medium for sustainable waste management. With this educational goal in mind, we followed through with these steps:

- Researched the current education program at McNeil
- Created a four part lesson plan for the schools to complete in the future
- Delivered preliminary lesson to class at four schools in the community
- Designed an on-site educational flowchart

As previously discussed, McNeil Consumer Healthcare is extremely involved with their surrounding community. In order to plan our education program, we researched McNeil's current program. Our liaison referred us to Maribel López, the Educational Coordinator. She is in charge of the four schools McNeil has "adopted," and is extremely involved in the interaction with the students. She was our main resource for information about McNeil's past educational experience. She has kept records of all of the community activities. A majority of these include the four schools that we visited. She gave us spreadsheets of the Community Outreach Plan 2004, which she keeps for McNeil's records. They contain a description of the particular activity, goals, cost, date, and person is responsible. This made our research very clear-cut and accessible.

The recycling program McNeil has implemented at the schools is very similar to what we hope will be accomplished with composting. We first had to teach the students about composting and then give the teachers lesson plans to follow up with for next year. Before we could visit the schools we designed a presentation about composting. The first step in designing a composting education plan was to understand the audience. In this case, the targeted viewers were small groups of middle and high school students at each of McNeil's adopted schools with interests in environmental issues. Because the students were older and somewhat experienced in the subject area, the lesson material had a moderate level of complexity and detail. It was, however, still designed to be simultaneously informative, interactive and fun. An important barrier that had to be considered was how much English the students were familiar with. Language has always been an important issue in regards to Puerto Rican education. From 1930 to 1948 the U.S. authorities insisted on making English be the language of instruction in schools in order to expose students to American culture. After years of resistance from the Puerto Rican society the primary language was switched back to Spanish. English is still required to be studied at every age level as a second language. In 1993, the island declared both English and Spanish to be their official languages (Countries Quest, 2005). Due to this language barrier, Maribel López translated and asked questions to make sure the students understood. This helped us to speak slower and helped the students participate during the presentation. The first lesson, which was introduced by us, included an overview of the waste management problem, the underlying biological process, composting methods, ideal conditions, and how to create your own compost pile. The presentation of this lesson by the authors is shown in Figure 10.

Figure 10: Educational Presentation

Before we began covering the material outlined above, we wanted to be sure we had the students' attention. To do this we used a simple metaphor involving food. On one end of the table we placed the ingredients needed to bake a cake: flour, sugar, eggs, milk and butter. On the other, we placed a baked, finished cake. The ingredients alone have little value, whereas the cake is a desired, useful product. This is very similar to composting, in that you take several things that alone have little use (the ingredients), combine them in the correct ratios (follow the recipe), allow them to sit in the heat (baking) and finally your efforts result in a useful, compost product (the cake). This is a simple overview of the process. We then cut and distributed the cake to the students and proceeded onto the main body of our presentation.

The first subject covered was a summary of the waste management problem. This served to explain why we were here speaking to them about composting and why it should be practiced. This included an analysis of why the problem of landfilling and waste disposal has become so severe. We also elaborated on efforts to address this problem, including recycling, the Green Industry movement, legislation, and composting.

The second subject covered was the biological process associated with composting, which despite the existence of different composting methods is all relatively the same. Using two process diagrams and flowcharts, we explained the how compost is created and what happens inside the compost pile. Due to the age level and language barrier, the delicate ecosystem of organisms that consume and digest the waste was simplified. In the diagrams cartoons were used to illustrate the process to make it easy to understandable. These diagrams are shown in Appendix B.

Although there are several, very different composting methods worth mentioning, the lesson was focused on small scale, simple backyard compost piles. The goal of this education plan was to encourage widespread personal composting. Thus the focus on smaller systems was more practical for the students. To inform them about McNeil's composting objectives the material included brief mention of the larger, more complex systems that are better suited for industrial applications.

Once the students understood the details of the compost process, the presentation progressed to the most important stage: how to create your own compost pile. Part of this discussion covered what types of materials can be composted. This included reference to many specific examples such as food scraps and yard waste. Unfortunately, due to time constraints and the upcoming summer vacation, we could not physically start the compost pile in the schoolyard as we had planned. However, McNeil plans to initiate this in the fall of 2005. Hopefully, physically starting the compost site with the students will help to put our lesson into action.

This outreach into the schools and communities surrounding McNeil is a very important social implication of this project. Upon conclusion of our presentation, we left Maribel López a detailed outline and lesson plan for our Introduction to Composting presentation. The lesson plan can be found in Appendix C. We also drafted several follow-up lessons, including interactive experiments, to leave with the teachers. These experiments invite the kids to actually work with different compost piles, exploring the conditions for an ideal compost pile. These additional lesson plans can be found in Appendix D. After visiting four schools to give our initial presentation we thought that the visits we successful. We exchanged contact information with the classes and encouraged the children to contact us with questions. This way they have us a resource as well as McNeil.

An additional component of the educational objective was installed at McNeil's manufacturing facility. We observed that every area of the plant contained flow charts and diagrams to help employees and visitors better understand the processes within. To be consistent with McNeil's efforts, we designed a colorful, bilingual diagram to be placed directly at the compost site. From a simple glance, anyone from plant mangers to construction workers will be able to have some understanding of what is happening and why.

3.3 Static Pile Composting Experimentation

Prior to considering any large-scale on-site composting solution, McNeil wanted to initiate a smaller-scale trial system utilizing only yard wastes and food wastes. No wastewater sludge was to be used in this trial system in order to avoid additional environmental requirements. The objective of this trial system was to give staff and employees experience with actual composting, provide an immediate reduction in biodegradable waste output, and lend credence to any future investments. In order to accomplish this, an unused portion of the McNeil site just outside the truck lot was leveled, poured with gravel, and hooked into the water supply system. Reinforcement bars and wire mesh were installed to create five large (5 foot by 5 foot) cylindrical static pile compost holders. A Vermeer™ BC625A yard waste shredder, a bin to hold the shredded material, several shovels and pitchforks to turn and move the material, and a tent to protect the tools from the elements were also purchased. This small-scale trail composting system can be seen in Figure 11.

Figure 11: On-site Static Pile Composting System

Composting with the on-site static piles began exclusively with yard waste. Dead or removed tree leaves, palm fronds, branches, and shrubbery were all fed into the yard waste shredder in order to reduce the total volume of waste and increase the surface area available to the microorganisms for composting. This shredded waste was then transported to the cylindrical mesh enclosures where it was placed and spread around. Water was also added to provide a moist but not overly wet shallow layer of shredded material. The following day, additional yard waste was shredded and added to each pile. This new material was mixed with the old, and water was once again added in judicial amounts. The procedure of shredding material, adding it to the piles, mixing the piles, and adding water as necessary was continued for several days. During this time, qualitative observations were made regarding odors and material texture. These observations were continued for the duration of the trail system.

After a few days of composting exclusively with yard waste, food waste was added to the static piles. The introduction of food waste was not without concern, however. The leftover food obtained from the cafeteria, while fairly small in volume, was nowhere near as consistent in moisture or composition as the shredded and mixed yard waste. Unfortunately, a shredder capable of processing moist food products was unavailable at the time. It was thus theorized that significant odors might emanate from the piles once the inconsistent materials were added. In addition, raw food can draw rodents or other pests, and as such might have upset the composting piles. Because of these concerns, all food wastes added to the piles were sorted to remove non-compostable materials and mixed with plenty of yard waste in order to minimize material differences. Care was also taken to make sure all the food was buried well below the surface of existing yard waste and was near the center of the pile if possible. Finally, food waste was not added every day as yard waste was, but was instead distributed in different piles on different days. This procedure of intermittent food addition, approximate daily yard waste addition, mixing, and judicial watering was continued until the piles were full. From then on, intermittent mixing and watering were all that was needed to maintain the piles and create great compost material.

3.4 Wastewater Sludge Analysis and Experimentation

The use of wastewater treatment sludge in the compost process was one of the biggest unknowns our team faced in this project. Little was known about its chemical composition, water content or density. We found that the wastewater sludge was being transported off site to another Johnson and Johnson facility for further processing. However, McNeil would like to process the sludge on-site as part of their composting efforts. Unfortunately, there were no clear examples of sludge being integrated with food and yard wastes to create a compostable mixture. These were all issues we had to address. They can be broken down into two broad questions. First, what are the properties of McNeil's wastewater sludge? Second, what is the best way to integrate the sludge into the compost mixture?

To establish the chemical properties of the sludge we relied on research and investigation on-site. We found that the sludge had a very low C:N ratio, a high density and a high moisture content. Because the overall properties of the sludge were less than ideal for composting, it was clear that further investigation would be needed.

In order to determine the usefulness of wastewater treatment sludge for composting, we conducted a series of small-scale composting experiments. We setup five miniature compost systems in total. Each system consisted of a plastic, five-gallon bucket with several small holes drilled in the bottom for drainage. It was important to monitor the drainage because composting with wastewater sludge requires a permit. In order to gather and monitor the drainage of each system, each bucket was placed on a makeshift leachate collector. This consisted of a square, metal bin with a stiff piece of metal grate welded on top, as shown in Figure 12. Any liquid produced in the compost process would trickle to the bottom of the bucket, out the drainage holes and finally into the collection bin.

Figure 12: Wastewater Sludge Experiment Setup

Five identical systems were set up and labeled 1 through 5. Each bucket had a different ratio of materials in order to see what proportions of materials would be most useful. The materials used were broken into three major categories: landscaping wastes, food wastes and sludge. In order to maintain a proper experiment, the first and last buckets were considered controls. Bucket 1 contained only wastewater sludge and bucket 5 contained only landscaping and food wastes. This was done so we could observe the material mixtures objectively. Based on our knowledge of the materials' properties as outlined in the background, we developed recipes for mixtures in buckets 2-4. The details of these mixtures are shown in Table 3.

Bucket	**1**	**2**	**3**	**4**	**5**
Yard Waste (lbs)	0	1	4	4	9
Food Waste (lbs)	0	4	4	1	1
Sludge (lbs)	10	5	2	5	0
Total (lbs)	10	10	10	10	10
Density (g/mL)	1.07	0.77	0.46	0.47	0.28
Moisture (%)	96	77	53	61	20
C:N Ratio	0.07	23	35	45	49

Table 3: Wastewater Sludge Experiment Recipes

All of the buckets had the same total mass of 10 lbs so that they could be easily compared. Bucket 1 consisted of only wastewater sludge, it had the highest density and moisture content and the lowest C:N ratio, overall these are not good composting conditions. Bucket 2 contained small amounts of food and yard wastes and a large amount of sludge. It had a lower C:N ratio, contained more water and was more compact than ideal conditions. It represented compost that is primarily sludge. Bucket 3 represented ideal conditions. It had a varied mixture of materials and resulted in good compost properties. Bucket 4 contained a mixture similar to that in bucket 3, however, it contained more sludge and had a slightly higher C:N ratio. It represented a compost mixture that is half sludge and half food/yard waste. The final bucket, bucket 5, was another control and consisted of only food and yard wastes. It had the lowest density and moisture content and the highest C:N ratio.

We attempted to create a variety of composting conditions so that we could see the effect of different levels of wastewater sludge on composting. The success of each small-scale compost system was determined by temperature. After the piles were established and allowed to sit for a few days, we stirred and recorded their temperature daily. An elevated temperature is indicative of a successful compost pile, therefore the system with the highest internal temperate was viewed as the best system and the best mix of materials.

3.5 Research and Compare Large-Scale Composting Solutions

In order to formulate and recommend a long-term composting solution for McNeil, it was necessary to first determine how McNeil's significant amount of wastewater sludge could be used in the composting process. The general methods we evaluated were anaerobic systems, aerobic windrows, and aerobic in-vessel systems. Once these general methods were evaluated, we conducted research into the availabilities and capabilities of different specific systems. There are countless composting products on the market, however. To narrow our search, only systems that met certain criteria were considered candidates. These candidates were then investigated further to determine the information necessary to appropriately compare and contrast them.

In following through with this process, the wastewater sludge proved to be the most problematic. As we discovered in our background research, McNeil produces approximately four times more sludge than the other compostable wastes combined. In addition, this sludge is extremely wet (~97% water) when shipped from the wastewater treatment plant. Aerobic composting cannot function in such wet environments because of lack of oxygen. Therefore, we chose to research methods of dealing with this moisture problem. One method we considered was separate anaerobic processing of the sludge in an enclosed facility. Another method was sludge dewatering prior to inclusion in traditional aerobic composting. These two techniques were the most commonly used methods in the liquid and solid waste treatment industry. Once they were evaluated, we were better able to pinpoint what criteria specific systems would need to meet.

The first criterion we selected to use when selecting systems for further analysis was McNeil's environmental regulatory requirements. These requirements included their Storm Water Pollution Prevention Plan and odor emission guidelines. Because composting could potentially produce polluting water runoff when processing materials such as dewatered wastewater sludge, it was mandatory that any composting system be capable of collecting this run off. In addition, ISO 14001 standards dictate that all non-regulated emissions, such as non-toxic odors, still minimize environmental impact if possible. Thus, it would be most desirable if McNeil's composting system could process and eliminate odors. McNeil's close proximity to the surrounding community also dictated a system capable of minimizing odors. Because of these two requirements, in-vessel composting solutions were considered the best candidates for McNeil if sludge were to be used in the composting process. Windrow systems, while potentially cheap and easy, are by definition open to the environment and thus could not fulfill the runoff and odor requirements for sludge processing.

The second criterion we used in selecting candidate solutions was the quantity of waste McNeil generates. While this is a significant amount from a residential standpoint, it is fairly small from an industrial standpoint. Some industrial composting facilities process 1 to 500 tons per day. Unfortunately, many sophisticated in-vessel composting technologies were designed for industrial scale composting facilities and would not have functioned well with the relatively small quantities of waste McNeil generates. Consequently, in-vessel systems selected for further consideration were all sized appropriately to process McNeil's total waste quantity.

Once a list of candidate systems was generated, we investigated these individual systems more extensively. This was accomplished by contacting each company be phone and discussing our particular situation with them. We inquired about capital and operational costs, leasing options, resources required, system complexity, compost process time, system capacity, input material flexibility, compost quality, and other operating details. We also investigated any previous installations that could act as references, and these were contacted for further information and evaluation. All of this information was then compiled in order provide an easy comparison between the different composting options. From this comparison, we were able to select and recommend the system that provided the best combination of properties for McNeil.

Chapter 4: Results and Analysis

In the course of this project, we obtained four main results: the on-site composting results, the long term compost system evaluation results, the educational presentations to Puerto Rican schools, and the long term educational lesson planning. Prior to accomplishing these four tasks, however, data on McNeil's waste material was collected and analyzed. While the waste material analysis took a significant amount of time, ultimately all results and deliverables were completed with a high degree of success.

4.1 Waste Material Analysis

Although there are many origins of waste, McNeil has identified three specific sources of waste targeted for their composting system: cafeteria waste, landscaping refuse, and wastewater treatment sludge. The relative amounts of these substances at McNeil are shown in Figure 13, and the current associated costs of disposal are shown in Figure 14 (personal communication, Julio López, 2005).

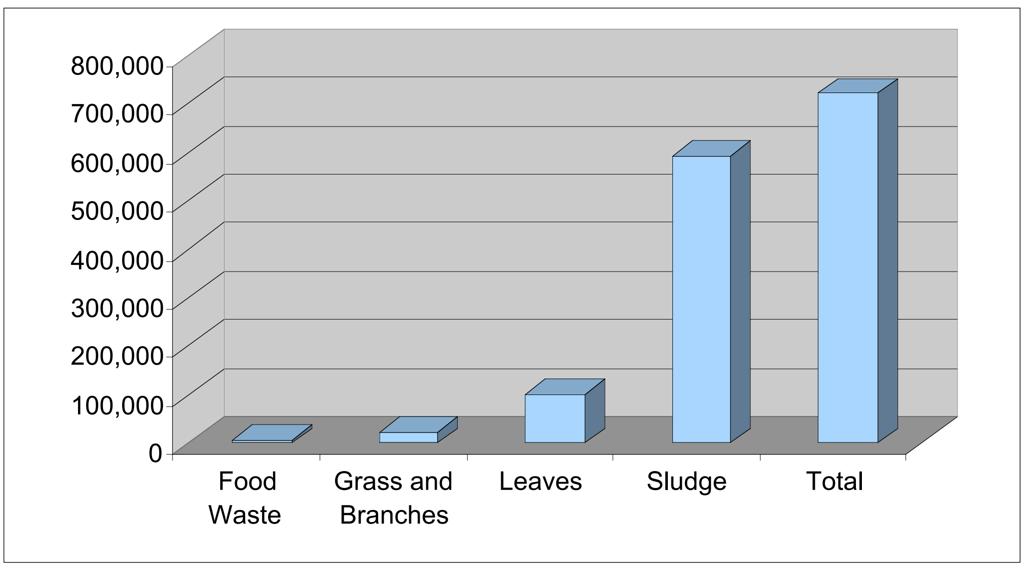


Figure 13: McNeil Waste Quantities in lbs/year

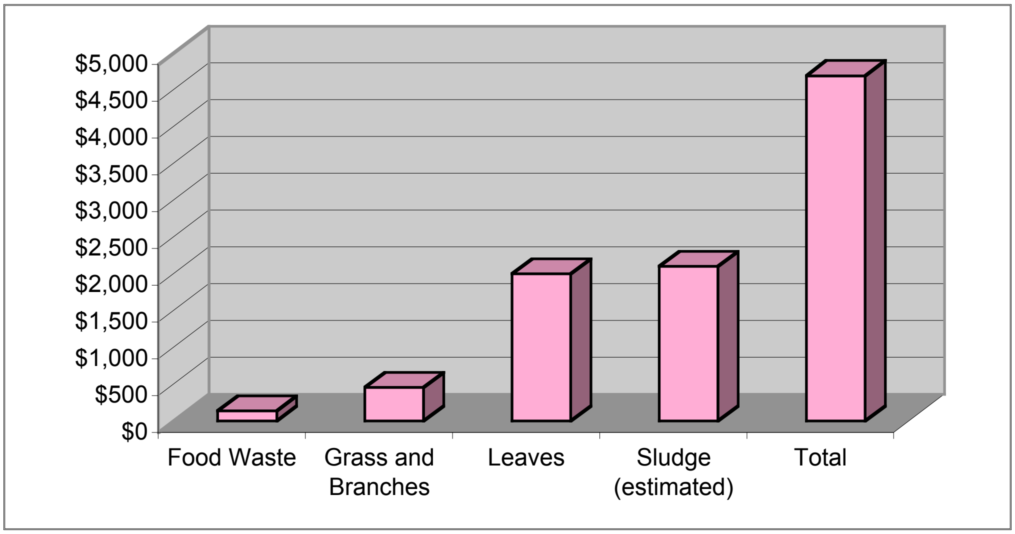


Figure 14: Cost of Disposal per Year

Food scraps are commonly associated with composting, therefore it is very appropriate that McNeil has chosen to include cafeteria wastes in their composting system. In this aspect, their previously established recycling program directly complements the composting effort. In the company cafeteria, we observed that all trays, plates and silverware are reusable. Employees are accustomed to separating their wastes into aluminum cans, glass bottles, plastic bottles and trash that consists primarily of food scraps and paper. In addition to scraps from the kitchen, this will serve as one source of McNeil's compost.

A second source of McNeil's compost will be landscaping wastes. Once arriving on McNeil's compound it is easy to see that their grounds are meticulously maintained. A highly landscaped facility results in a considerable amount of waste, such as grass clippings, leaves, branches and more. These materials are ideal for composting. In talking with maintenance staff, it became apparent that this material would be collected then processed through a shredding machine before being added to the composting process.

McNeil's third and final source of compost material, wastewater treatment sludge, is less traditional than food scraps and yard wastes. Still, we observed that McNeil's on-site wastewater treatment plant is very typical for an industrial plant. All process and sanitary water is sent to collection areas where it is filtered to remove excess solids. It is then pumped to a very large equalization tank where the untreated water is stored for some time. This minimizes fluctuations in volume, composition, and pH. After the equalization tank, the untreated water is pumped into two sequential batch reactors. The effluent from the equalization tank is divided in two and half of the effluent goes to each batch reactor. In the batch reactors, the sludge is mixed with specially designed microorganisms that consume some of the chemicals and hazardous materials in the wastewater. After the microorganisms have had considerable time to interact with and digest the sludge, some of the batch reactors' content is transferred to the final stage: the digestion tank. This tank is periodically agitated to ensure further digestion of waste, however it is also tranquil for long periods of time to allow the liquid and solid materials to separate. The liquid on the top of the tank is removed, tested to ensure sufficient treatment and then sent to a municipal wastewater treatment facility for further processing. The solids that settle to the bottom are the remaining, unprocessed wastes, also known as sludge. This waste is removed from the liquid by a pump at the bottom of the tank. It is currently pumped to a storage shed where it sits for approximately three weeks and then is shipped to a nearby Johnson & Johnson facility for further processing and disposal. It is this final sludge that McNeil wishes to use for composting.

Each of these three compost material sources has very different properties. We discovered through research that ideal composting occurs when the material bulk density lies between 0-0.5 g/cm^3, moisture content is in the range of 50-60% and the carbon to nitrogen ratio is approximately 30:1 (Trautmann, 2002). Most food wastes have a very high density and a slightly low C:N ratio, whereas most landscaping wastes have a reasonable density, but a very high C:N ratio. Wastewater treatment sludge is very dense, very moist, and has an extremely low C:N ratio of approximately 1:14. This information is more conveniently outlined in Table 4 (Green Mountain Technologies, 2004).

	Density (g/cm^3)	Moisture Content	C:N Ratio
Ideal Conditions	**0-0.5**	**50-60%**	**25:1-35:1**
Food Wastes	0.9	69%	15:1
Leaves	0.27	80%	54:1
Shrubs	0.26	15%	53:1
Wood Shavings	0.24	20%	500:1
Grass	0.8	82%	17:1
McNeil Sludge	1.07	96%	1:14

Table 4: Properties of Potentially Compostable Waste

Therefore, by combining the three substances in the correct proportions, conditions in the ideal ranges can be met. Detailed information about a range of specific substances can be found in Appendix A.

4.2 Composting Experiments

Prior to developing a plan for McNeil's composting program, it was import to initiate actual composting on-site. This was done with yard and food waste in static piles as well as with sludge in smaller-scale buckets. Throughout the course of these experiments, several observations were made. These observations were necessary in order to help integrate composting with their existing waste management program as well as provide better final recommendations.

4.2.1 Static Piles

The results of the bin composting systems, set up for small scale observation purposes, were encouraging in some respects while flaws in such a system were also exposed. Working with the composting directly gave us the opportunity to experience the physical results firsthand. The ease of composting yard and cafeteria waste in such as system is notable, as seen in Figure 15. In the right conditions and without much care the composting process began quickly.

Figure 15: Yard and Food Waste Composting

Shredding the compost material was a great way to generate a loose aerated mix of ingredients. No major difficulties surfaced from shredding and it allowed for much larger quantities of yard waste to be added. Large tree branches are not appropriate if the composting system is intended to be efficient, because more surface area is needed to allow the microbes to complete their decomposition process rapidly. The bin system is also not the best option for composting of wastewater treatment sludge. This is because pathogens and metals are present in the sludge causing it to be inappropriate for release into the environment. Storm water and general watering for maintaining moisture levels would carry some of these harmful elements out of the piles and into the ground water. Sludge is amenable to composting, but a leachate and water collect system would have to be incorporated. Cafeteria waste does not need to be shredded and would compost well with the yard waste.

The cafeteria waste added to the yard waste posed no major difficulties or shortcomings. Within a couple days, 25 pounds of food were found to be virtually unnoticeable within the pile. Odors were minimal with a yard waste to food waste ratio of 2:1, with no perceptible foul odors when standing near the piles. Some odor arose when turning exposed the food waste after too short of a time period within the yard waste pile, but was not noticeable when positioned several feet away. This will keep major odor problems from arising in the small bin systems.

Animals were prevented from accessing the cafeteria waste by the wire bins surrounding the compost. Insects however, were not stopped from inhabiting the compost. In McNeil's case, this was not a problem for the process, because insects are only a nuisance if the piles are positioned too close to a building, attracting the insects from the pile to the building. Fire ants have infested two or more of the compost bins, therefore extra care is needed when turning the compost to avoid injury. After working with the compost, it can be said that the effort required to maintain the compost is reasonable with a few difficulties.

The size of the bins imparts a limit to the size of the compost pile. One cannot fill the bin entirely and be able to turn the compost with ease. There was some difficulty in turning the compost manually with the bin only half full, because there is limited space to move composted material and put uncomposted material in its place (Figure 16).

Figure 16: Limited Space for Turning

The most effective way to turn the piles would be to remove all of the material from the bin, mix it, and replace it. For more ease of turning and to compost larger quantities of materials, a bin type system would not be the most efficient or optimal solution. Bin composting is a simplistic form of composting and good for small home systems, but not as suitable for a large industrial waste stream.

Seasonal changes have an effect on outdoor bin composting. Puerto Rico has dry and rainy seasons with the hurricane season from June 1st to November 30th. During the dry season, moisture content must be carefully maintained so that the piles do not become so dry the composting fails to continue. For the rainy season, the possibility of too much moisture would have to be closely monitored, and added turning would be needed to sustain a correct level. A hurricane would pose a separate problem of total destruction of the system. No viable precaution can be taken for this situation. Another system would not necessarily be more durable in such an environment, but a bin composting system would be one of the least robust in the case of a hurricane. Only the extreme edges of climate would cause difficulties; excessive heat could dry out the piles quickly and large quantities of snowfall would impede turning among other difficulties. The outdoor temperature is on average 82 degrees Fahrenheit, which coincides well with the needs of an outdoor open composting pile.

Overall composting in the bins demonstrated the readiness of yard and food waste to compost. Shredding aided in the ability of the waste to compost by increasing aeration and the creation of more surface area for the microbes to feed off. The sludge would not be appropriate for such a system due to environmental concerns. Animals are deterred by the bins housing the compost; however insects, although not harmful to the process, can pose a few problems. The size of the bins also adds some difficulties in the turning of the compost. The humid and warm environment of Puerto Rico is advantageous to composting with some added care needed during changing conditions as would be need in any outdoor composting system.

4.2.2 Small-Scale Sludge Experiments

Wastewater sludge is a very predominant part of McNeil's waste. Eliminating the sludge that goes to the landfill will greatly reduce their output of total solid waste. Currently, it is shipped to a nearby Johnson & Johnson plant. There it is dewatered and the sludge cake is then transported to a landfill. It would be ideal to remove sludge from the landfilled waste stream. Before a composting system is selected and purchased it must be determined how much sludge McNeil will be able to compost. Adding too much sludge that has not been dewatered makes the compost pile too wet, while only adding a minimal amount may not be worth the effort. In order to verify the ideal mixture of sludge, we conducted experiments as discussed in methodology section 3.4.

After observing the buckets for two weeks, we concluded that this small-scale composting experiment was not an accurate model of the eventual large-scale composting system. Although the experiment was not useful in determining exactly how much sludge can be composted, it was still a worthwhile experiment, as we learned a lot about what to do or not to do while composting.

The first bucket contained just wastewater sludge as a control. After only a couple of days, the top of the sludge began to dry up. However, after a few days of rain, we concluded that it was not going to dry completely. In hindsight, it was good to have the sludge bucket as a control because it did not create as much of an odor as we originally expected. This way we knew the food waste rather than the sludge created the overall smell of the system. The second bucket produced the most odors. There was too much sludge and cafeteria waste for anything productive to occur. Ants, as well maggots, fed off of the rotting food waste. Mixing the bucket was repulsive. Bucket three contained what we considered to be ideal carbon to nitrogen ratios. It was not as repellent as the second one, but it was still infested by ants. The fourth bucket had more yard waste than cafeteria waste. This reduced the smell significantly, however, two frogs were found in this bucket, showing the attraction of unwanted vectors to the food. The last bucket, which contained only yard and food waste, did not have any pests living in it and the smell was minimal. We concluded the reason for this was the large amount of yard waste.

Overall, the results of the buckets were unexpected. Very little composting took place. This may be due to the small amount of material used in each bucket. There was not enough mass for the mixtures to heat up and follow through with the total composting process, and the materials in the buckets showed little change over time. The food waste also created a problem, by producing foul odors and attracting insects. The more food waste the bucket had the more ants and maggots were present. A few frogs also decided to make these buckets a comfortable home. If this experiment were to be repeated, a few steps should be changed. As far as small scale composting goes, there is a minimum amount of material that should be added. Five gallon buckets were not enough to promote good composting results. Another factor inhibiting the compost was that the material was too wet from the wastewater sludge. However, this worked in our favor because we were able to discover that the sludge will work best if dewatered prior to composting. The buckets should be kept in an area where foul odors would not create a problem. They also should not be placed near woods or grass where animals may interfere with the experiment. After performing this experiment, it is apparent that if the compost piles do not have the right ratio of material and are not maintained properly, there will be problems. Therefore, although the results of the experiments were not ideal, it was a very instructive process.

4.3 Large-Scale Composting Options

We investigated several areas in the effort to find a long-term composting solution for McNeil. A major determinant of the final solution was McNeil's desire to include the wastewater sludge in the composting process. Consequently, we fist considered two broad ways of dealing with this sludge. The first included separate anaerobic sludge processing along with simple aerobic processing of other wastes. The second included sludge dewatering and subsequent aerobic processing of the combined waste stream. After evaluating the wastewater sludge composting potential and the sludge dewatering options available, however, we believed that the latter solution was the most desirable method. In addition, we found that in-vessel systems represented the best option for aerobic solutions regardless of whether or not the sludge would be included. Following these findings, we investigated and compared many specific in-vessel aerobic systems in order to determine the best long-term options for McNeil. A flowchart of this decision and evaluation process is shown in Figure 17.

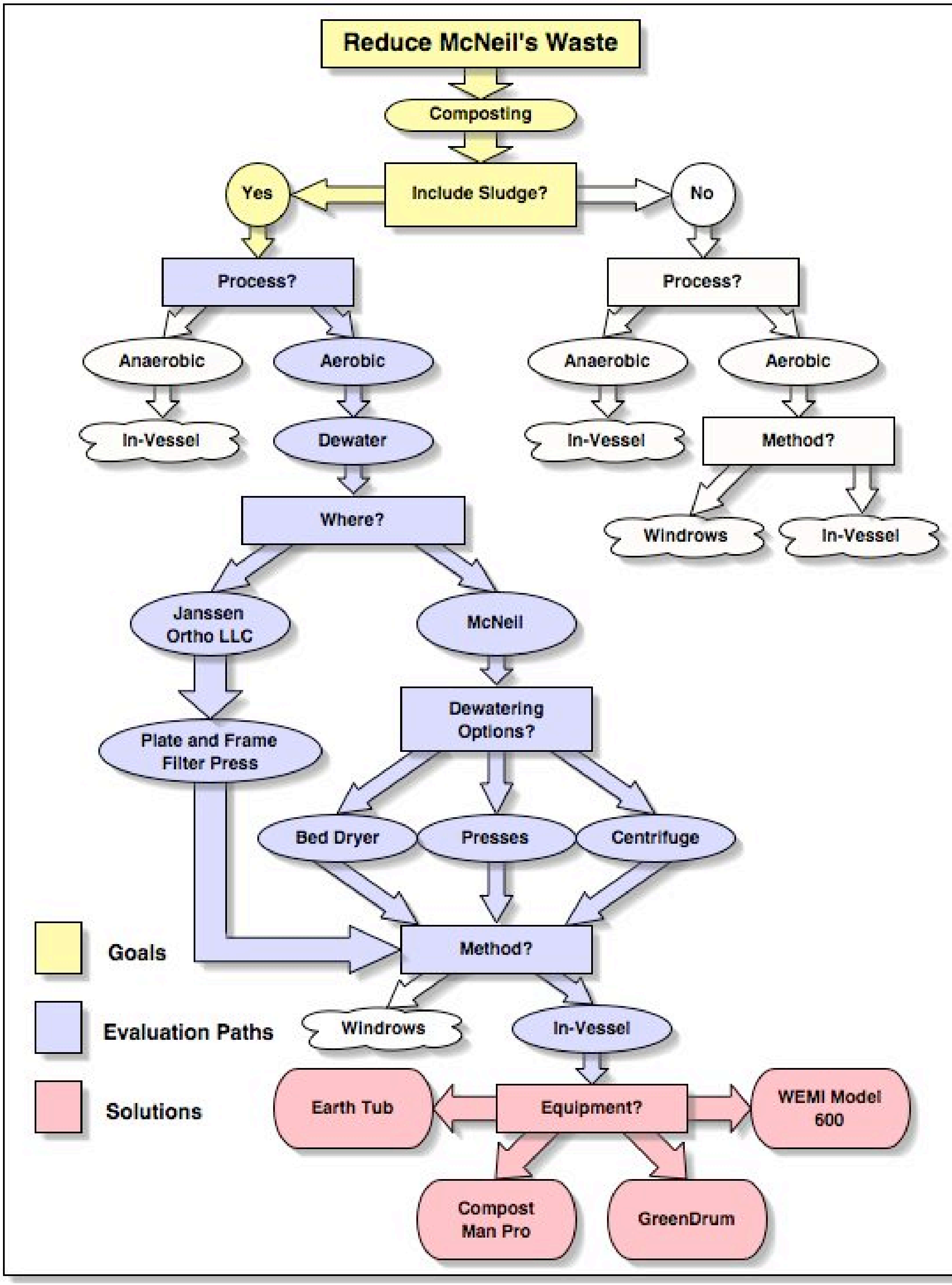


Figure 17: Decision and Evaluation Process

4.3.1 Anaerobic and Aerobic Evaluation

As discussed in our background research, there are two different methods of composting: anaerobic and aerobic. Anaerobic methods do not require oxygen while aerobic methods do. Aerobic methods therefore include turning and aeration systems, while anaerobic systems do not.

The anaerobic process was considered as a solution for this composting project due to the heavy percentage of sludge in McNeil's waste stream. The anaerobic method tolerates a higher moisture level; therefore the wet sludge is suitable. The other advantage of the anaerobic process is that it requires less labor and simpler operation because turning and aeration are not necessary. Even though there is less labor involved, the overall anaerobic process takes longer than aerobic composting. In some cases anaerobic in-vessel systems can take over six months to process the wastewater sludge (On-site Power Systems, 2005). In McNeil's case this would require construction of a facility capable of processing over 300,000 pounds of wastewater sludge at one time. In addition, the nature of the anaerobic process generates significantly more odors than a well-maintained aerobic system. For large-scale anaerobic composting, an in-vessel system is necessary due to the low percentage of solids and odor control. This enclosed system also is necessary for environmental regulations since wastewater sludge will be used. Because of the long process times and enclosure requirements, large anaerobic systems have a high capital cost. It creates a material called humus, which is a black, extremely moist substance that can be used as fertilizer.

Besides anaerobic composting, there are two different types of aerobic composting: windrows and in-vessel systems. These are not necessarily the ideal options for McNeil, however, because they need to dispose of their wet sludge. Since windrow systems consist of open piles, adding sludge would create problems with environmental regulations. This may still be considered a valid option if McNeil does not choose to include the sludge. Windrows have a low capital cost, and therefore would be an inexpensive trial to see if composting is right for them. Nevertheless, a lot of manual labor is involved, because the piles must be turned either by hand or a front-end loader at least once a week.

An in-vessel system, on the other hand, is a more expensive but faster process. It can generate compost in as little as a few days to a couple of weeks. The labor is not as intensive as a windrow system, and usually only requires loading and unloading of the machine and monitoring the process. The drawback to this method is that it cannot handle McNeil's wet wastewater sludge. The sludge would need to be dewatered.

4.3.2 Dewatering Options

The high moisture content of the sludge can cause odor problems in the compost by limiting the oxygen supply. Therefore, if McNeil chooses to effectively compost this wet wastewater sludge in an aerobic composting system, it will be necessary to remove some water from the sludge. There are several options available for sludge dewatering. These fall into three broad categories: drying beds, belt/filter presses and centrifuges.

Drying beds are the simplest of the three methods. The bed consists of a large cement bunker with a bottom layer of gravel and a top layer of approximately 30 cm of sand. The sludge thickens by a combination of water evaporation and liquid drainage through the sand. As shown in Figure 18, the bunker has cement walls to prevent overflow and runoff and a drainage system to collect leachate. At McNeil, the liquid collected in this drainage system would be sent to the WWTP for reprocessing. The "wet" sludge, consisting of approximately 3% solids, is poured onto the bed and allowed to thicken over several weeks. This timeframe may be longer or shorter depending on weather conditions. Hot, dry weather will expedite the process, whereas rainy conditions will add more water to the sludge, causing the process to take longer. The sludge can be thickened to approximately 20% solids with this method (United Nations Environment Programme, 2000).

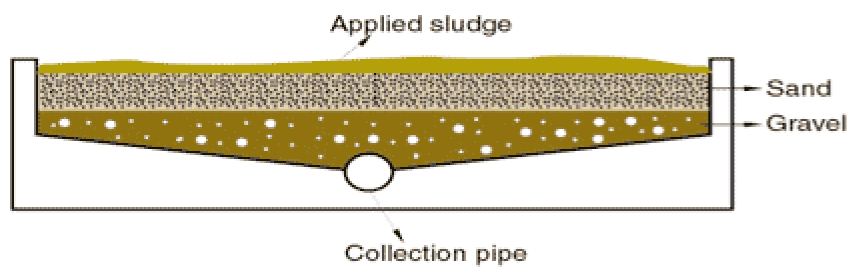


Figure 18: Sludge Drying Bed (United Nations Environment Programme, 2000)

Drying beds are advantageous because they are simple and low-cost. However, they require a significant amount of space and are subject to the uncertainty of weather conditions. The process time is relatively long in comparison with the other methods. They also lack the environmental and odor controls that are essential to McNeil's environmental policy.

The next category of dewatering equipment includes processes that use gravity and pressure to physically remove water from the sludge. These include belt presses and filter presses. Figure 19 shows that in a belt press the "wet" sludge is fed between two porous belts and passed through a system of rollers. The rollers squeeze out the excess water and eventually the dewatered sludge exits the conveyor system as sludge cake with a solid percentage of 20 or more. There are many variations on this technology, however there are several similarities between the basic designs. Almost all belt presses consist of a gravity drainage zone, a low-pressure squeezing zone and a high-pressure squeezing zone. This sequence of increasing pressure ensures that as much water is removed as possible (EPA, 2000).

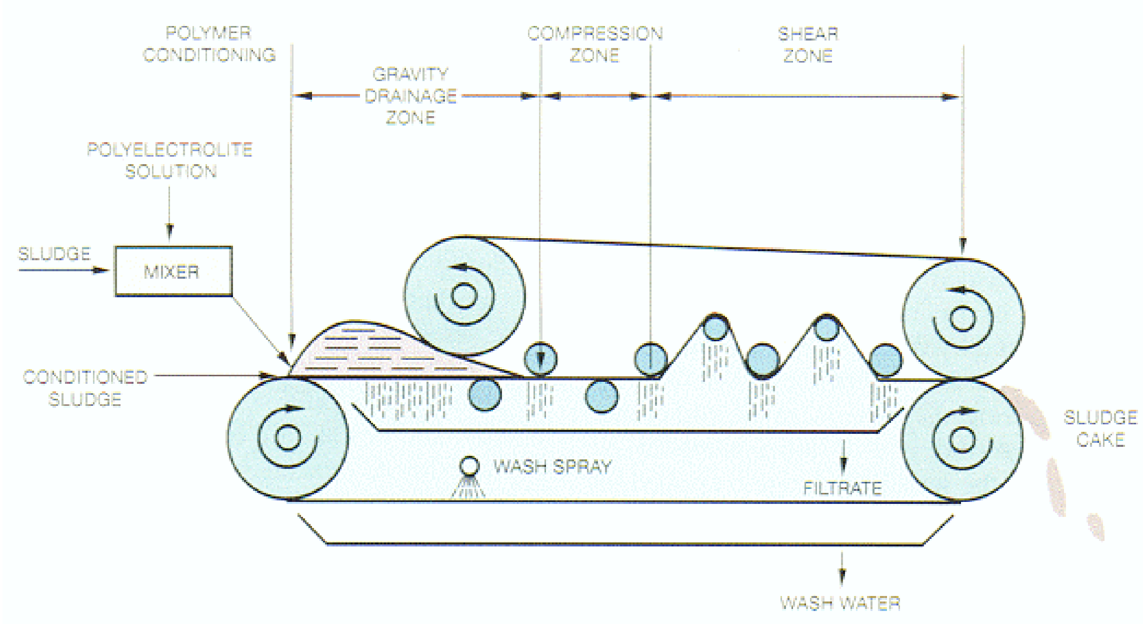


Figure 19: Belt Press Diagram (Dutch Science Forum, 2005)

Belt presses are very commonly used in wastewater treatment. They are efficient, low maintenance and easily monitored. The only major maintenance cost is belt replacement. They can be fully enclosed in order to control odor and other environmental concerns such as runoff. The effluent liquid removed from the sludge and from washing can be collected in a drainage system and pumped to the WWTP for reprocessing. Because McNeil's sludge is already filtered and equalized in the WWTP, the major disadvantage of belt systems is the cost of investing in a piece of mechanical, industrial equipment (EPA, 2000).

The third and final option for dewatering equipment is the centrifuge. The centrifuge represents one of the most traditional pieces of equipment in wastewater treatment and has been used since the 1930s. Centrifuges are cylindrical in shape and utilize the forces generated from high-speed rotation to separate materials of varying densities. As the centrifuge spins, the solids and liquids separate. Many centrifuges are equipped with a large, internal, screw-like conveyor. This serves to mechanically scrape the solid materials off the wall and push them towards the solid discharge area. The liquid effluent moves in the opposite direction, towards the liquid discharge area, as shown in Figure 20 (EPA, 2000).

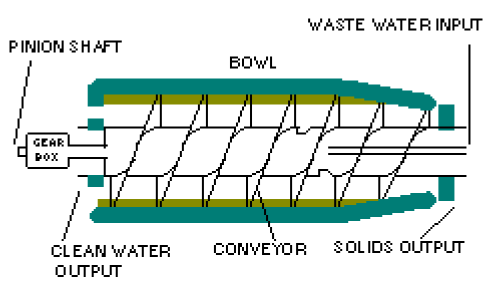


Figure 20: Centrifuge Diagram (The ABB Group, 2005)

Centrifuges have been used in wastewater treatment for decades and have proved very successful. They can be continuously fed and require little manpower once in stable operation. They are also capable of efficiently removing water to yield sludge with approximately 20% solids. Centrifuges take up little space, however they must be set on a stable platform for proper operation. Disadvantages include high capital and operational costs, high noise level and complicated mechanical maintenance.

An additional alternative for McNeil's dewatering operation is to take advantage of the resources available at another Johnson & Johnson facility. Currently, McNeil's wastewater sludge is shipped to the Janssen Ortho LLC plant in nearby Gurabo, Puerto Rico. There it is mixed with Janssen's waste and processed through a plate and frame filter press, which removes water and yields sludge cake of approximately 20% solids. The plate and frame filter press is similar to a belt press in that it uses pressure to squeeze the water out of the solid sludge (Figure 21). The sludge is located between the vertical metal plates and when sufficient water has been squeezed out, the plates are separated and the dewatered sludge cake is scraped into a bin. This sludge cake is currently sent to a landfill, however, if McNeil were to use this dewatering option, a portion could be returned to McNeil's facility for composting.

Figure 21: Plate and Frame Filter Press at Janssen Ortho LLC

Using Janssen's pre-existing filter press has many advantages. The equipment has already been purchased and is currently in use at Janssen. This would save McNeil the money and time needed to purchase and install a new piece of equipment. Because they are both Johnson & Johnson companies, Janssen dewaters McNeil's sludge at no additional cost. The logistics of shipping the "wet" sludge to Gurabo are already established. The only disadvantage of using Janssen's equipment would be the cost associated with transporting the dewatered sludge cake back to McNeil.

All dewatering options are viable possibilities for McNeil's aerobic composting system. Each piece of equipment has its strengths and weaknesses, therefore, the money, space and manpower available for dewatering operations will most likely determine the system McNeil chooses. Nevertheless, if McNeil desires an aerobic composting system to include wastewater treatment sludge, one of the above options must be implemented to ensure successful composting.

4.3.3 Overview of Specific Solutions

As we found in our preliminary research, McNeil has many options for a composting system, and the market is full of different composting products. Nevertheless, the job of investigating this list was made significantly easier by only choosing to fully examine those products that met McNeil's waste volume and processing requirements. Since the best method found for processing all of McNeil's waste was through sludge dewatering and subsequent aerobic integration, McNeil's total compostable waste volume requirement was calculated at 500 to 600 pounds per day. This assumes McNeil were to employ industry standard dewatering technology capable of producing sludge cake with 20% or more solids by mass. The inclusion of the sludge also dictated that any solution for McNeil be an in-vessel system in order to meet water runoff regulations and odor minimization goals. This demand for an in-vessel system capable of processing 500 pounds per day eliminated all but four possible solutions:

- Earth Tub™ by Green Mountain Technologies®
- CompostMan Pro™ by Renewable Carbon Management®
- Greendrum™ Model 408 by BW Organics®
- WEMI Model 600 by Wright Environmental Management, Inc®

The first solution capable of meeting all of McNeil's basic needs and requirements is the Earth Tub™ by Green Mountain Technologies®. The Earth Tub™ is an insulated and self-contained aerobic composting drum that is 90" in diameter, 48" high, and has a capacity of three cubic yards. It represents a simple in-vessel system capable of processing up to 200 pounds of waste per day in batches or continuously. Waste material is loaded through a top hatch in the rotating drum cover, and final compost material is unloaded through a discharge door in the side of the drum. While inside the drum, material is fed through a motorized auger system attached to the cover in an offset location. Human labor is then used to rotate the cover and move the auger around the bin. This provides complete and powerful mixing of the compost. In order to provide appropriate aeration and odor prevention, air is pulled through the compost by a blower system and then exhausted through a bio-filter. Leachate is collected near the bottom of the tub in a small plenum and then removed either to a sewer system or other holding tank for later disposal. Typical processing times for waste material range from three to four weeks. Following this active composting, a few weeks are necessary for appropriate curing (stabilization of the chemical compounds). If the wastewater sludge is dewatered to 20% solids, McNeil's total waste disposal breaks down to approximately 600 pounds per day. Consequently, three earth tubs would be necessary to process all of McNeil's compostable waste. A diagram of the Earth Tub™ is displayed in Figure 22 (Green Mountain Technologies, 2005).

Figure 22: The Earth Tub (Green Mountain Technologies, 2005)

There are many benefits to the Earth Tub™ system. In addition to being self-contained, it can easily be placed in any location. No additional infrastructure is necessary other than hard-packed ground and an electrical connection. This would fit well with McNeil's current composting site and would only require the installation of electrical access. Another advantage of the Earth Tub™ is its size and price. While a single unit is not big enough to handle all of McNeil's waste disposal needs, the system is easy to handle, inexpensive, and scalable with multiple units. Unfortunately, the Earth Tub™ is not automated, and thus human labor is required to mix the waste material before composting, regulate the aeration cycle, unload the compost when finished, and take daily temperature readings required to fulfill EPA guidelines for pathogen elimination. Still, the Earth Tub™ is small enough that labor remains minimal and is competitive with other systems.

The second solution capable of meeting all of McNeil's needs is the CompostMan Pro™ by Renewable Carbon Management®. The CompostMan Pro™ system is a series of insulated aerobic composting vessels. Each 35 cubic-foot container is hooked together in order to share leachate collection and aeration plenums. Waste material is shredded and prepared in batches for processing in a separate mixer. It is then loaded by hand or by conveyer into the vessels. Each vessel then processes the material for 20 to 30 days. During this time, temperature feedback sensors on each bin regulate airflow in order to maintain optimal composting temperatures. Process air is exhausted into the atmosphere through a blower and bio-filter for odor removal while leachate is collected from the common plenum for disposal. Once the composting process is complete, the bins are disconnected from the system and unloaded by hand or by forklift. It is then necessary to allow a few weeks of curing time for stabilization of the compost. Assuming McNeil's entire compostable waste is processed in this manner, including wastewater sludge dewatered to 20% solids, 16 bins and two bio-filters would be necessary. A diagram of a typical CompostMan Pro™ setup of this scale is shown in Figure 23 (Renewable Carbon Management, 2005).

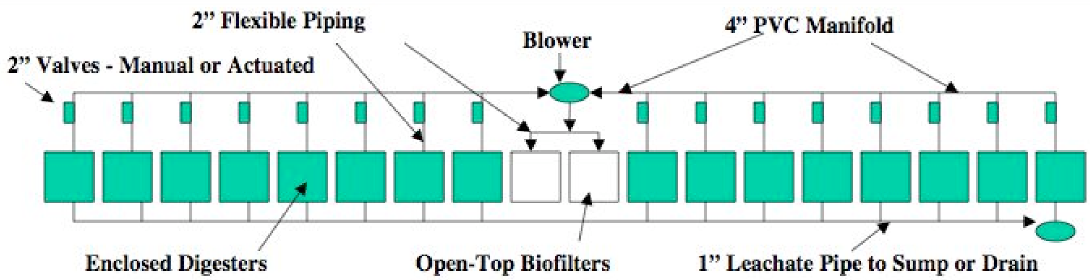


Figure 23: CompostMan Pro System (Renewable Carbon Management, 2005)

While the CompostMan Pro™ includes an advanced temperature and airflow control system, it also has many important site requirements. The most significant requirement is space. Because of its distributed setup, the CompostMan Pro™ will necessitate significant land area. In addition, this land area must be improved with a concrete pad in order to allow forklift access to each bin. In the case of a system designed for McNeil's waste processing, the required pad would be approximately 25' x 50'. This amount of space is physically available at McNeil's current composting site, however installation of concrete requires additional time and money. Beneficially, however, the CompostMan Pro™ system is durable. This is due to its static nature and lack of moving parts. It also has few labor requirements due to a separate mixing unit and automated aeration and temperature controls. Manual labor is still needed to load and unload the bins, however this can be enhanced with mechanized equipment such as forklifts or tractors already present on the McNeil facility. In all, the CompostMan Pro™ offers a unique yet capable composting solution for McNeil.

The third candidate system capable of meeting McNeil's composting requirements is the Greendrum™ Model 408 by BW Organics®. The Greendrum™ Model 408 is an insulated, three-cubic-yard cylindrical drum mounted on a trailer for easy transportation. An enhanced version of the model 408 comes with an integrated mixing unit and auger for a more complete composting solution. Waste material from the mixer is transported into the vessel via the auger and front access door. The material remains in the drum for three days of processing before it is discharged out the rear access door and manually transported away. While inside, the drum continuously rotates the material in order to provide aeration and additional mixing. The rotation also moves the material lengthwise through the drum. This allows continuous compost loading and unloading. The entire setup is automated and pre-wired at the factory for simple installation and operation. The only on-site resource required is power. An image of the basic Greendrum™ model 408 is shown in Figure 24 (BW Organics, 2005).

Figure 24: Basic Model 408 Greendrum (BW Organics, 2005)

The Greendrum™ composting vessel offers its own unique combination of advantages and disadvantages. One advantage is its self-contained nature. This allows rapid and easy setup on-site. Another advantage is the integrated pre-mixing unit on the enhanced model. This allows the materials to be more homogenous prior to composting and results in better compost. The actual composting process is also afforded better aeration due to the continually rotating drum. One significant disadvantage, however, is the three-day process time. While a three-day process time may sound advantageous, it is not enough time to produce high quality compost. Because of this, higher quality compost can only be achieved with a significant amount of post processing and curing. This curing does not improve the compost quality to that of a highly controlled, longer duration composting system, but it does help. According to EPA bio-solids standards, however, three days is enough time to adequately eliminate pathogens. Therefore, post-processing can be more flexible and less constrained by environmental variables.

The final solution capable of meeting McNeil's composting requirements is the Model 600 by Wright Environmental Management, Inc®. The Model 600 is a large, insulated, boxy tunnel twenty feet long, six feet high and six feet wide. It comes with an integrated material mixer and bucket lifter. Once material is mixed, it is automatically loaded through one end of the tunnel and placed on a tray attached to a conveyor. This conveyor moves the material from the loading end to the discharge end in 14 days. Along the way, the material is subject to forced aeration from below. This air is then discharged out the top of the vessel and passed through an odor capturing bio-filter. Rotating spinners installed near the front of the tunnel provide additional aeration and mixing five days into the compost cycle. The moisture of the material is also controlled and automated throughout the process with an integrated runoff recirculation and water spray system. A diagram of the internal function of a Wright composting system is shown in Figure 25 (Wright Environmental Management, Inc, 2005).

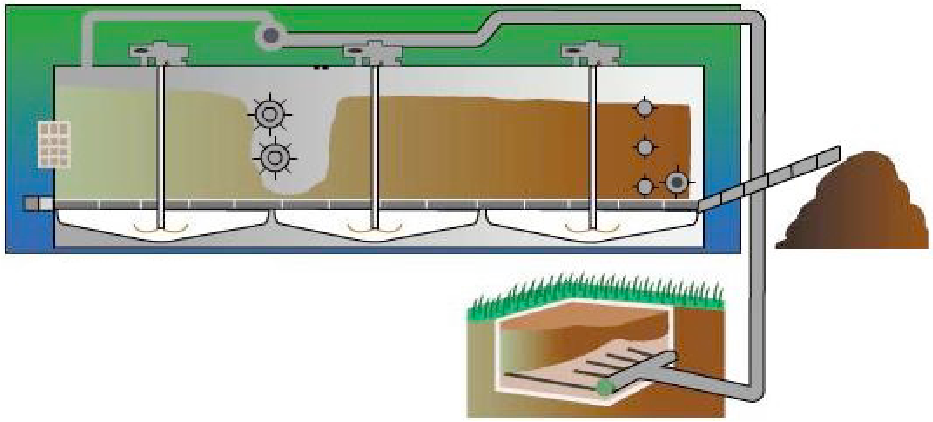


Figure 25: Wright Composting System (Wright Environmental Management, 2005)

The Wright system offers a unique approach to composting because of its extremely sophisticated automation and control systems. This control is broken into three sections along the tunnel. Each of these three sections has independent monitoring and control of airflow, temperature, and moisture. This level of automation is a huge benefit to the composting process, and very high quality material can be produced in the 14-day process cycle. This material also requires little post-process curing time. Unfortunately, the advantages of this advanced monitoring and control system are offset by its significant price. In addition, the Wright tunnel must rest on a concrete pad due to its weight. This disadvantage further increases the price and installation complexity.

Overall, each of the four candidate composting solutions employs a unique set of technologies in order to transform waste material into useful compost. Because each is capable of meeting McNeil's waste processing needs, no solution is clearly better than the other three. Each has its own set of advantages and disadvantages. Some take longer than others, some need more manual labor, and some are more costly. A list of the different properties found through research and communication with the companies is shown in Table 5. Regardless of differences, all systems perform best when used in conjunction with the ideal conditions outlined in the waste materials analysis section.

	Earth Tub	CompostMan Pro	GreenDrum	Wright Tunnel
Purchase Price Estimate (US$)	$8,495 x 3	$50,000	$23,395	$120,000
Estimated Labor (Man-Hr / Wk)	15	9	5	6
Process Time Estimate (days)	25	20	3	14
Process Type	Continuous	Batch	Continuous	Continuous
Capacity (lb/day)	200 x 3	500	1000	600
Site Requirements	Packed-Earth	Concrete	Packed-Earth	Concrete
Temperature Monitoring	Manual	Automatic	Automatic	Automatic
Moisture Control	Manual	Manual	Manual	Automatic
Initial Compost Quality	Medium	Medium	Low	High

Table 5: System Comparison

4.4 Educational Results

The evaluation of the educational portion of the project is much more qualitative. However, it seems that the educational program was a success overall. This was determined by the perceived level of interest, educational deliverables and potential for continuation of the program.

We determined the level of interest of the audiences we spoke to based on attentiveness and participation. The students were respectful, attentive and asked questions about composting. After the presentation, the students were eager to take pictures with us (see Figure 26) and gave small thank you gifts of fruit and candy. The teachers were very thankful and interested in exchanging e-mail addresses so that we could stay in contact. We were invited to return to two of the schools later in the week. At one middle school, Escuela de la Comunidad Santiago Torres, we were guests at their Earth Week Celebration, which consisted of performances and contests. The program coordinator requested that we participate by judging some of the contests. At a high school, Escuela Superior Ramón Power y Giralt, we were invited to the inauguration of their recycling center. At both schools we were introduced as special guests and received applause from the students. Based on the thank you gifts, participation during our talk and invitations to return, it seems that the schools were interested in our educational experience before, during and after our composting presentation.

Figure 26: Our Student Audience

An additional measure of the success of the educational program can be determined by the existence of tangible results. We prepared a package including electronic and hard copies of the four lesson plans, our Introduction to Composting PowerPoint presentation and a letter to the educator. This letter can be found in Appendix E. We gave this packaged curriculum to McNeil's Community Outreach Coordinator, Maribel López, to be passed along to the schools. Having physical deliverables makes it easier for teachers to continue this composting education program in the future. We had hoped to create a compost pile at each of the schools, however, the upcoming summer vacation made it impractical. Instead we incorporated this idea into the additional lesson plans.

The potential for continuation of this educational program is another way to measure its success. We did not want our school presentations to be a one-time occurrence, but rather an educational program that will be continued and reach as many students as possible. We ensured that the program could be continued in the future by passing our educational materials along to educators. Likewise, the three additional lesson plans were designed to build upon each other. The first lesson is a broad overview of composting. The second lesson is intended to physically construct a compost site at the school, and the third and fourth lessons use this constructed site to conduct experiments. Because the curriculum is cumulative it helps to assure that composting will be thoroughly explored.

The subject of composting is already becoming more popular in the adopted schools. We began to see evidence of this success very quickly. At one of the adopted schools the students make floats and have a parade as an end of the year activity. We know that our efforts to introduce composting were successful because one student group has chosen the subject of composting for their float.

Although the long-term success of the composting education program cannot be determined at this time, it is safe to say that the immediate results were promising. The continuation and emphasis of this curriculum is now out of our hands. Hopefully our involvement in Puerto Rico's environmental education reaches as many students as possible and composting can begin to have a positive social impact on the local community.

Chapter 5: Conclusions and Recommendations

There are two primary components of our recommendation: the technical composting solution, and the educational outreach plan. While these recommendations may appear independent of one another, they are interrelated. Establishing a technical composting solution is a form of education for the corporate world. Together these solutions will move society toward more sustainable waste management.

5.1 On-Site Composting Recommendations

Based on our on-site composting experiments and research into large-scale composting systems, we can make several recommendations for McNeil's composting program. These recommendations apply to their current static pile system, future system selection and purchase, and future material and resource disposal. While these recommendations apply specifically to McNeil for this project, they can easily be extended to other corporations or facilities with similar waste management problems.

The first recommendations apply to McNeil's current static pile composting method. While this has so far been fairly successful, it is limited and cannot support McNeil's waste disposal in the long run. One limitation is the fact that it can only be used for yard and food waste due to runoff regulations. In other words, none of McNeil's sludge can be dealt with using these piles. Another limitation is the total system capacity. Even if used for only yard and food wastes, the system would still need to process approximately 130,000 pounds per year in order to completely fulfill McNeil's waste disposal needs in these areas. As stated in our previous research, static piles such as these take nearly six months to completely process compost, so 65,000 pounds of material would be composting at one time. Currently McNeil's static bins can only support continuous processing of 15,000 pounds of material. Therefore more than 21 bins would be needed to process all of McNeil's yard and food waste. This is not a very desirable option given the space and labor requirements of this method. Due to these limitations and the fact that the five existing bins are nearly full already, we recommend McNeil transition to larger-scale options as soon as possible.

Regardless of what these large-scale options may be, the existing static piles still represent a good initial investment of resources. They were inexpensive to fabricate and have helped introduce McNeil's landscaping crews, cafeteria operators, and members of the environmental management department to the processes and procedures of composting. Because of this, we recommend they be continued at least until the large-scale system has been installed. In order for them to remain successful, however, we recommend that the employees follow the procedures outlined in Appendix F. These procedures are not exhaustive, but they do provide a basic formula for pile maintenance. Once the large-scale system is installed, these piles can either be continued until the current batch of material is complete, continued indefinitely for educational purposes only, or eliminated in favor of the larger system. If they are eliminated, the currently composting material could be easily moved into the new system. It is up to McNeil to decide how this transition should be accomplished. In any case, the piles have proven their worth.

Our second set of recommendations applies to McNeil's choice of a large-scale, long term composting system. McNeil has many options in this regard, however we found in our research that four particular systems were especially capable of meeting McNeil's waste volume and processing requirements. Each of the four has distinct advantages and disadvantages. After evaluating the different properties and features of these systems, however, we conclude that the Greendrum™ by BW Organics® represents the best composting option for McNeil. It offers a good combination of installation requirements, labor requirements, and complexity while simultaneously providing extremely fast process time in a fairly small package. In addition, BW Organics® has already expressed excitement in having McNeil as a potential customer, and they are willing to provide full company support for this project. All of these attributes make the Greendrum™ our recommended composting solution for McNeil.

In support of this recommendation, we have found that Toyota Motor's manufacturing facility in Georgetown, Kentucky already implements a BW Greendrum in much the same way as McNeil would. They produce a substantial amount of yard and food waste, and they compost this on-site in order to reduce landfill disposal requirements. They also use the resultant compost for their facility's landscaping. In discussing the Greendrum™ with representatives from this facilities plant, it was apparent this product has helped them achieve their waste reduction goals. As Ms. Sandra Sissel of the Environmental Management Department stated, "We absolutely love it." This is high praise for any product, and it certainly helps establish the Greendrum™ as a viable option for McNeil.

In spite of the Greendrum's many advantages, it has one particular drawback: compost quality. The rapid composting time that helps keep equipment size to a minimum also leads to compost that is biologically active and somewhat chemically unstable when removed from processing. This does not pose a significant handling problem because the three-day retention time at approximately 60˚C kills most pathogens. Still, active compost like this can potentially harm sensitive plants. In these circumstances, it is necessary to allow the material to sit in piles and stabilize for a few weeks prior to application. While general landscaping plants are not unduly sensitive, this curing may still be a good idea at McNeil. Consequently, we recommend that the material removed from the Greendrum™ be placed in three to four foot piles for two to three weeks prior to distribution and use. These piles do not need sophisticated infrastructure. In theory, the compost could be piled directly on the ground for curing, however in order to keep rain from making the piles too wet, we recommend they be kept under a tent or in small ventilated bins constructed out of non-biodegradable materials such as plastics. Actual space required for these piles would be minimal (approximately 10 cubic yards for two weeks of retention), and so they could be housed under the existing tent on the composting site. Placing the material in piles such as these would also provide a convenient location for storage and distribution.

If space permits, we also recommend that McNeil leave the material inside the Greendrum™ for more than the specified three-day process time. This will allow final curing to occur partially or entirely within drum depending on the ultimate retention time. As a result, the finished product will be higher quality and require little or no outside curing time. This extra retention method is currently used by the Toyota facility in Kentucky, and they report very high quality compost product directly out of the drum.

They have a larger Greendrum™ model, however, so they have enough space to leave the material inside for longer than the maximum of six days McNeil could expect. Thus, McNeil would still require curing even if additional composting time was possible. Regardless of the additional processing required, the Greendrum™ still represents a good composting solution for McNeil.

Our third set of recommendations applies to the waste materials McNeil plans on using in the composting system. As we have found through research and experimentation, certain combinations of materials and material properties compost better than others. McNeil has three primary waste streams that it wishes to compost: yard waste, food waste, and wastewater sludge. Therefore, it is appropriate to recommend how best to combine these three waste streams in order to provide good composting results. Before doing so, however, it should be noted that BW Organics® supplies waste reference material and recommended waste usage guidelines with their Greendrum™. While these reference materials are not specifically directed toward McNeil's waste stream, they can be used in the future to roughly answer waste material or mixture questions.

The first type of waste McNeil wishes to compost is yard waste. As we have found in our research, yard waste typically has low density, low moisture and high carbon content. Because of these properties, it actually composts very well alone so long as a little moisture is added. It also works well in mixtures with other materials as long as they do not increase the density or the nitrogen content by too much. Because of these qualities, we recommend that McNeil use all of its yard waste in the composting process. Compost operators should not be concerned about creating an ineffective mixture due to too much yard waste.

Food waste, on the other hand, does not compost well by itself; it is too dense, moist, and high in nitrogen. As such, it requires the addition of other materials to create a favorable equilibrium. Because yard waste composts well on its own, however, there is no maximum amount of yard waste that can be added to the food waste. The only limitation of the mixture is the density and moisture, and as long as enough yard waste is added to bring these values down, the mixture should compost well. The amount necessary to do this is typically greater than the same mass of food waste it is diluting. Consequently, we recommend that the yard waste to food waste mixture ratio be no less than 1:1. If the compost is used in a static pile, this ratio should be even higher in order to minimize odor formation. If the ratio becomes too high, we also recommend that additional moisture be added prior to composting. Given McNeil's small annual amount of food waste relative to their large annual amount of yard waste, this ratio poses no problem. We can thus recommend that all of McNeil's food waste be composted so long as it is mixed with an amount of yard waste equal to or greater than its own mass at the time of composting.

One concern with directly composting food waste is that some materials may be present that do not compost well. After all, food wastes from cafeterias tend to be mixed with things such as plastics wrappers, aluminum foil, or other non-biodegradable wastes. Because of this, we recommend that McNeil sort their food waste prior to including it with the compost. The kitchen staff has already been doing this for the food included in the static pile experiments, however we recommend that consumers sort the food themselves. This will reduce the burden on the kitchen staff in the future. In order to have consumers sort the food themselves, the existing recycling center in the cafeteria could be modified to include a bin just for excess food. The contents of this bin could then be added to the composting system with little further considerations necessary.

McNeil's third waste material, wastewater sludge, is not as straightforward as yard or food waste. As stated in our investigations of different composting methods, we concluded that the best way of processing McNeil's sludge was to dewater it prior to composting. This can either be accomplished by purchasing dewatering equipment for McNeil's wastewater treatment facility, or by returning sludge dewatered at Johnson and Johnson's Janssen Ortho LLC facility back to McNeil for composting. Regardless of which solution McNeil selects, we recommend that the wastewater sludge be dewatered to greater than 20% solids. This will decrease the total sludge mass to 17.5% its original weight or approximately 104,000 pounds per year. We recommend this dewatering goal because it is easily obtainable with general-purpose dewatering equipment. We have also found from research that any sludge to yard waste ratio greater than 1:1 does not compost well due to the large amount of moisture contributed by the sludge. As such, this goal also represents the approximate amount of dewatering necessary for McNeil to compost all of their wastewater sludge with all of their yard waste.

While any dewatering option McNeil selects could theoretically support their composting activities, we suggest McNeil utilize Janssen Ortho LLC in Gurabo for sludge dewatering. Janssen already has an established dewatering system and support infrastructure capable of dewatering sludge to 20% solids, and they are already accustomed to the transportation required to work with McNeil's wastewater. In addition, members of the Environmental Management department at Janssen Ortho expressed support in McNeil's composting goals during conversations about their wastewater processing facility. In discussing the sludge transportation issue, they also felt that transferring some dewatered sludge back to McNeil would not pose any significant challenges. The only requirement would be a small storage container at McNeil to hold the intermittent sludge drop-offs. This storage would provide a quantity buffer and thus allow continuous composting of the sludge. By taking advantage of Janssen's dewatering facilities, McNeil would thus avoid the significant capital investment, labor requirements, and complexity of constructing an on-site dewatering system. Return transport of the wastewater sludge would require some financial investment, but it would be minimal since the sludge volume returning would only be a fraction of that transported there in the first place. Preliminary analyses of these costs as well as the other costs associated with running McNeil's composting site are shown in Appendix G.

Given the optimum combinations of McNeil's three waste types and 20% sludge dewatering, we conclude that the entire compostable waste stream can be successfully composted in the Greendrum™ if combined in ratios relative to their current annual disposal amounts. Consequently, we recommend that any waste added to the composting system be mixed in approximately these ratios before processing (Table 6). While some experimentation with these values may be a good idea, they represent a basic initial guideline for McNeil's composting system.

	Total Yard Waste	Food Waste	Dewatered Sludge
Total Annual Amount (lb)	122,846	6,760	103,797
Relative Ratio	18.2	1	15.4

Table 6: Actual Composting Mixture Ratios

Aside from the technical details of composting and the fact that both are subsidiaries of Johnson and Johnson, it should be noted that McNeil's relationship with Janssen Ortho LLC for sludge dewatering is important for other reasons. Perhaps the most significant of these is the fact that it affords McNeil an opportunity to promote composting throughout other Johnson and Johnson companies and thus establish more significant social change in waste management. One limitation with the current situation is that only McNeil's portion of the sludge can be returned for composting. This could change, however, if other companies' yard and food wastes were added to balance out the mixture ratios. Ideally, a structure could evolve where wastewater sludge from McNeil and Janssen could be dewatered at Janssen, while yard waste and food waste from both companies would be composted at McNeil along with all the dewatered sludge. This would of course require a larger composting facility, but combining operations could potentially reduce cost as well as environmental impact. Another possible outcome could be a large composting system at Janssen Ortho, where the combined wastewater sludge they currently receive could be composted with yard and food waste imported from other Johnson and Johnson companies including McNeil. The opportunities are endless, and because of this, we recommend McNeil continue to pursue waste management relationships with nearby local companies once their initial system is established. Doing so will help further Johnson and Johnson's goal of reduced waste disposal and advance the practice of sustainable waste management. It would also set a different kind of positive example – not just one company composting, but different companies cooperating for the greater good.

5.2 Educational Recommendations

Based on our experiences speaking at McNeil's four adopted schools, there are several recommendations we can make to continue and improve composting education in the community of Las Piedras, Puerto Rico. Although it would be ideal to eventually expand this education program to all students, we believe it would be most beneficial to start with the students who have an interest in environmental issues. McNeil has sponsored a Recycling Team at each school where interested students join this club to help promote recycling and environmental efforts. Of the students we spoke to, these were the ones who were the most attentive and asked questions. It will be easier to encourage these students to begin composting. The composting education should be expanded to the whole school only after there is some success in educating and encouraging the Recycling Team. Perhaps the Recycling Team could be renamed the "Earth Team" so that it includes recycling, composting and potentially other activities.

The next recommendation is to complete all four lesson plans in order. They were designed to build upon each other; therefore if one lesson is omitted the curriculum would be incomplete. Following the lesson sequence ensures that composting is not just a temporary subject, but an ongoing topic.

Lastly, when composting education is eventually expanded to include other students, some type of motivation is needed to encourage the students to participate. Perhaps there could be a contest at each school and a prize for the class that creates the most successful compost pile. This would appeal to the students' sense of competition and give them a reason to compost. A similar contest was run with the recycling program, the classroom that collected the most recyclable materials was rewarded. Hopefully by educating the students and promoting composting the students will go home and start compost piles with their families.

An additional recommendation is to educate employees as well as plant visitors about McNeil's composting project. A good way to do this is to post an educational display at the composting site. This will ensure that anyone who visits the site will be able to look at a diagram and better understand the process. Once McNeil has made their final decisions about the project and have begun implementation, we suggest that they create and post an educational diagram on-site. We created a sample diagram that can be found in Appendix H.

We also advocate that McNeil attempts to make knowledge of their composting project public. They have already done this to some extent. For example, Gloria Picò, a composting expert and representative from the Department of Agriculture, learned of our project from the local schools and came to visit McNeil's compost site. She was impressed by our efforts and McNeil's environmental initiatives. She expressed that McNeil was an environmental leader and that their positive example will encourage many companies in the area to start compost sites of their own. Therefore, by publicizing their efforts, McNeil is helping to educate members of the corporate world.

We began the education process by reaching out to a small number of students at local schools. However, if our recommendations are followed, this educational movement will expand to include other students, employees, visitors and other companies. The expansion of the educational program will help to achieve our goal of improving the community by not only introducing composting as a waste management technique, but also encouraging it as a widespread practice.

References

Abuyuan, Hawken, Newkirk, and Williams. (1999). *Waste Equals Food: Developing a Sustainable Agriculture Support Cluster for a Proposed Resource Recovery Park in Puerto Rico.* Yale School of Forestry and Environmental Studies Bulletin. 106. 303-349.

Ackerman, Frank. (1997). *Why do we recycle: markets, values, and public policy.* Washington, D.C.: Island Press.

Allenby, Braden R. (1999). *Industrial Ecology: Policy, Framework, and Implementation.* Englewood Cliffs, New Jersey: Prentice-Hall Inc.

Cairncross, Frances. (1995). *Green Inc.* Washington D.C.: Island Press

Caribbean, Puerto Rico. Retrieved on March 29, 2005 from: http://www.countriesquest.com/Caribbean/Puerto_rico.htm

Caribbean Recycling Foundation, (2001). *Solid waste statistics for Puerto Rico and the Caribbean.* Retrieved January 21, 2005. From: http://ourworld.compuserve.com/homepages/crf/statisti.htm

Cheremisinoff, N. P. (2003). *Handbook of Solid Waste Management and Waste Minimization Technologies.* New York: Butterworth-Heinemann.

Cornell University. (2002). *Composting in Schools.* Retrieved March 16, 2005. From: http://compost.css.cornell.edu/schools.html

Courtney, J. Dasso, R. Holland, J. Mier, D. (2004). *Evaluation of Puerto Rico's Current Recycling Program.* Puerto Rico: Project Center D04.

Coalition for Environmentally Responsible Economies (CERES). (2005). Retrieved on February 5, 2005. From: http://www.ceres.org

CompostCalc [Computer Software]. (2004). Bainbridge Island, WA: Green Mountain Technologies.

CompostMan Pro. (2001). Renewable Carbon Management. Retrieved April 11, 2005, From: http://www.composter.com/

Deschenes, P.J, and Chertow, Marian. (2004). *An Island Approach to Industrial Ecology: Towards Sustainability in the Island Context.* Journal of Environmental Planning and Management. 47(2), 201-217.

Earth Tub. (2004). Green Mountain Technologies. Retrieved March 23, 2005, From: http://www.gmt-organic.com/

Environmental Defense. (2000). *Report of the Starbucks Coffee Company/ Alliance for Environmental Innovation Joint Task Force.* Retrieved on January 30, 2005. From: http://www.environmentaldefense.org/documents/523_starbucks.pdf

Environmental Protection Agency. (2003). *Municipal Solid Waste in the United States: 2001 Facts and Figures.* (Report No. EPA530-R-03-011). Retrieved on January 15, 2005. From: http://www.epa.gov

Environmental Protection Agency. (2000). *Biosolids Technology Fact Sheet: Belt Filter Press*. Retrieved April 18, 2005, from http://www.epa.gov/owm/mtb/belt_filter.pdf

Environmental Protection Agency. (2000). *Biosolids Technology Fact Sheet: Centrifuge Thickening and Dewatering*. Retrieved April 14, 2005, from http://www.epa.gov/owm/mtb/centrifuge_thickening.pdf

Epstein, Elion. (1997). *The Science of Composting*. Technomie Publishing Company, Inc. Lancaster, PA.

Feinbaum, Robert. (1995). Gauging Attitudes towards Source Separation. [Electronic Version] *BioCycle*, 36(7), 69-72.

Food Scrap Management. (2004). California Integrated Waste Management Board. Retrieved April 11, 2005, From: http://www.ciwmb.ca.gov/FoodWaste/Compost/InVessel2.htm

Frequently Asked Questions. (2005). On Site Power Systems. Retrieved April 22, 2005, From: http://www.onsitepowersystems.com/

Garland, G. A. Grist, T. A. (1995). The Compost Story: From Soil Enrichment to Pollution Remediation. [Electronic Version] *BioCycle*, 36 (10).

Glenn, J. (1999). The State of Garbage in America. [Electronic Version] *BioCycle*, 40(4).

Golueke, Clarence G. (1977). *Biological Reclamation of Solid Wastes.* Emmaus, Pennsylvania: Rodale Press.

Golueke, Clarence G. (1989). Composting Rationale and Activity. *The Biocycle guide to Composting Municipal Wastes*. Emmaus, Pennsylvania: The JG Press Inc.

Gourlay, K. A. (1992). World of Waste: Dilemmas of Industrial Development. Atlantic Highlands, New Jersey: Zed Books Ltd.

Heimert, Chrystie. (2004). *Turn it Up to Cool it Down.* Retrieved on January 29, 2005. From: http://www.benjerry.com/our_company/press_center/press/thermoacoustics.html

International Source Book On Environmentally Sound Technologies for Wastewater and Stormwater Management. (2000). *United Nations Environment Programme.* Retrieved April 14, 2005, from http://www.unep.or.jp/ietc/Publications/TechPublications/TechPub-15/main_index.asp

Institute for Local Self-Reliance. (1991). *Beyond 40 percent: record-setting recycling and composting programs*. Washington, D.C.: Island Press.

Lauzon, Robin. (1999). *I Scream, You Scream, We all Scream for ECO-Pints - Ben and Jerry's Homemade Inc. introduces environmentally friendly carton.* Retrieved on January 30, 2005. From: http://www.findarticles.com/p/articles/mi_m1279/is_1999_August/ai_55226116

McNeil Consumer Healthcare. (2004).Environmental Community Outreach Program. Las Piedras, Puerto Rico.

McNeil Consumer Healthcare. (2004). Storm Water Pollution Prevention Plan. Las Piedras, Puerto Rico.

Midwest bio-systems, Inc. Aeromaster Composting Equipment. (2005) Retrieved on March 30, 2005 from: http://www.aeromasterequipment.com/ACS/composting_equipment.html

Miranda, M. L. (2005). Paradise recovered: energy production and waste management in island environments. [Electronic Version] *Energy Policy*, 33, 1691-1702.

Organic In-Vessel Composters. (2005). B W organics. Retrieved April 11, 2005, From: http://www.neto.com/bworgani/top.htm

Porter, Richard. (2002). *The Economics of Waste.* Washington, D.C.: Resources for the Future.

GreenBiz.com. (2005). *Starbucks Wins Gold for Farmer-Friendly C.A.F.E. Initiative.* Retrieve on January 27, 2005. From: http://www.greenbiz.com/news/news_third.cfm?NewsID=27626

Rynk, Robert. (1992). *On-farm composting.* Natural Resource, Agriculture, and Engineering Service, Cooperative Extension. Ithaca, New York: Northeast Regional Agriculture Engineering Service.

Rynk, Robert. (2003). What it Takes for an Odor Turnaround at a Composting Site. [ElectronicVersion] *BioCycle*, 44 (8), 40-44.

Trautmann, Nancy M. (2002). The Science and Engineering of Composting. *Cornell Waste Management Institute.* Retrieved on January 16th 2004. From: http://compost.css.cornell.edu/science.html

United States Environmental Protection Agency (EPA): Municipal Technology Branch. (2002). *Biosolids Technology Fact Sheet.* Retrieved on January 24, 2005. From: http://www.epa.gov/owm/mtb/combioman.pdf

World Environment Center (WEC). (2005). *WEC Gold Medal for International Corporate Achievement in Sustainable Development.* Retrieved on February 5, 2005. From: www.wec.org/wecgm.htm

Wright Tunnel. (2005). Wright Environmental Management. Retrieved April 11, 2005, From: http://www.wrightenvironmental.com/

Appendix A: Waste Material Properties

Material	Type of Value	C:N Ratio (by weight)	Moisture Content (% by weight)	Bulk Density (lb/yd^3)
Crop Residues				
Apple filter cake	Typical	13	60	1,197
Apple pomace	Typical	48	88	1,559
Apple-processing sludge	Typical	7	59	1,411
Cocoa shells	Typical	22	8	798
Coffee grounds	Typical	20	-	-
Corn cobs	Range	56-123	9-18	-
	Average	98	15	557
Corn stalks	Range	60-73	12	32
Cottonseed meal	Typical	7	-	-
Cranberry filter cake	Typical	31	50	1,021
Cranberry filter cake with rice hulls	Typical	42	71	1,298
Cranberry plant (stems, leaves)	Typical	61	61	-
Cull potatoes	Typical	18	78	1,540
Fruit wastes	Range	20-49	62-88	-
	Average	40	80	-
Olive husks	Range	30-35	8-10	-
Potato-processing sludge	Typical	28	75	1,570
Potato tops	Typical	25	-	-
Rice hulls	Range	113-1120	7-12	185-219
	Average	121	14	202
Soybean meal	Typical	4-6	-	-
Tomato-processing waste	Typical	11	62	-
Vegetable produce	Typical	19	87	1,585
Vegetable wastes	Range	11-13	-	-
Fish and meat processing				
Blood wastes (slaughterhouse waste and dried blood)	Range	3-3.5	10-78	-
Crab and lobster wastes	Range	4.0-5.4	35-61	-
	Average	4.9	47	240
Fish-breading crumbs	Typical	28	10	-
Fish-processing sludge	Typical	5.2	94	-
Fish wastes (gurry, racks, and so on)	Range	2.6-5.0	50-81	-

	Average	3.6	76	-
Mixed slaughterhouse waste	Range	2-4	-	-
Mussel wastes	Typical	2.2	63	-
Poultry carcasses	Typical	5	65	-
Paunch manure	Range	20-30	80-85	1,460
Shrimp wastes	Typical	3.4	78	-

Manures

Broiler litter	Range	12-15	22-46	756-1,026
	Average	14	37	864
Cattle	Range	11-30	67-87	1,323-1,674
	Average	19	81	1,458
Dairy tie stall	Typical	18	79	-
Dairy free stall	Typical	13	83	-
Horse-general	Range	22-50	59-79	1,215-1,620
	Average	30	72	1,379
Horse-race track	Range	29-56	52-67	-
	Average	41	63	-
Laying hens	Range	3-10	62-75	1,377-1,620
	Average	6	69	1,479
Sheep	Range	13-20	60-75	-
	Average	16	69	-
Swine	Range	9-19	65-91	-
	Average	14	80	-
Turkey litter	Average	16	26	783

Municipal wastes

Garbage (food waste)	Range	14-16	69	-
Night soil	Range	6-10	-	-
Paper from domestic refuse	Range	127-178	18-20	-
Pharmaceutical wastes	Typical	19	-	-
Refuse (mixed food, paper, etc)	Range	34-80	-	-
Sewage sludge	Range	5-16	72-84	1,075-1,750
Activated sludge	Typical	6	-	-
Digested sludge	Typical	16	-	-

Straw, hay, silage

Corn silage	Range	38-43	65-68	-
Hay-general	Range	15-32	8-10	-
	Average	-	-	-
Hay-legume	Range	15-19	-	-
	Average	16	-	-

Hay-non-legume	Range	-	-	-
	Average	32	-	-
Straw-general	Range	48-150	4-27	58-378
	Average	80	12	227
Straw-oat	Range	48-98	-	-
	Average	60	-	-
Straw-wheat	Range	100-150	-	-
	Average	127	-	-

Wood and paper

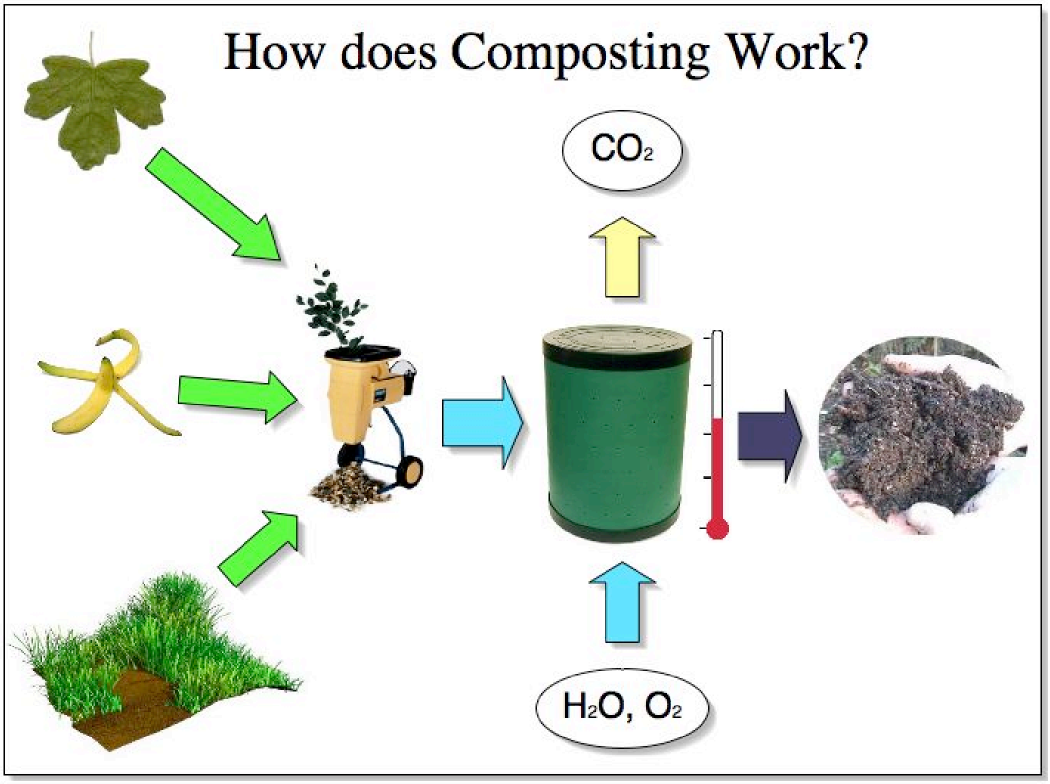
Bark-hardwoods	Range	116-436	-	-
	Average	223	-	-
Bark-softwoods	Range	131-1,285	-	-
	Average	496	-	-
Corrugated cardboard	Typical	563	8	259
Lumbermill waste	Typical	170	-	-
Newsprint	Range	398-852	3-8	195-242
Paper fiber sludge	Typical	250	66	1140
Paper mill sludge	Typical	54	81	-
Paper pulp	Typical	90	82	1403
Sawdust	Range	200-750	19-65	350-450
	Average	442	39	410
Telephone books	Typical	772	6	250
Wood-hardwoods (chips, shavings, etc)	Range	451-819	-	-
	Average	560	-	-
Wood-softwoods (chips, shavings, etc)	Range	212-1,313	-	-
	Average	641	-	-

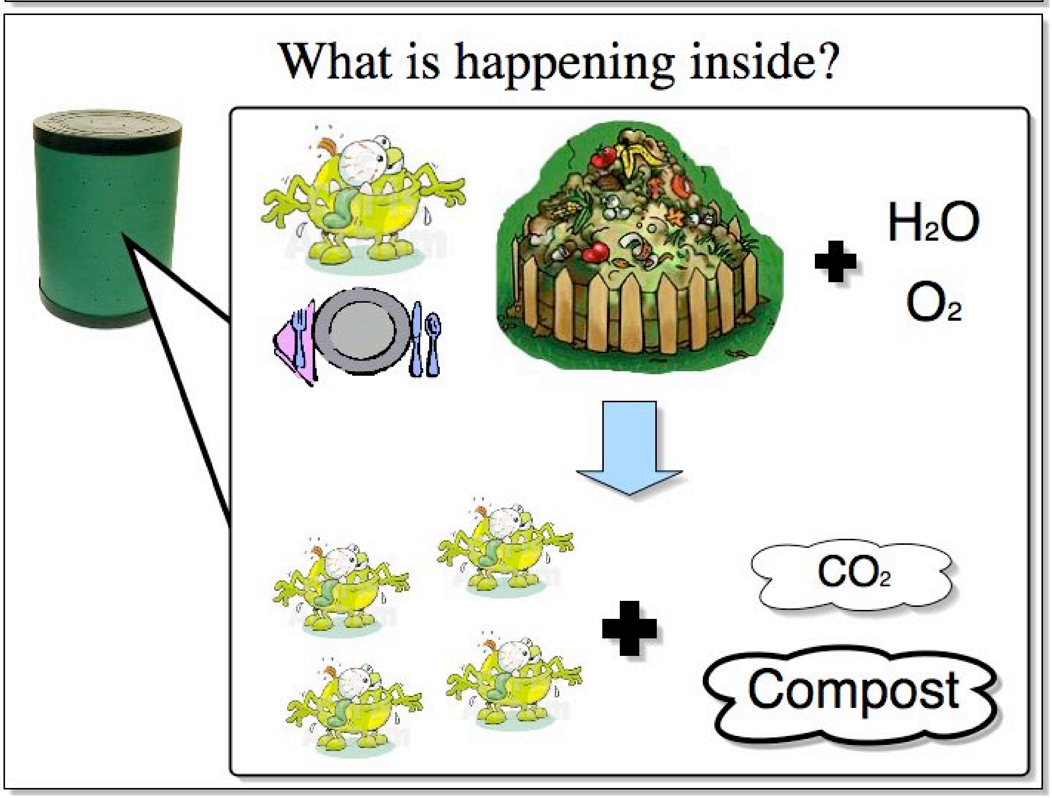
Yard wastes and other vegetation

Grass clippings	Range	9-25	-	300-800
	Average	17	82	500
Leaves	Range	40-80	-	100-500
	Average	54	38	300
Seaweed	Range	5-27	-	-
	Average	17	53	-
Shrub trimmings	Typical	53	15	429
Tree trimmings	Typical	16	70	1,296
Water hyacinth-fresh	Typical	20-30	93	405

Source: On-farm composting, by Robert Rynk (1992).

Appendix B: Composting Education Diagrams





Appendix C: Lesson Plan 1

Lesson Plan 1: Introduction to Composting

Grade Levels: 7-12

Subject Areas: science, biology, ecology, environmental education

Concept: Introduction to the composting process.

Objective: To understand the importance of composting, the biological compost process, the factors that affect it and the uses of compost.

Materials:
-PowerPoint presentation
-portable projector
-baking supplies (flour, sugar, butter, eggs, milk)
-cake
-serving tools (knife, forks, plates)

Keywords: anaerobic, aerobic, in-vessel system, windrow system, microorganisms, decomposition, biodegradable, composting

Background:

There is a significant waste management problem in the world today. This problem has grown because of overuse of landfills, littering, and an increase in waste volume. Side effects of this growing issue include health problems, air and water pollution and an unpleasant appearance. These problems are intensified in Puerto Rico by the island's small size and delicate geography.

There are several efforts being made to attempt to fix this problem. These include composting, recycling programs, environmental legislation, the Green Industry Movement and educational initiatives. Hopefully these endeavors will make progress towards reversing some of the damage that has been done by poor waste management practices.

Although composting is a complex process, the labor required is very simple. Biological materials such as leaves, food scraps and grass clippings are collected and shredded into small pieces. The waste is then allowed to sit in a bin or container for a period of time with occasional mixing and watering. Small microorganisms digest the material and produce the compost product. These organisms require oxygen, water and food, and they produce compost and carbon dioxide. Compost piles generate heat, which is due to the microorganisms' activity and reproduction.

There are several composting methods available. In-vessel systems are complex, highly automated and highly mechanical systems. They are primarily used for industrial applications. Windrow systems are less complex, they are long rows of composting material that are periodically rotated and aerated. Backyard composting is the simplest method and the focus of this lesson.

Backyard composting requires organic, biodegradable materials such a yard trimmings, food scraps and some paper/wood products. Be careful to avoid any metals, meat or dairy products because they may lead to pollution or attract pests. The pile should be placed in a dry, shaded place to avoid too much or too little moisture. It may be placed in a backyard, but not too close to any buildings. To properly maintain the pile it must be periodically turned and watered. A successful compost pile generates heat and does not smell bad. Therefore, bad odors or a lack of heat are indicative of a problem. Finally, the end product can be used as a substitute for fertilizer in gardens and houseplants. Composting is easy to do, good for the environment and produces a useful product.

Procedure: Present the general idea of composting to the students first through an extended metaphor. Place the baking ingredients on one side of the table and liken them to the raw composting materials: individually they are not very useful. Then place the cake on the other end of the table and compare it to the final compost product because it is now a desirable, valuable product. Explain that composting is very similar to baking in that by combining several "ingredients" in the right ratios and allowing them to sit and "bake" for some time, the result is a useful product.

Then cut and distribute the cake to the students and deliver the "Introduction to Composting" presentation. Leave room for questions at the end.

Follow-up: Give our contact information to the students and encourage them to send us any questions they have. Also outline a few additional lessons that the teachers may use in the future to further explore the complexities of composting.

Appendix D: Additional Lesson Plans

Lesson Plan 2: Create Your Own Compost Pile

Grade Levels: 7-12

Subject Areas: science, design, engineering, ecology

Concept: How to build a compost site.

Objective: To design and build a compost site for use in experimentation in a science curriculum.

Materials:
-chicken wire
-shovel
-work gloves
-biodegradable waste material

Keywords: anaerobic, aerobic, microorganisms, decomposition, biodegradable

Background:

There is a significant waste management problem in the world today. This problem has grown because of overuse of littering, landfills and an increase in waste volume. Side effects of this growing issue include health problems, air and water pollution and an unpleasant appearance. These problems are intensified in Puerto Rico by the island's small size and delicate geography.

Although global waste reduction is a huge effort, it is fueled by individual efforts. Starting your own compost pile is a great way to begin to address the waste management problem.

Backyard composting requires organic, biodegradable materials such a yard trimmings, food scraps and some paper/wood products. Be careful to avoid any metals, meat or dairy products because they may lead to pollution or attract pests. The pile should be placed in a dry, shaded place to avoid too much or too little moisture. It may be placed in a backyard, but not too close to any buildings. To properly maintain the pile it must be periodically turned and watered. A successful compost pile generates heat and does not smell bad. Therefore, bad odors or a lack of heat are indicative of a problem. Finally, the end product can be used as a substitute for fertilizer in gardens and houseplants. Composting is easy to do, good for the environment and produces a useful product.

Some important factors to consider when setting up a compost site are location and design of the compost bin. The site should be in a warm spot, however avoid locations that are very sunny or subject to a lot of wind. Both sunlight and wind can dry out the pile and reduce the effectiveness of the compost process. The compost pile should be placed away from buildings in order to avoid rodent and insect problems. When designing the system, it must be large enough to generate heat, but no so large that the material is not sufficiently aerated. The fencing or mesh that is used to construct the bin should not have very large holes. This is so that the compost doesn't spill out and it also discourages animals from rummaging in the compost. Designing the compost bin will give the students a simple introduction to engineering principles.

In order to be useful for experimentation, the compost site built at the schools should consist of several, identical bins so that conditions can be varied. A set-up like this will be conducive to conducting research about how composting works and ideal conditions.

Procedure: The overall plan to design and build a composting site for the school will occur in several steps. During the planning and construction phases, place a plastic bucket with a lid in the classroom to collect the students' lunch scraps and other compostable materials.

1. Discuss the idea of building a compost site with the class. Ask for student participation and brainstorm ideas for the design. Consider size, shape, material and more. Write all ideas on the board, discuss and select the best one. Also choose a location for the site on school property.
2. Pose the idea of installing 3 or more identical compost bins. Ask the students why is this a good idea? What can we do with more than one bin? Pursue the idea of using multiple bins for experiments. Brainstorm a list of variables the students could experiment with.
3. Create a list of materials needed for construction and obtain them.
4. Take students to the designated site and construct the bins as previously discussed. Try to delegate small jobs to different student so as to involve as many people as possible.
5. Once the bins are set up, discuss any possible design improvements (water runoff collector, bin cover, etc.)

Follow-up: Now that the bins are set up, go back to the list of potential variables previously brainstormed and choose a few of interest. How could you design an experiment to explore these concepts? Refer to the following lesson plans for a few examples.

Encourage the students to go home and start compost piles with their families. The big picture of this lesson is to help raise a generation with good composting habits so that it becomes more widely practiced.

Lesson Plan 3: Turning the Compost Pile

Grade Levels: 7-12

Subject Areas: science, environmental education

Concept: How does turning affect composting efficiency?

Objective: To determine the ideal turning frequency for a compost pile

Materials:
-3 identical compost piles
-pitchfork
-shovel
-pencil
-Compost Observation Log (attached)

Keywords: anaerobic, aerobic, leachate, microorganism

Background: A properly maintained compost pile must be turned and mixed periodically so that the pile receives sufficient oxygen. The microorganisms that digest the waste need oxygen to survive. A properly aerated pile functions aerobically, or with oxygen. A pile that functions without oxygen is said to be anaerobic. Anaerobic digestion is a slower process that emits bad odors. Bad odors are a sign that the pile is operating anaerobically, possibly because it has not been turned and aerated enough.

Procedure:

1. Use three identical compost bins as outlined in Lesson Plan 2: Create Your Own Compost Pile.
2. Check to make sure the contents of each bin are similar in materials, size and moisture.
3. Label the bins 1, 2 and 3.
4. Decide on three different turning frequencies, for example, don't turn pile 1, turn pile 2 once per week and turn pile 3 everyday.
5. Turn piles as scheduled with a shovel and pitchfork. Mix and fluff the materials so that air is distributed.
6. Once per week observe the pile and complete the Compost Observation Log.
7. After several months discuss the progress of each pile and decide which one was the most efficient.

Follow-up: Apply the conclusions to future composting efforts and home compost piles.

Compost Observation Log

Name:

Date:

Time:

Pile: 1 2 3 (circle one)

Last time pile was turned:

Visual Observations:

Is the pile moist?

Temperature?

Odors?

Leachate?:

Based on the above data, do you think the pile is operating aerobically or anaerobically?

Lesson Plan 4: Watering the Compost

Grade Levels: 7-12

Subject Areas: science, environmental education

Concept: Compost piles need water.

Objective: To determine how much water a compost pile needs to operate efficiently.

Materials:
-3 identical compost piles
-watering can
-thermometer
-pitchfork
-shovel
-pencil
-Compost Observation Log (attached)

Keywords: anaerobic, aerobic, leachate, microorganism

Background: The microorganisms that digest compost materials need water to survive. Therefore, to operate a good compost pile you need to make sure it doesn't dry out. Sometimes natural rain is sufficient to keep the pile moist, however, in a dry climate such as Puerto Rico, water must be added to the pile. If the pile is too dry the waste will not decompose, but if the pile is wet it will result in anaerobic digestion and bad odors. It is essential to have the right amount of moisture in the pile.

Procedure:

1. Use three identical compost bins as outlined in Lesson Plan 2: Create Your Own Compost Pile.
2. Check to make sure the contents of each bin are similar in materials, size and moisture.
3. Label the bins 1, 2 and 3.
4. Do not water pile 1, water pile 2 once per week and water pile 3 everyday. Add the same amount of water every time (For example add 2 cups of water to pile 2 weekly and 2 cups of water to pile 3 daily)
5. Water the piles as scheduled with a watering can.
6. Mix and fluff the materials occasionally with a shovel and pitchfork
7. Once per week observe the piles and complete the Compost Observation Log. Record the temperature.
8. After several months discuss the progress of each pile and decide which one was the most efficient.

Follow-up: Apply the conclusions to future composting efforts and home compost piles.

Compost Observation Log

Name:

Date:

Time:

Pile: 1 2 3 (circle one)

Last time pile was turned:

Visual Observations:

Is the pile moist?

Temperature?

Odors?

Leachate?:

Based on the above data do you think the pile is operating aerobically or anaerobically?

Appendix E: Letter to the Educator

Dear Educator,

Please find attached four lesson plans and a PowerPoint presentation for composting education. This curriculum was designed for grades 7-12. The first lesson, Introduction to Composting, is a PowerPoint presentation that outlines the basics of composting and briefly discusses how to start composting at home. The second lesson, Create Your Own Compost Pile, is an exercise in engineering and design where students plan and build a composting site on school property. The third and fourth lessons, Turning the Compost Pile and Watering the Compost, are experiments that aim to find ideal pile maintenance.

During these lessons it is important to encourage the students to compost at home. We hope that educating students about composting will help it become a more widespread process. You may wish to contact the parties below with any questions.

Sincerely,

Ashley Bourgault
Witt Guinn
Kate Herchenroder
David Stechmann
Composting for Sustainable Use Team
Worcester Polytechnic Institute
Composting-D05@wpi.edu

Additional Contacts:

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McNeil Consumer Healthcare
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Appendix F: Bin Composting Procedure

One of the most important aspects of composting is careful preparation of materials. For the preparation of yard waste, shred the materials into smaller particles. Shredding adds oxygen to the compost by loosely mixing the ingredients together. Grass clippings are shredded by nature but can be too compact for efficient composting; therefore, it is necessary to have such materials well mixed with supplementary waste to produce the desired compost density. Shredding also allows for faster composting because there is more surface area exposed to the microbes digesting the waste. It would take much longer to compost whole tree branches than the wood chips produced by shredding. A mix of half brown and half green yard waste ingredients is generally a good ratio for composting. After shredding the material, move the yard waste to the bins, adding it to the top of the pile.

Cafeteria and food waste must be monitored to preserve optimal composting. Many impurities are often found in cafeteria waste, such as metal foils, plastics, papers and other unwanted materials. Some of these impurities will not compost and therefore should be separated out of the waste before adding to a compost pile. Directly add the food waste to the compost pile by creating a small cavity in the center of the pile roughly six inches from the top. Place the food in this cavity and cover it over with yard waste. This placement aids in the compost of the food by positioning it near the center of the pile where a large amount of microbes are present to digest the food quickly. The surrounding yard waste will filter much of the odors generated by the cafeteria waste.

Turning the material is an essential part of maintaining an efficient compost pile. Turning the compost aids in the compost process by loosening the materials adding oxygen, removing excess water, and moving uncomposted material to the center of the pile where much of the composting takes place. During composting occurs the materials will become more compact, not allowing as much oxygen for the microbes to survive and carry out their work. Turning is vital to keeping the materials loose with oxygen in sufficient supply throughout the compost. Manually turn the piles with a pitchfork for the small bins. When large windows are created a front end loader would be the most efficient method of turning the compost.

Foul odors will arise from the compost if the pile lacks oxygen or excess water is present. This kind of environment is beneficial to anaerobic composting, thus creating unpleasant odors. If profuse foul odors exist, turning is needed. This will add oxygen as discussed previously and will allow for moisture to evaporate from the pile when surplus water is present. Compost must be kept moist on the inside so that the microbial life can survive to digest the organic material. If the pile is saturated with water or becomes too dry the aerobic microbes cannot survive. In case the pile is too dry, simply add water to give the correct moisture level.

The center of the pile should have a temperature of 60-70°C. When this temperature falls, turn the pile. The decrease in temperature means that materials in the center have completed composting and should be removed from that area to allow for new materials to begin composting. If temperature is in the correct range and pungent odors are not prevalent the compost needs no turning. Turning is usually necessary roughly once a week. When the temperature of the pile fails to increase after turning and, the compost is finished and can be removed from the bin for landscaping use.

Appendix G: Economics and Contact Information

BW Organics Greendrum

Capital Cost:

Equipment	$13,950
Auger	$2,900
Mixer	$5,250
Electric	$1,295
Shipping	$3,791
Total	**$27,186**

Labor	260 hrs/yr	$12/hr
Electric	1089 kWH	.109/kWH
Tipping Fee		$40/ton
Sludge transport to Janssen		$550/month

Annual Composting Cost:

Staff*	$3,120
Electric	$119
Sludge Transport*	$7,700
Other	
Total	**$10,939**

*estimated

Annual Landfill Savings:

Food Waste	$135
Grass and Branches	$457
Leaves	$2,000
Sludge	$2,100
Sludge Transport*	$6,600
Fertilizer*	$1,000
Total	**$12,292**

Annual cost savings **$1,353**

Contact information:
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Rt. 8, Box 729 / CR 2300
Sulphur Springs, TX 75482
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Appendix H: On-site Diagram