The Limits of Zero Waste Policies: Navigating Post-Recycling Realities for Sustainable Waste Management

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(33)

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List of Acronyms:

Abbreviation	Definition
MSW	Municipal Solid Waste
WTE	Waste-to-Energy
EPA	Environmental Protection Agency
GHG	Greenhouse Gases
LMOP	Landfill Methane Outreach Program
CH_4	Methane
CO_2	Carbon Dioxide
PAHs	Polycyclic Aromatic Hydrocarbons
VOCs	Volatile Organic Compounds
LCD	Land Clearing Debris
C&D	Construction and Demolition

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Abstract:

Using case studies from Milan, San Francisco, Kiel, and the European Zero Waste organization, this research paper examines the limitations of zero waste initiatives. The weaknesses of the current zero waste initiatives will be identified to highlight the urgent need to handle residual waste properly and an analysis of Landfills and WTE plants' efficacity will be completed to find the proper method for successful post-recycling management.

Introduction

The world generates 2.01 billion tonnes of municipal solid waste annually (1). These staggering statistics highlight the importance of waste management on a global scale. According to EPA estimates, the average American produces 4.4 pounds of waste per day. In fact, waste production has increased significantly, and we expect to produce 4.30 billion tonnes of waste by 2050 (1). A recent study by Lu et al. looked at the total amount of waste in various cities across the globe. And, according to the researcher's results the amount of solid waste created increases in direct proportion to the size of the city (2). This emphasizes even more the environmental challenges associated with urban population growth.

Consumption and innovation are today's society's main priorities, causing changes in consumer behavior over time, ultimately leading to a detrimental impact on the environment. Several countries have used the zero waste principle as a solution to tackle this issue.

Zero waste is a 21st-century philosophy that encourages a reconsideration of waste monitoring. It places a strong emphasis on complete waste reduction by not only aiming to minimize but also as eliminating toxicity in materials to recover and preserve all resources. Zero waste initiatives stem from the world's escalating waste issues and their negative impact on various categories, including environmental, economic, and health factors. (1)

Figure 1: Zero Waste Hierarchy of highest and Best use 8.0 developed by the ZWIA (3)

Research Question:

What is the reality behind post-recycled waste in cities that claim zero waste status, and how does this challenge the validity of the zero waste philosophy?

Zero Waste Principles and Their Challenges:

Despite being admirable, the concept of zero waste is more of an ideal than a practical reality; its name has become ubiquitous and with many conflicting definitions (4). These insights form the basis of my thesis: No city has fully achieved zero waste despite significant efforts and strict regulations, raising doubts about the feasibility of zero waste as an achievable objective at this time. Consequently, it is crucial to focus on the development and implementation of effective post-recycling waste management systems. This paper therefore explores and questions the feasibility of zero waste policies in light of current waste management practices.

In 2014, Lu et al published a paper about the scaling of waste production in relation to city size. It was shown that as urban population cities rise, the volume of MSW escalates as well. Figure 1c illustrates this linear relationship, highlighting the need for effective waste management solutions (2). The aim of the zero waste concept to completely eliminate trash remains elusive. The same figure demonstrates that despite cities having strict waste policies, their amount of waste produced is significantly higher in proportion to their population size. This discrepancy illustrates the gap between the aspirational, idealist goals of zero waste policies compared to their practical outcome in urban areas. One example highlighted in Lu et al is the comparison between Seattle, in the United States and Lilongwe in Malawi. Despite them having similar population sizes, Seattle produces approximately eight times more MSW than Lilongwe, which according to Figure D can be attributed to their different GDP per capita; wealthier cities like Seattle generate much more waste per capita compared to less wealthy cities like Lilongwe.

Despite numerous and rigorous efforts, no city has yet fully adopted the ambitious zero waste goal. The following case studies - examining cities like Milan, San Francisco, and Kiel demonstrate complex realities faced in the quest for zero waste and the reality of post-waste management.

The extent to which urban centers are ready to go towards reducing rates is shown through the unique policies and strategies of these cities. Despite significant advancement in recycling and waste management practices, each case study reveals dependencies on either landfills or waste-to-energy facilities.

Methods:

The paper includes a mixed-methods approach. It combined quantitative data analysis of waste production and management in selected cities with qualitative observations to understand the current challenges and successes of different waste management policies.

Case Studies of Cities

The city of Milan, Italy is a significant example in addressing the concept of zero waste and its practicality. Despite Milan's recycling and composting system that separates waste into five streams (5) - paper, glass, compostable organics, metal, and other post-recycling waste, in every building as well as the implementation of strict policies, including fines that exceed $250 or imprisonment not to exceed 15 days" (6) for non-compliance, the journey towards zero waste remains a complex challenge. According to the data presented in Figure 2, the city of Milan has a recycling plus composting rate of 40% and declares to achieve "zero landfilling", as all post-recycling waste is sent to Waste-to-Energy (WTE) power plants.

However, the term "zero landfilling" can be misleading to "zero waste" - both terms are not synonymous, and represent different goals and outcomes in waste management. In reality, a significant portion, 59.6% of Milan's municipal solid waste is converted into energy rather than being completely reused, recycled or composted. The data demonstrate that even in a city as environmentally conscious as Milan, with strong public engagement and a rigorous waste management system, achieving absolute zero waste remains unattainable. This emphasized the significance of focusing on creating efficient post-recording waste management solutions, such as WTE, for coping with the inevitable residual waste. This strategy may not achieve the purist goal of zero waste, but it is a practical step toward sustainable waste management in the current setting.

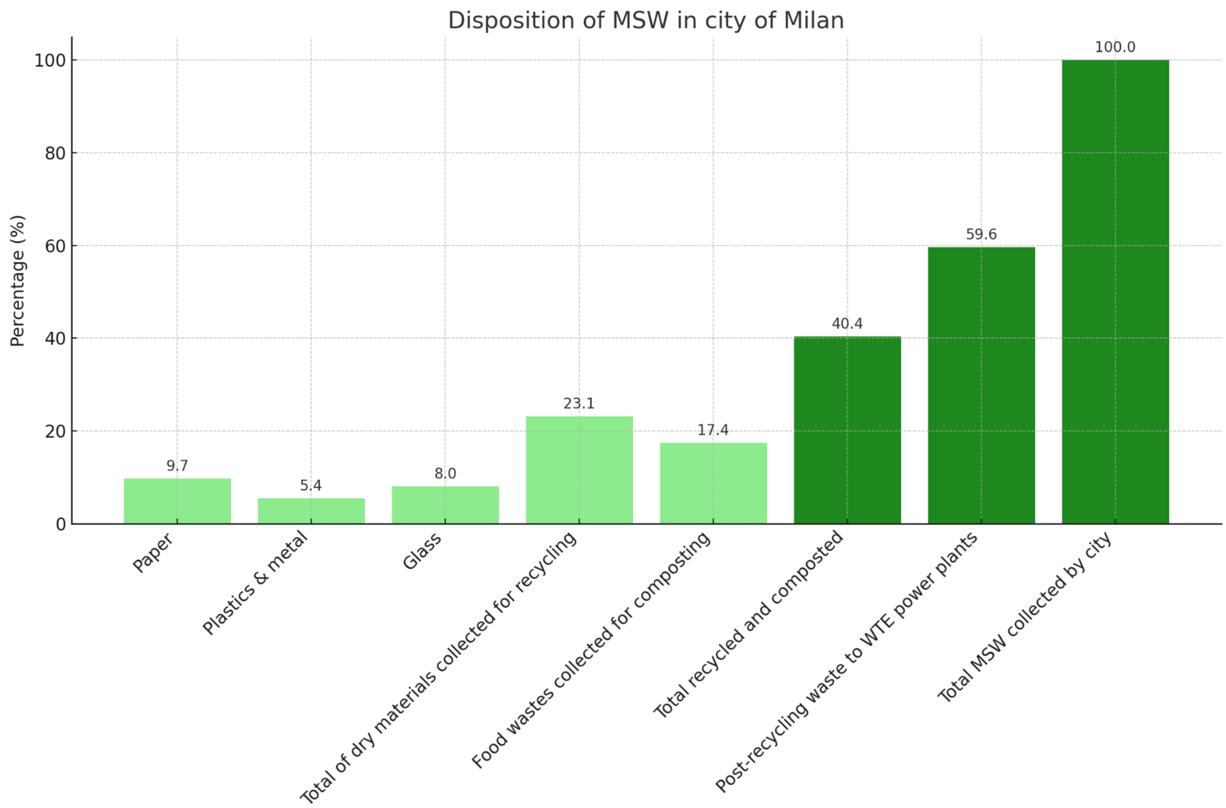

Figure 2: Disposition of MSW in Milan, Italy (11)

San Francisco is one of the greenest cities in North America and has been actively involved in waste management. The city's implementation of the three-cart collection system, which separates recyclables, organic, and residuals, highlights its commitment to sustainability (7). Their policies are further focusing on spreading awareness and engagement through the "Waste Zero Team" which educates and manages recycling and composting programs in public areas such as in schools and restaurants (San Francisco Government, 2024). Additionally, in 2007, under the Safe Medicine Disposal Program legislative measures banned the usage of polystyrene foam food service ware, exemplifying the city's dedication to reducing waste and protecting the environment (9).

Yet, despite these green efforts, the journey of San Francisco towards zero waste has been found harder than expected. The city's population, recorded at 808, 437 in 2022 contributes to the waste management dynamics. On average, San Francisco residents and businesses "discard approximately 1,500 tons of refuse every day" (10). In addition, in 2018 the quantity of waste sent to landfills reached 472,000 tons, a notable increase from the 367,000 tons recorded in 2012. (Trickey, 2019) The decline in the percentage of waste recovered through recycling and composting - from 59.5% in November 2016 to 40.1% in November 2023 further demonstrates San Francisco's difficulties in reducing waste (9).

To understand what happens to the waste, let's delve into San Francisco's percentage of landfills. About 80% of solid waste is diverted from landfills. Despite its landfilling of 0.49 short tons of waste per capita, being lower than the US average (0.63 short tons), there is still a long way to go for San Francisco to be called zero waste (12) The government updated zero waste commitments to reduce solid waste generation to 15% and disposal to landfill by 50% by 2023 (13) underscoring the limitations of the current strategies of waste management. Moreover, the introduction of WTE plants and new operating systems in the city could benefit the economy, including job growth, evidenced by the assertion that "20 more jobs are created when you recycle than if you put that material in landfill (14)

Kiel, Germany, serves as another example of the misconstructed notion of "zero waste". Known for its efficient and operational waste management system, Kiel has made positive contributions to energy supply, environmental benefits, and economic stability, yet these achievements should not be mistaken for the attainment of zero waste. During the first 8 years of operation, the so-called MSW Incinerator power plant, a type of WTE, processed 870,000 of waste. And through combustion, with a capacity of 140,000 Mg a^{-1} (15). Kiel's facility generated 1.793 billion kWh of heat over 8 years, from which 1.9 millions tons of these were generated for the commercial sale of district heat (15). Kiel's commitment to maximizing energy output while minimizing waste input is shown by their city plant possessing an advanced CoG energy delivery system.

Additionally, through the recovery of energy, Kiel has saved a lot of money by preventing 37 million gallons of foreign oil from being imported (16). With a population of 247,548 people in 2019 (17), Kiel processes approximately 140, 000 tons of municipal solid waste annually, redirecting all post-recycling municipal waste to WTE plants. The complete eradication of landfills is a huge improvement in waste management. It stands in sharp contrast to US standards, where 88% of waste still ends up in landfills and just 12% of waste is converted to energy (18). Despite Kiel being certified as Germany's first zero Waste City," garbage still persists there (19). The attribution of the zero waste city certificate in Kiel can be misleading.

Even if Kiel has removed the need for landfills, the presence of waste still remains. Although zero landfill is an important environmental accomplishment, it is not the same as the ultimate objective of zero waste which is still unattainable. Again, it is crucial to understand the difference between zero waste and zero landfilling.

Table 1 - Kiel Resource Recovery Facility (RRF) operating Statistics from 1975 to 1982 (15)

Category	Value	Unit
Refuse Disposal	108,912	STIPY
Heat Release	1,793	million kWh
Electrical Consumption	53.64	million kWh
Oil Consumption	69.73	thousands Gallons
Water Consumption	269.38	million gallons

Lastly, a good illustration of how waste management organizations communicate their strategies is provided by Zero Waste Europe. Even though the organization claims to be committed to the cause, its website lacks reference to how much waste is actually sent to landfills. This omission from their website; which ignores crucial aspects of post-recycled waste management, questions the feasibility of zero waste.

Results:

In conclusion, the analysis of the cities claiming to be zero waste shows that efficient post-recycling methods are essential for managing waste. To close the gap between zero waste goals and real-world obstacles, new strategies must be put into practice.

Background of Waste Management Technologies:

The concept of zero waste management appears to exclude post-waste management. Most individuals do not consider where their trash goes once the garbage trucks empty their bins. Municipal solid waste management differs throughout the world. There are two main types of waste management technologies, namely landfills and energy recovery through WTE power plants. In 2018, “more than 146 millions tons of MSW”, which represents 50% of the total waste “were landfilled”. While on the other hand, using energy recovery, nearly 35 million tons of MSW (11.8%) were combusted. (13). "In the US, from the total municipal waste, 30% is recycled and composted, 7% is sent to energy plants, and 60% ends up in landfills, with the US having some of the largest landfills, which account for 35% of this disposal." (12)

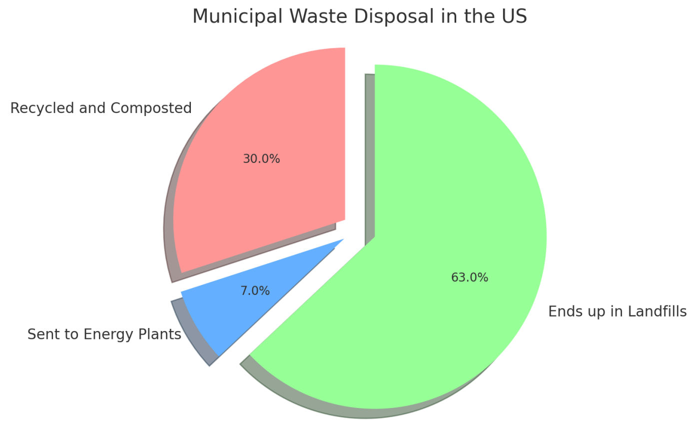

Figure 3: Municipal Waste Disposal in the US (12)

Landfills are areas designated for waste disposition either above or below the ground. There are numerous sorts of landfills, each with unique procedures and features, such as construction and demolition (C&D) debris landfills, industrial waste landfills, and land clearing debris (LCD) landfills. Each landfill's design has different degrees of sustainability depending on the waste it recycles (20).

This paper will focus on Municipal solid waste (MSW) landfills. MSW landfills are the one “designed to receive household waste, as well as other types of non-hazardous wastes” (13). In 2009, it was estimated that the US possessed 1,908 MSWLFs. As the paper is trying to find the best solution for post-waste management, a deeper understanding of MSW landfill operants is crucial.

They include fundamental structures, with some built to handle specific environmental risks. In landfills, a bottom liner system is used to prevent water pollution from leaching, which is the liquid that remains after decomposing garbage. The landfill is divided into cells for old and fresh rubbish, and heavy machinery is used to compress and dump trash in the landfill. They also possess a stormwater and leachate collection system to efficiently manage and treat water contamination. Additionally, the methane collecting device captures the methane gas produced during the decomposition process. Lastly, to minimize leakage, the landfill is sealed with a cover on top and then covered with two feet of earth. Vegetation is later planted on top to prevent soil erosion due to rainfall and wind. Landfills are monitored for 30 years to minimize detrimental effects on the environment (21)

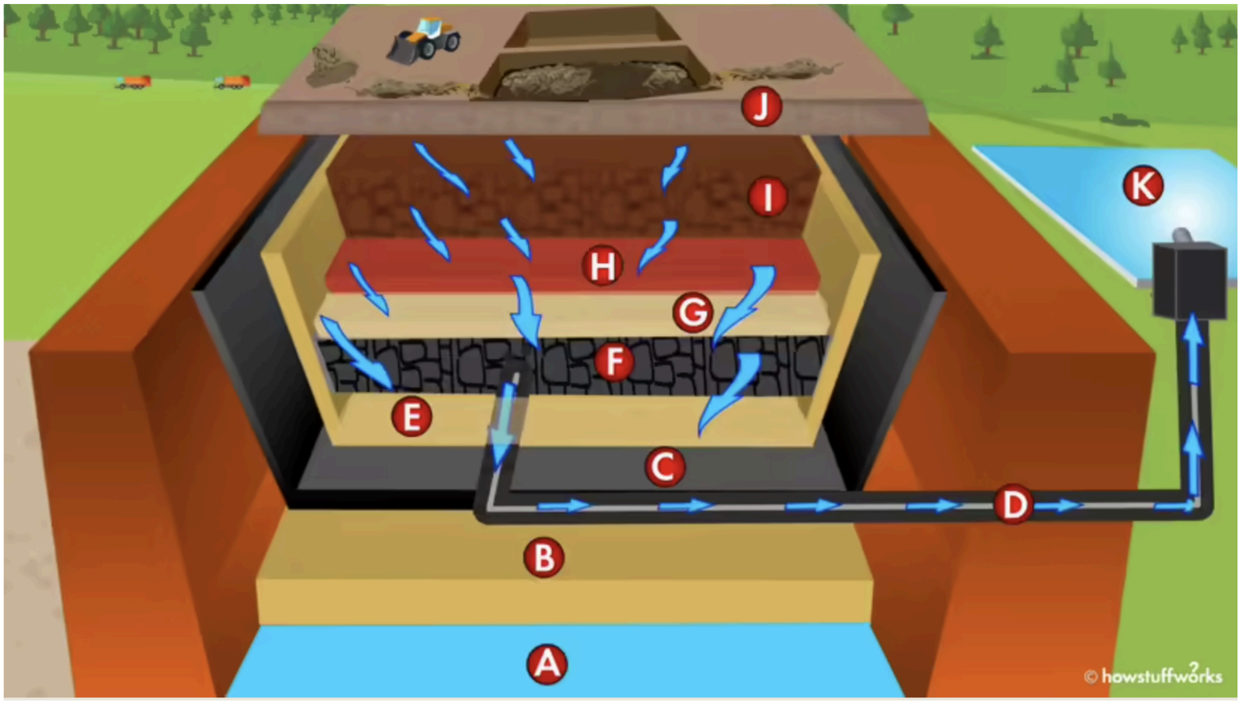

Figure 4 - Structure of MSWLFs (arrows indicating the flow of leachate-contaminated substance) (21)

- Groundwater (A)
- Compacted clay (B)
- Plastic Liner (C)
- Leachate collection pipe (D)
- Geotextile Mat (E)
- Gravel (F)
- Drainage layer (G)
- Soil layer (H)
- Old cell (I)
- New cells (J)
- Leachate Pond (K)

Despite strict regulations and improved design, landfills continue to be sources of air, water, and soil pollution. This is mainly caused by inadequate cap and control, and the spatial and ecological footprints of the landfills.

Impact of Landfills:

Several researches were conducted to identify landfill's impact.

1) Air Pollution and Human Health

The adverse effects of landfills on human health and air pollution can be identified through the study conducted by Conte et al, in southern areas of Italy (22). In their study, they examined the impact of MSWLFs on air pollution. Their method consisted of collecting air samples at three different landfills and identifying the presence and concentration of hazardous substances. These included PM10 , inhalable particles that can worsen respiratory disease, (California Air Resources Board), Polycyclic Aromatic Hydrocarbons (PAHs), chemicals naturally occurring in coal, crude oil, and gasoline which can cause cancer and affect other organs such as the eyes, kidneys and liver (23) , VOCs such as Benzene, Toluene and Xylene as well as extremely toxic substances like polychlorinated dibenzo p dioxins and dibenzofurans which are known for their short as well as long health risk including irritation, cancer and immune system impairment (24).

The researchers found differences in the amounts of pollutants at various waste sites and determined that heavy machinery and traffic on surrounding streets are the main causes of high pollutant concentration at the Cavallino landfills. The researchers also found that the concentration of benzene, xylene, and toluene diversified in different directions, suggesting that the wind had an effect on the dispersion of pollutants. Therefore, it was concluded that management strategies and site-specific factors influence air quality. This is why strict policies should be implemented and vary across all landfills to minimize such risks. However, this remains very complicated and makes landfills not an ideal solution for managing post-recycled waste as they require significant effort and are difficult to control. Each landfill is unique due to the varying characteristics of every area on the earth.

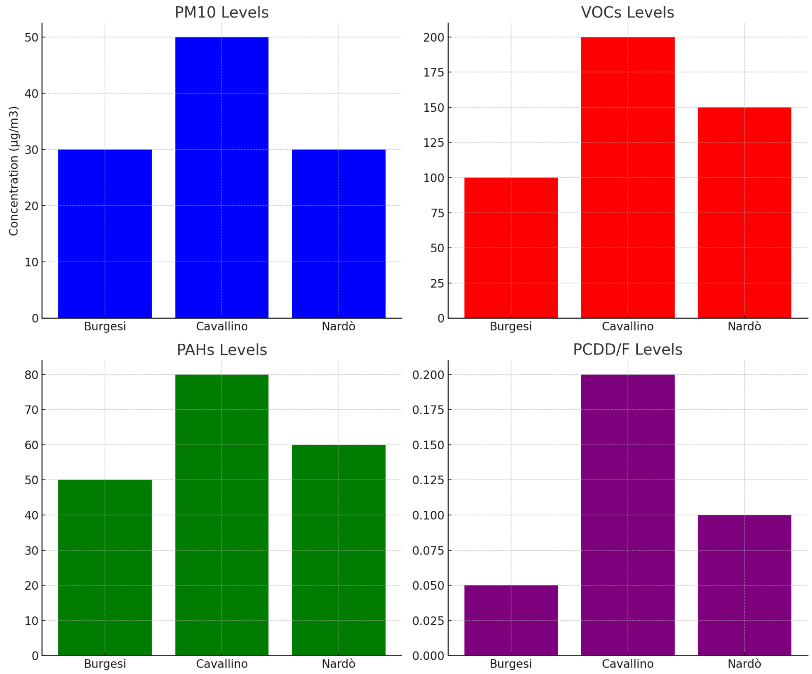

Figure 5 - Average concentration of pollutant at different MSW landfills in Southern Italy (22)

2) Methane and Climate Change

Another issue with landfills is the release of major toxic gasses including ammonia, sulfides, CO_2 and methane. Methane release from landfills causes a pressing issue for global warming.

Following China, which emits 55.7 million metric tonnes of methane per year, the United States is the second greatest methane emitter, releasing 31.8 million metric tonnes annually (25). Furthermore, MSWLFs are the "third largest source of human-related methane emissions in the United States," generating 3.7 million metric tonnes of methane per year, or approximately 295 million metric tonnes of CO_2 over 20 years (26). The methane gas generated from the food waste in the landfills is 20 to 25 times more potent than carbon dioxide.

When fresh organic matter in landfills is compressed with the material above, it prevents oxygen from reaching the organic matter. This produces methane gas which is a hazard causing higher temperatures, changing landscapes, wildlife risks, rising seas, increased drought, more heat-related illness as well as economic losses as plastic production and composition are energy-intensive processes. Consequently, failure to recycle results in a lost opportunity to reduce energy usage (27)

In an interview, Professor Themelis, the Director of Graduate Research in Sustainable Waste Management at Columbia University, highlighted a concerning industry silence on the actual amount of methane released into the atmosphere from landfills.

It was estimated by EPA that "landfill methane emissions were two to four times lower than the actual number" (28). Themelis et al conducted a comparative analysis of methane emissions from landfills from EPA Greenhouse Gas Reporting Program Data with Columbia estimates. Columbia University analyzed landfills participating in the EPA landfills methane outreach program (LMOP). They collected data of both methane generation from 1,164 operating MSW landfills and the capture efforts of 396 landfills. The results showed that the average methane generation rate at US MSW landfills was approximately 0.05 tons CH_4 per ton of waste landfilled. Of this, the LMOP operating landfills captured 0.024 tons of methane per ton of MSW landfilled. This shows a higher methane emission (2.8 times) reported from Columbia than from GHGRP estimates. A reference Arial study also confirmed that the methane emissions from landfills were 2.7 times higher than those reported in the GHGRP data. The differences in the reported amounts indicate a persistent methane emission underestimation in standard regulations. (28)

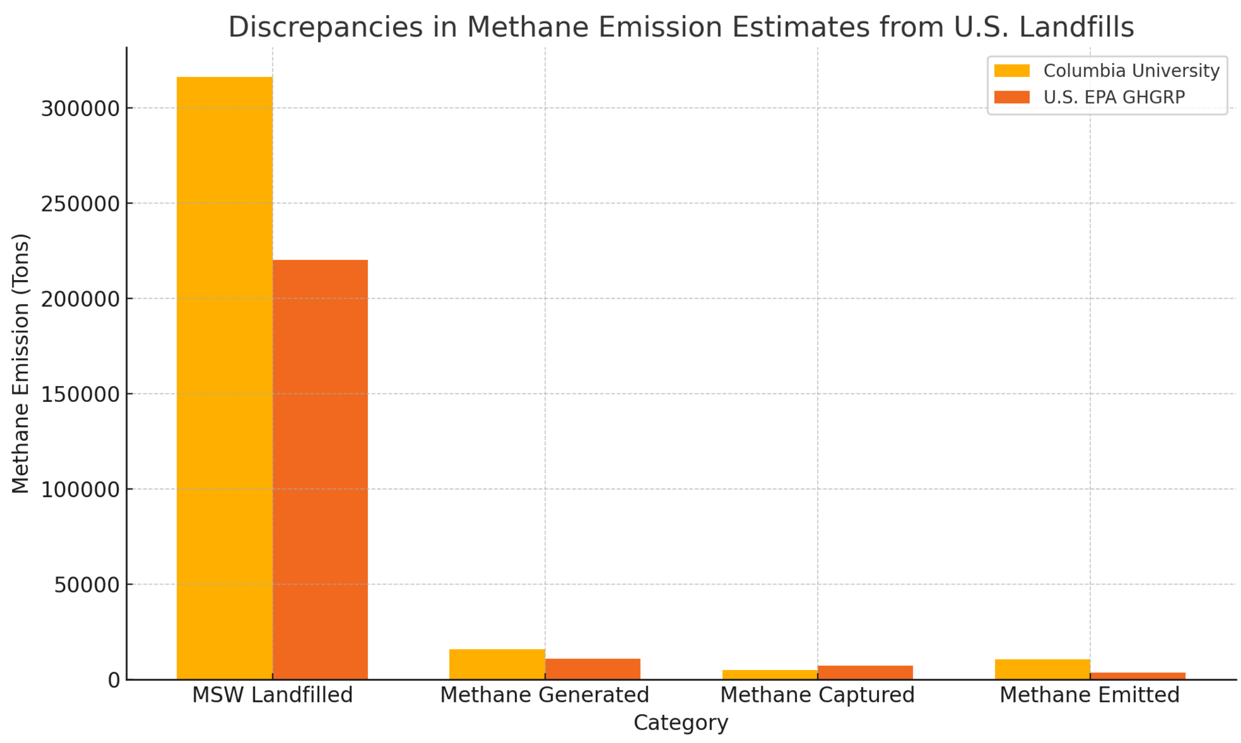

Figure 6 - Discrepancies in Methane Emission Estimates from U.S Landfills: Columbia University vs EPA Data (28)

Overall, the difficulty in currently monitoring and controlling landfills' environmental impacts is highlighted by the underestimation of methane emissions. Furthermore, reinforcing that landfills are not the ideal solutions for managing post-recycled waste, as their complexities make it hard to enforce and implement effective and consistent measures across all areas. Better reporting procedures are necessary to actually help policy makers understand and improve the current situation. More effective laws and procedures are required to manage or exploit this powerful methane emitters technology.

Waste-to-Energy (WTE):

All information considered, the two reports effectively highlight the persistent environmental issue that stems from landfilling, questioning current waste management practices' efficacy. The best alternative would be to invest in Waste to Energy facilities. These waste management technologies focus on energy recovery from waste. The plants convert waste into electrical or thermal by incinerating, gasifying, or pyrolyzing MSW to produce steam in a boiler, which then powers an electric generator turbine (18) The process of generating electricity in a mass burn waste to energy plant occurs in a seven-step process:

1) Garbage trucks dump waste into a large hole.
2) Waste is collected by a crane's enormous claw and dumped into a combustion chamber.
3) As the fuel (waste) burns, heat is released.
4) In a boiler, the heat causes water to transform into steam.
5) Electricity is generated by a turbine generator's blades being turned by high-pressure steam
6) Prior to the combustion gas being expelled through a smokestack, contaminants are removed from it by an air-pollution control system.
7) Ash is gathered from the air pollution control system and boiler.

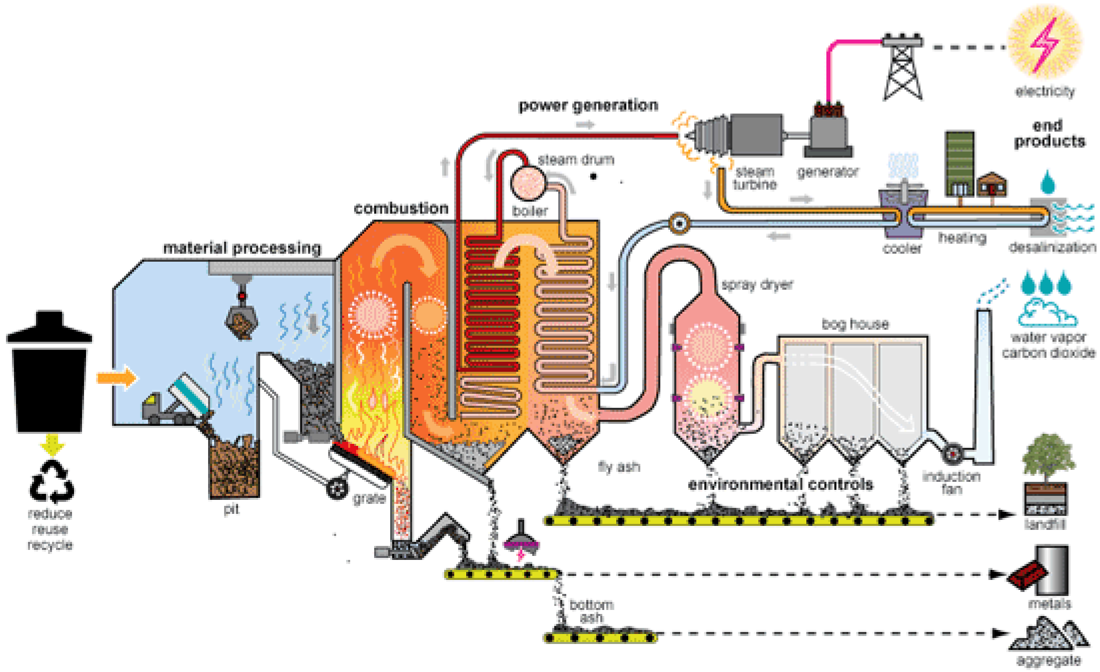

Figure 7 - A Mass-Burn Waste to Energy Plant Process (28)

This technique benefits not only the environment as it reduces "greenhouse gas emission by one ton of carbon for every ton of waste processes" (28) , but also energy production by creating renewable energy, leading to a reduction of the use of coal, oil, and natural gasses. All the process is continuously monitored to comply with state and federal standards, such as the Clean Air Act and the Maximum Achievable Control Technology Regulation, which accelerates the creation of regulations to cut emissions of hazardous pollutants (28). This adherence to strict standards aligns with the EPA's preference for WTE as the preferred method of disposal (30)

However, adoption of such techniques worldwide can be very complicated, due to a lack of money, lack of public understanding, and opposition to innovative waste management systems.

China leads in the integration of WTE plants, with 510 facilities deployed across 300 cities, boasting an annual capacity of 193 million tons (28) This contrasts with the United States's WTE capacity which remains at about 27 million tons, representing only 11% of its post-recycling MSW, with the remaining 89% being sent to landfills (18).

As previously stated, population growth correlates with an increase in waste. China's household waste accumulated 170 million tons, and its untreated MSW over the years has reached 7 billion tons with an annual increase of 8.10% (31) In addition, China's difficulty in disposing of MSW has led to direct economic losses amounting to 1474 billion dollars. The rapid urbanization of China has led to an increase in MSW, from 148.413 million tons in 2006 to 170.809 million tons in 2012 (32) As a result of this waste generation, Chinese national policies invested in WTE plants to convert the waste into electricity. This implementation of new technology has led to an increase in harmless disposal capabilities from 78.726 million tons in 2006 to 144 895 million tons in 2012 (32).

Figure 8: Trends in Waste Management and Incineration in China from 2006 to 2012 (32)

China’s WTE technologies have positively impacted both the environment and the economy. However, even though WTE plants show improvement and promise, achieving a zero waste disposal system, especially in urban developing cities remains a challenge. Nevertheless, China is an excellent case study of a society that is willing to spend more on sustainable practices as opposed to landfilling. This shift demonstrates how modern waste management technologies are becoming increasingly important in urban settings.

This kind of approach is also evident in Vienna, where a WTE plant is not only openly located in a residential area near to a hospital, but it is also a source of community pride. Visitors can tour the plant for $8, demonstrating the city's commitment to ecologically friendly techniques and recycling (33). This integration promotes recycling and waste reduction by showing communities the positive outcomes of prioritizing environmental awareness over financial concerns.

Before implementing such technologies, it is important to take into account its financial aspects The graphic below illustrates the charges related to WTE plants, from equipment and construction costs to maintenance and environmental monitoring costs (32). This detailed breakdown highlights the substantial amount of money required to maintain these technologies, reinforcing the commitment required to implement advanced waste management techniques.

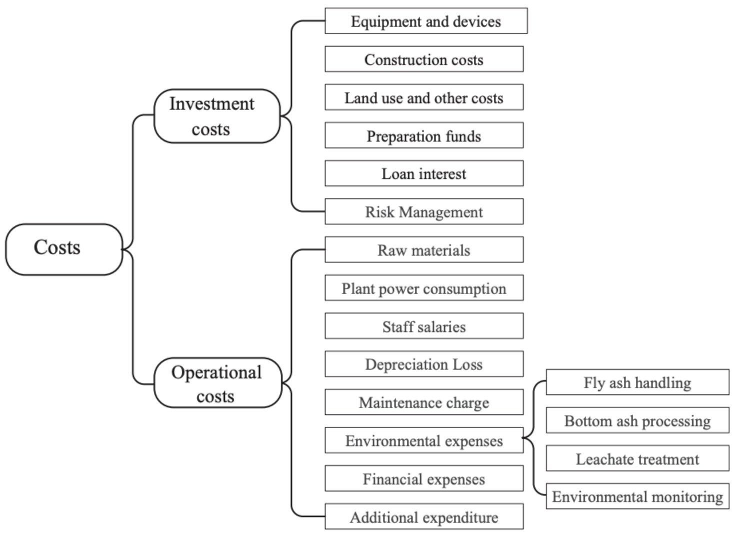

Fig. 2. The cost structure of WTE plants.

Figure 9: The cost structure of WTE plants (32)

Public Education and Engagement:

Academic institutions such as Columbia and NYU can contribute to the goal of zero waste by means of their teaching initiatives. The founder of Columbia's Earth Engineering Centre, Professor Themelis, suggested in an interview that waste management courses could be added to academic curricula in order to transition students from abstract ideas to practical, long-lasting solutions. Our ability to distinguish between recycling and landfilling will allow us to greatly enhance the health of the earth. Thus, it can be claimed that efficient waste management necessitates a thorough awareness of the various disposal techniques.

Conclusion:

In conclusion, given the existing state of urban waste management, zero waste targets, while aspirational, remain unachievable. Eliminating the need for landfills is necessary, and waste can be managed sustainably by turning it into a useful source of energy. Every city's government must impose new, stringent regulations in order to install cutting-edge technologies like WTE plants. We can guarantee a sustainable future and the ability to produce cleaner, healthier plants by acting decisively now.

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