Waste power plant: waste to energy study in Medan city area

A Sihite1, ST Kasim1 and F Fahmi1,2,*

1 Department of Electrical Engineering, Faculty of Engineering, Universitas Sumatera Utara, Medan Indonesia
2 Centre of Excellence Sustainable Energy and Biomaterials, Universitas Sumatera Utara, Medan Indonesia

e-mail: fahmimm@usu.ac.id

Abstract. This study discusses the waste to energy processing technology in the area city of Medan Sunggal. Waste management is considered to be the optimal solution to reduce the volume of waste and its growth in Medan. Through the calculation and assessment of the data obtained, we can find out the volume of waste in Medan Sunggal is more than 132 m³ per day with a weight of 28,512 tons per day. The proposed waste to energy utilization method is the thermochemical method. Garbage is processed first in specific way as to reduce the water content in order to obtain a higher calorific value. The garbage has the potential to generate electricity at 1.8 MW theoretically, but the effect of 80% boiler efficiency, 25% steam turbine and 90% generator will affect the actual output to be around 451.46 kW. With the selling price of electricity in accordance with Ministry of Energy and Mineral Resources regulation number 44 of 2015, the implementation of Waste Power Plants (WPP) meets the feasibility of economic analysis. Based on the calculation of the economic analysis, the net present value of WPP obtained at Rp 970,964,221.25 and payback period does not exceed the economic life of the plant and benefit cost ratio is greater than Zero. These criteria can be used as a reference for evaluating the feasibility of developing Waste Power Plants in the area.

1. Introduction
Population growth has a direct influence on the volume of waste produced by the community because waste comes from activities in daily lives. The higher the population growth, the higher the rate of waste will be. This is directly proportional to the increasing volume of waste [1]. Population density causes a decrease in land in urban areas and conversely the volume of waste produced by the community increases from time to time. Waste becomes a big problem in urban areas that interfere with the comfort of the city and requires proper treatment to overcome these environmental problems [2].

At the other side, the existence of waste is also a potential source of renewable energy since its availability is very abundant, but until now has not been utilized optimally. In Indonesian Law No.18 of 2008, waste management has been regulated accordingly for the sake of the realization of improving public health and environmental cleanliness and making waste as a resource. The law also mentions that the intended waste management is a systematic, comprehensive, and sustainable activity which includes the reduction and handling of waste [3,4]. The purpose of this study is to analyze the feasibility of waste power plant applied in a specific area of Medan city.
2. Material and method

Garbage is a solid waste or residual material from a natural process or from human activities. According to SNI, garbage is solid waste consisting of organic and inorganic substances that are considered useless and must be recycled so as not to endanger the environment to protect population.

2.1. Waste classification

Based on its chemical properties, waste is divided into two types [5], namely:
1. Organic waste consists of organic materials from plants and animals that come from nature.
2. Inorganic waste comes from non-renewable natural resources such as minerals and petroleum, or from industrial processes.
3. Hazardous toxic substances; in hazardous or toxic (B3) garbage, waste occurs from organic and inorganic chemicals and heavy metals, which generally come from industrial waste. Hazardous waste management cannot be mixed with organic and non-organic waste. Usually, there is a particular body established to manage B3 waste according to applicable regulations.

Based on its physical properties, waste is divided into two types, namely:
1. Garbage, a waste that consists of organic material and has easy to rot properties.
2. Dry Waste, waste composed of organic and inorganic materials, which is slow or not decomposed and can be burned.

2.2. Waste power plant (WPP)

WPP is one type of power plant where the primary energy comes from waste. The working principle of this power plant is not much different from PLTU in general [6]. The difference lies in the fuel processing system only. The generation mechanism can be done in two ways, namely the thermochemical conversion process and the biological conversion process [7,8]. The thermal conversion process utilizes incinerator technology, pyrolysis, and gasification technology. While in the biological conversion process, it is done with anaerobic digestion and landfill gasification. In this study, the technology used is thermochemical. Calculations made for the conversion process can be expressed in the following equations:

\[ H_{ar} = \left( H_{ad} - 0.1119 \times M_{adb} \right) \times \left\{ \frac{\left( 100 - M_{ar} \right)}{\left( 100 - M_{adb} \right)} \right\} + 0.1119 \times M_{ar} \]  

Where: \( H_{ar} \) = hydrogen as received (%), \( M_{adb} \) = Moisture air dried (%), \( M_{ar} \) = Total Moisture as received (%)

\[ NCV_{thermochemical} = GCV - (5.72 \times (9 \times H_{ar}) \right) \]  

Where: \( NCV \) = Net Caloric Value (kcal/kg), \( GCV \) = Gross caloric Value (%), \( H_{ar} \) = hidrogen as received (%)

\[ W_c = W_{gross} \times waste \]  

Where: \( W_{gross} \) = overall weight of the waste component (Tons / day), \( W_c \) = net weight of each garbage (Ton / day)

\[ W = W_{gross} \times W_c \]  

Where: \( W \) = Total Waste Quantity (Ton/day), \( W_{gross} \) = Total Waste Dump (m³ / day); \( W_c \) = Waste Composition (%)

\[ ERP = \frac{NCV_{Gross} \times W \times 1000}{860} \]  

Where: \( ERP \) = Energy Recovery Potential (kWh), \( NCV \) = Net Calorific Value (kcal/kg), \( W \) = Total Waste Quantity (Ton), 1000 kg waste, 860 Unit Conversion (1 kWh = 860 kcal)
\[ P = \frac{\text{ERP}}{24} \]  

Where: \( P \) = Power Generation Potential (kW), ERP = Energy Recovery Potential (kWh), 24 from 1 day use unit (24 hours)

2.3. Technical economics analysis

This analysis is needed to review the feasibility of WPP construction based on investment costs, economic age, present value, and the payback period to provide recommendations for WPP development. At this stage, alternative identification is carried out; each alternative has characteristics. Then the comparison and selection of alternatives are done by using economic analysis and technical analysis, which includes analysis NPV (Net Present Value), PBP (Pay Back Period).

2.3.1. Depreciation.

The estimated economic life of the plant is around 20 years, and at the end of the plant's life, there is still a residual value remaining of around 10% of its useful life. Residual value (10%) = Initial investment.

\[
\text{Depreciation} = \frac{\text{Investment} - \text{Residual}}{t} 
\]

Where: Depreciation = Value Depreciation (IDR), Investment= Initial Construction Cost Value (Rp), Residual= Residual Value at the End of Goods Life (IDR), T= age / usage period (years)

2.3.2. Preparation of cash flow.

The preparation of cash flow uses several parameters, including:

1. Depreciation rate = %
2. Economic age of the generator = n Years.
3. Load Factor = m (integer); based on assumptions.

2.3.3. NPV (Net Present Value).

NPV is the present value of the whole Discounted Cash Flow or a description of the total cost or total project revenue seen by the present value (the value at the start of the project). Mathematically the NPV value can be expressed as the following equation:

\[
\text{NPV} = -\text{CoF} + \frac{C_1}{(1+i)^1} + \frac{C_2}{(1+i)^2} + \ldots + \frac{C_n}{(1+i)^t} 
\]

Where: I= Depreciation rate used, COF= Cash outflow / Investment, C= Cash inflow in period t, N= The last period of cash flow is expected, NPV= Investment costs - Receipt costs

2.3.4. Payback period (PP).

The payback period can be approached by using following equations:

\[
\text{PBP} = \frac{\text{Investment Cost}}{\text{Annual CIF}} 
\]

Where :PBP = Payback period / investment return period (years), Investment cost = Large investment costs (IDR), Annual CIF = Annual income fee (IDR)

2.3.5. Benefit cost ratio (BCR).

By using the following equation, the BCR value can be calculated as follows:

\[
\text{BCR} = \frac{\sum_C + \text{CIF}}{\text{Investment cost}} 
\]

Where BCR= Benefit Cost ratio, Investment Cost= Investment Cost (IDR), CIF= Annual Revenue (IDR)
2.4. Data mining

This research was conducted in one area of the city of Medan in the district Medan Sunggal. The data to be processed was obtained from the Medan City Sanitation and Landscaping Office. The duration of this study is 2 (two) months. The variables observed in this study include:

4. The type and volume of waste that is in the garbage disposal location.
5. The heat value of waste and electricity generated by WPP and the proceeds from the sale.
6. Economic Analysis
7. SWOT analysis

Figure 1 below shows the flowchart of the conducted research.

3. Results and discussion

3.1. Waste composition and volume

The waste composition analysis aimed to find out the forming components of the waste to be processed. By knowing the composition of the waste produced by the community and by calculating the volume of each component of waste would make it easier for us to calculate the calorific value of the garbage as shown in Figure 2.
Figure 2. Percentage of each waste composition.

The volume of Waste obtained from the relevant city office can be seen in Table 1.

| No | Truck   | Volume | Type       |
|----|---------|--------|------------|
| 1  | Truck 1 | 10 m3  | Container  |
| 2  | Truck 2 | 6 m3   | R. Sweeper |
| 3  | Truck 3 | 6 m3   | R. Sweeper |
| 4  | Truck 4 | 6 m3   | R. Sweeper |
| 5  | Truck 5 | 6 m3   | Compactor  |
| 6  | Truck 6 | 24 m3  | T. Arm Roll|
| 7  | Truck 7 | 6 m3   | R. Sweeper |
| 8  | Truck 8 | 6 m3   | R. Sweeper |
| 9  | Truck 9 | 6 m3   | T. Arm Roll|
| 10 | Truck 10| 6 m3   | R. Sweeper |
| 11 | Truck 11| 18 m3  | Container  |
| 12 | Truck 12| 6 m3   | R. Sweeper |
| 13 | Truck 13| 20 m3  | Container  |
| 14 | Truck 14| 12 m3  | Container  |

Volume Total >>132 m3

3.2. Weight of garbages and electric power production

The volume of waste in Medan Sunggal District was more than 132 m3 / day. Assuming every 1 m3 of waste is 216 kg/m3. Then the weight of garbage ranges from 28,512 tons / day. By using the equations based on the theory, it is obtained the potential of waste if used as WPP fuel can produce power of 1,805 MW. The details of the calculations can be seen in Table 2.

| No. | Garbage | ERP    | hours/day | Power (kw) |
|-----|---------|--------|-----------|------------|
| 1.  | Leaves  | 19,193.46 | 24        | 799.73     |
| 2.  | Wood    | 3,095.72  | 24        | 128.99     |
| 3.  | Paper   | 11,144.59 | 24        | 464.36     |
| 4.  | Plastics| 8,668.03  | 24        | 361.17     |
| 5.  | Rubber  | 1,238.29  | 24        | 51.60      |

Total 1805.84
Assuming the efficiency of WPP ± 25%, the power generated is 451.46 kW

3.3. Investment cost

The amount of investment costs to build a WPP is shown as in Table 3.

| No | Description                                      | Price (IDR)       |
|----|--------------------------------------------------|-------------------|
| 1  | Generator and Turbine Package (1mw)               | 12,811,543,053.00 |
| 2  | Control system and supporting facilities         | 200,152,510.00    |
| 3  | Collecting land                                  | 1,506,594,081.00  |
| 4  | Construction Materials and Labor                 | 3,518,270,741.00  |
| 5  | Project Management and Construction              | 2,500,962,445.00  |
| 6  | Engineering Costs                                | 2,500,962,445.00  |
| 7  | Unforeseen expenses                              | 3,000,000,000.00  |
| 8  | Total Before Tax                                 | 26,038,485,275.00 |
| 9  | 10% tax                                          | 2,603,848,527.50  |
|    | Total Investment                                 | 28,642,333,802.50 |

3.4. Receipt fee

Calculation of electricity sales or purchase price of National electric company (PLN) from WPP according to regulation [9] has been improved, e.g., Sanitary landfill: IDR 1,650 - 2160 / kWh; incinerator type IDR 1,870 kWh (medium to High) and IDR 2,240 / kWh (Low). Power that can be generated / hour = 451.46 kW.

Power generated in:
- 1 day = 451.46 kw x 24 h = 10,385.4 kwh
- 1 month = 325,051.2 kwh/ month
- 1 year = 3,900.614.4 kwh/year

Total power provided to PLN = 3,900,614.4 kwh per year, then revenue per year would be 3,900,614.4 kwh / year * IDR 1,870 or equal to IDR 7,294,148,928.

3.5. Depreciation costs

The estimated economic life of the plant is around 20 years, and at the end of the plant's life, there is still a residual value remaining of around 10% of its usage period.

Initial investment = IDR 28,642,333,802.50
Residual value (10%) = IDR 2,864,233,380.25

Depreciation Cost = \( \frac{\text{Investment} - \text{Residues}}{t} \) = IDR 1,288,905,021.11

3.6. Estimated preparation of cash flow

The preparation of cash flow uses several assumptions, including:
1. Discount rate = 15%
2. Discount Factor = 25%
3. The economic life of the plant = 20 years
4. Load Factor = 0.65
3.7. Investment valuation

3.7.1 NPV (Net Present Value).
By using equation (8) the NPV (Net Present Value) value can be calculated with

\[
NPV = Total\ investment\ costs - Total\ revenue\ costs = IDR\ 28,642,333,802.50 - IDR\ 17,901,458,626.56 = IDR\ 10,740,875,175.94
\]

3.7.2 Payback Period (PP).
By using equations (9):

\[
PBP = \frac{Investment\ Cost}{Annual\ CIF} = \frac{IDR\ 28,642,333,802.50}{IDR\ 4,427,419.133,00} = 6.5\ year
\]

3.7.3 Benefit Cost Ratio (BCR)
Using equation (10) the BCR value can be calculated as follows:

\[
BCR = \frac{\sum_{t=0}^{n} CIF_t}{Investment\ cost} = \frac{88,548,382,660.00}{28,642,333,802.50} = 3.0
\]

In this study, the calculation used is just one of the thermochemical methods, so for the continuation of this study, several Thermochemical methods, gasification, pyrolysis, etc. can be compared, and compare the results to obtain better results for the application of WPP types. WPP location selection needs to be well considered in order to obtain the operating efficiency of WPP.

4. Conclusions
The composition of waste found in Medan Sunggal sub-district is the same as in all regions of Medan City. The composition of solid waste consists of leaves (31%), food waste (16%), wood (5%), paper (18%), plastic (14%), rubber (2%), metal (4%), glass (2%) and others (8%), with a weight of 28,512 tons. However, not all waste can be used for WPP, which can be used is around 70% that the weight of the waste used is 19,958 kg (around 20 tons).

By using the calculation of the thermal method obtained the potential electricity generated by Gross power output 1,805.84 kW and Net Power output power (influenced by generator efficiency) 451.46 kW. By using the least cost method, the result of NPV calculation is IDR 17,917,061,218.75 which means that the project is profitable according to the NPV project eligibility criteria> 0 and the payback period is 6.5 years, (not exceeding the economic life of a plant). The benefit cost ratio between costs shown by the BCR is a positive number that is 3.0 Greater than 0. Waste management in Medan City must be improved in order to facilitate the processing of waste to support WPP, coordination, and synergy between the Government, the community and the developer are needed.

References
[1] Fatimah A 2009 Thesis: Analisis kelayakan Usaha Pengolahan Sampah Menjadi Pembangkit Listrik Tenaga Sampah (PLTSa di Kota Bogor) (Bogor: Institut Pertanian Bogor)
[2] Syamsyarief B 2017 Thesis (Depok: Universitas Indonesia)
[3] Nizar M, Munir E, Irvan and Waller V 2018 The integrating of zero waste principles from national to local regulations: Case study of Banda Aceh, Indonesia IOP Conf. Ser: Earth and Environ. Sci. 216 012043
[4] Nizar M, Munir E, Munawar E and Irvan 2018 Implementation of zero waste concept in waste management of Banda Aceh City ) IOP Conf. Ser: Journal of Physics 1116 052045
[5] Dinas Kebersihan dan Pertamanan Kota Medan 2013 Kajian Model Pengelolaan Sampah dan SDM Kebersihan Di Kota Medan (Medan: Pemerintah Kota Medan)
[6] Safirzal 2014 Thesis Universitas Islam Nahdlatul Ulama
[7] Purba N 2016 Final Project (Medan: Universitas Sumatera Utara)
[8] Sari AJ 2012 *Final Project* (Depok: Universitas Indonesia)
[9] Republik Indonesia 2015 *Regulation of Ministry of Energy and Mineral Resources Nr. 44/2015* (Jakarta: Sekretariat Negara)