Waste-to-Energy Plants

June 2010

Peter Meisen
President, Global Energy Network Institute (GENI)
www.geni.org
peter@geni.org (619) 595-0139

Ilona Phipps-Morgan
Research Associate, Global Energy Network Institute (GENI)
snuubaa@gmail.com

Table of Contents

Table of Figures

Table of Tables

Abstract

Historically, the waste generated by households and industry has simply been sent away to distant landfills, following an "out of sight, out of mind" mentality. However, this method of waste management has become outdated. People have begun to take notice of landfills' gas emissions, in particular, the greenhouse gas methane; other environmental impacts through leakages into groundwater; space as populations grow; and the waste of energy involved. Increasingly, people have advocated the "three R's" — reduce, reuse, and recycle — to limit the amount of newly generated waste. In addition, with technological advances, waste-to-energy plants have become popular in Japan and several European countries as a more efficient and beneficial alternative to landfills. Currently, there are over 400 waste-to-energy incinerators across Europe. Yet in the United States this number is a mere 87, and over half of our waste continues to be sent to landfills.

The new waste-to-energy plants are cleaner and more efficient than older models and can generate a fair amount of energy. This energy, in the form of heat and/or electricity, can be used not only to power the plants themselves, but can return a portion to the electrical grid as well. The emissions typically contain fewer pollutants than those from standard nonrenewable energy sources such as coal or oil and significantly fewer pollutants than those from landfills. Not only is energy from waste-to-energy plants preferable to that from nonrenewable sources; by implementing waste-to-energy plants more extensively, we could significantly decrease the amount of toxins that currently enter the atmosphere from landfills. Furthermore, much of the bottom ash can be recycled, offsetting the use of this raw material.

Reducing, reusing, and recycling continue to be the best methods of waste management and should be our priorities. In order to make our effect on the Earth more sustainable, we should first increase reduction, reuse, and recycling. The vast majority of the remaining waste should be sent to waste-to-energy incinerators in order to recover energy and limit pollutants, and only that portion of waste which can neither be reused/recycled nor incinerated should be sent to landfills. If we reduced our waste to 69% of the current waste generation per capita, increased recovery of waste to 45%, and increased incineration of waste to 40%, we would be able to produce over 1% of our electricity consumption in addition to heating. More importantly, we would largely avoid the use of landfills and the associated environmental impacts.

1 Current Trends in U.S. MSW Generation and Treatment

In 2008, the United States generated 250 million tons of Municipal Solid Waste (MSW) (Kaplan 1711). MSW includes household waste such as packaging, food scraps, grass clippings, computers, tires, and refrigerators rather than industrial, hazardous, or construction waste ("Municipal Solid Waste Generation..." 2). By material, the largest portion of the MSW in 2008 consisted of paper (31.0%), followed by yard trimmings (13.2%), food scraps (12.7%), and plastics (12.0%) (Figure 1). By category, containers and packaging composed the largest portion of waste (30.8%), followed by nondurable goods (23.5%) and durable goods (18.3%) (Figure 2). Of this MSW, Americans recovered 33.2% of the original 250 million tons, or 83.1 million tons (61 million tons were recovered through recycling and 22.1 million tons through composting). We combusted 32 million tons of the remaining waste for energy recovery and disposed of the rest (134.9 million tons) at landfills and a few incinerators without energy recovery (Figure 3) ("Municipal Solid Waste Generation..." 2).

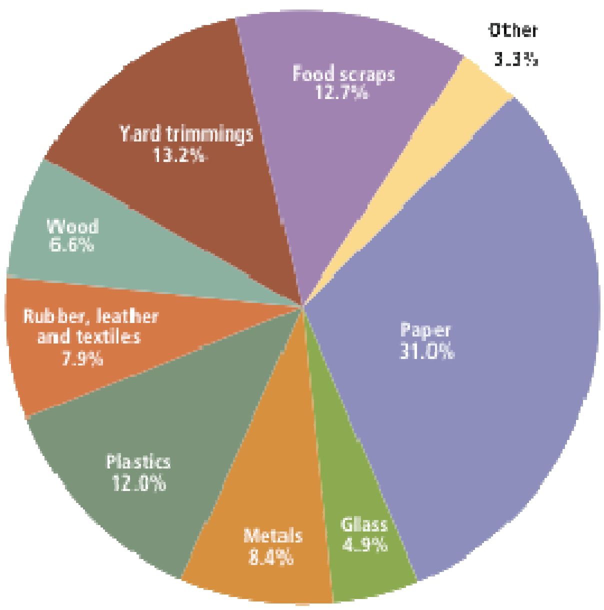

Figure 1: Total MSW generation (by material), 2008. 250 million tons (before recycling)[1]

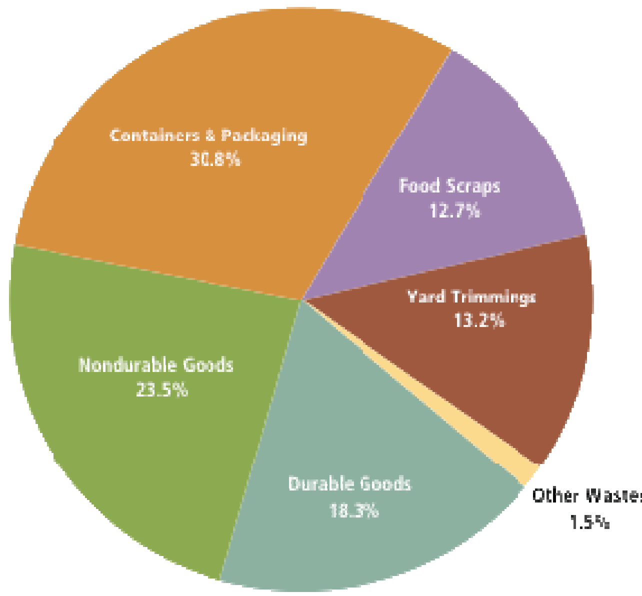

Figure 2: Total MSW generation (by category), 2008. 250 million tons (before recycling)[2]

[1] "Municipal Solid Waste Generation..." 4

[2] "Municipal Solid Waste Generation..." 6

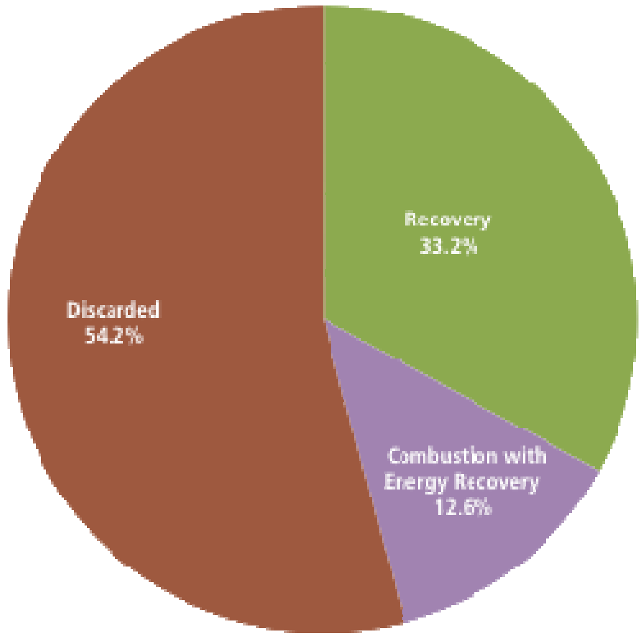

Figure 3: Management of MSW in the United States, 2008[3]

Interestingly, the trends over the past few decades show that even though Americans have increasingly recycled their waste and correspondingly decreased the proportion of waste sent to landfills, after a first surge in 1990, the use of incinerators has remained fairly constant (Figure 4, Table 1).

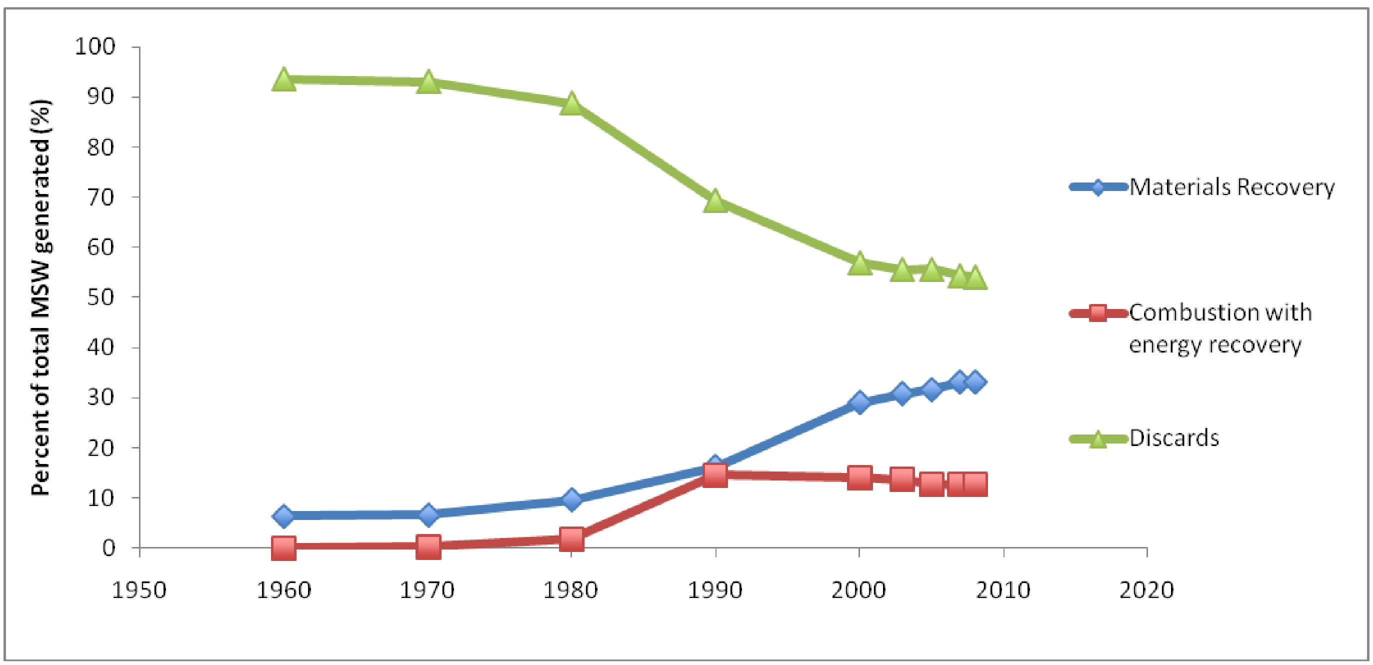

Figure 4: Materials recovery, combustion with energy recovery, and landfill rates of MSW, 1960 to 2008

[3] "Municipal Solid Waste Generation..." 3

Table 1: Generation, materials recovery, composting, combustion with energy recovery, and discards of MSW, 1960 to 2008 (in millions of tons)[4]

Activity	1960	1970	1980	1990	2000	2003	2005	2007	2008
Generation	88.1	121.1	151.6	205.2	239.1	242.2	249.7	254.6	249.6
Recovery for recycling	5.6	8.0	14.5	29.0	52.9	55.6	58.6	62.5	60.8
Recovery for composting*	Negligible	Negligible	Negligible	4.2	16.5	19.1	20.6	21.7	22.1
Total materials recovery	5.6	8.0	14.5	33.2	69.4	74.7	79.2	84.2	82.9
Combustion with energy recovery†	0.0	0.4	2.7	29.7	33.7	33.1	31.6	32.0	31.6
Discards to landfill, other disposal‡	82.5	112.7	134.4	142.3	136.0	134.4	138.9	138.4	135.1

* Composting of yard trimmings, food scraps, and other MSW organic materials. Does not include backyard composting.

† Includes combustion of MSW in mass burn or refuse-derived fuel form, and combustion with energy recovery of source separated materials in MSW (e.g., wood pallets, tire-derived fuel).

‡ Discards after recovery minus combustion with energy recovery. Discards include combustion without energy recovery.

Details might not add to totals due to rounding.

Indeed, if anything, combustion with energy recovery has become slightly less used. One may compare the years 1990 and 2008 in Table 2 and note that in both years, the generation of MSW per capita was 4.50 pounds per person per day. However, in 1990, 0.73 pounds per person per day were recovered, 0.65 were combusted for energy, and 3.12 were discarded to landfills or elsewhere, whereas in 2008, 1.50 were recovered, 0.57 combusted, and 2.43 discarded. Part of this may be that an equivalent portion of the waste that would have been combusted in 1990 would have instead been recovered in 2008. Also, after the first wave of incinerators were constructed in the 1980s and 1990s, few have been constructed since, and thus the incinerator capacity in the United States has not grown significantly in the past two decades. In the United States today, a total of 87 incinerators exist, most of which are at least 15 years old, and few are being planned for the future (Rosenthal, "Europe Finds..." 1). Furthermore, although the pounds of MSW per person per day discarded to landfills may have decreased, a significant quantity of waste is still discarded to landfills because of a growing population and a generally increasing total MSW generation, and that quantity is expected to increase (Kaplan, Decarolis, and Thorneloe 1711), as indicated in Figure 5.

4 "Municipal Solid Waste Generation..." 8

Table 2: Generation, materials recovery, composting, combustion with energy recovery, and discards of MSW, 1960 to 2008 (in pounds per person per day)[5]

Activity	1960	1970	1980	1990	2000	2005	2007	2008
Generation	2.68	3.25	3.66	4.50	4.65	4.62	4.63	4.50
Recovery for recycling	0.17	0.22	0.35	0.64	1.03	1.08	1.14	1.10
Recovery for composting*	Negligible	Negligible	Negligible	0.09	0.32	0.38	0.39	0.40
Total Materials Recovery	0.17	0.22	0.35	0.73	1.35	1.46	1.53	1.50
Combustion with energy recovery†	0.00	0.01	0.07	0.65	0.66	0.58	0.58	0.57
Discards to landfill, other disposal‡	2.51	3.02	3.24	3.12	2.64	2.58	2.52	2.43
Population (millions)	179.979	203.984	227.255	249.907	281.422	296.410	301.621	304.060

* Composting of yard trimmings, food scraps and other MSW organic material. Does not include backyard composting.

† Includes combustion of MSW in mass burn or refuse-derived fuel form, and combustion with energy recovery of source separated materials in MSW (e.g., wood pellets, tire-derived fuel).

‡ Discards after recovery minus combustion with energy recovery. Discards include combustion without energy recovery.

Details might not add to totals due to rounding.

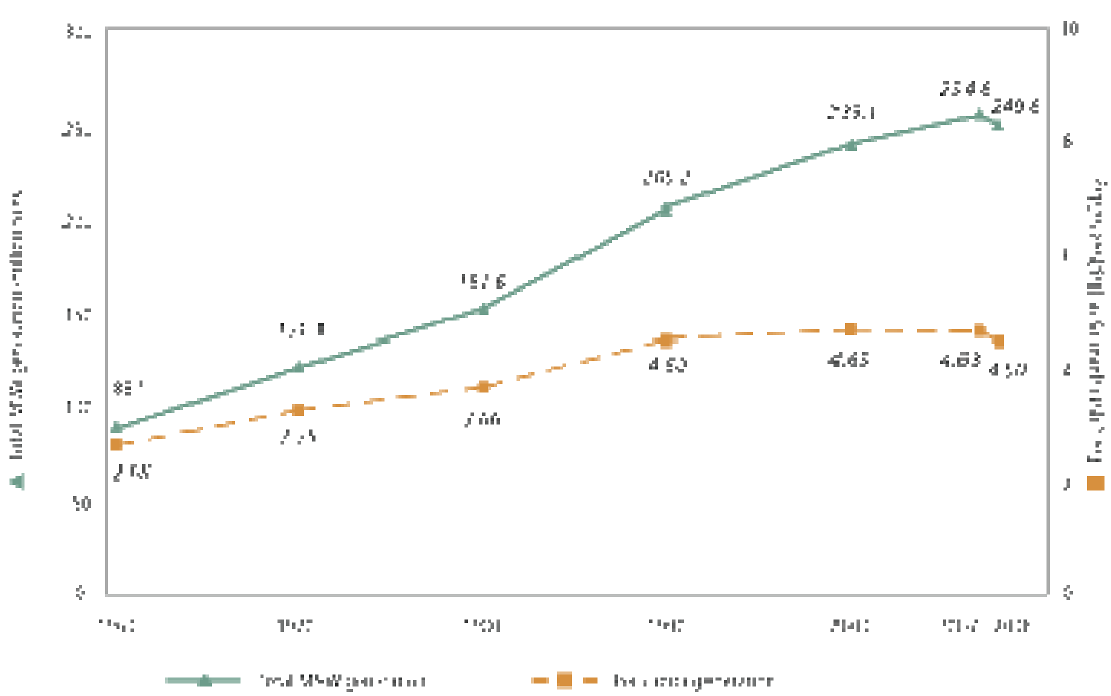

Figure 5: MSW generation rates, 1960 to 2008[6]

5 "Municipal Solid Waste Generation..." 9

In contrast, in several European countries, most notably Denmark, Sweden, the Netherlands, and Germany, waste-to-energy incinerators have become a staple in waste disposal and energy production, while the use of landfills has dropped drastically. Across Europe, there are around 400 waste-to-energy incinerators total (Rosenthal, “Europe Finds...” 1).

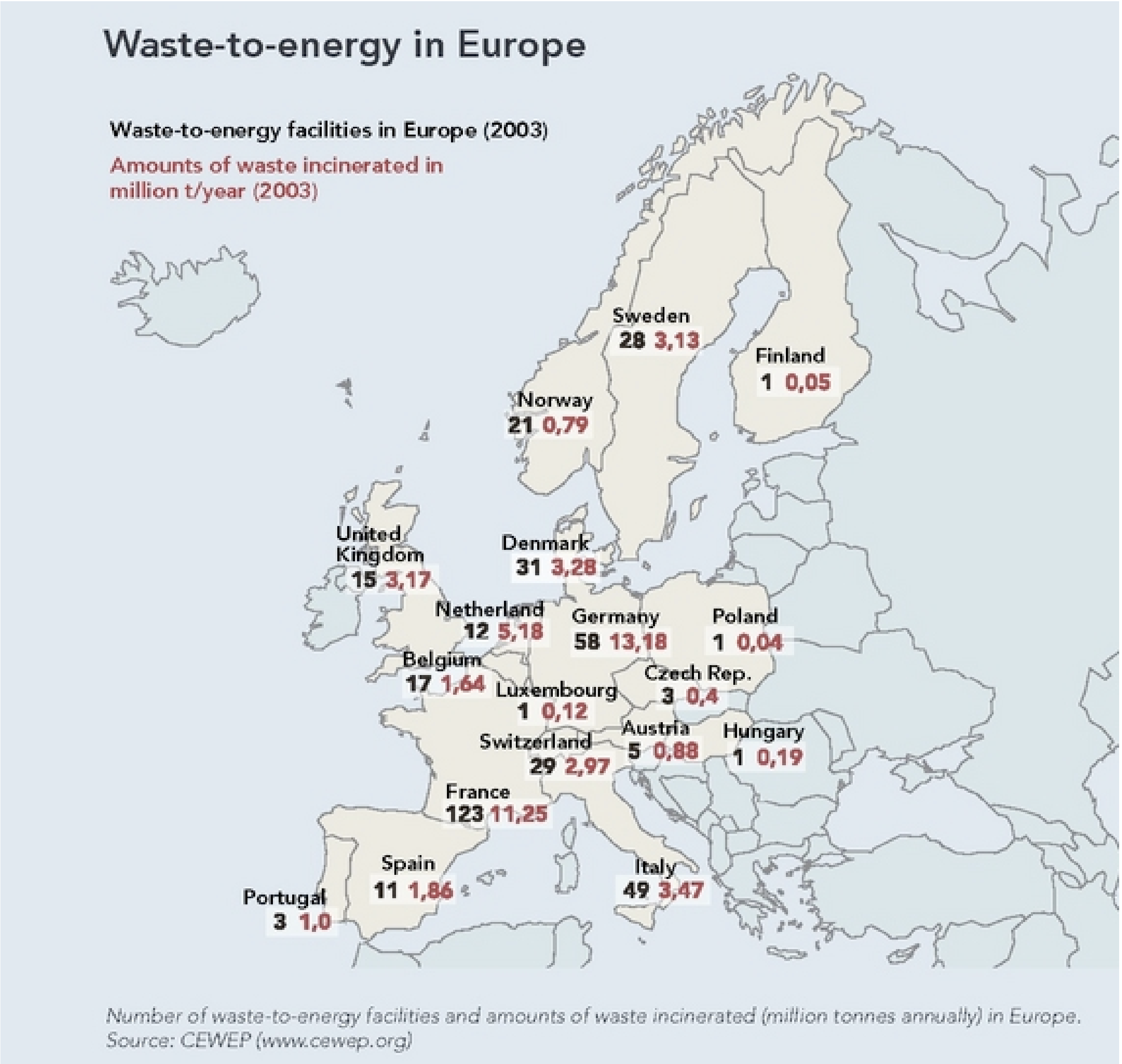

Figure 6: Waste-to-energy in Europe[7]

[6] “Municipal Solid Waste Generation...” 1

[7] *Waste-to-Energy in Denmark* 18

2 Background

2.1 Landfills

Figure 7: Landfill[8]

Most waste in the United States today goes to landfills. Landfills are, in essence, a depression in the ground or built on top of the ground into which waste is dumped and then eventually covered. In a secure landfill, the wastes should avoid any hydraulic connection with the surrounding environments, in particular the groundwater ("Landfills: Hazardous..."), and landfills are designed accordingly (Figure 8).

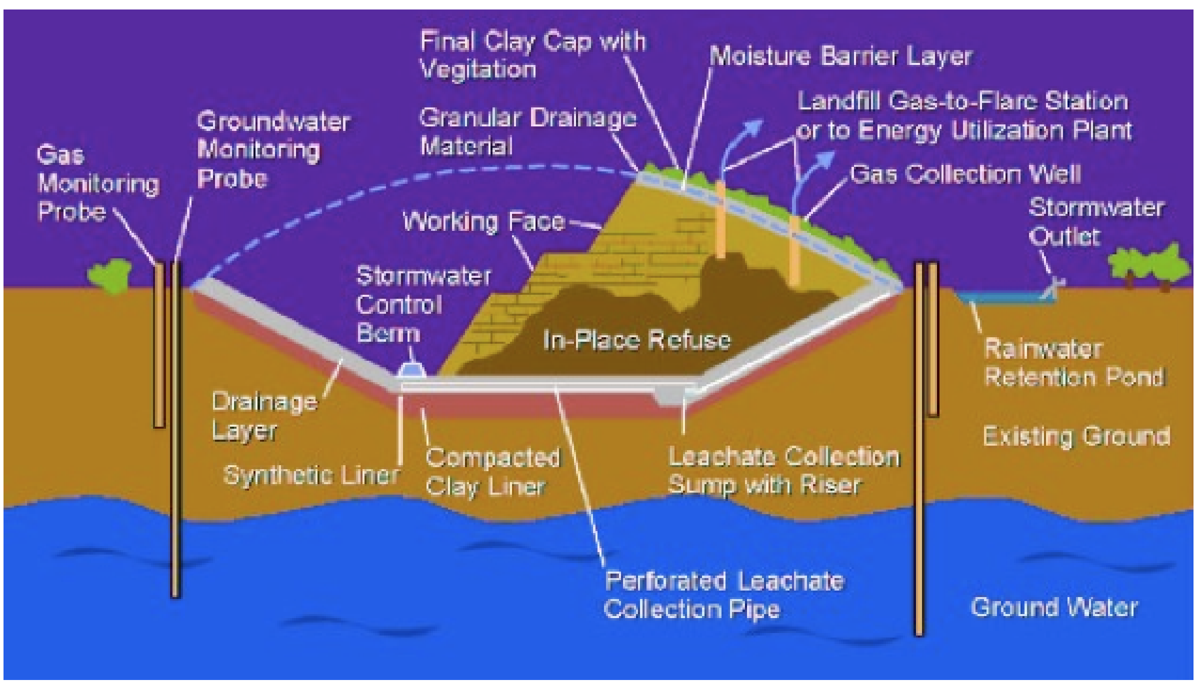

Figure 8: Cross section of a typical modern MSW landfill[9]

[8] http://swamplot.com/wp-content/uploads/2007/04/landfill-landscape.jpg

[9] http://www.environmentalistseveryday.com/issues-solid-waste-technologies-regulations/landfills-garbage-disposal/index.php

Despite careful designs, landfills invariably leak, particularly in the form of landfill gases (LFG), which are composed of roughly 50% CO_2 and 50% methane (CH_4, a greenhouse gas with a global warming potential 21 times that of CO_2) generated from the anaerobic decomposition of the waste (Kaplan, Decarolis, and Thorneloe 1711). The Clean Air Act (CAA) regulations require the LFG of large landfills to be captured and controlled by a gas collection system installed within five years of the waste placement and which can be expanded as more waste is buried (Kaplan, Decarolis, and Thorneloe 1711). Even so, not all LFG is collected — due to initial delays of installing the collection system as well as later leaks — and between 60% and 85% of the methane generally escapes from landfills (Kaplan, Decarolis, and Thorneloe 1711). Indeed, the methane leakage from landfills is so high that the E.P.A. estimates that it accounts for 25% of all methane releases linked to human activity (Rather 1).

In some states, the methane that is successfully captured is subsequently flared, i.e. burned off, to prevent its release into the atmosphere (Rather 1). However, in others, the captured LFG is combusted in an engine or turbine to generate electricity (Kaplan, Decarolis, and Thorneloe 1711). For example, in New Jersey, over half of the captured LFG generates electricity in this way, and LFG in New York, New Jersey, and Connecticut together generate 169 MW electricity, which is just under the power generation of a small conventional generating station (Rather 1). As of 2008, Waste Management was planning to spend $400 million to build LFGTE (landfill gas-to-energy) projects at 60 more landfills across the United States (Rather 1).

2.2 Waste Reduction and Recovery

Another destination for waste — and one far preferable to landfilling in terms of environmental impact and energy savings — is waste reduction and recovery by reusing, recycling, and composting. Although recycling can be an intensive process requiring large amounts of energy, it still saves significantly on energy and toxic emissions, because the need to harvest and process new materials is avoided. As a life cycle analysis of recycling versus incinerating or landfilling concluded,

> ***"Recycling has substantial benefits compared with disposal in terms of reducing energy consumption and environmental burdens imposed by methods used for managing solid wastes. … The main reason … is that the pollution prevention and resource conservation benefits of manufacturing products out of recycled materials tend to be an order of magnitude larger than the environmental burdens imposed by recycling collection, processing and shipping systems. These upstream benefits of recycling also are much larger than the energy production offsets from whatever method is used to generate energy directly from waste"*** (Morris 283-284).

In fact, some of the main opposition to waste-to-energy incinerators in the United States comes from environmentalist groups worried that the use of incinerators will undermine reducing, reusing, and recycling, as both may compete to use the same waste (Gies). Furthermore, because the monetary costs of building an incinerator are so high, the incinerator must be fed a constant supply of waste for many years in order to recoup costs — frequently, incinerator operators contract with local authorities to supply them with waste for 25 to 30 years (MacGuire). Those opposing incinerators argue that this will encourage waste production rather than reduction (MacGuire), and advocates of "zero waste" claim that waste is the result of bad planning and therefore is not inevitable, so we should be focusing on redesigning society rather than accepting waste.

3 Waste-to-Energy Plants

Waste-to-energy (WTE) plants convert waste, both household and industrial, into heat and/or electricity. Most commonly, such plants burn the trash, but other technologies for generating electricity from trash exist as well.

3.1 Incinerators

In incinerators, the process used is combustion, i.e. the waste is heated in the presence of oxygen. An example of a combustion process is that of cellulose, $C_6H_{10}O_5$. When heated (to around 450˚ F, the ignition point of cellulose) in the presence of oxygen, cellulose recombines with the oxygen to produce carbon dioxide, water, and more heat:

$C_6H_{10}O_5 + 6\ O_2 + \text{heat} \rightarrow 6\ CO_2 + 5\ H_2O + \text{heat}$ ("Pyrolysis... Part 1").

There are three variations of combustion: stoichiometric combustion, excess-air combustion, and sub-stoichiometric (or starved-air) combustion. Stoichiometric combustion is the combustion process described above, where the material is burned with exactly the amount of oxygen needed according to the idealized reaction of theoretical complete combustion ("Pyrolysis... Part 1"). Excess air combustion is the same combustion reaction, except that the material is burned with more oxygen than that needed for theoretical complete combustion ("Pyrolysis... Part 1"). Likewise, in sub-stoichiometric combustion, the material is burned with less oxygen than that needed for theoretical complete combustion ("Pyrolysis... Part 1").

Because more heat is produced by the combustion reaction, the process is exothermic and can sustain further combustion reactions in addition to producing excess heat. This excess heat is used to turn water into steam, which in turn runs a turbine and electric generator (Kaplan, Decarolis, and Thorneloe 1711).

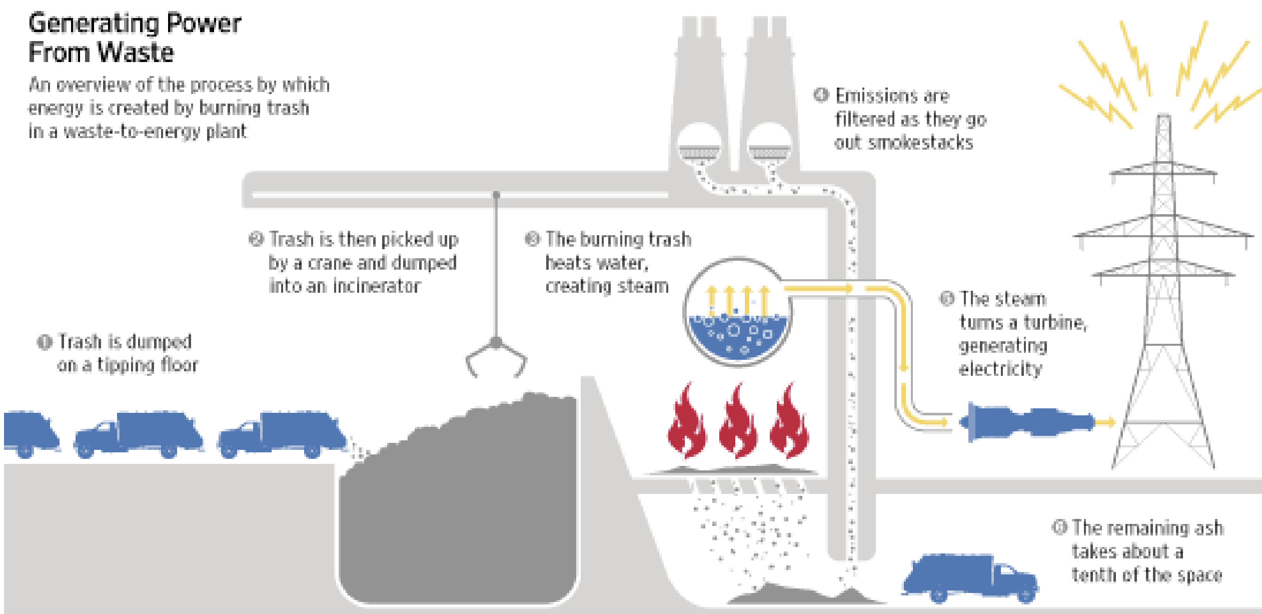

Figure 9: Generating power from waste[10]

[10] Brat

However, complete combustion doesn't actually happen inside an incinerator, as the waste is composed of a mixture of materials, both biogenic and fossil (Kaplan, Decarolis, and Thorneloe 1711). The heated elements may recombine to produce other products in addition to those from complete combustion, some of which are polluting. These pollutants, including hydrochloric acid, sulfur dioxide, nitrogen oxides, dioxins, furans, heavy metals, and small particulates, must subsequently be captured by a series of filters and scrubbers (Rosenthal, "Europe Finds..." 2). Fortunately, over the decades, the technology for limiting stack gas emissions has developed and improved, and performance data in the United States indicate that actual emissions are less than the regulatory requirements set by CAA regulations (Kaplan, Decarolis, and Thorneloe 1711). In Denmark, where state-of-the-art incinerators are used, the plants run so cleanly that the dioxin emissions are lower than those released from home fireplaces and backyard barbecues (Rosenthal, "Europe Finds..." 1). Such Danish WTE facilities consist of ***"a reception and waste feeding system, one or more incineration units complete with bottom ash handling system, boiler, flue gas treatment system, and stack. … If the facility is a CHP [combined heat and power] plant, the boiler is a steam boiler. The steam produced is led to a steam turbine, which drives a power generator. The residual heat of the steam is recovered for the production of district heating"*** (*Waste-to-Energy in Denmark* 7).

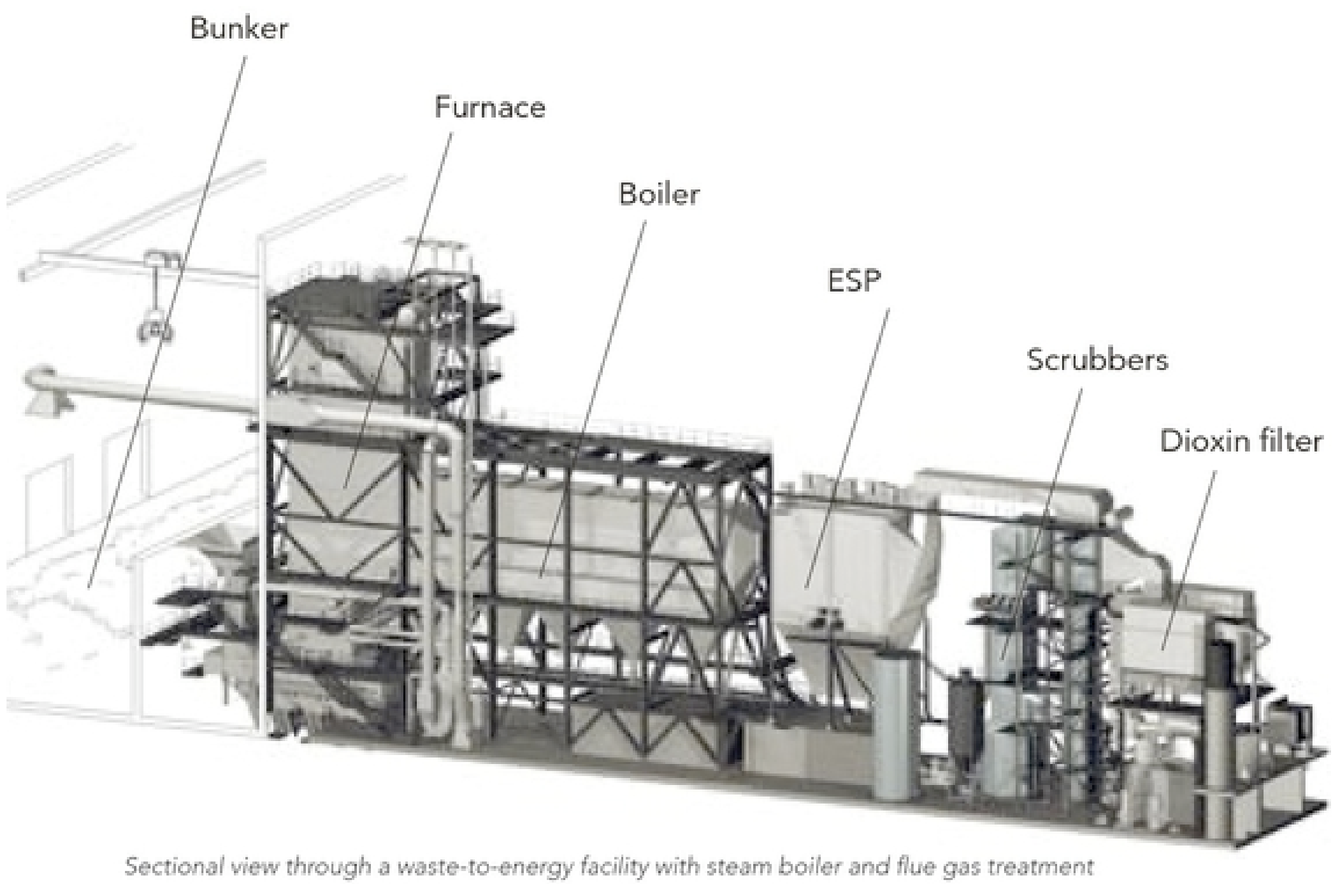

Figure 10: Waste-to-energy facility[11]

In addition to filtering the emissions, acids, heavy metals, and gypsum must be extracted and can be sold for use in manufacturing or construction (Rosenthal, "Europe Finds..." 3), and ferrous material from the incoming waste stream and bottom ash can be recovered with a 90% recovery rate, displacing the virgin ferrous material used to manufacture steel (Kaplan, Decarolis, and Thorneloe 1713). Only the highly

[11] *Waste-to-Energy in Denmark* 7

concentrated toxic materials, which form a paste, must be specially dealt with — in Denmark, this paste is shipped to warehouses for highly hazardous materials (Rosenthal, "Europe Finds..." 3). As Ivar Green-Paulson, the general manager of Denmark's largest plant, pointed out, ***"The hazardous elements are concentrated and handled with care rather than dispersed as they would be in a landfill"*** (qtd. Rosenthal, "Europe Finds..." 3).

3.2 Pyrolysis & Plasma Gasification

Besides the combustion reaction described above, there are a couple of other processes for converting waste into trash. Pyrolysis is similar to combustion, except that the material is decomposed without the addition of air or oxygen ("Pyrolysis... Part 2"). There may still be some oxygen in the process, either trapped along with the waste or in the chemical composition of the waste itself, but this is significantly less oxygen than in standard combustion ("Pyrolysis... Part 2"). Pyrolysis may either take place at relatively low temperatures (750 – 900˚ F) and for short times, which is called "fast" or "flash" pyrolysis, or at higher temperatures (1500 – 2000˚ F) for longer times ("Pyrolysis... Part 2"). Fast pyrolysis is generally used for biomass, among other applications, whereas the higher-temperature pyrolysis is used for medical waste ("Pyrolysis... Part 2").

In pyrolysis, several reactions take place ("Pyrolysis... Part 2"). To take the example of cellulose, the following four reactions occur when cellulose is heated in the absence of oxygen ("Pyrolysis... Part 2"):

- $C_6H_{10}O_5 + \text{heat} \rightarrow CH_4 + 3\ H_2O + 2\ CO + 3\ C$
- $C_6H_{10}O_5 + \text{heat} \rightarrow 2.5\ CH_4 + 1.5\ CO_2 + 2\ CO$
- $C_6H_{10}O_5 + \text{heat} \rightarrow 2.5\ CH_4 + 2.5\ CO_2 + C$
- $C_6H_{10}O_5 + \text{heat} \rightarrow 5\ H_2 + 1.5\ CO_2 + 2\ CO + 2.5\ C$

Unlike combustion, pyrolysis is endothermic, so the reactions require heat in order to be sustained ("Pyrolysis... Part 2").

The third main WTE process is plasma gasification, in which material is heated at much higher temperatures to decompose with limited amounts of air or oxygen. Plasma is the fourth state of matter (the others being solid, liquid, and gas) and is characterized by highly ionized gases ("Pyrolysis... Part 2"). Lightning is an example of plasma gas in nature (Circeo 2). Because the gas is ionized, plasma can conduct electricity. In plasma gasification plants, the plasma is generated by flowing a current between an electrode and the waste in its container (which acts as the other electrode), between one electrode and an electrode in the molten waste, or between two electrodes contained within a "plasma torch" ("Pyrolysis... Part 2"). The torch contains a carrier gas, which becomes ionized to create the plasma ("Pyrolysis... Part 2") and which can reach temperatures as high as 25,000˚ F — even a few feet from the torch, the temperature can be 5,000 – 8,000˚ F ("The Complete Recovery of Waste...").

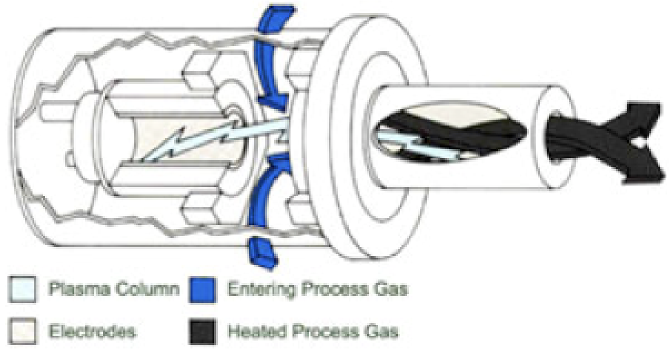

Figure 11: Diagram of how a plasma torch operates[12]

This temperature is sufficiently hot that the waste, which does not need to be sorted, is broken down into its elemental components ("The Complete Recovery of Waste..."). The organic portion of the waste is converted into a fuel gas. When a limited amount of air is added, this byproduct gas, called "producer gas," has a low heat content, whereas when a limited amount of pure oxygen is added in place of air, the byproduct gas, called "syngas," has a higher heat content ("Pyrolysis... Part 2"). The inorganic waste is converted into an inert vitrified glass, called "slag" ("The Complete Recovery of Waste...").

After being cleansed of traces of harmful chemicals such as hydrochloric acid, the syngas is burned like natural gas (Koerner). Furthermore, steam from the heat can be used to power steam turbines ("Florida County..."). Even without the additional energy provided by the steam turbines, burning the syngas not only produces enough electricity to sustain the plant's processes, but also yields excess electricity that can be sold to the electrical grid (Koerner). The slag must also be cleaned by removing highly toxic heavy metals such as mercury and cadmium (Koerner). However, the clean slag can then be sold for use in road and construction projects ("Florida County...").

Because the waste is broken into its elemental components, plasma gasification theoretically produces few, if any, emissions — although this has yet to be indisputably achieved, as plasma gasification is still a relatively new technology ("Florida County...") — and no ash ("The Complete Recovery of Waste..."). In practice, even though the gasification process itself may or may not release emissions, the gas-powered turbines that create the electricity do ("Florida County..."). Nonetheless, because the emissions from the plasma gasification reactors are lower than those from incinerator reactors, the stack emissions of plasma gasification plants, including those added by the turbines, tend to be lower as well ("The Complete Recovery of Waste..."). In addition, plasma gasification is more efficient at electricity production, producing more kilowatt-hours of electricity per ton of MSW fed into the plant than incinerators (Circeo 11).

Although it is useful to understand the various WTE technologies, in the remainder of this paper the focus will be on incinerators, which have been studied extensively in terms of environmental effects. Because there have been relatively few plasma gasification plants so far and the technology is still developing, it is more difficult to evaluate their potential and effects.

12 "The Complete Recovery of Waste..."

4 Costs of Waste Destinations and Energy Sources

One of the main deterrents today to installing WTE plants is the cost. Waste-to-energy incinerators typically involve upfront expenditures of a few hundred million dollars; one of the more expensive planned incinerators in Frederick County, Maryland, is expected to cost almost $600 million (Greenfield). However, in the Northeastern United States, transporting waste to landfills can also cost millions, as the landfills are often several states away (Rosenthal, "Europe Finds..." 2). In 2009, New York City spent $307 million to export over four million tons of waste to other states, including Ohio and South Carolina. New York City also processed a small portion of its waste at two WTE plants in Newark and Hempstead, N.Y., at $65 a ton, which is currently the city's cheapest waste disposal option (Rosenthal, "Europe Finds..." 2).

In the Western United States, where land is more plentiful, landfilling is cheaper than incineration, but these monetary costs do not factor in environmental effects. Even though the price today for landfilling waste may be cheaper, it is vital to also consider costs that will affect not only our lives currently but those of generations to come. What is the cost of global warming accelerated by the methane escaping from landfills? What will be the cost of fuel if we continue to deplete nonrenewable resources without investing in other methods, including WTE plants? In order to gain perspective, we must evaluate the environmental effects of the waste treatment methods — WTE plants, landfills, and reduction/reuse/recycling — and of energy production methods — such as WTE, landfill gas-to-energy (LFGTE), coal, and natural gas.

In a 2009 study, researchers Kaplan, Decarolis, and Thorneloe from North Carolina State University and the United States Environmental Protection Agency (U.S. EPA) compared the life-cycle inventory (LCI) emissions from WTE and LFGTE, setting the results alongside the emissions from the alternative waste treatments of venting (landfills with no controls on the LFG) and flaring (landfills where the LFG is collected and flared without energy production) and from the alternative energy sources of coal, natural gas, oil, and nuclear. They identified landfills' emissions as coming from (1) the site preparation, operation, and post closure operation, (2) the anaerobic decay of waste, (3) the landfill operation and LFG management operation equipment, (4) the diesel production for operating vehicles at the landfill site, and (5) the treatment of the leachate (Kaplan, Decarolis, and Thorneloe 1712). The emissions from WTE result mainly from (1) the waste combustion (the stack gas), (2) the production and use of limestone in the control technologies (the scrubbers), and (3) the disposal of ash into a landfill (Kaplan, Decarolis, and Thorneloe 1713). With regard to the disposal of remaining ash, it should also be noted that the cleaned ash can be used as filler for asphalt or concrete ("Pollution from Waste-to-Energy Incinerators"). Kaplan et al. found that the emissions associated with manufacturing the turbines and boilers for the WTE facilities are insignificant (Kaplan, Decarolis, and Thorneloe 1713).

With the exception of nuclear energy, WTE plants consistently produce among the lowest emissions of CO_2 equivalents, sulfur oxides, and nitrogen oxides (Figures 11, 12, 13) relative to the other energy sources considered (LFGTE, coal, natural gas, oil, and nuclear). Kaplan et al. also calculated the emission factors for other criteria pollutants and found that besides CO and HCl emissions, WTE and LFGTE produce lower emissions than those for coal-fired generators (Kaplan, Decarolis, and Thorneloe 1714). Furthermore, in this study, only electricity generation is considered because that is most common form of energy produced by WTE and LFGTE plants in the United States. However, in several European countries, the WTE incinerators are combined heat and power (CHP) plants, which are generally more efficient.

Lastly, WTE plants are an order of magnitude more efficient at producing energy from waste than LFGTEs. Kaplan et al. point out that ***"Hypothetically, if 166 million tons of MSW is discarded in regional landfills, energy recovery on average of ~10 TWh or ~65 (kWh)/ton of MSW of electricity can***

be generated, whereas a WTE facility can generate on average ~100 TWh or ~600 (kWh)/ton of MSW of electricity with the same amount of MSW" (Kaplan, Decarolis, and Thorneloe 1714).

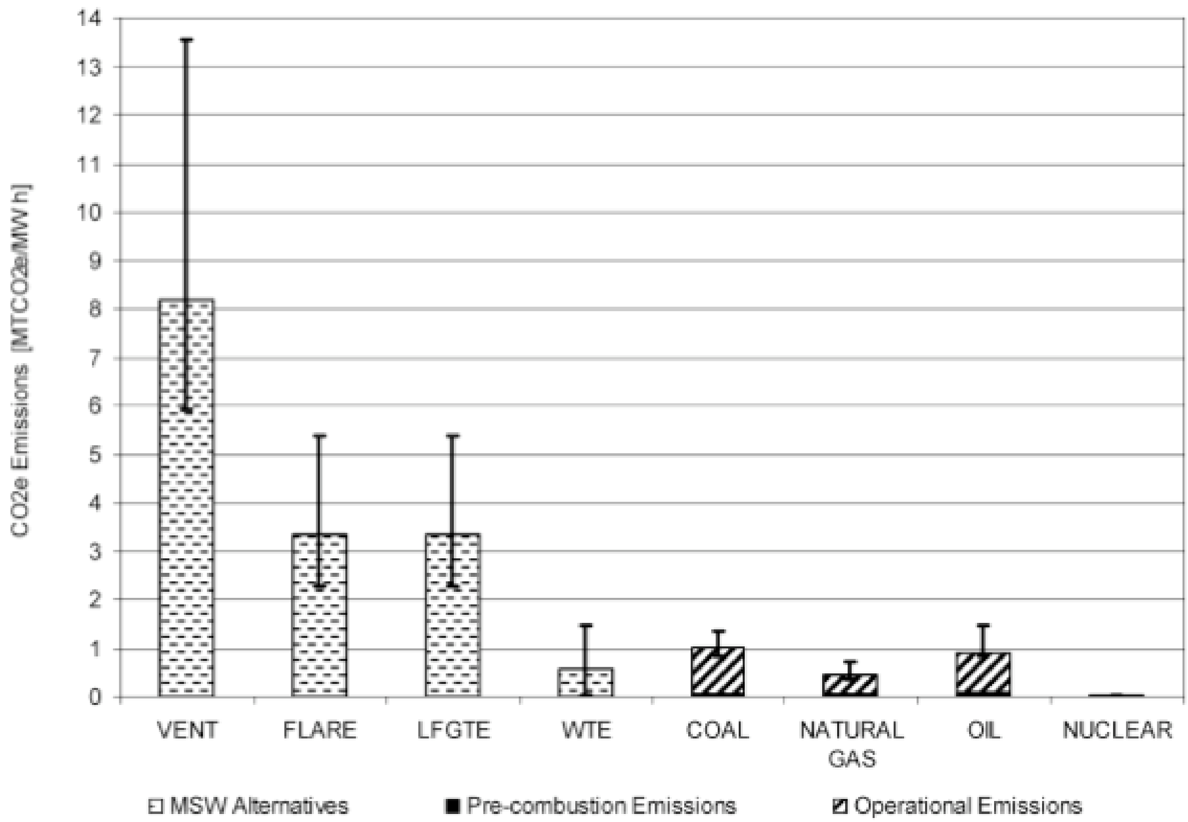

Figure 12: Comparison of carbon dioxide equivalents for LFGTE, WTE, and conventional electricity-generating technologies. Note that the CO_2e emissions are much higher for all landfill scenarios due to the relatively large amount of methane released by landfills, which has a much greater greenhouse effect than CO_2.[13]

[13] Kaplan, Decarolis, and Thorneloe 1714

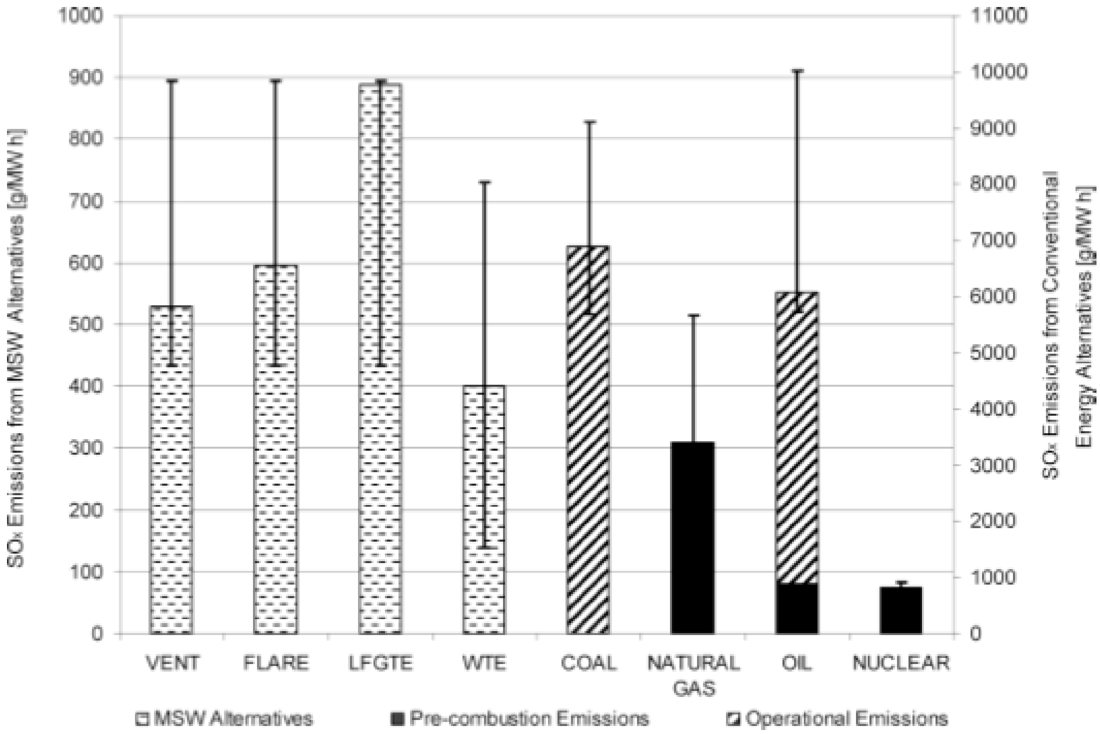

***Figure 13: Comparison of sulfur oxide emissions for LFGTE, WTE, and conventional electricity-generating technologies. Note the different scales for MSW alternatives' emissions and conventional energy alternatives' emissions.*[14]**

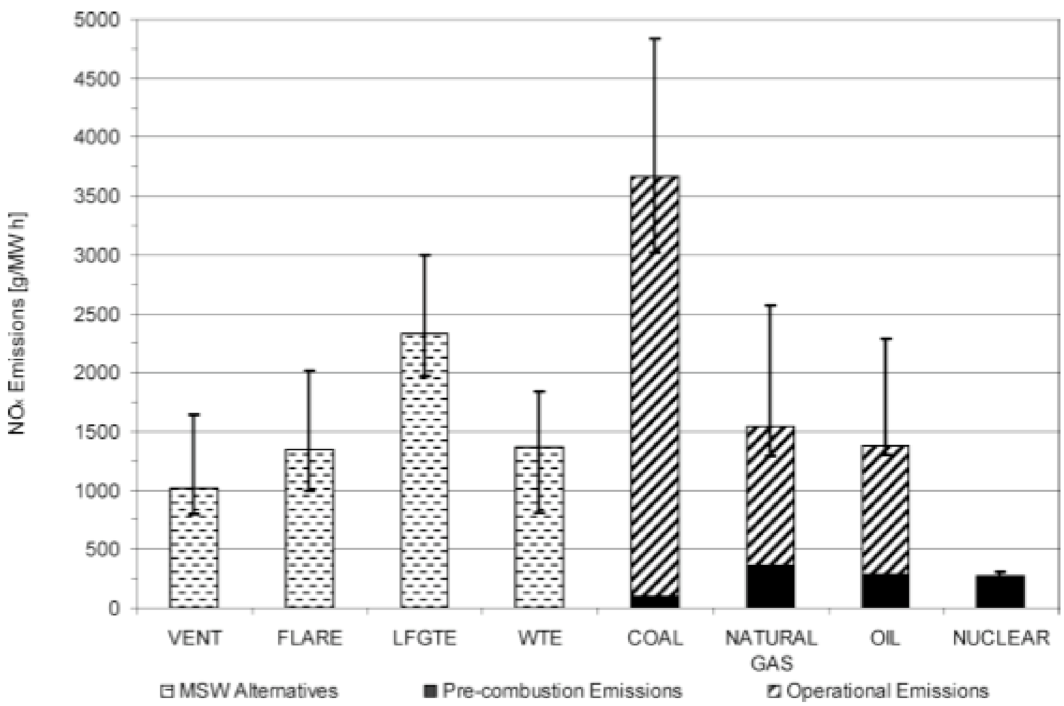

***Figure 14: Comparison of nitrogen oxide emissions for LFGTE, WTE, and conventional electricity-generating technologies*[15]**

---

[14] Kaplan, Decarolis, and Thorneloe 1715

[15] Kaplan, Decarolis, and Thorneloe 1715

A Swedish study by scientists Eriksson, Finnveden, Ekvall, and Björklund assessed energy sources for the production of heat, both through district-heating generation (DH) and through combined heat and power generation (CHP). Eriksson et al. considered 14 scenarios of different combinations of fuels, forms of energy recovery (DH or CHP), electricity scenarios (the form of marginal electricity production — if the particular fuel in question weren't used, would the alternative electricity production have a high or low environmental impact?), and the avoided waste treatments (would the waste be recycled/reused or would it be landfilled if it weren't sent to WTE plants?) (Table 3).

Table 3: Combinations simulated for Eriksson et al.'s study[16]

Nr	Fuel	Energy recovery	Electricity scenario	Avoided waste treatment
1	Waste	CHP[a]	High environmental impact	Material recycling
2	Waste	DH[b]	High environmental impact	Material recycling
3	Biofuel	CHP	High environmental impact	—
4	Biofuel	DH	High environmental impact	—
5	Natural gas	CHP	High environmental impact	—
6	Waste	CHP	High environmental impact	Landfilling
7	Waste	DH	High environmental impact	Landfilling
8	Waste	CHP	Low environmental impact	Material recycling
9	Waste	DH	Low environmental impact	Material recycling
10	Biofuel	CHP	Low environmental impact	—
11	Biofuel	DH	Low environmental impact	—
12	Natural gas	CHP	Low environmental impact	—
13	Waste	CHP	Low environmental impact	Landfilling
14	Waste	DH	Low environmental impact	Landfilling

[a]CHP = combined heat and power generation.
[b]DH = district-heating generation.

They found that when incineration replaces recycling (scenarios 1, 2, 8, and 9), there is net use of non-renewable energy (Figure 15) — which holds regardless of whether the replaced electricity would have had high or low environmental impact — because once incinerated, new plastic needs to be made using oil (Eriksson et al. 1353). However, when incineration replaces landfilling (scenarios 6, 7, 13, and 14), renewable energy is produced and non-renewable energy used, for a net saving of energy — again, this holds regardless of whether the replaced electricity would have had high or low environmental impact (Eriksson et al. 1353). In fact, when incineration replaces landfilling, WTE with CHP yields the greatest energy savings, followed by WTE with DH (Figure 15).

[16] Eriksson et al. 1353

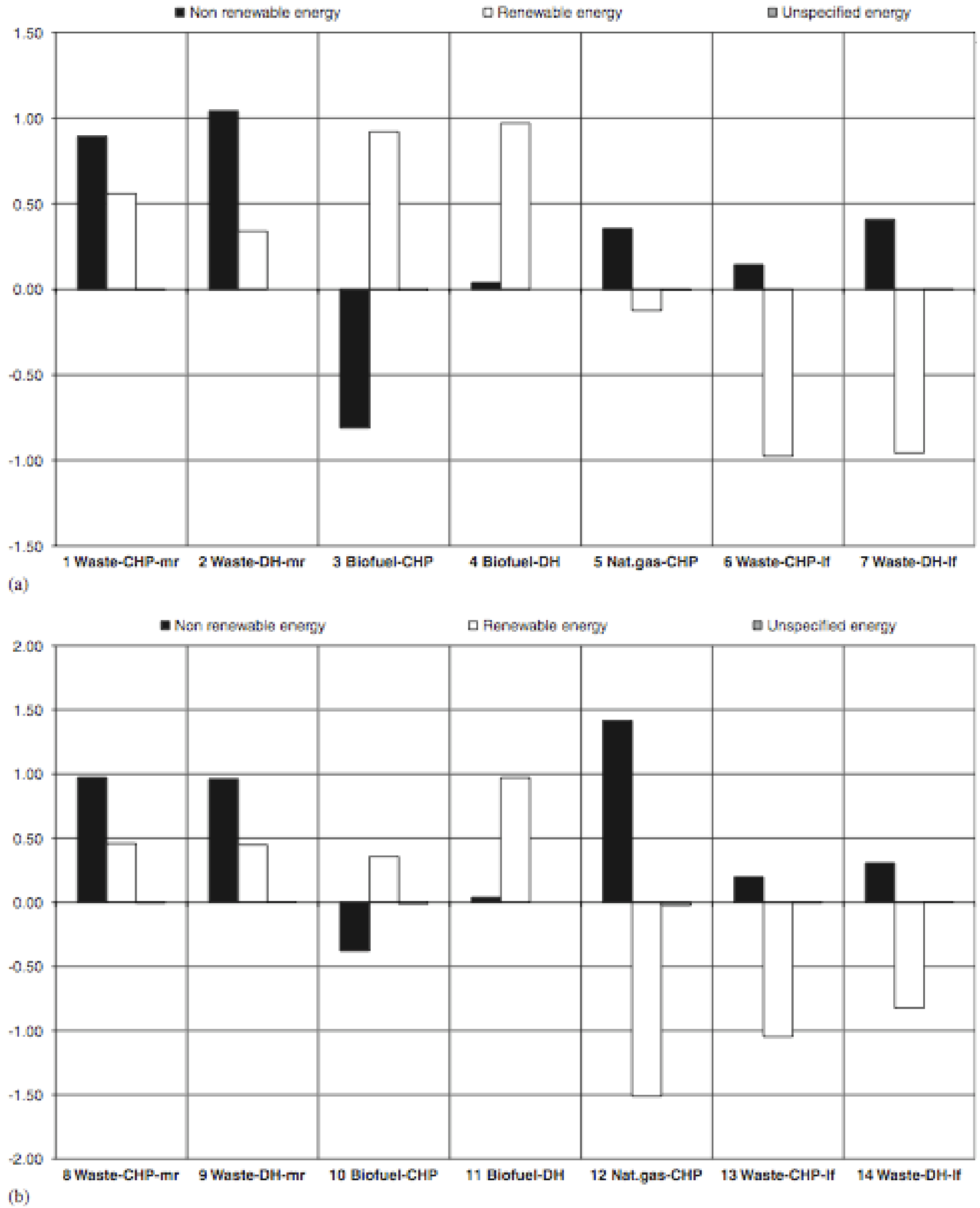

Figure 15: Primary energy turnover for (a) scenarios 1 – 7 (high environmental impact) and (b) scenarios 8 – 14 (low environmental impact). Units in MJ/MJ heat[17]

Eriksson et al. also found that when incineration replaces landfilling, the global warming potential over the next 100 years for both WTE with CHP and WTE with DH is significantly lower than for any other fuel considered (Figure 16). In contrast, when incineration replaces recycling, the overall effect of WTE incineration is considerably worse than nearly every other alternative.

[17] Eriksson et al. 1354

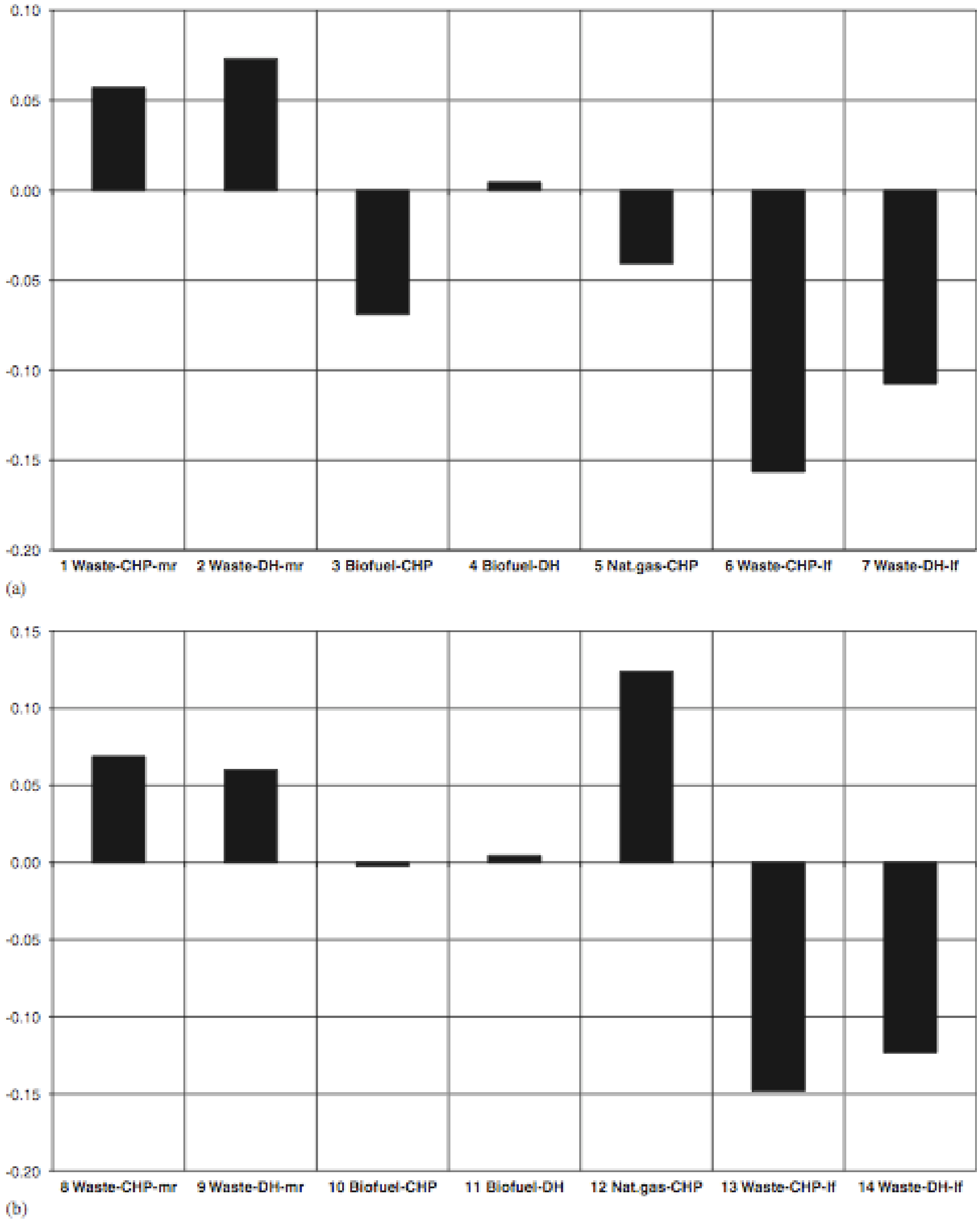

Figure 16: Global warming potential (100 years) for (a) scenarios 1 – 7 (high environmental impact) and (b) scenarios 8 – 14 (low environmental impact). Units in kg CO_2e/MJ heat [18]

Finally, the study included a weighted result of the environmental impacts of the various fuel sources (Figure 17). Eriksson et al. used Ecotax 02 as the weighting method because ***"the idea behind Ecotax 02 is that we can use taxes and fees as expressions of the value society places on damages relating to the environment"*** (Eriksson et al. 1352). According to this weighting method, using WTE in place of landfilling clearly has the lowest environmental impact (where WTE with CHP has a slightly lower impact than WTE with DH).

[18] Eriksson et al. 1355

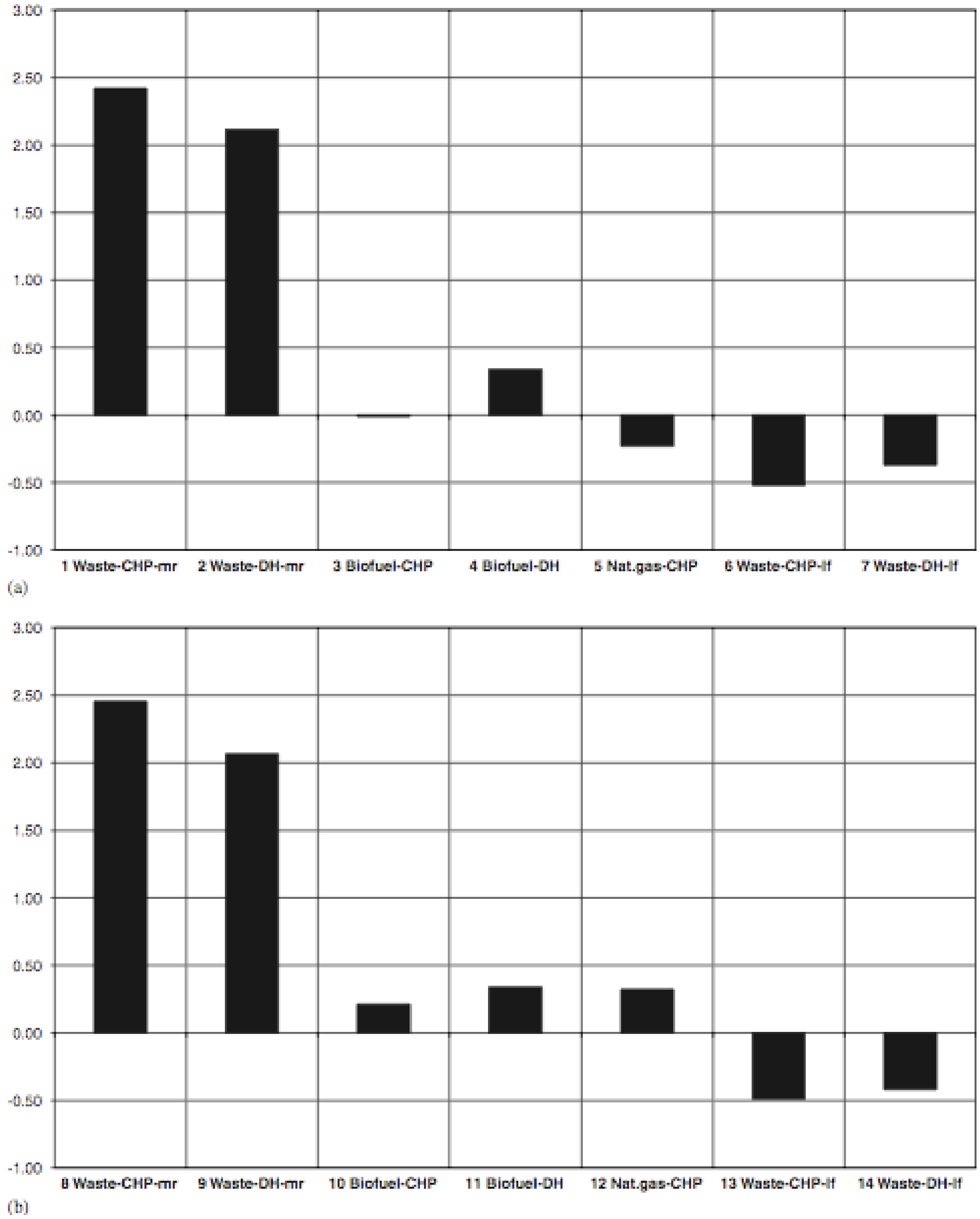

Figure 17: Weighted results for (a) scenarios 1 – 7 (high environmental impact) and (b) scenarios 8 – 14 (low environmental impact). Units in SEK/MJ heat[19]

To check the weighting method's robustness, Eriksson et al. also used three other versions of the Ecotax method to separate short-term from long-term emissions and two commonly used LCA (life cycle assessment) weighting methods, Eco-indicator 99 and EPS 2000 (Eriksson et al. 1352). Although the relative environmental impacts of the fuel sources were not always the same as those shown in Figure 17, the overall results were very similar. The study concluded that ***"The results for waste incineration are very much dependent on the alternative waste management. Waste incineration is often (but not always) the preferable choice when incineration replaces landfilling. It is however, never the best choice (and often the worst) when incineration replaces recycling"*** (Eriksson et al. 1357).

[19] Eriksson et al. 1356

5 WTEs at Work in Denmark

Denmark, a country of 5.5 million, incinerates the largest percentage of its waste in Europe with its 29 WTE plants serving 98 municipalities (Rosenthal, "Europe Finds..." 1). Aiding the success of incineration in Denmark is government involvement promoting environmental and consumer friendliness. The municipalities control the destinations for all waste by collecting household waste and assigning treatment and disposal facilities for commercial and industrial waste (*Waste-to-Energy in Denmark* 11). The waste management and energy production are both heavily regulated, and all suitable waste must be reused and recycled first; of the remaining waste, everything that can be incinerated must be incinerated at a WTE plant; and finally, the remaining waste that cannot be reused, recycled, or incinerated may be landfilled (*Waste-to-Energy in Denmark* 4). As a result, Denmark has the highest overall recycling rates and the most efficient waste incineration system in Europe (*Waste-to-Energy in Denmark* 21). In fact, because approximately 20% of the waste that enters incinerators is non-combustible, such as glass, iron, and other metals, these parts exit the WTE facility in the bottom ash, which is also recycled (*Waste-to-Energy in Denmark* 8). If this recycling were included in the statistics, it would have contributed another 8% of waste to recycling in 2003 (*Waste-to-Energy in Denmark* 9).

Moreover, because of municipal waste management, the WTE plants are supplied with the entire amount of waste suitable for incineration and that cannot be reused or recycled (*Waste-to-Energy in Denmark* 11). Taxes further promote first recycling, then incineration, and lastly, landfilling: there is a landfill tax of DKK 375 (€51)/ton, a lower incineration tax of DKK 330 (€44)/ton, and recycling is tax free (*Waste-to-Energy in Denmark* 13). According to RenoSam, an association of 33 Danish and 2 Faroese waste management companies, ***"Apart from Denmark, waste-to-energy is most widespread in Sweden, Switzerland, the Netherlands, and Germany. In these countries, local governments play a significant role in the organization of the waste sector. In countries like the UK, where waste is primarily managed by private companies, the great proportion of the waste is still landfilled and waste-to-energy is less widespread and at relatively high cost"*** (*Waste-to-Energy in Denmark* 3).

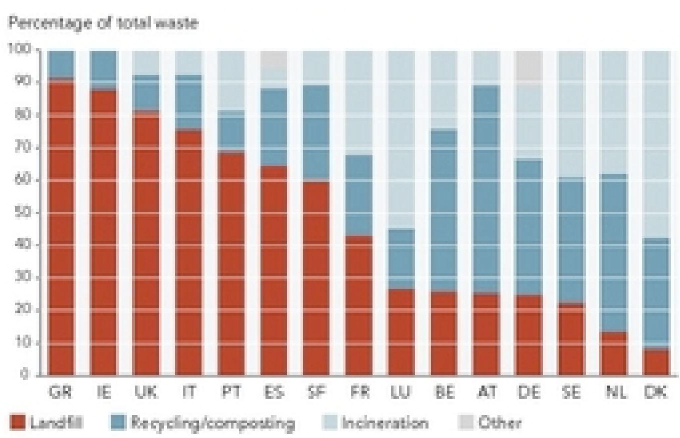

Figure 18: Treatment form of municipal waste in Western Europe. This figure only includes municipal waste; if industrial and commercial waste were included, the percentages would be different. For example, in Denmark, landfill would be 8%, recycling/composting 66%, and incineration 26%[20]

The municipal involvement also ensures low prices for household waste disposal, which is typically less than DKK 2.5 (€0.33) a week for waste treatment by incineration — the same as the household's waste collection bag (*Waste-to-Energy in Denmark* 3). Most of the waste management costs are not for household waste incineration, but to finance the cost of collection, schemes for bulky waste and recycling, hazardous waste management, and taxes and VAT (*Waste-to-Energy in Denmark* 3).

20 *Waste-to-Energy in Denmark* 10

In addition, since 1979, municipalities could dedicate certain areas to district heating to which households in those areas must connect ("Best Practice..." 1). Thus, WTE facilities that are connected to the district heating supply systems know that they can sell the heat produced (*Waste-to-Energy in Denmark* 11). Also, subsidies and taxes promote environmentally friendly electricity and heating production. Biomass-based electricity, including that from WTE plants, is subsidized, and there is no energy tax on heat production from biomass, whereas heat production from fossil fuels is heavily taxed ("Best Practice..." 3). Due to these taxes, combined with the European CO_2-quota trading system, CHP production based on biomass is more cost-effective than CHP production based on fossil fuels ("Best Practice..." 3). To protect consumers from high heating costs, the Heat Supply Act guarantees that the price for heat from incineration does not exceed the lowest of the cost-based price and the substitution price, which is what the price for heat from other available sources would be, were district heating not in place (*Waste-to-Energy in Denmark* 13). Consequently, the price of heat from waste incineration in Denmark is typically lower than the price of heat from other sources (Figure 19).

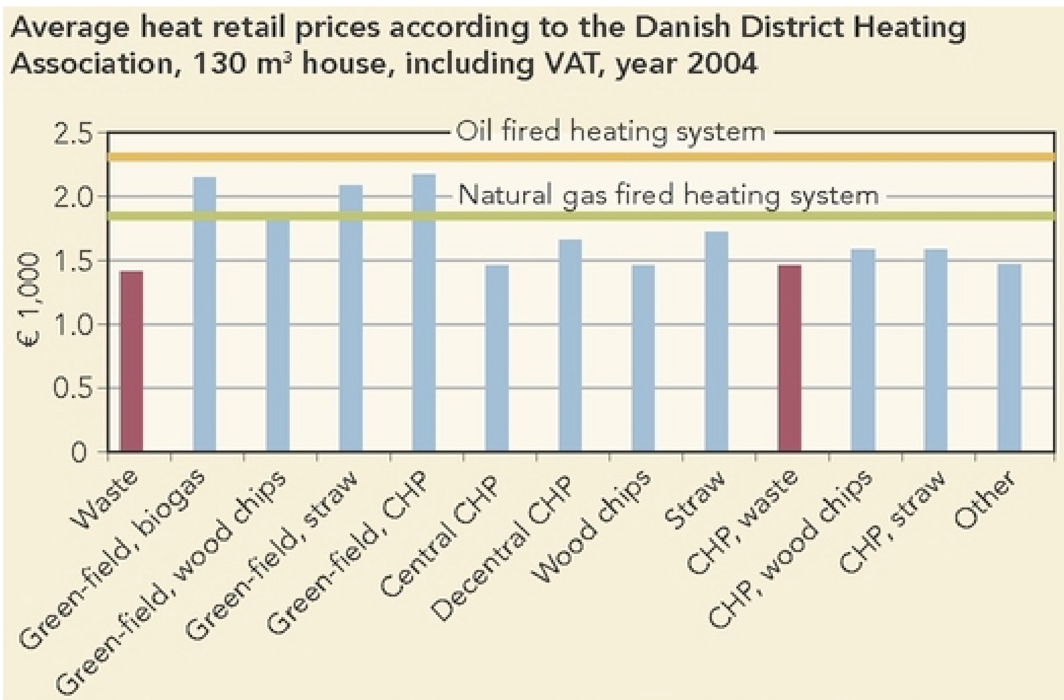

***Figure 19: Average heat retail prices*[21]**

Many of the WTE facilities themselves are owned by municipalities or inter-municipal companies. This ensures that the waste is managed ***"according to the principles of proximity and self-sufficiency"*** (*Waste-to-Energy in Denmark* 3). Denmark concentrates on CHP production, which is more efficient than either pure electricity production or pure heat production. Accordingly, over the last decade, all large and medium-sized WTE plants have been converted to CHP production (*Waste-to-Energy in Denmark* 4). Another reason the municipalities have control over several facilities is that WTE is a difficult market for perfect competition, and they wish to avoid one or two companies' dominating the market (*Waste-to-Energy in Denmark* 17). The establishment of WTE facilities is very capital-intensive (in Denmark, it typically costs €100 – 200 million), and so entering the market is difficult and risky (*Waste-to-Energy in Denmark* 17). Additionally, because of the district heating in Denmark, the demand for heat is limited and subject to competition in only a few areas, which makes free pricing for energy from WTEs difficult (*Waste-to-Energy in Denmark* 6). In countries without district heating system, WTE facilities can have freer pricing, but they aren't ensured the sale of heat and so may also have higher gate

[21] *Waste-to-Energy in Denmark* 13

fees than in Denmark, as costs that aren't covered by selling generated energy must be covered by gate fees (*Waste-to-Energy in Denmark* 17). In Denmark, the gate fees at WTE facilities are a mere DKK 200 (€27)/ton of waste, excluding taxes and VAT, which are the lowest gate fees in Europe (the highest are €200, in Germany) (*Waste-to-Energy in Denmark* 14). The WTE plants are subject to a cost coverage principle, meaning that they must balance expenses and receipts over a small time span to show neither profit nor loss (*Waste-to-Energy in Denmark* 13).

In 2003, Denmark generated 12.7 million tons of waste total, 66% of which was reused or recycled, 26% of which was incinerated at WTE plants, and the remaining 8% of which was landfilled (*Waste-to-Energy in Denmark* 5). One metric ton of incinerated waste produces roughly 2 MWh district heating and 0.67 MWh electricity (Figure 20). Thus, in 2003, WTE contributed ~3% of total Danish electricity production and ~18% of total district heating production (*Waste-to-Energy in Denmark* 11). The plants produced enough energy to cover the consumption of ~430,000 out of a total of 2.5 million households and enough heat to cover the consumption of ~360,000 households (*Waste-to-Energy in Denmark* 11).

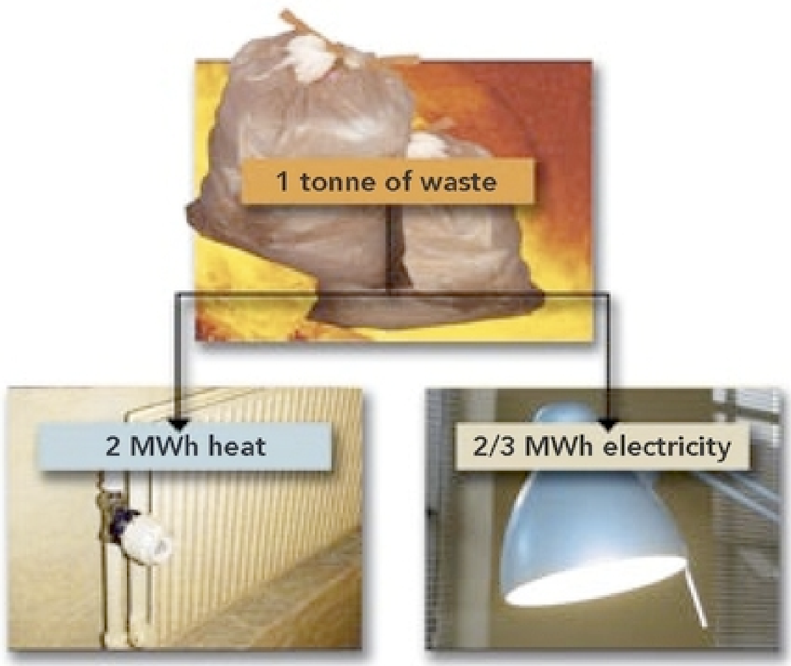

Figure 20: Heat and electricity from one metric ton of waste in Danish WTE facilities[22]

The waste that leaves the WTE facilities as bottom ash is sorted, and the iron and other metals recovered (*Waste-to-Energy in Denmark* 9). The remaining bottom ash is then recycled for construction; overall, 98% of the bottom ash ends up being recycled (*Waste-to-Energy in Denmark* 9). The small amount that cannot be recycled due to environmental requirements must be landfilled (*Waste-to-Energy in Denmark* 9). Otherwise, residues from flue gas treatment (50% of which derive from the waste itself, the other 50% of which are from reaction products from the lime and activated carbon added to clean the flue gas) are sent to special treatment and recovery centers in Norway or Germany (*Waste-to-Energy in Denmark* 9).

[22] *Waste-to-Energy in Denmark* 8

6 Proposed Model for Incinerator Use

Based on the relative environmental impacts of incineration versus the alternative waste management methods of reducing/reusing/recycling and landfilling, it's evident that our priorities should be to first reduce/reuse/recycle, then to incinerate, and to landfill only the waste that cannot be disposed of otherwise. The U.S. EPA also advocates the ranking of waste management practices in this order of preference: reduction, reuse, recycling, waste-to-energy incineration, and landfilling (Gies). Waste incineration need not compete with reduction/reuse/recycling efforts, but instead should be part of an integrated plan to manage our waste with minimal environmental impact.

An optimistic but still, I believe, realistic goal for the United States to achieve by 2020 is to first reduce municipal solid waste generation from the current 1,643 lbs down to 1,135 lbs per person per year (i.e. to 69% of our current generation). This is equivalent to that of Sweden in 2008, which is among the developed countries with the least waste production ("Municipal Waste"). Even so, there are several countries (including Japan, Belgium, and Norway) that generate less waste per capita ("Environment...," "Municipal Waste"). If each American produced 1,135 lbs of MSW each year, then with the current population of 307 million, we would produce 348.5 billion lbs of MSW total per year, or 174 million tons of waste per year.

Then, with a MSW recycling/composting rate of 45% — this just under Sweden's 47.6% in 2008, and although again it's one of the highest rates in the European Union, Germany's is 62.4% and Belgium's is 55.7% ("Municipal Waste"), so 45% is not overly ambitious — and an incineration rate of 40% — which is above Germany's 33.2% but below Denmark's 54% and Sweden's 48.5% ("Municipal Waste")* — we would be left with a landfill rate of 15%, which is an enormous improvement over our current discard rate of 54.2% ("Municipal Solid Waste Generation..." 3), although still higher than the landfill rates of Denmark and a few other countries.

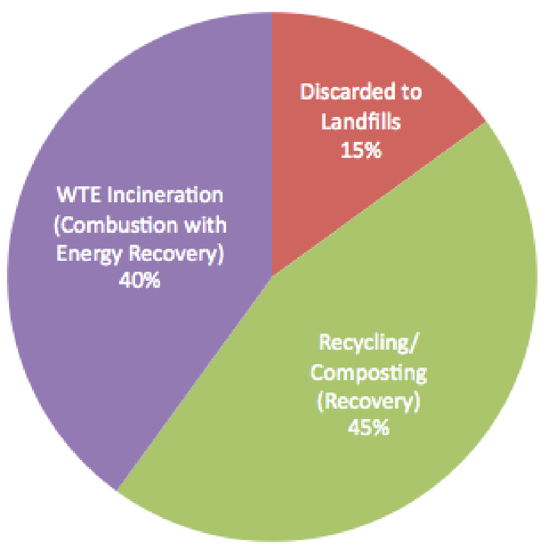

Figure 21: Management of MSW in the United States, according to proposed model. Compare to current management of MSW shown in Figure 3.

---

* These statistics do not quite mesh with those given in Figure 18 (*Waste-to-Energy in Denmark* 10), where it appears that the MSW incineration rates for Germany, Denmark, and Sweden are around 33%, 58%, and 39%, respectively. Most likely this is due to somewhat different interpretations of what MSW includes. The "Municipal Waste" recycling/composting rates also do not exactly match those in Figure 18. However, even considering the statistics in Figure 18, an incineration rate of 40% and a recycling/composting rate of 45% still seems plausible and manageable, though it may not be easy!

Naturally, our MSW composition will not be exactly the same as that of Denmark, Sweden, or any other given country, which may affect the percentages of waste that can be recycled/composted and incinerated. This is partly why, although my goals for U.S. recycling/composting and incineration rates are fairly optimistic, I have not set them to match the highest of other countries, in order to give room to accommodate for discrepancies in MSW composition.

Incinerating 40% of our reduced MSW (i.e. the 174 million tons of waste per year calculated above) would use 69.7 million tons of waste per year. An expanded incinerator in Fort Myers, Florida can process 1,200 tons of waste per day (438,000 tons/year) (Brat), while the Danish incinerators have an average capacity of about 125,500 tons/year each (calculated based on the total amount of waste that Denmark incinerates and the number of WTE plants in Denmark). To incinerate our 69.7 million tons of waste per year, we'd need roughly 159 large incinerators such as that in Fort Myers or 556 smaller ones like those in Denmark. We already have 87 incinerators (Rosenthal, "Europe Finds..." 1), although these should be updated to more efficient, cleaner models. As for the remaining necessary incinerators, ideally we should install a mixture of large and small: larger ones (which are generally more efficient, all else being equal) in urban areas with sufficient waste generation and smaller ones in less densely populated areas, in order to avoid transporting waste long distances and the associated financial and environmental costs. The plants themselves need not be ugly neighbors — several of the plants in Denmark have sleek, elegant designs, and others throughout Europe have been designed or retrofitted with aesthetics in mind (Figure 21) — nor undesirable ones — in Denmark, having a nearby WTE plant often raises home values, and the plants produce no noticeable odors (Rosenthal, "Europe Finds..." 3). The plants may be privately owned, as existing incinerators in the U.S. usually are, or publicly owned à la Danish system.

Figure 22: The Spittelau waste-to-energy plant in Vienna, which now generates heat[23]

The less efficient WTE models in the U.S. produce 590 kWh of electricity/ton waste ("Two Approaches to Waste"). Given 69.7 million tons of waste/year, such WTEs would yield 41,100,000 MWh/year. This is 1.06% of the total U.S. electricity consumption of 3,872,598,000 MWh in 2008 ("International Energy

[23] Rosenthal, "The Incinerator…".

Statistics”). The state-of-the-art CHP incinerators in Denmark are significantly more efficient and yield 2 MWh district heating and 0.67 MWh electricity per (metric) ton of waste (*Waste-to-Energy in Denmark* 8), or 1.8 MWh district heating and 0.61 MWh electricity per (short) ton of waste. With such efficiency, our 69.7 million tons of waste/year could generate 125,400,000 MWh district heating and 42,500,000 MWh electricity per year.

One should also recall that reducing, reusing, and recycling waste saves significantly more energy than incinerating or otherwise disposing of it. As a result, our estimation of U.S. WTEs’ generating 1.06% of the electricity we consume should in fact be higher, as our electricity consumption would drop with our increased reduction, reuse, and recycling of waste. Furthermore, although generating just over 1% of our energy consumption may appear negligible, the greatest benefits of using WTEs will come not through energy production, but by limiting the use of landfills and thereby significantly lessening our waste’s environmental impact. Finally, note that these calculations take only MSW into account rather than all waste.

7 Conclusion

In order to make our lives and impact on Earth more sustainable, we need to redesign our waste system. Rather than landfilling over half of the millions of tons of waste we produce each year, we should focus on reducing, reusing, recycling, and incinerating waste, and reserving landfills as a last resort. Given that several countries where the standards of living are similar to those in the United States, such as Sweden and Belgium, generate significantly less waste per capita than the United States, we should be able to reduce our waste generation at least to their levels by 2020. The waste we do produce should be recycled and composted more extensively before incinerating that which we cannot reuse or recycle. Not only will WTE facilities produce some energy — thereby displacing energy from nonrenewable energy sources such as coal, which have much higher environmental impacts — but their emissions are typically better than those from landfills, and often materials that go through incinerators can be recovered for recycling as well.

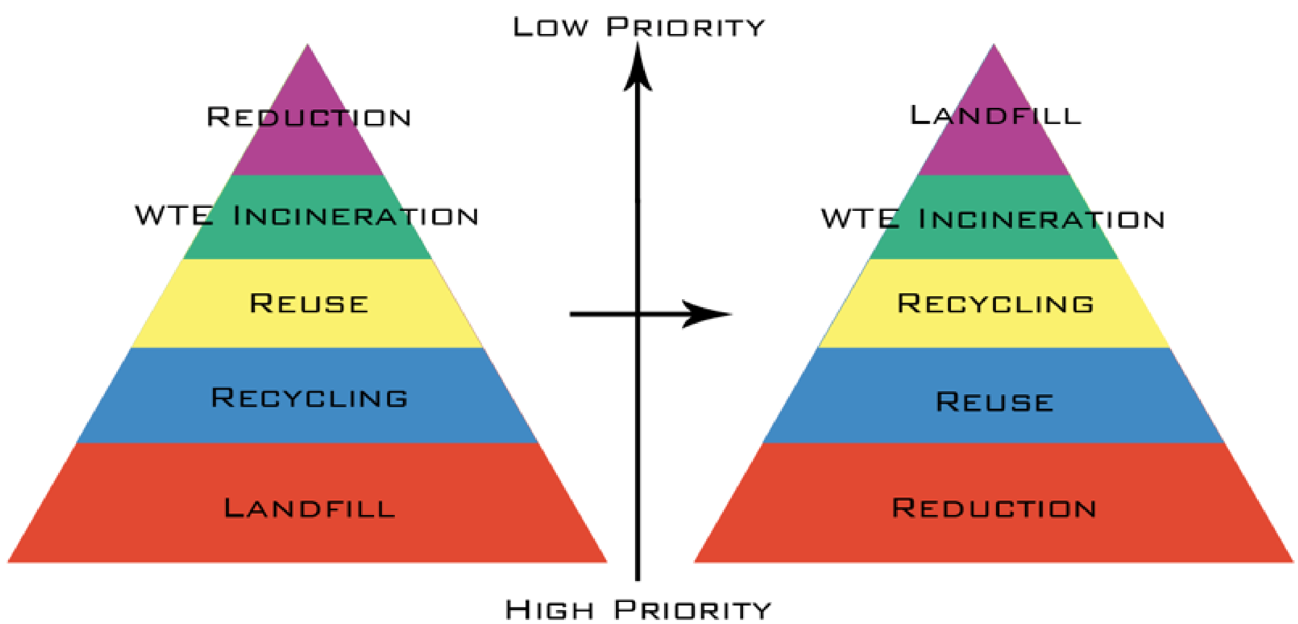

Figure 23: Current and proposed waste management priorities

If, as zero waste advocates propose, waste is not inevitable but is merely the result of bad design, and we decide to radically redesign society in order to eliminate waste, then incinerators can still be incorporated during the transition period towards zero waste. In that case, we should install enough incinerators to manage the non-reusable and non-recyclable waste we continue to produce while attempting to phase such waste out, but not so many incinerators that we cannot provide them with sufficient waste to maintain their running- and cost-efficiency. However, even recycling produces waste. For example, even though old newsprint is recyclable, the actual recycling process damages some of the wood fibers “to the point where they are too short to make strong paper,” which may result in a loss of 12 – 20%, depending on the composition of the newsprint (Holusha). The recycling process also has a sludge byproduct, containing 30 – 50% solids consisting of short fibers, fillers, and ink from the de-inking process (MacGuire). Both the damaged fibers and the sludge byproduct are not further recycled, but can be incinerated for energy recovery instead. Other materials, such as sanitary products or medical waste, cannot be reused or recycled either, for obvious hygienic reasons, but can be incinerated (it should be noted, though, that the emissions from medical waste incinerators are rather more toxic than those from typical industrial waste or MSW incinerators; there are hopes that with plasma gasification, medical waste disposal will produce far fewer pollutants).

Nevertheless, current trends indicate that our waste generation, including that which cannot be recycled, continues to rise, and with an increasing world population, even if the waste generation per capita diminishes, the overall production will still be significant. To improve efficiency, the WTE plants should ideally have CHP production. Indeed, cities currently lacking district heating may wish to consider moving to implement it, for in conjunction with CHP, district heating provides "high energy efficiency in large cities which are densely populated and developed similar to Copenhagen" ("Best Practice..." 4).

Once the plasma gasification plants have been tested more thoroughly, if the emission results in practice turn out favorably, plasma gasification may be preferable to WTE incineration. It may even be cost effective and environmentally friendly to transfer remaining waste from buried landfills to plasma gasification facilities, thereby eliminating further emissions from the landfill and generating significant power.

Bibliography

"Best Practice: District Heating System." *NYC Global Partners' Innovation Exchange.* New York City Global Partners, 21 Dec 2009. Web. 21 Jun 2010. <http://www.nyc.gov/html/unccp/gprb/html/bphome/home.shtml>.

Brat, Ilan. "Cities Give Waste-to-Energy Plants a Second Look." *Wall Street Journal* 6 Dec 2008. Web. 18 Jun 2010. <http://online.wsj.com/article/SB122851537257083869.html>.

Circeo, Louis J. "Plasma Arc Gasification of Municipal Solid Waste." Georgia Tech Research Institute, n.d. Web. 21 Jun 2010.

"Environment: Municipal Waste Generation." *How Canada Performs.* The Conference Board of Canada, Oct 2008. Web. 18 Jun 2010. <http://www.conferenceboard.ca/hcp/details/environment/municipal-waste-generation.aspx>.

Eriksson, Ola, Göran Finnveden, Tomas Ekvall, and Anna Björklund. "Life Cycle Assessment of Fuels for District Heating: A Comparison of Incineration, Biomass- and Natural Gas Combustion." *Energy Policy* 35. (2007): 1346-1362. Web. 21 Jun 2010.

"Florida County Plans To Vaporize Landfill Trash." *USAToday.* The Associated Press, 9 Sep 2006. Web. 21 Jun 2010.

Gies, Erica. "Waste-to-Energy Plants a Waste of Energy, Recycling Advocates Say." *The New York Times* 4 Jul 2008. Web. 18 Jun 2010.

Greenfield, Sherry. "Frederick County Officials Approve Incinerator Plan." *Gazette.Net* 25 Jun 2009. Web. 21 Jun 2010.

Holusha, John. “Technology; The Tough Business of Recycling Newsprint.” *The New York Times* 6 Jan 1991. Web. 21 Jun 2010.

Kaplan, P. Ozge, Joseph Decarolis, and Susan Thorneloe. "Is It Better To Burn or Bury Waste for Clean Electricity Generation?" *Environmental Science & Technology* 43.6 (2009): 1711-1717. Web. 21 Jun 2010.

Koerner, Brendan I. "Can We Turn Garbage Into Energy? The Pros and Cons of Plasma Incineration." *Slate* 2 Jan 2008. Web. 21 Jun 2010.

"Landfills: Hazardous to the Environment." *Zero Waste America.* Zero Waste America, 14 Mar 2010. Web. 21 Jun 2010.

MacGuire, Frances. "Paper Recycling: Exposing the Myths." *Friends of the Earth.* Friends of the Earth Ltd, Jun 2001. Web. 21 Jun 2010.

Morris, Jeffrey. "Comparative LCAs for Curbside Recycling Versus Either Landfilling or Incineration with Energy Recovery." *International Journal of Life Cycle Assessment* 10.4 (2005): 273-284. Web. 21 Jun 2010.

"Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2008." United States Environmental Protection Agency, Nov 2009. Web. 21 Jun 2010.

"Municipal Waste." *Eurostat.* European Commission, 22 Apr 2010. Web. 18 Jun 2010. <http://epp.eurostat.ec.europa.eu/portal/page/portal/waste/data/sectors/municipal_waste>.

"Pollution from Waste-to-Energy Incinerators." *Alternative Energy.* Alternative Energy, 14 Oct 2006. Web. 21 Jun 2010.

"Pyrolysis, Gasification and Plasma Incineration: Part 1." *GAIA.* Web. 21 Jun 2010. <http://www.no-burn.org/article.php?id=880>.

"Pyrolysis, Gasification and Plasma Incineration: Part 2." *GAIA.* Web. 21 Jun 2010. <http://www.no-burn.org/article.php?id=881>.

Rather, John. "Tapping Power From Trash." *The New York Times* 13 Sep 2008. Web. 18 Jun 2010.

Rosenthal, Elisabeth. "Europe Finds Cleaner Energy in Trash, but U.S. Lags." *The New York Times* 12 Apr 2010. Web. 18 Jun 2010.

---. “The Incinerator as Eye Candy.” *The New York Times* 13 Apr 2010. Web. 21 Jun 2010.

"The Complete Recovery of Waste Using Current Technologies Including Plasma Gasification."

Recovered Energy. Recovered Energy, Inc., n.d. Web. 21 Jun 2010.
Tonto: "International Energy Statistics." *U.S. Energy Information Administration: Independent Statistics and Analysis.* Energy Information Administration, 2008. Web. 18 Jun 2010. <http://tonto.eia.doe.gov/cfapps/ipdbproject/iedindex3.cfm?tid=2&pid=2&aid=2&cid=r1,&syid=2007&eyid=2008&unit=BKWH>.
"Two Approaches to Waste." *The New York Times.* Web. 18 Jun 2010. <http://www.nytimes.com/imagepages/2010/04/13/science/earth/13trash.html?ref=earth>.
Waste-to-Energy in Denmark. Trans. Susanne Nilsson. Denmark: RenoSam and Rambøll, 2006. Web. 18 Jun 2010. <http://viewer.zmags.com/showmag.php?mid=wsdps>.