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Advantages and Design Considerations of Biomass Gasifier Chp Systems and the Mass and Energy Balance of the Enerfab Tm -Wbg 7.5© System

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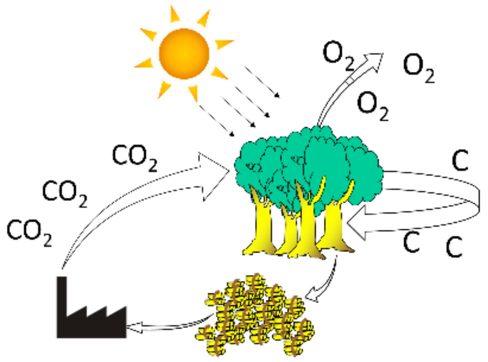
Abstract

This paper presents special design considerations, used in the Enerfab ™ gasification systems, mass and energy balance of the Enerfab ™ -WBG 7.5© system, and the benefits of biomass gasification systems to produce clean electrical and thermal Energy. The combined heat and power system presented in this paper was designed by the author to deliver clean energy using woody biomass as fuel. The design methodology has adapted essential safety, hazard mitigation and emission standards outlined in the "Handbook for small biomass gasification CHP in Canada" published by the National Research Council Canada. The gasification system is designed and manufactured by Enerfab Green Engineering (Pvt) Ltd. Sri Lanka, together with Enerfab Green Energy inc. Canada. The average capacity of the system is designed to deliver 7.5kW of electric power output with a thermal output of 11 kW. All calculations for energy and mass balance are carried out for the maximum design capacity (11.74 $kW_{e,}$ & 18.38 kW_{th}). The design methodology is used for systems up to 1.5 MW electrical power output. Larger systems can be used as an array of 1.5 MW systems in large scale grid-connected biomass power-plant.

Introduction

Biomass is considered a renewable and carbon-neutral energy source ([1]; [5]; [9]; [10] and Veziroğlu, 2008; [13]; [15]). Figure 1 illustrates the carbon cycle for biomass energy [3]. Efficient technologies to harvest biomass energy in a more meaningful manner has become important owing to depleting fossil fuel reservoirs and challenges with high greenhouse gasses in the atmosphere. Short rotation coppicing, the use of agricultural and industrial residue are the most reliable methods of extracting biomass as a fuel in a sustainable manner ([7]; [9]; [15]).

Figure 1: Carbon Cycle for Biomass Energy



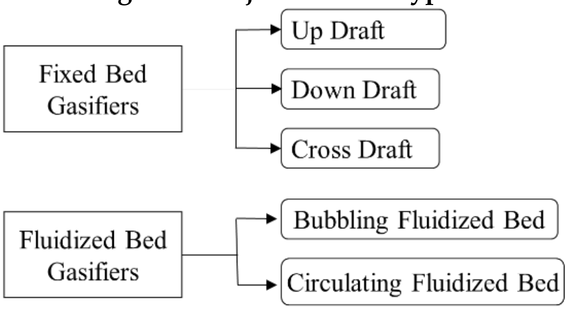
A gasifier converts solid fuel into gaseous fuel. The conversion of woody biomass to a state that is easily controlled, enables solid biomass to be used in more applications. A gasifier is similar to an oil refinery which converts crude oil into more user-friendly forms. A proper gasifier design enables the conversion of the majority of carbon and hydrogen present in the biomass as well as the moisture content of biomass combustible gasses.

Enerfab Green Engineering Private Ltd (EFGE) is a company designing, manufacturing and operating gasification systems in Sri Lanka ([6], ; [11]. The design in this document is a result of incremental design improvements of over 15 years of field experience of gasification systems, designed, built and operated by EFGE in Sri Lanka together with combustion research carried out by the author. The systems provide both thermal and electrical energy to a variety of industries. Gasification systems from 7kW up to 2MW thermal output have been operating safely from the year 2006 to date to deliver both thermal and electrical energy.

The Design of Enerfab Wbg 7.5 Gasification System

Gasification is a thermochemical process. Heat energy is used to convert solid biomass to a combustible gas mixture in a gasifier [3]. The heat for the gasification process is produced by combusting part of the biomass to be gasified or by the use of an external source [12]. There are several configurations of gasifiers discussed in the literature [3]; [12]. Figure 2 shows the major gasifier types. The system described in this paper is a **fixed bed downdraft gasifier**.

Figure 2: Major Gasifier Types

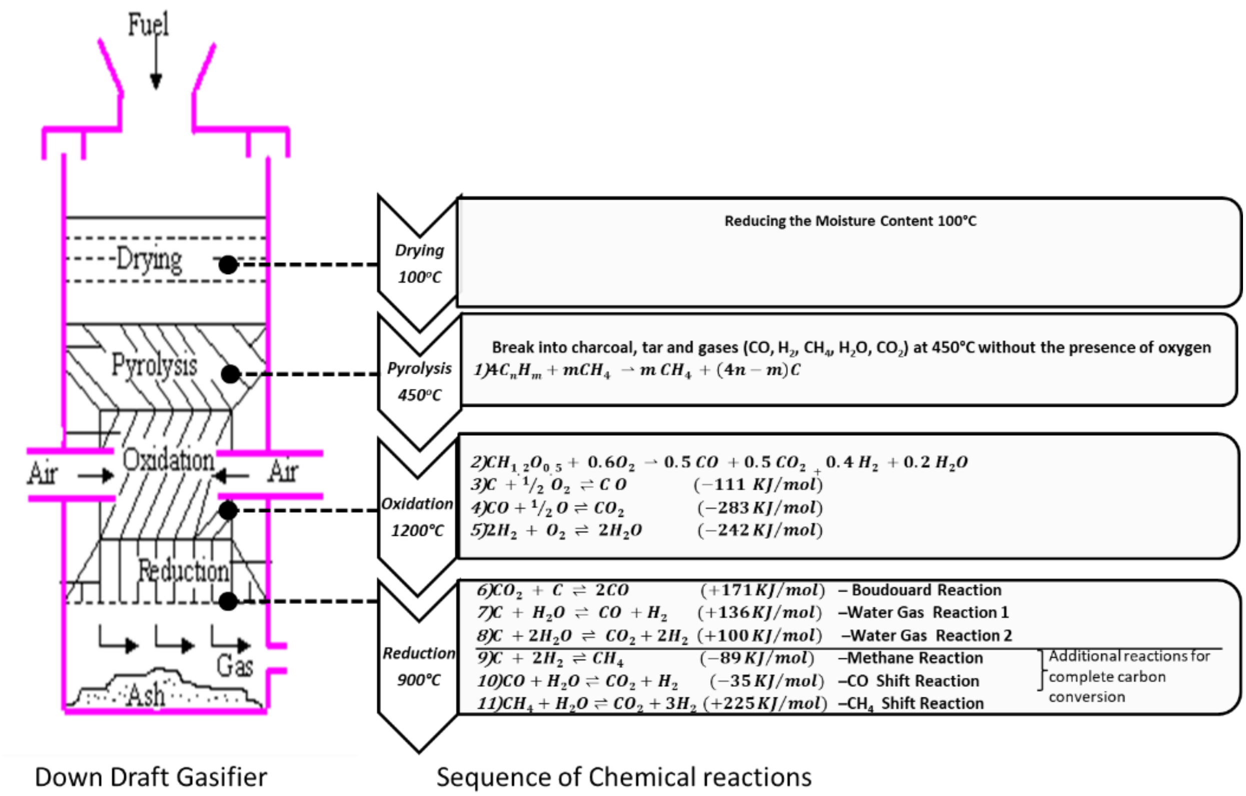


The downdraft gasifier generates less tar in producer gas [12]. Figure 3 shows a schematic of the downdraft gasifier on the left-hand side of the image and the sequence of chemical reactions taking place in each area of the reactor, on the right-hand side.

The oxidation reactions in equations 2, 3, 4 and 5 in Figure 3, provide the energy for the heterogeneous (solid and gaseous phase) endothermic reactions in the reduction zone. For a complete carbon conversion, gaseous phase reactions shown in equations 10 and 11 would be present ([4]; [8]).

Air enters the gasifier directly to the oxidation region where the exothermic reactions take place. Heat from reactions provide the necessary energy for the endothermic reactions downstream of the gasifier and provide the heat for drying the biomass. The producer gas is transported out of the gasifier using a gas blower. Maintaining proper air and fuel flow as well as providing sufficient heat to the endothermic reactions are challenges in a gasifier design. The final goal is to convert the total carbon atoms in the feedstock to CO and to maximise the production of H_2 using the water gas reaction in the reduction zone.

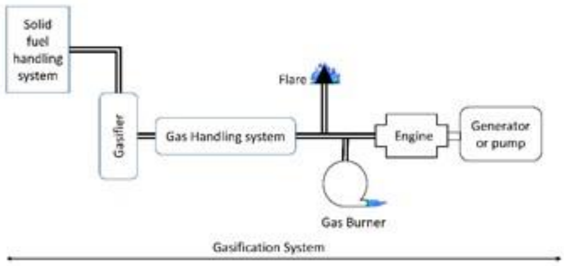
Figure 3: The Downdraft Gasifier and the Sequence of Chemical Reactions



Gasification Systems

Figure 4 is a generic gasification system. A basic system consists of a solid-fuel handling unit, a reactor where the chemical reaction takes place (gasifier), a gas processing system (suitable for the final process), a flare out for testing the flame, and finally, the engine or burner where the producer gas is combusted. Biomass gasification converts 60% to 90% of the available energy in solid biomass to producer gas [4]; [12].

Figure 4: Gasification System to Produce Mechanical or Thermal Energy



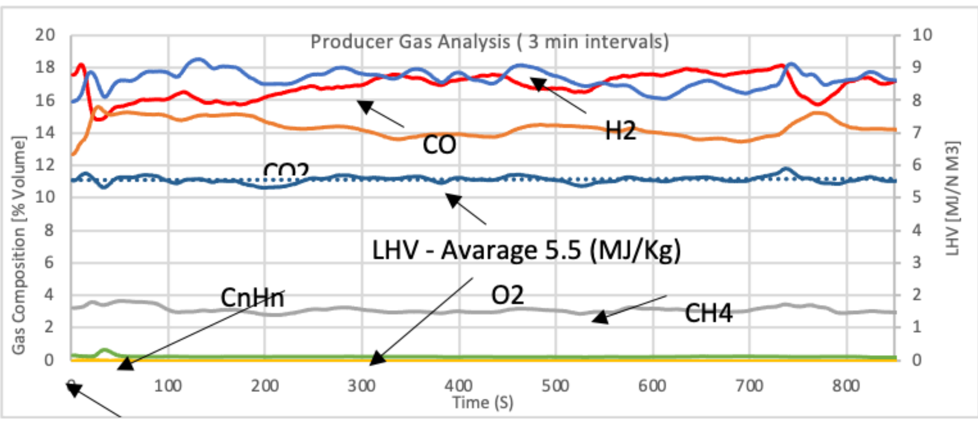
Producer gas consists mainly of CO, H_2, CH_4, CO_2 and N_2 [2]; [3]; [12]. Some typical gas compositions are listed in Table 1. The combustible gasses are CO, H_2 CH_4 and in some cases, traces of other compounds such as C_2H_6 [2]. The lower calorific value of the gas can vary between 4.5 MJ/m^3 to 12 MJ/ m^3 at standard temperature and pressure, depending on the design of the gasifier and the composition of the feedstock.

Table 1: Typical Producer Gas Compositions of Several Gasification Systems

Source	CO	CO_2	H_2	CH_4	C_2H_6	LHV (MJ/Nm^3)
Harboøre [2]	23%	12%	19%	5%	0%	6.72
Güssing [2]	31%	17%	37%	9%	2%	11.89
Viking [2]	20%	15%	30%	1%	0%	6.09
Enerfab([6]	19%	10%	18%	3%	0%	5.87
Biomass Energy Foundation [12]	22%	10%	15%	1%	0%	4.74

Figure 5 depicts a gas analysis where the gas quality was captured every 3 minutes in a gasification system of capacity 200kW$_e$ designed, manufactured and installed Enerfab Green Engineering (Pvt) Ltd. to use wood offcuts in an industry in Sri Lanka.

Figure 5: Composition and LHV Variation of Producer Gas at a Sampling Interval of Three Minutes



The gas composition anticipated in the Enerfab-WBG 7.5 design, will be almost the same compositions as shown in Table 1 for Enerfab gasifiers. The composition taken for calculations is stated in Table 2.

System Design
The design parameters are the following

Maximum Electrical Capacity	11.74 kW
The Efficiency of the engine generator set	35%
Woody biomass moisture	25%
Ambient temperature	25 °C
Ambient pressure	100 kN/m^2
Ambient air relative humidity	20%
The efficiency of all heat exchangers (assumption)	90%

The gasifier system discussed in this paper is designed for the gas quality shown in Figure 5 which is slightly rich in CO and H_2 compositions than the gas quality shown in Figure 5. Preferred woody biomass sizes range from 25mm up to 100 mm in length and 10mm up to 25mm in diameter. The wood pieces are preferred to be a homogenous mix. Air is assumed to be at normal conditions.

Table 2: Average Values of the Composition of Producer Gas and LHV Anticipated from the Gasifier Reactor

Composition	
Component	**Volumetric composition**
CO	19.5%
H_2	18.5%
CH_4	4.0%
CO_2	6%
N_2	52%
Lower Heating Value	
LHV	5.86 MJ/Nm3

The ash-flow rate out of the system is anticipated to be 3% of the biomass feeding rate. The biomass ash can be utilised as a soil amendment agent. [4], p. 60 Chapter 4.4.1)

The exhaust from the internal combustion engine comprises products from combustion taking place between producer gas with the composition in Table 2 and stoichiometric air. However, the engine will be operated using a lean mixture, thus reducing the concentration of combustion products and further lowering the NO_x production.

A lower NO_x production is anticipated due to the relatively lower combustion temperatures in the combustion chamber than a stoichiometric air/fuel mixture. SO_x in the combustion products are a contribution from the fuel supplied to the combustion system. However, clean wood chips used in this system is not a major concern due to lower sulphur levels in biomass. ([4], p. 96 Chapter 7.1.2.2).

The exhaust from the spark-ignition engine will be directed to a three-way catalytic converter to ensure the emission targets required from the system ([4], p. 111 Chapter 7.2.5.1).

USEPA emission standard in Table 3 was followed for the control of exhaust gas.

Table 3: USEPA Emission Standard

Item	**Contaminant**	**Intensity Rate (kg/MW-hr)**
1.	Carbon monoxide	<3.5
2.	Non-methane hydrocarbons	<0.19
3.	Nitrogen oxides	<0.40
4.	Particulate matter	<0.02

Electrical energy is produced by combusting the producer gas to suit the quality requirements of the selected engine. The electrical output specifications are as follows:
- 7.5 kW /9.275 kVA, 50Hz 1500 rpm
- 3phase. 230V/400V at 0.8 Lag
- Protection class IP23.

Usable thermal energy is captured in 3 stages; while conditioning the producer gas, cooling the combustion products and from the circulating engine coolant. The useful thermal energy is captured in a manner that preserves the exergy of the system by minimizing the mixing of flows.

The gasification system up to the engine will be controlled by a programmable logic controller. The engine will be controlled by a smart control module which will come with the engine – generator set.

Gas Tightness of the System and Pressure Relief Valves

The system will have double sluice lock doors for biomass feeding and ash removal from the reactor. The double sluice doors ensure air tightness and most importantly prevent an overdose of oxygen from entering the system. Gasket material and flange selections are made to ensure gas tightness of the system under the exposed temperature and pressure. The system will operate partly below atmospheric pressure and partly at 60 mbar above atmospheric pressure. Gas leakages will be diagnosed by pressurising up to 200 mbar and testing with a soap spray to ensure airtightness.

Pressure relief valves will be fitted for sudden pressure rises in the system over 8 bars. [4], p. 51 Chapter 4.2.3.1). NFPA 68 will be followed to incorporate pressure relief valves in the systems. ([4], p. 51 Chapter 4.2.3.2). The use of welded connections is adapted wherever possible

CO monitors will be fitted in the immediate enclosed surroundings. Ventilator fans will be fitted to flush the system in the event of detecting CO in the enclosed surroundings of the system. The control panel will be maintained at positive pressure to ensure no gas leakages into the control panel in an event of gas leakages near the control cabinet. Adequate fire extinguishers will be provided in the vicinity of the system to be used in an emergency.

System Boundary, System Schematic Diagram and the Mass and Energy Balance

Figure 6: Gasifier CHP System Boundary

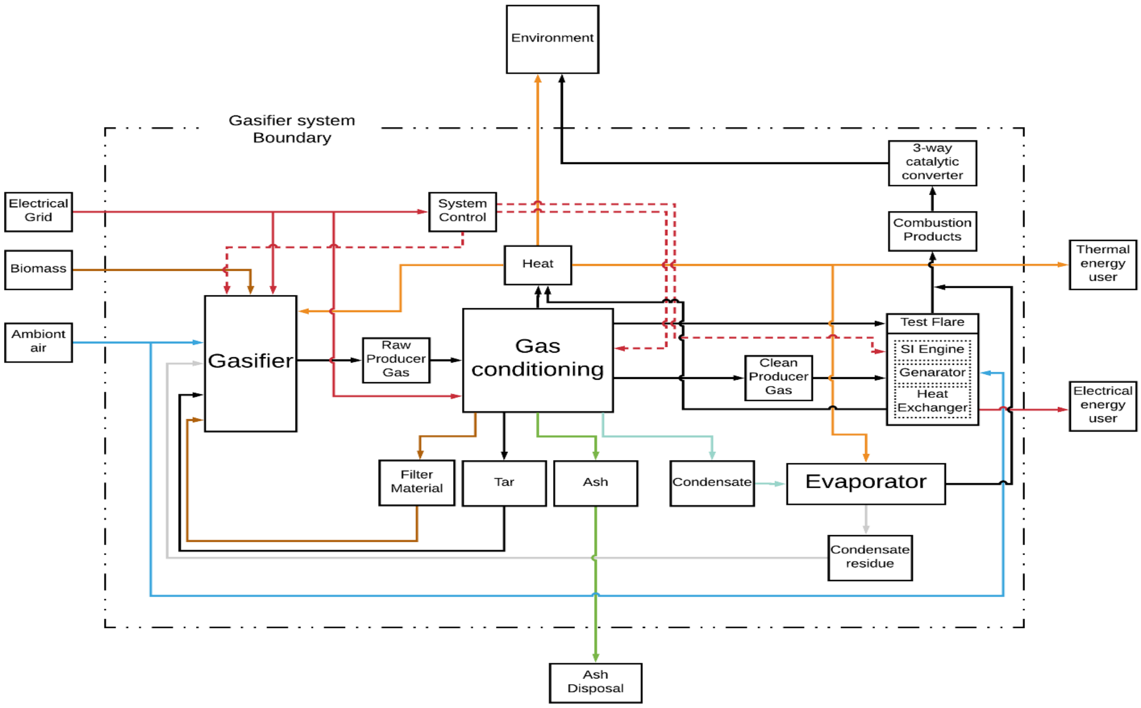
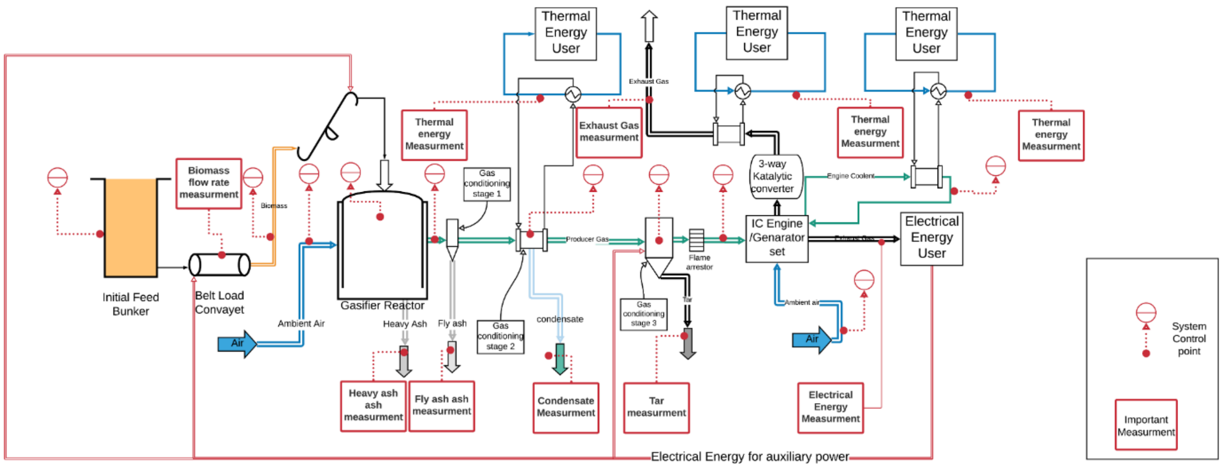


Figure 6 depicts the mass and energy crossing the gasification system boundary. Air and biomass enter the system boundary. Only ash and exhaust gases exit the system boundary. The tar and sludge from the filters are returned to the gasifier for thermal cracking together with fresh biomass. The condensate is evaporated while the sludge from evaporated condensate is recycled back to the system for thermal cracking([4], p. 100 Chapter 7.1.4 Paragraph 3). Recycling the tars increase the efficiency of the system. However, the design of the system is pointed towards the reduction of tar formation and condensate formation. Combustion products from the engine are conditioned using a three-way catalytic converter to fit the prevailing emission standards([4], p. 111 Chapter 7.2.5.1)

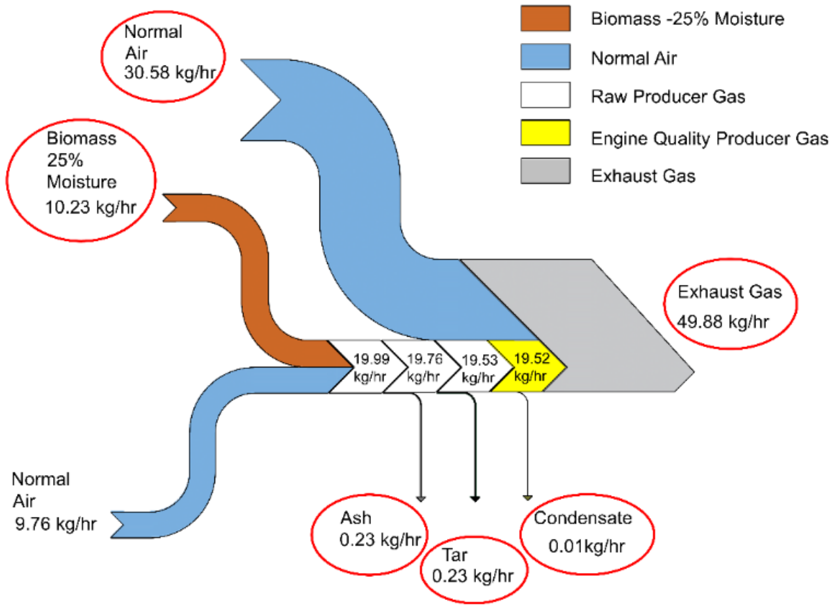
Figure 7: Schematic Diagram of the Gasification System indicating the Main Points of System Measurements and Important Control Points.



Note:

The red boxes in the diagram show the various measurements taken to ensure the proper functionality of the system. The red circles indicate system control points to enhance the smooth running of the system. The control points are connected to the PLC

Figure 8: Mass Flow of the System running at Maximum



The above mass flow diagram shows how the mass of air and biomass is converted to exhaust gas, ash, tar and condensate to produce thermal and electrical energy from the system. The important measurements taken from the system are circled in red.

Figure 9: Energy Conversion of the System

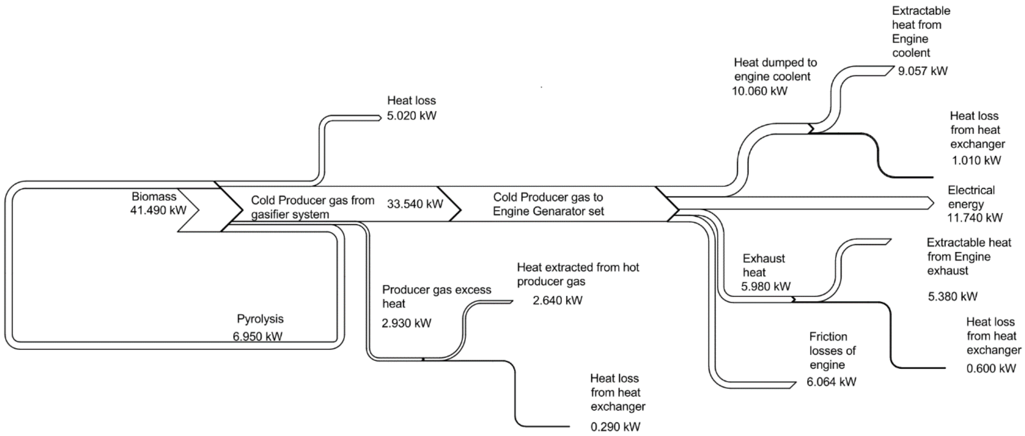


Figure 9 shows the flow of chemical energy stored in biomass to useful electrical and thermal energy. The loss of energy in the system is due to heat loss from surfaces and friction losses in the system. The external energy for the machinery is not accounted for in this diagram. The diagram only addresses the conversion of the chemical energy in the biomass feedstock.

Table 4: Summary of Technical Details

Energy Output		
Maximum electrical energy output	11.74	kW (60Hz, 3phase. 120V/480V at 0.8 Lag)
Maximum thermal energy output	18.38	kW
Hot gas Efficiency	81%	
Cold Gas Efficiency	74%	
Biomass Input		
Consumption	0.83	kg/kWh
The moisture content of biomass	25%	
LHV of Biomass	15,680.00	kJ/kg
Size-25mm – 100 mm in length to 10mm to 25mm in diameter		
Assumed Ambient Conditions		
Temperature	25	C
Pressure	100	kN
RH	20%	
Clean Producer Gas output		
CO	20%	
H_2	19%	
CH_4	4%	
CO_2	6%	
N_2	52%	
LHV	5.87	MJ/Nm^3
Producer gas tar content	<100	mg/Nm^3
Relative Humidity @ 40°C 106 kPa	22%	
Solid Waste Output		
Ash output	3%-7%	As a percentage of the biomass feeding rate
Expected Exhaust Emissions		
Species	mg/Nm^3	
CO	500<	
NO_x	200<	
SO_x	450<	
PM	3<	
Electrical Energy input		
Auxiliary Power input	1.57	kW

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