Energy Innovative of Waste to Energy Enhancement in Palestine/Hebron Case Study

Authors: Dr. Makawi Diab Hraiz, Dr. Iyad Hashlamon, Dania Kurd, Yumna Allami

***Abstract*— Hebron, a heavily populated and industrialized city in southern Palestine, is grappling with two critical challenges: ineffective waste management and ongoing energy shortages. The city generates approximately 450–500 tons of municipal solid waste daily, of which 55% is organic, while experiencing an energy shortfall of about 15%. This situation calls for a comprehensive and sustainable approach to address both issues. The study examines the city's current waste practices—primarily landfilling at the Al-Minya site, open waste burning, and minimal recycling—all of which present significant health and environmental hazards. A comparative evaluation of waste-to-energy (WtE) technologies is conducted, including incineration, gasification, anaerobic digestion, and plasma gasification. Incineration emerges as a practical option due to its capability to process a broad range of waste materials and its efficiency in reducing waste volume while producing usable heat and electricity. Nonetheless, the adoption of such technology in Hebron faces several barriers, including limited land availability, high operational costs, inadequate waste sorting at the source, and public concern over pollution. Despite these challenges, the integration of modern emission control systems and active community involvement could make incineration a key component in reducing landfill use and generating clean energy. The study suggests that, with coordinated institutional backing, appropriate funding, and public awareness initiatives, Hebron has the potential to lead in implementing a scalable WtE strategy aligned with Palestine's sustainability and energy independence goals.**

I. INTRODUCTION

Hebron is situated in the southern part of the West Bank, approximately 30 kilometers south of Jerusalem. As an important industrial and commercial hub, it hosts a population expected to reach 863,797 by mid-2025 (PCBS 2021)[1]. The city faces significant environmental stress, largely due to high population density, limited land availability, and inadequate infrastructure. Municipal Solid Waste (MSW) generation is estimated at 450–500 tons/day (HJSC), with individual waste generation at approximately 1 kg/day [2]. Energy consumption in Hebron stands at roughly 350 GWh annually(HM), yet the city faces an energy deficit of about 15%. Around 88% of electricity is imported from Israel [3], highlighting the need for local and sustainable energy alternatives.

Hebron Governorate faces several problems in the waste management sector. These are mainly due to the lack of legislation, the absence of comprehensive data, and the shortage of equipment, modern technology, and infrastructure. The situation is further complicated by restrictions imposed by the Israeli occupation on land and other resources. Additionally, as the population continues to grow, the rate of waste generation increases as well. The only legal landfill that serves the Hebron and Bethlehem region is Al-Minya (World Bank 2020) [4], which is expected to reach its full capacity soon.

A. Waste Composition

The composition of waste is crucial for many reasons, including determining the type of management or treatment process required [5]. Therefore, it is very important to know the waste's composition, whether through exact measurement or estimation. The composition of waste in a specific region depends on the nature of that region — whether it is rural or urban [6] — as well as factors like individual income, lifestyle, and the number of commercial and industrial facilities.

Hebron includes various areas; some are rural, where people rely mainly on agriculture, while others are more urban and depend on industrial and commercial activities. According to the Hebron Joint Services Council (HJSC), the estimated daily generated waste is around 400 tons. This waste can be categorized by source into residential, industrial, and hazardous medical waste. The percentage of each category, based on HJSC's 2023 report, is shown in Figure 1. Residential waste makes up the largest share, amounting to 220 tons, followed by industrial waste at 156 tons, and 24 tons of hazardous medical waste.

Since Hebron is highly populated, residential areas contribute to more than half of the total waste. The industrial waste is also relatively high

978-9950-8599-0-6

compared to other governorates, as Hebron is the largest industrial and commercial hub in the West Bank.

However, this generated waste can also be classified according to its material composition, as shown in Table 1. Addressing the characteristics and components of waste helps in selecting the most suitable and efficient treatment method. As the table shows, organic material constitutes about half of the total waste, followed by 16.3% plastic waste of various types, and a smaller portion of glass, metal, and other materials.

Table 1: Categories and percentage of waste in Hebron Municipality

Waste Fraction	Percentage %
Organics	48
Plastics	16.3
Paper	10.9
Textile	6.1
Glass	2.3
Metal	1.8
Others	14.6

Understanding the composition of Hebron's waste stream provides a foundation for discussing how this waste is currently disposed of or managed, which will be discussed in the following subsection, along with the impacts of these disposing methods on human health and the environment in the subsequent one.

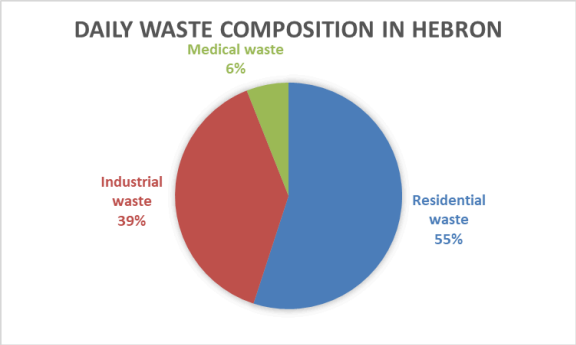

Figure (1): Daily Waste Composition in Hebron.

B. Waste Disposal Practices

The various disposal methods used are mostly traditional, including sanitary landfilling, open burning, and very limited recycling. The main landfill serving the southern governorates of the West Bank, including Hebron, is the Al-Minya landfill. This landfill is operated by the Hebron and Bethlehem Joint Services Council and has been in use since March 2014. It was originally designed with a lifespan of 20 years and a daily capacity of 630 tons. However, its operational lifespan has been reduced to 13 years, as it is now required to receive waste from Israeli settlements, resulting in a current intake of around 1,300 tons per day[7].

The second method is open burning in the open space, which is more commonly used in rural and refugee camps, near residential zones. This harmful process causes a release of different toxic chemicals and hazardous substances due to the incomplete combustion of the various types of waste [8]. As a result, this leads to serious health risks in the first place and contributes significantly to air pollution. Another dangerous phenomenon regarding the open burning is the combustion of electronic devices and e-waste to get the raw material, such as metals, which is notably seen in Idna, west of Hebron[9]. Another concern is the presence of illegal dumpsites, many of which are located near households; around 32% of the waste in the West Bank ends up in these random landfills[10].

Finally, a very small portion of the generated waste is recycled. Only about 5% of the waste is

recycled by informal waste pickers[2], who mostly collect glass, paper, and cardboard. Although informal efforts exist, a formal and authorized recycling system should be established to help increase the overall recycling rate. Additionally, more attention should be given to the high organic content in the total waste stream. In the following section, different technologies are investigated.

C. Environmental and Health Impacts

Improper waste disposal presents serious environmental and health hazards. Whether waste is openly dumped, poorly managed in landfills, or improperly incinerated, the consequences can be widespread and long-lasting.

The most common form of waste disposal in Hebron is *landfills*; they can contaminate soil and groundwater, which could pollute the drinking water for the areas around them and affect the living animals and plants. Additionally, the anaerobic decomposition of organic waste in landfills produces methane (CH_4), a potent greenhouse gas that significantly contributes to climate change. If not properly collected and treated, landfill gases also contain hazardous air pollutants like benzene and vinyl chloride, which are harmful to human health.

In many parts of the city, open dumping and burning are still practiced. These methods are extremely harmful. Burning waste releases toxic chemicals like dioxins, furans, and fine particles that can damage the lungs and even increase the risk of cancer. These impacts are especially dangerous for waste workers and nearby communities, including children, who are often the most exposed.

Even when waste is burned in a controlled facility such as an incinerator, there are still risks. Without the proper air pollution control systems, these plants can emit harmful gases and heavy metals. The leftover ash can also be hazardous if it's not safely managed.

Besides the direct health risks, poorly managed waste sites can make neighborhoods less livable. They can cause bad odors, attract pests, and even lower property values. Over time, this leads to environmental degradation and reduces the overall quality of life for people living nearby.

That's why modern, well-planned waste management is so important. Approaches like recycling, composting, energy recovery, and safe landfilling combined with strong environmental controls, can make a huge difference in reducing harm and protecting both public health and the environment.

II. Waste-to-Energy Technologies

A comparative evaluation of WtE methods is shown in table 2:

table (2): waste to energy technologies that could be used in hebron

Technology	Principle	Advantages	Disadvantages
Incineration (waste combustion) [11] [12]	burning waste with the presence of oxygen to extract heat and energy	- Reduces waste volume significantly - Energy recovery	- Air pollution (dioxins, CO_2) - Expensive infrastructure
Gasification [13] [12]	burning waste with the limited absence of oxygen to generate syngases	- Produces useful syngas - Lower emissions than incineration	- High cost and technical complexity - Requires pre-treatment
Anaerobic digestion [14] [12]	Breakdown of organic materials by microorganisms in the absence of oxygen	- Produces biogas (renewable energy) - Useful digestate (fertilizer)	- Only suitable for organic waste - Slow process
Plasma gasification [15]	relying on an external energy source to generate and maintain the high temperatures required.	- Handles hazardous waste - Very low emissions - Produces inert slag and clean syngas	- Very high capital and operating costs - High electricity demand - Limited large-scale use
Landfills [12]	Disposal of waste in the ground, allowing slow decomposition (often anaerobic)	- Low immediate cost - the simplest way for waste disposal	- Methane emissions (can be captured and used for energy recovery) - soil, water and land pollution

III. Proposed Solution for Hebron

The proposed solution discussed in this paper is incineration, a thermal waste treatment method that generates heat and energy through the combustion of waste at high temperatures. Unlike other technologies that are limited to specific feedstocks, incineration can process nearly all types of waste, including municipal solid waste (MSW), biomass, industrial, and hazardous materials [12]. The incineration process primarily produces heat, flue gases, and ash. The thermal energy generated can be used to heat water and drive a steam power plant, following the Rankine cycle, to produce electricity and thermal energy [16]. Flue gases, which may contain harmful pollutants, are treated using advanced air pollution control systems such as filters, scrubbers, and electrostatic precipitators before being safely released into the atmosphere [17]. The resulting bottom ash can either be disposed of in landfills or repurposed in sectors such as construction and manufacturing, where it can serve as a component in building materials [12]. By the end of the incineration process, the mass of waste is typically reduced by 70–80%, and the volume by 80–90%, compared to the waste's original, compressed state when collected by garbage trucks [17]. This significant reduction makes incineration not only a means of energy recovery but also a strategy for minimizing landfill dependency.

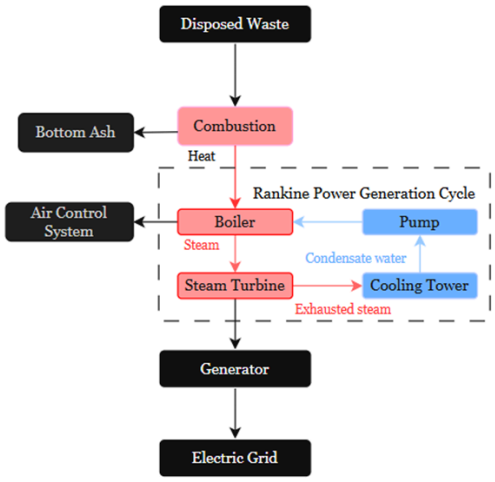

Fig (2): WtE incineration plant working concept

IV. Challenges

While incineration is a promising waste treatment for reducing waste volume and energy recovery, implementing it in Hebron faces several key challenges, both technical and socio-economic.

A. Infrastructure Limitations

In Hebron there is a lack of land because of land confiscation by the Israeli occupation, which causes that the suitable land for this treatment is close to population centers and villages. Also this treatment needs a reliable electricity source and water supply.

B. High Operational Costs

Incineration systems are expensive to build and operate. In Hebron, where financial resources are limited and budgets are stretched across many pressing needs, the high initial investment and ongoing costs of operating such a facility can be a major barrier. These systems require specialized equipment, trained workers, and regular maintenance, not to mention the advanced filters and emission control technologies needed to meet environmental safety standards.

C. Lack of Waste Segregation

One of the big challenges in Hebron is that waste is usually not separated at the source. Households and businesses often throw everything (organic waste, recyclables, plastics, and hazardous items) into the same bins. This makes it much harder to run an efficient incineration process. Wet or poorly sorted waste doesn't burn well, can damage the equipment, and may produce harmful emissions. For incineration to work properly, there needs to be a solid system in place for waste sorting, along with community awareness and participation.

D. Public Perception and Opposition

People in Hebron are understandably concerned about the idea of burning waste near their homes. There are fears about air pollution, bad smells, and the potential health effects of living close to an incinerator. In the past, poorly managed waste

sites and a lack of transparency from authorities have made the public distrustful of large waste projects. Without clear communication, proper environmental protections, and real involvement of the local community, there's a high chance that any incineration project will face resistance or rejection from residents.

V. Conclusion

The case of Hebron highlights the urgent intersection between waste management inefficiencies and energy insecurity in one of Palestine's most industrialized cities. With organic waste forming the majority of daily solid waste and landfills nearing capacity, the city faces both environmental degradation and public health risks. While current disposal methods remain inadequate and often hazardous, they also reveal the untapped potential of converting waste into energy.

Among the evaluated technologies, incineration offers a practical solution due to its capacity to handle mixed waste streams, reduce overall volume, and generate electricity. However, realizing these potential demands overcoming significant barriers—chiefly infrastructure constraints, financial limitations, poor waste segregation, and local opposition. Addressing these challenges will require a phased, inclusive approach: securing political and institutional support, investing in public awareness, and embedding modern pollution control measures to gain community trust. With its high waste generation rates and strategic importance, Hebron is well positioned to become a national leader in adopting scalable waste-to-energy solutions.

Ultimately, this study underscores that a transition toward energy recovery and circular waste systems is not only feasible but essential. With integrated planning, strong governance, and technological investment, Hebron can serve as a model for other Palestinian and Mediterranean cities aiming to build sustainable, resilient futures.

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