Alternative Technologies for New York City's Waste Disposal

Above: Fresh Kills, New York, NY. Closed 2001. Source: The City of New York Department of Sanitation

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Executive Summary

This *Report* was compiled by the members of the New York City Solid Waste Disposal Workshop Group to address a proposal by the City Council to require the Sanitation Department to dispose of at least 5,000 tons of waste each day without landfilling or incinerating the waste. In sequential order, the topics covered include:

The History of Solid Waste Disposal in New York City

This section is included to provide the reader with a background of the problem of garbage in New York City. This section will take the reader from the early days of New York City to current times. This analysis will help provide a historical context for the City's current waste disposal problem.

The Effects of New York City's Solid Waste Disposal Strategy

This section will detail the effects of New York City's solid waste disposal strategy. These analyzed effects will include economic, environmental, and political impacts.

Solid Waste Management Legislation in New York City

This section will detail the mechanisms of solid waste disposal as laid out in the City's Administrative Code and address the proposed legislation that provides the proposal for our research.

Technologies to Achieve the Desired Goal

This section will introduce the team's proposed solutions to the problem of waste disposal. It provides a description and analysis of gasification and anaerobic digestion: two new waste management technologies in use throughout the world that hold promise for New York City.

Measuring the Success of the Solutions

In this section the report will focus on the desired aims and achievements that will be indicative of success. We will identify baseline issues that must be met in order to meet the legislation's objective, and include methods for measuring whether or not these issues have been fully addressed and alleviated.

Conclusion

The final section of this report will include a comprehensive analysis of the semester's work. It will summarize the major findings of our scientific research, and propose a future framework within which the plausibility of our proposed solutions will be examined next semester.

History of Solid Waste Disposal in New York City

In 1898, when legislation brought the five boroughs together to form New York City, there were grand visions of an efficient and centrally run metropolis. Displaying a great level of prescience, city planners made many efforts to preserve and develop vital pieces of infrastructure in the face of rapid growth. Primary examples of this foresight are New York City's drinking water, parks, and transportation systems. On one critical front however, the city has experienced shortcomings time and again: the management of its solid waste.

In the days before the charter of New York City, the population was smaller and most products were made from naturally occurring substances. These factors made waste management fairly easy. However, by 1881, due to the lack of an organized plan to deal with solid wastes, some streets of the boroughs were several feet deep in manure and garbage. In response, the Department of Street Cleaning (later to become the Department of Sanitation) was formed, relieving the Police Department of waste management responsibilities. With the vast ocean nearby, then viewed as an inexhaustible depository for waste, the department's strategy was to simply throw the majority of the waste (75% throughout the 1880's) into the waters surrounding the city.[1]

In1895, Col. George Waring Jr., a former Civil War officer, was appointed to be the first director of sanitation. Seeing problems with ocean dumping and a chance to produce revenue from the waste stream, he hired thousands of workers for a dollar a day to collect three types of wastes: ash, rubbish and food wastes. After collection, the ash was buried in a landfill, rubbish was sorted to reclaim any marketable items, and food wastes were steamed and pressed to yield grease and fertilizer. This new waste management plan was halted in 1918 and ocean dumping resumed, supplemented by the landfilling and incinerating of waste. Over the next few decades, the negative environmental repercussions of ocean dumping became evident. Neighboring New Jersey coastal cities, feeling the brunt of this pollution, brought a federal lawsuit to stop the inundation of waste from neighboring New York City. Finally, in 1935, ocean dumping was halted, and the City was left with only two local options for the disposal of solid waste: landfilling and incineration.

As the Great Depression and World War II dashed plans for the construction of new incinerators, waste disposal infrastructure began to lag behind the City's needs. During this time, most garbage was landfilled or used as fill for public works projects such as highways and parks. With landfills nearing capacity and a shortage of municipal incinerators, the city stopped collecting commercial waste in 1957. This attempt to stem the production of waste and preserve the infrastructure to deal with it led to organized crime control of collection and disposal industry that eventually priced its services so far above market prices that it took federal prosecution to topple the cartel in 2000.

Even with commercial waste being diverted to disposal sites outside of the city, the solid waste disposal infrastructure continued to face unsustainable demands from waste generated by residents. One method to deal with this residential waste, besides municipal incinerators and landfills, was the use of small-scale incinerators in over 17,000 apartment buildings throughout the five boroughs.[2] By 1960, almost a third of the total residential waste was being burned by either municipal or apartment building incinerators. While this solution kept waste away from neighboring cities and out of landfills, it caused alarming amounts of air pollution. City residents, tortured by lingering haze and the adverse health effects that came with it, put pressure on the local government to phase out incineration. Since the 1960s, no additional incinerators have been built and all existing facilities have been gradually phased out. As the last incinerator closed in 1994, the city was left with only one remaining local waste disposal option: landfilling.

Throughout the same period of time that incinerators were being shut down, local landfills were reaching their capacity. Between 1965 and 2001, six landfills reached capacity and were closed. The city's last remaining landfill, Fresh Kills was finally closed in 2001 due largely to political forces.[3] This decision, the main goal of which was the placation of constituent forces, left the city with only one solid waste management strategy: the exportation of its waste to areas outside of the city.

In the following sections, we will examine the consequences of the city's current solid waste management strategy, a new proposed law that attempts to mitigate some of these effects through the introduction of new waste management technology, and a summary of the technologies that we propose to meet the legislation's requirements.

The Effects of New York City's Solid Waste Disposal Strategy

The estimated 8 million residents and thousands of businesses throughout the five boroughs of New York City produce approximately 26,000 tons per day (tpd) of waste that is not recyclable under current programs. New York City's Department of Sanitation (DOS) is responsible for approximately 13,000 tpd of this total amount,[4] and private waste-hauling companies handle the remainder. To deal with the portion of waste for which the DOS is responsible, the City Council devised a 20-year management strategy that relies solely upon the exportation of its solid waste.[5] Many see this as an unsustainable waste management strategy due to economic, environmental, and political considerations. In this section, we will discuss each of these considerations.

Economic Considerations

Two areas of economic concern have been voiced about the City's 20-year waste management plan. The first is its reliance on an increasingly consolidated waste management industry. In recent years, the number of publicly traded waste management firms in the United States has decreased to just seven.[6] These seven companies have been contracted to transport 58% of the total waste generated in the United States.[7] As a result of this consolidation, the few major companies that are involved have gained considerable economic clout.

Another part of the national waste management industry in which we are witnessing consolidation is in landfill ownership. Roughly three-quarters of all non-recycled municipal waste is disposed of in landfills. The Environmental Protection Agency's (EPA) Subtitle D regulations for landfill management have introduced operational procedures that make it difficult for small firms to maintain landfills. Consequently, a few large firms have bought many of the smaller landfills. Current estimates show that seven publicly held firms now control approximately 61% of the total available landfill capacity.[8] Furthermore, proposed legislation in Pennsylvania and

Virginia, two states that New York relies upon to dispose of its waste, may also affect the economics of solid waste disposal by limiting the expansion of existing landfills and the construction of new facilities. Indeed, with increasing costs for landfill management and operation, and fewer companies offering disposal services, New York City faces near certain increases in future waste management costs.

Due mainly to a shortage of capacity, landfill management companies have been steadily increasing tipping fees. Several northeast states (New York, Vermont and Massachusetts) have less than ten years of capacity remaining, which limits the amounts of available space and places a higher cost on disposal.[9] Currently, parts of the Northeast including New York State face the highest tipping fees in the US, which is significantly increasing New York City's cost of landfilling waste.[10]

Environmental Considerations

Aside from the economic concerns associated with the disposal of the New York City's waste, there are environmental considerations that should be taken into account when examining the City's waste disposal strategy. Currently, all waste generated by the City must be exported from the city to a landfill or incinerator. Our findings will demonstrate that there are environmental problems associated with each of the final disposal methods, as well as the types of transport used.

<u>Transportation</u>

Transport of New York City's waste is accomplished using three different methods: truck, rail and barge. While barges and rail are still important to the exportation of the City's waste, more than 90% is transported out of the City by diesel trucks.[11] This fleet of trucks consumes roughly ten million gallons of fuel every year and is the source of many environmental problems stemming from their emission of nitrogen oxides (NO_x) and carbon dioxide (CO_2).[12] For example, if 1,000 tons of waste were transported one mile using a diesel truck, more than 300 pounds of CO_2 would be emitted into the atmosphere.[13] Since the majority of landfills that serve New York City are located in Pennsylvania, Ohio, New Jersey, and Virginia, the CO_2 emissions associated with transporting the City's waste over great distances are far greater than this calculation.

Diesel engines, used in the majority of garbage trucks, though more efficient than gasoline engines in many respects, have a higher NO_x output because they have a higher compression temperature. One way to reduce NO_x emissions is to lower the engine temperature, but this strategy has a significant drawback. Since higher temperatures maximize engine efficiency, lowering the temperature causes incomplete fuel combustion and eventually leads to higher hydrocarbon (HC) and particulate matter (PM) emissions.[14]

Serious health effects are associated with these air pollutants. NO_x can lead to lung damage, respiratory problems, and various types of cancer. PM is the leading source of asthma, chronic bronchitis, and lung cancer, with children and the elderly suffering the highest risk. HCs, another group of airborne pollutants, may cause difficulty in breathing, lung damage, reduced cardiovascular function, and various forms of cancer.

Furthermore, air pollutants and greenhouse gases have an enormous impact on the climate as well. Acid rain, caused by a high concentration of acidic molecule species in the air, can contaminate groundwater sources and threaten the overall health of an ecosystem. Ozone, haze, and excessive smog have long residence times in the atmosphere and have long-term effects on Earth's climate.

Noise pollution is another side effect of transporting and collecting waste. In New York City, noise is the number one public complaint registered by the City operated "311" non-emergency public hotline. A study conducted by the EPA also showed that road traffic is a leading source of community noise.[15] Although it may seem insignificant compared to other pollution, noise pollution can cause health concerns such as hearing loss, sleep disturbances, cardiovascular and psychological problems, performance reduction, annoyance response, and adverse social behavior.

There is also the risk of accidents resulting in spills while the waste is in transit. Following the trend of increasing distances to final disposal sites, the chance of accidents while en route continues to rise. Each of the transportation methods cited above involves risks, with trucking having the greatest level of potential risk. Though accidents involving barges and trains are not as frequent, they may pose an even greater environmental threat due to the higher volume of solid waste being transported. If an accident were to occur using any method of transport, cleanup costs of the solid waste cargo would be large, especially if the spill were to occur in an aquatic environment.[16]

Incineration

According to the EPA, incineration is "the destruction of solid, liquid, or gaseous wastes through the application of heat within a controlled combustion system."[17] It is one of the oldest, yet most effective methods employed in solid waste disposal. Unlike New York City's inefficient and polluting apartment incinerators, modern, high temperature incineration is relatively clean and can be used to generate electricity. Through high temperature combustion, all water content in organic waste products is evaporated and the physical and chemical properties of the waste are altered. Consequently, the total volume of waste products is reduced. However, landfills remain the final destination of all post-incineration residues from municipal solid waste. Incineration also serves to reduce the toxicity of solid waste. The application of heat in the combustion chamber changes the chemical composition of toxins, like household cleaning supplies, and in turn minimizes the effects of hazardous materials in landfills. Organic wastes are usually sorted out from the waste stream as "feeds" for the incineration plant. Organic wastes have numerous forms. In simplified terms, the formula $C_6H_{10}O_4$ is used to approximate the chemical composition of all organic waste. When combustion occurs in the presence of sufficient oxygen, each mole of $C_6H_{10}O_4$ generates 6 moles of CO_2. This 1 to 6 molar ratio can be used to explain the significant negative environmental impacts associated with incineration emissions.

Among all the byproducts of incineration, sulfur oxides (SO_2), hydrochloric acid (HCl), polychlorinated biphenyls (PCBs), volatile organic compounds (VOCs), PMs, dioxins, and heavy metals are the leading toxins found in the residue ash. The precise composition of the byproducts is dependent on the type of furnace used. Dioxins are chlorine-derived chemicals, mostly from PVC-based packaging, cables, polyethylene, bleached paper, and other chlorine containing products. During the incineration process, the formation of dioxins increases with temperature. Thus, as the temperature in the incinerator rises, the formation of dioxins increases. PM less than 1 micron in diameter is most harmful to human health. Unfortunately, air pollution control devices are only capable of filtering PM of size 0.25 microns or more in diameter. Therefore, smaller particulate matter is released into the atmosphere and can eventually enter the human body. A major component of post-incineration residue is ash. Due to the potential presence of small amounts of toxic waste, ash can inherit some of the toxic nature of solid waste. Depending on the toxic content, ash may be sent directly to landfills, because some toxic contents are exempted from landfill regulations. Ash accounts for up to 25% of all the unprocessed waste.[18]

Following EPA mandates, incinerators are equipped with pollution reduction devices to collect PM, remove acids, and filter dioxins during the combustion process. Unfortunately, the filtering devices can only trap larger particles and tend to only have a 5 - 30% efficiency level.[19] Exhibit 1 summarizes the health threats linked to each toxic chemical.

Exhibit 1: Health effects associated with incinerator derived chemicals

Toxins	**Health Threats**
SO_x	Respiratory tract irritation
HCl	Tissue and respiratory tract irritation
PM	Respiratory problems
Dioxins	Developmental & reproduction problems (unborn and infants most susceptible)
Heavy Metals	Lung, gastric, esophageal cancer, etc.

Source : United States Environmental Protection Agency.

Landfills

A landfill is an excavation in the ground that is designed to hold solid waste. To avoid introducing solid wastes to the surrounding environment, a lining is generally placed at the bottom of the excavation. The EPA Federal Landfill Standards were designed to minimize adverse impacts on environmental systems surrounding landfills. Landfills must be built in areas that are away from sensitive environments such as wetlands. Most important to the protection of groundwater sources is the requirement for plastic liners that are "reinforced with two feet of clay on the bottom and sides of landfills."[20]

In 1991, the EPA issued a requirement for all municipal landfills to install plastic liners and systems to collect the liquid run-off, or leachate, within two years. However, precautions such as these for preventing solid waste from impacting a landfill's surrounding environment are often undermined by systematic problems. A major problem with plastic liners is their tendency to deteriorate or puncture, leading to the release of leachate into groundwater systems. Clay layers, although thicker than plastic, are permeable and prone to cracking which provides a release route for waste into groundwater.

In order to understand the implications of toxic landfill releases into water systems, it is important to understand the general composition of leachate. Formed as a result of rainfall and moisture in landfills, leachate is meant to be contained by systems built into the landfill. However, the EPA Federal Register states that "even the best liner and leachate collection system will ultimately fail due to natural deterioration."[21] Over 150 different VOCs found in landfill leachate, some of which are carcinogenic, cause respiratory problems, dizziness, visual disorders, or memory impairment. The sources of VOCs in municipal solid waste are paints and lacquers, cleaning supplies, building materials, glues, and adhesives. Common VOCs found in landfill leachate are HCs, benzene, and PCBs.

There are also many dangerous heavy metals that accumulate in landfills and are sometimes found in high concentrations in leachate. Some of the most harmful metals are cadmium, lead, mercury, arsenic, and chromium. Cadmium is a potentially lethal heavy metal that causes stomach irritation and can lead to vomiting, kidney damage, and weakening of bones. It comes from various sources such as batteries, pigments, and plastics. Lead causes nervous disorders, reproductive problems, kidney failure, and anemia. Contamination of lead comes from the disposal of wastes such as plastics, ceramics, and paint. Lead has also been known to cause significant damage to aquatic ecosystems, including the death of various waterfowl. Mercury causes nervous disorders, and damage to kidneys and the immune system. The sources of mercury in landfills include items such as batteries and thermometers.[22]

Leachate contamination and landfill gas have an adverse impact on human health. For example, a 1990 study found an increased incidence of bladder cancers in northwestern Illinois where a landfill had contaminated a municipal water supply with VOCs. A 1989 study by the EPA examined 593 solid waste sites in 339 US counties that revealed increased occurrences of bladder, lung, and stomach cancers in counties with the highest concentration of waste sites. In addition, a study was conducted that examined the occurrence of cancer among men and women living near 38 different landfills. The results concluded that the incidence of seven kinds of cancer was elevated for women living near landfills. In men, the study found elevated incidence of lung cancer, bladder cancer, and leukemia.

Along with groundwater contamination, landfill gas is also a problem because it can pollute the air around municipal solid waste landfills. The decomposition of waste in landfills creates gas consisting of 54% methane; the remainder is composed of CO_2 and VOCs.[23] Pressure forces these gases to escape from the waste through the surrounding soil. Landfill gasses carry toxic chemicals such as solvents, paint thinner, pesticides, and other hazardous VOCs. In 1996, the EPA made the installation of gas collection and control systems mandatory for all new and modified landfills. Some landfills collect methane to be re-used for energy production. However, collection of this potent greenhouse gas is often inefficient and much is released into the atmosphere.

Political Considerations

Large amounts of waste being exported to locations outside of the jurisdiction of New York City increases the visibility of the City's problem in other counties and states. Increased visibility generates political challenges that could lead to even higher disposal costs than predicted due to the economic and environmental factors discussed previously. The three main political challenges are: federal regulation of interstate waste and the creation of new landfills, further incentive for the consolidation of waste management industry, and local resistance to siting future waste disposal and transfer facilities.

Facing pressure from constituents who are upset about New York City's waste being transported to or disposed of in their communities, legislators have begun to take action. Two bills that are currently in the US Senate would authorize local and state entities to prohibit or limit the receipt of out-of-state solid waste.[24] These pieces of proposed legislation would have a direct impact on the City by giving states that currently receive waste the authority to make waste imports more difficult.

As New York City's waste disposal problems attract more attention, more public concern is generated. This results in more local resistance to the siting of new publicly owned landfills or incinerators, which is consistent with the City's history. In the absence of new DOS facilities, the city will be forced to renegotiate contracts with private waste management companies who will have the upper hand due to a lack of alternate possibilities for the disposal of the City's waste.

Solid Waste Management Legislation in New York City

As we have tracked the history and current status of waste management in New York City, several problems have been demonstrated. It is evident that a lack of local infrastructure to manage the large amounts of waste generated by the City complemented by increasingly difficult, costly, and environmentally damaging export options has put the City in a difficult position. The City is currently attempting to remedy this situation by developing a long-term waste management plan.

<u>Solid Waste Management Plans</u>

The Environmental Conservation Law of New York state, Section 27, requires that Solid Waste Management Plans be prepared by the state and local governments. The Comprehensive Solid Waste Management Plan (CSWMP) for New York City is prepared by the Department of Sanitation (DSNY) and submitted for approval by the New York State Department of Environmental Conservation (NYSDEC) in accordance with this legislation. The CSWMP is adopted by New York City pursuant to subdivision (c) Section 16-140 of the Administrative Code. Exhibit 2 illustrates elements of past plans.

Exhibit 2: New York City's Waste Management Plans and Laws

Year	**Authority**	**Document**	**Reason for Preparation**	**Amendment to the Administrative Code**
1987	NYSDEC	New York State Solid Waste Management Plan (1987-1997)	First NY Solid Waste Management Plan	N/A
1992	DSNY	Comprehensive Solid Waste Management Plan (1992-2002)	Initial CSWMP adopted by NYC	Local Laws 23, 69 and 72 of 1992
1998	DSNY	Comprehensive Solid Waste Management Plan (1992-2002)	Amendment to accommodate for the mandated closure of Fresh Kills by 1/1/02	Local Law 72 of 1998
2004	DSNY		Scoping process initiated for new twenty-year CSWMP	Introduction 95 of 2004

The Administrative Code of the City of New York

The Code is the City's major legal instrument that enables local government to manage solid waste in the five boroughs. Sections that relate to the management of solid waste begin with Title 16, Chapter 1. This chapter concentrates on the Department of Sanitation and outlines provisions for record keeping, the transport, storage and disposal of solid waste, disposal rates and regulations for disposal and compost facility use, containerization and disposal of hazardous waste, permission and rules for dumps, transfer stations and landfill facilities, the establishment of a solid waste management plan, and the study of commercial solid waste management system. Chapter 2, entitled "Solid Waste Management," outlines provisions for facility management, waste acceptability, charges and facility funding, record keeping, regulation, and enforcement. This section of the Code is of primary concern to the topic of finding and implementing alternatives to New York City's waste management strategy because it is this section that must be amended if the City wishes to enact any changes to the handling and disposal of its municipal solid waste.

Introduction 95

A recent proposal to amend Chapter One of the Administrative Code of the City of New York called Introduction 95 appears to be a good start toward waste disposal independence for New York City. Introduction 95 was crafted specifically to encourage the City to deal with its own waste. If passed, it will amend Chapter One of Title 16 of the Code, creating an additional section (Section 16-141). It states:

"The Commissioner shall be required to provide for the final disposal of no less than five thousand tons per day of non-recyclable solid waste by a method other than landfilling or incineration no later than July 1, 2015"

Perspectives on Introduction 95

New York City has had difficulty dealing with its waste management infrastructure. Introduction 95 attempts to put into law the final disposal of almost one half of all the daily municipal solid waste (to be referred to as solid waste) generated by the City. If it is passed and an appropriate technology is implemented, this amendment could significantly reduce the economic, environmental, and political impacts associated with landfilling and incinerating waste that the City currently endures. Furthermore, it could be used to spur the development and acceptance of new technologies making New York City a model for other cities around the world with similar waste management issues.

Some critics have pointed out that the legislation still fails to address a lack of emphasis on environmental responsibility. Environmental conservation is mentioned as the goal of only one subsection of the City's waste management legislation (Title 16, Chapter 3 of the Administrative Code). Recent problematic changes to recycling practices and the current policy of free-of-charge residential garbage collection ultimately encourage the generation of large volumes of waste.

Technologies to Achieve the Desired Goal

There are several technological processes that have been developed to dispose of waste. These are generally classified as chemical, biological, and thermal. The application of chemical treatment is typically used in the disposal of hazardous waste, and therefore does not apply to the solid waste of New York City. Biological treatment is the decomposition of organic waste by microorganisms. This includes the processes of aerobic digestion (in the presence of oxygen) and anaerobic digestion (in the absence of oxygen). Aerobic digestion would be extremely difficult to implement in the city because its processes require an open-air forum—a forum that is recommended to be a great distance from a local population. In the densely populated city of New York, this technology might pose health and odor problems to the surrounding residents. The City might consider locating this facility on an island or on land purchased outside of the City. The thermal methods of waste disposal include incineration, which was previously described, gasification, and pyrolysis. The latter methods differ in that gasification involves applying extreme heat in a near-inert environment to reduce waste, while pyrolysis is carried out in the complete absence of oxygen.

Of these methods there are two different technologies that have been developed which would allow New York City to meet the requirements of the proposed legislation: plasma pyrolysis and anaerobic digestion. Both are new technologies, and are still being adapted and improved. Though neither has yet achieved a daily operational capacity specified in the legislation, plasma pyrolysis may have the potential to do so. Anaerobic digestion has a limited capacity and feed constraints, and would not meet the entire requirement by itself. There are inherent advantages and disadvantages within both processes.

Plasma Pyrolysis

The thermal reduction of waste takes on many forms. Our focus is on the innovative technology of plasma pyrolysis, as our research indicated it is the most efficient gasification method. Plasma pyrolysis, a form of gasification, is a process in which all refuse is heated to extreme temperatures–often hotter than the sun at 7000^oC. The procedure differs from incineration in that it is conducted in the *absence* of oxygen. The process is broken down into three stages: waste breakdown, gas cleaning, and conversion to power.

<u>Stages</u>

In the first stage various types of waste, including organic, inorganic, medical, and low-level radioactive, are introduced into a mass storage container by a transport vessel. Here the refuse awaits release into the pyrolysis heating chamber. Once released the waste is heated in an inert environment to temperatures of 1200-7000^oC by a plasma arc torch. This torch is powered by gas, primarily composed of oxygen and nitrogen, which is ionized by the passage of electricity (Figure 1). The extreme temperatures essentially melt the waste by inducing the dissociation of the molecular components of the waste, producing a vitrified slag. This slag is then removed from the chamber.

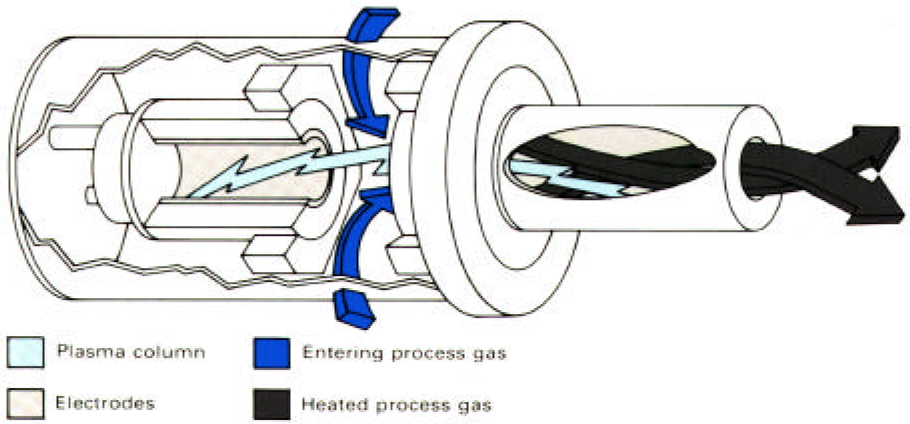

Figure1. The Plasma Arc Torch. Source: City of Honolulu Review of Plasma Arc Gasification and Vitrification for Waste Disposal

The second stage of the process involves the cleaning and refining of gas. The heating process conducted in stage one produces gas and steam, both of which are captured and separated within the system. The gas is then refined to produce a product that is primarily composed of hydrogen and carbon monoxide, though other constituents are present as well (Exhibit 3). The excess products are recycled within the system in stage three.

Exhibit 3. Constituents of the Refined Gas

Gas Component	**Contribution of Refined Gas**
Hydrogen (H)	41 - 53 %
Carbon Monoxide (CO)	26 – 31 %
Carbon Dioxide (CO_2)	8 – 10 %
Nitrogen (N_2)	9 – 16 %
Methane (CH_4)	0.5 – 2.5 %
Complex Hydrocarbons	0.5 – 1 %

Source: Rich Madrak, President, TOR Trading Co.

In the final stage, the excess gas and steam created within the process is utilized by gas and steam turbines to generate power. Typically the power is then transferred to an on-site power plant which distributes the electricity throughout the plant and the surrounding area. It is estimated that one ton of solid waste can generate as much as 9.4 million British Thermal Units (BTU) of gas, 0.4 million of which are used per hour to operate the plasma arc torch. Therefore, the process includes a net gas production in the approximate amount of 9 million BTU per hour for each ton of waste. In operating a 5,000 tpd facility, an approximate 1.8 billion BTU per hour surplus would be available to generate power in amounts of 1,000 Megawatts per day, or to be sold to industries for profit.[25] The gas could be used as a source for hydrogen fueling or even as a source of methanol. Below (Figure 2) is an overall view of what a plasma energy pyrolysis facility might resemble. The process is fairly complicated, yet is efficient and capable of extreme waste reduction. It is estimated that nine tons of waste results in one ton of glassy slag.[26] Anything but explosives can be introduced into the pyrolysis chamber, which implies that all types of solid waste could be processed and condensed.

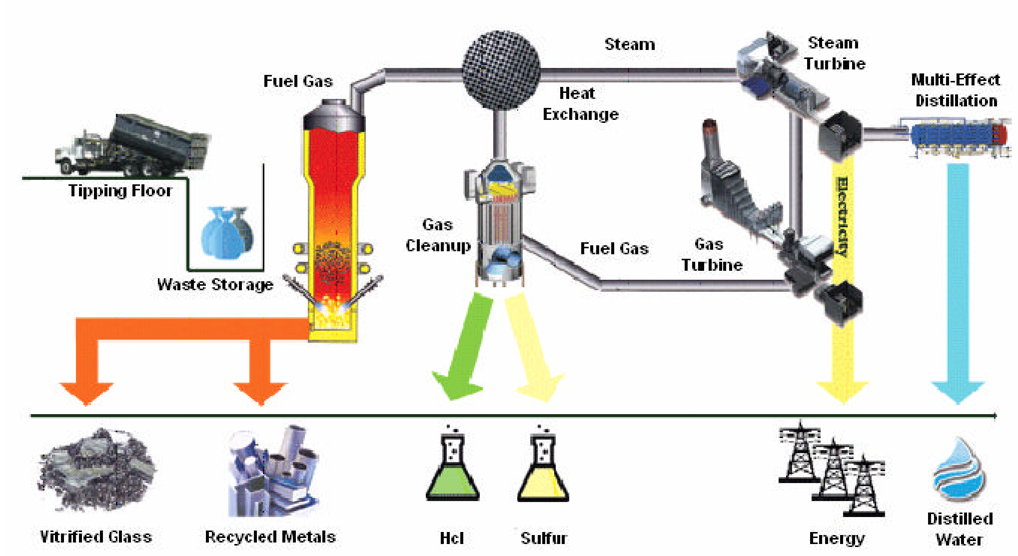

Figure 2. Plasma Energy Pyrolysis Facility. Source: http://www.recoveredenergy.com/ overview.html#zero

Issues and Controversies of Plasma Pyrolysis

There is much debate about the limitations of the pyrolysis process. Though used in many parts of the world, the technology is relatively new. There have been issues and uncertainties among facilities in operation and these concerns must be addressed before the technology can be applied.

First, there are environmental concerns. Emission measurements taken at five in plasma pyrolysis plants in different countries revealed that either no contaminant emissions were present, or that the amounts present ranging below one thousand times the US EPA's standards.[27] Additionally, the proponents of the technology claim that the gasses produced in the process have levels of dioxins that are a hundred times lower that of an incineration plant.[28] However, not all estimates agree. In fact, a study conducted by the UK Department for Environment, Food and Rural Affairs found comparable levels of dioxins and furan emissions to incineration, with the emissions from pyrolysis being lower by a factor of 8×10^{-9}. The same study also found that the process actually emitted higher levels of mercury, arsenic, cadmium, and sulfur dioxide than incineration.[29]

There is also debate concerning the safety of the slag. The produced slag shown below (Figure 3) is presented by proponents as a widely applicable construction material or as a supplement to mend asphalt roads that have been worn down over time.[30] Westinghouse, a manufacturer of the plasma arc torch, claims that the produced slag passed the EPA test as a non-leachable and therefore non-hazardous material.[31] This implies that whatever contaminants are present in the slag will remain sealed within it. Yet there is no consensus that this seemingly harmless product is indeed safe for re-use. For instance, while the Japanese government has classified the slag as a safe product that may be used in construction processes, there is no market for the slag in private industry due to its content.[32] There is actually concern that certain hazardous substances that exhibit high boiling points remain in the slag, and could eventually leach into the environment. Silica, for example, is a substance of concern. This chemical has a structure that is conducive to capturing heavy metals. Some research has indicated that it is very plausible that these heavy metals could be released from the slag by using a simple acid solvent.[33] In a region where acidic disposition is prevalent, this scenario could be realistic and problematic to the surrounding environment.

Figure 3. Examples of Produced Slag. Source: http://www.rcl-plasma.com/Whats%20New_archive.htm

In addition to the environmental concerns there are capacity concerns that must be considered before one can realistically apply this method to the city of New York. There are a limited number of pyrolysis facilities operating throughout the world and even fewer plasma arc facilities. None of these scarce facilities has been scaled to handle the amount of waste (5,000 tons per day) that the City Council is proposing to handle with alternative technologies. Whether or not this could be accomplished needs to be investigated.

One can imagine the development of four facilities to manage the waste in sizeable portions. These smaller plants, to be located in various boroughs, could operate with amounts of waste that have been demonstrated to be achievable. Yet still looming is the possibility of operational failure. About two years ago in Minamata, Japan, a simple work mistake at a pyrolysis facility caused an accident involving the explosion of a furnace. This led to a small fire, culminating in the injury of ten workers, and the plant was closed for at least a month while the effects were mitigated and repaired.[34] If such an incidence occurred in New York the impact might be considerable.

Plasma energy pyrolysis may meet the solid waste needs of New York City. The City could profit from being able to process a vast quantity and quality of waste with this technology. Additionally, the remnants from the process could potentially provide the City with added revenue. However, the emerging technology requires further research before its implementation can occur. It is our recommendation that in addition to supplementary research, a pilot facility be tested in the area before a scaled facility is constructed. This would help to ensure that a pyrolysis facility is conducive to the area and to the needs of New York City.

Anaerobic Digestion

Composting waste is not a new process and occurs internationally by various methods. Our focus lies with the more recently emerged process of anaerobic digestion, which is the composting of organic, biodegradable solid waste in an inert, heated environment. The process produces a biogas composed primarily of methane (CH_4) and carbon dioxide (CO_2). Several configuration designs of anaerobic digesters are in operation at varying temperature ranges (mesophilic range, 30-40°C; thermophilic, >40°C). Thermophilic processes require a majority of the biogas generated to be used for heating in order to keep the temperature in the furnace at a high level. Other factors that affect the efficiency and rate of anaerobic digestion are volume capacity, number of stages, and continuous versus batch processes, each of which are capable of further complicating the process based on the total solid content in the feed.[35] This process is broken down into separate active and curing stages and like pyrolysis, also has potential benefits and concerns.

<u>Stage 1</u>

The first active stage, termed hydrolysis/liquefaction, entails the breakdown of the organic waste by microorganisms including bacteria, fungi, actinomycetes, and protozoa. These fermentative organisms are released into a closed chamber where they convert the insoluble complex organic matter to monomers. The organisms secrete hydrolytic enzymes (lipases, proteases, cellulases, amylases, etc.) to break down the long-chained polymers so that a shorter digestion period and higher methane yield are achieved.[36] The most common reactions are the conversion of lipids to fatty acids, polysaccharides to monosaccharide, protein to amino acids, and nucleic acids to purines and pyrimidines.

In the second stage of acetogenesis, acetogenic bacteria, such as syntrophobacter wolinii and sytrophomonos wolfei, further break down the monomer products from stage one. They are converted into simple organic acids, such as acetic acid, propionic acid, and butyric acid. The creation and addition of buffers, such as ammonia and bicarbonate, is the next step, which is necessary to control the pH and buffer the created acids. A typical reaction is shown below.

$$C_6H_{12}O_6 \ ? \ 2C_2H_5OH + 2CO_2$$

This stage is necessary for increasing the pH of the waste mass, due to the requirement of the third stage, which cannot operate below a pH level of 6.5.[37]

The final or, curing stage of methanogenesis, involves the conversion of the soluble matter by bacteria into methane and carbon dioxide, produced by two means: cleavage of acetic acid molecules or reduction of carbon dioxide with hydrogen, which is performed by methanogens (methane fixation bacteria). The latter can produce a higher quantity of methane, with hydrogen being the limiting factor; otherwise, the acetate reaction would dominate in the production of methane.[38] The reactions can be summarized by the following chemical formulas:

$$2C_2H_5OH + CO_2 \ ? \ CH_4 + 2\,CH_3COOH$$
$$CH_3COOH \ ? \ CH_4 + CO_2$$
$$CO_2 + 4H_2 \ ? \ CH_4 + 2H_2O$$

The waste that remains in the chamber is in the form of compost, which could potentially be used for agricultural purposes. There is typically a 50% volume reduction of the organic waste into compost.[39] The November 1998 Report published by the Regional Information Service Centre for South East Asia on Appropriate Technology (RISE-AT) estimated the breakdown of products from the anaerobic digestion process.

Exhibit 4: Typical Biogas Composition

Methane	55-70% (by volume)
Carbon dioxide	30-45% (by volume)
Hydrogen sulphide	200-4000 ppm (by volume)
Energy content of AD gas product	20-25 MJ/m^3
Energy content of CH_4 per ton of waste	167-373 MJ/ton

Source: Regional Information Service Centre for South East Asia on Appropriate Technology

Several factors affect the efficiency of the anaerobic digestion process. One factor affecting the process is the growth rate of microorganisms leading to variation in digestion rate. Additionally, the separation of the waste stream can change the content of the outputs. The organic component of a waste stream is the main source of the anaerobic digestion process. Inorganic materials can harm the process. The combustible component of these materials inhibits the effectiveness of degrading waste under the anaerobic conditions, while the inert component tends to wear down equipment and potentially increase maintenance costs. Below (Figure 4) is an illustration of the entire process. The final stage in the illustration shows the creation of power, which involves extracting the methane gas and conveying the gas to engines, where it is converted into electricity. This generation makes the powering of the anaerobic digestion plants self-sufficient. The ability to capture methane gas also reduces overall greenhouse emissions and promotes the practice of waste-to-energy technology without incineration. This step is common among anaerobic facilities.

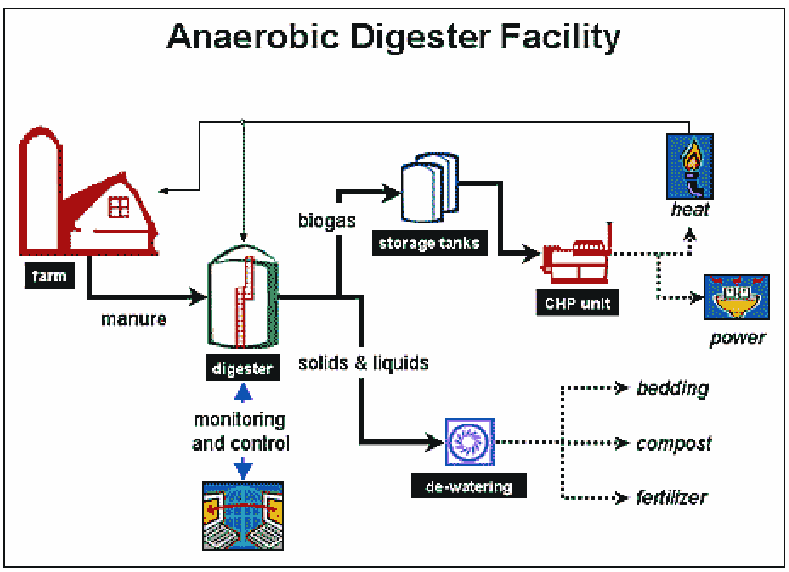

Figure 4. The Anaerobic Process. Source: http://www.microgy.com/technology.htm

Issues and Controversies of Anaerobic Digestion

Anaerobic digestion could facilitate the final disposal of New York City's organic waste. Additionally, the process is much more simplified than that of pyrolysis. Despite these benefits, there still exist numerous problems with the technology and its feasibility for use in the City.

One concern of the process is the quality of the output compost. The methodology used in presorting the waste is crucial for the success of anaerobic digestion. If a contaminated source enters the digestion reactor, the output compost will either require further treatment before it can be used, or it will have to be land filled. Neither of these outcomes is desirable in NYC, especially if the compost required final disposal in a landfill. This scenario would not comply with the proposed legislation. Numerous studies indicate that good quality, useable compost can be produced, particularly for the purposes of agriculture fertilizer. Yet there is not general consensus on this issue. In Ontario, Canada, feasibility studies for anaerobic digestion show that the composted material produced is not expected to be of a useable quality.[40] In the Vargon facility in the Netherlands, where solid waste is separated centrally and the compost is used as feedstock, the output compost still does not meet the required specification for agricultural use.[41] This uncertainty makes the sale of this type of compost difficult in the private market. The public is not often willing to take risks with potentially hazardous materials.

There are also health concerns related to the process. The process produces air-borne microorganisms that involve abundant pathogens. The process is contained, but the bacteria and viruses present in the feedstock could pose a risk to the plant workers. Of particular concern is the fungus *Aspergillus fumigatus*, which is produced in significant amounts and is a known Class 2 pathogen.[42] This pathogen could potentially be harmful to the workers or to the surrounding area in the event of operational failure. Using thermophilic rather than mesophilic temperatures in the process greatly reduces this risk, yet would not rid the process of the pathogens entirely. Further complicating the matter is that the system is much more difficult to manage at higher temperatures.

Operational concerns are relevant in this process as well. The retention time of the feedstock in the digestion reactor is uncertain. The typical retention time is 10 to 20 days, though some studies indicate the time frame to be as long as 60 days. The microorganisms used in the process control the retention time, size, and cost of the digestion reactor.[43] If the stages of digestion are separated by adding reactors, as in the multi-stage type of production, each reaction can be optimized and its retention rate decreased. If the tanks are made more conducive for the particular bacteria, the population will increase, and the process can move more quickly. If the pre-processing step is improved, the waste will be more easily degradable which will lead to less time in the tank. Higher water content and better mixing can also help the bacteria perform its job more quickly. Current research indicates that retention time of 2-5 days may be possible.[44]

Conversely, the level of mixing within the digestion reactor can disrupt the bacteria and slow down the process. If presorting is not done effectively, large pieces of waste may clog the system. If toxic materials such as metals and detergents get into the digestion reactor, it would need to be shut down and diluted to reduce the toxicity level. The pH within the digestion reactor is crucial for both methane production and digestion reactor time. Depending on the feed composition and retention time, pH levels could drop too low and digestion could be stopped. This is most prevalent in batch systems.[45] Problems with biogas production are also possible. The formation of scum in the tank could block the release of biogas and halt digestion in the tank.

Finally, an important issue surrounding the application of anaerobic digestion to the City is the limitation of the feed. The process is very selective to what materials may be inputted. Strictly organic wastes may be used, as any other type of solid waste would contaminate the process. According to the statistics of solid waste generation in New

York City, approximately one fifth (excluding paper) of the total municipal waste stream of 13,000 tpd (about 2,600 lbs) is classified as organic waste, which is biodegradable through the anaerobic digestion process.[46] Processing this amount of waste could aid in the City's waste dilemma, but would only meet approximately half of the requirement of the proposed legislation. If anaerobic digestion were used in the City, another scheme would have to be developed to allow for the disposal of a greater component of the waste.

As with pyrolysis, further research is needed before the implementation of an anaerobic digestion facility could occur. The ability to successfully scale a system to handle the amount of New York City's garbage, at the needed capacity with effective sorting and reduced residence time, is the biggest challenge facing the implementation of this technology. Manufacturers claim the technology is scaleable, but it has never been done at the level needed by the City. Advancements in technology such as additional reactors for increased capacity and pipe design to minimize throughput time are increasing the viability of this solution for New York City's waste stream. Anaerobic digestion technology is growing and potential problems should decrease as the technology becomes more widely used. Currently organizations such as Earth Pledge are working with the EPA and the city of New York to develop small-scale digestion reactors in the city. This is a promising first step and may help reveal the applicability of the technology for large waste streams, yet only time will tell.[47]

Measuring the Success of the Solutions

The proposed legislation to develop alternative disposal methods may be challenging to meet. Many technologies that have the prospect of achieving the desired goal are in the preliminary stage of development and application, and are not ready to be scaled to handle the size of New York City's waste stream. However, our research holds that there are some processes which may be able to dispose of the large, daily quantity of waste. The success of these proposed solutions will be difficult to quantify. Yet there are some measurements that could be used to gauge the technologies' success.

Legislative Success

As indicated by the proposed amendment to NYC's Administrative Code, achieving the amendment's goal means disposing of 5,000 tons of solid waste every day by means other than land-filling or incineration by the year 2015. If plasma pyrolysis, anaerobic digestion, or a combination of the two methods can be used to dispose of the City's garbage, then the legislation and its solution will be deemed successful.

Economic Success

Currently, it costs $95 per ton of garbage to dispose of the City's waste at regional landfills and incineration facilities. The cost to dispose of the City's garbage is quickly becoming cost-prohibitive due to a near-monopolistic waste management market, a lack of local waste management facilities, and the enormous daily amount of garbage produced within the City. If plasma pyrolysis, anaerobic digestion, or a combination of the two methods can be used to dispose of New York City's garbage at a reduced cost per ton in comparison with the current cost, then the new waste management method will be deemed economically successful. Preliminary data indicates that the electricity generated by these technologies would actually more than pay the cost of disposal.

Exhibit 5: Cost of Disposal

Method	Cost per ton
Current Disposal (landfill and incineration)	$95
Anaerobic Digestion	($0.36) profit
Gasification	($37) profit

Source: Current disposal cost from Mayor's Mgt. Report for 2004; AD number for large facility from Bluestems SW Agency & Iowa Dept. of Nat'l Resources; Gasification number from Rich Madrak

Environmental Success

The current waste management methods, landfilling and incineration, produce three waste streams: air emissions, water emissions, and solid residues. The environmental pollutants found in the waste streams are regulated primarily through the Clean Air Act, Clean Water Act, and the Resource Conservation and Recovery Act, as implemented by the New York Department of Environmental Conservation (NYDEC). If plasma pyrolysis, anaerobic digestion, or a combination of the two methods can be used to dispose of New York City's garbage, while keeping the polluting waste stream components to a minimum in accordance with the various regulations, then the new waste management method will be deemed environmentally successful.

In order to gauge whether pollutants are kept to a minimum under regulations, the waste streams from plasma pyrolysis and anaerobic digestion need to be monitored, as outlined by the NYDEC. Current waste management regulations are designed for landfills and incineration. With the implementation of new technologies, new permitting will likely be developed. Permitting is typically determined on a facility-specific basis, and monitoring requirements of the facilities will include the pollutant-indicators of air emission, water emissions, production of solid residues.

Additionally, the large transport distance for disposing of waste is an environmental problem associated with current waste management methods. Based on a rough calculation, using average distances between New York City, Harrisburg, PA, and Richmond, VA, as representation of typical a typical garbage hauling trip, the average disposal distance was calculated to be 430 miles per truck (round trip).[48] If plasma pyrolysis, anaerobic digestion, or a combination of the two methods can be used to dispose of New York City's garbage within a 100 mile radius of the city where facilities will be located, thus reducing average transport pollution by 50%, then the new waste management method will be deemed environmentally successful. Success will be defined as reducing this average by 50%.

Conclusion

The proposed legislation dealing with the disposal of municipal solid waste recently put forth by the City Council may lead the City in new and innovative directions. These technologies seem to be more environmentally sound and more efficient than current practices, and have been demonstrated to work around the globe.

Whether or not these technologies could be applied to New York City is worthy of further analysis. Anaerobic digestion in itself would not meet the legislative requirement, but could aid in reducing a large quantity of organic waste. Plasma pyrolysis has the potential to meet the entire requirement of the legislation, but may not be conducive to the city. There are uncertainties in using both methods, and these concerns must be further researched and addressed before implementation can be considered. If New York City considers either of these technologies as viable options, we suggest that pilot plants be implemented to analyze their feasibility in New York City. This would allow the public to be introduced to the new technologies, and discourage future protest if the plants were scaled to meet the proposed waste disposal needs. These pilot plants would need to be constructed in the near future in order to meet the time constraints set forth by the legislation.

In the coming semester we will conduct research concerning these issues. We will research the likelihood of scaling these facilities to meet the waste disposal needs of New York City. In addition, we intend to reveal the applicability of these technologies to the City by examining the economic, social, and political realities as they currently stand. Furthermore, we will closely examine possible locations, to ascertain if an anaerobic or pyrolysis facility could be positioned within the narrow confines of available space.

The technologies of anaerobic digestion and plasma pyrolysis have been used and are in operation on a global scale. Both methods are slowly gaining acceptance as the number of facilities expands, and the processes become known. The United States, however, is only now being introduced to these technologies on a national level. New York City could become a pioneer in the disposal of municipal solid waste, and pave the road for others to follow.

Figures

Figure 1. *City of Honolulu Review of Plasma Arc Gasification and Vitrification for Waste Disposal (Final Report)*. R.W. Beck, 1/23/ 2003

Figure 2. Recovered Energy Inc. Accessed 2 August 2004 from <http://www.recoveredenergy.com/overview.html#zero>.

Figure 3. RCL Plasma, Inc. Accessed 12 July 2004 from <http://www.rcl-plasma.com/Whats%20New_archive.htm>.

Figure 4. Microgy Cogeneration Systems, Inc. Accessed 31 July 2004 from <http://www.microgy.com/technology.htm>.

Tables

Exhibit 1. United States Environmental Protection Agency. Accessed 10 August 2004 from <http://www.epa.gov/ttn/atw/hapindex.html>

Exhibit 2. Adapted from The Administrative Code of the City of New York

Exhibit 3. Rich Madrak; President , TOR Trading Co. (personal correspondence)

Exhibit 4. Regional Information Service Centre for South East Asia on Appropriate Technology (RISE-AT) (1998). *Review of Current Status of Anaerobic Digestion Technology for Treatment of MSW.*

Exhibit 5. Current disposal cost from Mayor's Mgt. Report for 2004;

AD number for large facility from Bluestems SW Agency & Iowa Dept. of Nat'l Resources; Gasification number from Rich Madrak

Notes

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