# The Integration of Gasification Systems with Gas Engine by Developing Wet Tar Scrubbers and Gas Filter to Produce Electrical Energy from Biomass

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**Abstract.** The need for energy especially biomass-based renewable energy continues to increase in Indonesia. The objective of this research was to design downdraft gasifier machine with high content of combustible gas on gas engine. Downdraft gasifier machine was adjusted with the synthetic gas produced from biomass. Besides that, the net energy ratio, net energy balance, renewable index, economic analysis and impact assessment also been conducted. Gas engine that was designed in this research had been installed with capacity of 25 kW with diameter and height of reactorwere 900 mm and 1 000 mm respectively. The method used here werethe design the Detailed Engineering Design, assembly, and performance test of gas engine. The result showed that gas engine for biomass can be operated for 8 h with performance engine of 84 % and capacity of 25 kW. Net energy balance, net energy ratio, and renewable index was 30 MJ/kW h electric; 0.89; 0.76 respectively. The value of GHG emission of Biomass Power Generation is 0.03 kg-$CO_2$ eq per MJ. Electrical production cost for Biomass Power Generation is about IDR 1 500 per kW h which is cheaper than solar power generation which is about of IDR 3 300 per kW h.

**Key words:** Biomass power plant, renewable energy, wet tar scrubber.

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# 1 Introduction

In 2015, Indonesia set a target to realize 23 % of primary energy supply from modern renewable energy by 2025 [1]. Indonesia is the largest country in ASEAN, so the need for energy continues to increase. The role of renewable energy is needed to meet the growth of energy demand. There is a large difference in the ratio of electrification throughout Indonesia, where for Papua the electricity ratio is less than 40 % while in the Jakarta is close to 100 %. The Indonesian state electricity company PT PLN (Persero) is seeking to increase the electricity ratio by 98 % in 2022 [2]. The ratio of electricity in Indonesia is only around 80 % on a national scale. For several regions lagging the ratio of the electricity is still 60 %, as in the area which isolated from electricity network system PT.PLN (Persero). At this region, electricity only life at night. One solution that can be done is use renewable energy sources [3].

The government has committed to realize 35 000 MW of electricity supply within 5 yr (2014 to 2019). The contribution of new and renewable energy-based power plants is still quite low, i.e. 9.9 % Hydropower (PLTA), Geothermal Power Plant (PLTP) of 2.6 % and other renewable energy (EBT) below 0.5 %. The process of gasification consists of four stages of the process based on the difference of temperature range, which are drying (T > 150 °C), pyrolysis (150 °C < T < 700 °C), oxidation (700 °C < T < 1 500 °C), and the reduction (800 °C < T < 1 000 °C) [4, 5]. The results of this system produce combustible gases (CO, $H_2$, $CH_4$, etc). Gasification technology is suitablefor the area which has large quantities of biomass, which currently have not been yet traversed by electrical network system such as PT.PLN (Persero) and private companies. In this area the price of diesel fuel is very expensive with price is about IDR 50 000 per liter. This condition caused the price of electrical energy per hours would be very expensive for all of them e.g. in the Island of Papua.

The gasification is designed to produce combustible gas (CO, $H_2$, $CH_4$) [4–9]. These combustible gas are produced to replace fossil fuel as engine fuel to generate electricity. However, the properties and characteristics of these combustible gas should meet the characteristic of the engine as every engine has its own specific characteristic. Some engines are designed working more properly with methane gas ($CH_4$) but some work more properly with carbon monoxide gas (CO) [10]. Biomass Power Generation (BPG) designed in this research adjusted with combustible gas produced that is CO and $H_2$. Therefore the objective was to design biomass gasification system that suits the dominant gas produced from biomass. High level of tar contained in produced combustible gas contaminates the engine filter rapidly. Therefore, the machine cannot be operated at a longer time. The objectives of this research is to design gasification system with high content of combustible gases (CO, $H_2$, $CH_4$, etc). The gasification system will be connected to gas engineto produce electrical energy from biomass. Besides that, the net energy ratio, net energy balance, renewable index, economic analysis, and impact assessment also been conducted.

# 2 Method

## 2..1 Tools and materials research

The biomass power generation (BPG) consists of biomass tank, reactor, cyclone, tar wet scrubber, gas filter and gas engine. Gasification engine was made using downdraft type in order to produce fewer tar values. The specifications of materials, materials and gasification machine capacity produced are shown in Table 1.

**Table 1**. Specification gasification engine/Biomass power plant

| No | Description | Technical specifications | Quantity |
|---|---|---|---|
| 1 | Gasification type | *Downdraft* gasifier | 1 set |
| 2 | *Carbon steel of* tube reactor | OD (3.81 to 5.08) m × 0.001 m thickness | 1 pcs |
| 3 | *Engine* | 25 kW | 1 pcs |
| 4 | *Blower* | Daya ¼ - ½ HP | 1 pcs |
| 5 | *H-Beam* | Steel, (0.508 to 1.016) m | 20 m |
| 6 | *Steel plat* | 0.05 m width x 0.005 m thickness | 20 m |
| 7 | *Pipe from carbon steel* | OD (0.254 to 0.508) m, 0.001 m thickness | 30 m |
| 8 | Power cable | Merk ETERNA | 50 m |
| 9 | Temperature indicator | Merk SIKA | 6 pcs |
| 10 | *Pressure indicator* | Merk SIKA | 4 pcs |
| 11 | *Control panel* | ASTM Standard | 1 set |
| 12 | Portable temperature | Thermometer laser and digital | 1 pcs |
| 14 | Heast resistant hoses | Material tahanpanas, ±100 °C | 5 m |

## 2.2 Research method

### *2.2.1 Analysis of synthetic gases*

The method used in this research was to analyze the gases produced from the downdraft gasifier system which was designed and made. The biomass utilized in this research was wood. Wood was fed on the top of downdraft gasifier and then enters biomass storage in gasifier. The biomass would enter pyrolysis phase about 200 °C to 700 °C, and then combustion and reduction phase about 1 000 °C to 1 400 °C. The gases produced passed the wet tar scrubber and gas filter to ensure the tar limit meet the requirement and clean gases was used to run the gas engine. Engine performance was measured by test the effectiveness power produced for specific time given.

### *2.2.2 Analysis of energy, econonmy, and life cycle assessment*

The important parameter regarding analysis of energy is Net Energy Ratio (NER), Net Energy Balance (NEB), and Renewable Index (RI). It can be stated as formula as below:

$$NER = \frac{E_o}{E_i} \tag{1}$$

$$NEB = E_o - E_{pr} \tag{2}$$

$$RI = \frac{E_{rn}}{E_{pr}} \leq 1 \tag{3}$$

The determination of the value of Input Energy ($E_i$), Process Energy ($E_{pr}$), Renewable Energy ($E_{rn}$), Output Energy ($E_o$) are shown onequations 4, 5, 6 and 7.

$$E_i = E_{bm} \tag{4}$$

$$E_{rn} = E_{bm} \tag{5}$$

$$E_{pr} = E_f + E_{bm} + E_{el} \tag{6}$$

$$E_o = E_{ge} \tag{7}$$

Where $E_i$ is input energy of biomass ($E_{bm}$); $E_{rn}$ is renewable energy of biomass ($E_{bm}$); $E_{pr}$ is process energy which is the sum of fossil energy ($E_f$), biomass energy ($E_{bm}$), and electrical energy ($E_{el}$), while $E_o$ is output energy of electric power generated by gas engine ($E_{ge}$). Impact Assessment was measured by using Life Cycle Assessment (LCA) method which is described below:

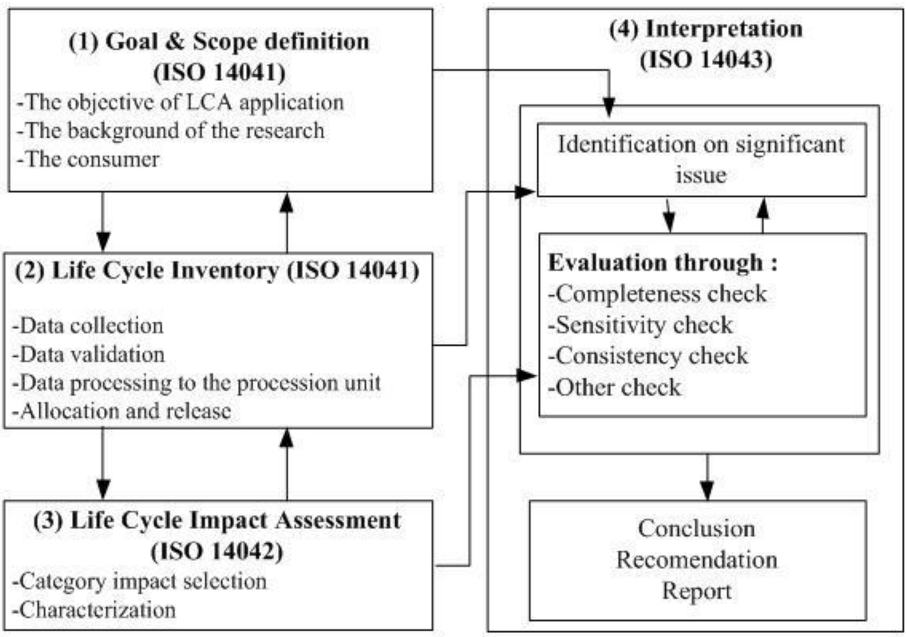



**Fig. 1.** Impact assessment by Life Cycle Assessment (LCA) method [11, 12]

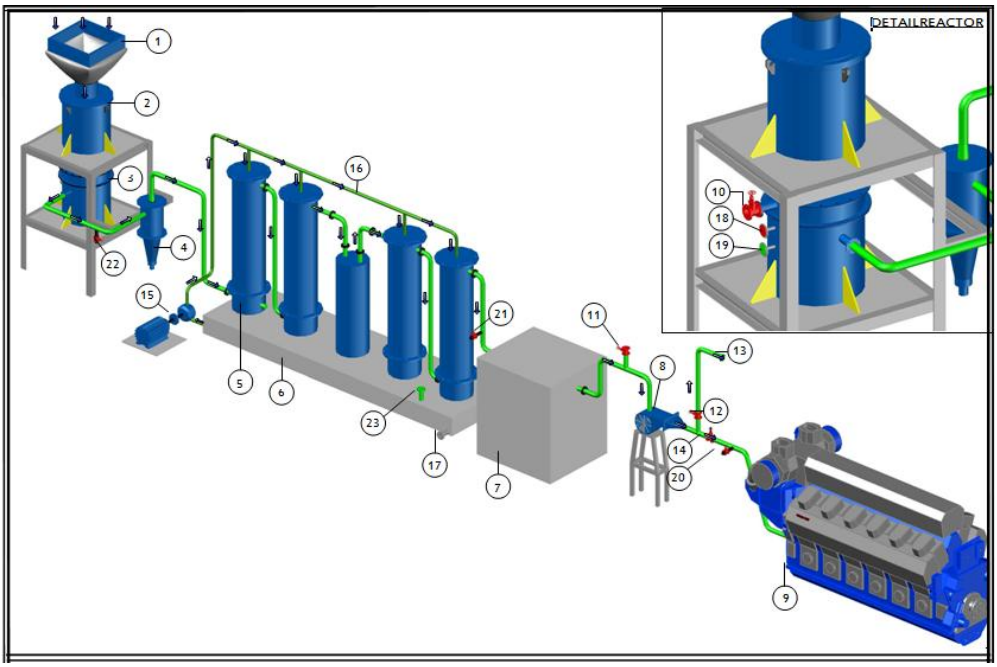
To estimate the economic feasibility, the parameter used is to compare electrical production cost frorm Biomass Power Generation and Diesel Power Generation in IDR per kW h unit.

## 3 Result

### 3.1 Biomass power generation

The biomass power plant produced has been connected to the gas engine which in its series already uses tar wet scrubber and gas filter. Overall the biomass power generation engine consists of tanks of biomass, reactor, cooler, cyclone, tar wet scrubber, gas filter, blower, and valve system control. The series of BPG engines generated in this study are shown in Figure 2. This gasification technology was aimed to produce combustible gas (CO, $H_2$, $CH_4$). This combustible gas is used to replace fossil fuel as an engine fuel used to generate electricity. The biomass fuel used in the research is wood. With relatively uniform shape and size, congestion can be avoided [5], so in this study,woodchopper was also used as a cutting tool that can produce uniformity of biomass sizes.

The type of downdraft gasifier designed in this study is a fixed bed downdraft gasifier with a direction of air flow from the bottom up as shown in Figure 3a and Figure 3b. The advantages of this type of downdraft are it is not too sensitive to tar and can easily adapt to the amount of biomass feed. Another advantage was that it appears to be cleaner because the tar and oil will burn. This is reinforced by the tar data generated from the various types of gasifiers produced as shown in Table 2.




Remarks : (1)Hopper input for biomass, (2)Biomass tank, (3)Reactor, (4)Cyclon, (5)Wet tar scrubber, (6)Water tank, (7)Gas filter, (8)Blower, (9)Gas engine, (10)Air inlet nozzle (Valve 1), (11)Valve 2, (12)Valve 3, (13)Exhaust gas, (14)Valve 4, (15)Circulating water pump, (16)Nozzle spray, (17)Nozzle drain, (18)Pressure gauge, (19)Thermometer gauge, (20)Sample gas nozzle 3, (21)Sample gas nozzle 2, (22)Sample gas nozzle 1, (23)Nozzle filling water

**Fig. 2.** A system gasification type downdraft and gas engine capacity of 25 kW.

**Table 2**. Tar content resulting from various types of gasification produced [7].

| Type of gasification | The average fuel gas concentrations in the tar is produced (g $Nm^{-3}$) | Tar percentage of biomass used |
|---|---|---|
| Downdraft | < 1 | < 2 |
| Fluidized bed | 10 | 1 to 5 |
| Updraft | 50 | 10 to 20 |
| Entrained flow | ignored | |

**Fig. 3a.** Gasifier type downdraft designed and used in this research.

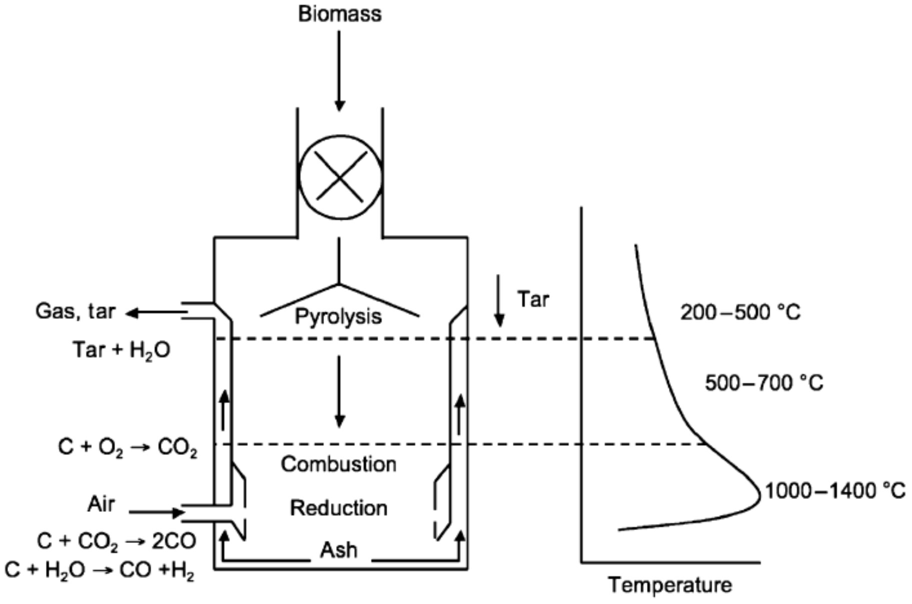



**Fig. 3b.** Commonly phase on Gasifier type downdraft [4].

### 3.2 Design and main components of biomass power generation with capacity of 25 kW

The gasifier used in this study has a total dimension of 1 340 mm diameter and a height of 2 455 mm as shown in Figure 3 above. Cyclon has a length of 580 mm, a width of 426 mm with a height of 1 766 mm. Gas filter has a length of 700 mm, a height of 700 mm and a width of 700 mm. Tar wet scrubber consists of five tubes (300 mm tube diameter) which are strung together with the aim of capturing the tar still contained in the combustible gas produced from the gasification reactor. Gasification reactor itself has total dimensions of 1 750 mm width and 1 300 mm height. The design has considered resident time of biomass in gasifier reactor in order to produce synthetic gas optimally. The comparison of height to diameter of 1.8 has been chosen. Overall this series of Biomass Power Plant with Engines is shown in Figures 4 and Figure 5.


**Fig. 4.** Biomass power generation with capacity of 25 kW.

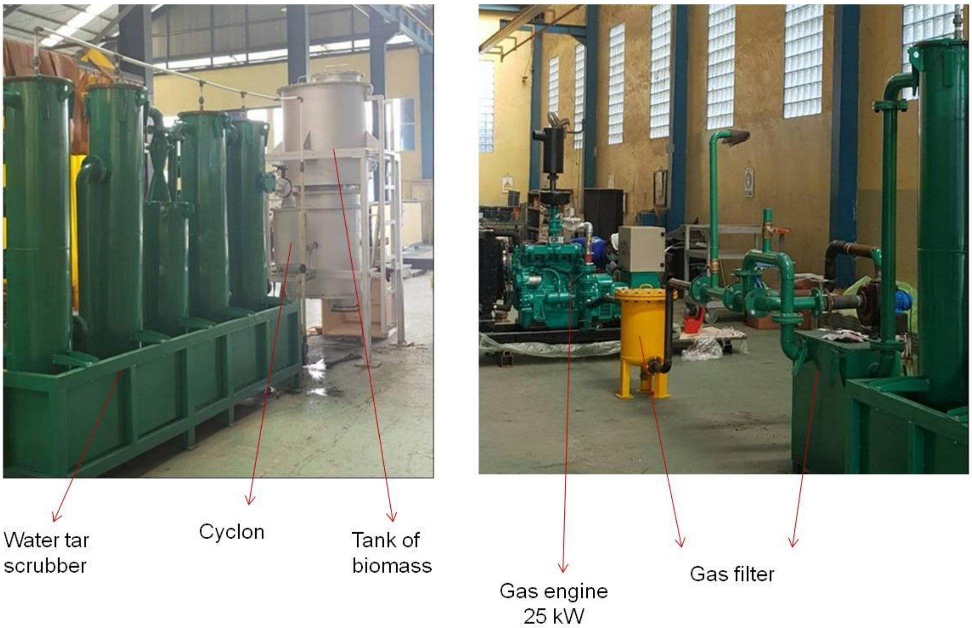



**Fig. 5.** Biomass power generation with capacity of 25 kW.

### 3.3 Engine performance test

To ensure the composition of the fuel gas content, the laboratory testing was carried out and the results is shown on Table 3. Laboratory test result that the gases produced contained combustible gas those are CO and $H_2$ in sufficient concentration. In case of biogas in which dominant gas was $CH_4$, then the gas engine designed is which is suitable for $CH_4$.

**Table 3**. The average composition of the combustible gases.

| No | Component name | Concentration (% vol) | Normalization 100 % |
|---|---|---|---|
| 1 | Hydrogen ($H_2$) | 11.22 | 11.43 |
| 2 | Nitrogen ($N_2$) | 48.23 | 51.45 |
| 3 | Carbon monoxide (CO) | 23.16 | 24.86 |
| 4 | Methane ($CH_4$) | 1.72 | 1.85 |
| 5 | Carbon dioxide ($CO_2$) | 10.26 | 11.02 |

The gas engine with capacity of 25 kW was operated in specified operating condition and run for 8 h. The result was that gas engine from biomass-based gas (synthetic gas) can give power with effectiveness of 84 %. The net energy ratio obtained in this research was 0.89. This value less than 1 because much of energy losses into the environment because the material of reactor body and gas piping have not been coated with insulators.

The renewable index (RI) on this research was 0.76 which is close to 1. The closer the value to 1 the better the renewable index is. This value assumed that the use of unrenewable fuel on this research was very little. The use of diesel/kerosene is only on the starting point, so are the electricity on blower as the initial trigger to pull the combustible gas from the reactor. Net energy balance on this research was 30 MJ/kW h of electric.

### 3.4 Economic feasibility

Economic feasibility studies has been conducted. The assumption used was the average price of biomass about IDR 700 per kg and the rate of biomass use on electricity production about (1.4 to 2) kg (kW h)$^{-1}$ of electrical. Therefore, the cost of electricity producedabout IDR 1 650 per kW h. This cost is cheaper than electrical production cost from Diesel Power Generation which is about IDR 3 300 per kW h.

### 3.5 Analysis of impact assessment

The calculation of greenhouse gas emission (ERK) was approached using Life Cycle Life Assessment Method ISO 14040. The GHG emission value for biomass power plant is 0.04 kg $CO_2$ eq per MJ, and the diesel power plant engine is 0.111 kg-$CO_2$ eq per MJ or in the other words the PLTBm GHG emission value was almost three times lower than the Diesel Power Plant. Siregar et al. [13] states that the production of biodiesel in catalyst can reduce global warming emissions 37,83 % compared to fuel oil (diesel). In the national arena this activity will support the government target to reach renewable energy mix up to 23 % by 2025. This activity is also in line with the achievement of 35 000 MW electricity production until 2019.

## 4 Conclusion

The conclusion of this research was that the Biomass Power Generation with capacity of 25 kW has already been designed and operated with performance test of 84 % from installed capacity. It resulted net energy balance, net energy ratio, and renewable index was 30 MJ/kW h of electric; 0.89; 0.76 respectively. The value of GHG emission of Biomass Power Generation is 0.03 kg-$CO_2$eq per MJ.Electrical production cost for Biomass Power Generation is about IDR 1 500 per kW h, whereas electrical production cost for Solar Power Generation is about IDR 3 300 per kW h.

The authors say thank you to KEMRISTEKDIKTI for its support under joint research INSINAS RISET PRATAMA KEMITRAAN 2017, No. 136/UN11.2/PP/SP3/2017.

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