Chapter 3

The Conversion of Jakarta City Solid Waste into Electrical Energy

Parino Rahardjo

A. Introduction

The high population in urban areas has both positive and negative sides. The negative side is public health and environmental problems in urban areas, especially air quality. This air quality is influenced by the presence of industry, transportation, as well as households, offices. Urban waste is a problem that is no less complicated; the amount continues to increase following the population, causing various diseases and contributors to greenhouse gases. In Indonesia, it is known that the handling and management of solid waste has not been carried out properly but is disposed of in landfills and temporary disposal. Waste generation in cities in the province of Java Island shows that the City of Jakarta with the largest population can have the largest waste generation, as seen in Table 3.1.

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Rahardjo, P. (2023). The conversion of Jakarta city solid waste into electrical energy. In S. Ariyanto & S. I. Heriyanti (Eds.), *Renewable energy: Policy and strategy* (37–64). BRIN Publishing. DOI: 10.55981/brin.900.c783 E-ISBN: 978-623-8372-25-6

Table 3.1 Amount of Solid Waste Generation in Cities on Java Island

No	Cities	Generated Solid Waste	Total Population
1	Jakarta	3.112.381	10.748.230
2	Tangerang Selatan	355.009	1.354.350
3	Cilegon	833.169	434.896
4	Tangerang	504.258	1.930.556
5	Serang	213.464	352.331
4	Bekasi	668.179	2.543.676
5	Bandung	581.877	2.527.854
6	Yogyakarta	110.643	466.950
7	Semarang	431.085	835.083
8	Surabaya	651.043	835.083

Source: SIPSN (n.d.)

The City of Jakarta as the object of study was chosen because, as the nation's capital, it has various functions and activities. With a population of ±10 million people, the waste problem is a problem that must be solved because it has an impact on public health and the environment. The volume of waste increases linearly with the population growth and lifestyle. Due to limited land, the Regional Government of Jakarta has been using the Bantargebang Area in Bekasi City as landfill since 1989.

Regional Regulation of the Province of Jakarta Capital Special Region No. 1 of 2012, concerning the 2030 Regional Spatial Plan (RTRW), regulates the Waste Management Facility and Infrastructure System in articles 51 to 58. Article 54 paragraph 1 reads, "Construction of TPST (Tempat Pengolahan Sampah Terpadu/Integrated Waste Management Site) infrastructure and facilities as referred to in Article 51 paragraph 1 letter c, intended as a place to carry out collection, sorting, reuse, recycling, processing and final processing of waste" and paragraph 2 contains, "Construction of TPST infrastructure and facilities as referred to in paragraph 1 is regulated by the provisions as following: a. may be in the form of an Intermediate Processing Facility; b. equipped with high-tech, environment-friendly and land-saving; c. equipped with waste processing facilities; d. can cooperate with the surrounding administrative area; e. may involve the role of the private sector in the supply and/or operation and maintenance; f. pay attention to the provincial spatial layout plan, administrative city spatial layout plan, and regency administrative area spatial layout plan; g. pay attention to the geological aspects of the environmental layout of the site and its surroundings; h. paying attention to the socio-economic aspects of the surrounding community; and i. maximizing waste management and/or 3R (reuse, reduce, recycle) activities that generate income." Public health control in waste management is stated in Article 53 which states that health control starts from the Waste Storage Place as intended in Article 51 paragraph 1 letter b, intended as a holding place before the waste is transported to an integrated recycling place (TPST), and in paragraph 2, point f. prevent leachate from entering groundwater, springs and water bodies; paragraph 2, point g. anticipate health impacts on the surrounding environment; and h. control the impact of odors, flies, mice, and other insects.

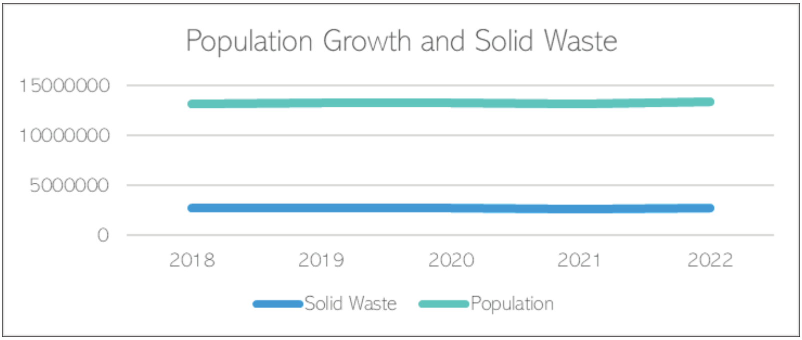


Figure 3.1 Solid Waste and Population Growth in Jakarta City

Based on the regional regulation regarding the 2030 Spatial Plan, waste management already has clear guidelines, especially those related to health and environmental issues. Without good waste handling and management, it will cause problems for public health and the environment. The volume of waste continues to increase along with the increase in population and only during the Covid-19 pandemic the amount of waste has decreased. This is due to people working from home. The relationship between waste volume and population in the City of Jakarta is shown in Figure 3.1.

B. The Problem of Urban Solid Waste in the Jakarta City

The final disposal site for solid waste in Jakarta City is located in Bantargebang District, Bekasi City. The Temporary Disposal Sites are spread across five areas of the City of Jakarta, with the closest distance to Bantargebang being 21 km and the farthest distance being 60 km. Temporary disposal sites in the City of Jakarta are located in five regions and spread over 15 places, as can be seen in Table 3.2. In 2021, the volume of waste transported will be around 86% of the total volume that must be transported. Compared to 2020, there was a decrease of around 5%, and trucks did not match the volume of waste that had to be transported.

Table 3.2 Location of Temporary Disposal Place and Distance to Bantargebang Bekasi Landfill

Location of Temporary Disposal Sites	The Distance to Bantargebang Bekasi Landfill from the Temporary Disposal (Km)
A. East Jakarta area	
1. RW 14, Jl. Telkom RW 14 Cibubur.	21
2. RW 13, Gg. Hanafi, Jl. Raya Centex Ciracas	28
3. PPSU RW 11 – Jl. Laut Banda Duren Sawit	25
B. South Jakarta area	
4.Kampung Kandang Jl. M Kahfi 1 Gg Tohir RW 04	32
5. Antam, Jl. Tanjung Barat Lama No. 139 Jagakarsa	30
6. RW 05 Komp. KODAM, Jl.. Pesang-grahan Raya J	38

Location of Temporary Disposal Sites	The distance to Bantargebang Bekasi Landfill from the temporary disposal (Km)
C. North Jakarta Area	
7. Terminal TG. Priok, Jl. R.E Martadinata	42
8. Honda RW. 09, Jl. Sunter Kemayoran RW. 09	36
9. RW 004, Jl. Inspeksi Kali Sunter Kelapa Gading	33
D. West Jakarta Area	
10. Jl. Kojan RW 06 Kalideres	58
11. RW 002 Tegal Alur, Jl. Bhakti Mulia Tegal Alur	60
12. RW 06 Pinggir Kali Pesanggrahan Kebon Jeruk	45
E. Central Jakarta Area	
13. Jl. Binatu RW 08 Petojo Utara Gambir	42
14. Menteng Tenggulun, Jl. Menteng Tenggulun	35
15. Rusun Benhil 2, Jl. Penjernihan 1 RW 08 Bendungan Hilir Tanah Abang.	37

Source: Defitri (2023)

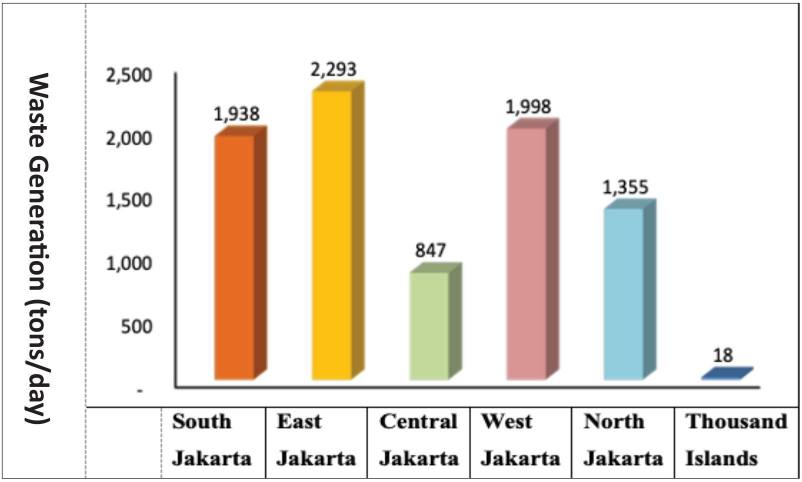
The large number of waste collection locations that are spread far from the solid waste final disposal site in Bantargebang Bekasi is a problem in urban solid waste management in the City of Jakarta. Table 3.3 shows the type and volume of urban solid waste from 2018 to 2022.

Table 3.3 Type and Volume of Urban Solid Waste from 2018 to 2022

Type of solid waste	Volume of solid waste (Ton)				
	2018	2019	2020	2021	2022
Organic	4009.43	3519.14	4078.28	3888.19	3761.9
Anorganic	3671.69	4139.86	3466.79	3305.2	3749.84
Toxic and Dangerous Materials	41.69	43.07	42.41	40.44	31.68
Amount	7722.81	7702.07	7587.49	7233.82	7543.42

Source: BPS Prov. DKI Jakarta (n.d.)

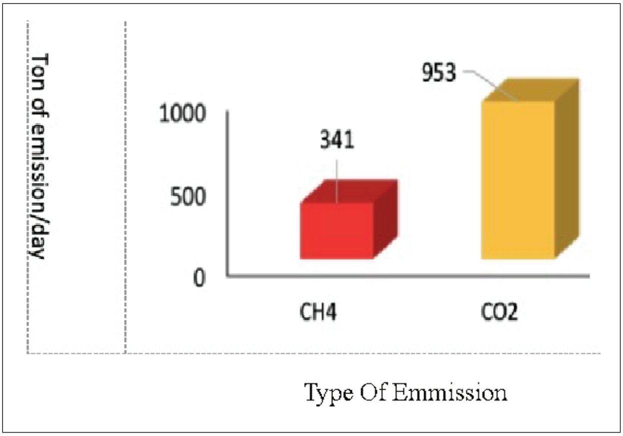
Figure 3.2 displays the volume of waste from five different parts of Jakarta City and one regency (Thousand Islands) that must be disposed of at the Bantargebang final disposal site. As we can see, between 2020 and 2022, less waste was transported to the final disposal site, which is thought to be a result of the Covid-19 pandemic, which has caused residents of Jakarta to stop going to work and school and instead stay at home.



Source: Dinas Lingkungan Hidup Provinsi DKI Jakarta (2022)

Figure 3.2 Estimated Daily Waste Production in Jakarta from Six Different Areas

The amount of waste produced, which is increasing in line with population growth, will undoubtedly endanger human health and the environment. Urban solid waste in the City of Jakarta produces emissions in the form of methane gas of 341 tons/day and CO_2 of 953 tons/day, as shown in Figure 3.3.



Source: Dinas Lingkungan Hidup Provinsi DKI Jakarta (2022)

Figure 3.3 Potential Greenhouse Gas Emissions from Solid (Organic) Waste in Jakarta

Bantargebang, as the final destination for waste, accommodates urban waste from Jakarta, where a waste processing system that stores without being closed has the potential to contribute to CH_4 and CO_2 greenhouse gas emissions. Bantargebang, as a final disposal site, has a land area and capacity, as shown in Table 3.4. The open landfill model is cheap and easy, but causes many losses, both for humans and the environment. The law regarding the environment Number 18 of 2018 prohibits waste management using the open dumping method at the final disposal site, as referred to in Article 29 paragraph 1F.

C. Environmental Impact of Urban Solid Waste Final Disposal

According to the United States Environmental Protection Agency (US EPA, 2023), methane emissions from urban landfills in 2021 will be roughly equivalent to greenhouse gas emissions from 23.1 million fossil fuel passenger vehicles, resulting in CO_2 emissions equivalent to 13.1 million household energy used for one year. At the same time, according to the World Bank (2022), the rate of waste generation is increasing worldwide. By 2020, the world is expected to generate

2.24 billion tons of solid waste, equivalent to an ecological footprint of 0.79 kilograms per person per day. With rapid population growth and urbanization, annual waste generation is expected to increase by 73% from 2020 to 3.88 billion tons in 2050.

The most pressing environmental problem regarding landfills is the release of methane gas. As the organic mass in landfills decomposes, methane gas is released. Methane is 84 times more effective at absorbing the sun's heat than carbon dioxide, making it one of the most potent greenhouse gases and a huge contributor to climate change, and the creation of landfills usually means destroying natural habitats for wildlife. The average landfill size is 600 hectares. For example, with more than 3,000 active landfills in the United States, 1,800,000 hectares of habitat have been lost (Vasarhelyi, 2021).

In Jakarta, the final disposal of urban waste located in Bantargebang, Bekasi has been carried out since 1989, initially using the open dumping method and then changing it to the landfill method. In 2019, following up Presidential Regulation No. 35 of 2018, the Bantargebang waste final disposal site has completed the construction of a waste management system that generates electricity in an effort to reduce the growing volume of urban waste generation.

Tabel 3.4 Types of Landfills in Bantargebang Bekasi City

Province	Location	Landfill type	Land Area (ha)	Capacity (m^3)	Existing Volume (m^3)
Jakarta	Jalan Raya Narogong Km 14 Pangkalan V Bekasi Jawa Barat	Open Dumping dan Controlled Landfill	111.97	21,879,000	22,387,370

Source: Dinas Lingkungan Hidup Provinsi DKI Jakarta (2022)

Generation of solid waste can produce leachate in landfills where the soil surface is not covered with waterproof materials such as geotextiles. Rainwater that falls on waste will seep into the soil and mix with surface water and groundwater, besides that it also causes air pollution (Alqassim, 2021).

Leachate can come from waste generation by mixing organic and inorganic waste. Chemical waste that is disposed of carelessly also has the potential to produce leachate-containing chemicals, such as from used batteries, electronic equipment, or household cleaners. The leachate content is influenced by several factors, such as the type of waste that is deposited to the conditions at the landfill site. The smell of leachate comes from the content of hydrogen sulfide. So, leachate is a pollutant, or causes severe contamination of groundwater and other water bodies (Rajoo et al., 2020). A study by Siddiqua et al. (2022) shows that landfills emit several gases, including sulfur dioxide (SO_2) and nitrogen dioxide (NO_2), that have a negative impact on the environment. Inhaling one of these gases can cause irritation of the throat and nose, which can potentially lead to asthma.

D. Urban Solid Waste Converted into Electricity: Experience in Other Countries

The availability of vacant land that has not been developed (not yet utilized), becomes an economical short-term waste disposal site. Landfilling is a technique used by most of the waste materials left over from incineration. The treatment of solid waste before disposing of it to landfill is mandatory in most developed countries, although such policies are often poorly implemented in developing countries.

In Indonesia, urban waste management is regulated in the Presidential Regulation of the Republic of Indonesia No. 35 of 2018, concerning the Acceleration of Development of Environmentally Friendly Technology-Based Waste Processing Installations into Electricity. Article 2 paragraph 1 states that waste management aims to improve public health and environmental quality, reduce the volume of generated waste, and the beauty of the city and water resources. In paragraph 2, it is stated that waste management is carried out in an integrated manner from upstream to downstream, and in paragraph 3, explains that the resources referred to in paragraph 1 are carried out to obtain added value as electrical energy. With Presidential Decree No. 35 of 2018, it is hoped that solid waste management in Jakarta will no longer be in the form of open dumping and make the City of Jakarta healthier with a controlled volume of waste generation.

Solid waste incineration is a simple incineration process. The incineration process, often described in the industry as heat treatment, uses a special incinerator that burns waste material to ash, heat, and flue gases (i.e., gases that escape from a chimney into the ambient air). In more modern facilities, the resulting by-products can be lumped and used for other purposes, by recycling them. For example, the heat generated from the combustion process can be used to generate electricity and solid waste, such as fly ash, which can be used as a material to make bricks, shingles, or tiles.

Burning trash is widely practiced, and really popular, in countries like Singapore, the Netherlands, and Japan, where land is scarce. Other European countries, such as France, Germany, and Luxembourg, also use incineration to dispose of Municipal Solid Waste (MSW). The inorganic material in the effluent that forms ash after combustion can be in the form of agglomerates or solid particles. There must be an adequate air supply for maximum combustion while eliminating the formation of carbon monoxide (CO) and dioxins. The heat generated from this process can be utilized as a source of electric power (Alqassim, 2021).

1. How a Waste Power Plant Works

The most common waste-to-energy conversion system in the United States is the mass combustion system. In this system, urban solid waste that is not recycled is burned in a large incinerator with a boiler and generator to generate electricity (U.S. Energy Information Administration, 2022). The amount of ash produced ranges from 15%–25% (by weight) and 5%–15% (by volume) of the processed urban solid waste. Generally, the remaining combustion consists of two types of materials, namely fly ash and bottom ash. Fly ash refers to fine particulate matter removed from flue gases and includes residue from other air pollution control devices, such as scrubbers. According to Meima and Comans (1997), combustion residues, such as bottom ash from urban solid waste incinerators, and alkaline coal fly ash produced worldwide in increasing quantities. Combustion residues, however, can pollute the environment due to the presence of potentially toxic elements relative to soils and sediments.

Fly ash usually amounts to 10–20 weight percent of the total ash. The remaining municipal solid waste (MSW) combustion ash is called bottom ash (80–90 percent by weight). The main chemical components of bottom ash are silica (sand and quartz), calcium, iron oxide, and aluminum oxide. Bottom ash usually has a moisture content of 22–62 percent dry weight. The chemical composition of the ash varies depending on the original MSW feedstock and the combustion process. The ash remaining from the MSW incineration process is sent to landfills (US EPA, 2023).

There is potential for air pollution due to the burning of urban solid waste, so each combustion furnace is equipped with a fly ash catcher as an effort to reduce air pollution in Indonesia. According to Syarifudin, at waste power plant/pembangkit listrik tenaga sampah (PLTSa) Bantargebang Bekasi, the ash left over from burning is used to make paving blocks. In 2020, 29.263 paving blocks have been produced (Wiryono & Maullana, 2021).

2. America's experience in managing urban solid waste into electrical energy

In the early 1990s, the United States burned more than 15% of all MSW. Most nonhazardous waste incinerators have pollution control equipment to remove mercury and dioxin emissions. The US Environmental Protection Agency (EPA) enacted the Maximum Achievable Control Technology (MACT) regulations in the 1990s. As a result, most of the existing facilities, which do not yet have pollution control equipment, have to be installed with closed or air pollution control systems. Currently, there are 75 facilities in the United States that recover energy from burning municipal waste. These facilities exist in 25 states, mainly in the Northeast. A new facility was constructed in Palm Beach County, Florida, in 2015 (US EPA, 2023). Other countries in the world that are densely populated and have limited land, for example, countries in Europe and Japan, have adopted burning waste that converts it into electrical energy as energy recovery due to limited land. The solid waste landfill option in America is a more viable option, especially in the short term, because of the lower economic costs of building a MSW landfill compared to building an incineration facility.

The reason for the slow pace of construction of municipal waste incinerator plants in the United States is due to public disapproval of factories that do not have emission control equipment, which causes air pollution. In addition, many residents do not want additional traffic jams due to the traffic of garbage trucks and the proximity of settlements to municipal waste incinerators. In addition, the investment required to build a MSW incineration facility can be significant, and the economic benefits may take several years to be fully realized. New factories usually need at least $100 million to finance their construction, and larger factories may need double to three times that amount.

MSW incineration facilities usually collect a tipping fee from an independent contractor who unloads the waste daily to recover costs. The factory also receives revenue after the electricity generated from the waste is sold to the power grid. The third possible revenue stream for the facility comes from the sale of ferrous and nonferrous scrap metals collected from the post-combustion ash stream (US EPA, 2023).

3. Sweden's experience in converting urban solid waste into electrical energy

In most countries, landfill is growing at an unsustainable rate. According to the International Solid Waste Association (ISWA), 40% of solid waste worldwide ends up in uncontrolled open landfills. As many as 38 out of 50 landfills are at risk of polluting the oceans and beaches, while 64 million people are directly affected, with serious health problems. Solid waste that decomposes in landfills produces methane gas, which is released into the atmosphere, causing climate change. At the current pace, at least 10% of global greenhouse gas emissions will come from the world's landfills by 2025.

As the world looks for ways to reduce the accumulation of solid waste in open dumps, the Swedish state sends less than one percent of its waste to solid waste landfills. Much of Sweden's success in reducing solid waste to open dumps is due to its high recycling rates. Between recycling solid waste and composting organic material, Sweden recycles about half of what it disposes of. Sweden is an early adopter of waste-to-energy. Its first factory went into operation amidst the post-war house building boom in the late 1940s. The new houses, which were built each had their heating connected to the district heating network, which was centrally located, and pumped it to each house so that each house did not have its own boiler.

For many years, most of the energy powering these district heating networks was supplied by waste-to-energy power plants, with major expansions beginning in the 1970s. Currently, Sweden has 34 waste-to-energy plants that supply heat to 1,445,000 households and 780,000 households with electricity, an impressive figure for a country with a population of only 10 million. In fact, Sweden has a shortage of waste to fuel in its waste-to-energy plants, so the rest of Europe now pays Sweden to take their 1.9 million tonnes of waste a year and burn it by converting it into energy that Sweden uses to heat its homes and earn as much as $100 million per year as a privilege (Sieg, 2022).

4. Urban Waste to Energy Project in China

The effective disposal of MSW is a serious environmental challenge in China. Due to rapid urbanization, China has become the second-largest producer of urban solid waste in the world. More than 35% of such waste is disposed of in inappropriate landfills, exposing residents to soil and groundwater contamination, as well as severe air pollution. According to the World Bank (EASUR, 2005), China has recently overtaken the US as the world's largest producer of MSW. In 2004, China's urban areas generated around 190,000,000 tons of MSW and by 2030 this amount is projected to be at least 480,000,000 tons. No country has ever experienced this large or rapid increase in waste generation. MSW generally refers to household and commercial waste as well as waste in urban areas. Estimates show that the People's Republic of China generates around 220 million tons of waste every year. The volume of urban waste increases every year in line with the increase in population and economic growth.

In 2009, not all urban waste was collected, sorted, recycled, and disposed of properly. Nearly 50% of the waste in the secondary urban areas of the People's Republic of China ends up in landfills and outengineered waterways. Failure to prevent such disposal practices and improperly managing MSW can lead to local, regional, and global environmental problems such as air pollution, soil and groundwater contamination, and greenhouse gas (GHG) emissions (ADB, 2015).

The newly amended Law of the People's Republic of China on the Prevention and Control of Environmental Pollution Caused by Solid Waste ("Solid Waste Law") came into force on September 1, 2020. This is the second major amendment after its enactment in 1995. The goals set by the Solid Waste Law are to protect and improve the ecological environment, to prevent and control environmental pollution caused by solid waste, to safeguard public health, to maintain ecological security, to promote ecological civilization development, and to promote sustainable economic and social development (Wang, 2020).

China is going a step further in urban waste management by introducing several waste collection solutions using advanced, intelligent, and unique technologies to help Beijing implement a waste classification system similar in Shanghai, Shenzhen, and 16 other cities across the country. Beijing has also introduced artificial intelligence (AI) in its waste management system. Facial recognition technology has been used in trash cans to encourage people to recycle more. The smart trash-can pilot program, which has been running since 2019, registered all participating citizens and took their photos. When residents take out their trash, the smart trash-can can automatically scans their faces to identify them. After the bin itself recognizes that the user is a resident, the lid is opened, and the recyclables are weighed. QR-coded trash bags ensure that the right waste has been dropped into the right bin. Residents are given prize credit for excelling at recycling. This step received appreciation from many parties (Lombard Odier, 2021).

With assistance from the Asian Development Bank (ADB), China is now developing waste-to-energy processing with appropriate and clean technology. Under a public-private partnership that offers concessions to urbanities, such factories have been built in four cities. This project uses advanced and reliable technology that does not require coal as an additional fuel. In addition, air emissions are treated to meet the world's most stringent environmental standards. Using the Asian Development Bank's innovative financing approach, a private company developed six waste to energy (WTE) plants that process 6,200 tons of urban solid waste, generating an additional 132 megawatts of power capacity and delivering 630 gigawatt-hours of electricity annually (ADB, 2015).

5. Japan's experience in converting urban solid waste into electrical energy: Improved collection efficiency and wide area transportation via transfer stations

Expansion of urban areas, encouraging the expansion of waste collection zones to increase the efficiency of collection and transportation operations in cities by building and adding waste transfer stations. Trash can be transferred from small or medium-sized dump trucks to larger trucks. Garbage collection operations and transportation costs constitute the largest weighting percentage of waste management. The expansion of the waste transfer station not only leads to cost reduction but also reduces CO_2 emissions, contributing to the prevention of global warming.

Determining whether or not to build a transportation station depends on its cost-effectiveness. In general, if the distance exceeds 18 km, the presence of transport stations must be considered. Improving the efficiency of collection and transportation leads to reduced costs while maintaining the principle of improving services to the population. Many roads are narrow in Japan, and garbage collection trucks weighing 1 to 2 tons were developed to be lighter to increase payload capacity. There are two types of garbage collection trucks, namely mechanical trucks (Mobile Packers) and compressor-type trucks.

Garbage with a high moisture content reduces the compression efficiency. However, with continuous modification, the truck can achieve a high degree of compression, with a load of 1.5 times more than a flat pile truck. The compressor-type truck presses the waste to the floor with a pressure plate, and after it has been broken down and the volume reduced, the waste is put into storage. The truck efficiently collects large solid waste that requires splitting, large PET bottles and plastic waste. Due to the problem of global warming all over the world, dump trucks of low pollution type, with electric motor drive and hybrid trucks, are being developed and put into practical use.

Since 1960, Japan has begun to manage urban solid waste by incineration. Currently, Japan has the world's leading incineration facilities. In the 2009 fiscal year, there were 1,243 incineration facilities. The process of burning solid waste uses several methods, such as stoker furnaces, fluidized bed furnaces, and fusion gasification furnaces. These methods aim to recycle ash. Stoker furnaces account for 70% of all furnaces, the improvement of this type of furnace is growing rapidly. At present, a high degree of environmental conservation technology is being introduced. Technologies related to high-efficiency power plants and technologies related to safe operation, such as automatic incineration devices and automatic cranes, are also being developed. Japan is accumulating know-how to handle various types of waste, from low-calorie waste generated when incineration facilities were first built to high-calorie waste. This technology can be utilized for the types of waste generated in the Asian region. The newest stoker furnace technology is low-air incineration aimed at high-efficiency power plants built in Japan. Other technologies were developed, including reducing dioxin emissions, removing acid gases and recycling combustion ash. The conventional stoker furnace has undergone significant improvements, with better heat recovery after combustion. This system allows for efficient, clean electricity generation compared to conventional methods. This new technology allows Japanese incineration plants to be safe and healthy while generating electricity efficiently (Japan Environmental Sanitation Center, 2012).

Japan already has high, reliable, safe and healthy technology for burning solid waste. When planning the construction of solid waste incineration facilities, the government engaged in communication with the local population, enabling rapid progress on plans for the construction of incineration facilities in urban and residential areas. There are many urban incineration plants, both large and small, which operate according to strict anti-pollution policies (Japan Environmental Sanitation Center, 2012).

The Japanese Ministry of Environment (2023) reports the condition of national waste in Japan as follows: (1) the total waste generated is 40.95 million tons, and 890 grams per day per person; (2) the total amount of waste and the amount of waste generated per person per day has decreased; (3) the number of waste incineration facilities has decreased (1,056 in 2020 to 1,028 factories in 2023); (4) the number of incineration facilities with power generation facilities reached 38.5% of the total, up from 36.6% in the previous fiscal year; and (5) the total amount of power generated at incineration plants increased (10,452 GWh, equivalent to the consumption of about 2.5 million households.

E. What Has Been and Must Be Done by the Government of DKI Jakarta in Terms of Urban Solid Waste Management

Presidential Regulation No. 35 of 2018 concerns the acceleration of development of environmentally friendly technology-based waste processing installations. The presidential regulation aims to reduce the volume of solid waste produced and generate electricity by utilizing solid waste as a raw material.

DKI Jakarta Government implements Presidential Regulation No. 35 of 2018 by building an installation named PLTSa Merah Putih, which was built in Bantargebang, in the final solid waste disposal area which was built in 2018, and in 2019 it was inaugurated by the Coordinating Minister for Maritime Affairs. Furthermore, in 2020 to 2022 PLTSa will be operated by the DKI Jakarta Provincial Government accompanied by BRIN. PLTSa is still in the small-scale pilot plant stage. Further steps are needed to optimize (Astungkoro & Ramadhan, 2023).

PLTSa Merah Putih uses thermal process technology combustion, which can destroy solid waste quickly, significantly and environmentally friendly. The PLTSa pilot project is designed to operate continuously 24 hours/day and 250–300 days/year, using solid waste fuel with a capacity of 100 tons/day and producing 700 kW of electricity, which will be used for the internal operations of the PLTSa unit (Wiryono & Maullana, 2021).

1. How efficient is the management of urban solid waste in DKI Jakarta?

In the following discussion, we will describe the management of waste into energy. The discussion is divided into three topics, namely operations, culture changes, and financing the construction of a solid waste processing plant into energy.

a. Operation

Bantargebang as a place for producing electrical energy called the Merah Putih Waste Power Plant (PLTSa) has the shortest distance of 21 km and the farthest distance of 60 km to the temporary solid waste disposal sites, which are spread over five areas in the City of Jakarta with 15 landfills. Long distances and heavy traffic conditions take a long time to travel, and the emissions emitted by trucks along the road are also increasing, as are the costs incurred. If the DKI Jakarta Provincial Government's plan to build four Intermediate Waste Management Facilities (FPSA) in the DKI Jakarta area can be realized, it will make efficient and effective waste management, especially if this temporary management facility is developed into a waste power plant (PLTSa).

Based on Japanese experience since 1960 in waste management, solid waste collection and transportation costs constitute a high percentage of all disposal operations to landfills. Improving the efficiency of waste collection and transportation leads to reduced operating costs while maintaining or improving services to the population.

Transferring to bigger trucks at transportation stations spread across five areas of Jakarta city, increasing transportation efficiency, and reducing truck fuel consumption. One large truck can replace 2–3 medium-sized trucks in transporting solid waste to the final storage location. This not only reduces operational costs, but also reduces CO_2 emissions, as one of the contributors to urban pollution.

Whether or not it is necessary to build transportation stations in five areas of the City of Jakarta following the experience of the Japanese State, if the transportation distance exceeds 18 km, a waste collection station should be considered, and using large trucks as transporters to be sent to the final collection point in Bantargebang, Bekasi. Collection of waste from residential areas requires small and medium trucks to transport waste to transit stations spread across 15 locations. From these 15 collection points, waste is transferred back to large trucks at transportation stations to be sent to final disposal sites to be converted into electrical energy.

The waste management process begins with sorting the type of waste that is carried out at temporary landfills, separating organic waste and non-organic waste, carried out with the aim of obtaining efficiency in the process of converting waste into electrical energy. Waste segregation can be carried out at solid waste final disposal sites at 15 locations in the city.

In the City of Jakarta, scavengers collect waste that has economic value. They operate in residential areas, bus terminals, and community gathering places. The waste they collect includes plastic drink bottles, cardboard, metal, glass, and electronic equipment. Apart from scavengers, in Jakarta there are many waste banks managed by the community. Phenomena like this can help reduce solid waste that has to be sent to landfills.

The quality of the outcomes of waste power plant combustion is highly dependent on the drying of waste as fuel. In general, organic waste that enters the combustion chamber has a high enough moisture content, so it does not achieve efficient results. The ideal is dry waste; the hotter it is burned, the higher the yield. To achieve self-burning, the waste that enters the bunker has a maximum moisture content of 55%. If the waste has a moisture content of more than 55%, additional fuel or pre-treatment is needed to reduce the moisture content before entering the bunker so that the combustion process can run optimally. The waste in the bunker is free from materials that are prohibited as fuel for burning, namely metal, glass, aluminum foil, PVC, and B3 waste. For large-sized waste, it will be set aside centrally before being brought to the factory (Manis et al., 2022). Since 2018, the DKI Jakarta Provincial Government has planned to build waste power plants (PLTSa), which convert waste into electrical energy. However, this plan has not yet been realized until 2023.

Sweden, which has almost the same population as the City of Jakarta, around 10 million people, has succeeded in managing its waste, thereby reducing waste. Nevertheless, there is another reason why Sweden is often described as the greenest country in the world. In the last few decades, the country has completely revolutionized waste management, drastically increasing its recycling rate and investing in technology to convert its waste into energy. Sweden is targeting households by implementing weight-based waste levies in an effort to encourage recycling. In addition, national laws prohibiting the accumulation of combustible and organic wastes, together with stricter standards for hazardous waste, landfill, and incineration imposed by the European Union on all its member states have allowed Sweden to reduce emissions and total waste landfill drastically. Since 1975, its recycling rate has jumped from a staggering 38% to 99%, and the country is now on the track to achieve its zero-waste goal, separating food waste, metal packaging, plastic, paper and glass, newspapers, electronics, tires, and batteries. To encourage everyone to do their part, Sweden built a waste collection station within 300 meters of all residential areas (Kim & Mauborgne, n.d.), and in the end, Sweden sold its waste management services to neighboring countries and made profits of up to 100 million dollars a year in foreign currency. Turning municipal waste into electrical energy in the United States can provide 2,700 MW of clean electricity for 24 hours per day, 365 days per year is enough to power about 2 million households (Pyper, 2011).

In Japan, in 2023, total power generated from waste incineration plants will reach 10,452 GWh, equivalent to the annual power consumption of around 2.5 million households (Ministry of the Environment and Forestry, 2023). Like Sweden, which earns foreign exchange by collecting state waste, Japan, which has experience in managing urban waste, has succeeded in selling waste management services and technology to other countries.

b. Culture Changes

In technology-based waste management, the human role remains the most important. Theory of environmentally responsible behavior (ERB) explains that having the intention to act is a key factor influencing responsible behavior to protect the environment. In addition to the intention to act, locus of control, attitude, sense of responsibility at a personal level, and knowledge are the main principles that influence the entire ERB (Siddiqua et al., 2022). In this theory, knowledge is the starting point for humans to understand, control themselves, and attitudes, which in the end humans will have the responsibility and positive behavior towards their environment. Waste management starts from oneself, home, school, workplace, then up to the city scale. Currently, waste management requires action and awareness from all elements of society, starting from disposing of waste according to its type, and in separate containers for its placement, for example, organic and non-organic waste disposal sites.

Changes in human and societal behavior regarding responsibility for the environment where the community is located require a long period of time. Changes in human behavior and society are in harmony with changes in the culture in which the community exists.

Culture is the way of life of a group of people—the behaviors, beliefs, values, and symbols that they accept, generally without thinking about it, and which are passed on through communication and imitation from one generation to the next. Culture is symbolic communication.

Thus, culture includes language, ideas, beliefs, customs, codes, institutions, tools, techniques, works of art, rituals, and ceremonies, among other elements. The term "cultural change" used by sociologists has changed. Communities take on new cultural characteristics, behavior patterns, and social norms. Community changes occur because of contact with other communities, because there is constant persuasion, related to waste handling, persuasions that are made, for example, how good it would be if our environment were free from garbage that makes life healthy and comfortable. This persuasion must be accompanied by examples, as well as providing motivation and ways to deal with waste in our environment. Community involvement in waste management independently is a form of community participation.

c. Financing the Construction of a Solid Waste Processing Plant into Energy

Urban waste management is the responsibility of the local government. However, as the nation's capital, the City of Jakarta should be able to work together with the central governments, as is the case in developing other infrastructure such as the mass rapid train (MRT) and light rapid train (LRT).

In most developing countries, governments face the challenge of meeting the growing demand for new and improved infrastructure services. Due to limited funds available from traditional sources, the government is motivated to look for alternative sources of funds to build infrastructure, such as waste-to-electricity processing plants.

Partnership with the private sector is an alternative to building a waste processing factory into electrical energy. In Indonesia, it is regulated in Presidential Regulation (Perpres) Number 67 of 2005 concerning Cooperation between the Government and Business Entities in the Provision of Infrastructure.

Because the infrastructure development budget owned by local governments is limited, the choice of financing instruments with the public-private partnership is an attractive option for the government as an off-budget mechanism created for infrastructure development for the following reasons: (1) the government does not require immediate cash outlay; (2) the private sector as a partner is not burdened with design and construction costs; (3) the private sector as a partner will bring advanced technology, so it is hoped that there will be transfer of technology and management of the conversion of waste into electrical energy.

In the financing scheme through the public-private partnership (PPP) mechanism, there are several models of financing instruments offered, including: supply and management contracts, turnkey, affermage/lease, concessions, private ownership of assets, and FPI Type. A description of all models of financing instruments can be seen in Table 3.5. In the case of solid waste management in the City of Jakarta, it is advisable to use a financing instrument with a concession scheme.

2. Concession

In this form of PPP, the government determines and grants special rights to private companies to build and operate facilities within a certain period of time. The government may retain final ownership of the facility and/or the right to provide the service. In concessions, payments can be made in two ways: the concessionaire pays the government for the concession right and the government can pay the concessionaire, subject to an agreement to fulfill certain conditions. Typically, such payments by the government may be required to make the project commercially viable and/or reduce the level of commercial risk taken by the private sector, with the concession period ranging from 5 to 50 years.

Tabel 3.5 Classification of PPP models

Brand Catagory	Main Variants	Ownership of Capital Asset	Respon-sibility of Investe-ment	Assumtion of Risk	Duration of Contract (years)
Suply and manage-ment contract	Outsourcing	Public	Public	Public	1–3
	Maintenance management	Public	Public/ Private	Public/Pri-vate	3–5
	Operational management	Public	Public	Public/Pri-vate	3–5
Turnkey		Public	Public	Public/Pri-vate	1–3
Affermage/ Lease	Affemage	Public	Public	Public/Pri-vate	5–20
	Lease	Public	Public	Public/Pri-vate	5–20
Conces-sions	Franchise	Public/Pri-vate	Public/ Private	Public/Pri-vate	3–10
	BOT	Public/Pri-vate	Public/ Private	Public/Pri-vate	15–30
Private ownership of assets and FPI Type	BOO/DBFO	Private	Private	Private	Indefinite
	PFI	Public/Pri-vate	Private	Public/Pri-vate	10–20
	Divestiture	Private	Private	Private	Indefinite

Source: Quium (2011)

In a build-operate-transfer or BOT type of concession (and its other variants, namely build-transfer-operate [BTO], build-rehabilitate-operate-transfer [BROT], build-lease-transfer [BLT] type of arrangement), the concessionaire makes investments and operates the facility for a fixed period of time after which the ownership reverts back to the public sector. In a BOT model, operational and investment risks can be substantially transferred to the concessionaire. The BOT scheme refers to the initial concession by a public entity, such as a local government, to a private firm, to both build and operate the project in question. After a set time frame, typically two or three decades, control of the project is returned to the public entity.

F. Closing

Garbage is an interesting phenomenon and is of global concern, from low-income countries to high-income countries. Many countries have realized that waste generation is one of the causes of the greenhouse gas effect because of the methane gas present in solid waste generation. Thus, integrated waste management in several countries by converting waste into electrical energy as a renewable energy substitute for fossil fuels can reduce emission levels and have a positive impact on emission control which leads to a reduction in the greenhouse gas effect. Many countries in the world have abandoned waste management using the open dumping method, which produces methane gas, which contributes to the greenhouse gas effect.

Management of urban solid waste using the waste-to-energy method by burning in an incinerator reduces waste by up to 80%–90%, and the ash from the combustion can be used as a raw material for making paving blocks which is a by-product other than electricity. With the combustion method that converts waste into electrical energy, the volume of solid waste generation and urban solid waste problems can be reduced. Learning from Sweden and Japan, waste brings blessings by bringing in foreign exchange for Sweden and Japan, which sells services and technology that converts waste into electricity.

The City of Jakarta has started to manage waste in an integrated manner using the burning method. PLTSa Bantargebang is already operating on a small scale and is planned to be built in four areas in DKI Jakarta. The electricity generated from the conversion can be used to drive public transport such as buses, MRT, and LRT, which can contribute to reducing emissions.

Even though waste management uses advanced technology, the role of humans remains the main factor, so education and outreach about waste is needed from an early age. Countries that have succeeded in managing waste by implementing integrated waste management require a long time to educate and socialize the society.

References

Alqassim, A. Y. (2021). Environmental health impacts of municipal solid waste landfilling and incineration in different health systems: A review. *Hail Journal of Health Sciences*, *3*(1), 13–24. http://dx.doi.org/10.4103/1658-8312.347572

Asian Development Bank (ADB). (2015, October 1). *The People's Republic of China's urban waste-to-energy project: A model approach to financing a state-of-the-art technology* [Report on ADB Energy Projects]. ADB Knowledge Events. https://events.development.asia/system/files/materials/2015/

Astungkoro, R. & Ramadhan, B. (2023, February 23). *Peneliti BRIN: PLTSa Bantargebang masih belum optimal*. Republika. https://news.republika.co.id/berita/rqhpo1330/peneliti-brin-

BPS Prov. DKI Jakarta. (n.d.). *Volume sampah yang terangkut per hari menurut jenis sampah di Provinsi DKI Jakarta (Ton), 2020-2022*. Accessed on August 20, 2023, from https://jakarta.bps.go.id/indicator/152/916/1/volume-sampah-yang-terangkut-per-hari-menurut-jenis-sampah-di-provinsi-dki-jakarta.html

Defitri, M. (2022, August 12). Tempat pembuangan sampah terdekat area Jakarta. *waste4change*. https://waste4change.com/blog/tempat-pembuangan-sampah-terdekat-area-jakarta/

Dinas Lingkungan Hidup Provinsi DKI Jakarta. (2022). *Dokumen informasi kinerja pengelolaan lingkungan hidup daerah Provinsi DKI Jakarta tahun* 2022. https://lingkunganhidup.jakarta.go.id/files/dikplh/DIKPLHDJakarta2022-FULL-REV1.pdf

EASUR. (2005). *Waste management in China: Issues and recommendations* (Urban Development Working Papers No. 9). World Bank. https://documents1.worldbank.org/curated/en/237151468025135801/pdf/332100CHA0Waste1Management01PUBLC1.pdf

Japan Environmental Sanitation Center. (2012, February). *Solid waste management reycling technology of Japan: Toward a susatinable society*. Ministry of the Environment of Japan. https://www.env.go.jp/content/900453393.pdf

Kim, C. & Mauborgne, R. (n.d.). Turning waste to energy: Sweden's recycling revolution. *Blue Ocean*. Accessed on August 18, 2023, https://www.blueoceanstrategy.com/blog/turning-waste-energy-sweden-recycling-revolution/

Lombard Odier. (2021, July 6). *How China is addressing its waste problem*. Bank Lombard Odier & Co Ltd. https://www.lombardodier.com/contents/corporate-news/responsible-capital/2021/july/how-china-is-addressing-its-wast.html

Meima, J. A., & Comans, R. N. J. (1997). Overview of geochemical processes controlling leaching characteristics of mswi bottom ash. In Goumans, J. J. J. M., Senden, G. J., Van Der Sloot, H. A. (Eds.), *Proceedings of the international conference on the environmental and technical implications of construction with alternative materials, WASCON '97: Waste materials in construction, putting theory into practice* (447–457). Elsevier. https://doi.org/10.1016/S0166-1116(97)80228-2

Ministry of the Environment. (2023, March 30). *Municipal solid waste generation and disposal in FY2021*. Government of Japan. https://www.env.go.jp/en/press/press_01276.html

Peraturan Daerah Provinsi Daerah Khusus Ibukota Jakarta Nomor 1 Tahun 2012 tentang Rencana Tata Ruang Wilayah 2030. (2012). https://pertamananpemakaman.jakarta.go.id/PERDA-01_TAHUN_2012-TENTANG-RTRW_2030.pdf

Peraturan Presiden Republik Indonesia Nomor 35 Tahun 2018 tentang Percepatan Pembangunan Instalasi Pengolah Sampah Menjadi Energi Listrik Berbasis Teknologi Ramah Lingkungan. (2018). https://setkab.go.id/wp-content/uploads/2018/04/Perpres-No.-35-Tahun-2018.pdf

Pyper, J. (2011, August 26). Does burning garbage to produce electricity make sense? *Scientific American*. https://www.scientificamerican.com/article/does-burning-garbage-to-produce-energy-make-sense/

Quium, A. (2011). *A guidebook on public-private partnership in infrastructure*. UNESCAP. https://www.unescap.org/resources/guidebook-public-private-partnership-infrastructure

Rajoo, K. S., Karam D. S., Ismail, A., & Arifin, A. (2020). Evaluating the leachate contamination impact of landfills and open dumpsites from developing countries using the proposed Leachate Pollution Index for Developing Countries (LPIDC). *Environmental Nanotechnology, Monitoring & Management, 14*, Article 100372. https://doi.org/10.1016/j.enmm.2020.100372.

Siddiqua A., Hahladakis J. N., & Al-Attiya W. A. (2022). An overview of the environmental pollution and health effects associated with waste landfilling and open dumping. *Environmental Science and Pollution Research,* 29, 58514–58536. https://doi.org/10.1007/s11356-022-21578-z

Sieg, K. (2022, April 8). *How Sweden sends just 1% of its trash to landfills.* Reasons to be cheerful. https://reasonstobecheerful.world/waste-to-energy-sweden-power-plants/

SIPSN. (n.d). *Timbulan sampah*. Kementerian Lingkungan Hidup dan Kehutanan. Accessed on August 20, 2023, from https://sipsn.menlhk.go.id/sipsn/public/data/timbulan

The World Bank. (2022, February 11). *Solid waste management*. https://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management

U.S. Energy Information Administration. (2022, October 31). *Biomass explained: Waste-to-energy (Municipal Solid Waste).* https://www.eia.gov/energyexplained/biomass/waste-to-energy.php

Undang-Undang Republik Indonesia Nomor 18 Tahun 2008 tentang Pengelolaan Sampah. (2008). https://peraturan.bpk.go.id/Home/Details/39067/uu-no-18-tahun-2008

United States Environmental Protection Agency (EPA). (2023, June 7). Energy Recovery from the Combustion of Municipal Solid Waste (MSW). https://www.epa.gov/smm/energy-recovery-combustion-Urban-solid-waste-msw

Vasarhelyi K. (2021, April 15). The hidden damage of landfills. *Environmental Centre Divison of student Affairs Environmental Center University of Colorado Boulder*. https://www.colorado.edu/ecenter/2021/04/15/hidden-damage-landfills

Wang, S. (2020, September 30). *Overview on the newly amended law of the peoples republic of china on prevention and control of environmental pollution caused by solid waste*. Lexology. https://www.lexology.com/library/detail.aspx?g=fb7afb41-8598-48f0-9a9e-c5816768240f

Wiryono, S. & Maullana, I. (2021, March 9). *Pilot project PLTSa Bantargebang, sulap 9.879 ton sampah jadi energi listrik.* Kompas.com. https://megapolitan.kompas.com/read/2021/03/09/22065281/pilot-project-pltsa-bantar-gebang-sulap-9879-ton-sampah-jadi-energi

Yuliani, M., Otivriyanti, G., Yusuf, N. R., Fani, A. M., & Purwanta, W. (2022). A Techno-economic study on the application of waste-to-wnergy incinerator in Indonesia (Case on City "X"). *Jurnal Teknologi Lingkungan*, *23*(2), 126–134. https://ejurnal.bppt.go.id/index.php/JTL/article/view/5302