PROJECT TITLE: An Integrated Waste-to-Energy Plan for New York City

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Introductory Note

As long as communities have been stationary, societies have had to deal with waste management. Each nation has selected its own methods for processing and disposing of its solid waste, which has resulted in many different environmental, public health, and cultural outcomes.

In The United States, as in other post-industrial nations, solid waste production has been steadily increasing. Due to market realities, many products and their packaging are intentionally designed for obsolescence. This is reflected in the EPA's findings for the USA's growing total and per capita Municipal Solid Waste (MSW) production, detailed in image below.

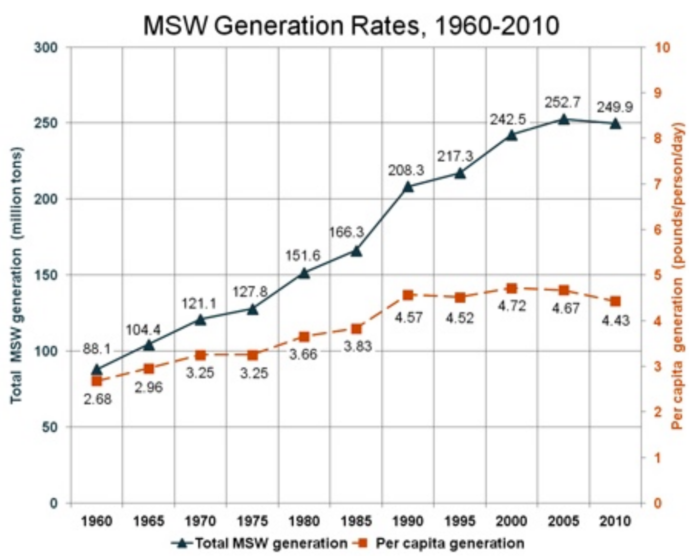

Figure 1: USEPA Estimates of Total and per Capita MSW generation from 1960-2010

Waste to Energy provides an opportunity to extract a product from waste, namely energy, which would otherwise take up space in a landfill. There are controversies with all solid waste management strategies, and the strengths and weaknesses of WTE will be discussed here. The research team also aims to provide a potential plan for New York City based on our findings in scientific data and public opinion survey results.

Key for Language used in this paper

APC	Air Pollution Control	MSW	Municipal Solid Waste
APCD	Air Pollution Control Devices	NOx	Nitrogen Oxides
ASR	Auto Shredded Residue	RDF	Refuse Derived Fuel
ISWMP	Integrated Solid Waste Management Plan	SOx	Sulfur Oxides
LCA	Life Cycle Analysis	TDF	Tire Derived Fuel
LFGTE	Land Fill with Gas To Energy	WTE	Waste To Energy
MPW	Municipal Plastic Waste		

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Abstract

This paper proposes an alternative to New York City's current curbside/containerized solid waste management plan. By incorporating fewer than two Waste-to-Energy facilities (mass burn) and incentivizing an aggressive recycling and composting plan, New York City can drastically cut the amount of waste it sends to landfills. Zero waste should always continue to be the goal for Solid Waste managers, but the reality of today's market means that products are designed for obsolescence and a true zero waste city is not yet possible.

Public opinion has historically been opposed to Waste-to-Energy in any form. WTE was not a well regulated technology forty or so years ago, and that could be imprinted to the memory of the city. A public opinion survey was conducted and results indicate that public perception maybe more open to incorporate Waste to Energy technology than in previous years.

Project Statements and Objectives

New York City's solid waste management plan is unsustainable. For the most part it is a conveyor system that collects solid waste and then exports the majority of that waste to landfills in Pennsylvania, Ohio, South Carolina and Virginia. PlaNYC 2030 has set a goal of diverting 75% of New York's 11.5 million tons of curbside/containerized solid waste a year from landfills by 2030. Where will this waste be diverted? Reduce, reuse and recycle programs while very necessary, are not capable of diverting over 8.6 million tons of waste per year. New York City therefore needs an integrated solid waste management plan that incorporates reduce, reuse and recycling with a waste management policy that provides a more sustainable alternative to landfilling.

It is the intent of this paper to examine the benefits that thermal WTE technologies can provide to New York City's solid waste management plan. In order to achieve this goal it will be necessary to examine the following topics in detail.

- A critical review of current WTE technologies, with a focus on real world implementation.
- Determine the applicability of WTE as a means to sustainably manage solid waste by reviewing case studies of WTE around the world and in the US.
- Take a look at New York City's history with waste, Waste to Energy, landfilling and the politics that surrounds the issues.
- Determine where a proposed WTE facility would be located in New York City.
- Distribute a public opinion survey to determine what New Yorkers know about their city's solid waste management plan, and also how they feel about WTE.

I. Trends in Waste to Energy

There are over 800 thermal waste-to-energy (WTE) facilities worldwide. Most reside in Europe, Japan, the U.S. and China (Themelis, 2012). A 2011 study by the Earth Engineering Center of Columbia University cited that nearly 220 of these 800 plus WTE facilities have been built since the beginning of 2000. The last three years alone has seen the construction or expansion of 48 WTE facilities (Themelis, 2012). This data indicates that thermal conversion WTE facilities are looked upon as practical solutions to regional Integrated Solid Waste Management Plans (ISWMP).

WTE is not a new technology and there are well-known and quantifiable reasons for implementing thermal conversion technologies to treat solid waste. The most common and easily understood reasons are:

- Thermal conversion of MSW reduces the total volume of as-received solid waste by 90% and total weight by 75%. Volume and weight reduction serves the purpose of conserving landfill space while also producing a more manageable, homogenous and possible valuable final secondary product.
- Thermal conversion of MSW has the added benefit of producing marketable primary products such as local electricity and steam for heat. Some WTE technologies have the potential to convert solid waste to gaseous, liquid and solid fuel through thermal processing (Rand et al 2000).

Volume and weight reductions in conjunction with energy production are well established and well documented benefits of WTE facilities. What is not as well known are the life cycle analysis (LCA) benefits derived from the thermal conversion of MSW. LCA studies, along with EPA WARM analysis and Municipal Solid Waste Decision Support Tool analysis, have all independently determined that the thermal conversion of MSW in almost all cases produces fewer greenhouse gases in its lifetime than conventional landfilling and landfilling with gas to energy (LFGTE) (Cherubinia et al, 2007; Psomopoulos et al, 2009; Assamoi et al, 2012; EPA WARM model). In particular, studies performed on WTE facilities cite significant total greenhouse gas emission reductions and improved kW/ Ton_e compared with standard landfilling and LFGTE technologies.

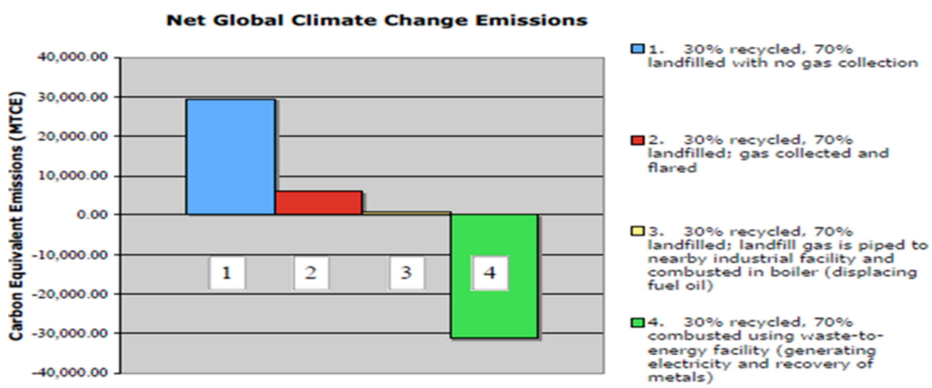


Figure 2: Greenhouse Gas Emissions by Source

II. Global WTE Technologies

At present, there are three commercially proven WTE technologies that convert post recycled MSW into energy, those technologies are combustion, gasification and plasma arc gasification. Pyrolysis is a technology that can thermally convert MSW to energy, however data on successful commercial and pilot scale facilities, as well as reports on efficiencies is severely lacking. As a result, pyrolysis will not be covered in this paper.

Of the three technologies mentioned, combustion is the most established and widely selected technology. Approximately 75% of all WTE facilities operating worldwide are based on combustion. Of the various combustion technologies, grate combustion of "as received" MSW is the dominant technology (Castaldi, et al 2012). Grate combustion's systems market dominance can be attributed to its technically straightforward operation, high unit availability, high throughput capacity and relatively simple requirements for operating personnel. However, grate combustion of as received MSW does have its detractors. Detractors often cite air emissions such as Dioxin, Mercury, SOx and NOx as the reasons why grate combustion is not the best way to convert waste into energy, even though emissions from grate combustion compare favorably or in some case's better than fossil fuel electric generation. As a result other technologies are often cited as being better alternatives to grate combustion. And although there have been many technologies that have been proposed as viable replacements to grate combustion, few have had long-term operational experience. Those technologies that do compare favorably to grate combustion are systems that process MSW in oxygen starved atmospheres. Two such technologies that compare well to grate combustion in certain environmental and residual waste categories are Gasification and Plasma Arc Gasification.

Before grate combustion, gasification and plasma arc gasification can be compared it is first important to understand the fundamental differences in the technologies as well as the challenges that both processes must overcome in order to generate energy from MSW.

III. Oxygen's Role in WTE technologies

In the most general of terms, all WTE thermal treatment technologies can be subcategorized on the basis of their oxygen requirements.

- Oxygen in the exact amount of what is required for complete combustion is called *Stoichiometric Combustion* leading to primarily heat, CO2 and H2O as final energy products. Because Stoichiometric combustion is an ideal condition and often too difficult to maintain in real world WTE applications, it is common practice to utilize oxygen (air is usually the source of oxygen) in excess of stoichiometric. This is referred to as *Excess Air Combustion* and helps to ensure complete combustion. Typical excess air operation ranges from 50% to 150% depending on the system.

- *Gasification and Plasma Gasification* are performed at sub-stoichiometric oxygen conditions. In this process, oxygen is present, however, it is a limiting reactant. The energy products that are the result of the gasification of MSW are a syngas consisting of carbon monoxide (CO), carbon dioxide (CO2), hydrogen (H_2), methane (CH_4) and other gaseous and liquid Hydrocarbons (HC). Gasification of MSW can be achieved through conventional gasification and/or plasma gasification. The differences between the two processes will be covered in greater detail later in this paper.

- *Pyrolysis* is the result of thermal treatment in the absence of oxygen. The lack of oxygen in the process results in a syngas energy product that is rich in liquid and tar-like hydrocarbons, pyrolysis oil and char.

The processes and oxygen requirements listed above only account for the energy product. It should be noted that processes produce residual solids, mostly ash that must be managed.

IV. Challenges of using Municipal Solid Waste as a Fuel

MSW is extremely heterogeneous in nature. This heterogeneous nature presents challenges both from a chemical and physical perspective when used as a fuel.

From a chemical perspective, MSW is a corrosive fuel due to its chlorine, sulfur, and volatile organic content. In addition, MSW can have a moisture content ranging from 10-40%. This moisture is in liquid form and is converted to steam during the thermal process. Due to the high heat capacity of water, additional energy must be put into a thermal system to convert the water to steam. This additional energy negatively affects the overall efficiency of a thermal treatment system because the energy is going towards the heating of water to steam and not to the thermal treatment of the waste.

Physically MSW can consist of almost any and all materials that are produced in our modern society. This often results in a difficult to handle physical mixture that can contain an unknown amount of combustible and noncombustible as well as organic and inorganic components. Because of the variability of MSW, some basic assumptions are made when describing its composition and energy value. These assumptions are based on empirical analysis and are averaged values. They are summarized in the table below.

MSW fuel characteristics	
Combustible Component	~55%
Non-Combustible Component	~24%
Water component Component	~20%
Energy Value	5,000BTU/lb or 10,700kJ/kg

Figure 3: Typical As Received MSW

Techniques can be employed to reduce the variability of MSW. Such techniques are the preprocessing of MSW to produce a waste that is uniform in size, moisture content and calorific value. Preprocessing MSW has the benefit of producing a uniform fuel that can expand the types and design parameters of the thermal treatment technologies that will use the waste as a fuel. The downside is that preprocessing can involve many steps which add costs to the process. The added costs associated with preprocessing are ideally offset by the increase in system efficiency that comes with using a higher heating value and uniform fuel source. However, efficiencies are not guaranteed. Figure 3 illustrates the steps that are involved when taking "as is" MSW and converting it to Refuse Derived Fuel (RDF).

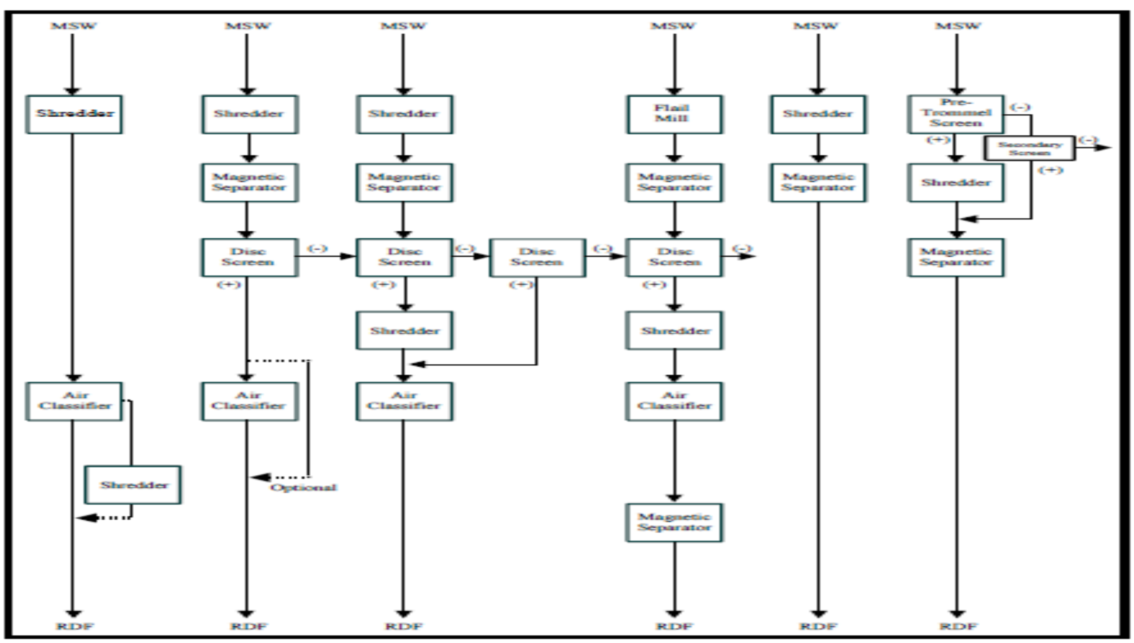


Figure 4: MSW Fuel Preparation

V. Review of Commercial Scale and Pilot Scale Waste to energy Technologies

As mentioned above, combustion, gasification and plasma arc gasification are three commercially available thermal technologies that convert MSW into energy. The remainder of this section will analyze the three methods and technologies. Each technology will be described and parameters such as pretreatment requirements, conversion efficiency, emissions, emissions treatment, residual composition, residual materials recovery and secondary materials recovery will be compared across each technology.

VI. Combustion of MSW in the US and Worldwide

Combustion of MSW is accomplished by two main processes, grate combustion and fluidized bed combustion. The dominant technology is grate (stoker) combustion. Fluidized beds have favorable attributes such as efficient heat transfer processes, however due to their needs for a uniform fuel, fluidized beds play a minor role in MSW combustion.

In 2010 there were 86 registered MSW combustion facilities in 24 states across the U.S. (Michaels, 2010). Combined they process 29 million tons of MSW per year (Rice, et al 2012). The most common technology used across these 86 facilities is a grate combustion process referred to as mass burn water wall (MBWW). In total MBWW accounts for approximately 63 percent of all combustion facilities in North America (LoRe, et al 2009). The remaining 37 percent is a mix of four other combustion technologies. Those technologies in descending order are: refuse derived fuel-spread stoker water wall units (RDF-SSWW), mass burn modular combustion units (MCU), mass burn rotary water wall units (MBRWW), mass burn refractory wall units (MBRW) and rotary water wall (RWW). The units and their total numbers in operation are listed in Table 2.

Mass Burn Technology	Units in operation in North America in 2010	Percent of total (%)
MBWW	54	63
RDF-SSWW	15	17
MCU	7	8
MBRW	5	6
RWW	5	6
Total	86	100

Figure 5: Mass Burn Units by Type in the U.S.

The dominance of MBWW does not apply only to the United States. MBWW has been the dominant technology in Europe and Japan for over 40 years. The chart below illustrates the total number and distribution of combustion facilities across Europe and the US.

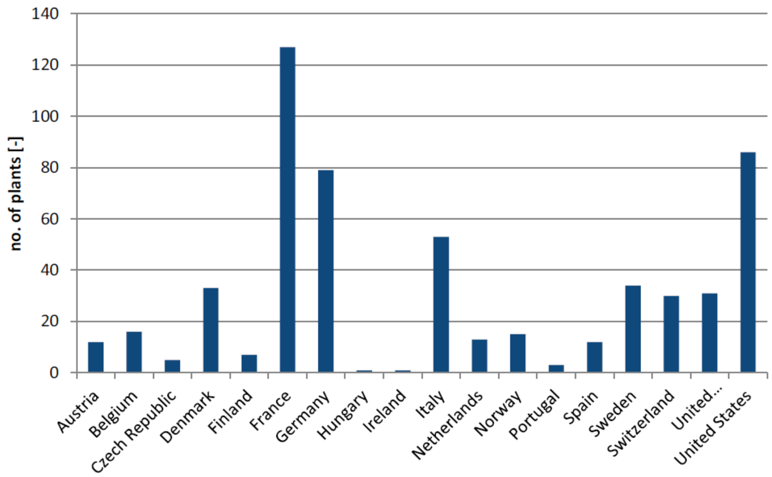


Figure 6: Europe and US Mass Burn Plants

Due to its overwhelming dominance and technological maturity, this paper will focus its combustion analysis on MBWW, which is also commonly called grate combustion.

VII. The Grate Combustion Process

The process begins when as received municipal solid waste (after removal of large, bulky items) is dumped into a refuse pit. An overhead crane collects the waste from the pit and charges the waste into a feed hopper. More waste than necessary is charged into the feed hopper so as to help close off the system from outside air and aid in controlled combustion. After entering the feed hopper the waste falls into a ram feeder where it is methodically pushed into the combustion chamber. Upon entering the chamber, the waste is carried by reciprocating or roller grates through the chamber. The grates are typically between 7-9 meters long and include 3 sections (Themelis et al, 2009). The initial section is designed to vaporize moisture from the waste prior to combustion. This is usually completed by the time the waste has reached a temperature of 300°F.The following section, often referred to as the primary combustion zone is where the majority of active burning takes place. Here the waste reaches temperatures of 500 to 1,300°F. This section is also where the majority of volume reductions take place. The third section is the finishing section. This is where the remaining combustibles are burnt out and the ash, referred to as bottom ash, is collected and treated. Total residence time on the grate is approximately one hour. (Themelis et al, 2009)

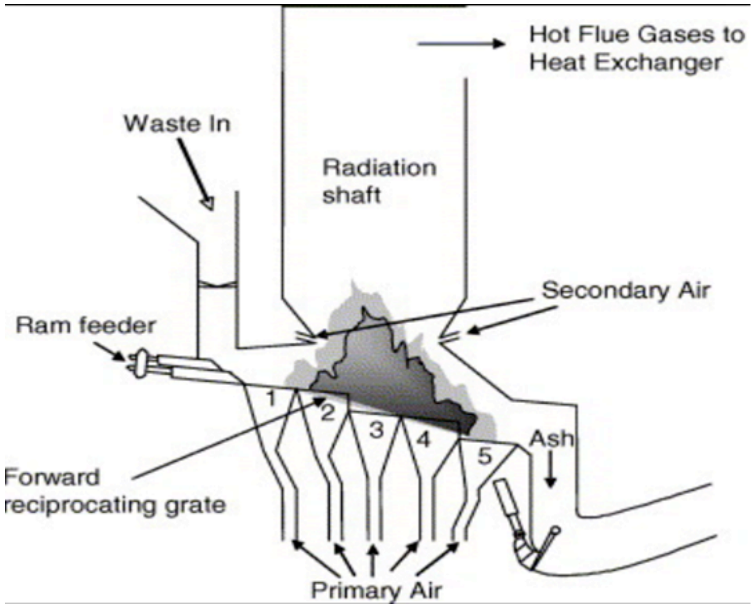


Figure 7: Mass Burn Combustion Chamber

The majority of grate combustion units have multiple air ducts beneath the individual grate sections. These multiple under fire air ducts allows for controlled burning along the entire grate. And although the system strives for complete combustion, this is not always the case, as it is common that the heterogeneous nature of MSW reduces and diverts airflow in the combustion chamber. This leads to air channeling which results in the incomplete combustion of organics in the combustion chamber. This incomplete combustion gives way to the production of corrosive chlorine, fluoride and sulfur containing gases. To further oxidize these gases, high pressure air nozzles located above the combustion chamber are used to inject secondary or over-fire air into the flue gas. This results in a secondary combustion zone that is responsible for oxidizing the corrosive gases and carbon rich fuel gases that are the product of incomplete oxidation in the primary combustion zone. A properly designed and operated over-fire air system is essential for good turbulence and oxidation of organics in the flue gas (Guyer, 2011). Optimal conditions in the secondary combustion zone typically have temperatures around 1,800°F and residence times between 1.0 to 2.5 seconds to ensure proper oxidation before the gases continue downstream (Guyer, 2011).

The flue gas then travels upward and into the water wall heat exchanger. Water wall heat exchangers are specially designed parallel metal tubes containing circulating pressurized water.
The high surface area created by the extensive water wall network is designed to extract the heat energy in the hot flue gas in order to heat the pressurized water in the water wall tubing. This now heated high-pressure water is then flashed to vapor and more heat is extracted via 2nd and 3rd passes to finally produce superheated steam (typical conditions are 400°C/40 bar or 752°F/580 psi). The steam is then pumped through a high-pressure nozzle where it drives a turbine to produce electricity. Once passing through the turbine the residual heat from the steam may be used to preheat internal process streams such as the under-fire and over-fire air. Doing this helps to improve overall plant efficiency. The residual steam can be run through heat exchangers to provide heat to commercial or residential

systems outside of the facility (cogeneration). Cogeneration has a great effect in improving overall plant efficiencies.

After giving up much of its heat energy to the water wall, the flue gases are then subject to both physical and chemical air pollution control devices (APCD). Typical grate combustion APCD includes Spray Dryer Absorbers or scrubbers designed to remove acidic gases, aqueous ammonia injection for selective non catalytic NOx reduction (SNCR), Activated Carbon Injection (CI) for mercury and dioxin capture and Fabric Filters (bag houses) which filter fine particles as well as mercury and dioxin particulates from the flue gas stream.

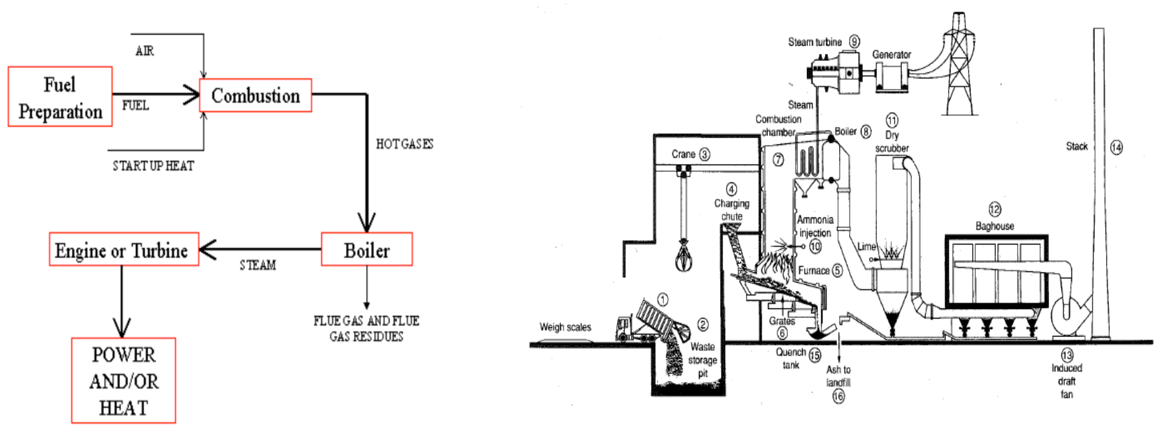


Figure 8: Combustion Flow Chart and MBWW Plant Layout

All modern grate combustion units are equipped with operational controls and feedback loops along the entire process. Feedback systems allow operators the ability to monitor unit performance and collect data, which may be used to optimize process controls and improve unit efficiency.

VIIA. Facility Sizing, Construction and Utilities Usage

Grate combustion facilities are field-erected units, sized according to the daily amount of solid waste they expect to receive. Facilities can vary in size from 200 to 3000 total tons per day (TPD), which is typically a function of the number of combustion chambers a unit employs. A review of the TPD processed by the 54 MBWW facilities operating in North America indicates that there is no standard facility size (Michaels, 2010).

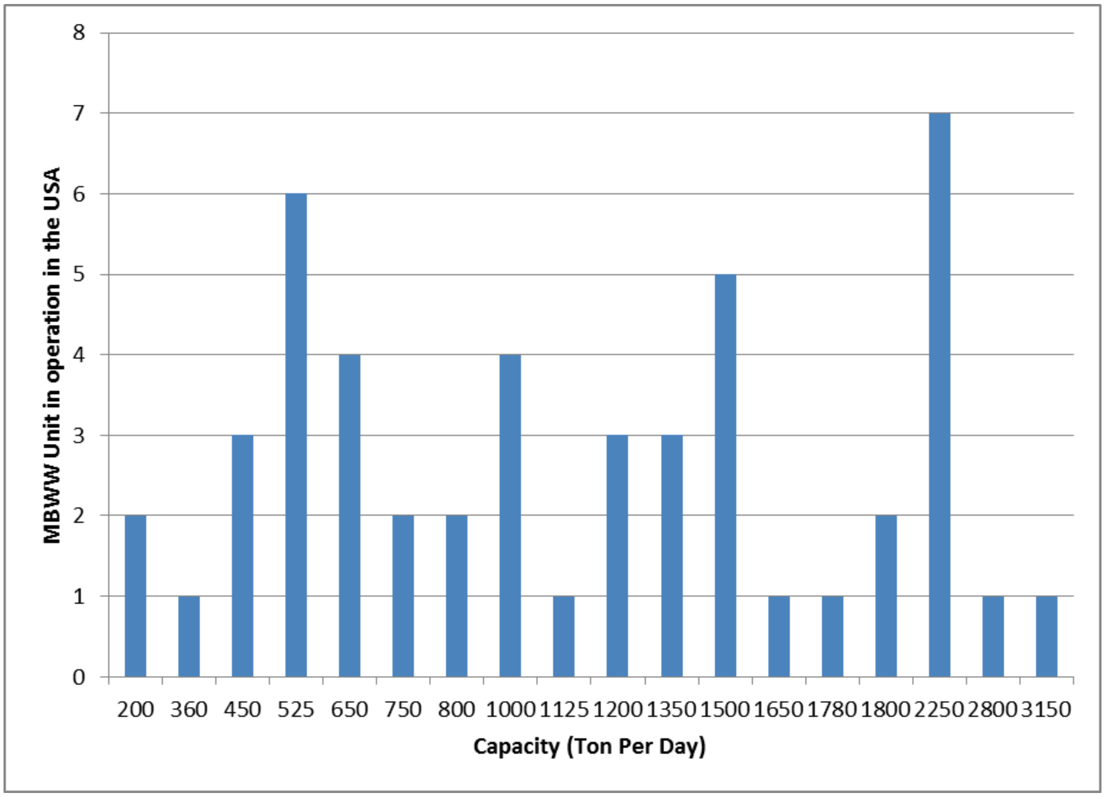


Figure 9: MBWW units and their daily processing capacity

Electrical consumption for a nominal 1,000 TPD facility is in the range of 80-110 KWH/ton (LoRe et al, 2009). Plant electrical consumption is debited from the gross electrical production of the facility.

Process water used for cooling ranges from 450-550 gal/ton in evaporative cooling systems and 75-150 gal/ton in air-cooled systems. Facilities with evaporative cooling towers utilize non-potable sources to reduce costs. (LoRe et al, 2009). Process water usage clearly benefits those facilities in climates where air-cooled systems can be employed.

Most facilities use natural gas as an auxiliary fuel. The exact amount of auxiliary fuel used per ton processed will vary by facility and is based on a number of variables such as total startups, shutdowns and incoming solid waste moisture content. Auxiliary fuel usage rates in the range of 20-40 Btu/lb are common. This represents less than one percent of the total heat input (Kiser, 2009).

VIIB. Facility Availability

The relative simplicity of use and common industrial hardware used in the MBWW process is demonstrated in the unit's 85 percent facility availability (Gesell et al, 2008), with 90 percent (8000 hours) as the current industry average (Themelis et al, 2009). These units are designed to run continuously on a 24 hour 7 days a week cycle. Figure 10 shows examples of typical mass burn availability as a function of age of the facility. It is evident that all are above 80% (i.e. 292 days at 24 hours continuous operation of being off line for 10 weeks in a year.) and most are near 90% availability or 5 weeks a year off line. This aggregate down time represents scheduled maintenance and unplanned downtime.

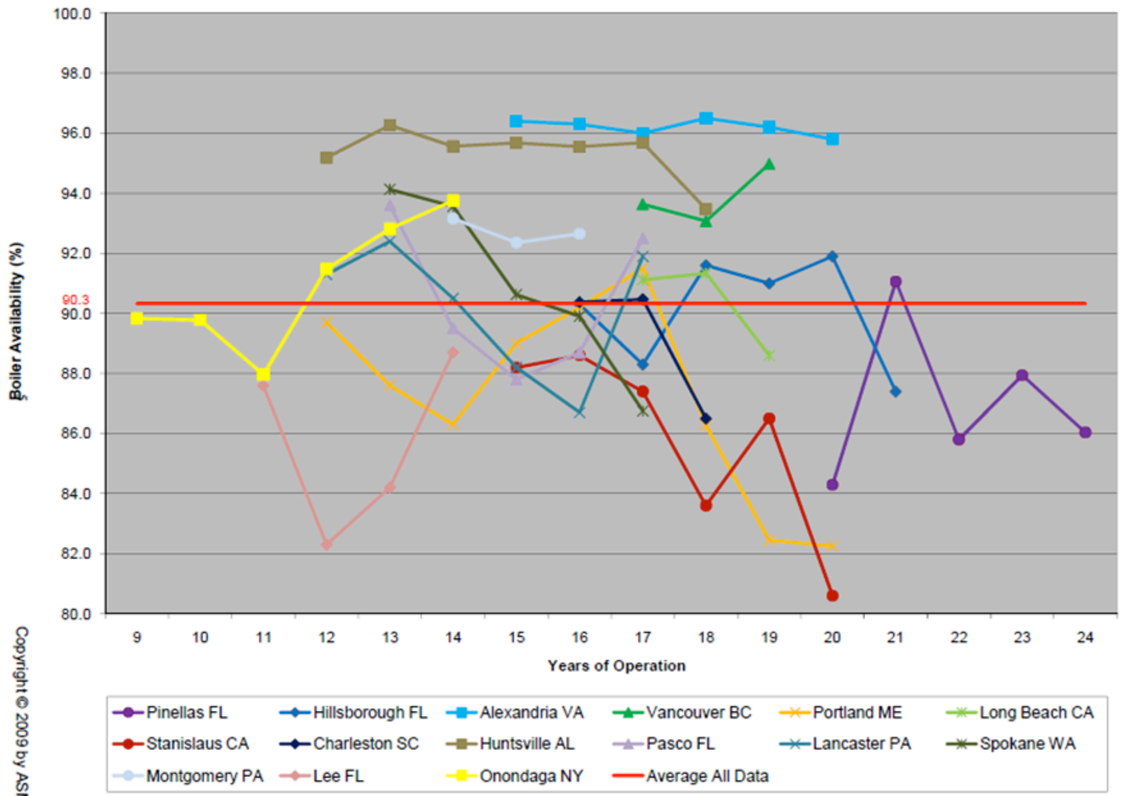


Figure 10: Select MBWW units and their Boiler Availability

VIIC. Solid Waste Processing

Grate combustion units are designed to run 24 hours a day seven days a week on "as receive" solid waste. The only preprocessing that is necessary is the removal of items too large to go through the feed system (i.e. refrigerators, washer/dryers). Usually local programs are implemented to separate household hazardous wastes (e.g., cleaners and pesticides) and recover certain recyclables to help ensure environmentally responsible incineration and resource conservation. Facilities vary in size from 200 to 3000 TPD.

VIID. Residual Solid Waste Volume and Composition

Residual waste is made almost entirely of two distinct types of ash. The first is bottom ash and it is classified as all material collected after the solid waste has passed through the combustion chamber. It is composed of all residue including fines and both large and moderate-sized unburned and unburnable matter. Ferrous and nonferrous metal is normally recovered from residue prior to disposal and is not considered part of the waste. Bottom ash comprises 75 to 90 percent of all the ash produced in the unit (EPA, 1996)

Fly Ash is the fine powdery material suspended in the flue gas and is physically collected in the air pollution control devices. Compared to bottom ash, fly ash tends to have a higher concentration of Lead, Mercury, Cadmium and organic materials. Bottom ash and fly ash are usually combined on-site in the US to facilitate storage, handling, and transportation. In Europe, the ash can find a secondary use in asphalt and road bedding.

The volume reduction that can be expected from a MBWW unit is approximately 75 percent by weight and 90 percent by volume (Clark, 2010). On a per ton basis, this equates to a 500lb of residual solid waste generated per ton of MSW processed.

VIIE. Net Electrical Efficiency

As to be expected, electricity per ton of waste processed will vary by unit. On average net electrical power per ton of waste processed is in the range of 550 kWh/ ton (Kaplan, 2005). The greatest factor influencing the kWh/ton is the inherent heating value of the waste processed.

Normal unit efficiencies are in the range of 18 to 27 % while high efficiency units can run up to 32% (ISWA 2013). Efficiencies gains can be realized as units are updated with improved feedback and monitoring loops. Overall efficiencies can be improved significantly through co-generation, 98% as in some European examples. Current work on improving net electrical efficiency is geared towards decreasing excess air in the combustion zones. Doing so can reduce the total air volume and increases boiler efficiency.

VIIF. Marketability of Primary and Secondary Products

The primary products are electricity and heat. Electricity is highly marketable product and the sale of heat energy is dependent on facility location. In addition, energy generated from solid waste is considered a renewable energy source in 31 states (Michaels, 2012). It is reasonable to think that if WTE facilities were present in every state, then more states would consider solid waste as a renewable energy. Energy from renewable sources could also be in greater demand than electricity generated from non-renewables such as coal.

The combined ash residue from the process is considered a secondary product as most of the residual ash is used as daily and final cover for landfills. There are other uses for the ash, for example as a substitute for the aggregate in road base materials. The use of ash as a road aggregate is not as common in the U.S as it is in Europe. Figure 11 cites the annual total breakdown of ash collected from U.S. MBWW facilities and its final use.

Beneficial Use Application	Annual Tonnage	Percent of Total Used
Daily Landfill Cover	2,557,119	87%
Construction (Road Fill, Sub-base)	337,131	11%
Landfill Grading Closure Material	35,672	>1%
Landfill Gas Venting Layer	6,424	<1%
Total	2,936,346	100%

Source: J. V. L. Kiser and M. Zannes, Integrated Waste Services Association, April 2004.

Figure 11: Ash Usage

VIIG. Emissions

Air emissions are the principal environmental concern associated with MBWW units. Depending on the characteristics of the MSW and the combustion conditions, the following pollutants can be emitted:

- Particulate Matter (PM)
- Metals (in solid form on PM, Mercury is the exception)
- Acid gases (HCl, SO2)
- CO
- NOx
- Dioxins and Furans (general term describing a group of hundreds of different chemicals that are formed by burning chlorine-based chemicals with hydrocarbons).

Emissions are managed across the entire facility. In the combustion chamber automated combustion controls, staged combustion and aqueous ammonia injection for selective non-catalytic NOx reduction (SNCR) help mitigate oxidize organics and reduce NOx emissions. Downstream of the combustion chamber are the spray dryer absorber (SDA) or scrubber, activated carbon injection (CI) and fabric filters (FF) or bag house. These devices are used to control acid gases, mercury, dioxins and particulate-related emissions respectively. These are not the only APCD used in a MBWW facility, but they are the most common.

Figure 12 lists the common emissions from a mass burn incineration plant. The large reductions that occurred after 1990 are the product of legislation by the EPA, which mandated that all facilities use the most modern air pollution control devices available to ensure that stack emissions are below acceptable levels. This has become known as the Maximum Achievable Control Technology (MACT) standards under the Clean Air Act for municipal solid waste combustors.

Emissions from Large and Small MSW Combustion Facilities Pre- vs. Post-MACT Comparison

Pollutants	1990 Emissions (tons per year)	2005 Emissions (tons per year)	Percent Reduction
Mercury	57	2.3	96%
Cadmium	9.6	0.4	96%
Lead	170	5.5	97%
Particulate Matter	18,600	780	96%
Hydrogen Chloride	57,400	3,200	94%
Sulfur Dioxide	38,300	4,600	88%
Nitrogen Oxides	64,900	49,500	24%

Figure 12: MSW Incinerator Emission

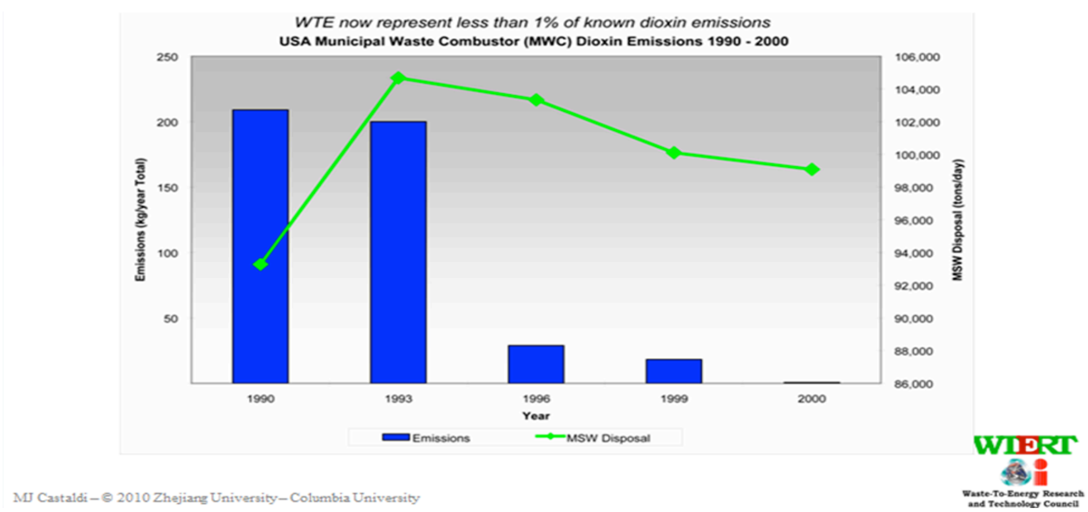


Figure 13: Mass Burn Dioxin Emissions

VIII. Gasification as an Alternative WTE Technology

The past few decades have seen increasing interest in alternative WTE technologies. The interest in these technologies mainly lies in the notion that alternatives to combustion can reduce emissions, improve recycling of secondary products and increase total efficiency of the plant. At present the technology that is getting the most attention is gasification. There are approximately 100 commercial and pilot plant solid waste gasification reactors operating or under construction around the world (Arena 2012). Figure 14 lists some of those facilities.

Company	Number of Gasifiers in Operation	Gasifier Type	Type of Waste accepted	Primary End Product Opportunites	Processing Capacity TPD/Gasifier*
AlterNRG (Canada) Westinghouse Plasma Corp, Hitachi Metals (Japan)	2	Plasma Gasifier	Shredded MSW, RDF	Electricity Via IC engine or gas turbine	13-123
Ebara TIFG (Japan)	12	Internally Ciculating Fluidized Bed	Shredded MSW, RDF	Electricity via steam Rankine Cycle	8-36
Energos (Norway/UK)	8	Moving Grate	Shredded MSW, RDF	Electricity via steam Rankine Cycle	4-32
Hitachi Zosen (Japan)	9	Bubbling Fluidized Bed	Shredded MSW, RDF	Electricity via steam Rankine Cycle	4-36
JFE (Japan) (Kawasaki Steel and NKK)	10	Down Draft Fixed Bed	Shredded MSW, RDF	Electricity via steam Rankine Cycle	10-35
JFE (Japan) Thermoselect (Switzerland)	7	Down Draft Fixed Bed	Shredded MSW, RDF	Electricity Via IC engine or gas turbine	14-92
Kobelco (Japan)	12	Bubbling Fluidized Bed	Shredded MSW, RDF	Electricity via steam Rankine Cycle	5-46
Mitsui (Japan)	7	Rotary Kiln	Shredded MSW, RDF	Electricity via steam Rankine Cycle	28-69
Nippon Steel Engineering (Japan)	32	Down Draft Fixed Bed	Shredded MSW, RDF	Electricity via steam Rankine Cycle	3-23
Plasco Energy Group (Canada)	2	Plasma Gasifier	Shredded MSW, RDF	Electricity Via IC engine or gas turbine	8-56
Takuma (Japan)	2	Rotary Kiln	Shredded MSW, RDF	Electricity via steam Rankine Cycle	64-161

sources: Arena 2012,
* Assumes an 85% availability

Figure 14: Energy Companies and Technologies

Points to note from Figure 14 are:

- Unlike grate combustion, there is no one dominant commercial gasifier design.
- Unsorted MSW is not suitable for most gasification technologies. As a result most units prefer and operate much more efficiently and effectively when they are supplied with well-defined shredded MSW or RDF. Many on these reactors also co-fire other fuels such as auto shredded residue (ASR), tire derived fuel (TDF) and municipal plastic waste (MPW) to enhance syngas heating value.
- Many of these facilities have a processing capacity of less than 300 TPD.
- Japan has a disproportionate number of the world's gasification facilities.

These points are important to note, because they make direct comparisons to grate combustion difficult.

VIIIA. Japan's Waste to Energy Practices

Japan's high relative use of gasification is of particular interest in this review. Japan is the world leader in converting their solid waste into energy. It is estimated that Japan produces about 65 million tons of MSW a year, of which approximately 40 million tons is sent to the 310 WTE facilities across the country (Themelis, 2012). Like the rest of the world, the majority of Japanese facilities are based on grate combustion technology**.** However, there are approximately 100 facilities across Japan that utilize WTE technologies which are not based on grate combustion (Themelis, 2008). Gasification's is one of these technologies and Japan has been using this process for the past two decades.

To understand why Japan utilizes alternative WTE technologies such as gasification it is important to understand that Japan has restrictive laws that all but prohibit the transportation of "as collected" MSW from one prefecture (municipality) to another. The result is that waste generated in an area is usually also thermally treated in that same area. As result, many of Japan's WTE facilities are relatively small. Having many small WTE facilities is very costly and such a system would not be possible if it were not for Japan's strong central government that redistributes tax revenues to rural areas allowing them to process their own MSW while also preventing them from accepting waste from other cities (Okuda & Thomson, 2007). In some cases MSW is shredded or preprocessed to RDF that is then transported to a central WTE facility that serves several communities (Themelis, 2008).

Overall, Japan's integrated solid waste plan allows for prefectures to work with WTE technologies on a smaller scale. This ability to work on a smaller scale gives alternative thermal treatment technologies such as gasification and plasma assisted gasification the ability to develop.

Japan is a unique case as their ISWP does not match how most countries manage their solid waste. As a result, worldwide use of gasification of MSW is still quite limited.

IX. The Gasification Process

Conventional gasification and plasma gasification involves the partial oxidation (sub stoichiometric) of carbon containing feed stocks, such as MSW. The processes can occur at both low temperatures (<900°C) or high temperatures (>1200°C) and are generally classified by the type of oxidizing agent fed into the reactor. The primary product of gasification is called synthesis gas or syngas. Syngas is comprised mainly of Carbon Monoxide (CO) and Hydrogen (H_2) with lesser amounts of Methane (CH_4) and Carbon Dioxide (CO_2). This syngas coming out of a gasifier has a heating value that can range from 75-537 BTU/ft^3, which is lower than natural gas (1050 BTU/ft^3) but still usable as fuel. Typically this syngas is converted to electricity in separate processing equipment, but it is also possible to store the syngas and use it at different times and sites to make products other than electricity (Arena, 2012).

In addition to CO and H_2, the syngas will have varying low amounts of particulates, tars, alkali metals, chlorine and sulfur containing gases (Heermann et al, 2001). Syngas purity is usually dependent on the feedstock, the oxidizing agent and the gasifier design (Gasification. 2009). The inorganic compounds that are not converted to syngas are collected as a byproduct at specific points along the process. Depending on the gasifier design, this inorganic material could be ash that is similar to combustion system ash. Alternatively, in extremely high temperature applications, a vitrified slag is produced. Both are considered usable byproducts of the process (Young, 2010).

Typically low temperature conventional gasifiers (>900°C) that use air as the oxidizing agent will produce a syngas with higher relative tar and a lower heating value of 75 to 215 BTU/ft^3. The lower heating value is due mainly to the high nitrogen content of air. This nitrogen is part of the syngas (up to 60%) (Arena, 2012) and serves to dilute the syngas and lowers it heating value. Due to the low quality of this syngas, it is typically directly fed into a high temperature (1300°C) combustion chamber (indirect combustion) where it is then converted from a syngas to a hot flue gas. Once converted into a hot flue gas it is then used in a steam turbine to make electricity and heat. This design is referred to as *heat gasifier.* Once the syngas is combusted the subsequent processes look very similar to grate combustion where the combustion gases then enter standard air pollution control devices such as acid gas scrubbers, NOx reduction catalyst and heavy metals and particulate filters.

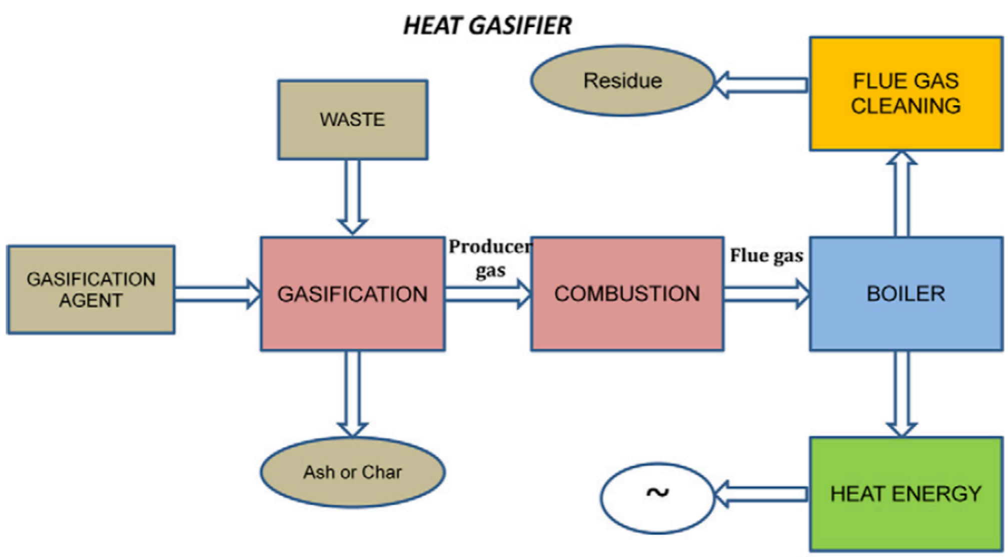


Figure 15: Heat Gasifier

High temperature conventional gasifiers and plasma gasifiers use oxygen enriched air, oxygen or plasma gas as the oxidizing agent. These gasifiers offer a higher quality syngas with a higher heating value (270 to 537 BTU/ft^3). Due to its heating value this syngas can be burned (if properly cleaned) in a high efficiency internal combustion (IC) engine or gas turbine. This process is called a *power gasifier* and can be a more efficient option over a *heat gasifier* when electricity is the desired end product.

Gasification processes that produce a syngas of high enough quality to be used in a power gasifier have claimed several advantages over traditional heat gasifiers and grate combustion of MSW. One advantage is that the syngas can be cleaned before it is combusted. This cleaning before combustion can result in the reduction of air emissions such as dioxin, furans, NOx, Sox and Chlorine.

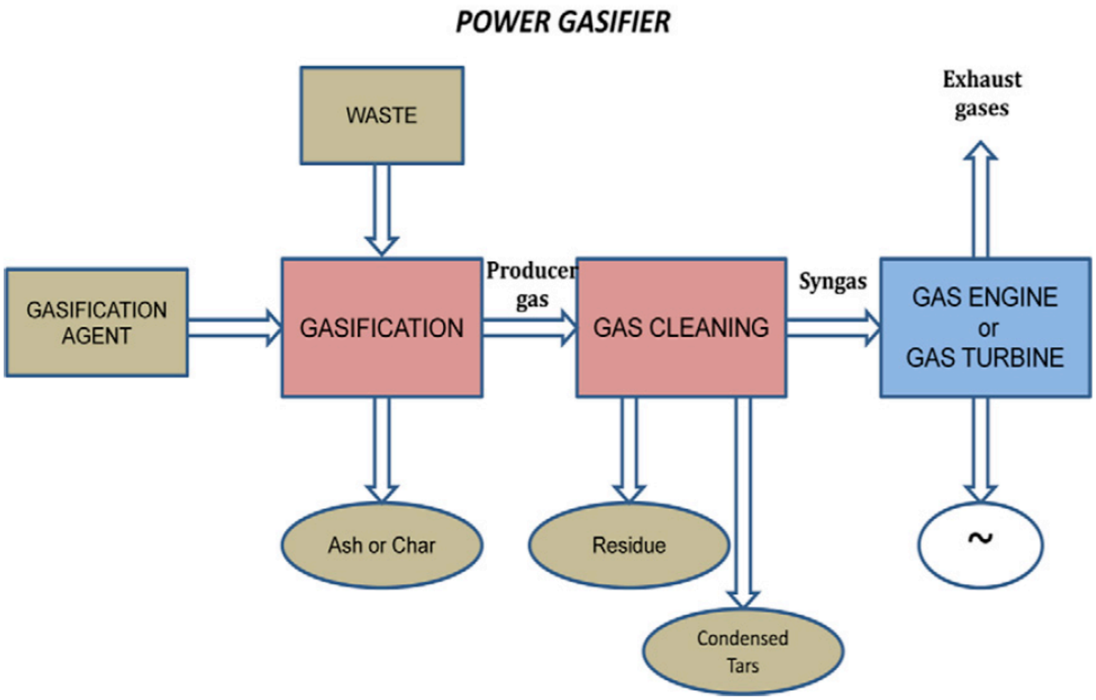


Figure 16: Power Gasifier

Additional options for the syngas are as a raw material to make a variety of chemical products such as hydrogen, ammonia, methane, methanol and transportation fuels. The limits on using syngas to make chemical products are mainly due to the syngas purity (Gasification Technology Council, 2009). And although gasification is a proven method for making chemical products, the gasification of MSW to chemical products is not an established technology. Figure 17 lists the option available for syngas to chemicals.

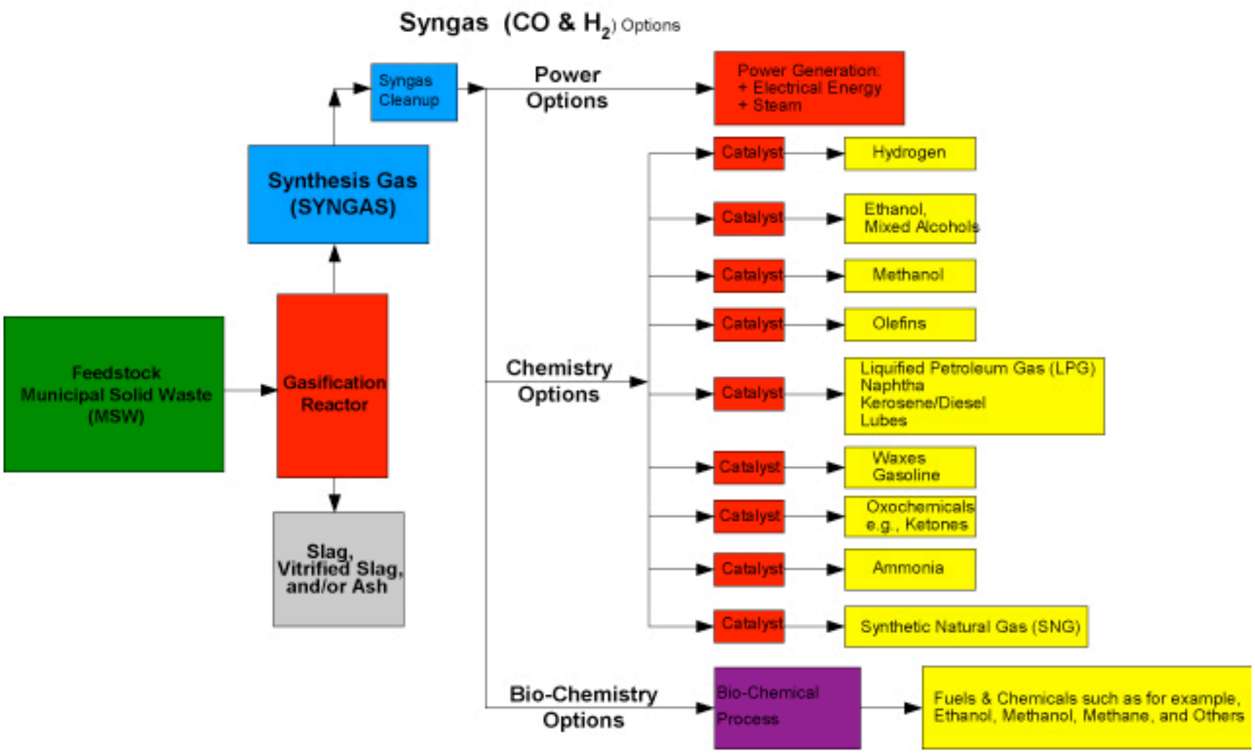


Figure 17: Syngas (CO & H2) Options

Both high and low temperature gasifiers use relatively low volumes of gas (as compared to mass burn). Most plants use either air, oxygen enriched air, pure oxygen or plasma gas. Because both processes occur in a low volume and low oxygen atmosphere, they are well suited for air pollution controls systems. Producing a syngas in a low oxygen environment also means that the gas can be cleaned before it is combusted which can result in the reduction of harmful air emissions. In addition, lower relative gas volumes reduce the overall size of a facility's APC equipment.

X. The different MSW Gasifier Reactor Designs

Unlike mass burn, which relies mostly on grate combustion technology, gasification has many different commercial reactor designs. The ones of relevance for MSW are:

A. Downdraft Fixed Bed Gasifier
B. Fluidized Bed Reactors
C. Rotary Kiln Gasifier
D. Plasma Gasification

XA. Downdraft Fixed Bed Gasifiers

Downdraft fixed bed gasifiers are high temperature gasifiers that can operate as both heat gasifiers and power gasifiers. The oxidizing agent is either oxygen enhanced air or pure oxygen which is introduced at the top or side of the reactor. The reactor is designed so that the gas moves downward over a packed bed of shredded MSW or RDF. The bed is supported by a perforated grate. Zones (drying, pyrolysis, gasification and combustion) are created across the bed as the waste and gases move downward through the packed bed. The reactor design is beneficial in that it forces the syngas to pass downward through the grate and over the hot char at the exit of the reactor. This passing of the syngas over the hot char is very effective at volatilizing any remaining long chain hydrocarbons (tars) in the syngas resulting in a relatively clean syngas that is then drawn out the bottom of the reactor. Downdraft gasifiers are relatively easy to design and operate on a small scale (>250 TPD) but are not well suited for large-scale use as temperature control becomes an issue. Downdraft fixed bed gasifiers have a tendency to clog over time when using ash producing fuel such as shredded MSW and RDF.

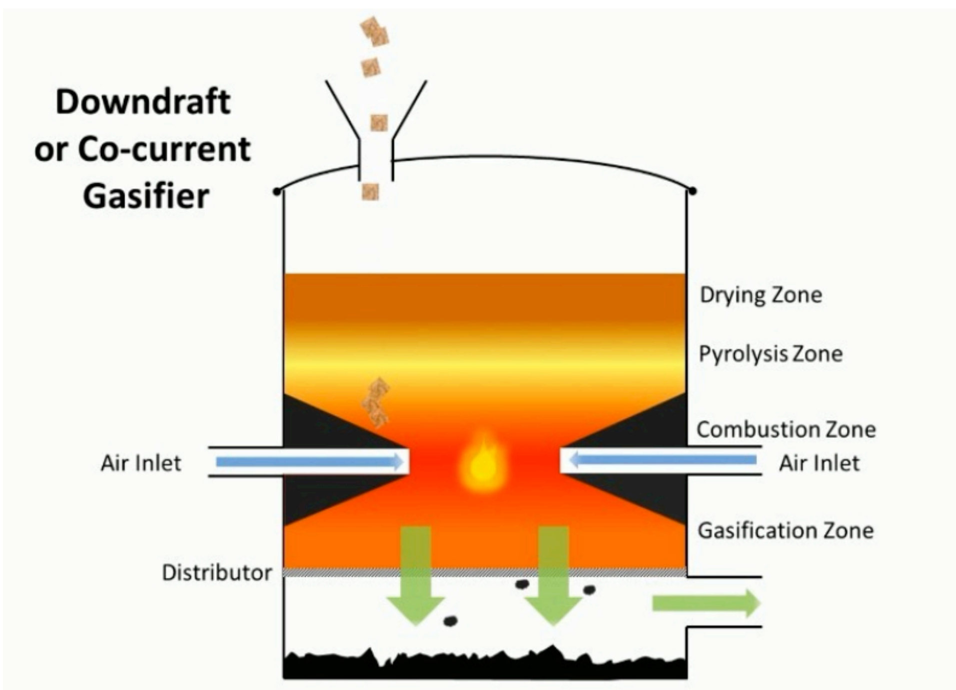
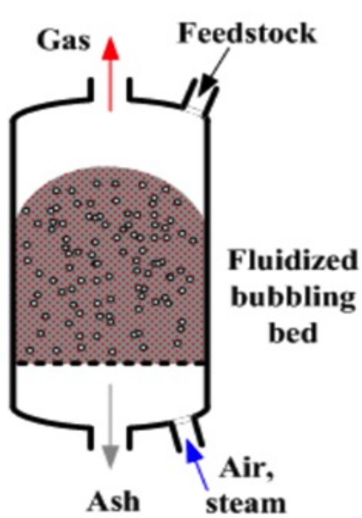


Figure 18: Downdraft or Co-current Gasifier

XB. Fluidized Bed Reactors

Fluidized bed gasifiers use a stream of gas (typically air or steam) that acts as both the fluidizing and oxidizing agent as it flows upward through a bed of shredded MSW or RDF plus an inert fluidizing agent such as coarse sand. Fluidized bed gasifier can be characterized as either a bubbling fluidized bed (BFB) or as a circulating fluidized bed (CFB). In BFB waste will remain fluidized in the bed for a substantial amount of time (minutes to hours). In CFB higher gas velocities are used to repeatedly circulate waste through a reactor loop. Fluidized-beds have the advantage of extremely good mixing and high heat transfer. Catalysts can also be co-introduced or co-fed with the waste bed to optimize syngas conversion. This results in homogeneous bed conditions and efficient reactions (Zafar, 2009), which makes the drying, pyrolysis, oxidation and reduction zones indistinguishable. As the waste is gasified the particles become smaller and lighter and will eventually leave the reactor as ash, or particulates. Fluidized beds reactors are relatively compact units and their design allows for good operational control. They are quite flexible as they can operate at both high and low temperatures and they have flexibility for feedstock waste. Both BFB and CFB are of the small scale variety (>250TPD) and scaling up requires extensive pilot testing. For MSW they exist commercially as heat gasifiers.

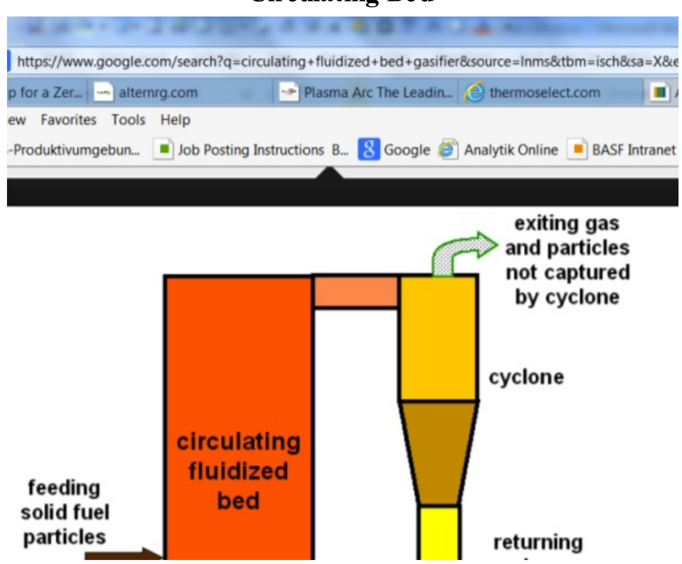
Fluidized Bed



Source: substech.com

Figure 19: Fluidized Bed

Circulating Bed



Source: csfmb.com/services

Figure 20: Circulating Bed

XC. Rotary Kiln Gasifier

In a rotary kiln gasifier waste is fed into a slowly rotating kiln. The tumbling action of the kiln enhances mixing of the waste with the oxidizing agent, which is typically air. The gasification of the waste occurs as the waste moves from the entrance of the kiln to the exit. Heat exchange is usually low, and as a result typical residence time in a rotary kiln in 1-2 hrs. Rotary kilns have the ability to process wastes of varying particle size. Therefore, the kiln has the ability to use less processed MSW as its feedstock. The major challenges in the use of rotary kiln gasifiers are the ability to control air ratios and the limited operational range of the process (Donatellia, et al 2010). Rotary kiln gasifiers for MSW are in the small-scale range (250 TPD) but larger units are possible. They exist commercially as heat gasifiers.

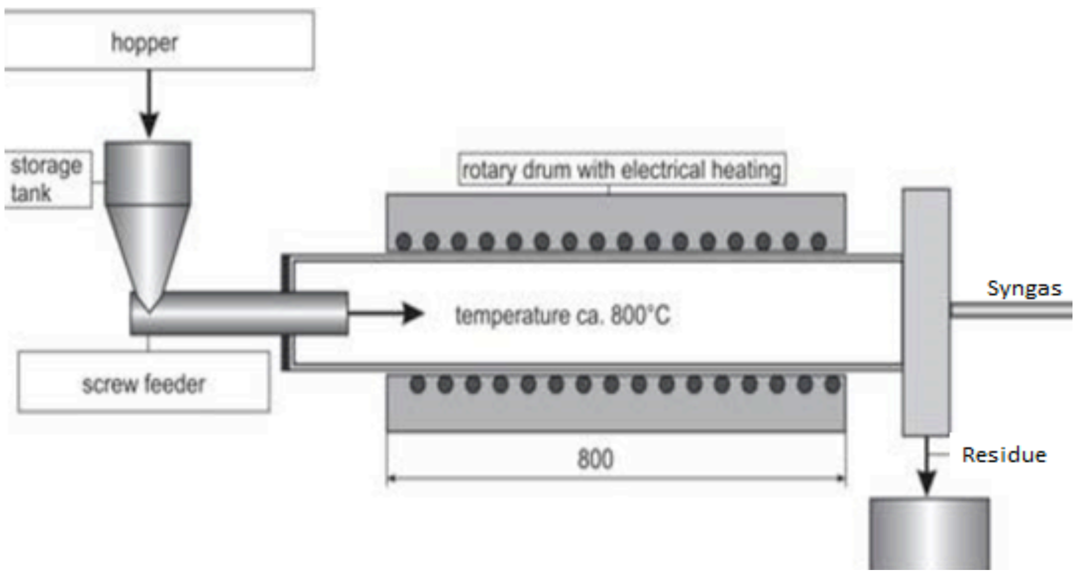


Figure 21: Rotary Kiln Gasifier

XD. Plasma Gasification

Plasma gasification uses plasma torches to produce a superheated column of electrically conductive gas at temperatures of 5500ºC (10,000˚F). Plasma torches have been used for many years to destroy chemical weapons, toxic wastes, medical waste and asbestos, but it is only in the last two decades that the process has been optimized for MSW treatment and energy capture. The great benefit of plasma gasification is its extremely high reactor temperature of 1500˚C (2700˚F). This high temperature is very effective at volatizing the tars, acid gases and dioxins that are present in syngas. Once volatized, these gases can be cooled and cleaned before they are combusted. Removing pollutants before combustion helps to reduce air emissions such as dioxins, furans and NOx. Non-organic materials entering the gasifier are also subject to this intense heat and as a result are melted and then cool into a vitrified slag.

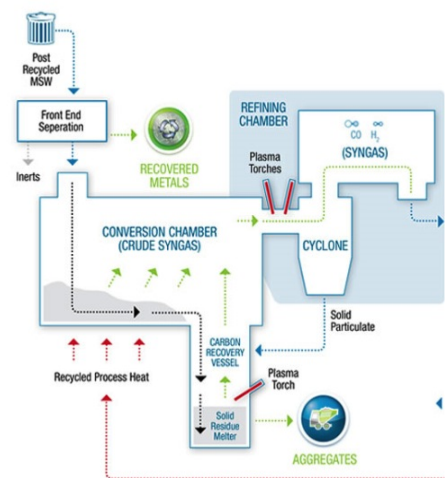
Plasma gasification has two variants. The first is where the plasma torch is in the waste conversion reactor. Here multiple torches directly gasify the waste into its elemental components (Figure 22). The second variant is where a conventional gasifier produces a syngas, which is then passed over plasma torches in order to "polish" the syngas (Figure 23). Plasma gasifiers are modular units that can be scaled to a desired TPD. At present, they exist on a small scale. Plasma gasification has large upfront investments and operating cost (Arena 2012). The plasma torches consume large amounts of electricity, which can consume 15-20% of a plant's gross electrical output (Arena, 2012). They exist as power gasifiers.

Plasma torch in reactor chamber

Source: www.westinghouse-plasma.com/waste_to_energy/

Figure 22: Plasma Gasification

Plasma torch outside reactor chamber



Source: Plasco energy Group

Figure 23: Plasma Gasification

XDi. Facility Sizing, Construction and Utilities Usage

Gasifiers that are based on syngas are relatively small-scale reactors having a predetermined MSW processing capacity. Figure 24 shows that current reactors range in processing capacity from 3-161

TPD with an average capacity of 65 TPD per reactor. The units are of a modular design, which makes them well suited for new construction as well as expansion of existing facilities.

Utility usage is heavily dependent on the type of gasifier, the preprocessing requirements of the waste and the oxidizing agent. In general, the lowest utility usage will come from conventional gasifiers that operate at lower temperatures (this would be BFB and CFB) and use air as the oxidizing agent. Utility usage will increase as conventional gasifiers operate at higher temperatures and use oxygen enriched air and pure oxygen (Down Draft and Rotary Kiln). Plasma gasifiers will have the highest energy usage due to the high electrical demand of a plasma torch. In all cases, plant electrical consumption is debited from the gross electrical production of the facility and units that have a high electrical demand will need to operate at higher efficiencies in order to be competitive.

XDii. Facility Availability

Literature on facility availability is lacking. What is known is that syngas from conventional gasifiers can contain high amounts of tars that lead to the malfunctioning of air pollution control systems and power generation equipment. Plasma gasifiers have a clear advantage over conventional in that the former uses plasma to “polish” the syngas of any remaining tars. This cleaner syngas is less problematic to processing equipment. However, no matter the technology it is reasonable to believe that the lack of available information is due to the technical problems associated with this still developing technology.

XDiii. Waste Processing

As is MSW is not a suitable feed for conventional or plasma gasifiers. As a result the pre-processing of waste into a homogenous shredded MSW or RDF is mandatory. This step requires large amounts of mechanical and human processing, which negatively impacts operating cost. Some estimates put this cost at 40-50 % of the total plant capital costs (Klein, 2002). Improved pre-processing cost can occur if the incoming waste comes from municipalities with good glass and food waste recycling practices.

XDiv. Residual Solid Waste Volume and Composition

In a conventional gasifier residual solid waste comes entirely from two distinct types of ash. The first is bottom ash and it is classified as the ash collected after the shredded MSW or RDF has passed through the gasification chamber. Bottom ash comprises 75 to 90 percent of all the ash produced in the unit.

Fly Ash is the other residual solid waste product. Fly ash is the fine powdery material suspended in the syngas. It is physically separated from the syngas in the air pollution control devices. Compared to bottom ash, fly ash tends to have a higher concentration of Lead, Mercury and Cadmium. Bottom ash and fly ash are usually combined on-site in the US to facilitate storage, handling, and transportation. In Europe, the ash can find a secondary use in asphalt and road bedding. The volume reductions that can be expected from a conventional gasifier is similar to a mass burn unit (75 percent by weight and 90 percent by volume). On a per ton basis, this equates to a 500lb of residual waste generated per ton of FDF processed.

Plasma gasifiers use the extremely high heat from the plasma torches to vitrify both the bottom ash and the fly ash into an inert and homogeneous slag. The slag is a much denser product than the ash and as a result has a much lower volume.

XDv. Net Electrical Efficiency

As to be expected, electricity per ton of waste processed will vary by unit. In general, unit efficiencies fall in the range of 13 to 19 % (ISWA 2013). On average, net electrical power per ton of waste processed is in the range of 400-700 kWh/ ton. The greatest factor influencing the kWh/ton is the inherent heating value of the syngas, the oxidizing agents used and the total electrical consumption of the unit.

XDvi. Marketability of Primary and Secondary Products

In conventional gasification the primary products are electricity and heat. Electricity is highly marketable product and the sale of heat energy is dependent on facility location. Similarly, in plasma gasification the primary products are electricity and heat, however, the greater potential with plasma gasification may lie in the ability for this technology to produce a variety of chemical products such as hydrogen, ammonia, methanol and transportation fuels. The limits on the process are on the purity of the syngas and the economics of production (Gasification Technologies Council 2009).

The combined ash residue from conventional gasification is also considered a secondary product as the residual ash can be used as a daily and final cover for landfills. Additional uses are as a substitute for the aggregate in road base materials. The use of ash as a road aggregate is not as common in the U.S as it is in Europe.

In the case of plasma gasification the molten inorganics are quenched to form a vitrified slag. This vitrified slag can be used as an aggregate in concretes and road materials or as a sand blasting grit. In addition, molten metals maybe be separated from the hot slag and may have a commercial value depending on quality and economics of separation. Power gasifiers also separate Sulfur, Nitrogen and Chlorine prior to combustion. These elements can have secondary markets if they are refined to an acceptable quality.

XDvii. Emissions

One of the main reasons why gasification is being considered as a viable alternative to combustion is due to the claims that gasification produces fewer Dioxin, Furan, NOx and SOx emissions per ton of waste processed. The claims are based on the starved oxygen environment of the gasifier having the advantage of limiting the formation of dioxins and furans in the syngas. In addition, the removal of nitrogen species such as ammonia (NH_3) and sulfur species such as hydrogen sulfide (H_2S) from the syngas before combustion can be of great benefit in reducing NOx and SOx emission. In the case of power gasifiers additional emissions systems similar to automobile catalytic converters may be allied to further clean the exhaust. While these claims are all theoretically true, there are still too few actual examples to prove conclusively that emissions from gasification outperform the state of the art conventional grate combustion units across the board. Particulate and metals emissions from a gasifier are handled in a similar manner as mass burn.

Gasification does have an advantage over grate combustion when it comes to the volume of gas per ton MSW processed and the required size of air pollution control devices. On average the total volume of a processed syngas will be < 1,000 m^3/Ton MSW, as compared to combustion which is 4500 m^3/ Ton MSW air (IAWG, 1997). The result is that gasifiers require smaller APCD devices that in turn require less area. Below is a list of some of the APC devices used to clean syngas prior to combustion in a boiler or internal combustion engine or gas turbine.

- Wet Venturi Scrubber: removes particulate and metals.
- HCl Scrubber: removes Chlorine by a re-circulating alkaline solution.
- H2S Removal: removes Sulfur by a dilute alkaline scrubbing solution.
- Activated Carbon Injection: surface adsorption of heavy metals and particulates
- Bag house: designed for particulate removal

XI. Comparison Matrix

	Grate Combustion	Conventional Gasification (Heat Gasifiers)	Conventional Gasification (Power Gasifiers)	Plasma Arc Gasification (Power Gasifiers)
Construction style	Build to suit	Modular Units	Modular Units	Modular Units
MSW Pre-processing requirements	Minimal - removal of bulky objects and white goods	Large upfront pre-processing required in order to produce a uniform fuel	Large upfront pre-processing required in order to produce a uniform fuel	Large upfront pre-processing required in order to produce a uniform fuel
Fuel	As receive MSW	Shredded MSW, RDF not uncommon to include TDF, MPW,ASR and carbon black	Shredded MSW, RDF not uncommon to include TDF, MPW,ASR and carbon black	Shredded MSW, RDF not uncommon to include TDF, MPW,ASR and carbon black
Average calorific value of fuel (kJ/kg)	10,700	14,000	14,000	14,000
MSW upfront material recovery	None	Materials recovery as part of pre processing	Materials recovery as part of pre processing	Materials recovery as part of pre processing
Facility MSW throughput (TPD)	250 - 3000	3 - 161	13 - 123	14 - 123
Plant availability (%)	85% - 88% guaranteed; industry average 90%	Unknown	Unknown	Unknown
Power Plant Type	Steam Turbine	Steam Turbine	IC engine or gas turbine	IC engine or gas turbine
Net Efficiency (1)	18%-27%	13% -19%	13% -19%	19%
Primary End Product	Electricity Heat	Electricity Heat	Electricity Heat	Electricity Heat Potentially: Methanol, Liquid fuels, Hydrogen
Net Energy (kWh/Ton MSW)	450 - 650	400-650	400-650	400-650
Air pollution control technology	Spray dryer absorbers Activated carbon injection Acid gas scrubbers NOx control Fabric filters	Spray dryer absorbers Activated carbon injection Acid gas scrubbers NOx control Fabric filters	Spray dryer absorbers Activated carbon injection Acid gas scrubbers NOx control Fabric filters	Spray dryer absorbers Activated carbon injection Acid gas scrubbers NOx control Fabric filters
Emissions (2)				
Dioxin/Furan (μg/Nm^3)	0.01 - 0.1	0.023 - 0.000051	0.001	0.001
Mercury (mg/Nm^3)	< 0.05	0.0032 - 0.0005	0.09	0.02
HCl (mg/Nm^3)	1-8	0.02 - 0.12	0.02 - 0.13	22 - 39
NOx (mg/Nm^3)	40-100	16 - 42	16 - 42	68 - 82
SOx (mg/Nm^3)	1 - 40	0.5 - 20	0.5 - 20	1 - 2
Particulate Matter (mg/Nm^3)	1 - 5	1 - 6	2 - 6	1 - 3
Total Residual solids after conversion	500lb/ton	470lb/ton	470lb/ton	470lb/ton
% Composition of total solid residue	bottom ash (75-90%) fly ash (10-25%)	bottom ash (75-90%) fly ash (10-25%)	bottom ash (75-90%) fly ash (10-25%)	vitrified slag (88-92%) Salts (4-6%) Sulfur (2-4%) Mixed metals (0-2%)
Secondary uses for residual products	Combined ash can be used as landfill cover, ferrous material recovered and recycled from ash	Combined ash can be used as landfill cover	Combined ash can be used as landfill cover	Vitrified slag can be used as construction aggregate, salt, sulfur and mixed metals can have value in a secondary market
Technology and Market maturity	High	Low	Low	Low
Technology and Market Risk	Low	High	High	High

(1) Ratio of energy from the waste as electricity after internal energy debits, divided by energy content of the feed stock

(2) Grate combustion emissions based on Best Available Technology (BAT), All numbers reported on dry gas at 0 C, l atm, 11% O2. Values for gasification are based on a limited number of reported site, as a result the error on these values could be large.

Sources: (Gesell, Fryklind, Spott, 2008), (ISWA January, 2013), (Arean, 2012), (Department of Energy), (Klien, Themelis 2003), (Placo Energy 2013)

Figure 24: Comparison Matrix

XII. Technology Discussion

The goal of this section was to provide an overview of the current state of thermal WTE technologies across the world. It by no means claims to present a complete overview of all thermal WTE technologies in the market or under development. In addition, the publicly available information gap between gasification and combustion is quite large, as information is severely lacking for gasification. As a result, some gasification data was aggregated in order to provide comparisons. This aggregated data may prove to be misleading as differing gasification technologies can have large discrepancies. This is not the case with combustion as there exists ample industrial and governmental information to provide quantifiable and meaningful data across the spectrum of facilities.

With that said, the current available data on gasification suggests that it is reasonable to assume it will continue to develop and improve over the coming years. As a result, more time will be necessary before a determination can be made on the feasibility of gasification as a marketable method to thermally treat MSW. As gasification of MSW improves, it should also be noted that combustion of MSW will continue to improve as well. This in turn will place additional pressure on gasification of MSW to establish a meaningful market presence.

In summary, if gasification is to become a preferred method to treat MSW then it must duplicate the successes of MSW combustion. Those successes are combustion's high availability, which is very important considering that a WTE facilty is under contract to process a predetermined amount of waste per year. In addition combustion units have high throughput capabilities while also meeting or excedding strict emissions compliance. This combination of unit availability, high throughput and strict emissions compliance are the most impressive features of a MSW combustion facility and have established it as a highly reliable low market risk technolgy.

XIII. Examples of Successful Waste Management using WTE Technology

A. European Union

The European Union offers some of the best examples of waste management, including energy recovery from waste. In the densely populated countries of Western Europe, where land is scarce and valuable, there is long history of incinerating waste to avoid landfill as well as to generate heat for buildings. European countries have also been largely dependent on foreign oil and gas for their energy needs, and the oil crisis of the 1970's accelerated energy recovery from waste along with other renewable energy strategies. The EU placed limits on landfill, created targets for carbon emission reduction and renewable energy production, and implemented taxes on carbon, encouraging WTE technologies. Northern European countries also have implemented robust recycling plans together with WTE, as can be seen in the graph in Figure 25.

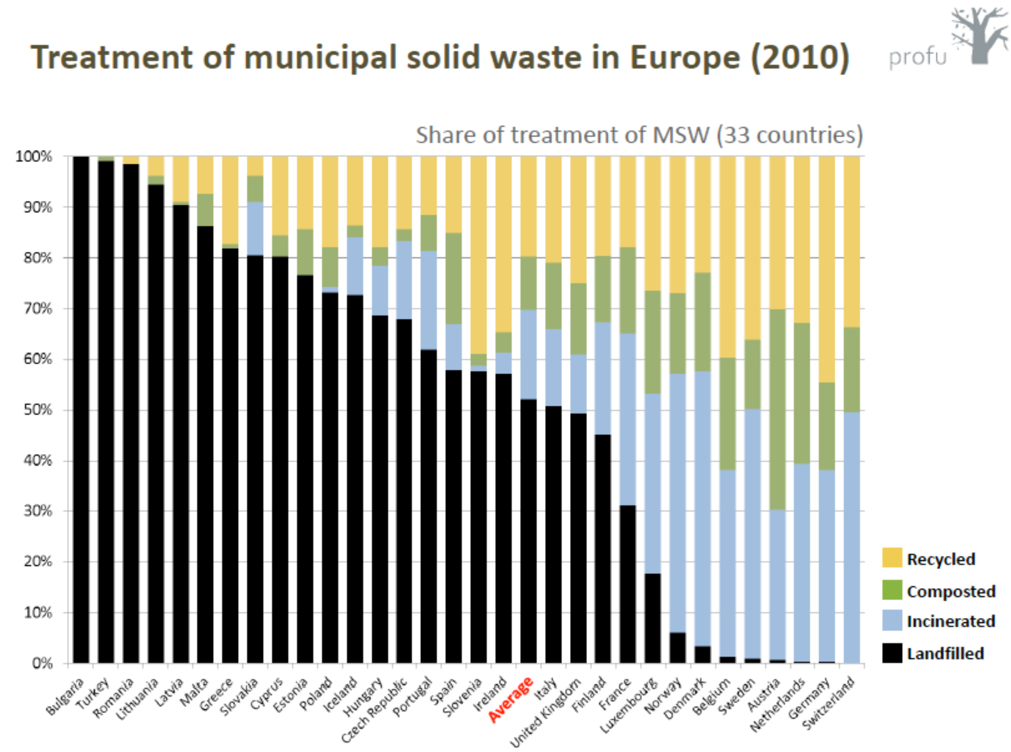


Figure 25: Assessment of increased trade of combustible waste in the European Union

In the graph above, it can be seen that the European countries with the highest share of WTE also send the least amount of waste to landfill, and recycle and compost at higher rates. The countries that landfill the most, recycle and compost the least, as well as have the smallest share of WTE. Recycling and WTE do not need to fight, there will always be waste that cannot be reused, recycled, or composted. WTE provides a sustainable solution for what remains.

The cold climate of northern European countries combined with high population density made district heating viable, allowing an increase in the efficiency of WTE facilities from 20-30% for electrical generation only to 80-90% with energy recovery for heating. At the same time, reuse and recycling of waste have increased. While the Scandinavian countries, as well as Germany, the Netherlands, and France all have significant WTE capacity; Sweden and Denmark have the greatest capacity per capita. Therefore, a more detailed examination of the history and current state of WTE in Denmark and Sweden can be useful for seeing the potential for New York City.

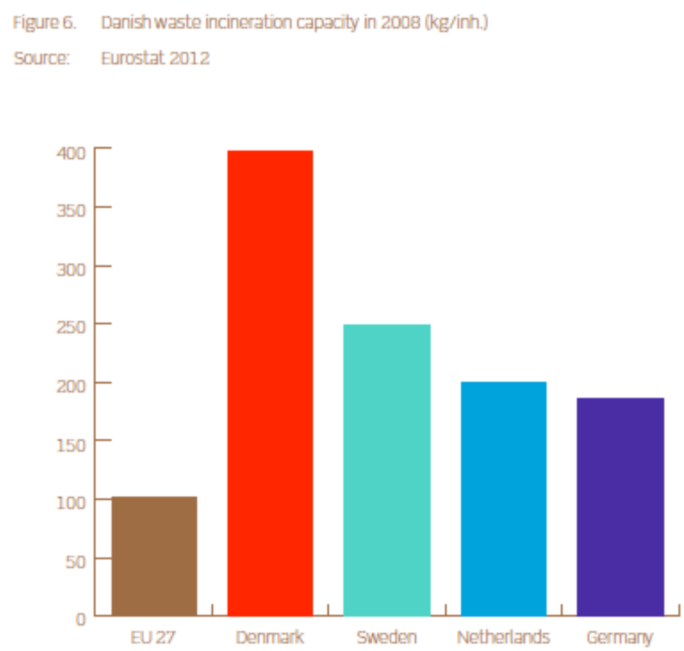


Figure 26: Denmark: We Know Waste

XIIIAi. Denmark

1. History of WTE in Denmark

In 1858, faced with growing urbanization and sanitary conditions that threatened public health, Denmark passed an Act requiring that all cities and towns accept responsibility for management of water, sewerage and municipal waste. This lead to the creation of landfill sites, but by the turn of the century Fredericksberg, a densely populated municipality within Copenhagen, was running out of space for waste disposal. At the same time, the first municipal electric works were being built in Denmark (Kleiss, et al, 2004).

Faced with this critical problem, Frederiksberg found a new, innovative solution, and in 1903 opened the first WTE facility in Denmark. Using its waste for fuel, to fuel multiple steam boilers, the facility was able to generate electricity while also generating heat for a municipal hospital. This was the first district heating system to be implemented in the country. Since that time, Denmark has had a continuous history of incinerating municipal waste to produce energy (The Most Efficient, 2006).

Two other WTE facilities in the municipalities of Gentofte and Aarhus followed in the 1930's, as well as reconstruction of the original facility in Frederiksberg. Each facility built upon previous technology. The replacement plant at Frederiksberg was the first to incorporate a reception pit with cranes to feed the waste into the incinerator as part of its initial design. There still was no separation of waste in the refuse pit, only very large items were removed. The facility design allowed for more efficient operation, requiring 17 workers rather than the 40 needed for the original plant, while processing the same amount of waste. The plant remained in operation until 1975 (Kleiss, et al, 2004).

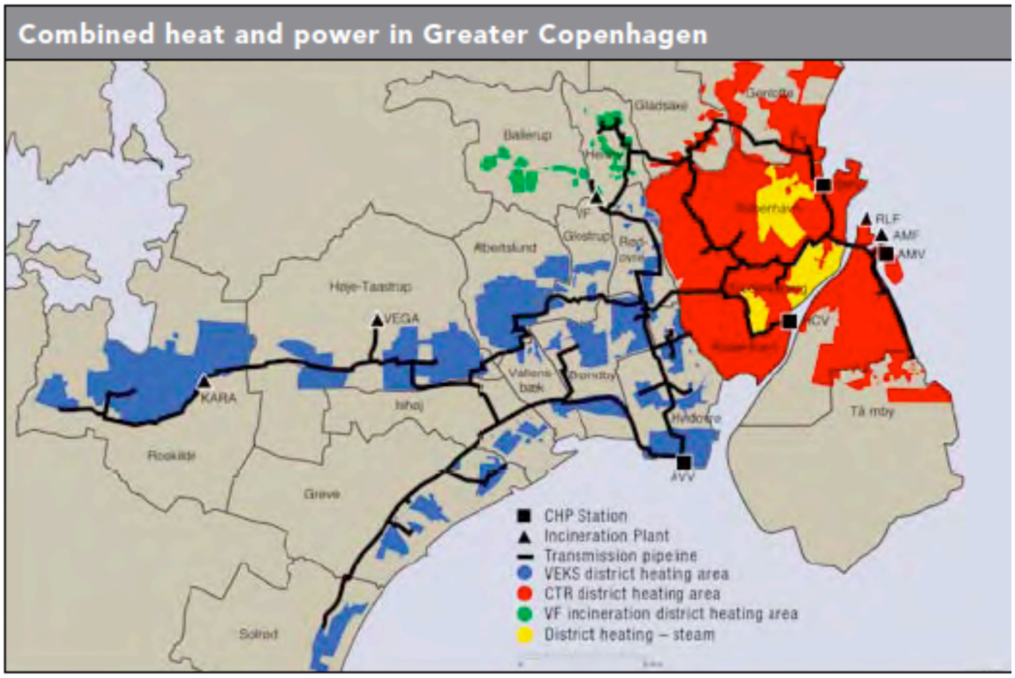
World War II delayed further development of WTE facilities, but also showed that in a time when fuel for heating was scarce, heating systems could continue to supply heat to the population. By the 1960's other facilities were opened, and a model of inter-municipal companies developed serving the owner municipalities. This has now become the basic model for WTE in Denmark (Kleiss, et al, 2004).

These early WTE facilities were largely unregulated, and growing environmental concerns lead to adoption of the Environmental Protection Act of 1973 that established regulations for clean air (Denmark: We Know Waste 2012). The same year the OPEC oil embargo and resulting worldwide oil crisis severely cut fuel supplies to a country totally dependent on foreign oil. Denmark realized that it needed to implement a policy of greater energy independence, and energy recovery from incineration of MSW became central to that plan (The Most Efficient, 2006).

Today waste management and WTE are highly regulated in Denmark. Waste must first be reused, and then recycled. What remains is then used for energy recovery. In 1997, Denmark became the first country in Europe to prohibit landfilling waste that is suitable for incineration in a WTE facility. Furthermore, it was established that "the energy must primarily be recovered in combined heat and power (CHP) plants, i.e. facilities that produce both electricity and heat in the form of district heating." This has resulted in an expansion of district heating systems, and conversion of all large and mid-size WTE facilities to CHP production, while also assuring that the greater part of waste is reused or recycled (The Most Efficient, 2006).

2. State of MSW Management and WTE in Denmark Today

Denmark sends about 26% of its total waste to WTE facilities, which is the highest quantity of waste per capita sent to WTE in Europe. In 2010, Denmark had 29 WTE facilities serving 98 municipalities, with 10 more planned or under construction. (Rosenthal, 2010) The existing plants treated approximately 4 million tons of waste, and the energy produced corresponds to the electrical consumption required for 430,000 households, and heating for approximately 360,000, representing 25% of the total district heating capacity. The municipalities own twenty-one of these facilities, and eight are owned by private firms that operate as contractors for the towns (The Most Efficient, 2006).



District heating transmission in Greater Copenhagen. Note the four waste incineration plants: Vestforbrænding, Amagerforbrænding, KARA and VEGA and the sludge incineration plant at the wastewater treatment plant of Lynetten. Source: VEKS

Figure 27: Greater Copenhagen District Heating Network

In 1989 the Danish Ministry of the Environment decided that local municipalities would be required to manage all waste generated within their boundaries, including commercial and industrial waste. There are about 40 inter-municipal waste management companies that are responsible for the overall management of waste including WTE facilities. They all operate on a non-profit basis. After the sale of energy all remaining costs must be made up through gate fees, the unit cost for emptying the waste, which are some of the lowest in all of Europe (The Most Efficient, 2006).

The Danish Environmental Protection Act and Waste Order of 2000 set important regulations regarding waste management, strengthening the responsibilities of local municipalities to register and track waste flows, assign treatment and disposal facilities, and administer the regulation of the facilities. No waste can be landfilled that is suitable for incineration, and none can be exported, with the exception of some residues from flue gas treatment at WTE plants, only because Denmark currently has no treatment facilities for that waste. That export requires permission from the Environmental authorities at the accepting state. (The Most Efficient, 2006)
A further Order on the Incineration of Waste was issued in 2003 that covered emissions from WTE facilities. Regulations were tightened for CO, TOC, HCl, HF, and SOx, along with six heavy metals, while new values were set for Dioxins, NOx, and another four heavy metals. All new plants were required to comply, and all existing plants given until 2005 to comply. Other Acts followed that assured that WTE plants could supply electricity to the grid and also connect to district heating networks (The Most Efficient, 2006).

Figure 28: New Combined Heat and Power WTE Plant in Copenhagen with Ski Slope on Roof

One ton of waste yields approximately 2 MWh of district heating and .67 MWh of electricity. The calorific value is estimated to be 10.7 MJ/kg, making one ton of waste equivalent of 0.25 ton of oil or 0.4 ton of coal. Approximately 20% of the total waste by weight remains as bottom ash, which is then sorted, with iron and other metals, such as aluminum, copper and stainless steel, recovered. Approximately 98% of this bottom ash is recovered and recycled. Residues from the flue gas treatment are sent to special treatment/recovery facilities in Germany and Norway. In 2003 this waste amounted to 88,000 tons (The Most Efficient, 2006).

In 2003, the European Union also adopted an IPPC directive mandating Best Available Technique (BAT) regarding the treatment of waste, with the qualification that it shall be applied under economically and technically viable conditions. However, it does not prescribe what the BAT would be for thermal treatment. This has lead to discussion of newer technologies; such as gasification and pyrolysis, as well as different flue gas treatment of mass burn technologies, and grate technologies (Kleiss et al, 2004). It is possible that the directive will influence the development and implementation of new technology that will increase energy production and decrease residual waste and pollutants.

XIIIAii. Sweden

Like Denmark, Sweden has a goal of fossil fuel independence by 2050. Approximately 2.1 million people live in the Stockholm metropolitan area, which represents approximately 20% of the total population of Sweden. Stockholm has an extensive district-heating network, and Sweden is second only to Denmark in the amount of waste incinerated with energy recovery per capita in Europe. In fact Sweden's capacity for WTE has made it a waste importer in recent years. In addition to having 32 WTE facilities, Sweden has extensive hydroelectric, biomass and wind energy production, and greater Stockholm has one of the most progressive transportation systems in the world. Currently, 45% of its energy is from renewable sources (Williams, 2011). All are critical to its goal to be fossil fuel free; however, Sweden's experience with WTE can provide useful lessons for New York City.

Sweden also has a long history with Waste-to-Energy facilities, its first facility opened in 1904. The oil crisis of the 1970's also had a major impact, and Sweden turned to nuclear and reintroduced coal. In the 1980's, Sweden turned increasingly to renewable resources, including WTE, for environmental and energy independence reasons. In 2009 approximately one-half of all household waste, or about 232 kg per person, was converted to energy (Williams, 2011).

Today in Sweden, WTE processes just over 4 million tons of waste, about equally divided between household and commercial waste, and provides heating for the equivalent of 810,000 households and electricity supplying the needs of about 250,000 homes. Landfilling of combustible waste has been prohibited since 2002, and of organic waste since 2005. Less than 4% of total waste is landfilled, about 50% is recycled or composted, and the rest processed in WTE facilities. In fact, as Figure 29 shows, the amount of waste that is recycled or composted has steadily grown, and in 2007 exceeded the amount of waste conversion by WTE (Towards a Greener Future).

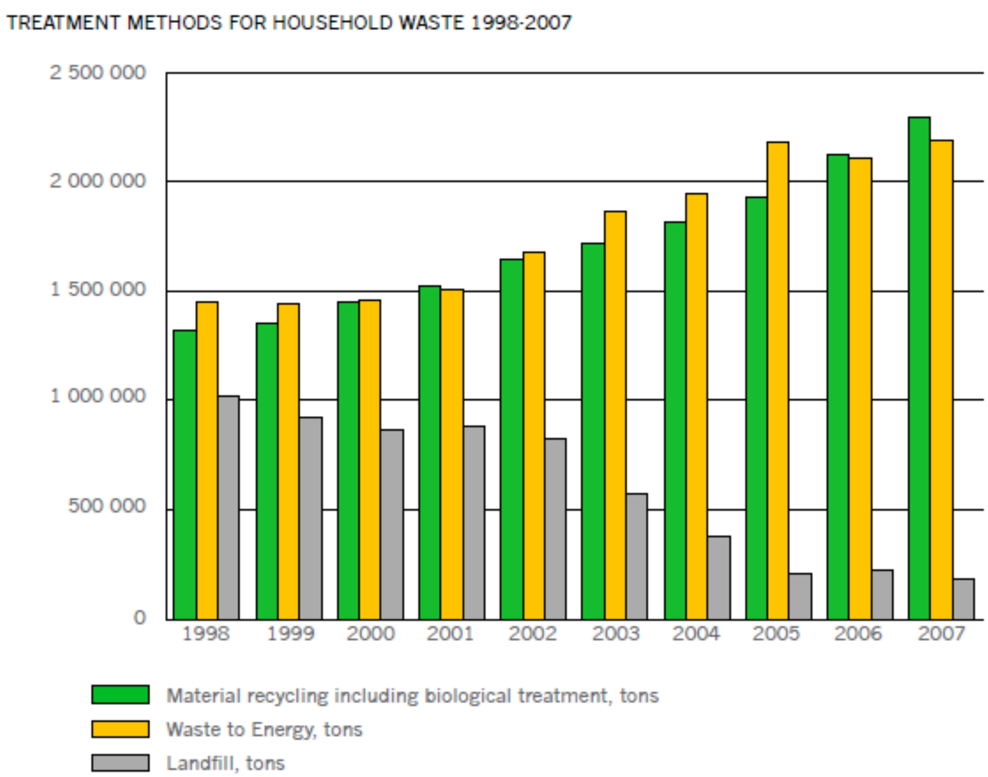


Figure 29: Treatment Methods for Household Waste 1998-2007

An example of a modern WTE facility in Sweden is the new Garstad facility that opened in 2005 (Figure 30). It receives waste from 600,000 persons in 30 municipalities, representing 15% of Sweden's total household waste. It processes 420,000 tons of waste per year, from which it generates 1,000 GWh of district heating and 200 GWh of electricity. It provides 90% of the heating through a district heating system for the municipalities of Linkoping, Borensberg, Mjolby and Skarblacka south of Stockholm (Jacobsson, et al).

Another plant expansion in Malmo, Sweden's second largest city uses new technology for increased efficiency. The plant processes 715,000 tons of waste annually, producing 1.4 TWh of heat and 0.3 TWh of electricity. It receives waste from approximately 500,000 persons living in 14 municipalities in Southern Skane. It is one of the largest WTE facilities in Europe (Waste-to-Energy CHP SYSAV).

Figure 30: WTE Plant at Gärstad in Linköping, Sweden

Sweden has received considerable attention over the last year because it has become so efficient at reuse and recycling, it imports 800,000 tons of waste annually from other European countries to fuel its WTE plants. The greatest amount comes from Norway, which finds it is less expensive to export their trash than to incinerate it in their own facilities. In return, Norway accepts the bottom slag from Sweden's plants, which have concentrations of heavy metals and dioxins and needs to be landfilled or treated in specialty facilities. Sweden is also beginning to import trash from Italy, Romania, Bulgaria and the Baltic countries, all of which primarily landfill their trash (PRI, 2012).

While importing of trash has been criticized, Sweden is providing a service to countries that cannot afford to build the facilities themselves, or in the case of Italy, does not have a climate that requires the district heating that makes WTE efficient and economically viable. For Sweden, which gets paid to accept the trash, and then benefits from the sale of the energy it generates, it is very smart economically. Meanwhile, in the PRI "Living on Earth" segment (PRI, 2012). Catarina Ostlund of the Swedish Environmental Protection Agency admits that this is an excellent but short-term solution to the problem of the amount of consumption and waste generated.

XIIIB. United States WTE Case Studies

Every two years, Columbia University conducts a study of the amount of Municipal Solid Waste (MSW) produced in the United States. Between 2002 and 2004, the amount of MSW produced increased 2.5 percent each year. They found that over 65 percent of the total MSW stream is landfilled, 28.5 percent is recycled, and just under 8 percent is combusted for power. The highest recycling rates are in coastal states while most WTE plants are on the East Coast; with Florida and New York states leading with 11 and 10 plants (respectively). The eighty-eight WTE plants nationwide are located in twenty-five different states. Together, they generate over 2700 megawatts of electricity each year and recover more than half a million tons of recyclable metals, mostly ferric materials (Psomopoulos 2009).

Also every two years, BioCycle and the Earth Engineering Center at Columbia University put out a "State of Garbage in America" report. The report published in 2010 (reviewing 2008 data) found that New York State was the highest exporter of MSW, shipping 4.8 million tons out of state . This amounts to a total of 14 million tons of exported waste per year. Michigan and Virginia were the highest importers of waste receiving 5.2 and 4.8 million tons of Municipal Solid Waste, respectively (BioCycle, 2010). Below are case studies from five states with existing waste to energy facilities and the social response, as were available from studies by different organizations.

XIIIBi. Oregon

This case study explores the performance and impact of Oregon's only WTE plant. This facility serves all of Marion County, which has a population of just over 300 thousand people and is approximately 1200 square miles. Marion is Oregon's largest agricultural producer, and the local economy is close to the average nationally per capita. A company now known as Covanta built the facility in 1986. This mass burn waterwall plant has two 275 ton per day boilers and is located in a sparsely populated area. Before construction of the energy recovery facility, Marion County dumped waste in a landfill that was located on a floodplain.

Today, Marion County has an extremely high recycling rate, reporting that about 50 percent of total waste generated is recycled. Energy recovery from thermally converting waste takes about 36 percent of the total waste stream away from landfills each year.

At the time of this study, the plant produced over 86 thousand megawatt hours of electricity annually, employed 38 permanent workers, and contributed 1.25 million dollars to the local economy through the purchase of goods and services. The WTE facility also recovers over four thousand tons of metals worth over $850,000 annually.

The WTE plant sits on 16 acres and treats 183 thousand tons of MSW each year; the study notes a landfill taking in this same amount of waste each year would need at least 160 acres. The study also found that these operations have reduced landfill demand by almost 90 percent for Marion County.

This plant operates with little to no political or community argument; representatives of the county agree that costs are kept low for residents by treating all the waste within county. The revenue from selling electricity and treating some outside carrier waste allows funding for recycling and waste reduction programming in the area (Berenyi 2013).

XIIIBii. Minnesota

The Olmstead County WTE plant is located in Rochester, Minnesota. Built in 1987, it is one of nine operating WTE facilities throughout the state. The county is 660 square miles and has a population of just over 100 thousand people. The plant occupies seven acres, and the local Kalmar landfill covers 160 acres. The three-boiler system (3^{rd} boiler installed in 2010) is about 38 percent of all county employment, which equals about 37 permanent employees.

About forty percent of the county's waste is recycled, 37 percent is processed at the WTE plant, and 23 percent goes to a landfill. The 1980 Minnesota Waste management Act placed a preference on WTE over landfilling, and the goal of the policy is to process or divert 90 percent of its solid waste stream. This preference also means that the facility receives renewable energy credits for the electricity it provides.

The waste heat from the Olmstead facility travels in a closed loop to provide steam to nearby hospital, prison, and school buildings. Producing electricity and capturing the steam heat for energy is called cogeneration. This process has improved the efficiency of the facility significantly. Each year, the plant produces 14 thousand megawatt hours of electricity and 679 million gigajoules of heat. Twenty-six buildings are tied to the steam loop, and the energy produced annually can serve the equivalent of nearly twenty thousand homes.

The Olmstead plant is owned and operated by the county, which is unique- most plants are privately owned. Each year, it injects almost 2.5 million dollars into the local economy through the purchase of goods and services or temporary hire of workers. The Rochester plant is half a mile from residential development and two miles from the nearest city but has faced little to no community or political argument (Berenyi 2013).

XIIIBiii. Florida

The Palm Beach County, Florida resource recovery facility is a refuse derived-fuel (RDF) waste-to-energy facility. It is one of thirteen RDF operations in the United States. The plant opened in 1989 and is owned by the county's solid waste authority. Palm Beach County is the largest county in Florida. There has been no 'significant' opposition to the plant, and the county is actually building a new 3,000 ton per day mass burn facility adjacent to the existing one (set to be complete in 2015).

Thirty percent of the county's trash is recycled each year, while forty percent is combusted and thirty percent is landfilled.

This facility combusts 605 thousand tons of MSW a year (2400 tons per day) and produces about 379 thousand megawatt-hours of electricity, which is enough to power 40,000 homes.
The plant employs 220 permanent workers and contributes at least $5 million to the economy through the purchase of goods and services. The plant recovers almost $10 million worth of metals each year and in 2010 underwent a $260 million upgrade that makes it one of the cleanest WTE plants in the US.

The plant is about 325 acres and within a recovery park, so the landfill that was there prior (which is still active) takes up the rest. This plant is located in the wealthiest county in Florida, but due to being is a resource recovery park, is not significantly close to residential areas (Berenyi 2013).

XIIIBiv. New York

The Westchester County, New York WTE plant was one of the first mass burn facilities built in the United States. This plant is located in a more densely populated area than the previous case studies. The construction of this plant and improved recycling practices reduced the county's need for landfill space by ninety percent.

In the county, about forty-one percent of MSW is recycled, forty-six percent is used for WTE, and thirteen percent is landfilled. A total of 700 thousand tons of waste is processed at this facility annually, which produces 412 thousand MWh of electricity. This can service about 41 thousand homes each year, in addition to powering the plant.

The plant employs 66 permanent workers and contributes about $6 million to the local economy through the purchase of goods and services each year. The WTE plant recovers about $3.4 million worth of metals each year.

Located in Peekskill, New York this plant has operated for over 26 years with little to no political or community opposition (Berenyi 2013).

XIIIBv. Michigan

The Detroit, Michigan Waste to Energy Plant was built in 1993, making it the newest plant explored in this paper. It occupies 17.8 acres and in 2006, processed 800 thousand tons of waste, or approximately 3,300 tons per day. It is owned by the City of Detroit. The plant recovered approximately 45 thousand tons of metals and employed about 160 permanent workers.
In that same year, it produced 210 GWh of electricity and 2.7 million pounds of steam for domestic heating. It is rated for 68 MW of electricity and 550 thousand pounds of steam per hour. It is the largest WTE facility explored in this paper, and appears to be the largest in the nation.

Not as much economic, environmental, or social information is readily available for the Detroit facility in an entire third-party case study. However, a document of public comment during the permit renewal did show that the facility, while claiming to be the 'cleanest in the nation', has in fact, surpassed their daily allowable limits on a recordable basis (GDRRA, 2013 & Renewable Operating Permit Staff Report, 2003).

XIV. Reimagining the Future of Municipal Solid Waste in New York City from a Sustainable Perspective

New York City currently does not process the bulk of its waste within its own borders. Of the average 11,488 tons per day of curbside/containerized waste collected in Fiscal Year 2013, only 15% was recycled, and the rest exported for processing (Annual Report, 2013). Approximately 8,400 tpd of the exported waste ended up in landfills in other states. Most of Manhattan's waste, approximately 1,400 tons per day, is processed at a WTE plant in Essex County, NJ, eight miles west of midtown (DeAngelo). While the City recently signed an agreement to export an additional 2,200 tons per day by 2016 to WTE facilities in Niagara Falls and Chester, PA, NYC will continue to export its waste rather than deal with it within the five boroughs. (Covanta Signs Long-term Deal, 2013). Since the closing of Fresh Kills in 2001, New York City's garbage has been someone else's problem at great cost, financially and environmentally. NYC spends almost $1B per year to export its waste, (Alm et al, 2004) largely via long-haul diesel trucks, the least desirable of all alternatives for waste management. NYC has no problem sending its waste to landfills in other places. This is not a responsible or sustainable solution for the largest city in the US. What can New York learn from the experience of other cities to implement a more sustainable MSW Plan?

A. The New York City Municipal Solid Waste Stream

In 2006, the New York City Department of Sanitation (DOS) released a Comprehensive Waste Management Plan that projected the content of the City's waste stream through 2026 and the costs of disposal using current methods (DSNY, 2006). The projections for 2015 are summarized in a chart from the DOS website, Figure 31.

Table II 2-4
FY 2015 Projected Generated Tonnage

FY 2015 Projected Generated Tonnage	Total	
	Tonnage	TPD
DSNY-Managed Waste for Export		
DSNY Curbside/Containerized Refuse Collection		
DSNY Containerized Collection	377,286	1,249
DSNY Regular Collection	2,789,474	9,237
Total DSNY Curbside/Containerized Refuse Collection	**3,166,760**	**10,486**
Other DSNY-Managed Waste		
Bulk	7,653	25
Lot Cleaning	10,114	33
Miscellaneous	2,025	7
Street Dirt	65,758	218
Other City Departments/Paid	110,738	367
Total "Other DSNY-Managed Waste"	**196,289**	**650**
Total DSNY-Managed Waste for Export	**3,363,049**	**11,136**
Recycling, Composting and Reuse		
DSNY-Managed Curbside/Containerized Recycling		
Paper and MGP Recycling		
Paper	663,671	2,198
Metal, Glass and Plastic	376,502	1,247
Total Paper and MGP Recycling	**1,040,173**	**3,444**
Other Agency Recycling		
Bulk Metal	5,500	18
Food composting (Rikers)	7,000	23
Christmas tree composting	2,500	8
Yard and leaf composting	50,000	166
Materials for the Arts (reuse)	1,000	3
New programs(1)	143,000	474
Total "Other Agency Recycling"	**209,000**	**692**
Total DSNY-Managed Curbside/Containerized Recycling	**1,249,173**	**4,136**

Figure 31: Table II 2-4 FY 2015 Projected Generated Tonnage

Table II 2-4 (continued)
FY 2015 Projected Generated Tonnage

FY 2015 Projected Generated Tonnage	Total	
	Tonnage	TPD
Other Recycled Wastes		
Derelict vehicle recycling	9,266	31
Auto tire recycling	1,591	5
Lot cleaning bulk metal recycling and dirt reuse	749	2
DOT asphalt recycling[2]	187,574	621
DOT millings recycling[2]	128,294	425
Interagency clean fill reuse[2]	315,619	1,045
Interagency road material reuse[2]	249,444	826
Total "Other Recycled Wastes"	**892,538**	**2,955**
Total Recycling, Composting and Reuse	**2,141,711**	**7,092**
Grand Totals and Diversion Rates		
A. Total DSNY-Managed Curbside/Containerized Recycling	**1,249,173**	**4,136**
B. Total DSNY-Managed Curbside/Containerized Refuse Collection & Recycling[3]	**4,415,933**	**14,622**
Curbside/Containerized Diversion[4]	**28.3%**	
C. Total Recycling, Composting and Reuse	**2,141,711**	**7,092**
D. Total (DSNY-Managed Waste for Export, Recycling, Compost and Reuse) Generation[5]	**5,504,760**	**18,228**
Total DSNY-Managed Diversion[6]	**38.9%**	

Notes:

(1) New programs may include those targeting waste prevention, other plastics recycling, or other streams.

(2) See Exhibit 1 at end of this section for a discussion of changes in the future status of these materials.

(3) "Total DSNY-managed Curbside/Containerized Refuse Collection & Recycling" is the sum of "Total DSNY Curbside/Containerized Refuse Collection" and "Total DSNY-managed Curbside/Containerized Recycling"

4) Curbside/Containerized Diversion is calculated as "Total DSNY-managed Curbside/Containerized Recycling" divided by "Total DSNY-managed Curbside/Containerized Refuse Collection and Recycling" (line A ÷ line B)

(5) "Total (DSNY-managed Waste for Export, Recycling, Compost and Reuse) Generation" is the sum of "Total DSNY-managed Waste for Export" and "Total Recycling, Composting and Reuse"

(6) "Total DSNY-managed Diversion" is calculated as "Total Recycling, Composting and Reuse" divided by "Total (DSNY-managed Waste for Export, Recycling, Compost and Reuse) Generation" (line C ÷ line D)

Figure 31: Table II 2-4 FY 2015 Projected Generated Tonnage (Continued)

The total curbside/containerized waste projection for 2015, including both "black bag" and DOS managed recycling waste is 14,622 tons/day. The projected recycling is 3,444 tons/day, which amounts to 24% of the total curbside/containerized waste collection. (DSNY, 2006) PlaNYC estimates the total potential curbside recycling based on waste content is 45% (Solid Waste, 2013).

However, the current actual diversion rate is significantly lower than either target. The Preliminary Mayor's Management Report from February 2013 reported a diversion rate of 14.8%, (Preliminary Mayor's Management Report) or one-third the total potential, which is corroborated by the DOS monthly report for June 2013, which reported a 15.2% rate. (Monthly Report, 2013) This shows a basic failure in an essential sustainable goal. The U.S. Environmental Protection Agency (USEPA) describes the Non-Hazardous Waste Management Hierarchy as: 1) Source reduction and reuse; 2) Recycling/composting; 3) Energy recovery; 4) Treatment and disposal (Air Emissions, 2013).

While the DOS may be behind the targets for 2015, it is useful to take those projections for assessing the potential impact that WTE could have in alleviating the landfill projections with higher recycling rates. The projected total DOS waste for export (disposal) in the 2015 projections is 11,136 tons per day, which includes "Other DSNY-managed Waste." (DSNY, 2006) If the curbside/container recycling amount were increased to 45% per the PlaNYC stated total potential, recycling would increase from 3,444 tpd to 6,268 tpd, an increase of 2,824 tpd. This would in turn leave a net 8,312 tons per day for disposal.

XIVB. State of Comprehensive Energy Plan for NYC: PlaNYC

New York continues to landfill the majority of its non-recyclable/reusable waste, 10,826 tons per day in FY12 (Preliminary Mayor's Report, 2013). While this waste may bring economic benefit to the communities where landfills are located, it is still the least desirable option, and one that requires long haul transportation, currently by truck and rail. Landfill is a poor use of real estate that could be used for other more direct benefit, such as parkland, commercial or residential development. What New Yorkers would not accept in their own back yard, they willingly send to someone else. Even with regulation, landfill has potential drawbacks: odors, vermin, and incomplete capture of methane, which is 72 times more potent GHG than CO2 by weight. With an incomplete recycling program, NYC waste includes plastics, glass, metals and other materials that may take thousands of years to decompose and release a wide variety of chemical species in the process, all of which require monitoring and mitigation.

PlaNYC, NYC's sustainable vision for 2030 includes goals for waste management, including reducing the amount of waste sent to landfill by 75%. In spring 2013, the Dept. of Sanitation expanded the categories of plastics it will collect for recycling to all rigid plastics and is considering a ban on Styrofoam. In order to increase the City's recycling rate, NYC made an agreement with Sims Municipal Recycling of NY to be the sole processor of NYC's metal, glass and plastic recycling, as well as a portion of the City's paper recycling. Sims is in the process of constructing a major recycling facility on a pier in Sunset Park, and this agreement is a major step towards reaching the DOS projections for recycling. Other programs are being piloted for food scrap, textile and electronics recycling. Mayor Bloomberg recently announced plans to collect as much as 100,000 tons per year of food scraps for composting (Navarro, 2013 & NYC Recycling Updates, 2012).

The DOS issued an RFP in the spring of 2012 in an attempt to implement WTE technology in or nearby the NYC (New and Emerging…, 2013); however, there is currently no strategic plan to eliminate or significantly cut back on landfilling waste. Technologies that have been proposed include composting, anaerobic digestion, and pyrolysis or gasification (The Plan – Solid Waste, 2013)—two thermal conversion technologies that are for the most part in the research and development scale, and are not currently economically feasible. While NYC could implement a small-scale program to help develop these technologies for future viability, the benefit now is negligible. It is essentially funding research into these technologies.

What the DOS has included, and would be an improvement although relatively minor given the quantity of waste shipped to landfills, is to dramatically cut long haul trucking of waste and substitute rail transportation. The plan includes rebuilding several abandoned marine transfer stations enabling intermodal transfer of waste via barge to rail (DSNY, 2006). This would reduce the carbon footprint of the process by reducing fossil fuel consumption.

Meanwhile, WTE is becoming part of the overall solid waste plan for the City, just not within its borders. While most of New York City's total disposable waste is being sent to landfill sites, the majority Manhattan's waste goes to a Waste-to-Energy facility in Essex County, NJ. Approximately 1,400 tons per day are currently sent to the Essex plant. A new agreement with Covanta announced in August 2013 would increase the NYC waste exported to WTE by an additional 2,200 tons per day by 2016, from newly renovated marine transfer stations in Manhattan and Queens (Covanta Signs Long-Term Deal, 2013). Together with increased recycling goals, this would make a dent, but the question remains: Is this a sufficient goal for a city that produces approximately 14,000 tons of waste every day? Other possibilities for waste management could further reduce waste for disposal, and will be discussed in later sections.

XIVC. Environmental Concerns and Energy Potential from WTE

The major critical comments of WTE today are that it pollutes, with dioxins often referenced, and that it discourages reuse and recycling of resources. Alternative technologies, such as anaerobic digestion are considered as being more acceptable. GAIA, an organization that is anti-WTE, calls Zero Waste the primary goal for modern society. GAIA claims that WTE plants are expensive, employ fewer persons than other technologies, rely on expensive foreign rather than domestic technologies, pollute, discourage reuse and recycling, and have negative energy impacts (GAIA, 2013).

Certainly WTE technology must fit with an overall plan for waste management. However, the pollution criticism is not substantiated by the facts, either from the strict regulations WTE must meet or from current technology in practice. Additionally, European and American examples show that recycling/reuse rates are highest where WTE deployment is also highest. The EPA calls WTE a renewable resource and reports that WTE saves 1 ton of GHG per ton of landfilled waste (Air Emissions, 2013). WTE can, and should be part of a comprehensive waste management plan that includes aggressive goals for waste reduction, reuse and recycling.

The US EPA has stringent requirements for emissions from WTE facilities under the Clean Air Act. Research by Pearl Moy for the Columbia University Earth Engineering Center assessed the comparative risks to human health for modern landfill, and WTE for NYC. Moy's Thesis references studies in the UK and Canada, and assesses the risks to human health from landfill and WTE facilities. Moy shows that both landfill and WTE are well within the cancer risk parameters established by the EPA, with the landfill option having higher risk primarily due to the emissions from long haul, diesel fueled trucks. WTE showed no significant human health risk. A table from Moy's Thesis is included in Figure 22 showing the relative concentrations and health risks of various chemical species from WTE emissions. The main risk was shown to be non-cancer respiratory symptoms which Moy states is from HCl concentrations, affecting 744 out of approximately 1.2 million persons, or less than one in 100 persons (Moy, 2005).

Table 10. Health risk results for WTE combustion (from mathematical model)

Compound	Annual Average GLC (ug/m³)	Non-Cancer Risk		Cancer Risk	
		Individual Non-Cancer Risk	Population risk	Individual risk	Population risk
Dioxin (TEQ)	1.90E-11	4.22E-07	5.02E-01	6.35E-08	7.54E-02
Mercury	3.16E-06	1.05E-05	1.25E+01	NA	NA
Cadmium	4.79E-07	4.79E-05	5.69E+01	2.01E-09	2.39E-03
Lead	6.84E-06	4.56E-06	5.42E+00	8.21E-11	9.76E-05
PM	1.02E-03	2.04E-05	2.42E+01	ND	ND
HCl	3.84E-03	4.27E-04	5.08E+02	NA	NA
SO2	5.88E-03	7.53E-05	8.96E+01	NA	NA
NO2*	4.03E-03	4.02E-05	4.78E+01	NA	NA
Totals	9.12E-02	Total HI 6.26E-04	Total HI 7.45E+02	6.55E-08	7.79E-02

GLC= Ground level concentration, HI=Hazard Index (Threshold=1.00E+00)
*NO2 concentration was calculated by multiplying the NOx concentration by 0.05 (27).
Population exposed= 1188648, See Appendix D for Calculation

Figure 32: Health Risk Results for WTE Combustion

The New York City Metropolitan Area is currently home to three major WTE facilities: the Essex County, NJ facility (1990) 8 miles west of midtown Manhattan, the Peekskill facility (1984) in Westchester County approximately 40 miles north of midtown, and a third in Hempstead, Long Island (1989), approximately 20 miles east of midtown. Together they process 7,550 tons of waste per day, and generate up to 2,005 megawatts of electricity that is sold to local utilities, enough electricity to power over 290,000 homes (Plain Facts, 2013 & Energy-from-Waste-Facilities, 2013).

Figure 33: Essex County WTE Facility

WTE is primarily a means of dealing with municipal solid waste (MSW) that cannot be recycled in a more sustainable way. While technology and knowledge has changed significantly in the last 100 years, and research promises new and more sustainable ways of processing MSW, it seems likely that a significant net quantity of MSW will require processing from either WTE or landfill for the foreseeable future. As Moy and others have shown, waste can be burned safely through WTE, and provide enough energy in the process to make it economical compared to other technologies. In Denmark, developments where WTE provides district heating are seen as desirable, rather than as a stigma that will hurt property values (The Most Efficient, 2006). The attitude in NYC so far has been against WTE. What is the difference, and how can successful examples instruct New York City?

XIVD. Relevance of European Experience to New York City

It can be seen that three of the major reasons for the success of WTE in Denmark are 1) the extensive district heating network, 2) the progressive national energy policy, and 3) localized management of waste. By far the greatest of these is district heating, which allows for a much higher efficiency of WTE production, and brings the benefit of WTE directly to the average household. District heating has a long history in Denmark, beginning with coal and oil-fired systems, now primarily fueled with WTE plants.

District heating systems were installed with urban expansion, and in existing cities and towns at great cost. Technology such as pre-insulated pipe was developed to help reduce costs. Steam distribution systems were converted to hot water, which operates at greater efficiency allowing much longer lengths of piping with less energy loss (Kleiss, et al, 2004). Areas of Denmark that have WTE plants and receive the benefits of the energy produced are popular and actually have higher real estate value, and a new facility designed by the Danish architectural firm Bjarke Ingels Group (Figure 19) has begun construction in the heart of Copenhagen. The result of a design competition, the plant will have a public ski slope on its sculpted roof, while providing electricity and heat to the city. WTE is popular, desirable and integrated into normal fabric of Danish municipal life.

Figure 34: Con Edison District Steam System of Manhattan

Con Edison operates a district heating system in Manhattan (Figure 34), with over 100 miles of steam mains and service lines from 96th Street to downtown Manhattan serving over 1,800 buildings, however the real estate needs for a full scale WTE plant—roughly 25 acres—far exceeds any available site in Manhattan (Ulloa, 2007). While the opportunity to include a heating component in a WTE facility has not been realized in the NYC area, the potential exists, with the increased efficiency and potential economic benefit it would offer.

One option could be for nearby areas that have a need for electrical generation and potentially district heating systems, to build plants that would accept NYC's trash, or that existing facilities with excess capacity arrange for the transfer. The economics and details would need to be studied, but this alternative offers a much better environmental solution than landfill. A recently signed agreement between the NYC Department of Sanitation and Covanta to send 800,000 tons of waste per year to Covanta's Niagara Falls and Delaware Valley WTE facilities is a major step in this direction (Covanta Signs Long-term Deal, 2013).

Meanwhile, like Denmark, the history of WTE in New York City reaches back to the early 20th century with at least one example of MSW being used to generate electricity at the Williamsburg

Bridge (Environmentalists Every Day). It also includes a modern effort during the Koch era that eventually failed during Mayor Giuliani's term. Understanding this history is essential in order to evaluate the current and future potential of WTE in NYC.

XV. A Brief History of MSW Management in New York City

A. The Early Years

The future of WTE in NYC cannot be understood except in the context of the overall history of NYC's handling of MSW. It is useful to summarize this history leading up to the attempts to implement WTE over the last three decades. This history, together with the findings of The Survey, can help to guide solutions and timelines for potential WTE solutions for NYC's waste.

In 1881, NYC addressed MSW for the first time as a City, creating the Department of Street Cleaning, which later became the Department of Sanitation. Until this time, residents disposed of trash in the streets (Alm, et al, 2004). The first trash incinerator to be built in NYC and the US was constructed on Governor's Island in 1885 (Martin, 1999). Steam generating incinerators were constructed in Manhattan in the 1880's (Stohr, 2002), and in 1905 a WTE facility under the Williamsburg Bridge began burning trash from Manhattan and the Bronx, generating enough electricity to light the bridge (Environmentalists Every Day).

Ocean dumping of trash was halted due to public protest in 1935, leaving landfill and incineration as the ways of disposing of municipal solid waste (Alm et al, 2004). Early landfills were simply dump sites, often sited in coastal areas, and leached many hazardous substances into ground water and waterways. NYC's waste increased with its growing population, and in 1947, Robert Moses opened the Fresh Kills landfill on Staten Island, promising that it would be temporary and receive only 'clean fill,' related to the construction of the Staten Island Expressway, saying that it would be open for only 3 years and receive no MSW. Moses also promised that one new municipal incinerator would be built in each borough within three years. 50 years later Fresh Kills remained operational, receiving 13,000 tons per day of NYC garbage. It covered as much as 2,000 acres and was once the largest landfill in the world. The incinerators Moses promised took 14 years to complete (Stohr, 2002 & Alm, et al, 2004).

Figure 35: Fresh Kills Landfill

By the 1960's, incineration of trash had grown tremendously. Apartment dwellers routinely deposited their trash into shuts, and it was burned on site. At its height, there were approximately 17,000 apartment incinerators and 22 large municipal incinerators in operation, which disposed of about one third of NYC's trash. Emissions from these facilities caused heavy pollution, and odors were a public nuisance. Public opposition grew, eventually causing a phase out of incineration in NYC (Alm, et al, 2004). The last municipal incinerator ceased operation in 1990, and the last apartment incinerator shut down in 1993 (DeAngelo, 2004). The last of the City's incinerators, a medical waste facility in the Bronx, was demolished in 1999, to public fanfare (Martin, 1999).

Similarly, NYC has had 89 landfill sites over the years. Stemming from an era of poor environmental or ecological understanding, these were all sited on salt marshes, which were seen as unhealthy wastelands that could be filled to make usable land. None of the sites had any of the modern environmental systems or controls, no liners, leachate recovery or monitoring wells. As the sites filled to capacity they were closed. The last, Fresh Kills on Staten Island, closed in 2001. During the phase-out, NYC began to ship its waste via truck and rail to landfills in other states (DeAngelo, 2004).

In retrospect, the mishandling of waste disposal, both via incineration and landfilling, understandably has resulted in a certain demographic of New York City's population having strong opinions about waste management. Politicians do not want to associate themselves with some of the worst environmental practices of the past and therefore ignore the issue. This has likely led to a populace that is generally poorly informed as to the current state of environmental controls for WTE facilities, which is one of the most highly regulated industries today resulting in a very environmentally compatible operation.

Figure 36: Former NYC Incinerator

Just outside NYC new Waste-to-Energy facilities were being constructed. Twenty miles east of midtown, in Hempstead, LI, a suburban town of 740,000, Parson and Whittemore/Black Clawson opened an Energy Recovery Facility in 1979 to convert the town's municipal solid waste to electricity. The facility adapted a technology that had been successful with wood pulp, but the waste did not burn cleanly enough. Testing showed that the plant exceeded state and federal guidelines for emissions. The EPA found dioxins in the emissions in July of 1979, and public opposition forced the plant's closure in March 1980. Despite an EPA report in 1981 that concluded that dioxins from the type of plant at Hempstead were not dangerous to public health, the plant was permanently shut down in 1982. Landfills sites nearby had reached capacity and were being closed, and the town was forced to ship its waste to a landfill site in Goshen, NY at a cost estimated at $1M/month (Aquino, 1995, Hickman, 2003 &McQuiston, 1981).

Concurrent with the discoveries at the Hempstead plant and its eventual closure, was the revelation of dioxin contamination at Love Canal in Upstate New York, and the high levels of cancer and birth defects suffered by the residents.

XVB. Waste-to-Energy Facility at Brooklyn Navy Yard

By the 1970's, the last of NYC's landfills were becoming filled to capacity and closing, and the largest, at Fresh Kills, was increasingly problematic. New York City needed a solution to its growing garbage problem. After years of study, and as it happened concurrent with the closing of the Hempstead facility, in 1979 Mayor Ed Koch announced plans to build state of the art Waste-to-Energy facilities in each of the City's boroughs. The first one would be built at the Brooklyn Navy Yard. This initial facility would be sized to handle up to 3,000 tons/day of garbage, and sited on a brownfield that had been an industrial site since the 18th century, most recently the Navy Yard (Shapiro, 1994). The Navy closed the site in 1966; it reopened in 1969 as an industrial park (Brooklyn Navy Yard, 2013). The Navy Yard is bordered by Williamsburg, home to Hasidic and Latino communities, and Ft. Greene, which was largely African American. These were all poorer communities that had essentially been separate and divided. That changed after the plans for the facility were announced (Shapiro, 1994).

In his thorough account of the opposition to the Navy Yard WTE facility, "A New Yorker's Take," Larry Shapiro, lawyer for the New York Public Interest Group (NYPIRG), described the opposition that developed and finally united the communities against the $500M project. The Hasidic community was better organized than the others due to their religious communality, and united against the project first. They were then joined by their Latino neighbors, and finally by the Ft. Greene community, forming CAFE, the Community Alliance for the Environment. The City proceeded with their plans, obtaining approvals and permits despite the opposition that continued to grow. The public opposition eventually pressured elected officials, finally succeeding in stopping the project (Shapiro, 1994).

NYPIRG got involved in the project early, which they saw as an environmental justice issue forcing a destructive project on underprivileged communities. NYPIRG was prominent in promoting reduction and recycling of waste, and in trying to stop "garbage incineration." Shapiro states his mistrust of the DEC, and the process of fighting projects that are legal, but which he and NYPIRG saw as destructive (Shapiro, 1994). He never mentions scientifically substantiated environmental concerns as a basis for opposing the proposed WTE technology, which would have had to meet all Clean Air Act regulations, including strict Maximum Allowable Control Technology (MACT) requirements enacted in 1990.

The project had to go through the State Environmental Quality Review Act process as well as obtain permits from the State and federal government. NYPIRG fought in the courts, and mobilized communities in both Staten Island and Pennsylvania where ash dumps were proposed. They successfully challenged an administrative law judge hearing the case for the DEC as having a conflict of interest. Although the project received a permit from NYS in 1985, the process dragged on, and the opposition and political pressure grew (Shapiro, 1994).

In 1993 a Brooklyn historian found an 18th century map showing the site was a burial ground for thousands of Revolutionary War soldiers who had been captured by the British, raising historic preservation issues that needed to be addressed (Young, 1993). Hazardous waste contamination had been discovered at the project site by the City in 1988 and not disclosed to the DEC for several years (Shapiro, 1994). When the Clean Air Act adopted the stricter MACT regulations in 1990, the opposition claimed the proposed Wheelabrator technology was out of date, referencing violations at other plants.(Hevesi, 1993) All required more time in the review process, and more time for community action to pressure the City against the project.

The opposition demanded that the City prepare a Supplemental Environmental Impact Statement (SEIS) to replace the initial EIS, which was now 10 years old. After the City balked, NYPIRG litigated. Under increasing pressure, in 1995 the City Council required that an SEIS be prepared in their approval of the DOS Solid Waste Management update (Godsil, 1996).

Amidst mounting public opposition and demonstrations, political support for the project finally died, and in 1996 Gov. Pataki signed a law requiring the closure of Fresh Kills landfill, and banning any WTE project at the Navy Yard that would have replace landfill. In a 2005 discussion on WNYC Radio on the subject of WTE and NYC, Jeff Lauber, a biochemist formerly with the DEC described the opposition this way, “Those that were stirring up the people and creating all this fear just didn’t understand the technology. It became pure hysteria…the devil burns and the lord recycles…that’s about how logical it was” (Eddings, 2005).

Meanwhile during this same time, the WTE facility at Hempstead was upgraded with a Deutsche Babcock Anlagen grate technology and reopened in 1989. It remains one of the most advanced and efficient WTE facilities in the region (Energy-from-Waste-Facilities, 2013).

Figure 37: Hempstead, LI WTE Facility

XVC. The Current State of Waste-to-Energy Implementation

In 2002, Mayor Mike Bloomberg, faced with the enormous cost of transporting NYC's waste to landfills in other states after the closing of Fresh Kills, brought up the possibility of implementing Waste-to-Energy technology into an integrated SWM plan for the City. His proposal was met with opposition from politicians and environmentalists, and his administration backed off the discussion, despite the fact that WTE technology was cleaner than ever (Eddings, 2005). In 2006, the cost of transporting waste to remote sites cost the City close to $1M per day (Lappen, et al, 2006). Since the late 1980's with the implementation of dry scrubber technology, emissions at WTE plants have dropped dramatically. Dioxin emission has dropped by 99%, to just 12 grams per year for all US WTE facilities—50 times less than dioxin emission from fireplaces and backyard barrel burning according to Dr. Nikolas Themelis, and mercury emission has dropped by 95%. Emission levels are now such that the USEPA considers WTE one of the cleanest methods available for generating electricity (Eddings, 2005 & Lappen, et al, 2006). Meanwhile, acceptance has lagged in NYC, unable to garner the political and popular support required to implement the technology.

In 2006, the Department of Sanitation issued a Comprehensive Solid Waste Management Plan (CSWMP) covering the years 2006 to 2026. The Plan omitted any reference to thermal WTE technology, rather looking to cut dramatically the transportation by truck to remote landfill sites in favor of rail and barge transport, thus cutting emissions related to transportation of waste. The Mayor's PlaNYC, first issued in 2007, calling for a Greener and Greater New York, targeted diverting 75% of the City's solid waste from landfills. It calls for waste reduction, increased recycling, and as of 2013 includes a Food Waste Challenge, calling for over 100 participating restaurants to reduce by 50% the amount of food waste sent to landfills by composting or other waste reduction strategies (The Plan - Solid Waste, 2013).

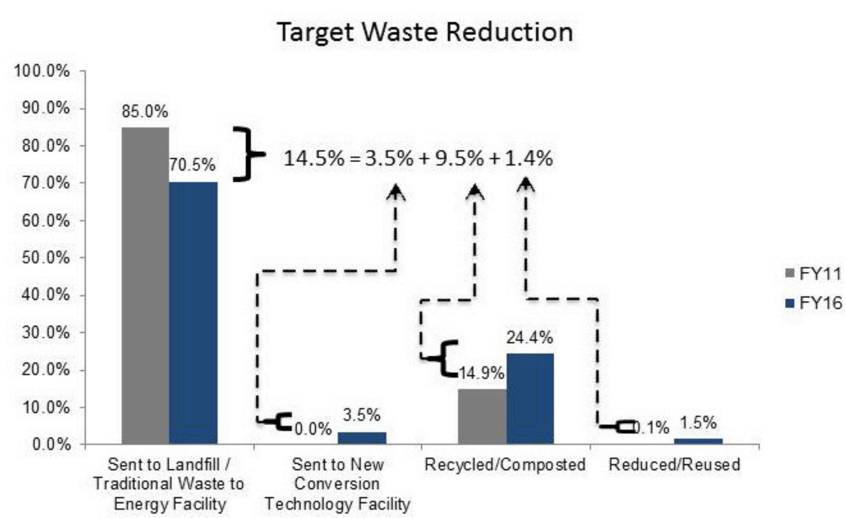


Figure 38: Target Waste Reduction

In 2012, NY Dept. of Sanitation issued an RFP under the heading "New and Emerging Conversion Technology" stating, "A substantial portion of the waste New Yorkers throw out could be recycled, composted or cleanly converted to energy," it called for increased reduction/reuse of waste, increased recycling and composting, reduction of landfill, and both an increase in new conversion technology processing and a reduction of waste sent to 'traditional Waste-to-Energy Facility' (New and Emerging, 2013). The graph below (Figure 38) from the DOS website summarizes the goals, and the modesty is immediately apparent. The reduction of landfill/traditional WTE is 14.5% and the offset for emerging technologies is a mere 3.5%. The bulk of the offset from increased recycling and composting.

In fact, the RFP called for the new technology to process a maximum of 450 tons of garbage per day, about what 45 sanitation trucks would hold, and a fraction of the over 10,000 tons per day the City generates. After a year of successful operation, the technology could double to 900 tons per day. The location of the facility could be within the 5 boroughs, or within an 80-mile radius of the City. Conventional, or 'mass burn' technology, was specifically excluded. Studies the City had commissioned recommended gasification, anaerobic digestion and hydrolysis technologies, which were all named in the RFP (Mayor Announces, 2013).

The RFP initially proposed a portion of the former Fresh Kills landfill site as a possible location for the new facility. NYPIRG organized protests and the NY Environmental Alliance joined in opposing a thermal processing facility referring to it as another industrial polluter. Staten Island elected officials joined in pressuring the Mayor to remove their borough from any siting consideration. In April, just a month after the RFP was issued, Staten Island was removed from consideration (Lentz, 2012 & Hughes, 2012).

While the DOS had said that results from the proposals would be forthcoming in November 2012, no details about any submissions have been released. Then, in August 26, 2013 The NYC DOS announced a 20-year agreement with Covanta to "sustainably dispose of municipal solid waste delivered to a pair of marine transfer stations in Queens and Manhattan" (News Room, 2013). NYC would deliver approximately 800,000 tons of waste per year for processing at two Covanta facilities—Niagara Falls and Delaware Valley. Waste would be transported in sealed containers using a multi-modal system of barges and rail, and the agreement has options for two additional 5-year periods. NYC will build the two transfer stations, and Covanta will invest approximately $110M in new equipment to be able to handle the waste transportation. Service from the Queens transfer station was expected to begin in early 2015, and from Manhattan in 2016 (Covanta Announces, 2013 & Simet, 2013). The amount of waste to be disposed of will amount to about 2,200 tons per day. This, together with the current 1,400 tons per day already being processed at Covanta's Essex plant will increase the total amount of NYC waste treated in WTE facilities to 3,600 tons per day.

While not the original intent of the RFP, this agreement goes much further towards reaching the PlaNYC goal of diverting 75% of NYC waste from landfills than the original RFP parameters. While the two facilities are not within 80 miles of the City—Niagara Falls is about 400 miles distant and Delaware Valley (Chester, PA) approximately 110 miles distant—they are closer than some of the landfill sites that receive NYC waste now, and the transportation by rail and barge is more sustainable than the predominate trucking that is currently used. Contrary to the graph in the RFP, no changes have been announced as to the amount of waste going to the Essex facility, and given this decision; it seems unlikely that the amounts would decrease.

There has been strong community opposition to the new 91st Street transfer station, which played a major role in City Council and Mayoral elections this fall, although Bill DeBlasio, the Mayor-elect has shown support for the project. The site, which was part of the Hudson River Park, was approved by the State Legislation and the City Council; however a critical Memorandum of Understanding needs to be signed by the Mayor, Governor, and leaders of both the Legislature and Senate agreeing to the replacement or payment for the parkland that is being removed to site the transfer station. As of November 7, 2013, it had not been signed, and action is not expected before the new Mayor takes office. The Covanta agreement is dependent on the transfer station being built (Anderson, 2013).

In Niagara Falls, there has been some community concern about the increased rail traffic associated with the agreement. Most centered on the construction of a rail spur to the facility and the additional rail traffic the NYC waste requires (Sondel, 2013). No additional capacity will be added to the plant; the NYC waste will replace expiring Canadian contracts for disposal (Bertola, 2013). At an August 14, 2013 Niagara Falls City Council public meeting attended by about 100 people, those who spoke were equally divided between supporting or questioning the additional rail construction. Opponents asked for a more thorough environmental review and questioned the effects of emissions on public health. Supporters pointed to job creation and other support Covanta has provided in the community (Besecker, 2013).

The Covanta agreement shows promise towards handling NYC's waste in a more responsible and sustainable way, and is related to Sweden's processing of waste from countries without the capacity to sustainably process it themselves. However, it still hinges on political support and the signing of a critical MOU. While the results of the Survey show that younger respondents are more open to its use in NYC, the current public attitude to WTE remains vocal enough to keep political support weak at best. It is possible that these agreements will bridge the time until public awareness about WTE as a clean and sustainable way of processing waste is more widespread, and possible coincide with newer technologies that could be more acceptable for whatever reasons.

XVI. Possibilities for a More Sustainable MSW Plan for New York City

A. Permitting of Waste-to-Energy Facilities

Article 10 of the NYS Public Service Law governs the process for licensing electric generating facilities. It was renewed in 2011 with some important revisions. The prior law exempted facilities that generated electricity from solid waste, and applied only to generating facilities of 80 MW or greater. The 2011 revision now applies to any new generating facility with a capacity of 25 MW or greater that sell power to the electricity grid (Rizzo, Plumb, 2012). For reference, the facilities at Essex, Hempstead, Peekskill, Niagara Falls and Delaware Valley all exceed this capacity. A facility matching the guidelines of the NYC RFP, with feedstock of 450 would not, but at the expansion capacity of 900 tons per day likely would. Facilities below the Article 10 threshold follow all local laws, for NYC, zoning, CEQRA, ULURP, DOB, and Fair Share regulations, all of which require lengthy review and demonstrable compliance (Rizzo, Plumb, 2012).

The intent of the revisions is to streamline the process, with four phases: pre-application, application, hearing and decision. The application must identify environmental or health impacts and mitigation. Reasonable alternatives must be presented, including alternate sites or changes to the SWM Plan. Most importantly, the Law requires a heightened consideration of environmental justice (EJ). The Board wants applicants to demonstrate that impacts have been avoided, minimized or offset. This is a stronger stance than SEQRA, which required disclosure of EJ impacts, but not necessarily action. The Board also wants to see that projects comply with local laws and regulations, and if not, credible reasons why not. The municipality is also a mandatory participant in the process. In the case of New York City, where EJ has been a recurrent issue raised by communities, this could make the approval process more difficult. Selecting sites where a WTE facility would be as-of-right, and building community support are essential (Rizzo, Plumb, 2012).

The intent of the law is to address all legal issues, environmental impacts and stakeholder concerns in the review process. For facilities that qualify, Article 10 is the sole regulatory body; municipalities cannot separately regulate the facilities. Together the new regulations will likely make siting of WTE facilities in NYC more challenging, both in terms of finding as-of-right or appropriate sites that are large enough, and in satisfying the environmental justice standards (Rizzo, Plumb, 2012). Regardless of the agency regulations and siting challenges, the most important factor is for everyday New Yorkers to understand that WTE technology offers a solution that is responsible and sustainable, cleaner for NYC and also for the world. We all share the same backyard, after all.

XVIB. Potential Siting of Waste-to-Energy Facilities in NYC

Throughout the history of New York City, many sites have been used as incineration sites, landfills, marine transfer stations, commercial waste transfer stations and chemical waste drop locations. Many sites of former single & double incineration sites remain, now unused brownfield sites. Marine transfer stations were formerly used to transfer waste to Fresh Kills by barge, and are currently part of NYC's plan to transfer waste via barge to rail for transport to remote landfill. The commercial transfer stations are active sites where waste is transferred to long haul trucks or rail for delivery to landfill sites. These sites, located throughout the five boroughs, provide opportunities for locating Waste-to-Energy facilities within NYC. Figure 39 below provides a map of these locations (DeAngelo, 2004).

Figure 39: Current vs. Former Waste Management

Additionally, there are other waste management sites, former landfills, hazardous waste cleanup sites & environmentally quarantined sites that could all be considered for WTE facility locations.
There are many considerations for siting facilities. Manhattan would be a very difficult location due to space limitations, and most of Manhattan's waste is already being processed at the Essex Covanta facility. Environmental justice concerns will need to be considered carefully. As the sites are at waterfront locations, flood protection will be a concern that will require design solutions. Public outreach, education, and neighborhood improvements will all be important to any future siting.

Figure 40: Current vs. Former Waste Management

Locations can be narrowed down to a conglomerate of existing marine and commercial transfer stations, together with the former municipal incinerator locations. Monica M. DeAngelo, in her Thesis "Siting of WTE Facilities in NYC Using GIS Technology," prepared for the Department of Earth and Environmental Engineering at Columbia University, investigated potential locations, and proposed three sites in the Bronx, Brooklyn and Queens. The map in Figure 40 shows these proposed sites.

DeAngelo identified two appropriate areas based on historical density of waste treatment facilities, both commercial transfer stations and incinerators, abandoned sites that would be available for cleanup and use, and proximity to existing marine transfer stations. Each is assumed to be brownfield site based on prior history. The first location, in the Hunt's Point industrial area of the South Bronx, is on the water, where current waste management facilities exist. The second is in Brooklyn on the border with Queens, and the site of both current and former waste management facilities, the active Newtown Creek Sewage Treatment Plant and the former Greenpoint Incinerator. Each is a former municipal incineration site with an adjacent marine transfer station (DeAngelo, 2004).

A significant part of the Municipal Solid Waste program in New York City is comprised of commercial waste transfer stations. Currently, there are roughly 170 active and permitted transfer stations that take in, on average, about 2 million tons of solid waste per year. Each station receives and processes about 12,500 tons of waste each year (Transfer Stations, 2013).

According to the Environmental Protection Agency's "Waste Transfer Stations: A Manual for Decision – Making," the most common and basic New York City transfer station is designed with a maximum capacity of 500 tons per day. However, as previously stated, the average station only takes in about 35 tons per day (based on the calculation that the average transfer station takes in less than 12,500 tons per year). With only a small intake per day, the typical station is approximately 40,000 square feet and sits on roughly a 25-acre site (Waste Transfer Stations, 2013).

Transfer stations can cause potential environmental issues including high truck traffic, noise, smells, and urban pests. Increased diesel truck traffic can cause higher levels of air borne particulates, which have been associated with increased childhood asthma rates. As NYC moves towards use of barge to rail transfer of waste, many of these commercial transfer stations are being closed, and could be available for siting WTE or other waste processing facilities.

XVIC. Possibilities for a New NYC Waste Plan with WTE

The Department of Sanitation's FY 2013 Annual Report of Curbside and Containerized collection, 11,488.2 tons per day (tpd) collected. Of this, 1,728.2 tpd was recyclable waste, resulting in a 15% recycling rate. (Annual Plan, 2013) If the City's PlaNYC goal of 45% recycling were met, recycling would increase to 5,170 tpd. Adding the capacity of waste currently sent to the Essex County WTE (1,400 tpd) and new agreements to Niagara Falls and Delaware Valley WTE (2,200 tpd) with Covanta the total amount of waste diverted from landfill by recycling and WTE processing would equal 8,770 tpd. This equates to 76% of the current total curbside/containerized collection (8,770/11,488) and meets the PlaNYC goal of 75% diversion from landfill. If NYC were to implement a contract for emerging technology WTE processing per the 2012 RFP even at the introductory rate of 450 tpd, the diversion rate would increase to 80%, exceeding the PlaNYC goal.

This is an ambitious goal that NYC has taken definite steps toward reaching. It is certainly achievable within the 2030 timeline, but is it enough? Even with this plan, approximately 2,270 tons per day of collected waste would be sent to landfills, and 2,200 tpd to distant WTE facilities. One long haul truck generates about 22 lbs of CO_2 per mile, and about 1,000 trucks daily leave the City for distant landfills. (Alm, et al, 2004) New York City once processed its waste within its own borders, and while admittedly not well, modern WTE technology allows for alternatives for the City do it again, responsibly and cleanly.   How can NYC better process 4,470 tpd of waste?

Figure 41: Bjarke Ingels Group/Glessner and Amager Resource Center

Two WTE facilities within the City's five boroughs with the capacity of the Hempstead plant would be sufficient to handle this quantity of waste, and DeAngelo has shown that sites exist that could accommodate plants of this size. The City could look to initiate emerging technology facilities; perhaps using anaerobic digestion and advanced thermal process facilities to offset one mass burn facility. Processing NYC waste within its borders, or within 8 miles including the Essex facility, would be a truly responsible plan.

New York City's vision for WTE should take inspiration from Bjarke Ingel's design for Copenhagen and make it a showcase for progressive environmental policy. Ingels has shown that WTE can be integral with recreation and a park in the middle of a major city with a facility that cleanly processes

400,000 tons of waste per year. NYC could provide a global example of WTE in the urban context—even within a park setting. WTE technology integrated into the fabric of the City is possible, and could include recreational and other community amenities, even district heating.

A new WTE facility could be the centerpiece for a major urban transformative development. The two areas highlighted by DeAngelo, the Newtown Creek and Hunts Point industrial areas, provide opportunities for brownfield redevelopment. Through creative zoning, property acquisition and Public-Private partnerships areas once seen as blighted could be transformed into recreational parks, destinations for local and wider communities. The new WTE plant could provide power and heat for those facilities and even spur further development through energy opportunities it can provide.

While Fresh Kills has been off the table politically, it is headed to being the largest park in NYC. A WTE facility integrated into the park design could be revolutionary in using the site of one of the worst examples of MSW disposal to highlight the best of today.

The main hurdle is public perception and acceptance. Modern WTE facilities meet or exceed very strict regulations for emissions, and provide one of the cleanest alternatives for waste disposal. They can be integrated into the heart of a modern city with ease. They can be attractive architecturally, and provide community amenities. With public and political backing, anything is possible. The new approval process per Article 10 of the NYS Public Service Law requires municipal participation and community consent. It is imperative that the City engages and educates its populace about environmentally responsible waste management. Public attitudes must change to include the facts about modern WTE technology, and the benefits to communities in any proposal must be definable and present tangible value on many levels. European examples have shown it is possible, and even desirable.

The Survey conducted as part of this research and reported on in the next section points to a change in perception among the younger respondents. This needs to be reinforced, so that people in NYC understand the benefits to themselves and others through using the best available technology to address the waste they create.

XVII. Survey

A. Introduction

The MS in Urban Sustainability program at City College in New York requires all graduates to complete a year-long capstone, or thesis project, on a topic of interest in small groups. The Waste to Energy (WTE) capstone group reviewed the facts about available WTE options, determined the most viable technologies, studied examples domestically and internationally, and worked to create proposal for Waste to Energy in New York City. When determining the best approach to planning, it occurred to the team that more background on the public's opinion of WTE was needed. In other words, the team did not want to create a proposal that makes sense scientifically and economically; and would not work socially as well.

Waste to Energy is not a new concept; the last time New York City had a large-scale WTE plan there were so many negative effects that the people of New York may still have a 'bad taste' in their mouths. We felt it was vital to determine the public sentiment about WTE in or close to New York City. A hypothesis was formed; that with the proper information people would be open to considering WTE as part of a comprehensive solid waste management plan.
A similar study of Public opinion in Greece found 58% of the respondents have heard of thermal treatment of MSW, but did not feel they had a clear view of the advantages and disadvantages of the system (Achillas et al. 2011). Of that same group, only five percent believed thermal treatment is safe for public health.

The survey also shows that most Greek citizens believe they pay too much for energy and seem to be open to a WTE facility if more information is provided. This creates the same overarching issue that is present in the United States. Most people have no adverse reaction to a WTE plant that is far away from where they live, a classic NIMBY (not in my backyard) response. Most also want to limit the costs of waste disposal. This education gap is really the burden of the corporations developing WTE technologies to share with the public, so they can embrace a system with multiple benefits rather than fear it. The air pollution recognized by the results of the Greece study are not unwarranted, Waste to Energy is not a perfect solution, but the research team wanted to determine if in New York City, like in Greece the acceptance threshold is high enough to allow WTE development (Achillas et al. 2011).

XVIIB. Methodology

Development of Survey Questions:

First, the team created a series of questions based on the information needed to determine possible public response to a Waste to Energy (WTE) plan for New York City. The team planned to determine several factors: New York City residents' actual knowledge about thermal conversion technologies, the acceptance level of those residents to having Waste to Energy facilities in their neighborhoods, and their level of interest in utilizing WTE over other available solid waste management strategies.

The team consulted with Master of Psychology student, Christine Lyman, to ensure the questions posed had no bias and did not allow the survey respondent to breach confidentiality. She also instructed the team on appropriate protocol when conducting research as a university group, which included getting approval from the Institutional Review Board (IRB).

After creating an initial draft of the survey, the team sought the assistance of Samantha MacBride, an Assistant Professor at the Baruch School of Public Affairs, to ensure the questions were focused and would truly provide answers to the research team. The final survey was agreed upon by all members of the WTE team as well as those providing some guidance.

Survey Software:

The team needed to utilize an online survey software with the following characteristics: free to use, no limit to number of questions, no limit to number of responses, blocks a user once they have completed the survey by only allowing one response per IP address, and allows respondents to remain anonymous.

They determined the best tool to complete this online survey was: eSurv.org (http://esurv.org/index.php) and created the template for responses utilizing several different response methods which included multiple choice, true and false, write ins, and opinion scales.

Institutional Review:

Each member of the research team and advisor Dr. Marco Castaldi completed Human Subject Research Training as required by the Institutional Review Board. This training program took about 4-6 hours to complete and created awareness among team members about the challenges and the required protections when using humans as subjects of research. Although an online survey is nearly always eligible for exemption from continued Institutional Review, in order to be considered for exemption, all teams must still complete this initial training.

The City College Institutional Review Board required all of the training certificates, a draft of the survey, confidentiality agreement, and documentation of predictable risks for Exemption Review. Once the research team received exempt status from the Institutional Review Board, meaning the survey and responses were not subject to continual update and review by the Board, they distributed the survey via email to all available networks. The body of the email requested that only New York City residents complete the survey.

The team aimed for five hundred survey responses, but could accept a minimum of two hundred for the study to be statistically relevant. Put some referenced information here about what you mean statistically sound After approximately one month, researchers closed the survey to analyze results and draw conclusions from the responses.

XVIIC. Data (Full Survey with Data, Responses and Graphs in Appendix)

Number of Responses: 363

1. Are you a NY State Resident?

Yes: 93.45%
No: 6.55%

2. How Many People live in your household, including yourself?

1-2: 35.27%
3-4: 40.00%
5+: 24.73%

3. What age category are you in?

18-25: 54.18%
26-35: 24.73%
36-50: 10.55%
51-60: 4.73%
61 and older: 5.09%

4. Please tell us the highest level of education you completed

Did not graduate High school: 0%
High school Diploma/GED: 37.09%
Trade School/ Associate's Degree: 10.55%
College Graduate: 31.27%
Post graduate: 20.36%

5. Please select your personal annual income range

$25,000 or less: 48.73%
$25,000-$35,000: 8.36%
$36,000-$50,000: 5.45%
$51,000-$70,000: 8.73%
Over $70,000: 10.18%

6. What is your ethnic background? (Select all that apply)

Caucasian: 45.36%
African American: 7.90%
Hispanic: 25.77%
Asian/Pacific Islander: 15.46%
Other: 5.50%

7. Where do you believe your trash goes after you throw it away?

It is taken to a landfill in my state: 32.36%
It is taken to a landfill outside of my state: 33.45%
It is taken to a Waste to Energy Facility: 2.55%
I am not sure: 30.91%

8. Please tell us how much you know about WTE

Never heard of WTE before this survey: 34.18%
Understand the purpose of WTE, but know little about the different technologies: 53.82%
Fully understand the purpose and different technologies: 10.91%
Other: 1.09%

9. When you hear WTE, do you feel a positive of negative reaction?

Positive towards WTE: 77.45%
Negative towards WTE: 6.55%
Neutral reaction towards WTE: 16.00%

10. Does your household recycle?

Yes: 93.84%
No: 6.16%

11. If you answered yes, your household recycles- please tell us why. (Select all that apply)

Landfill Space is limited: 13.10%
To be a good citizen: 27.31%
For the environmental benefit: 40.77%
I will be fined if I don't: 13.10%
For the money: 3.32%
Other: 2.40%

12. If your household recycles, what items do you recycle?

Plastic: 24.52%
Metal: 19.06%
Glass: 21.36%
Paper/Cardboard: 22.32%
Electronics and other specialty recycling items: 11.49%

13. Which of these methods of waste disposal in NYC do you think produces more GHG over its lifetime?

WTE facility: 28.14%
Landfilling trash: 64.64%
Other: 3.04%

14. To your knowledge, have you lived anywhere where waste is turned to energy?

Yes: 20.15%
No: 79.85%

15. Are you aware of any WTE facilities in and around New York City?

Yes: 10.57%
No: 89.43%

16. If NYC had a robust recycling program, would you consider using the remaining waste that is non-recyclable as fuel for a WTE facility?

Yes: 84.03%
No: 1.90%
Not Sure: 14.07%

17. Given what you know now about Waste to Energy and Landfilling, where would you prefer your trash go?

To a landfill: 1.14%
To a local WTE facility: 87.88%
None of the above: 5.68%
Other: 4.55%

18. True or False: Waste to energy technology is considered a renewable energy in New York State.

True: 70.72%
False: 23.95%
Other: 5.32%

19. How would you feel about a mass burn WTE plant in your neighborhood?

Excited: 4.94%
Accepting: 21.29%
Neutral: 24.33%
Slightly Against: 28.52%
Strongly Against: 15.97%

20. How do you feel about having a pyrolysis or gasification WTE plant in your neighborhood? **Recall from the introductory information that pyrolysis and gasification are still thermal technologies, but they occur at higher temperatures.

Excited: 4.33%
Accepting: 23.23%
Neutral: 35.04%
Slightly Against: 23.62%
Strongly Against: 12.60%

21. Which type of Waste to Energy Technology do you prefer? (Please give each option a number of stars. 1 being least preferred, 5 being most preferred)

	1	2	3	4	5	Responses	Total
Mass burn	**27.17%**	**12.20%**	**37.01%**	**12.99%**	**10.63%**	**254**	**680**
Gasification	**15.35%**	**13.78%**	**43.31%**	**15.35%**	**12.20%**	**254**	**750**
Pyrolysis	**18.11%**	**11.42%**	**38.58%**	**21.26%**	**10.63%**	**254**	**749**
I have no preference	**34.25%**	**5.91%**	**18.50%**	**7.09%**	**34.25%**	**254**	**765**
I am against any and all WTE technologies	**73.62%**	**5.91%**	**8.27%**	**3.94%**	**8.27%**	**254**	**425**
	78.74%	**5.12%**	**7.87%**	**1.18%**	**7.09%**	**254**	**388**

22. Where can you find out more information about solid waste or related practices if you want to? (Select all that apply)

NYC Dept Sanitation: 33.08%
Newspapers: 11.72%
Internet: 39.89%
TV: 5.10%
Radio: 3.97%
Don't Know: 6.05%

23. Do you think NYC handles its solid waste in a responsible and sustainable way?

Yes: 11.81%
No: 33.46%
Unsure: 50.79%
No opinion: 3.54%

XVIID. Results and Analysis

Three hundred and sixty-three people completed the survey. With a completely random sample, this gives a 95 percent confidence for New York City, with a population of 8.5 million people. However, the sample group does have limiting factors such as: demographics of the population that will open and complete an online survey, the research team's access to networks with a wide range of backgrounds, and the capabilities of utilizing a free software tool while keeping all responses anonymous.

The United States Census Bureau in 2010 reported that the average per capita income for New York City was $31,417, which means as detailed in Figure 42 below, that approximately 56% of survey respondents are below that income level.

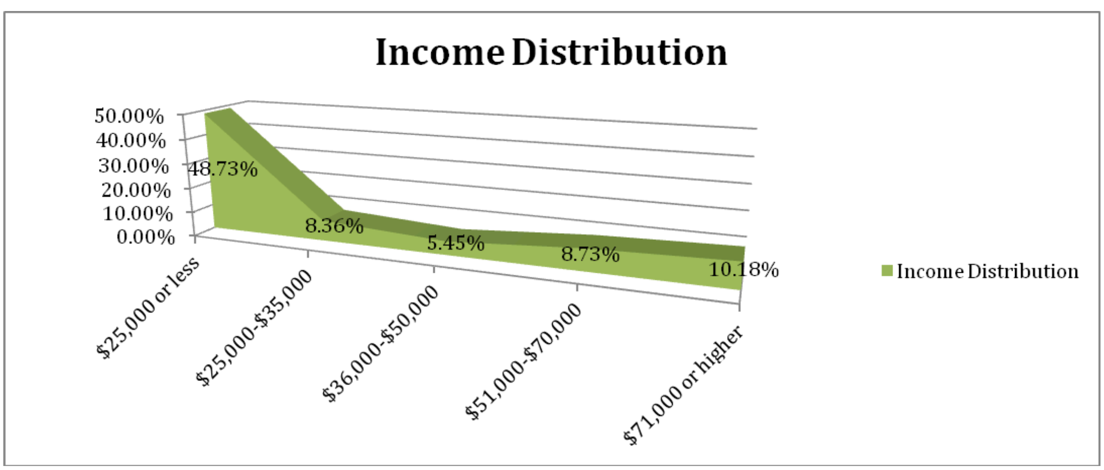


Figure 42: Income Distribution

The low income level seems to be supported by results detailed in Figure 43, which shows that more than half of those surveyed are between the ages of eighteen and twenty five years old, who typically are just starting their careers or are still in college.

So, the results may represent a unique population of young, lower income families.

Since new WTE infrastructure development will likely first occur in areas where plots are the least expensive, this sample group might actually represent the truest response for the neighborhoods impacted by the program the team ultimately recommends.

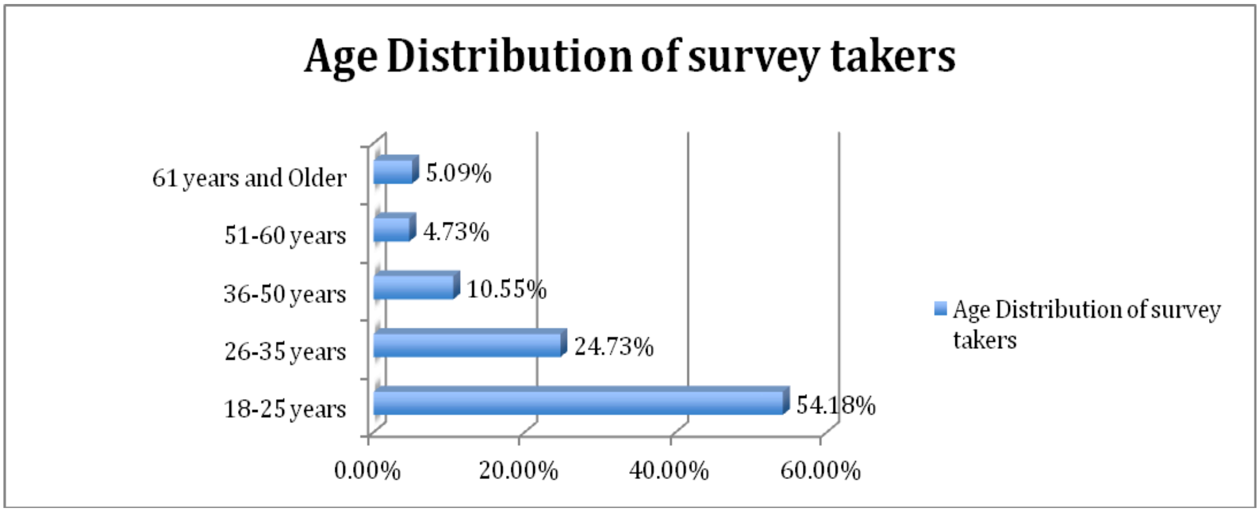


Figure 43: Age Distribution of Survey Takers

However, despite the age and income gaps, survey respondents are close to the US 2010 Census in level of education completed. According to the census data, about 79% of people living in New York City had completed high school or higher, and 33% had a bachelor's degree.

As visible in Figure 44 below, this survey sample group's levels are comparable; 31.62% of respondents had a Bachelor's degree, and 100% had earned a minimum of a high school diploma (or equivalent). This means that the level of understanding in reading about the technologies, and existing understanding about New York City's solid waste management is likely very typical of a New York resident.

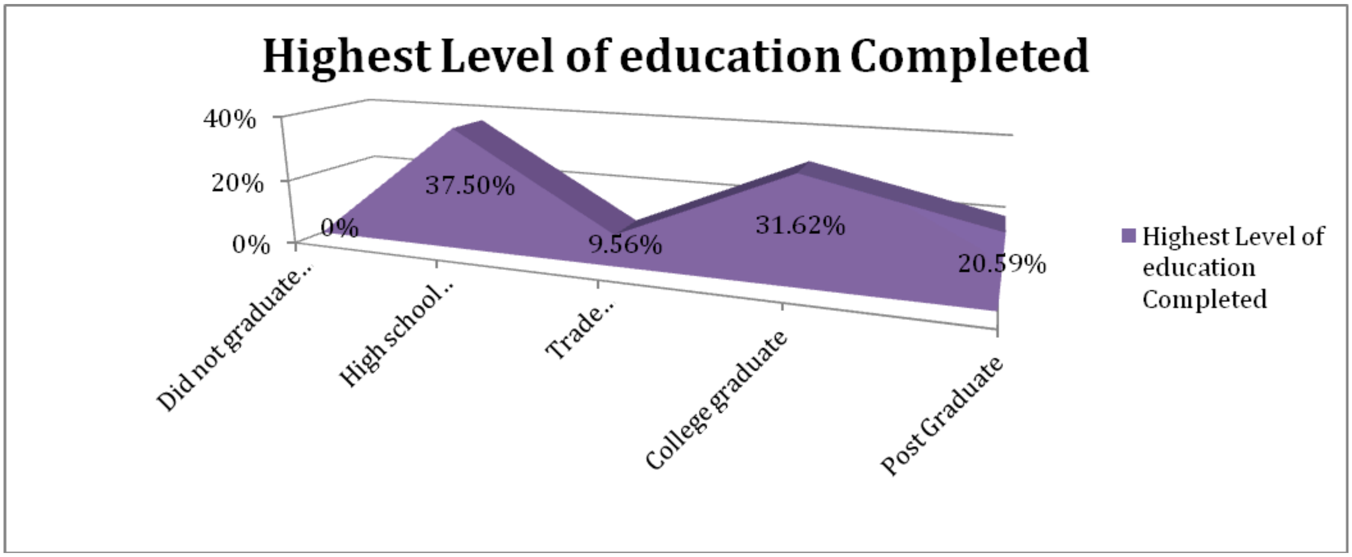


Figure 44: Highest Level of Education Completed

Researchers provided some background on Waste to Energy Technology during the first few pages of the survey, but followed up by asking how much the survey takers knew about Waste to Energy before that information. A strong majority of 53.82% (see Figure 45) knew the term and understood what it aimed to achieve, but did not know detailed information. Some comments noted they had been told that waste to energy was still experimental because it is not yet viable technology. Therefore, increased educational outreach and awareness could benefit the WTE industry.

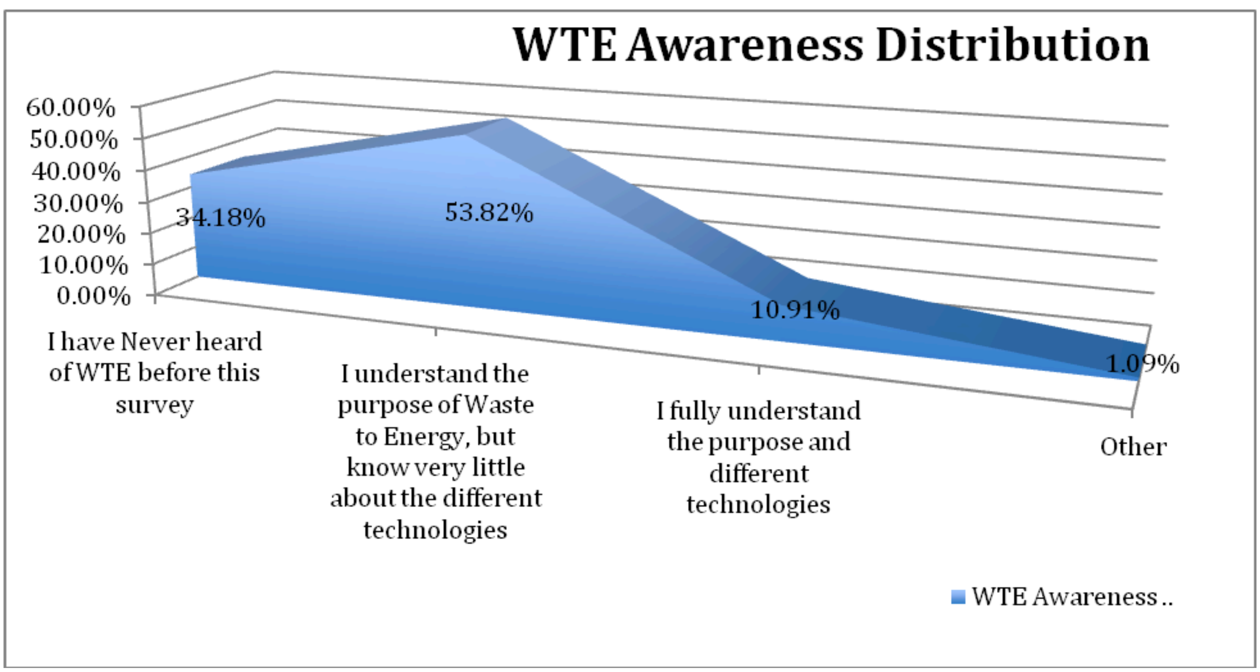


Figure 45: WTE Awareness Distribution

After determining that the size and background distributions of the survey takers made their answers relevant, researchers asked respondents where their waste goes for disposal (See Figure 46 below). About two-thirds, or 65.81%, believe their waste goes to a landfill. The other major third of responses did not know where their trash went after the curb. A small percentage (2.55%) believes their trash goes to a WTE facility. Approximately 1,400 tons per day are being sent to the Essex, NJ WTE plant, which is about 50% of its total. (Sierra Club, Covanta). In addition another 800,000 tons per year will go to WTE facilities based on the NYC mayor's recent announcement – which will raise the amount of trash treated to nearly 40% of the city's total. Based on the factual information, researchers should have gotten between 10-20% of respondents whose trash goes to WTE facilities. However, Figure 47 indicates that NYC residents are unaware of where their waste goes, despite believing they do and possibly even selecting an option in the survey that is incorrect.

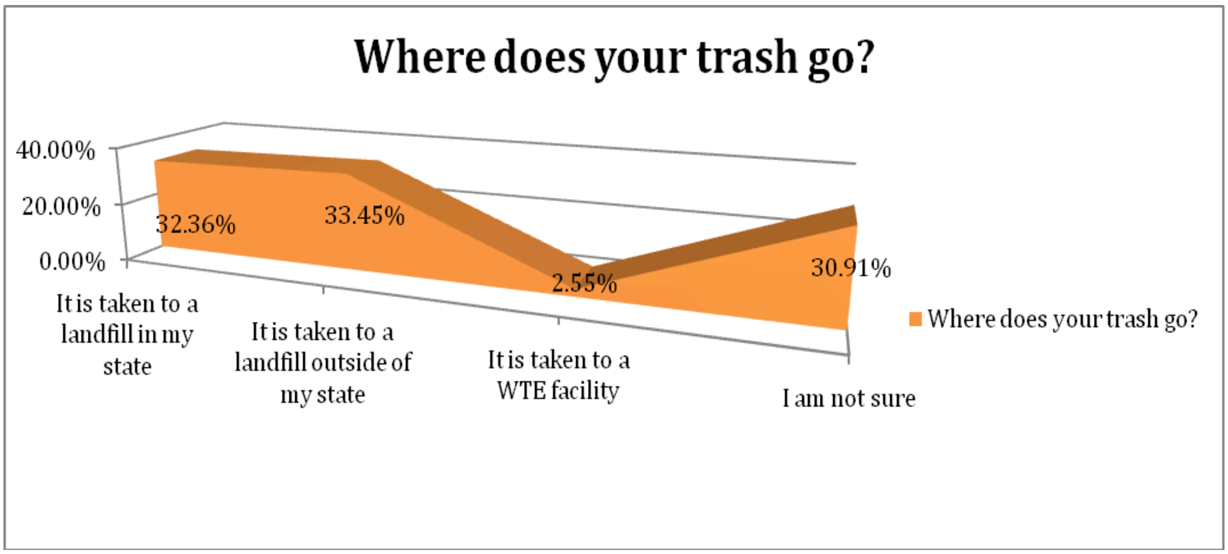


Figure 46: Where Does Your Trash Go?

Next, researchers tried to determine if New York City residents are aware of Waste to Energy being utilized to manage solid waste currently. They asked if the respondents are aware of any facilities in or around New York City. A large majority, 89.43%, was not aware of any facilities in the state (see Figure 47). This is an interesting finding in light of the information provided in Figure 42 which shows ten active WTE sites in New York State.

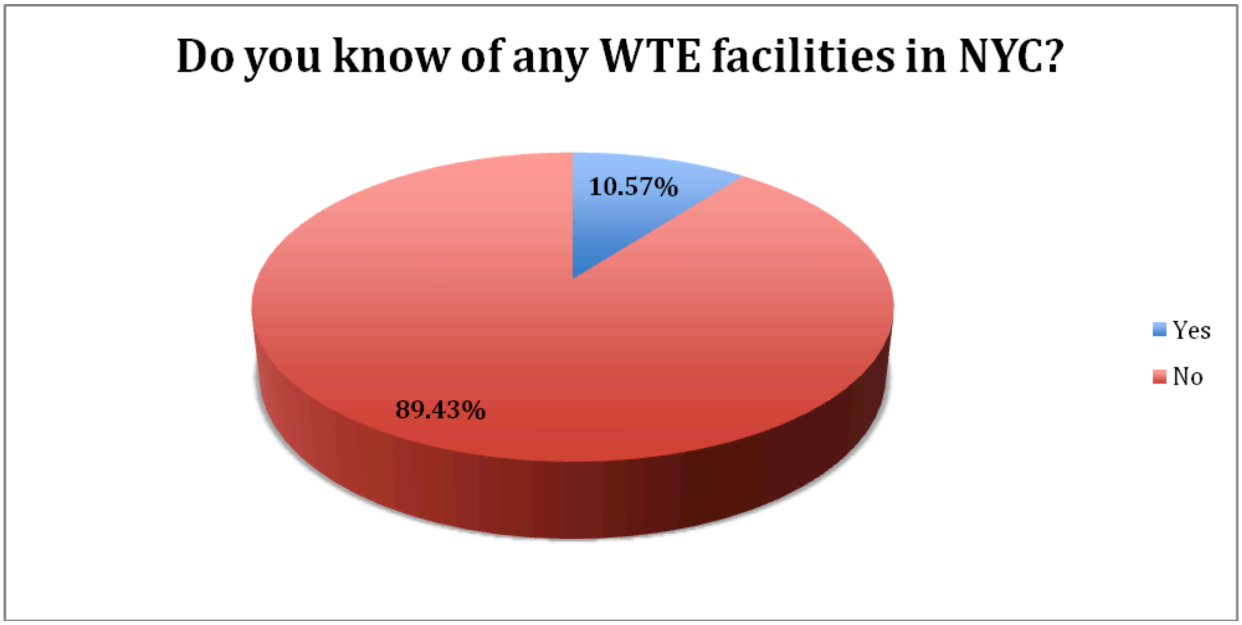


Figure 47: Do You Know of Any WTE Facilities in NYC?

Based on the results of Figures 46 and 47, we can infer that most New York City residents are unaware of how their solid waste is managed once it is thrown 'away'. This also means the majority of solid waste infrastructure is not near places where our sample population lives. This agrees with our research that shows a large amount of New York City's trash is shipped outside of the state; namely to New Jersey, Ohio, Virginia, and Pennsylvania.

The issue of New York City residents not knowing where their trash goes once they throw it 'away' is not an issue unique to this city. However, residential garbage is the largest contributor of national trash at 65% of the total and as such requires particular focus (National geographic, Human Footprint).

Next, the research team tried to determine the level of Not in my Backyard (NIMBY) syndrome of the sample group; that is, they tried to determine if the survey respondents would be ok with a WTE facility to treat their trash, just not in their neighborhoods. In Figure 48, after learning about Waste to Energy technology, and the differences between the thermal conversion options, 87.88% said they would prefer their trash go to a WTE facility.

The responses guiding Figure 48 indicate a large majority of respondents would prefer a product from their solid waste. When diving in deeper to the responses, only 1% prefers a landfill to another option. The respondents selecting 'None of the above' do not offer another solution and may require a better understanding of material flows in today's society- there simply is no way in the foreseeable future to eliminate waste altogether; while zero waste is an important goal to strive for, products are designed for obsolescence and until that changes, the issue with handling a city's waste will remain. Most respondents are unaware of WTE or where their waste goes.

However, nearly all want something other than landfill for their waste; furthermore, a majority of respondents are more resistant to any kind of treatment or processing in their own neighborhoods. So despite having factual information and being accepting of WTE, many still prefer the treatment occur out of their sight. This is described below in more detail.

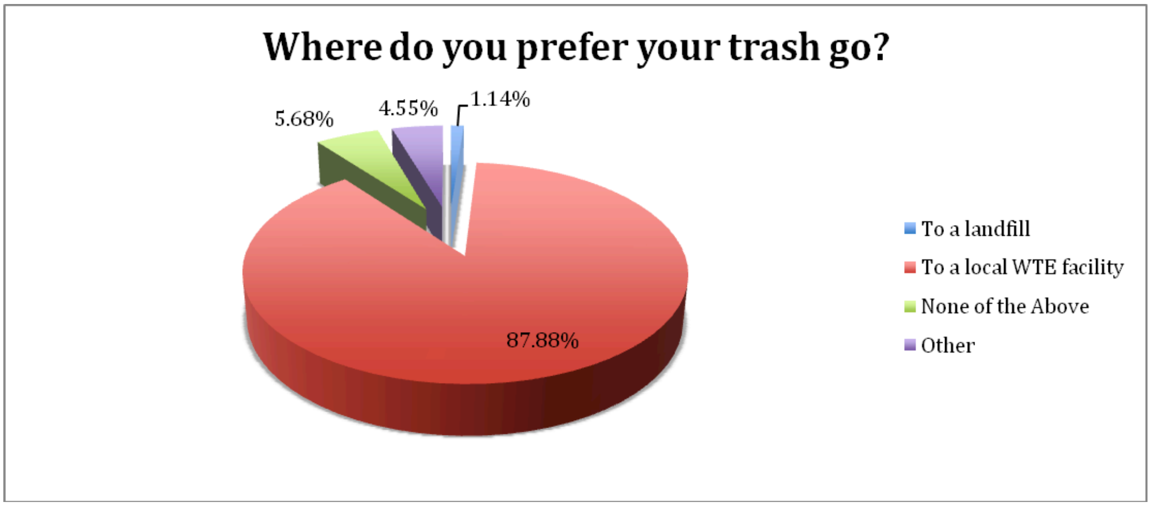


Figure 48: Where Do You Prefer Your Trash Go?

In Figures 49 and 50, the research team put this to the test by asking how the respondents would feel about two different kinds of WTE facilities in their neighborhood. This brought the reality closer to home for the group. A total of 44.49% of respondents were slightly too strongly against a mass burn facility in their neighborhood, and 36.22% were slightly too strongly against a pyrolysis or gasification plant in their neighborhood.

While the overall majority of respondents were neutral to excited in their response to a Waste to Energy plant (Figures 49 and 50), we can see that the possibility of this infrastructure in our sample group's neighborhood still makes them uneasy.

When looking more critically at Figures 49 and 50, the team observed that overall the percentage of the population that accepted WTE facilities in their neighborhood did not change when the option of a higher temperature technology was offered. Similarly, the percentage of the population strongly against remained relatively stable. However, when comparing between mass burn and a higher temperature technology like pyrolysis, the slightly against and neutral positions responded with a change. Whereas more of the group was slightly against mass burn than neutral towards it, more of the group was neutral toward pyrolysis in the follow up question.

This implies there is an underlying belief that a higher temperature technology is "cleaner".

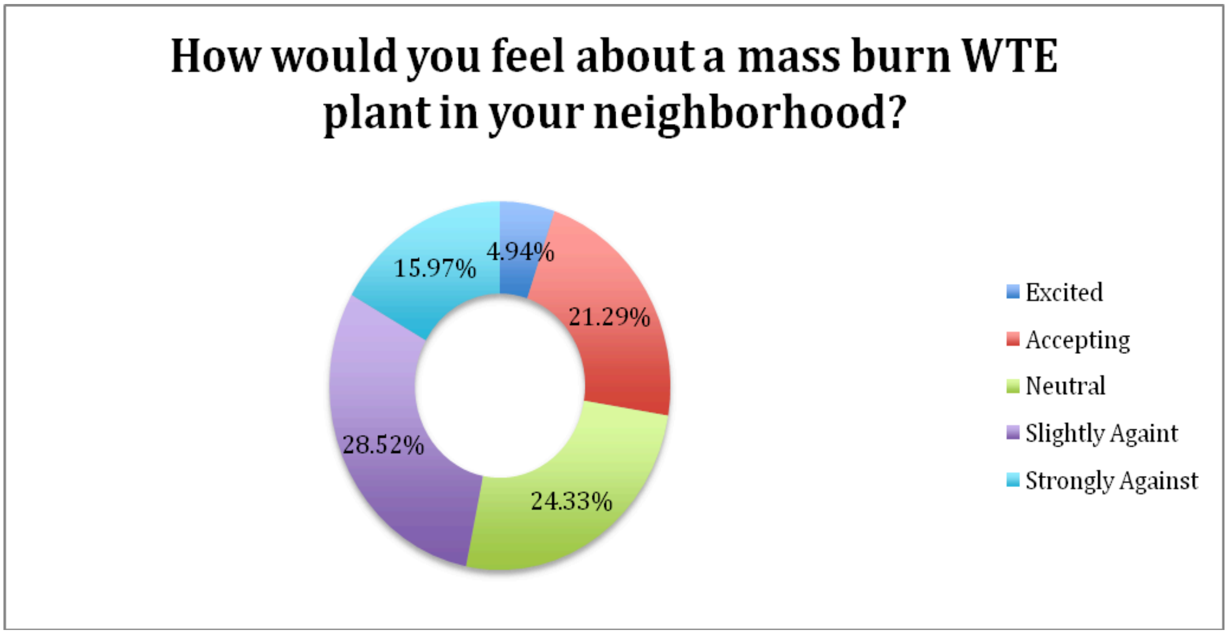


Figure 49: How Would You Feel About a Mass Burn WTE Plan in Your Neighborhood?

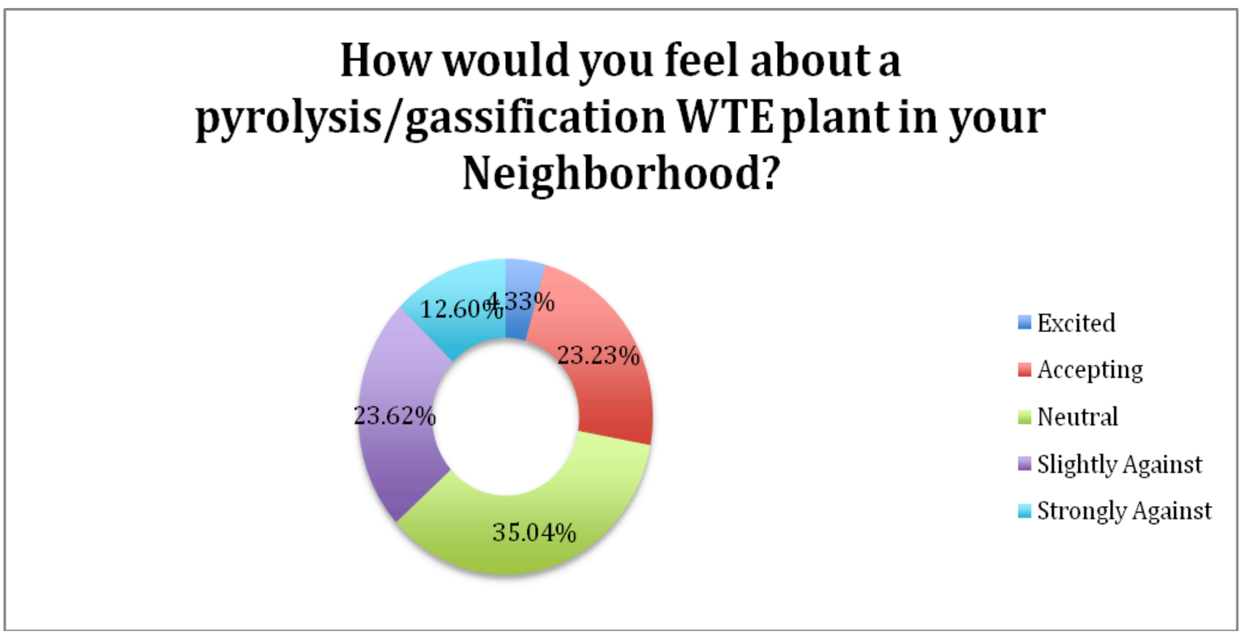


Figure 50: How Would You Feel About a Pyrolysis/Gassification WTE Plan in Your Neighborhood?

Figures 46 through 50 indicate that New York City residents need more education about the solid waste management programs of their neighborhood. The NYDEC has a three hundred million dollar annual budget for waste, most of which goes to transportation of waste out of state. Nationally, solid waste transportation and processing is a 47 billion-dollar a year business; it employs nearly 400 thousand people and requires 148 thousand vehicles to move materials to just over 1,700 landfills and 87 incinerators (National geographic, Human Footprint).

Figure 51 shows the NYDEC's map of WTE facilities currently operating in New York State. The Westchester plant is approximately forty miles from mid-town Manhattan, and a WTE plant in Essex, New Jersey is eight miles distant, and the Hempstead WTE plant is 20 miles, therefore within a 40 mile radius there are three actively operating WTE plants. The team reasons that since nearly 90% of the sample group is unaware of WTE facilities in New York City (Figure 47) and 80% do not know they ever lived in an area where waste was turned to energy (see data question 14), the WTE infrastructure is not currently producing any noticeable issues. This means that some of the reasons for respondents' hesitations may be misplaced.

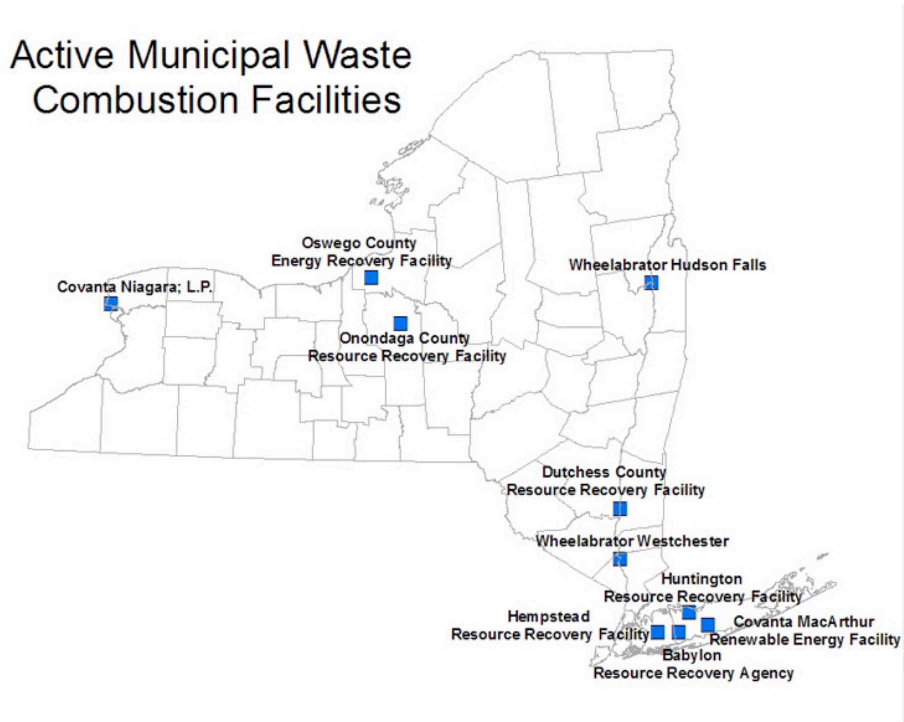


Figure 51: Active Municipal Waste Combustion Facilities

In Figure 52, the researchers cross-referenced respondents who believe they have lived in an area where trash is treated at a WTE facility with age category. The 51 to 60 age category has the highest level of awareness about WTE facilities in their neighborhoods. When compared to Figure 53, this is the age group that has the highest amount of resistance to WTE in their neighborhoods, despite the technology.

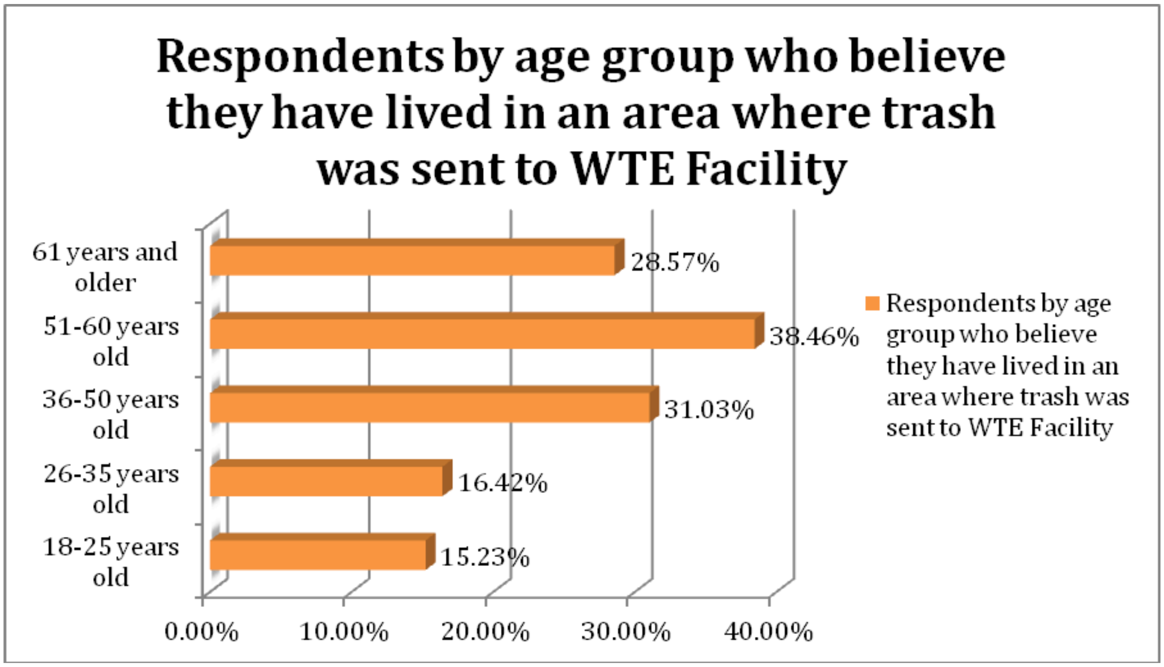


Figure 52: Respondents By Age Group Who Believe They Have Lived in an Area Where Trash Was Sent to WTE Facility

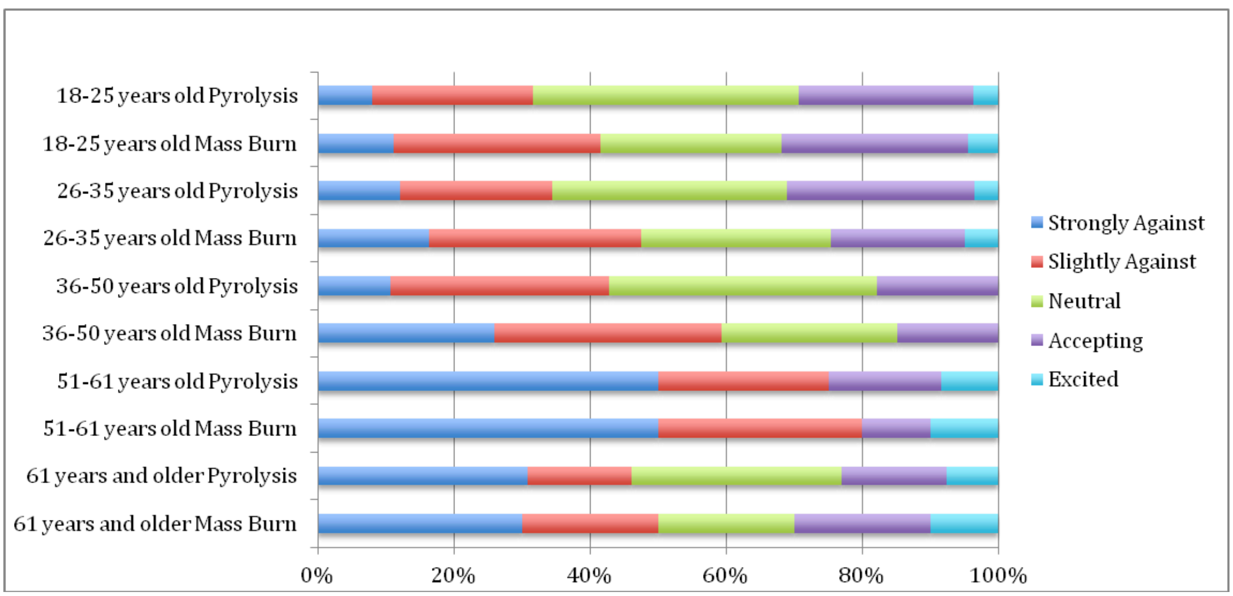


Figure 53: Which Type of Waste-to-Energy Technology Do You Prefer? (By Age)

When comparing Figures 52 and 53 from the accepting side of the image, the younger age groups, 18 to 25 years and 26 to 35 years, are the most accepting of either type WTE facility in their neighborhoods. These age groups also appear to be the least aware of any existing WTE infrastructure. Considering the entire sample group has at least a high school education, this leads the research team to question whether the 51 to 60 age group is basing their opinions more on the information provided or the memory of a smog-ridden city and the unchecked incinerators of the 1970's.

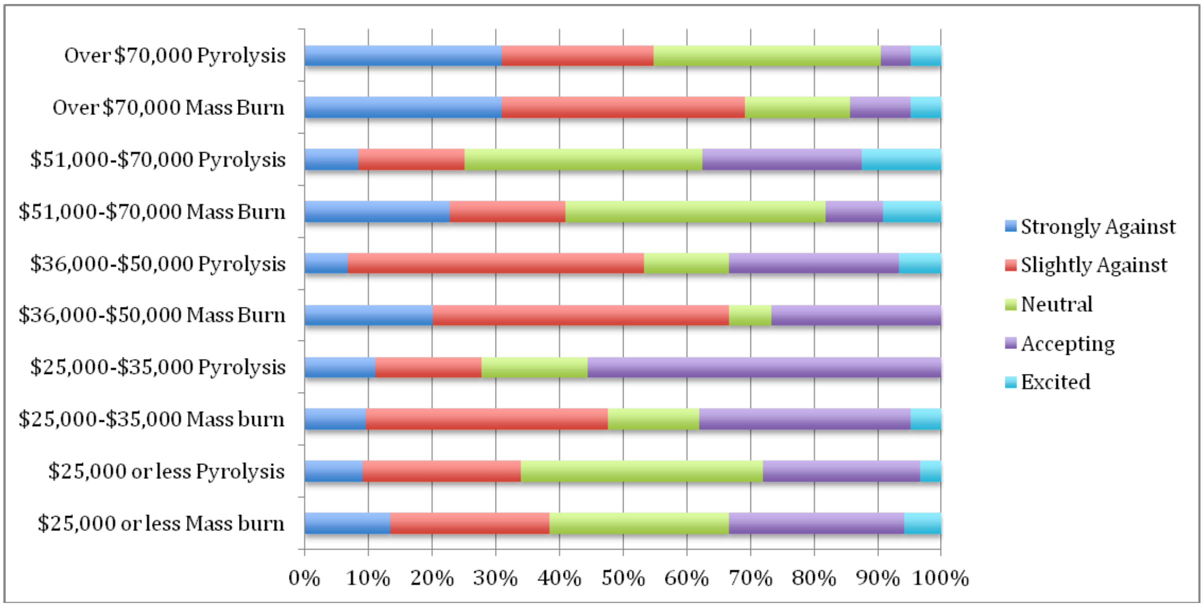


Figure 54: Which Type of Waste-to-Energy Technology Do You Prefer? (By Income)

In Figure 54, researchers looked at level of acceptance of two kinds of Waste to Energy infrastructure against annual income bracket of survey respondents. Overall, the respondents making between $36,000 and $50,000 per year have the strongest objections to any kind of WTE facility. Here it seems there is no real trend as those making over 70K resist as much as those between 36-50K.

Results suggest the acceptance level of WTE facilities, with any technology, is highest among respondents making $35,000 per year and below.

XVIII. Conclusions

Imagine a city in the US that actually pays to import trash, and powers itself on the waste of others. Landfills are uncapped and 'mined' for waste to feed local WTE plants allowing that land to be utilized for a host of new uses, and cities can provide power at a discount to their citizens. The industrial ecology ideal of 'waste is food' begins to permeate through manufacturing, life cycle, and waste management stages. This is not an impossible vision; many locations throughout Europe are moving towards and striving for that result.

The history of NYC's waste disposal shows the city once handled its own waste, albeit not very responsibly. Ocean dumping was an early practice that ended in the 1930's. Landfill dumping was also an early practice, mostly in critical coastal marshes due to low cost and lack of regulation. About one-third of the City's waste was irresponsibly incinerated on-site at some 17,000 apartment buildings and in 22 municipal incinerators. That practice was eventually eliminated due to air quality standards. Landfill outlasted incineration; Fresh Kills landfill on Staten Island at its height received 13,000 tons of the city's trash per day. Since closing Fresh Kills in 2001, NYC has since opted to export its solid waste, and associated problems, to landfill sites in other states, and to one WTE facility in nearby Essex County, NJ. This practice is extremely costly, at an estimated 1 million dollars per day. In addition to being costly, exporting waste is unsustainable because it causes adverse environmental impacts from long distance trucking as well as leaching and methane releases from landfills.

If New York City is going to fulfill its solid waste objectives set out by PlaNYC then it must handle its waste using more sustainable methods. Part of the way the NYC can handle its waste more responsibly is by implementing proven state of the art thermal WTE technologies such as mass burn. If the city reached its recycling goals set out by PlaNYC and continued to send a portion of its waste to WTE facilities outside the city (i.e. Essex, NJ and Niagara Falls, NY), then all that would be necessary is for NYC to build a single additional thermal WTE facility that could handle the remaining *curbside/containerized* solid waste stream. Incorporating the *commercial* waste stream would require more WTE facilities.

However, WTE in NYC has a very troubled past. The Koch administration in the 1970s had plans to build five WTE facilities, one in each NYC borough. The plan was halted, mostly by public sentiment that turned political pressure against it. Despite recent efforts during the Bloomberg administration to revive WTE within the City, NYC still does not appear to accept it as a preferred method of managing solid waste. The team feels this is a missed opportunity, as many cities and nations around the world have agreed solid waste is best managed with the incorporation of WTE.

Since NYC resident public perception is the crux of the issue, a survey was conducted in order to understand New Yorkers' perception of WTE. The results of the survey have limitations, namely slightly skewed age distribution of respondents. The results nonetheless demonstrated that opinions of WTE are more progressive than some might have believed.

Overall, respondents were accepting of WTE technologies, and the more advanced technology (pyrolysis or gasification) did not have significant impact on the percentage of accepting versus strongly against responses. There is still an issue with NIMBY syndrome- that is, the majority of respondents preferred not to have any solid waste treatment in their own neighborhood. This will likely not change no matter the SWM technology. This does provide an opportunity for the City of New York to educate its citizens about the costs and benefits of the available options. Additional education about current versus future practices would be extremely beneficial since 90% of respondents did not believe they ever lived near a WTE facility, and there are three within 30 miles of New York.

As a result, the implementation of a solid waste plan for NYC that incorporates thermal WTE technology may not be looked upon as negatively as it has in the past.

XIX. Recommendations for Future Work

This project explores a very important and complex issue, namely the possibility of sustainable municipal waste management in NYC. Due diligence to the subject matter requires that additional work is needed in order to generate a complete and thorough understanding. That work should include but is not limited to:

- A more comprehensive social and political understanding of NYC unique circumstances regarding sustainable solid waste management.

- An expanded public opinion survey of New York City Residents, comparing results with these findings.

- An information campaign aimed at informing the public of sustainable WTE practices. That campaign would address improving reduction, reuse, and recycling practices as well as WTE.

- A thoroughly researched and actionable WTE facility implementation plan. One that states where, when and how a facility will be financed, constructed and operated, and explored possibilities for Public-Private partnerships.

- A guarantee of state, federal, and EPA oversight to ensure operational and environmental performance over the building’s lifetime.

- An urban planning study that researches possibilities for a WTE facility to be the center of a transformative development, for instance developing brownfield sites into urban recreational parks with WTE providing district heating and power.

XX. Figures

Figure 1: USEPA Estimates of Total and per Capita MSW generation from 1960-2010 *(USEPA.com)*

Figure 2: Greenhouse Gas Emissions by Source *(Support Tool for Materials and Waste Management. WM Journal 2006 August Thorneloe SA, Weitz K, Jambeck J. Application of the U.S. Decision)*

Figure 3: Typical As Received MSW *(EPA WARM v12)*

Figure 4: MSW Fuel Preparations *(www.netl.doe.gov/technologies/coalpower/gasification/gasifipedia/pdfs/production-refuse-derived-fuel-chapter12.pdf)*

Figure 5: Mass Burn Units by Type in the U.S.*(LoRe, et al 2009)*

Figure 6: Europe and US Mass Burn Plants *(ISWA, Waste To Energy-State of the Art Report 2013)*

Figure 7: Mass Burn Combustion Chamber *(Waste Management, V27, Issue 5, 2007)*

Figure 8: Combustion Flow Chart and MBWW Plant Layout *(www.esru.strath.ac.uk ; County Sanitation Districts of Los Angeles County)*

Figure 9: MBWW units and their daily processing capacity *(Micheals 2010)*

Figure 10: Select MBWW units and their Boiler Availability *(LorRe, 2009)*

Figure 11: Ash Usage *(J.V.L. Kiser and M. Zannes, Integrated Waste Services Association, April 2004)*

Figure 12: MSW Incinerator Emission *(http://www.epa.gov/waste/nonhaz/municipal/wte/airem.htm)*

Figure 13: Mass Burn Dioxin Emissions *(WIERT)*

Figure 14: Energy Companies and Technolgies *(Arena 2012)*

Figure 15: Heat Gasifier *(Arena 2012)*

Figure 16: Power Gasifier *(Arena 2012)*

Figure 17: Syngas (CO & H2) Options *(Arena 2012)*
Figure 18: Downdraft or Co-current Gasifier *(http://biofuelsacademy.org)*

Figure 19: Fluidized Bed *(substech.com)*
Figure 20: Circulating Bed *(csfmb.com/services)*

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XXII. Appendix

CITY UNIVERSITY OF NEW YORK
City College of New York
Department of Urban Sustainability

CONSENT TO PARTICPATE IN A RESEARCH PROJECT

Project Title: Social Response to Waste to Energy Facilities in the 5 boroughs of New York City

Principal Investigator: Ms. Casey Cullen, Mr. Eric Fell, Mr. David Salmon, Mr. Ron Russo
Graduate Student
City College
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(908) 447-5446

Faculty Advisor: Professor Marco Castaldi
Associate professor, Chemical Engineering
City College
307 Steinman Hall
New York City, New York 10031
(212) 650-6679

Site where study is to be conducted: Via the internet

Introduction/Purpose: You are invited to participate in a research study. The study is conducted under the direction of Ms. Casey Cullen, Mr. Eric Fell, Mr. David Salmon, Mr. Ron Russo, and Dr. Marco Castaldi. The purpose of this research study is to determine the general public's awareness and feelings about Waste to Energy facilities in New York City. The results of this study may help determine the level of public awareness about existing technologies, describe the level of education needed to inform the public about their waste management options, and inform our final report which will recommend a particular layout for waste to energy facilities in the five boroughs.

Procedures: Approximately 500 individuals are expected to participate in this study. Each subject will participate in one anonymous online survey. The time commitment of each participant is expected to be 30 minutes. Each session will take place at your most convenient computer access point.

Possible Discomforts and Risks: Your participation in this study may involve providing personal demographic information. To minimize these risks we do not ask for your name or any identifying information. We simply wish to determine if there are patterns in levels of knowledge. If you are upset by a line of questioning as a result of this study you should email Ms. Casey Cullen at cullen00@citymail.cuny.edu.

Benefits: There are no direct benefits. However, participating in the study may increase general knowledge of Waste to Energy technology and its possibilities for New York City.

Voluntary Participation: Your participation in this study is voluntary, and you may decide not to participate without prejudice, penalty, or loss of benefits to which you are otherwise entitled. If you decide to leave the study, please contact the principal investigator, Casey Cullen, to inform her of your decision.

Confidentiality: The data obtained from you will be collected via survey website. The collected data will be accessible to IRB Members and Staff, the Waste to Energy Capstone Team, and Dr. Castaldi. The researcher will protect your confidentiality by securely storing the data. The collected data will be stored on a computer in a password protected file, with consent kept separate from data.

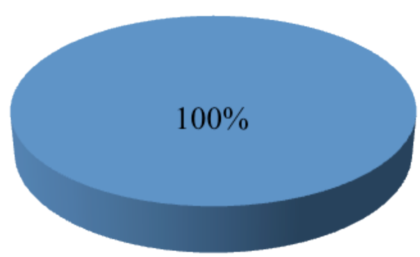
Contact Questions/Persons: If you have any questions about the research now or in the future, you should contact the Principal Investigator, Casey Cullen, (908) 447-5446, ccullen00@citymail.cuny.edu. If you have any questions concerning your rights as a participant in this study, you may contact Ms. Tricia Mayhew-Noel, tmayhewnoel@ccny.cuny.edu.

Note: All results based on 366 participants

Survey Question #1

<u>Statement of Consent</u>: “I have read the above description of this research and I understand it. I have been informed of the risks and benefits involved, and all my questions have been answered to my satisfaction. Furthermore, I have been assured that any future questions that I may have will also be answered by the principal investigator of the research study. I voluntary agree to participate in this study. By signing this form I have not waived any of my legal rights to which I would otherwise be entitled." Please write "I agree or I understand"- do not provide your name for confidentiality purposes.

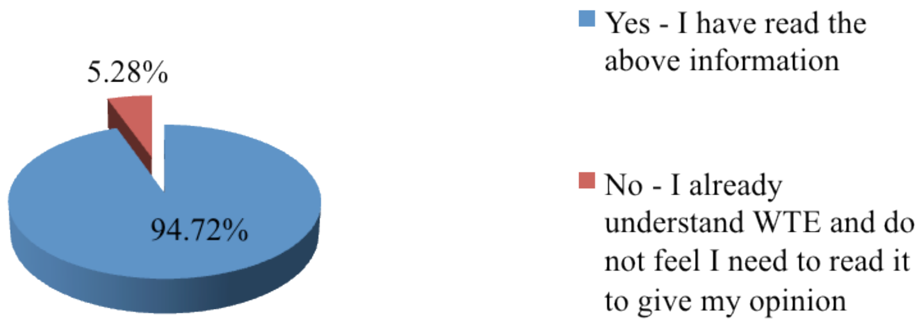
Result



Survey Question #2
(Introductory Information)

On average, each person in the US generates about 4 pounds of trash per day, resulting in about 250 million tons of waste generated per year. Of this waste, about 54% is sent to landfills, 33% is recycled and 13% is sent to Mass Burn facilities across the country. These facilities burn solid waste in a closed system to produce steam that can be used to make electricity and in some cases heat. An ash product is left over after the burning process that can be used in concrete mixtures for road construction, as a cover for landfills, or be buried. The process of converting solid waste into energy is a thermal process commonly referred to as Waste to Energy (WTE). Mass Burn is the dominant thermal WTE technology used in the world today. This is due to its relatively simple operation, high capacity to convert trash, strict emissions requirements and ability to make electricity. In some places the extra heat that is created is also used to provide ‘district heating’ to homes and businesses. There are two additional but less common technologies that thermally convert solid waste into energy, they are Gasification and Pyrolysis. They offer some qualities that mass burn does not, such as modular construction, the ability to make liquid fuels and some processes produce fewer harmful lower air emissions (pollution) and ash. However, gasification and pyrolysis are technologies that are still in the development stages in regards to processing solid waste because solid waste can be very different from batch to batch. WTE has become an important topic recently, as the city of New York has set an ambitious goal of diverting 75% of its solid waste from landfills by the year 2030. Part of reaching this goal will require that NYC as a whole increase its recycling, reuse and composting rates while also utilizing some form of WTE. The survey below is intended to gauge public perception of WTE as a method to manage New York City’s municipal solid waste. The information provided will be used for research purposes and is completely anonymous. Do not provide any personal information on the form.

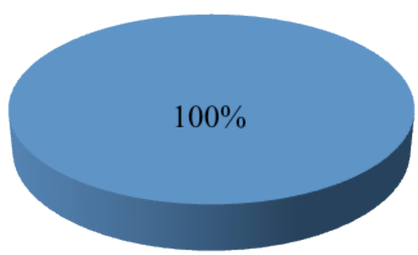
Result



Survey Question #3
(Background Information)

3) I agree to allow my responses to be used for research purposes and understand that my answers will remain anonymous. Please type "Yes" or "I agree" below.

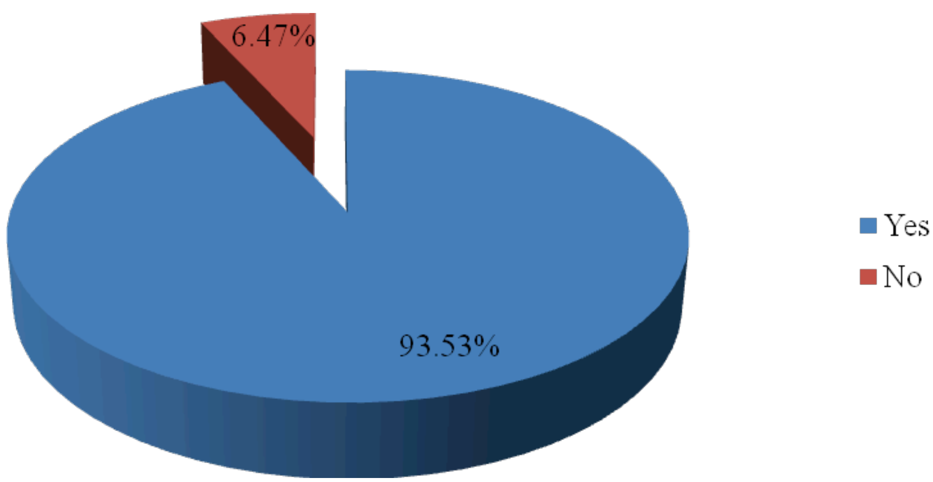
Result



Survey Question #4
(Background Information)

Are you a New York State Resident?

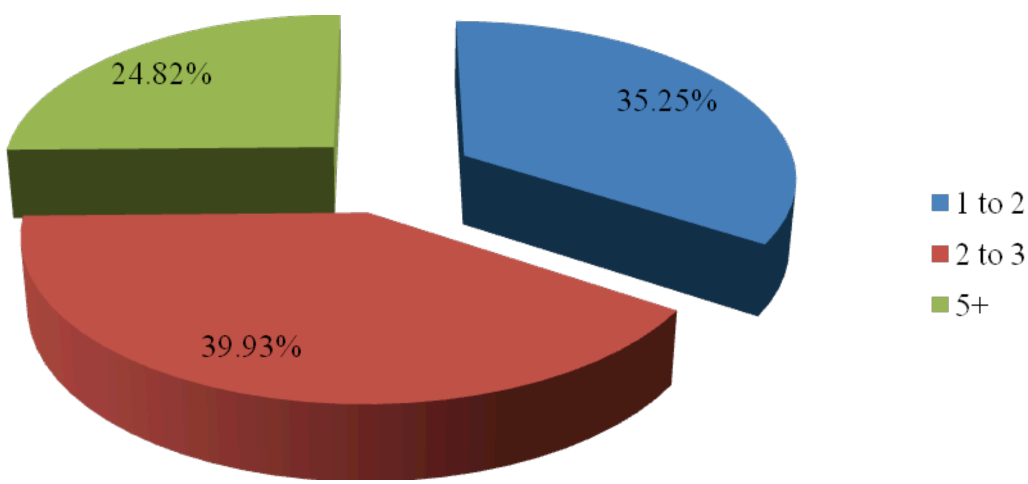
Result



Survey Question #5
(Background Information)

How many people live in your household, including yourself?

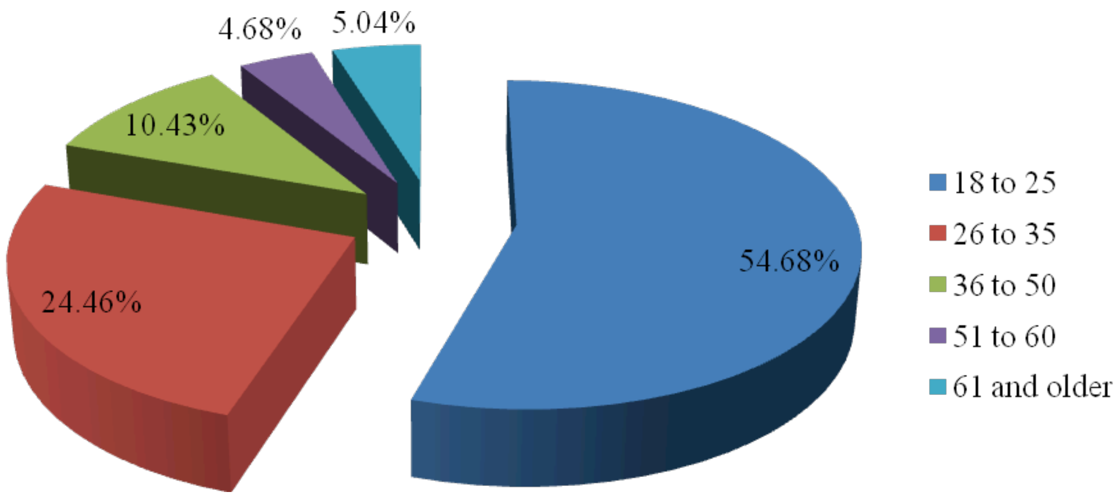
Result



Survey Question #6
(Background Information)

What age category are you in?

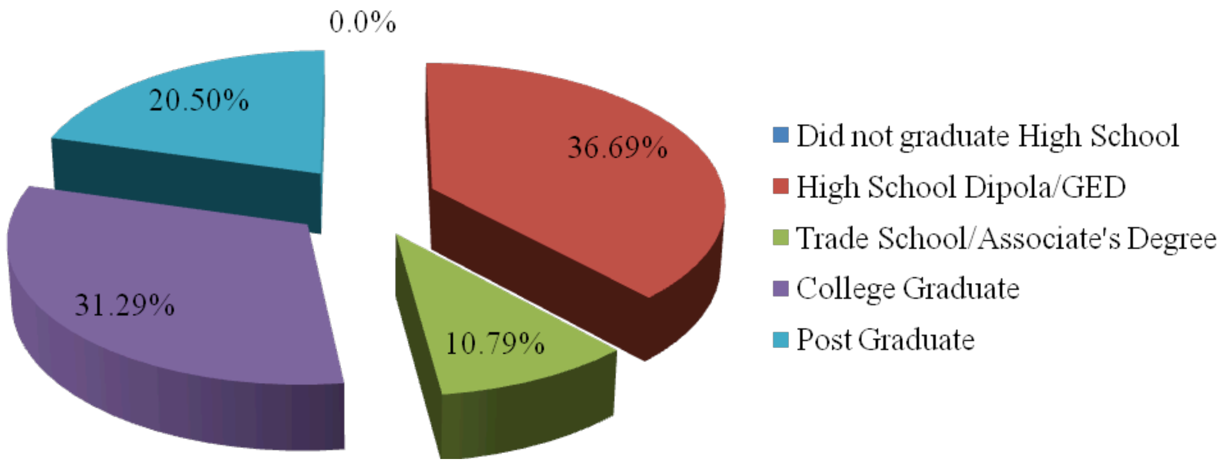
Result



Survey Question #7
(Background Information)

Please tell us the highest level of education you completed.

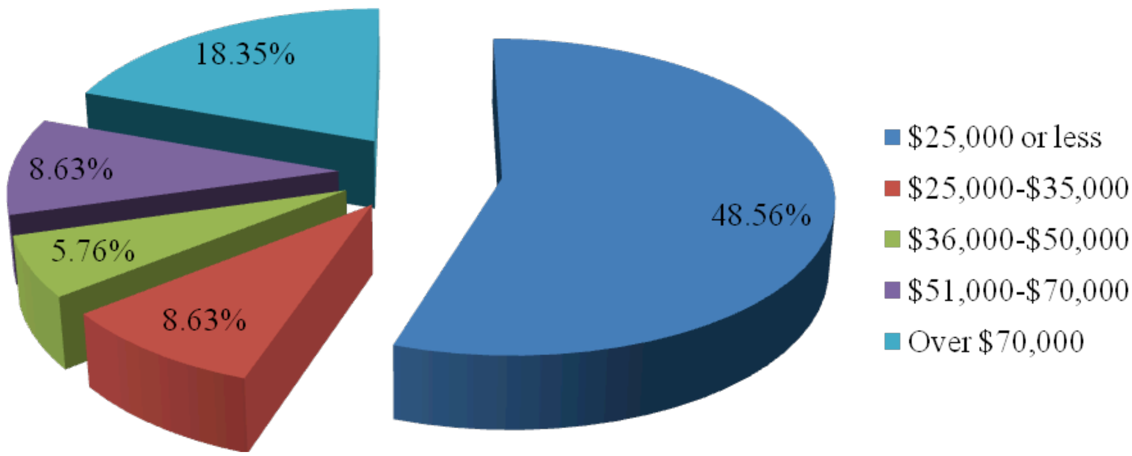
Result



Survey Question #8
(Background Information)

Please select your personal annual income range.

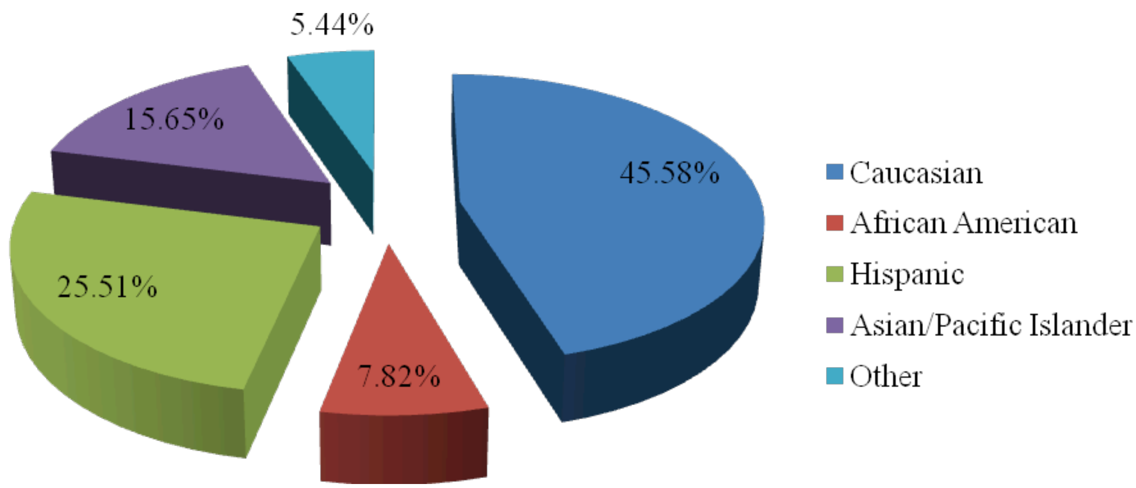
Result



Survey Question #9
(Background Information)

What is your ethnic background (Please select all that apply)?

Result



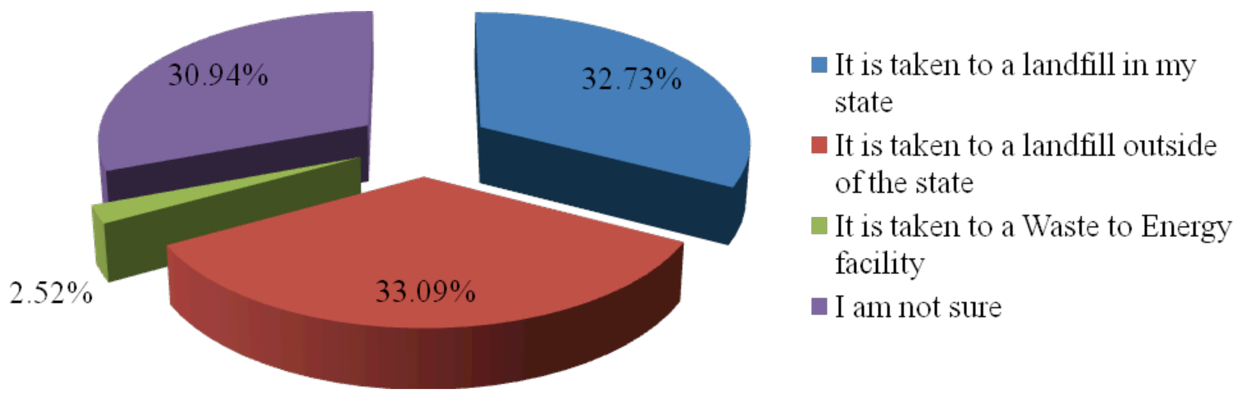
Other Responses as follows:

- Arab American
- West Indian
- Middle Eastern Arab

Survey Question #10
(Background Information)

Where do you believe that your trash goes after you throw it away?

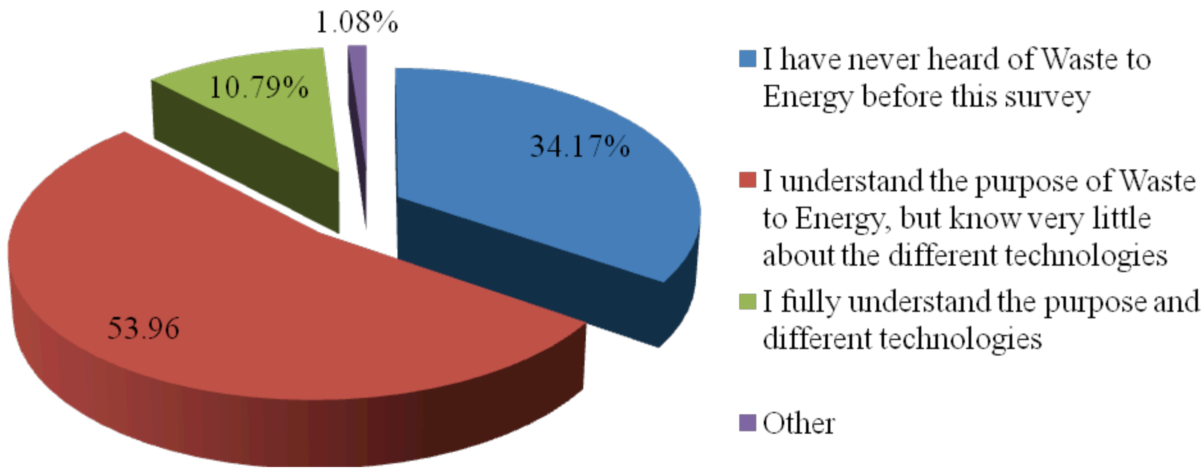
Result



Survey Question #11
(Background Information)

Please tell us how much you know about Waste-to-Energy?

Result



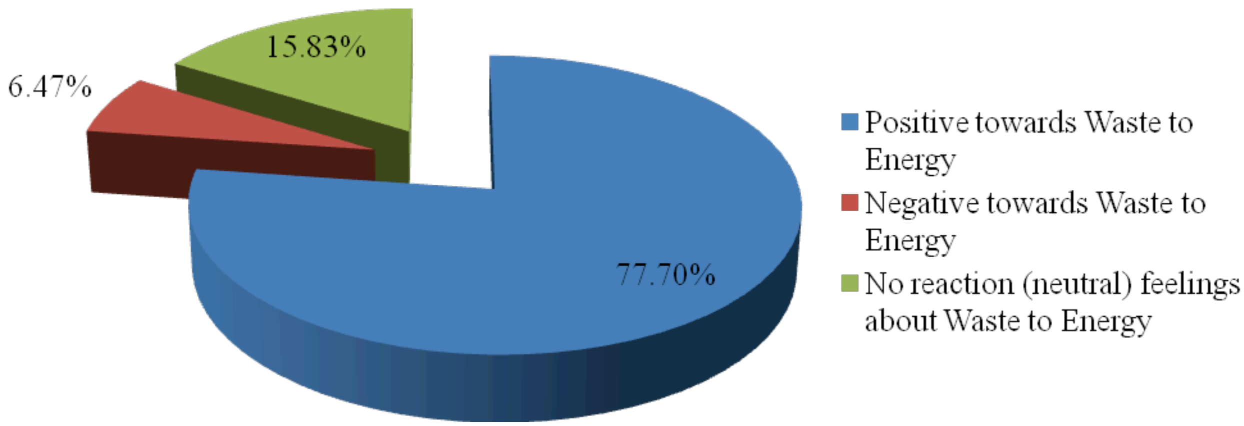
Other Responses as follows:

- I have read about WTE, but also heard it was a bit too expensive and therefore still small scale.
- I have done some research on WTE and have observed gasification devices in operation, but I do not know about mass burn technology.
- I have just learned about WTE from the introduction of this study.

Survey Question #12
(Background Information)

When you hear "Waste-to-Energy", do you feel a positive or negative reaction?

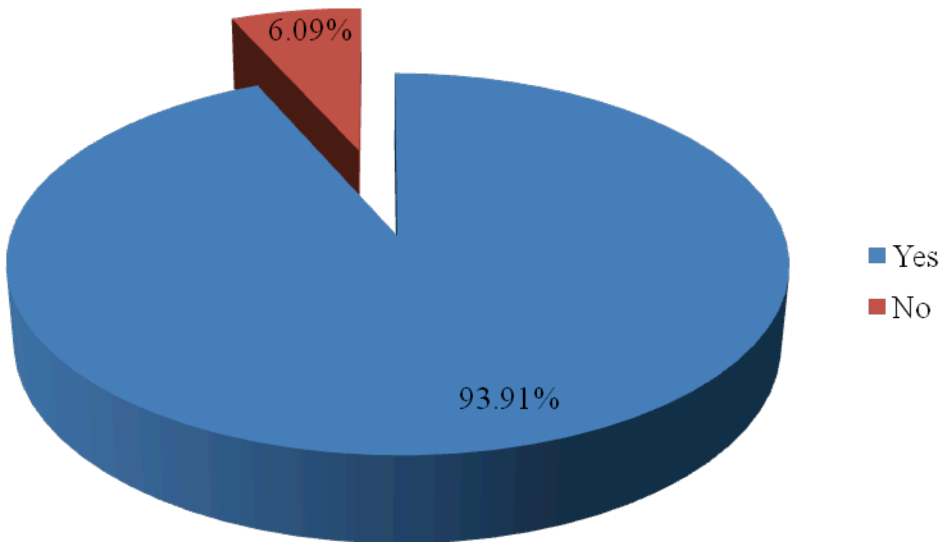
Result



Survey Question #13
(Background Information)

Does your household recycle?

Result



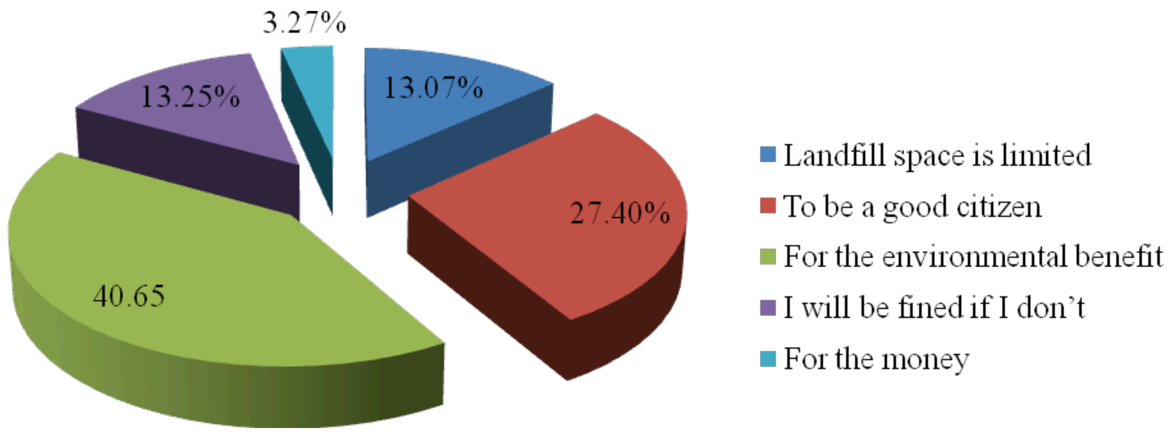
Other Responses as follows for "If no, what roadblocks have prevented your home from recycling?":

- What can be recycled and not recycled
- Awareness, parents laziness, parents were not raised with recycling, parents claim it is a waste of time
- Not enough recycling facilities nearby
- Time and not very promoted around my location
- Little to no understanding on how recycling works or where it is taken to
- Others in the household do not care
- The building I live in does not recycle
- Too much work and we do not know who picks it up
- The city we live in does not take all recyclable items

Survey Question #14
(Background Information)

If you answered yes, your household recycles – Please tell us why (Select all that apply)?

Result



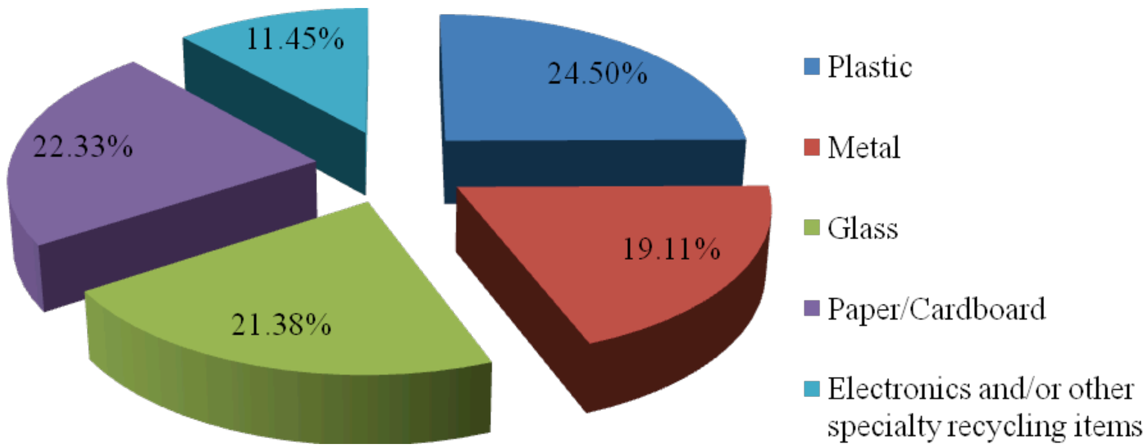
Other Responses as follows:

- Habit
- I do not want the super to lecture me
- It is just as easy as throwing out the trash, so I do not see why not
- It is the right thing to do
- It is an easy way to send a non-renewable resource back into the cycle and not to WTE facilities in Scandinavia or to end up as particulate matter in the Pacific Ocean
- The city picks it up
- Recycling increases NYC's revenue, which indirectly benefits its citizens
- It is a requirement where I live

Survey Question #15
(Background Information)

If your household recycles, what items do you recycle (Select all that apply)?

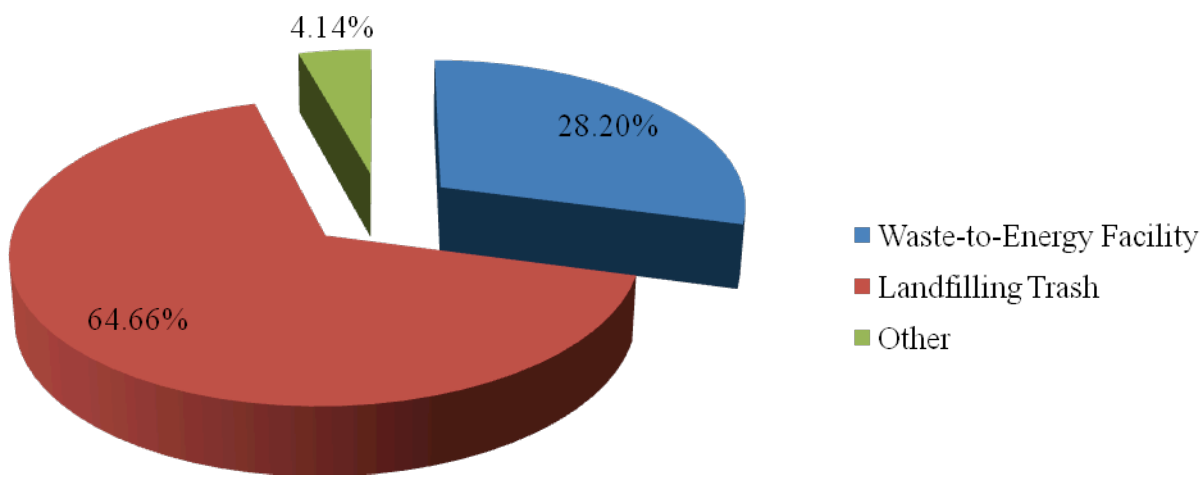
Result



Survey Question #16
(Waste Management in NYC)

Which of these methods of waste disposal in NYC do you think produces more Green House Gases over its lifetime?

Result



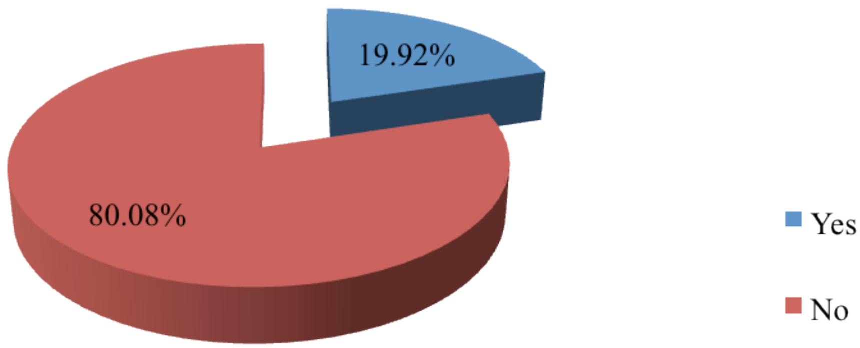
<u>Other Responses as follows:</u>

- I am not sure
- I would like to see some research on the green house gases produced in each method of disposal
- I do not know
- Burning it
- I have no idea
- Similar amounts
- Unsure
- Don't forget about the opportunity cost of landfilling: burning more fossil fuels for energy (rather than trash)

Survey Question #17
(Waste Management in NYC)

To your knowledge, have you lived anywhere where waste is turned into energy?

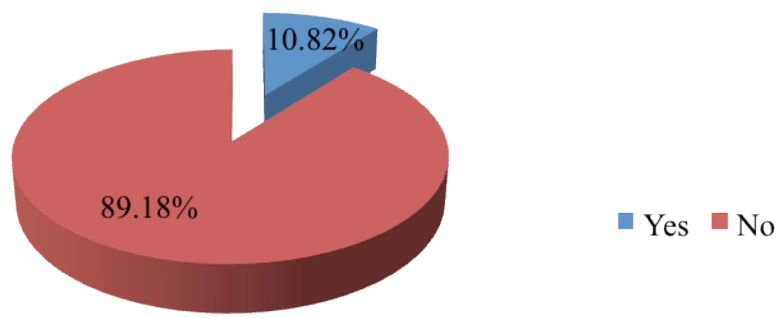
Result



Survey Question #18
(Waste Management in NYC)

Are you aware of any WTE facilities in and around New York City (if yes, please tell us which)?

Result



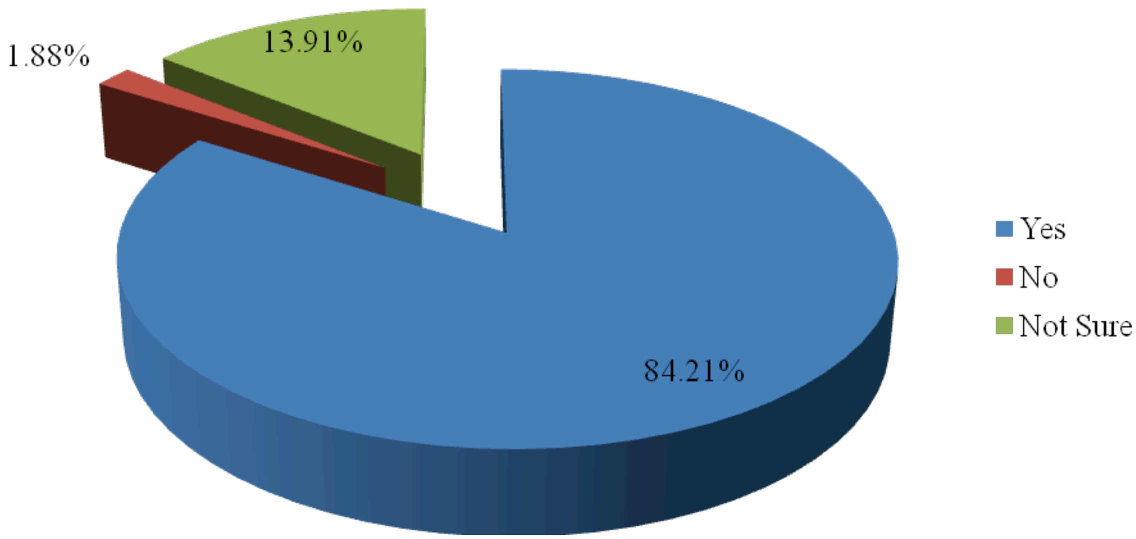
Other Responses as follows:

- Peekskill, NY
- Newark, NJ
- Controversial Sites in Harlem/Upper East Side
- Southwestern Connecticut
- Bridgeport, CT
- Morristown, NJ
- North of Manhattan/Bronx
- NJ Turnpike
- Washington Heights

Survey Question #19
(Waste Management in NYC)

If NYC had a robust recycling program, would you consider using the remaining waste that is non-recyclable as fuel for a Waste-to-Energy facility?

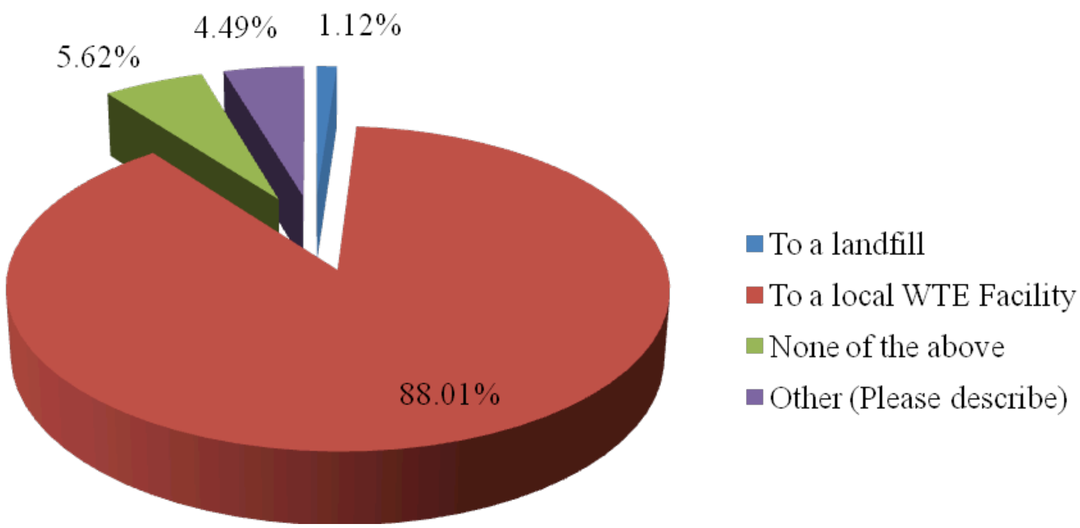
Result



Survey Question #20
(Waste Management in NYC)

Given what you know now about Waste-to-Energy and landfilling, where would you prefer your trash go?

Result



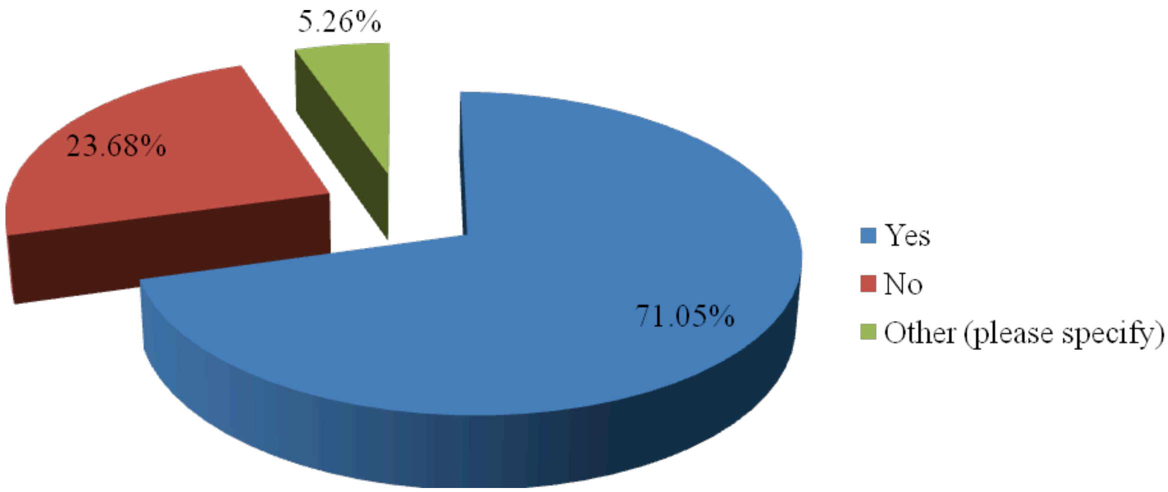
<u>Other Responses as follows:</u>

- To a WTE Facility in New Jersey
- 100% recycling with a ban on products that cannot be recycled
- Gasification or Mass Burn
- A more comprehensive recycling facility
- Everything should be recycled
- Compost and recycling
- Where it would be most beneficial with the least amount of pollution
- Recycled, re-used or re-purposed
- Composted

Survey Question #21
(Waste Management in NYC)

True or False: Waste-to-Energy technology is considered a renewable energy in New York State?

Result



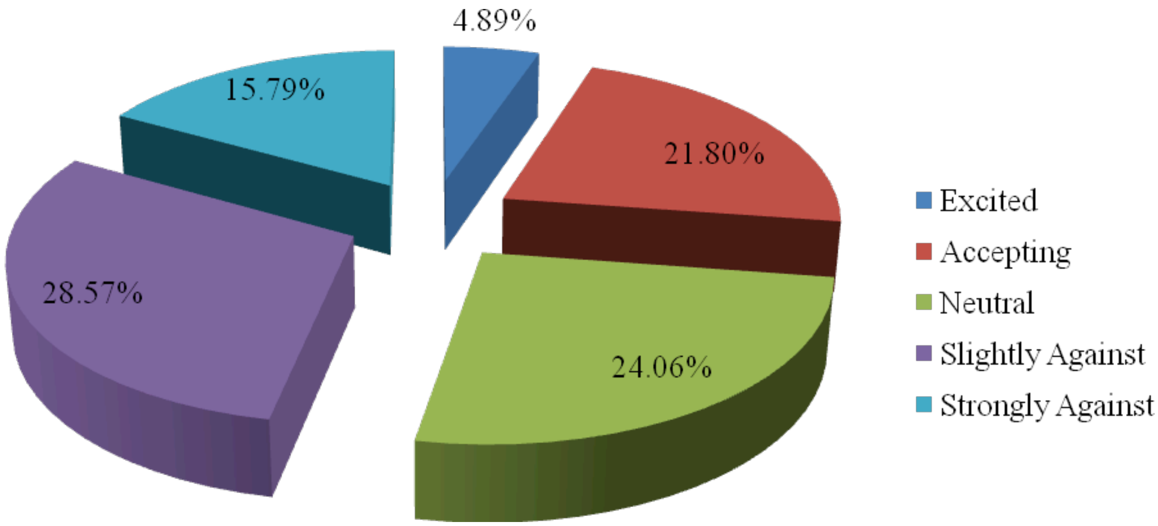
Other Responses as follows:

- Do not know
- Just because something is called renewable does not mean that it actually is
- I consider it renewable, but I cannot speak on behalf of all of New York State
- Unsure
- Unknown

Survey Question #22
(Waste Management in NYC)

How would you feel about a mass burn WTE plant in your neighborhood?

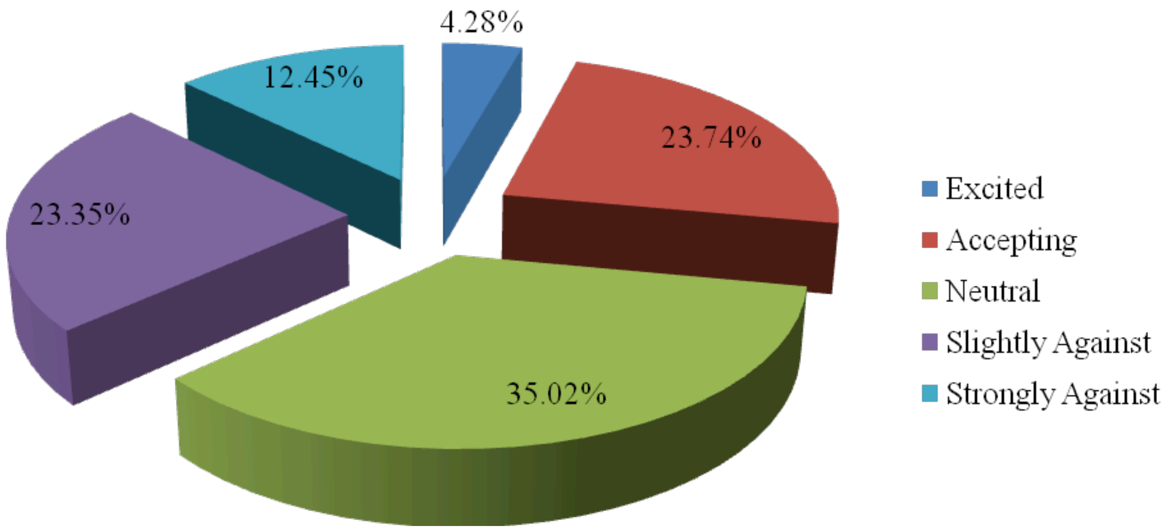
Result



Survey Question #23
(Waste-to-Energy in NYC)

How do you feel about having a pyrolysis or gasification WTE plant in your neighborhood (Recall from the introductory information that pyrolysis and gasification are still thermal technologies, but they occur at higher temperatures)?

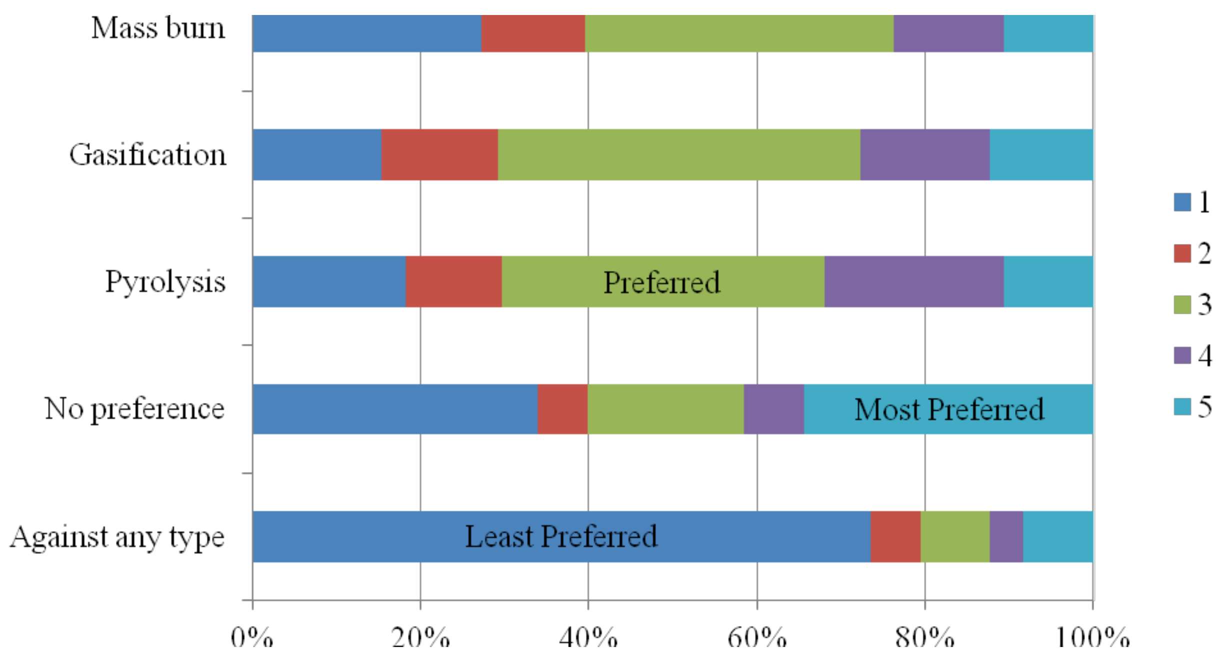
Result



Survey Question #24
(Waste-to-Energy in NYC)

Which type of Waste-to-Energy technology do you prefer (please rank each type: 1 being least preferred and 5 being most preferred)?

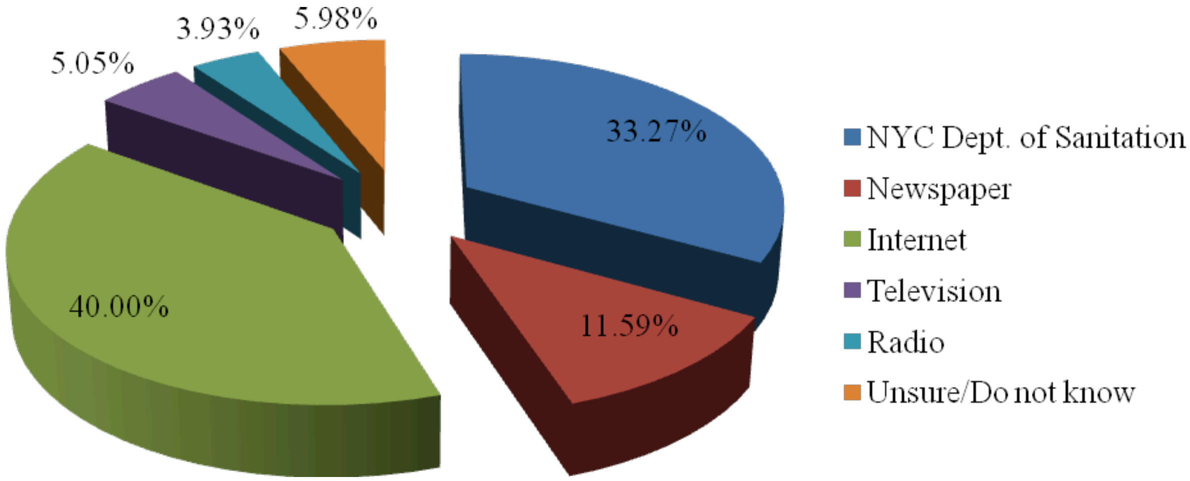
Result



Survey Question #25
(Waste-to-Energy in NYC)

Where can you find out more information about solid waste or related practices if you want to (please select all that apply)?

Result



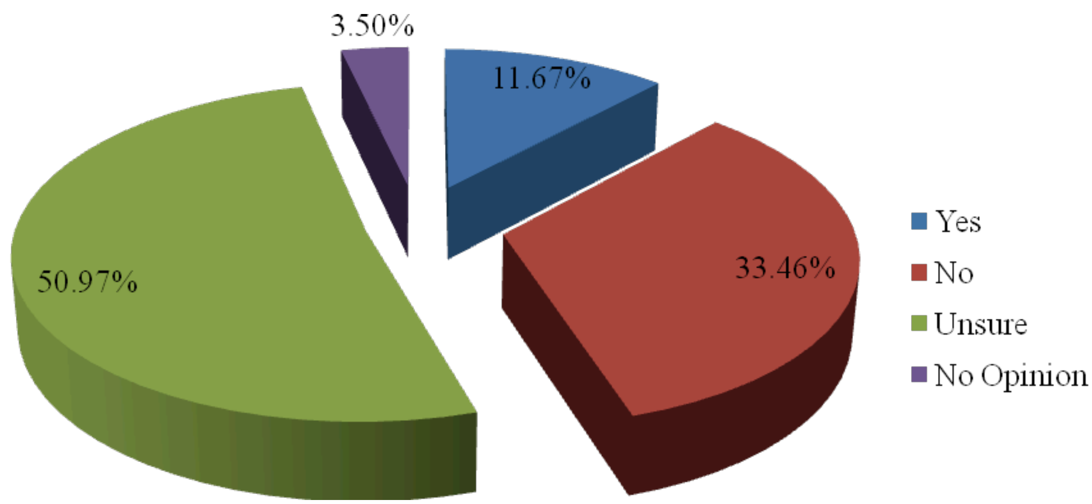
<u>Other Responses as follows:</u>

- Businesses
- CCNY Grove School of Engineering
- Research
- Colleagues
- Government agencies
- Non-government organizations
- Department of Environmental Protection
  Environmental Protection Agency
- GrowNYC
- NYSERDA

Survey Question #26
(Waste-to-Energy in NYC)

Do you think NYC handles its solid waste in a responsible and sustainable way?

Result


3.50%
11.67%
33.46%
50.97%
Yes
No
Unsure
No Opinion