



THE WASTE-TO-ENERGY ACT OF 2011



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Acronyms

CAA	Clean Air Act
CO ₂	Carbon Dioxide
GHG	Greenhouse Gas
GWP	Global Warming Potential
IRS	Internal Revenue Service
LCA	Life Cycle Analysis
MSW	Municipal Solid Waste
MWh	Megawatt hour
NO _x	Nitrogen Oxide
SO _x	Sulfur Oxide
USEPA	United States Environmental Protection Agency
WtE	Waste-to-Energy
WWTP	Wastewater Treatment Plant

Cover Photos:

Rosenthal, Elisabeth. (2010). *The Incinerator as Eye Candy*. The New York Times.
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TABLE OF CONTENTS

Table of Contents	3
Executive Summary	4
Introduction.....	5
1. The Proposed Legislation	6
1.1 Intent of the Bill	6
1.2 Implementation Overview	6
2. The Waste Management Problem.....	7
2.1 Waste Composition	7
2.2 Traditional Municipal Solid Waste Management	8
2.3 Wastewater Treatment	10
3. Landfills in Depth.....	11
3.1 Landfill Structure and Maintenance.....	11
3.2 Landfill Leachate	12
3.3 Landfill Air Pollutants	12
3.4 Greenhouse Gas Emissions	13
3.5 Waste Transportation Impacts.....	14
4. The Need for Alternative Energy Sources.....	15
4.1 Local Atmospheric Pollution from Fossil Fuels	15
4.2 Global Climate Change	15
4.3 The Energy Problem	17
5. What is Waste-to-Energy?.....	18
5.1 Biological Treatment Technologies	18
5.2 Thermal Processes: Combustion, Pyrolysis, Gasification, Plasma Arc.....	20
5.3 Integrated Waste Treatment.....	24
5.4 Benefits of Waste-to-Energy Technology.....	25
6. Reactions to Waste-to-Energy	26
6.1 Common Misconceptions about WtE Technology	26
6.2 Science-Based Standards for Waste- to-Energy	29
6.3 Lessons to Learn for the Future	30
7. Measuring Program Success	31
7.1 Metrics for Evaluation	31
7.2 The Long-Term Impacts of WtE Technologies	31
7.3 Lifecycle Analysis	33
Conclusion	36
Bibliography	37

EXECUTIVE SUMMARY

Waste management is a ubiquitous challenge in modern society. Landfilling is the most common solution in the United States, and this presents a host of environmental and human health risks that make it infeasible in densely populated areas. The Waste-to-Energy Technology Act of 2011 incentivizes investment in new solutions that compliment recycling and generate surplus electricity. Innovative WtE technologies use biological and thermal processes to break down waste material to generate energy in the form of direct heat, liquid fuels, or gaseous fuels. While public perception of WtE has often been marred by the outdated practice of waste incineration, it is important to understand that it produces less pollution and fewer emissions. It has the potential to reduce greenhouse gas emissions and the production of toxic wastes relative to landfilling and coal burning. WtE represents a new solution for the waste management problem in the United States that is already operating in other developed countries. It provides a cleaner form of energy and it provides a more efficient method for managing waste.

INTRODUCTION

While the average American might see the wisdom in the saying, “One man’s trash is another man’s treasure,” he may find it harder to believe that one man’s trash is another man’s heat, electricity, or fuel. In order to understand the paradigm shift of waste-to-energy (WtE), one must understand that it has little to do with traditional incineration. WtE technology has rapidly advanced in the last 30 years in response to the lack of landfill space in many cities and the rising energy costs at a global level.

According to the Energy Recovery Council, the leading national trade organization for WtE in the United States, 86 plants were operating in 24 states in 2010, with the capacity to process more than 97,000 tons of municipal solid waste (MSW) per day (Michaels, 2010). The same group estimates that the WtE facilities in the U.S. have the capacity to generate the energy equivalent of 2,790 megawatt hours of electricity, which is less than 1% of the national energy demand (USEIA, 2009).

Many U.S. WtE plants were built after the 1973 oil crisis during a period of high energy costs. However, very few have been built in the last 15 years due to tax reforms and policy changes that removed incentives for the development of WtE facilities (Carlin, 1994). The U.S. is now once more affected by rising energy costs; and this is coupled with a growing waste problem in many parts of the country. Cities such as New York transport waste hundreds of miles every day to landfills in other states. As a result many Americans have little awareness of how much waste they produce; and they fail to comprehend the challenge of dealing with their waste in the long-term.

A growing “green” awareness is emerging in many parts of the country, with emphasis on local produce, energy efficient buildings, and recycled products. Americans are increasingly conscious of the need to reduce, reuse and recycle; however there are many products that must be landfilled or destroyed, and these items present serious risks to public and environmental health. Finally, policymakers and the general public increasingly accept that climate change is a scientific fact and the levels of carbon dioxide and other greenhouse gases are impacting the global climate. Innovations in WtE facilities present a new opportunity to address the question of waste in a way that responds to multiple social and environmental concerns: waste management, renewable energy, and the mitigation of climate change.

1. THE PROPOSED LEGISLATION

1.1 Intent of the Bill

The *Waste-to-Energy Technology Act of 2011* (HR 66) would amend section 48(a)(2)(A) of the Internal Revenue Service (IRS) Code of 1986 to extend a 30% investment tax credit to qualified waste-to-energy facilities. A WtE facility refers to a site that processes municipal solid waste or sewage sludge and converts the output to heat, fuel, or energy. MSW is waste from households and commercial establishments, while sewage sludge consists of the solids left over from publicly owned wastewater treatment plants (WWTPs). There are different technologies and processes for generating energy from this waste, including anaerobic digestion, combustion, pyrolysis, and gasification that produce different forms of direct energy and fuel. The proposed legislation simultaneously addresses the issues of waste management, energy production, and environmental protection by incentivizing the development and implementation of new WtE technologies.

1.2 Implementation Overview

The Secretary of the Treasury will approve qualified facilities under terms in consultation with the Administrator of the Environmental Protection Agency (EPA). The criteria for eligible projects includes requiring financial viability, least use of recyclable materials, limited production of air pollutants and greenhouse gases, a measured reduction in energy consumption, and reduced risks to environmental and human health. Specifically excluded are facilities that re-circulate leachate, a practice that can improve the efficiency of biological processes, but does not qualify as energy production. Another disqualifying activity is delaying installation of the cover on a landfill once it reaches maximum capacity.

Within 180 days of enactment, the Administrator will award tax credits to applicants that meet the criteria of the bill. The entire program is capped at one billion dollars and no project will be considered that already receives an IRS tax credit or an American Recovery and Reinvestment Act grant, nor one that was placed in service before the date the bill was passed.

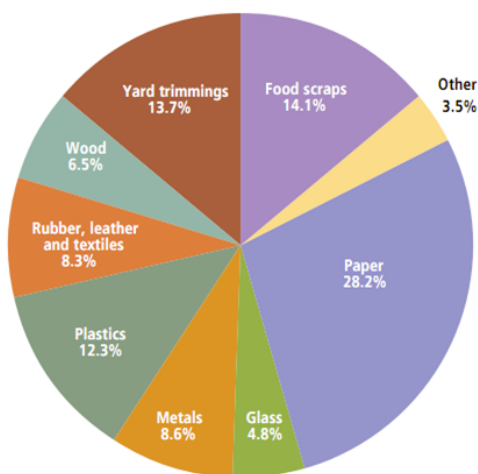
Project sponsors must submit an application within two years of enactment and supply all documentation and evidence to prove that their facility meets the requirements within one year of application. Upon complete allocation of funds, the Secretary and the Administrator will report to Congress concerning applicant names, amounts allocated, a cost-benefit analysis of the program, the administrative effectiveness of the program, and recommendations for future funding. Information on credit recipients will become public record.

2. THE WASTE MANAGEMENT PROBLEM

2.1 Waste Composition

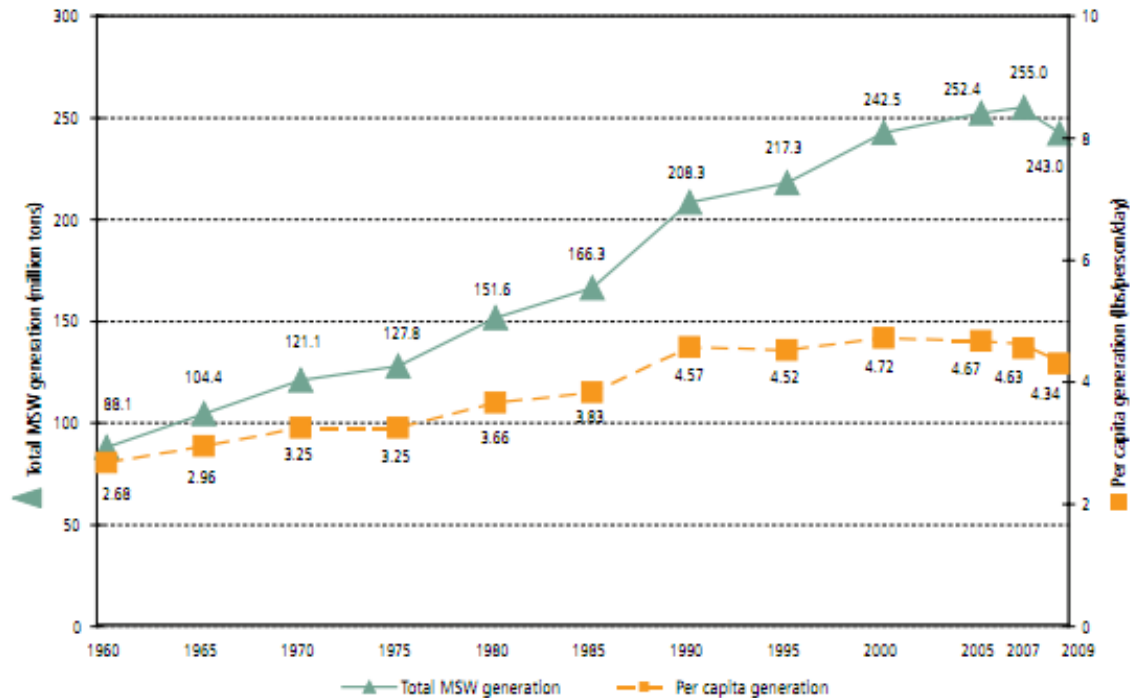
The impact of municipal solid waste in the United States is the most significant environmental problem addressed by the new legislation. MSW is defined as common trash or garbage, generated by households, schools, hospitals, and businesses (USEPA, Municipal Solid Waste: Electricity from Municipal Solid Waste, 2011). It consists primarily of non-toxic biodegradable materials such as paper, cardboard, wood, yard trimmings, and food scraps, as well as non-biodegradable plastic, metal, and glass (see Figure 1).

Figure 1: Total MSW Generation in the U.S. by Type (USEPA, Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2009, 2009)



In 2009, Americans produced about 243 million tons of MSW, or about 4.3 pounds of waste per person per day (USEPA, Municipal Solid Waste: Electricity from Municipal Solid Waste, 2011). Of this material, 82 million tons were either recycled or composted, leaving 161 million tons that were dumped into landfills (USEPA, Municipal Solid Waste: Electricity from Municipal Solid Waste, 2011). Figure 2 shows a steady rise in U.S. MSW production from 1960 to 2007. While it is important to note that this did decrease slightly in 2008 due to increased recycling, increased population growth will likely increase total MSW production.

Figure 2: Total U.S. Annual Municipal Solid Waste Generation and Per Capita Generation from 1960 to 2009 (USEPA, Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2009, 2009)

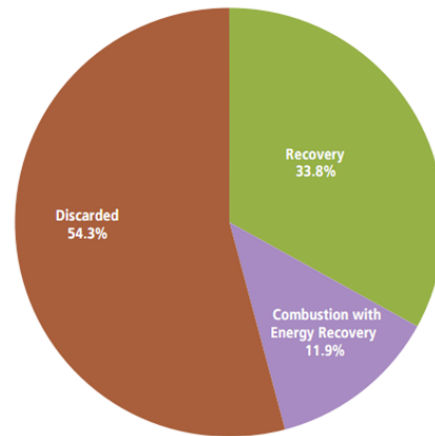


This high level of waste production requires different management approaches in different parts of the country that are influenced by economic, social, and environmental factors. This is discussed in greater detail in the following section.

2.2 Traditional Municipal Solid Waste Management

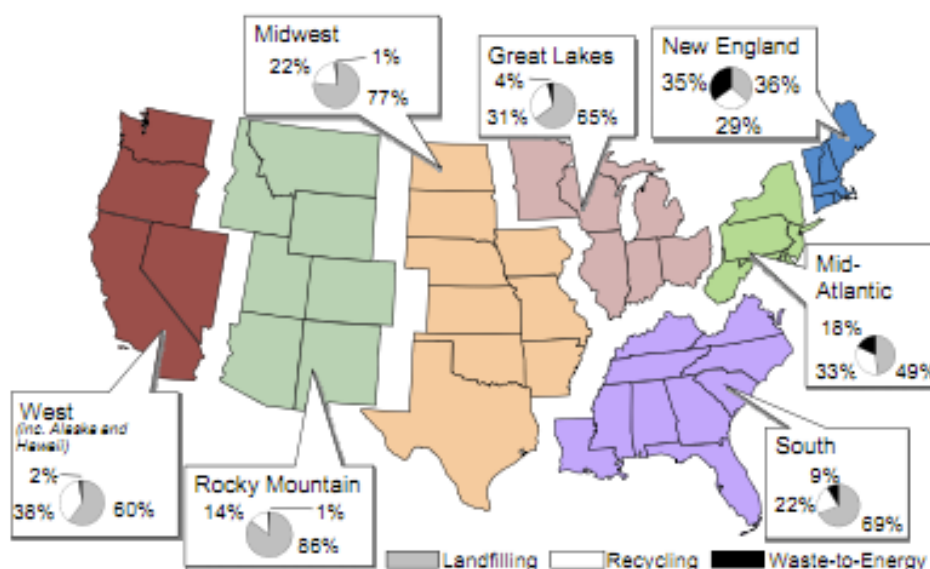
In the past, waste incineration created many environmental problems. For example, in New York City between 1910 and 1968, there were almost 17,000 private incinerators with no emission controls and 32 municipal incinerators with close to no controls (Walsh, Chillrud, Simpson, & Bopp, 2001). Municipal incinerators emitted almost one million tons of pollutants into the atmosphere between 1910 and 1968 (ibid.). Toxic emissions included nitrogen oxides, sulfur oxides, and other hazardous chemicals such as dioxins and lead. With the passage of the Clean Air Act in 1970, many facilities were forced to close due to the cost of compliance with pollution control regulations. When these facilities closed, the waste was redirected to landfills. Today, landfilling is the most prevalent form of waste disposal in the U.S., receiving over half of all MSW (see Figure 3).

Figure 3: Management Practices for Municipal Solid Waste in the United States (USEPA, Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2009, 2009)



Landfills accept all types of nonhazardous wastes (hazardous waste is sent to special landfills which are not considered eligible for WtE) and remain open until they reach capacity. Several unsustainable consequences result from landfilling, including the pollution inherent with hauling trash from its source to landfills, the use of valuable and ultimately limited space, the production of methane gas (CH₄) during the anaerobic decomposition of waste, and the potential for pollution from both improper management and insufficient regulation. Figure 4 shows the percentage of total waste landfilled in different parts of the country.

Figure 4: Regional Differences in the Management of MSW (University of Michigan Center for Sustainable Systems, 2010)



While parts of the nation may still have sufficient space to dispose of MSW in nearby landfills, urban areas are finding it increasingly difficult to dispose of their trash locally and often haul trash to distant places.

2.3 Wastewater Treatment

The second major waste source targeted by the legislation is sewage sludge, the byproduct of public wastewater treatment plants (WWTPs). There are currently over 16,000 WWTPs and 2,000 central sludge processing facilities in the U.S. (USDOE, 2004). The undesirable pollutants from wastewater are processed in the treatment facility and are broken down into a number of different forms, depending on the level of treatment. During the primary treatment phase, the sludge is made up of large solids that settle due to gravity. Next, the sludge is submitted to aerobic biological treatments, yielding a mass of organic matter known as “activated sludge.” Finally, the sludge goes through anaerobic biological processes like denitrification to produce a more refined biomass (Niessen, 2002).

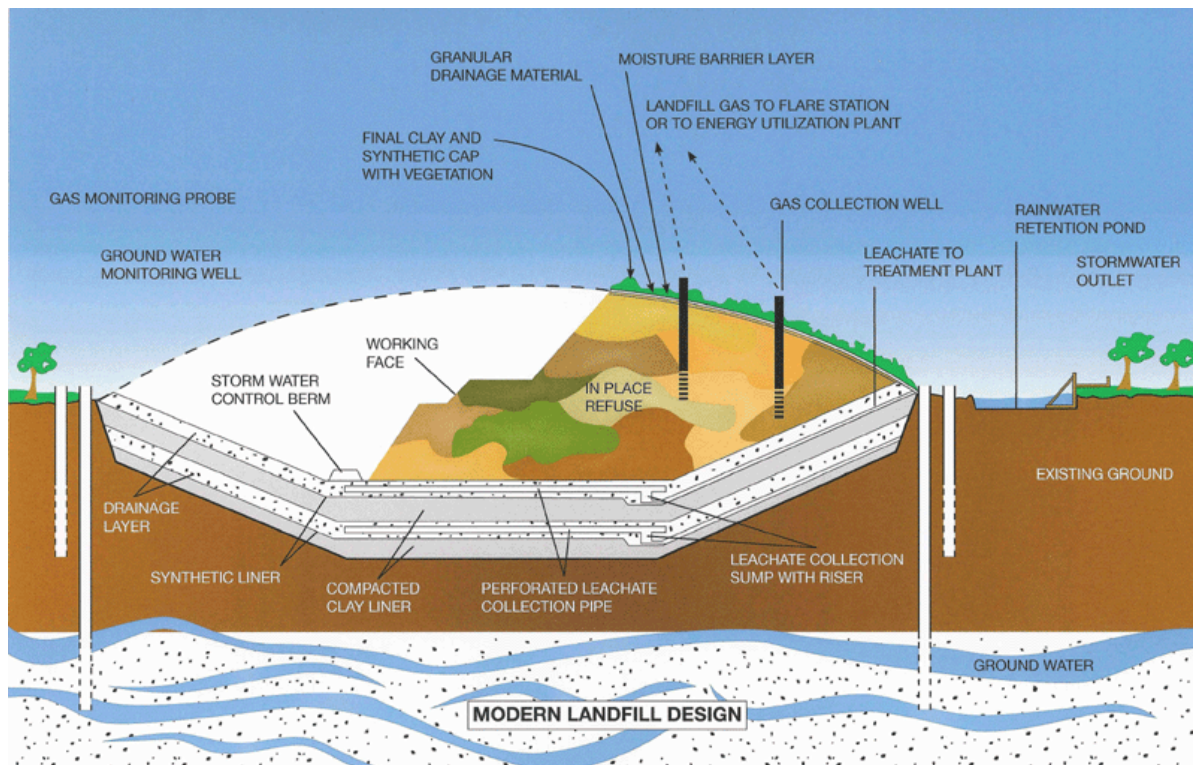
When sludge undergoes anaerobic digestion, it produces methane gas which can be used as a fuel source. This reduces facility operating costs; since sewage contains 10 times the amount of energy a WWTP needs (WERF, 2011). Utilizing methane, a powerful greenhouse gas, ensures that it will not be released into the atmosphere. However, only 650 processing facilities nationwide use anaerobic digestion to produce methane gas (WERF, 2011). The remaining waste is dried and then composted, incinerated or landfilled (WERF, 2011).

3. LANDFILLS IN DEPTH

3.1 Landfill Structure and Maintenance

The age of a landfill determines the construction and maintenance standards to which it must adhere. In the past, landfills were unregulated exposed dumps that accepted all kinds of waste, resulting in a greater likelihood of air and water pollution. In the late 1970s, the development of hazardous waste disposal sites diverted hazardous materials from MSW landfills to facilities with stricter disposal standards and specialized treatments. In 1993, the Resource Conservation and Recovery Act required that landfills use protective synthetic liners and layers of clay to protect the ground before filling in the area with waste. Modern landfills feature surface covers that prevent rainwater infiltration, and gas collection wells to capture landfill gas. Although modern landfills follow these more stringent regulations, they still do not fully prevent the releases of significant air and water pollution.

Figure 5: Modern Landfill Design (Runco Environmental Inc., 2010)



3.2 Landfill Leachate

One of the most severe environmental impacts of landfills is the pollution of surface water and groundwater by leachate. Leachate is formed when rainwater filters through the waste and dissolves organic and inorganic materials. It can be released during the operational period of the landfill and for many years after its closure. Leachate produced earliest in the lifecycle of a landfill is most toxic (Kjeldsen, Barlaz, Rooker, Baun, Ledin, & Christensen, 2002). Should the cover fail, a landfill can continue producing leachate until it is repaired or all of the toxic materials have dissolved. The main chemicals of concern are dissolved organic matter and nutrients that cause soil pollution and eutrophication. Eutrophication is the release of excessive amounts of nitrogen into water bodies, causing imbalances in marine ecosystems such as algal blooms and de-oxygenated “dead zones.” Landfills can also leach heavy metals such as cadmium, chromium, copper, lead, and industrial chemicals including pesticides and plasticizers.

Leachate reaches groundwater sources through any breach in the landfill liner. The federal government requires both the monitoring of these liners for leaks and the testing of nearby groundwater sources. Leaks are detected by a network of monitoring wells positioned between the final barrier layer and groundwater. The efficacy of this system depends on the number of wells in place, as more wells provide more opportunities to detect small-point leaks. Unfortunately building wells adds to the overall monitoring costs of a landfill and can become prohibitively expensive. Testing groundwater determines if a leak has occurred but fails to prevent groundwater pollution since it only alerts monitors after contamination; hence each landfill represents a compromise between environmental and fiscal responsibility (NNEMS, 1998).

3.3 Landfill Air Pollutants

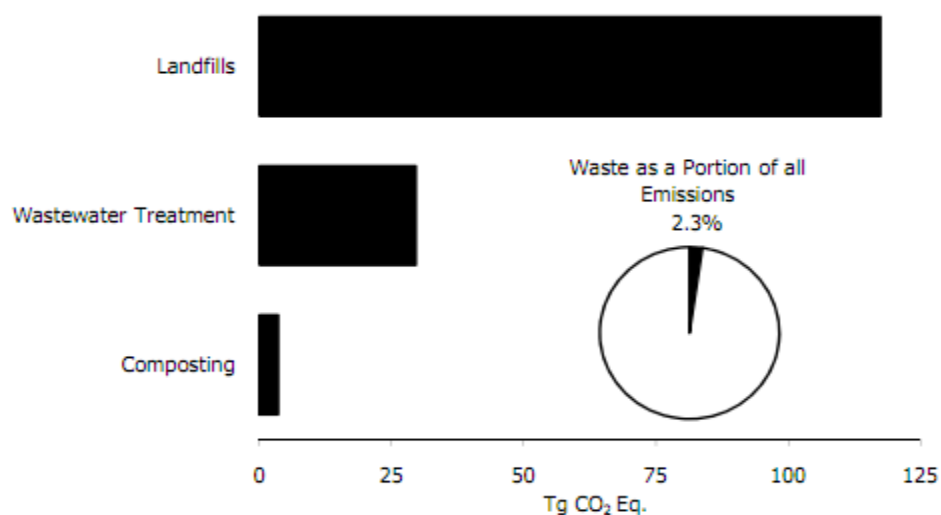
Some MSW material has the potential to release hazardous air pollutants (HAPs) as it decomposes in landfills. This includes cleaners, paints, solvents, pesticides, and adhesives which can release toxins such as vinyl chloride, ethyl benzene, toluene, and benzene. The negative impacts of these toxins on human health includes central nervous system damage (in the case of vinyl chloride and toluene), cancer (vinyl chloride and benzene), and reproductive problems (toluene and benzene) (CCCC, 2001).

HAPs present in leachate that can become gaseous are called volatile organic compounds (VOCs). They are produced from paints, aerosols, cleansers, insect repellents, air fresheners and other similar household products. VOCs contribute to local smog production and ozone formation, as well as numerous health impacts such as respiratory problems, loss of coordination, and kidney and central nervous system damage. Lastly, landfills produce sulfur oxides (SO_x) and nitrogen oxides (NO_x) which contribute to local pollution problems such as smog and acid rain.

3.4 Greenhouse Gas Emissions

According to the EPA's 2011 U.S. Greenhouse Gas (GHG) Inventory Report, waste activities in 2009 generated emissions of 150.5 teragrams of equivalent carbon dioxide (Tg CO₂e), which represents just over 2% of total U.S. GHG emissions (see Figure 6). Of the 150 Tg CO₂e emitted, the vast majority comes directly from landfills, close to 125 Tg CO₂e. The other two sources, wastewater treatment and composting, make up a far smaller fraction, only 25 Tg CO₂e, of total GHGs emitted through the processing of waste.

Figure 6: Teragrams of Equivalent CO₂ from Waste Management Sources (USEPA, U.S. Greenhouse Gas Inventory Report, 2011)



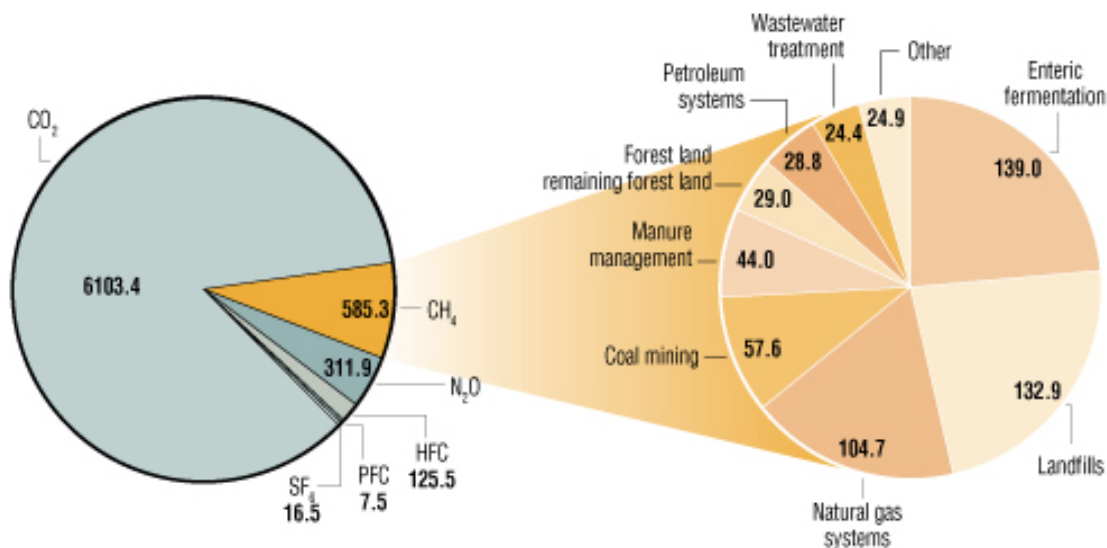
Methane gas is the primary atmospheric GHG released by landfills and wastewater treatment plants through anaerobic decomposition. Methane is an important contributor to global warming and has a global warming potential (GWP) 21 times greater than CO₂ (see figure 7). This means that relatively small amounts of methane can cause proportionately greater warming. The concept of GWP was developed to compare the ability of each GHG to trap heat in the atmosphere relative to other gases. The definition of a GWP for a particular GHG is the ratio of heat trapped by one unit mass of the GHG to that of one unit mass of CO₂ over a specified time period.

Figure 7: Global Warming Potential of Common Greenhouse Gases (USEPA, Non-CO₂ Greenhouse Gas Emissions from Developed Countries: 1990-2010, 2010)

Greenhouse Gas	Global Warming Potential
Carbon Dioxide (CO ₂)	1
Methane (CH ₄)	21
Nitrous Oxide (N ₂ O)	310

Landfills account for 17% of methane emissions in the U.S. while WWTPs are responsible for about 4% (see Figure 8). Other sources contributing to atmospheric methane gas concentrations include rice cultivation, ruminant livestock emissions, resource extraction, and the burning of fossil fuels (USEPA, Methane: Sources and Emissions, Where Does Methane Come From?, 2011). Significant methane production typically begins one or two years after the disposal of waste in a landfill and continues for another 10 to 60 years (USEPA, 2011 U.S. Greenhouse Gas Inventory Report, 2011).

Figure 8: Total GHG and Methane Emissions in the U.S. in 2007 in Millions of Metric Tons (BioCycle, McComb, 2009)



While landfills capture about 75% of methane gas with current technologies, the remaining 25% is released into the atmosphere (USEPA, Compilation of Air Pollutant Emission Factors, 1995). The gas that is captured is flared to convert methane to carbon dioxide or used to generate energy (known as landfill gas-to-energy).

3.5 Waste Transportation Impacts

Pollution releases from MSW begin in the first stage of truck collection. According to USEPA, the nationwide average waste transport distance by truck is 20 miles. In the example of New York City, waste is loaded onto trucks and driven to states as far away as Virginia, Ohio, and Pennsylvania (Cohen, 2008). Between collecting the waste from homes or apartment complexes, to compiling it at transfer stations and then redistributing it onto trucks, MSW collection and disposal is a dirty, dangerous and costly process (Cohen, 2008). Accidents can spill or dump waste at any point along the journey and gases are released into the atmosphere as the process of decomposition has already begun.

4. THE NEED FOR ALTERNATIVE ENERGY SOURCES

4.1 Local Atmospheric Pollution from Fossil Fuels

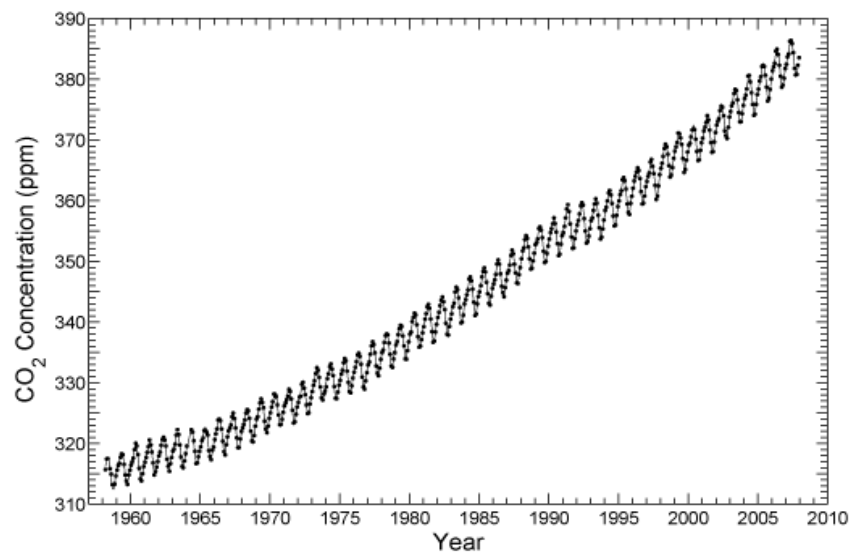
A cursory look at the environmental problems associated with fossil fuel combustion highlights significant contributions to annual CO₂ emissions in the U.S. Fossil fuel combustion contributes to increased atmospheric concentrations of nitrogen oxides (NO_x), sulfur dioxide (SO₂) concentrations, and heavy metals. NO_x and SO₂ emissions create smog, acid rain, and regional haze. In 2008, 66% of the national SO₂ inventory came from power plants, 98% of that portion specifically from coal-fired power plants (Schneider, 2010).

Numerous health toxicity studies in the U.S. further emphasize the dangerous nature of pollution from fossil fuel combustion. Fine particle matter from fossil fuel combustion lodges in human lungs, leading to health effects such as heart attacks, asthma, and premature death. Additionally, power plants are a source of the release of dioxin. Dioxin has been proven to cause reproductive and developmental problems. By reducing the amount of fossil fuels consumed in the U.S., WtE can reduce the number of these local air pollutants.

4.2 Global Climate Change

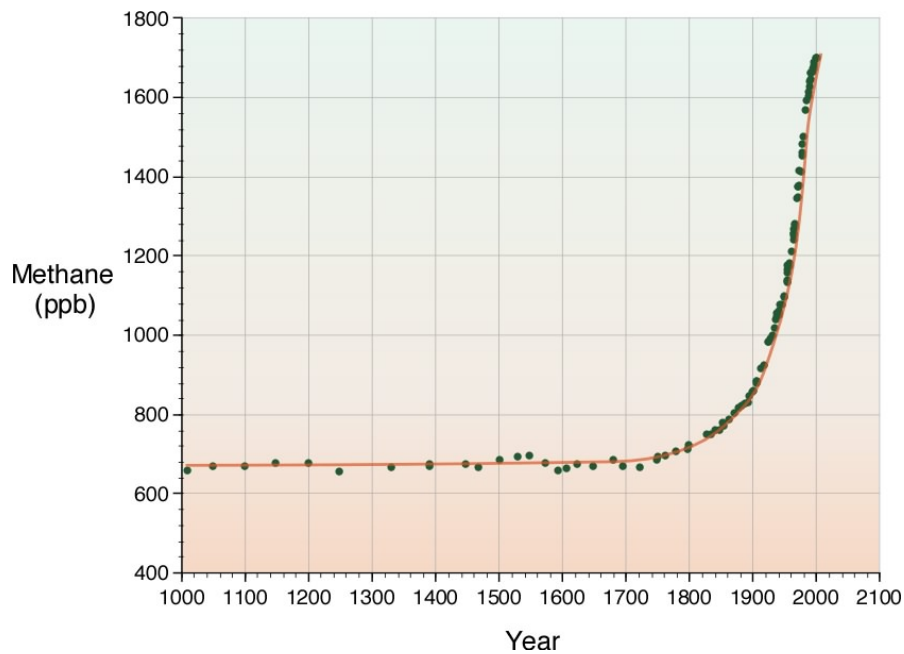
Current climate change trends are a result of increasing global averages of both air and ocean temperatures. This is primarily due to GHG emissions from the burning of fossil fuels. They contribute to global climate change by trapping heat, much like glass does in a greenhouse. According to the EPA, climate change is any significant change in measures of climate (such as temperature, precipitation, or wind) lasting for an extended period of time. Human consumption of fossil fuels since the industrial revolution has caused a steady and unnatural increase in atmospheric CO₂ levels (see Figure 9).

Figure 9: Keeling Curve Recorded in Mauna Loa, Hawaii (Scripps CO₂ Program, 2011)



The result of this anthropogenic change has been increased rates of global warming. Atmospheric concentrations of methane gas were also relatively constant prior to significant human land use changes beginning in the late 1800s (see Figure 10).

Figure 10: Atmospheric Methane Gas Concentrations over the Past Thousand Years (Reay & Hogan, 2010)

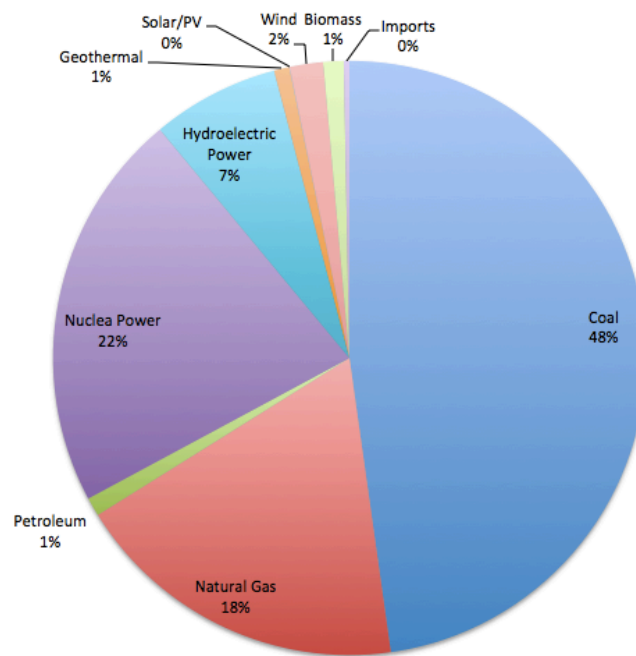


The legislation aims to mitigate the effects of current GHGs emissions and, by extension, climate change. Reducing GHG emissions from waste management and energy production will help to lessen the current rates of atmospheric CO₂ and methane emission and their potential global warming effects.

4.3 The Energy Problem

A major issue addressed by the legislation is the need for a greater number of clean domestic energy sources in the U.S. As the national population continues to grow, energy consumption continues to increase demand for fossil fuels, a finite resource. Figure 11 shows the breakdown of current energy sources. Note the absence of WtE sources.

Figure 11: U.S. Electricity Production by Source for 2009 (USEIA, 2009)



The conversion of MSW to energy in WtE facilities would help alleviate some of the dramatic consequences of global fossil fuel energy use by providing the U.S. an additional source of domestic energy production. While the total potential energy that could be generated from all of the non-recycled and non-composted MSW in the country would replace just 4% of the electrical energy generated by coal combustion annually (Kaplan, DeCarolis, & Thorneleo, 2009), WtE could provide some percentage of national energy needs beyond current combined wind, solar and geothermal energy capacity and reduce dependence on fossil fuels and harmful environmental impact.

5. WHAT IS WASTE-TO-ENERGY?

In this section each of the main waste-to-energy technologies are presented in detail according to the two distinct types of processes: biological and thermal. Biological processes utilize naturally occurring chemical processes whereas thermal processes are strictly engineered.

5.1 Biological Treatment Technologies

Microbial activity degrades organic material in oxygen-starved (anaerobic) environments such as natural bogs. This biochemical activity goes through several stages of breakdown including hydrolysis, fermentation (acidogenesis), acetogenesis, and methanogenesis. This same microbial activity can break down sewage sludge or organic municipal solid waste. WtE technology allows the process to be carried out in a gas-tight reactor, where temperature, moisture content, and pH may be controlled so that the desired products are separated and harvested.

Predominantly, biological waste treatment involves wet organic waste fermentation to yield biogas, which can be combusted to generate renewable energy. Organic waste is broken down anaerobically, and microorganisms such as bacteria decompose the organic matter into methane and CO₂, which can be used as a biofuel, with the residual solid material treated aerobically for soil purposes (see Figure 12). Biological waste treatment has potential to recover biofuels and chemicals such as ethanol and methanol from the organic material digested by adjusting the temperature, the pH, and the mix of microbes.

Hydrolysis adds water across chemical bonds, breaking the complex hydrocarbons into simple sugars and amino acids. These smaller molecules may then undergo fermentation, or acidogenesis, where they are reduced to simple organic acids, such as acetic acid, the acid found in vinegar. Acetogenesis further breaks down the material to acetates, CO₂, and hydrogen gas. Finally, ethanogenesis forms methane and CO₂ (Demirbas, Balat, & Balat, 2010). See Figure 12 for an overview of each process with the chemical inputs and outputs.

Hydrolysis

Sugar + Water → Organic Acids + Carbon Dioxide + Hydrogen Gas

Acidogenesis

Sugar → Simple Organic Acids + Carbon Dioxide + Hydrogen Gas

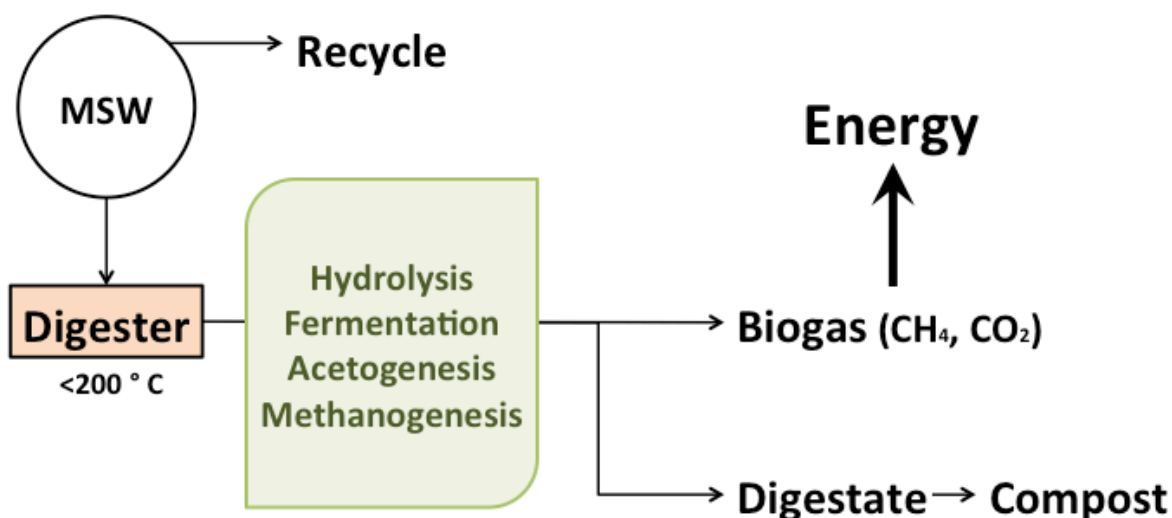
Acetogenesis

Sugar + Water → Acetates + Carbon Dioxide + Hydrogen Gas

Methanogenesis

Organic Acids → Methane + Carbon Dioxide

Figure 12: Flow Diagram of Biological Treatment Technologies



The biogas produced from methanogenesis and the residual solid material, or digestate, may be thermally processed or further biologically reduced (aerobically) to produce compost. Average yield of biogas is approximately 1 ft³ per pound of material feed, depending on the mix of organic material used (RIS International, 2005). The volume of the digestate material is about one tenth that of the original feedstock (ibid.).

5.2 Thermal Processes: Combustion, Pyrolysis, Gasification, Plasma Arc

Thermal treatment technologies apply to non-recyclable and non-reusable waste, and they have the general benefit of reducing the volume and mass of waste, generating thermal energy and electricity, and minimizing air and water pollutants (WtERT, 2011). In all thermal processes, filtering and scrubbing processes (control strategies) must be installed to reduce air pollutant emissions. In both biological and thermal processes, contaminants such as hydrogen sulfide and hydrochloric acid must be chemically removed from the produced gas so that it does not present pollution problems when it is burned for energy (Niessen, 2002). However, each technology detailed below presents a sequential environmental improvement over the previous technology demonstrating substantial advancements. For example, dioxin and furan emissions may be greatly reduced with either plasma arc gasification or fluidized bed gasification systems (Young, 2010). Air quality control strategies can be quite varied, since both feedstocks and technologies vary for each facility.

Combustion

Also known as mass burn or incineration, combustion is the oldest and simplest technology of all the thermal processes, currently the most widely used. Resource material is fed into an incinerator, and a flame is applied as a source of ignition in the presence of air. The resource material is dried, then gasified by the heat, then burned in a chemical reaction. Average furnace temperatures are around 500 °C (ibid.). The air takes part in the chemical combustion process, creating various products, which result in gaseous emissions, various liquids and solids, and ash residue. Mixed inputs, such as those typically found in MSW are acceptable inputs, along with digestate from anaerobic processes, although the residual energy composition of digestate is extremely low, since much of the energy from this resource has already been extracted (ibid).

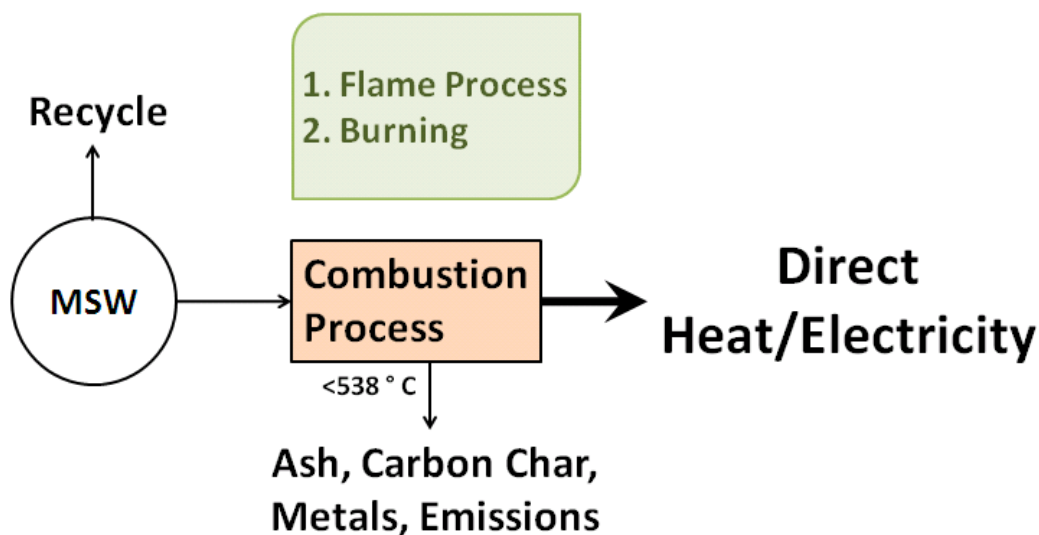
An example of a combustion reaction, where $(CH_2O)_x$ represents a general formula for organic materials, such as plastics, yard waste, paper, food scraps, etc.:

Combustion



Metallic compounds may also combust, combining with air to produce oxidized metallic compounds and contaminants. The contaminants vary, based on the feedstock mix, as well as the specific temperature zones of the incinerator. Some of these contaminants include nitrogen oxides, sulfur oxides, heavy metal oxides, and dioxins and furans (Young, 2010). End-of-process scrubbing and filtering removes contaminants, as required by law, while the ash and other residues require disposal (ibid.). The energy retrieved from this conventional WtE process is heat or steam which can be used to drive turbines for electricity generation or used more directly to supply heat (ibid.). Figure 13 provides a visual representation of this process.

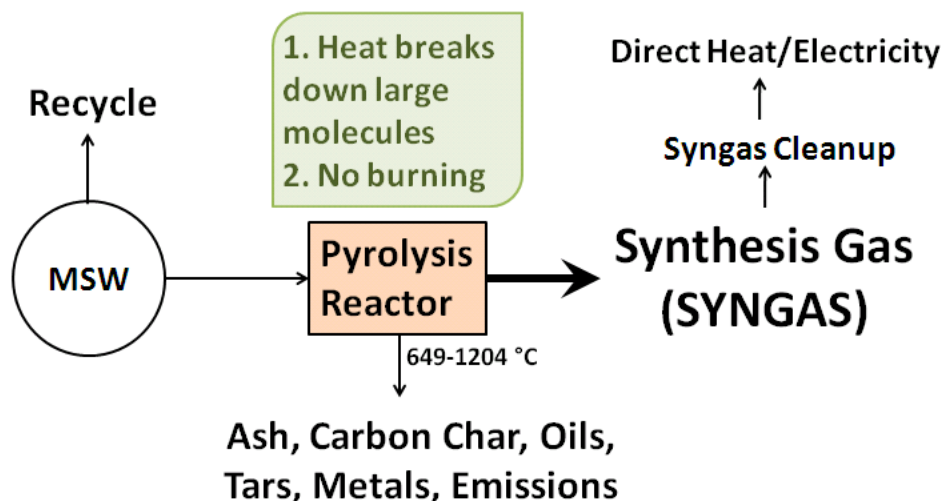
Figure 13: Flow Diagram of the Combustion Process



Pyrolysis

This technology involves breaking down large molecules into smaller molecules by applying a high temperature (649 – 1,204° C) in the absence of oxygen, or with very limited amounts of oxygen (Young, 2010) (see Figure 14). This is neither incineration nor combustion. Inorganic material will also be reduced to ash from which metals may be recovered for recycling (Young, 2010). The drawback to pyrolysis is that incomplete breakdown of organic materials yields less carbon monoxide and hydrogen, called synthesis gas or syngas, than newer processes, along with char (solid carbon), tars, and oils. The char is used as fuel, and oil and tars are used as lubricants and sealants or in the ingredients of other industrial processes. The ash is not melted and fused (vitrified) because the temperature is too low, and instead must be landfilled. Leaching of ash carries the same potential risks of contamination as landfill leachate (Zemba, Binder, Ames, & Lester, 2010). Individual facilities utilize scrubbing processes, according to the technology employed for energy conversion, in order to reduce pollution (Pytlar, 2010).

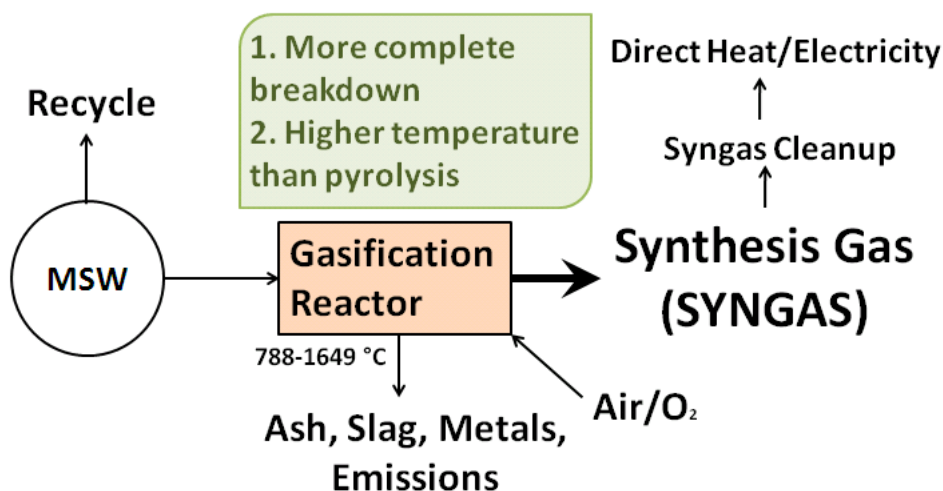
Figure 14: Flow Diagram of the Pyrolysis Process



Gasification

This process is similar to pyrolysis, except that steam is added and the reactor is held at higher temperatures (788 – 1,649 °C) (Young, 2010) (see Figure 15). More complete reduction of organic material may be accomplished, producing a higher yield of syngas, while also breaking down inorganic materials more completely than pyrolysis. The higher temperature may also melt and fuse the ash into a slag, creating a solid that stabilizes contaminants to the extent that it may be used for construction purposes. The three types of gasification reactors are: the moving bed/fixed bed reactor, the fluidized bed reactor, and the entrained flow reactor (Pytlar, 2010; Young, 2010). Of these, the entrained flow reactor produces a higher carbon conversion rate than the others, and the byproducts are minimized (Pytlar, 2010).

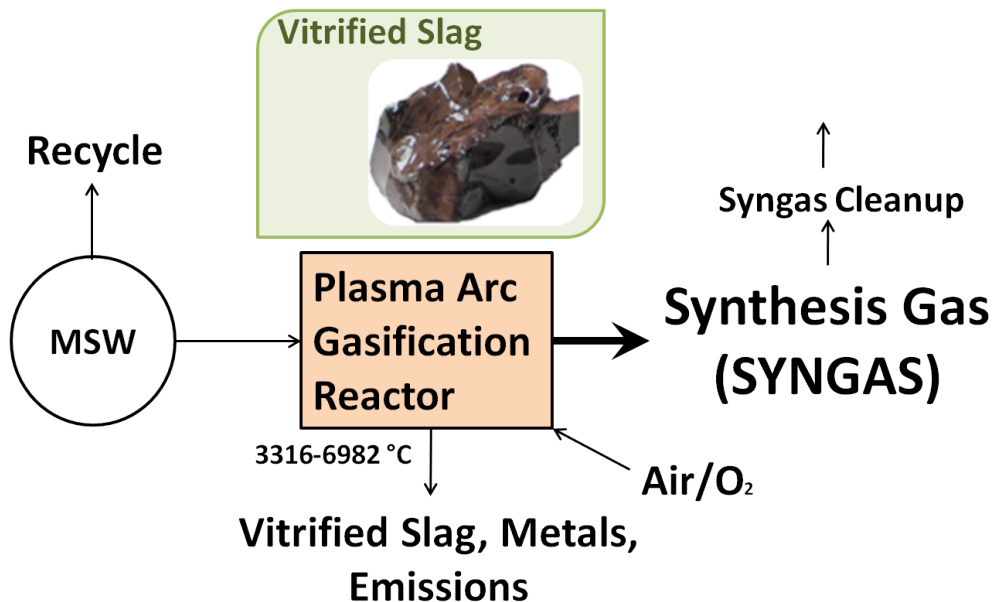
Figure 15: Flow Diagram of the Gasification Process



Plasma Arc Gasification

Plasma arc gasification is the newest and most efficient WtE technology and has high energy recovery with low pollution effects. Although this technology has yet to be utilized in the U.S., it is found in Japan, Denmark, Germany, and other European countries. Plasma is created by passing an intense electric arc through an inert gas wherein the gas becomes ionized. Using a plasma torch, the reactor is allowed to reach very high temperatures (3,316 – 6,982 °C) (Ducharme & Themelis, 2010; Young, 2010) (see Figure 16). At these extreme temperatures, virtually all chemical bonds break, including bonds in hazardous materials containing substances such as polychlorinated biphenyls, dioxins, furans, benzene, and other organic toxins (Hsien-Tsung & Bozzelli, 2001). Cooling the gas also quickly inhibits dioxins and furans from reforming (Ducharme & Themelis, 2010) so that this technology is viewed as able to handle medical waste, electronic waste, and even low-level nuclear waste (Young, 2010). The ash produced is vitrified and is very stable. Using the Toxicity Characteristic Leaching Procedure developed by the EPA to test for risks from leachate, vitrified slag surpasses EPA standards for cadmium (by a factor of nearly 1000), chromium (factor of 2000), lead (factor of 200), arsenic (factor of nearly 10,000), and mercury (factor of 5000) (Fernandez & Menendez, 2011). As a stable product, it can be used for many commercial products, such as roof tiles, floor tiles, landscaping blocks, and insulation (Young, 2010).

Figure 16: Flow Diagram of the Plasma Arc Gasification Process

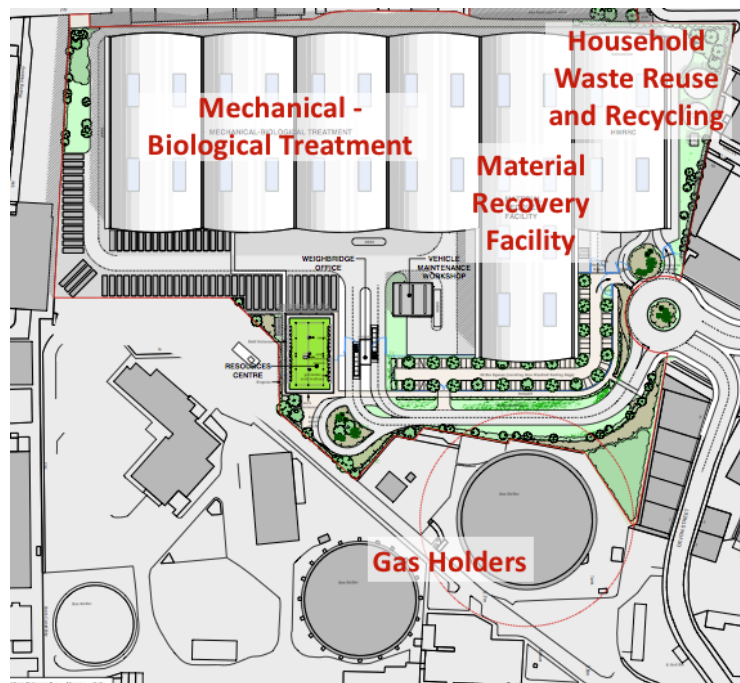


5.3 Integrated Waste Treatment

One final emerging solution is the construction of integrated waste treatment facilities that combine a number of waste processing steps in one location. It is primarily an improvement in the management process and is useful in reducing transportation and labor costs. This involves a recyclable sorting component to minimize the number of recycled materials in the treated waste stream (MBT, 2008; Keppel Seghers, 2011). Additionally, the organic waste is sorted for biological treatments such as composting and anaerobic digestion. The outputs from this process include digestate for fertilizers, biogas as alternative fuels, and an overall reduction in the waste volume. The sludge and remaining waste solids are combusted, which may yield similar outputs to the isolated combustion and thermal technologies delineated above. This approach to waste management is relatively new, so demonstrated efficiency and capacity is difficult to estimate for the long-term.

Figure 17 is a recent example of an integrated waste management facility which is being built in the Greater London area of the United Kingdom. The close proximity of these services to a highly populated waste generating area reduces transportation costs. The project will include a materials recovery facility, a mechanical biological treatment plant, a household waste reuse and recycling facility, all in the same location.

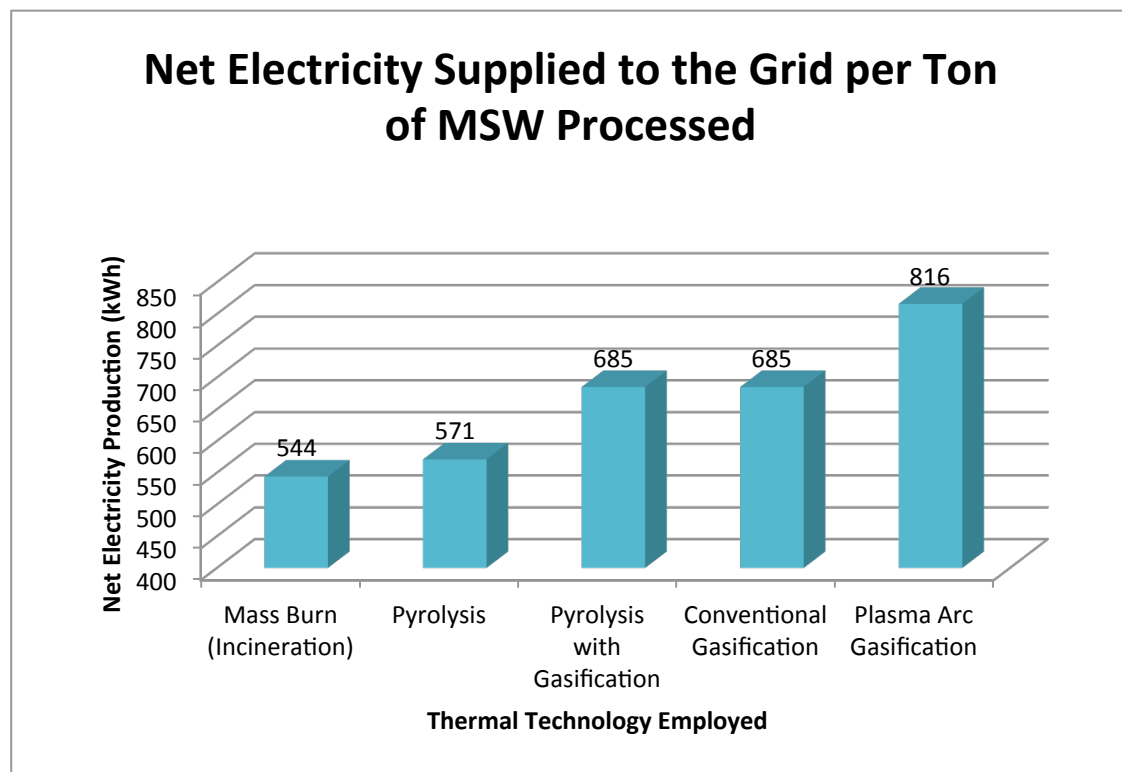
Figure 17: Detail from the Masterplan of the Integrated Waste Management Facility Being Built by Veolia Environmental Services in Southwark, Greater London, UK (Veolia, 2011)



5.4 Benefits of Waste-to-Energy Technology

The use of waste as an energy source displaces fossil fuels and reduces the emissions from extraction and processing, Figure 18 shows the net energy production of WtE technologies. A full lifecycle analysis for each WtE facility will be required in the future to fully determine GHG reduction impacts; however it is estimated that WtE will generate less pollution than traditional energy sources (see Section 7.2).

Figure 18: Net Electricity Supplied to the Grid per Ton of MSW Processed (Young, 2010)



Depending on the technology employed, the volume of waste is reduced to very low levels due to intense resource recovery and because what is not recoverable may be processed to an inert form. Metals, glass, and plastics will be separated for recycling, thereby reducing the need for extraction of raw materials for new products. Other problems addressed by these technologies are pollution and greenhouse gases. Air emissions are lower than traditional waste processing facilities and lower than coal-fired plants (Jenkins & Legrand, 2010; Niessen, 2002; Young, 2010). GHGs are reduced by using waste as a resource, rather than letting it decompose in a landfill.

6. REACTIONS TO WASTE-TO-ENERGY

The term “waste-to-energy” can lead the public to think of smoke stacks spewing black clouds into the air. This may have been the case with municipal solid waste incineration in the 20th century; however such practices were replaced many years ago with cleaner technologies. This connotation reveals that public concerns about WtE are often based on a lack of knowledge about the environmental and economic benefits of the technology. Criticisms of WtE center on several key points: GHG emissions, air pollution, toxic waste, and competition with recycling. These points are analyzed below.

6.1 Common Misconceptions about WtE Technology

Climate Change

WtE is defined by the Intergovernmental Panel on Climate Change as a measure of mitigation of global warming; the CO₂ emissions from WtE are less than one tenth that of landfill methane emissions. For each ton of MSW combusted, rather than landfilled, the overall CO₂ reduction can be as high as 1.3 tons of CO₂ when both the avoided landfill emissions and the avoided use of fossil fuel (in energy generation) are taken into account (IPCC, 2007). Additionally, compared to fossil fuel power plants, the CO₂ emissions from WtE are lower. Figure 19 shows that CO₂ emissions from a typical WtE power plant are less than emissions generated with other fossil fuels.

Figure 19: CO₂ Emissions from Different Fuels Used to Generate Electricity (SWANA, 2006)

Fuel	CO ₂ (Pounds per Megawatt Hour)
MSW	837
Coal	2,249
Oil	1,672
Natural Gas	1,135

In 2011, the EPA released a “Deferral for CO₂ emissions from Bioenergy and Other Biogenic Sources.” This means that for three years, the EPA will conduct a detailed examination of the science associated with biogenic CO₂ emissions from stationary sources. This study will consider technical issues that the Agency must resolve in order to account for biogenic CO₂ emissions in ways that are scientifically sound and also manageable in practice (EPA, EPA to Defer GHG Permitting to Requirements for Industries that Use Biomass, 2011).

Atmospheric Pollution

Old incinerators had very serious problems with atmospheric pollutants and the concern about the air pollution of modern facilities is based on this history. However, modern facilities are equipped with advanced air pollution control devices that reduce the contaminants produced. According to the EPA, all WtE facilities comply with EPA's Maximum Achievable Control Technology standards for hazardous air pollutants. After analyzing the inventory of WtE emissions, EPA concluded that these facilities produce electricity "with less environmental impact than almost any other source of electricity" (Michaels 2010). The emissions of toxins also have been reduced; dioxin and furan emissions declined more than 99% (from 4,400 grams in 1990 to 15 grams in 2005) thanks to the strict emission regulation and the technical improvements (EPA, Air Emissions from MSW Combustion Facilities, 2011).

Figure 20: Reduction of Air Pollution in WtE facilities in the U.S. from 1990 to 2005 (Air Emissions from MSW Combustion Facilities, EPA, 2011)

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%

Compared to landfills, WtE facilities have much lower emissions of volatile organic compounds and the emissions produced by the transportation to long distances are avoided if facilities are sited within municipalities.

Toxic Waste

Another serious concern among opponents to WtE is the production of sub-waste products due to waste burning, creating toxic ash or slag that must be landfilled. It is a fact that the ash produced by WtE facilities is rich in pollutants, but fortunately technical solutions exist for safe disposal. In addition, there are new and clean WTE technologies like gasification and plasma-arc gasification that are able to convert the ash into reusable construction products or an inert vitrified slag which has several commercial uses.

Impact on Recycling

The concern about how WtE can reduce public effort to recycle and reduce waste is one of the biggest environmental controversies about this type of technology. However, recycling is completely compatible with WtE: communities using WtE for disposal in the U.S. are recycling at about 33.3%, higher than the national rate (Brettle, 2009). Energy recovery from waste is not competing with recycling, but rather complementing it in a sound waste management plan (Klein, 2002). The Waste-to-Energy Technology Act of 2011 specifically addresses concerns about recycling in stating that the criteria for receiving the tax credit depends on a project using the least amount of recyclable materials possible. In fact, the best alternative for recovering the energy in the non-recyclables is WtE.

WtE technologies have better performance when the recyclable or non-combustible materials are removed. Raw MSW can be converted into a better fuel for power generation by making it more homogeneous. Several WtE plants create a refuse-derived fuel, through the separation of inert materials, size reduction, and densifying (Klein, 2002). If the separation is made before the disposal as a part of a recycling plan, the cost of the fuel is avoided.

In order to summarize these issues, Figure 21 shows the potential problems with each WtE technology and its solution.

Figure 21: Potential Problems and Possible Solutions Related to WtE Technologies

Technology	Potential Problems	Possible Solution
Combustion	• Produces suite of emissions associated with burning trash including CO₂, NO_x, SO_x, fly ash, dioxins, furans. • Energy-intensive process.	• Emissions can be efficiently controlled with the best technology available. • Energy efficiency increases with feed separation.
Pyrolysis	• Only processes dry waste; requires drying and sorting beforehand. • If other recycling/composting processes rise in popularity and use, limits the necessity and use of such technologies.	• Moisture in feed can be controlled before the process. • Could be an option in places with little recycling capacity.
Gasification	• Non-combustion heating in the presence of oxygen produces fewer emissions • Requires treatment of emissions and landfilling of byproducts.	• Emissions can be controlled with high quality pollution control devices.
Plasma Arc Gasification	• Requires large energy input. • Expensive. • New technology, limited availability.	• Greatest net energy production. • Initial cost can be recovered with energy sales and metals recovery.
Anaerobic Digestion	• Only processes organic waste. • Yields less energy overall than other processes.	• This technology should be used in conjunction with others in an integrated waste treatment plant.

6.2 Science-Based Standards for Waste- to-Energy

WtE is not new; in fact it is widely used in Japan and Europe where legislation requires a treatment of waste before disposal. In the U.S., WtE facilities are subject to the existing Clean Air Act (CAA) rules for municipal waste combustors. These standards depend on the location of the facility and whether or not the location falls under the National Ambient Air Quality Standards threshold for permitting. However, these rules do not define the technology of the facility, rather the required types of pollution control technology; thus there is no exigency in the use of the best available WtE conversion processes. As a comparative example, the European Commission Institute for Prospective Technological Studies gives specific information about techniques and WtE processes, emission, and consumption levels, and the description of

the best available technologies. The European Union has a fundamentally different structure that regulates the WtE technology rather than the pollution control technology.

Another barrier for WtE is the high cost of implementation, especially for the more efficient technologies. Compared with a typical landfill, the initial cost of WtE facilities is much higher; nevertheless, these costs in the long term may be compensated with the revenues from energy sale, and material recuperation. During the 1980s and early 1990s many WtE systems were developed in the U.S. but investments came to a stop when the Supreme Court rejected the practice of waste flow control in 1994. According to the Court, garbage was viewed as “commodity in commerce” and it was unlawful for a municipality to steer waste to a publicly owned waste transfer facility. Prior to this decision, waste flow control had been used as a way to finance large WtE facilities by ensuring supplies of solid waste for waste hauling and landfill companies. Consequently, waste was increasingly directed to mega-landfills, associated with negative environmental impacts (Gohlke & Martin, 2007).

In Japan and Europe, the technology continued improving and now those regions have appropriate policies for their facilities to ensure the development of improvements in energy efficiency and pollution control. Political distrust for WtE is related to misconceptions about the technologies and their health effects; moreover, principal detractors are local environmental and community groups concerned about health and social aspects like the decrease in property value, known as the “not in my back yard” effect. Regarding health impacts, studies show that health risks from the use of landfills may be greater than WtE treatment, not only for the time of exposure, but also for the amount of emissions from landfills and from the transport of waste to them (Moy, 2005).

6.3 Lessons to Learn for the Future

Some of the concerns about WtE technologies are based on outdated technologies that have been outpaced with advanced technologies. However, public awareness of these new technologies needs to keep pace to spur support for new facilities. It is important to take into account the necessity of controlling the feeding phase to improve the overall performance of the technologies; all processes using WtE have better performances with a correct pre-processing of the incoming waste. Too much water in the feed can require too much energy for evaporation, and the waste will not break down completely (Schmid et. al, 2000). To minimize the residue amount and toxicity, some materials have to be separated (like ferrous and non-ferrous metals).

Secondly, emissions to air and water must be strictly controlled with the best technology available to remove the dangerous pollutants; proper disposal of ashes and reuse of vitrified slags are also important. As technology improves, total emissions from thermal processes are likely to be further reduced in the future (Schmid et. al, 2000). WtE must be effectively implemented with oversight by the EPA and other government agencies as required.

7. MEASURING PROGRAM SUCCESS

7.1 Metrics for Evaluation

Program success is determined by assessing whether or not the pre-determined goals of a program are met. In the case of the Waste to Energy Technology Act, the overall objective is to increase the number and capacity of WtE in the United States through tax incentives to stimulate investment and construction by government municipalities and by the private sector. The bill stipulates that qualifying facilities meet the following stringent environmental criteria. Figure 22 suggests selection criteria and indicators for this selection process.

Figure 22: Selection Criteria for Eligibility Providing the Key Indicators for the Program

Criteria	Indicator
Projects that use the least amount of materials which are commonly recycled	Percent reduction of recyclables from waste stream
Produces the fewest greenhouse gas emissions over the lifecycle of the facility	Lifecycle greenhouse gas emissions
Provides the greatest net impact in avoiding or reducing air pollutants	Reduction in air pollutant emissions
Provide greatest net energy to the public grid	Amount of net electricity generated (gross production not just net)
Pose the fewest risks (other than climate risks) to environmental and human health	Reduction in leachate contamination

Municipal solid waste is regulated by the EPA under the Resource Conservation and Recovery Act, while waste incineration is covered by the Clean Air Act. Subsequent to the CAA, the EPA issued the National Emission Standards for Hazardous Air Pollutants; this includes standards of performance and emission guidelines for MSW landfills. The criteria listed above will establish qualifying facilities under the Waste to Energy Technology Act that promote the development of new WtE facilities that address issues of waste, energy, and environmental health.

7.2 The Long-Term Impacts of WtE Technologies

The Waste-to-Energy Technology Act of 2011 lists the parameters that are necessary to measure the success of the bill while considering the energy, recyclable materials used, environmental factors and lifecycle gases.

Energy

As shown in Chapter 5, the different WtE options discussed have varying net energy output. While some processes, such as plasma arc gasification require large energy inputs, it is important to note that the outputs show a large net positive production of energy (see Figure 18 on page 26).

Environmental Emissions

When landfills are compared to WtE waste processing technologies, one sees significant decreases in key emissions of sulfur dioxide, nitrogen dioxide and CO₂. Similarly, when coal combustion is compared to WtE, one sees significantly lower levels of NO₂ and CO₂.

Figure 23: Environmental Pollutants Emitted from Different Energy Technologies

Technology	SO ₂ (g/MWh)	NO ₂ (g/MWh)	CO ₂ (Mton/MWh)
Landfill Gas to Energy	890	2300	3.3
Coal Combustion	620	3700	1.1
Waste-to-Energy	400	1400	0.6

Environmental – Solid Byproducts

When byproducts of traditional waste management (landfill leachate) and electricity production (coal ash) are compared, one sees reduced levels of heavy metals (see Figure 25). The one exception is fly ash from pyrolysis, which has elevated amounts of chromium and lead. Plasma arc gasification has a significantly lower level of all substances because the process is performed at such a high temperature that these elements either break down or are vitrified into inert material.

Figure 24: Chemical Byproducts of Waste-to-Energy Technologies (EHSO, 2008; Cerbus, 1995; Kjeldsen 2005)

Waste Management Practice	Cadmium (mg/L or ppmv)	Chromium (mg/L or ppmv)	Lead (mg/L or ppmv)	Arsenic (mg/L or ppmv)	Mercury (mg/L or ppmv)
Landfill Leachate	0.0001-0.4	0.02-1.5	0.001-5	0.01-1	0.00005-0.16
Coal Ash	0.024	0.018	0.051	0.280	0.040
Fly Ash from Pyrolysis	0.0013	1.41	12.19	0.011	0.011
Vitrified Slag From Plasma Arc Gasification	0.0002 - 0.0014	0.00026 - 0.0022	0.023 - 0.104	0.0006	<0.0005
2008 EPA TCLP Standards	1.0	5.0	5.0	5.0	0.2

7.3 Lifecycle Analysis

Life cycle analysis (LCA) is an important tool for policymakers to analyze the environmental burden for waste management technology (Zaman 2010). Figure 25 provides a broad overview of the level of greenhouse gas production at different stages of the waste management and energy processes. As a baseline, one can look at the extraction, processing, and end-of-life phases for coal. At all stages this resource has a high impact in terms of global warming, first in mining, then in transportation and combustion, and finally by ash disposal.

Landfills, by contrast, have low extraction impact as waste is generated from previously processed materials. The waste input must be transported and deposited underground, which does contribute to greenhouse gas emissions. Landfills have a period of high methane and CO₂ output for many years as the waste decomposes.

In comparison, WtE technologies do not require GHG intensive inputs for extraction or acquisition (similar to landfills). Processing does generate GHGs, though less than coal as also shown in Figure 25. In terms of the end-of-life phase, however, advanced WtE technologies produce inert compounds such as slag that have no climate change impact.

Figure 25: Comparison of Greenhouse Gas Emissions from the Extraction, Processing and End-of-Life (Disposal) Phases of Coal, Landfilled Waste, and Waste-to-Energy

Technology	Extraction/Resource Acquisition	Processing	End-of-Life
Coal Burning	HIGH Coal mining and fuel burning by machines and vehicles result in high emissions	HIGH Burning coal produces a lot of GHGs, none are captured	HIGH Any GHG emissions related to coal is higher than landfilling and WtE because it is outside of the carbon budget (releasing stored energy)
Landfilled Waste	LOW No significant energy extracting activity	MEDIUM Methane released from landfills are high; even when captured, there are significant releases compared to WtE	MEDIUM GHG does not end when landfill is capped; in addition, the emission in this case is methane, which has a higher global warming potential than CO ₂
WTE	LOW Limited emissions associated with sorting MSW for materials usable for WtE	MEDIUM All GHG emissions designed to be captured	LOW GHG potential is in the ash produced, which varies according to the technology

A lifecycle analysis examines the emissions of greenhouse gases at every stage. First the carbon intensity of the fossil fuel based and biological based inputs are assessed. The EPA has developed a tool, called the Waste Reduction Model (WARM), to assess the carbon intensity of average MSW and the carbon benefits of recycling decisions. For biological inputs, the EPA has not yet developed a framework for analyzing the GHG emissions from the use of biomass as a fuel input; however the agency is developing guidance for this analysis (see Chapter 6). Figure 26 shows a conceptual framework for the lifecycle analysis of the GHG outputs of different WtE technologies.

Figure 26: Conceptual Greenhouse Gas Lifecycle Analysis Framework

Lifecycle Stage	GHG Positive or Negative	Explanation	Information Source
Fossil fuel based Inputs	+	GHG emissions associated with input materials (includes extraction, transport, consumption, disposal)	USEPA WARM tool gives inputs for average MSW
Biological Inputs	–	Estimated GHG of Biomass	Not Available (See EPA Biomass Deferral, Section 6.1)
GHG Emissions from WtE process	+	Equals GHG emissions from WtE process	See estimated GHG emissions by WtE technology, Figure 26
Avoided fossil fuel electricity/ heat	–	Equals net quantity of energy produced by WtE expressed in CO ₂ e for the local grid	USEPA Power Profiler tool
Avoided Landfill Gas releases	–	Equals reduction in methane releases	USEPA Landfill Gas Environmental Benefits Calculator
Recovered Recyclables	–	Equals GHG reductions from recycling v. disposal	USEPA WARM tool inputs for all major recyclable categories
TOTAL NET LIFECYCLE GHG EMISSIONS	TBD	Sum of above	

WtE technologies emit GHGs in collecting and processing waste but also generate sufficient amounts of energy to power the facilities and provide surplus energy to the public grid. This energy, when compared to coal, is much less polluting and it provides the additional waste management benefit. This is described in Figure 26 as the avoided amount of fossil fuel electricity and heat. WtE also minimizes the need for landfilling and the release of methane into the atmosphere. This contributes to the net reduction in greenhouse gas production. A final point is that WtE compliments recycling and the intention of the legislation is to promote both processes. USEPA must develop its methodology for calculating lifecycle GHG emissions for the biological and thermal WtE technologies described above. This will contribute to the policy discussion and will be a key factor in selecting projects and evaluating the ultimate success of the legislation.

CONCLUSION

Waste-to-Energy is a promising waste management approach that significantly reduces the amount of disposal in landfills while also reducing pollutants. WtE addresses the problem of waste transportation and the associated emissions. Recent advances in WtE technologies are being implemented in many parts of the world, and the lack of policy incentives in the U.S. has resulted in the delay of constructing new facilities. The Waste-to-Energy Technology Act of 2011 incentivizes the development of WtE with tax credits for projects that meet certain eligibility criteria.

Although landfilling and combustion are currently the most accepted and widely used technologies, they are inefficient in converting waste to energy. Much current controversy is due to public misconceptions about the various WtE solutions. These facilities may yield environmental and human benefits relative to existing technologies.

WtE should be prioritized in densely populated urban areas, where municipalities can process public waste without the need for long-distance transportation. Integrated Waste Management practices should also be encouraged by emphasizing the recyclable separation aspect of the proposed legislation. Priority should be given to applicants who use the best available technology for conversion efficiency and pollution reduction. Guidelines on lifecycle greenhouse gas emissions analysis must be developed that motivate more efficient waste management and reduce the amount of waste sent to landfills.

WtE may be a feasible option to reduce problems associated with waste management and to decrease, at least to some extent, reliance on nonrenewable sources of energy in the United States. Currently, WtE solutions are focused on waste with the advantage of energy production; however in the future these types of facilities can be one of the solutions for a low-carbon energy supply around the world. Waste could one day be viewed as a resource and not as an burden.

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