Techno-Economic Analysis of Municipal Solid Waste Gasification System for Electric Generation, Case Study: City at Central Java

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Abstract. Municipal Solid Waste (MSW) management is a problem in Indonesia because of the rapidly increasing volume and limited land. The Waste to Energy (WTE) concept is a concept that will be carried out for municipal solid waste management where the solid waste will be managed into electrical energy and reduce the volume of solid waste significantly by building a Gasification – engine system, one of which in Surakarta Central Java. MSW management infrastructure in one of the infrastructures that can be cooperated with the scheme of Public Private Partnership (PPP) in the form of investment project with a 20-years concession period and the BOOT (Build, Own, Operate, and Transfer) method. Downdraft Fixed bed gasification from Ankur scientific Energy Technologies Pvt, Ltd used for electric generation. Around 300 tons/day new municipal solid waste and 700 tons/day old waste as fuel resources. Potential power generating capacity of 8 MW (Gross) with an investment cost of Rp. 367.622.450.000. Techno economic analysis used the Capital Budgeting method. Result calculations obtained NPV is positive, IRR on project of 14.5%. Operation of MSW gasification system can reduce CH₄ emission with equivalent 85.126,86 tCO₂/year.

1. Introduction
On 2020, Indonesia has recorded a total population of 270 million people, it is directly proportional to the production of waste every day. According to the data from the Indonesia’s Ministry of Environment and Forestry. They stated that currently Indonesia produced at least 67.8 million tons of waste annually [1]. The current condition of waste management still follows the old paradigm, that is to mention by moving waste from the source to the final Processing Site. Urban waste management becomes very difficult considering the decreasing number of lands as a final processing site.

Based on Law no. 18/2008, the responsibility for waste management rests with the government and local governments [2]. The challenge in waste management at the district/city level is the existing fiscal capacity and human resources. The waste management budget of each local government is charged to the state budget, which is very small, when compared to the local government's responsibilities in waste management, such as maintenance and repair of waste management facilities including transportation equipment as well as increasing human resources. The lack of a waste management budget has forced the local government to implement it by considering two targets by reducing the amount of waste in the final processing site and getting income from waste management as a solution. Currently, the Government is paying attention to the use of waste as an energy source through the use of certain
The waste produced by the community can be one of the energy sources that can be used for development. Revenue from waste management is a challenge for local governments because it takes into account the capacity of human, technological and financial resources. Local governments can involve the private sector in revenue generation and waste management. Public Private Partnership (PPP), which known as Regional Government and Business Entity Cooperation is a financing model developed for cooperation between the government and business entities in the provision of Infrastructure for the public interest by referring to the specifications that have been previously determined by the Minister/Head of Institution/Head of Region/State Owned Enterprise/Business Entity Regional Owned, which partially or wholly uses the resources of the Business Entity by taking into account the risk sharing between the parties [3]. Based on presidential decree, No. 38 of 2015 the construction of Waste to Energy (WTE) infrastructure can be carried out by means of PPP ways.

The development of WTE technology that has been very proven and widely used is the Incinerator, statistically the number that has been used in Europe is 455 plants in 2012 [4]. Moreover, in China, there was an increase from 54 plants in 2004 to 188 plants in 2014 [5]. The evolution of modern Incinerator technology is getting better at handling environmental impacts, but public protests are still worried about the health risks due to dioxin/Furan gases that arise during combustion [6].

The future is developing in a big enough direction to use WTE options based on Gasification and Pyrolysis. WTE-based on gasification/pyrolysis refers to a thermochemical process to decompose municipal solid waste into combustible gas (syngas), then syngas is connected to an Internal combustion generator engine to become a generating system [7]. Compared to combustion incinerator, burning into syngas is more environmentally friendly and efficient[8].

Surakarta city as a part of the government's program planning in waste processing using WTE in 12 cities (Presidential Decree, 2018), the local government of Surakarta utilizes PPP facilities in the development of the WTE Power Plant at Putri Cempo final processing site. Putri Cempo final processing site is located in Jatirejo, Mojosongo, Jebres District, about five (5) kilometers from the center of Surakarta. The area of Putri Cempo final processing site is about 17 hectares with the distribution of land allocation as follows:

(i) Fourteen (14) Ha as a dump site;
(ii) One (1) hectare as a place for waste processing, and
(iii) Two (2) hectares of road, warehouse and office infrastructure.

Waste management at the Putri Cempo final processing site still uses the simplest method by direct open dumping. Waste is simply thrown away, placed and levelled, and so on and left to pile up until one day the final processing site can no longer accommodate the waste. The volume of waste that enters the final processing site is strongly impacted by the seasons. In the dry season the average volume of incoming waste reaches 250 tons/day, while in the rainy season or holidays it reaches around 300 tons/day, with the largest contributor is household waste [9]. Utilization of municipal solid waste as a source of fuel for power plants by using a gasification system and gas engine to achieve economy, energy sustainability and environmental friendliness, so that the problem of how the economics of investing in the implementation of the Gasification system in WTE Power Plant is formulated.

2. Methodology
2.1. Investment in PPP Projects
Generally, investment can be interpreted as all forms of activities to invest funds both by individuals and companies to obtain income and increase from investments that have been made [10]. PPP is an activity that often occurs in Indonesia. Chosen to conduct a PPP because of the difference in investment or funding gap that occurs due to limited costs for infrastructure development. To avoid the funding gap, a PPP scheme was formed.
Public Private Partnership (PPP) does not have an official definition, but it can be concluded that PPP is a form of agreement between the Public sector or the Government and the Private sector to provide public service facilities that are bound by an agreement and are divided into several forms, depending on the contract and risk sharing. Part or all of the cooperation uses the resources of the business entity by taking into account the risks of various parties and referring to the specifications that have been set by Regional and State Owned Enterprise/regional institutions/regional heads/previous ministers [11].

2.2. Investment Feasibility Analysis with Capital Budgeting

Capital Budgeting is a concept that refers to the whole process of collecting, evaluating, selecting, and determining investment alternatives that will provide income for the company for a period of more than a year [12].

Investment appraisal using capital budgeting is based on the relevant increase in cash inflow and cash outflow from a new project.

Some common methods in capital budgeting used to determine the feasibility of an investment proposal, comprises: Net Present Value (NPV), Weighted Average Cost of Capital (WACC), Internal rate of return, Payback period. This can be formulated as follows:

\[ WACC = \frac{D}{D+E} K_d (1 - t) + \frac{E}{D+E} K_e \] (2.1)

Whereas:
- \( D \) = amount of interest-bearing loan used (debt)
- \( E \) = own capital (equity)
- \( K_d \) = cost of debt (interest rate on debt in project financing)
- \( K_e \) = cost of equity (desired rate of return on stock investment)
- \( t \) = tax rate

\[ NPV = \sum_{t=1}^{n} \frac{CF_t}{(1+k)^t} \pm CF_0, \] (2.2)

\( CF_t = (Cash \ Flow) \) annual after-tax cash flow in period \( t \) (value can be positive or negative)

\( k = \) Appropriate discount rate, i.e. required rate of return or cost of capital

\( CF_0 = \) Initial cash disbursement for project investment

\( n = \) Expected project age

The internal rate of return is defined as the discount rate or interest rate that equates the present value of the project’s expected cash flows with the initial outlay of the project (NPV = 0). Mathematically the internal rate of return is defined in the following equation:

\[ 0 = \sum_{t=1}^{n} \frac{CF_t}{(1+k)^t} - CF_0, \] (2.3)

The decision criteria using the Internal Rate of Return (IRR) can be stated as follows:
- IRR Required rate of return: Accept
- IRR < required rate of return: Reject

\[ \text{Payback Period} = \frac{\text{Investment Value}}{\text{Cash inflow}} \] (2.4)

2.3. WTE Power Plant Surakarta Scheme

MSW is a raw material for making gas by means of gasification, which will then be used as fuel for power plant engines which are expected to support efficient and reliable power plant operations for the long term in the base load operating pattern for local 20 kV State Electricity Enterprise distribution system.

The initial processing of municipal solid waste raw materials with new waste of 300 tons/day and old
waste of 700 tons/day into feedstock, must be able to meet the requirements of the type of gasification reactor to be used, both in terms of calorific value as well as physical and chemical properties of products processed.

WTE Power Plant Surakarta with a capacity of 5 MW (Net) will be designed to be able to meet continuous operating conditions with an electricity capacity factor that is expected to reach 90% in a year, and taking into account the surrounding environmental conditions.

To be able to achieve this goal, the main equipment in the WTE Power Plant must be reliable and with due regard to the technical aspects of the generating system. The main equipment that must be considered is the technology of generating equipment, interconnection and cooling systems as well as safety equipment.

The gas engine that will be used to burn Low BTU syngas fuel must be adjusted to the syngas characteristics, for example the compression ratio and ignition timing.

The following picture shows the scheme of the gasification process from ANKUR Scientific Ltd, from handling syngas to its utilization to generate electricity:

![Figure 1. WTE Power Plant Surakarta Scheme](image)

Characteristics of the Type 400 GFT-J gas engine when using syngas at a loading pattern of 100% ISO conditions:

- Electrical output : 400 kW
- Input energy : 1.096 kW
- Electrical Efficiency : 36.5%
- Heat energy that can be utilized : 477 kW
- Brake Mean Effective Pressure : 8.7 bar
- Compression Ratio : 11 : 1

Exhaust gas produced by the gas engine will be used as an energy source to heat the air which will then be used as an energy source for drying MSW through a rotary dryer.

3. Research Result
3.1. Cost Analysis

Power plant construction costs, Engineering, Procurement, Construction (EPC) costs are usually assumed to be a "lump sum price", including:

i. Equipment price escalation until the Commercial Operation Date (COD) is reached

ii. Having considered the provisions/regulations on the Domestic Component Level (TKDN)

EPC costs include VAT, with a Net installed capacity of 5 MW and Gross 8 MW. EPC costs have the largest portion of the Total Project Cost. EPC cost estimation is made based on the standard scope of WTE Power Plant which consists of a gas engine with a capacity of 8 MW Gross, gasification reactor and its supporting equipment including civil, mechanical, electrical works.
EPC cost estimates were also developed by considering the specific scope of the land location such as the 20 kV Medium Voltage Network (JTM) as far as 6.32 km from the generator to the 20 kV Palur Substation.

Project development costs include the costs of works and services that support project development before construction begins. Initial Working Capital (IWC) is all costs incurred in the initial stages of the project. Financial costs are part of the soft costs or costs to fund Investment Costs and interest during construction (IDC) on loans will be added and capitalized into loans. The total loan amount is calculated based on Total EPC Fee, Development Cost, IWC, Funding Cost and IDC. The total investment costs are shown in Table 1.

Table 1. Total Cost of Surakarta WTE Power Plant Development

| No | DESCRIPTION | ESTIMATED COST (USD) |
|----|-------------|----------------------|
| 1  | EPC Power Plant and JTM 20 kV Cost | 21,561,164 |
|    | Sub Total (Including 10% VAT) | 23,717,280 |
| 2  | Non-EPC Fee | |
|    | 1) Development Cost | 444,640 |
|    | 2) Interest Working Capital (IWC) | 100,000 |
|    | 3) Interest During Construction (IDC) & Funding Fee | 1,180,000 |
|    | Sub Total (Including VAT) | 1,724,640 |
|    | Total Project Cost (Including 10% VAT) | 25,441,920 |

Operation and Maintenance (O&M) costs for a power plant vary depending on the type and characteristics of the plant. For the purposes of this research, the estimated fixed and variable O&M costs are as shown in Table 2.

Table 2. Operation and maintenance Cost

| No | Item | Year | 0   | 1   | Increase 2 forward |
|----|------|------|-----|-----|--------------------|
| 1  | Operation Cost | 0,0% | 0,0% | 4,0% |
| 2  | Maintenance of Gasifier Plant 3% of Mech, Elec &Vech cost with 5% increase onward | 0,0% | 0,0% | 2,0% | 5,0% |
| 3  | Maintenance of machineries & Vehicle 1% of cost with 1.5% increase onward | 0% | 0% | 0% | 1,0% | 1,5% |
| 4  | Repairs of construction: 0.5% of cost with 1% increase onward | 0,0% | 0,0% | 0,5% | 0,5% | 1,0% |
| 5  | Other repairs : Lump Sum | 0,0% | 0,0% | 50,000 | 50,000 |

Table 3. Economic Assumption

| Economic Assumption | Description | Unit | Score | Information |
|---------------------|-------------|------|-------|-------------|
| USD to IDR | 14,450 |
| Equity | 30% |
| Debt | 70% |
| Interest Rate (per Year)/Interest rate (pa) | 7% |
| Grace Period (year, interest only) | 2 |
| Tenor (year) | 10 |
| Depreciation & Amortization | Per year |
| Corporate Income Tax | 25% |
| Growth Rate | Income Revenue | Per year | 0% |
| Operational Expenditures | Per year | 4% |
| Weighted Average Cost of Capital (WACC) | 6.96% |
| Electricity Price | 13,35 Cents USD/kWh | Presidential decree 15 of 2018 |

From the costs mentioned above, a financial analysis was carried out using the following assumptions on Table 3. From the calculation with a capacity factor of 90% obtained the value:
IRR = 14.5%
NPV = 14,078,390 USD
Payback Period : 7 Years
3.2. Greenhouse Gas Control Analysis
In the Surakarta Greenhouse Gas emission inventory, the waste management process will be divided into 2 main activities (based on data availability), comprises: solid waste final disposal site, and domestic waste processing sanitation. The following is a general review of the emission load overall calculation result for waste management, that are to mention methane and nitrogen dioxide. Methane emissions from waste management in Surakarta reached 6,900.24 tons/year and nitrogen dioxide emissions reached 15.90 tons/year. The biggest contributor to methane emissions from waste management is the Putri Cempo Final processing site of 4,053.66 tons/year is equivalent to CO2 of 85.126,86 tons/year.

4. Conclusion
By using raw materials for new city solid waste of 300 tons/day and old waste of 700 tons/day, 8 MWe (Gross) of electrical energy can be obtained. With an investment of 25,441,920 USD, a Positive NPV and IRR 14.5% are obtained, greater than the company’s WACC of 6.96% so it is feasible to implement.

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