CHAPTER III

METHODOLOGY

In this chapter, the methodology consisted of two parts, firstly, developed management model, based on the main factors of SBGPGS that were supported by experimental data and secondary data, and secondly, evaluation of the technical performance, economic condition and environmental impacts of BGPGS which was developed at SERT, Naresuan University, Phitsanulok, Thailand.

The management model is necessary for sustainable generating power from biomass. It will be the guideline of local administrative organization to manage not only the technical system but also the fuel supplied system. In this study, sustain of BGPGS based on 1) technical performance, 2) biomass supplied system, 3) economic condition, 4) environmental standards and 5) community. This management model would be supported and integrated numerical values from experimental and/or secondary data including reasonable social concept.

The main sub-models of SBGPGS in this study focused on biomass supplied system (plantation area, logistics and storage) and community.

Nevertheless, some sustain factors of BGPGS such as technical performance, economic condition, and environmental impacts would be supported by experimental method following BGPGS, case at SERT for comparing between own technology and secondary data that were accepted for commercial.

For continuous evaluation processes, the first three factors, technology performance, biomass supplied system, and economic condition, had to be considered first because they were strongly related to and affected each other. The methodology flow chart of this could be shown in Figure 6.

Next, environmental impacts of this system would be evaluated and finally, sub-management model of community would be developed following secondary data and reasonable social concept.

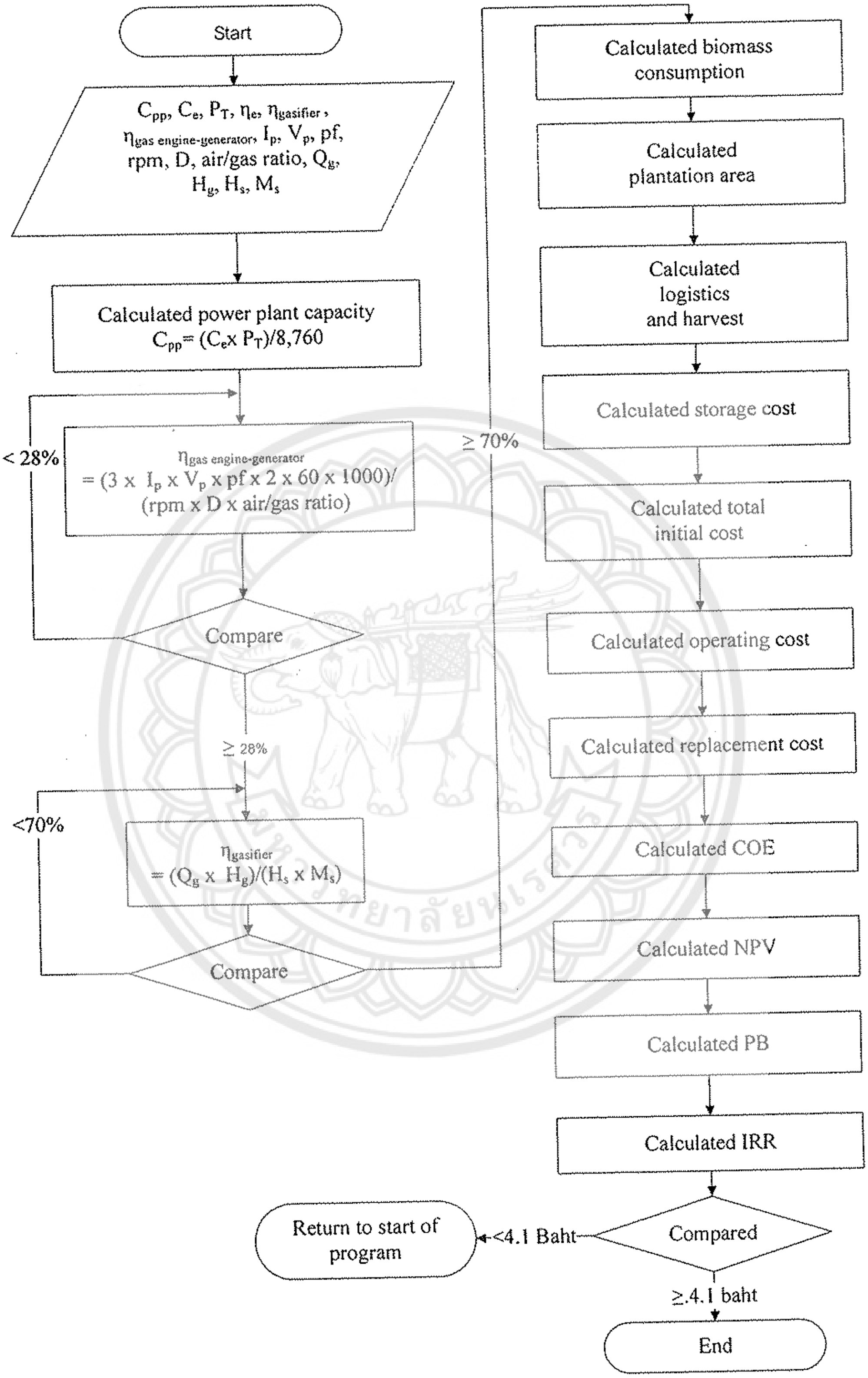


Figure 6 Methodology flow chart of technical performance, biomass supplied system and economic condition

Technical performance evaluation

1. Description of the system

The prototype of BGPGS in this study is shown in Figure 7 (Left) and was developed and tested by academic co-operations, namely; SERT, Wire & Wireless Co., Ltd., Thailand and Wind Ltd., Japan. This study aims to evaluate the system performance. The system comprised of two main parts, namely, downdraft gasifier system that is combined with the cleaning system and gas engine-generator system. Eucalyptus residues shown in Figure 7 (Right) were used for fuel for the gasification system.

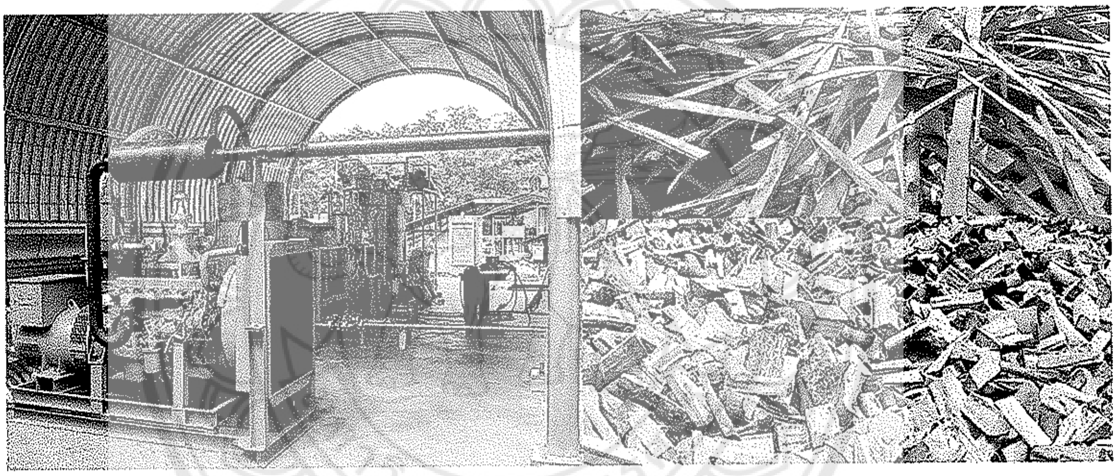


Figure 7 The BPGSP at SERT (Left) and Eucalyptus residuals were used for fuel (Right)

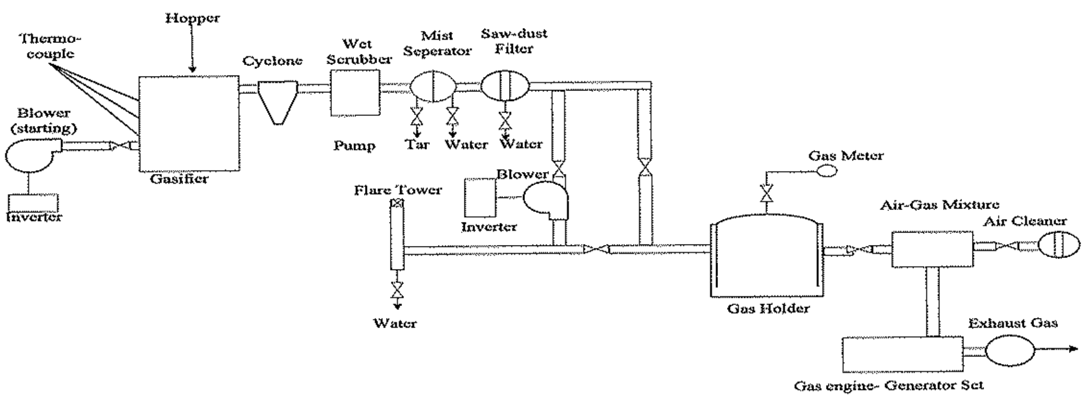


Figure 8 Schematic block diagram of BPGSP at SERT

1.1 The downdraft gasifier system

The gasifier was downdraft type with one air entrance opening. The throat was approximately 400 mm. Gasifier consisted of a well-insulated cylindrical reactor, fixed type stainless- steel grate and an induced draft fan. The reactor was a cylindrical steel shell insulated from outside with fiberglass of 25 mm thickness and covered with stainless steel. The air distribution unit supplementing the air taken through the electrical blower consisted of an air tuyere of 65 mm diameter and 165 mm length. The tuyere consisted of 20 holes (10 mm diameter of holes). This tuyere was placed at 350 mm above the grate in the middle of the gasifier. The grate was fabricated from stainless-steel. The grate area (0.12 m^2) was designed from specific gasification rate (SGR) of 417 kg h^{-1} m^{-2} and a fuel input rate of 50 kg h^{-1}. The ash fell into the ash pit tank, which was fabricated from stainless steel sheets of 6 mm thickness. The volume of ash pit (0.12 m^3) was sufficient to allow operation without removal of ashes for many hours (around 30 h).

To start the gasifier, not only was an electronic air supply blower, capacity 0.5 kW, used to supply air, but also an electric suction blower, capacity of 0.7 kW, was used to suck a flame torch to ignite wood chips inside the gasifier. After the gasification was developed well and the engine operated by producer gases, the suction blower was switched off, but the main air supply blower was left on continuously.

The technical specifications of the gasified system are given in Table 4.

Table 4 The technical specifications of the gasified system

Gasified system	Technical specifications
Type	Downdraft, (closed top, throat-less)
Biomass	Eucalyptus wood chips
Biomass consumption rate	50 kg h^{-1}
Capacity	607 MJ h^{-1}
Ash removal unit	Manual rotating type
Fuel feeding	Manual per batch
Gas discharge	Electric suction blower for starting up

Normally, gas cleaning/cooling system is integrated with gasifier. It is necessary for internal combustion engine. The main functions of gas cleaning/cooling system are removing tar and particulate and cooling gas for gas engine.

Gas cleaning/cooling system consisted of the following.

Cyclone filter: when producer gas from gasifier was passed on to the cyclone filter, the coarse particulates were separated from the gas stream in a high efficiency cyclone separator by centrifugal force.

Wet scrubber: tar and some tiny particulates were cleaned and cooled by wet scrubber. The contact of the sprayed water from the upper scrubber and producer gas that flow from cyclone filter made the gas temperature cool down. Therefore, the volatile substances in producer gas were condensed and discharged with water. In this part the particulates in producer gas that were not cleaned by cyclone filter were captured by water again. Waste water from wet scrubber was treated before being reused for closed system.

Mist separator: gas from wet scrubber had to be separated from the water vapor by mist separator before flowing to the internal combustion engine.

Saw-dust filter: for confidence of using producer gas in engine, there was no water vapor; gas would pass through sawdust and the water vapor would be absorbed by sawdust.

Gas holder: Producer gas was stored in the holder that could be flexible following the amount of producer gas. It was used to run the system continuously.

1.2 Gas engine-generator system

In this study, the spark ignition engine was run on producer gas alone. Diesel engine was converted to full producer gas operation by lowering the compression ratio and installing a spark ignition system. Gas was introduced into the engine after being mixed with air. Engine speed was kept constant at 1,500 rpm.

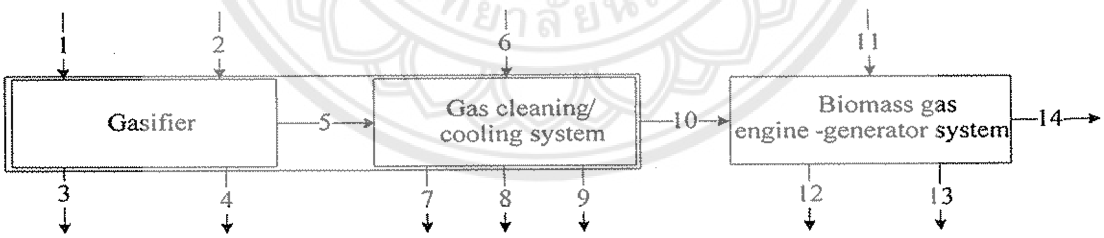
A modified diesel engine converted the engine's shaft power to electricity. The produced gas was proven to be excellent fuel for spark ignition engine. The 4-stroke engine is a natural aspirated six cylinder ($6 \times 1{,}000$ cc), spark ignition engine operating at full load. The engine was connected to producer gas and liquefied petroleum gas (LPG). LPG was used during start up and shut down for cleaning tar at the cylinders of the engine. It is possible to operate the engine on producer gas, LPG or any mixture of the two.

This performance evaluation focused on only producer gas to operate an engine. The produced electricity was supplied to dummy load. In future concept, it will be supplied to an electric grid.

The alternator is a short-circuit proof, self-excited internal pole machine in synchronous construction with the following specifications: power output 62.5 kVA, power factor cos phi 0.8, voltage 380/220 V and frequency 50 Hz.

2. Theoretical considerations

Schematically, a gasifier system operating in conjunction with a spark ignited engine can be depicted as shown in Figure 9. Three primary components are recognized: (1) the gasifier, (2) the gas cleaning or scrubbing system necessary to prove gas quality by removing tar, particulate matter, and water, and to cool the gas for the internal combustion engine, and (3) the engine-generator system. Each has material and energy flows as shown in the figure. Of interest for evaluating the first-law thermodynamic performance of the system is the thermal efficiency, which is defined as an overall system thermal efficiency, or taken at intermediate points depending on the application.



1, fuel; 2, air supply for gasification; 3, char; 4, heat transfer from the gasifier; 5, hot producer gas; 6, water into the gas scrubbing system; 7, water out of the gas scrubbing system; 8, particulate matter, tar and condensed water from the gas scrubbing system; 9, heat transfer from the gas cleaning system; 10, scrubbed producer gas; 11, engine combustion air; 12, engine exhaust; 13, heat transfer from the engine; 14, output power.

Figure 9 Mass and energy flows of biomass gasifier-engine system.

An important factor determining the actual technical operation is the gasification efficiency. For the gasifier, a "hot gas" efficiency (evaluated at point 5 of Figure 14) is normally defined which measures the ratio of the total gas power (sensible plus chemical) to the input power of the reactor (primarily in the form of fuel energy).

A "cold-gas" efficiency (point 10) is recognized, which relates the gas power at the outlet of the gas scrubbing system to the input power of the reactor (primarily in the form of fuel energy).

An overall system efficiency (point 14) is defined as the ratio of total power (the engine brake power that was extended to generator) to the gasifier input power.

If the gasifier input power is taken (for approximation) as the fuel power, the overall system efficiency can be written as:

$$\eta_e = \frac{p_o}{P_i} \times 100\% \qquad (3.1)$$

where η_e is the plant energy conversion efficiency or overall system efficiency (%), p_o is the total output power of balance for three phase (W), and P_i is the fuel power (W) [55].

The output power is the sum of all phase powers. For balance of the three phases, the output power can be written as:

$$p_o = 3 \times V_p \times I_p \times pf \qquad (3.2)$$

where V_p is phase volts (V), I_p is phase current (A) and pf is power factor [56].

The input power, P_i can be written as:

$$P_i = H_s \times M_s \qquad (3.3)$$

where H_s is lower heating value of gasifier fuel (kJ kg^{-1}), and M_s is gasifier solid fuel consumption (kg h^{-1}) [10].

3. The efficiency evaluation of the entire system

In this study, the evaluation of the overall system efficiency can be classified into two main parts, namely gasification system and diesel generator set. Technical performance of BGPGS can be evaluated by equation 3.4 shown below. And the schematic of this system can be shown in Figure 10.

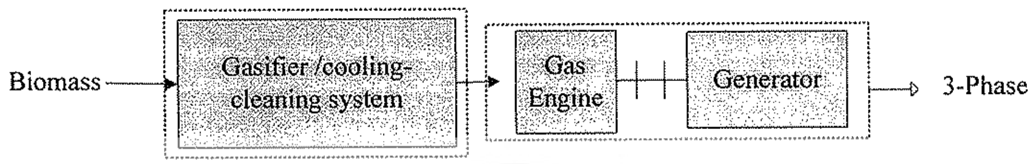


Figure 10 Schematic of basic of BGPGS

$$\eta_e = \eta_{gasifier} \times \eta_{gas\ engine\text{-}generator} \quad (3.4)$$

where

η_e = The plant energy conversion efficiency (%) or overall system efficiency (%)

$\eta_{gasifier}$ = The efficiency of gasifier (%)

$\eta_{gas\ engine\text{-}generator}$ = The efficiency of diesel generator (%)

3.1 Gasifier efficiency

An important factor determining the actual technical operation, as well as the economic feasibility of using a gasifier system, is the gasification efficiency.

The ratio of the out put rate (in terms of the energy content of the cold gas) to the energy input is through biomass consumption rate.

A useful definition of the gasification efficiency if the gas is used for engine applications is [10]:

$$\eta_{gasifier} = \frac{H_g \times Q_g}{H_s \times M_s} \times 100\% \quad (3.5)$$

In which

$\eta_{gasifier}$ = Gasifier efficiency (%) (mechanical)

H_g	= heating value of the gas (kJ m^{-3})
Q_g	= volume flow of gas (m^3 s^{-1})
H_s	= lower heating value of gasifier fuel (kJ kg^{-1})
M_s	= gasifier solid fuel consumption (kg s^{-1})

Generally, a cleaning/cooling system will be included in gasifier system.

3.2 Gas Engine-Generator Set

A modified diesel engine that was connected by generator, converted the engine's shaft power to electricity. The gas had proven to be excellent fuel for spark ignition engines. The high hydrogen contents in the gas resulted in a very efficient combustion.

Diesel generator efficiency can be calculated from dividing the power output by the power input and then multiplied by 100% as shown in equation 3.6.

$$\eta_{\text{gas engine-generator}} = \frac{\text{Power output}}{\text{Power input}} \times 100\% = \frac{3 \times V_p \times I_p \times pf}{H_g \times Q_g} \times 100\% \quad (3.6)$$

where

$\eta_{\text{gas engine-generator}}$	= the efficiency of diesel generator
V_p	= the phase volts (volt, V)
I_p	= the phase current (amp, A)
pf	= power factor (%)
H_g	= heating value of the gas (kJ m^{-3})
Q_g	= volume flow of gas (m^3 s^{-1})

The maximum gas intake of the engine can be calculated by the equation below.

$$\text{Max.gas in take}(Q_g) = \frac{\text{rpm} \times D}{2 \times 60 \times 1000} \times \text{stoichiometric air/gas ratio} \quad (3.7)$$

Volume flow of gas, Q_g ($m^3\ s^{-1}$) depends on

1. rpm of the engine
2. Displacement volume (D) in cylinder of the engine
3. Air/gas ratio (stoichiometric oxygen demands of combustible gas component)

The power output from an engine operating on producer gas would be determined by the same factors as engines operating on liquid fuels, namely:

1. The heating value of the combustible mixture of fuel and air which enters the engine during each combustion stroke.
2. The amount of combustible mixture which enters the engine during each combustion stroke.
3. The efficiency with which the engine converts the thermal of the combustible mixture into mechanical energy (shaft power).
4. The number of combustion strokes in a given time (number of revolutions per minute: rpm).

Conversion of an engine to producer gas or dual-fuel operation will generally lead to a reduced power output. The reasons for this and possibilities to minimize the power loss will be discussed below.

1. Heating value of the mixture

The heating value of producer gas depends on the relative amounts of the different combustible compositions: carbon monoxide, hydrogen and methane. The heating value of these three gases is given in Table 5.

In order to achieve combustion however, the producer gas needs to be mixed with a suitable amount of air. The combustible mixture will have a lower heating value per unit volume than producer alone.

Table 5 Heating values and stoichiometric oxygen demands of combustible gas components.

Gas	Effective Heating (kJ mol^{-1})	Heating Value (kJ m^{-3})	Stoichiometric Oxygen demand (m^3 m^{-3})
Carbon monoxide	283660	12655	0.5
Hydrogen	241300	10770	0.5
Methane	801505	35825	2.0

The amounts of oxygen necessary for complete burning (stoichiometric combustion) of each of the combustible components are also presented in the Table 5.

The heating value of such a stoichiometric mixture can be calculated from the following formula:

$$H_g = \frac{12680\ V_{CO} + 10800\ V_{H_2} + 35900\ V_{CH_4}}{1 + 2.38\ V_{CO} + 2.38 V_{H_2} + 9.52\ V_{CH_4}} \quad (3.8)$$

Where

H_g = is the heating value of a stoichiometric mixture of producer gas and air in kJ m^{-3}

V_{CO} = Volume fraction of carbon monoxide in the gas (before mixing with air)

V_{H_2} = Volume fraction of hydrogen in the gas (before mixing with air)

V_{CH_4} = Volume fraction of methane in the gas (before mixing with air)

A power loss of about 35% can be expected as a result of the lower heating value of a producer gas/air mixture.

2. Amount of combustion mixture supplied to the cylinder

The amount of combustible mixture, which actually enters the cylinder of an engine, was determined by cylinder volume and the pressure of the gas in the cylinder at the moment the inlet valve closed.

3. Engine efficiency

The efficiency which an engine can covert the thermal energy in the fuel into mechanical (shaft) power, depends on the first instance on the compression ratio of the engine.

The influence of increasing the compression ratio of an engine can be calculated from the following formula.

$$\eta_1 - \eta_0 = \varepsilon_1^{1-k} - \varepsilon_0^{1-k} \tag{3.9}$$

In which

η_1 = engine thermal efficiency at compression ratio 1

η_0 = engine thermal efficiency at compression ratio 0

ε_1 = engine compression ratio in situation 1

ε_0 = engine compression ratio in situation 0

k = a constant equal to 1.3 in the case of producer gas

4. Engine speed

Because the engine power output is defined per unit time, the engine power output depends on the engine speed.

For diesel engine, the power output is nearly linear the rpm. When the power output of a 4- stroke engine is calculated, allowance must be made for the fact that only one of every two rotations represents a compression and combustion stroke.

The maximum speed of engines fuelled by producer gas is limited by the combustion velocity of the combustible mixture of producer gas and air. Because this speed is low as compared to combustible mixtures of petrol and air, the efficiency can drop dramatically if the combustion speed of the mixture and the average speed of the piston become of the same order of magnitude [10].

The specific gasification rate, ψ (kg m^{-2} h^{-1}), is defined as [55]:

$$\psi = \frac{M_s}{A_r} \tag{3.10}$$

where A_r is the reactor cross-sectional area (m^2).

4. System operation and analysis

Proximate and ultimate analysis of fuel was conducted before the test by the Department of Science Service, Ministry of Science and Technology, Bangkok, Thailand. Size of Eucalyptus wood chips ranges from $2 \times 2 \times 5$ to $4 \times 4 \times 7$ cm^3. Bulk density of Eucalyptus wood chips is 284 kg m^{-3}. A bomb calorimeter was used to measure the lower heating values of biomass fuel.

Generally, the system was operated 8 hours per day. At starting time, about 35 kg of wood chips were loaded up to the air nozzle level. At that time, the electric air supply blower was started, drawing air for starting gasification for around 30 minutes, after that, 15-20 kg of fuel was loaded up on top of the gasifier.

At start up, gas went to the flare tower and was ignited for burning gas. At that time, the gas engine was started by LPG for keeping warm and cleaning the engine. Then the producer gas became combustible gas, observed by ignition producer gas at the flare tower. After that, the gas and air control valves were opened to air-gas mixture of 1:1 ratio before being passed to the engine and, thereafter, LPG valve and the suction blower were shut down. A stand with ladder was provided with the system for facilitating manual fuel feeding and other operations. Analysis of the feedstock is given in Table 6, and Table 7.

Table 6 Proximate analysis and calorific value data of Eucalyptus wood chips

Average proximate analysis data and energy content of Eucalyptus wood chips	
Moisture content (As received basis)	8.3
Volatile matter (% weight dry basis)	78.91
Ash (% weight dry basis)	0.37
Fixed carbon (% weight dry basis)	20.72
Total	100.00
Gross calorific value (kcal/kg)	4,653
Net calorific value (kcal/kg)	4,381

Table 7 Ultimate analysis data of Eucalyptus wood chips

Ultimate analysis	% Weight dry basis
Carbon	57.5
Hydrogen	5.3
Oxygen	36.7
Nitrogen	0.1
Sulfur	0.03
Total organic (C + H + O)	99.5

Performance measurements were taken after the stable operation of the system was observed, i.e., constant energy output as 25 kW of electricity. The feeding interval was about 25 minutes per 20 kg of fuel batch.

5. Measurement systems

The measured parameters included temperature, air flow rate, gas composition and tar and particulate content of the produced gas as shown in Table 8.

Table 8 The measured parameters, methods and equipments

Parameters	Methods and equipments
1. Volume flow of air (m^3 s^{-1})	Airflow meter type YAMATAKE Gas flow meter CMG
2. Lower heating value of gasifier fuel (kcal kg^{-1})	Bomb Calorimeter at the Department of Science Service, Ministry of Science and Technology, Bangkok, Thailand.
3. Temperature (°C)	1) Thermocouple (Chromel-Alumel type K) Range –200 °C to +1370 °C 2) Data Recorder (YOGOGAWA type HR 2300)
4. Moisture content of feed- stock (%)	1) Infra-red moisture meter type SANXD, AQ-10 AQUATEST 2) Drying at 110 °C, 72 hours by oven and weighing by digital weight balance type Sartorius MC1 Analytic Model AC 210S, ±0.0001.
5. Size of feed stock (mm)	Ruler
6. Average composition of gas (%)	1) Gas chromatography, type GC-2014 SHIMADZU GAS CHROMATOGRAPH [Flame ionization detector & Thermal conductivity (FIT&TD). 2) Gas Analyzers, PORTABLE GAS ANALYZER type ZFY BP111-A-Z, detected CO gas range 0-50/100%, Fuji Eletric Co., Ltd.
7. Total tar & particulate contents of gas (%)	NIOSH Method No. 0500, 0600 by Gravimetric method with air sampling model AirPro 6500, air flow meter model MSA class Optiflow 65 at flow rate 1.97 L min^{-1} and polyvinyl chloride (PVC) filter pore size 5 µ.

Biomass supplied system

1. Biomass plantation area

The main factors of biomass supplied system are technical performance, heating value of biomass fuel, power plant capacity, biomass consumption rate and the annual plant operating hours. First of all, we had to know the power plant capacity for community that can be calculated by the equation below.

1.1 Power plant capacity

The power plant capacity can be calculated by many methods but this study was calculated by means of the average of electric consumption per capita a year and total population of each community that is shown in the 3.11 equation below.

$$C_{pp} = \frac{C_e \times P_T}{8,760} \tag{3.11}$$

Where C_{pp} is power plant capacity of community (kW), C_e is electricity consumption per capita a year (kWh capita^{-1} year^{-1}) and P_T is total population of community (capita).

1.2 biomass consumption rate of BGPGS

Quantity of biomass fuel for the BGPGS can be considered by the flow of energy conversion as shown Figure 11. From the system perspective, the technical performance of biomass energy production plants were characterized by the overall conversion efficiency, which dictated the required biomass amount for a given power output and, at the same time, was strongly dependent on the adopted technology and the plant size.

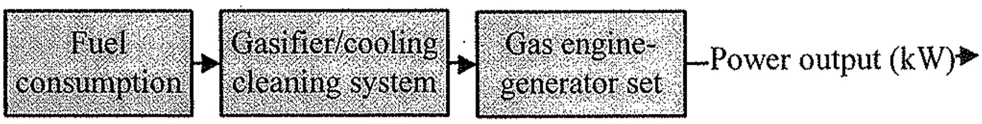


Figure 11 Energy conversion flow of fuel consumption quantity in BGPGS

As a consequence, for the purpose of this work, the plants were simply modeled as black boxes having a transfer function between the input biomass flow rate, M, (t $year^{-1}$) and the net electrical energy power output, P_o, (kW) or C_{pp}. More specifically P_o results were directly proportional to the biomass amount M, the biomass low heating value (LHV) (kJ kg^{-1}) at dry basis, and the plant energy conversion efficiency η_e, and inversely proportional to the plant annual operating hours, OH (h $year^{-1}$), as shown in Figure 12.

Figure 12 Biomass consumption rate of BGPGS

Therefore the algorithm adopted to estimate the biomass flow rate, required to produce the desired electrical energy is shown in Figure 13, resorting efficiency-power output relationship.

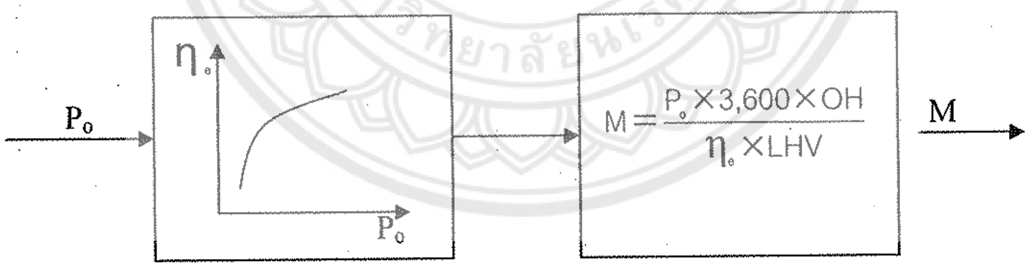


Figure 13 Flow-chart of adopted algorithm

Normally, biomass can contain more than 50% moisture (wet basis) when it is cut; it is generally desirable to dry biomass containing more than 25% moisture (wet basis) before gasification. This study assumed that biomass was about 50% moisture (wet basis) and was desirable to dry biomass containing from 10 percent to 20 percent of moisture content (wet basis). Therefore, biomass consumption rate, M, (t year^{-1}) has to be converted from moisture as dry basis to % of the moisture as wet basis following the equation below [14, 55].

$$M_{\%wet} = \frac{(100+\%M.C.)\times M_{\%dry}}{100} \qquad (3.12)$$

Where M.C., (%) is moisture content of biomass, $M_{\%wet}$, (t year^{-1}) is biomass consumption rate as wet basis and $M_{\%dry}$, (t year^{-1}) is biomass consumption rate as dry basis.

1.3 Plantation area

The plantation area for BGPGS was classified to two main specific characteristics of plants, tropical hardwood plants and fast growing plants, and can be considered in the following energy conversion that is shown in Figure 14. Capacity factor is assumed at 80% of power plant, it means a full-load plant operation time of 7,008, $(80\times 365\times 24)$ h year^{-1}, and plantation area is square area.

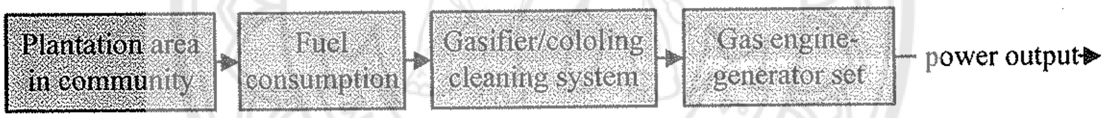


Figure 14 Energy conversion flow of plantation area in BGPGS

The detail constraints are explained following below.

1. Tropical hardwood plants.

Thailand has hot climate, so tropical hardwood plants can be assumed to be the C_4 plants whose growth rate is about 80 ton dry matter per hectare per year or productivity ($P_{dry\ basis}$) of tropical hardwood plants as dry basis is 12,800 kg Rai^{-1}year^{-1}.

Owing to being an agriculture country, people should be in sufficient economy and manage their areas to be 4 parts following the ratio, 30:30:30:10 (rice field 30%, reservoir 30%, tropical hardwood plants 30% and dwelling 10%) [11]. Harvesting by means of cutting branches is preferred to cutting whole stem of the tropical hardwood plants because it will take a long time for fuel sources. Hence, biomass plantation area (Rai) in community can be calculated by the equation below.

$$A_{bp} = \frac{C_{pp} \times 3600 \times OH}{\eta_{gas\text{-}engine\ generator} \times \eta_{gasifier} \times LHV \times P_{dry\ basis} \times 30\%} \qquad (3.13)$$

Where

A_{bp} = Biomass plantation area (Rai)

C_{pp} = Power plant capacity (kW)

LHV = Lower heating value of biomass fuel (kJ kg^{-1})

$\eta_{gas\ engine\text{-}generator}$ = Gas engine-generator efficiency (%)

$\eta_{gasifier}$ = Gasifier efficiency (%)

$P_{dry\ basis}$ = Productivity of Biomass as dry basis (kg $Rai^{-1}year^{-1}$)

OH = The plant annual operating hours at 80% power factor (h $year^{-1}$)

30% = Proportion of tropical hardwood plantation area of new theory farming

For the $P_{\%wet}$ can be calculated by the following this equation [14].

$$P_{\%wet} = \frac{(100+\%M.C.)\times P_{\%dry}}{100} \qquad (3.14)$$

$P_{\%dry}$, is productivity of biomass at dry basis (kg $Rai^{-1}year^{-1}$) and $P_{\%wet}$, is productivity at wet basis (kg $Rai^{-1}year^{-1}$)

On the other hand, A_{pp} of tropical hardwood plants can be assumed as equation 3.15.

$$A_{pp}\,(Rai) = \frac{M_{dry\ basis}}{P_{dry\ basis} \times 30\%} \qquad (3.15)$$

2. Fast growing plants

Fast growing plants consist of three specific characteristics of suitable short-rotation forest (SRF) for growing in Thailand such as Eucalyptus camaldulensis, Leucaena leucocephala, and Acacia mangium. Land suitability area for SRF plantation is assumed to follow the country using a computer program called THAI program. Biomass productivity and rotation of SRF were concluded by the secondary data of Forest and Plant Conservation Research Office, National Park, Wildlife and Plant Conservation Department, Thailand. Biomass productivity, P (t Rai^{-1} $year^{-1}$) as dry basis is classified by the amount of rain in any region of Thailand shown in Table 26 of appendix, and the rotation of SRF is 2 years. Plantation area of each characteristic of fast growing plants can be calculated by equation 3.16 below.

$$A_{bp} = \frac{M_{dry\ basis} \times R}{P_{dry\ basis}} \qquad (3.16)$$

where

R is the rotation of SRF (year $times^{-1}$). The SRF crop can be harvested in 2 years.

2. logistics

The effects of main logistic variability are specific vehicle transport costs, vehicle capacity, biomass distribution density and a mapping of logistic constraints on plant profitability in the specified capacity.

2.1 Specific vehicle transportation cost (baht km^{-1})

Specific vehicle transportation cost, C_{VT} (baht km^{-1}) can be calculated from the proportion of an oil price, C_{oil} (baht L^{-1}) of diesel or gasoline fuel by specific vehicle consumption, C_{SV} (km L^{-1}) following equation 3.17 below.

$$C_{VT} = \frac{C_{oil}}{C_{SV}} \qquad (3.17)$$

However, the cost of oil fuel is rapidly increasing continuously. At present, the retail oil price in Bangkok was presented by Energy Policy & Planning Office, Ministry of Energy, Thailand (EPPO) and showed that the average diesel hi-speed oil price was 28.64 Baht per liter and the average gasoline 91 oil price is 30.89 baht per liter on November 9, 2007 [57]. The average specific vehicle consumption, C_{SV} (km L^{-1}) of a motor tricycle using a 4-stroke, 125 c.c., is 35 km per liter for a commercial motorcycle at a constant speed of 60 km per hour [58], a pickup truck is 9.9 km per liter [59], these estimates are based on the Government of Canada's approved criteria and testing method. The actual fuel consumption of these vehicles may vary. And a truck fuel consumption is 2.5 km L^{-1} [60] from sources of 1965 to 1994: U.S Department of Transportation, Federal Highway Administration, Higway Statistics Summary to 1995, FHWA-PL-97-009 (Washington, DC: July 1997), table VM-201A and source of 1995 to 2005: lbid., Highway Statistics (Washington, DC: Annual issues) table VM-1.

Nevertheless, the average specific vehicle consumption, C_{SV} (baht km^{-1}) of a tricycle is different from the other vehicles. It can be assumed that mankind that is very active, participates in physical sports such as jogging or mountain-biking each day or hold a labor-intensive job such as a construction or bicycle messenger, will consume an average energy of around 2,182 kilocalories per day. It is the average energy consumption per day of the men (2,646 kilocalories per day) and women (1,717 kilocalories per day) who are between the ages of 20 to 60 years, height between 5 to 6 feet, and weight between 40 to 80 kg [61, 62, 63]. The detail of energy consumption per day of very active mankind are shown in Table 28 of appendix.

Normally, the same amount of energy man consumed per day would be used that day. Density of energy in a gallon (3.785411784 L, 1 atm of liquid) of gasoline contains about 31,000 kilocalories. Energy density of gasoline equals 31,000 kilocalories per gallon, but energy density of diesel equals 137,000 kilocalories per gallon. Hence 2,182 kilocalories is equal to 0.2665 liter of gasoline oil or 0.0159 liter of diesel oil. From the average specific vehicle consumption, C_{SV} (km L^{-1}) of a motor tricycle is 35 km per liter of gasoline oil, so energy of 2,182 calories can transport biomass of 9.3275 km. The lowest labor cost rating of the Department of Labour Protection & Welfare, Ministry of Labour, Thailand is 144 baht per day, announced on

January 1, 2007 [64]. The average specific vehicle transportation cost, C_{VT} (baht km^{-1}) of a tricycle can be assumed as 15.36 baht per km, when compared to gasoline engine.

2.2 Vehicle capacity (t vehicle^{-1})

This study specifically referred to the residuals of Eucalyptus camaldulensis from sawmill near Naresuan University Phitsanulok Thailand. Vehicle capacity is performed by interview at the sawmill. Vehicles can be classified to four specific characteristics of vehicles, 1) a tricycle, 2) a motor tricycle, 3) a pickup truck and 4) a truck, where vehicle capacity of a tricycle and a motor tricycle is equal to 0.334 tons per vehicle, a pickup is equal to 1.86 tons per vehicle and a truck 7 tons per vehicle.

2.3 Biomass distribution density (t km^{-2} year^{-1})

Biomass distribution density, D_{BD} can be conversed from the productivity in kg Rai^{-1} year^{-1} of tropical hardwood plants, Eucalyptus camaldulensis, Leucaena leucocephala, and Acacia mangium, to ton km^{-2} year^{-1} by this equation.

$$D_{BD}\,(\text{t km}^{-2}\text{ year}^{-1}) = \frac{P_{\text{dry basis}}\,(\text{kg Rai}^{-1}\text{ year}^{-1})}{1000\,(\text{kg t}^{-1})} \times \frac{1}{1.6\times10^{-3}}\,(\text{Rai km}^{-2}) \qquad (3.18)$$

2.4 A mapping of logistics and harvest direction is shown in Figure 15. It can be assumed from the total square plantation area.

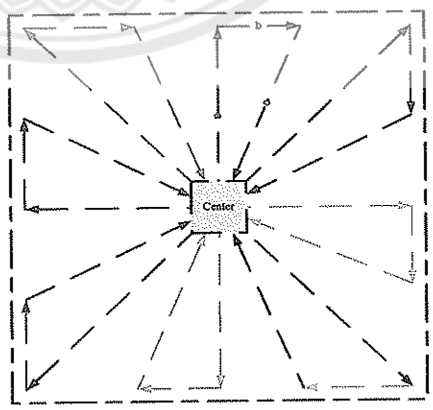


Figure 15 The logistic direction of biomass fuel for square plantation area.

Therefore, radius of the total square plantation area can be calculated from the equation below.

$$r\ (\mathrm{km}) = \frac{\sqrt{A_{bp}(\mathrm{Rai}) \times 1.6 \times 10^{-3}(\mathrm{km}^2\mathrm{Rai}^{-1})}}{2} \tag{3.19}$$

The mapping of logistics direction was shown in figure 15. Average distance (km) from the center of the power plant can be calculated following the equation below.

$$\text{Average distance from the central, } c\ (\mathrm{km}) = \sqrt{a^2 + b^2} \tag{3.20}$$

$$\text{Average round trip distance of plantation area, } D_A\ (\mathrm{km}) = 2 \times \sqrt{r^2 + \left(\frac{r}{2}\right)^2} \tag{3.21}$$

Then, total distance could be applied for calculation of the cost of logistic biomass.

2.5 Total distance

Total distance, TD (km year^{-1}) calculation can be done by the average distance from the center of plantation area, power plant location, multiplied by the number of area per vehicle a year, N_{AV} (vehicle yea r^{-1}) following the equation below.

$$TD\ (\mathrm{km\ year}^{-1}) = D_A\ (\mathrm{km}) \times N_{AV}(\mathrm{vehicle\ year}^{-1}) \tag{3.22}$$

The number of area per vehicle per year, N_{AV} (vehicle year^{-1}) can be fined out from the proportion of plantation area per year, A_{bp} (km^2 year^{-1}) by area per vehicle a year, A_V (km^2 $\mathrm{vehicle}^{-1}$ year^{-1}) by the 3.23 equation.

$$N_{AV}\ (\text{vehicle}) = \frac{A_{bp}(\text{km}^2\ \text{year}^{-1})}{A_V\ (\text{km}^2\ \text{vehicle}^{-1}\ \text{year}^{-1})} \tag{3.23}$$

Area per vehicle per year, A_V (km^2 vehicle^{-1} year^{-1}) can be calculated by the equation below.

$$A_V\ (\text{km}^2\ \text{vehicle}^{-1}\ \text{year}^{-1}) = \frac{1}{N_{VC}\ (\text{vehicle km}^{-2}\ \text{year}^{-1})} \tag{3.24}$$

When N_{VC} is the number of vehicles (vehicle km^{-2} year^{-1}).

2.6 Number of vehicles

The number of vehicles, N_{VC} (vehicle km^{-2} year^{-1}) can be considered from the proportion of biomass distribution density, D_{BD} (t km^{-2} year^{-1}) and vehicle capacity (t vehicle) by the 3.25 equation.

$$N_{VC}\ (\text{vehicle km}^{-2}\text{year}^{-1}) = \frac{D_{BD}\ (\text{t km}^{-2}\ \text{year}^{-1})}{VC\ (\text{t vehicle}^{-1})} \tag{3.25}$$

Biomass distribution density, D_{BD} (t km^{-2} year^{-1}) had to be converted from dry basis to 50% wet basis and from per Rai to per km^2 as seen in the equation below.

$$D_{BD}\ (\text{t km}^{-2}\ \text{year}^{-1}) = \frac{P_{50\%wetbasis}\ (\text{kg Rai}^{-1}\ \text{year}^{-1})}{1.6} \tag{3.26}$$

After we knew biomass plantation area, A_{bp} (Rai), we could calculate the vehicle cost, V (baht year^{-1}) by this equation.

$$V\ (\text{baht year}^{-1}) = TD \times C_{VT} \tag{3.27}$$

This equation represented the combination of all equation above for calculation of vehicle cost of square plantation area.

$$V = 2\times\sqrt{\left(\frac{\sqrt{A_{bp}\times 1.6\times 10^{-3}}}{2}\right)^2+\left(\frac{\sqrt{A_{bp}\times 1.6\times 10^{-3}}}{2}\times\frac{1}{2}\right)^2}\times A_{bp}\times\frac{P_{50\%wet}}{1.6\times VC}\times\frac{C_{oil}}{C_{SV}} \quad (3.28)$$

2.7 A mapping of logistics direction shown in Figure 16 is assumed as the total circular plantation area. The main concept for calculation of vehicle cost from the circular plantation area was similar to the square plantation area.

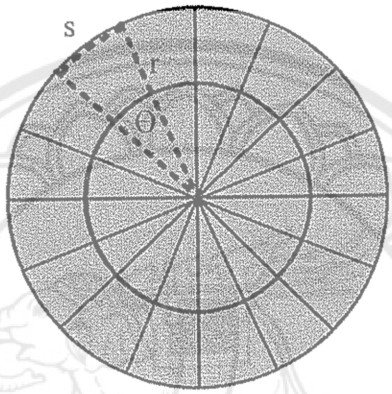


Figure 16 The logistic direction of biomass fuel for circular plantation area.

Average round trip distance of circular plantation area, D_A (km) = $(2\times r) + s$ (3.29)

Circular area, A_{bp} (Rai) can be calculated by this equation.

$$A_{bp}\,(\text{Rai}) = \pi r^2 \quad (3.30)$$

Therefore, radius of circular plantation area can be calculated by the equation below.

$$r\,(\text{km}) = \sqrt{\frac{A_{bp}(\text{Rai})\times 1.6\times 10^{-3}(\text{km}^2\ \text{Rai}^{-1})}{\pi}} \quad (3.31)$$

And distance of circular section area can be calculated as:

$$s = r\theta \tag{3.32}$$

Area per vehicle a year, A_V (km^2 vehicle^{-1} year^{-1}), Circular section area, could be calculated by the equation below, when θ is radian angle [65].

$$A_v = \frac{1}{2} \times r^2 \times \theta \tag{3.33}$$

Therefore, D_A (km) can be shown following the equation below.

$$D_A(\text{km}) = (2 \times r) + \left(\frac{A_V \times 2}{r}\right) \tag{3.34}$$

This equation represented the combination of all equation above for finding vehicle cost of circular plantation area.

$$V = \left[\left[2 \times \sqrt{\frac{A_{bp} \times 1.6 \times 10^{-3}}{\pi}}\right] + \left[\frac{2 \times VC \times 1.6}{P_{50\%wetbasis} \times \sqrt{\frac{A_{bp} \times 1.6 \times 10^{-3}}{\pi}}}\right]\right] \times A_{bp} \times \frac{P_{50\%wet\,basis}}{1.6 \times VC} \times \frac{C_{oil}}{C_{SV}} \tag{3.35}$$

3. Storage

The rainy season in Thailand lasts around 5 months a year from the middle of May to the middle of October [15]. In general, most biomass is unfortunately low in heating value or has a seasonal availability only. Storage is necessary particularly during rainy seasons because of difficult logistics and the drying of biomass. Five months of biomass storage is necessary for the continuous feedstock of power plants, so the amount of biomass storage and warehouse could be calculated by equations 3.15 and 3.16, consequently, energy conversion is as shown in Figure 17.

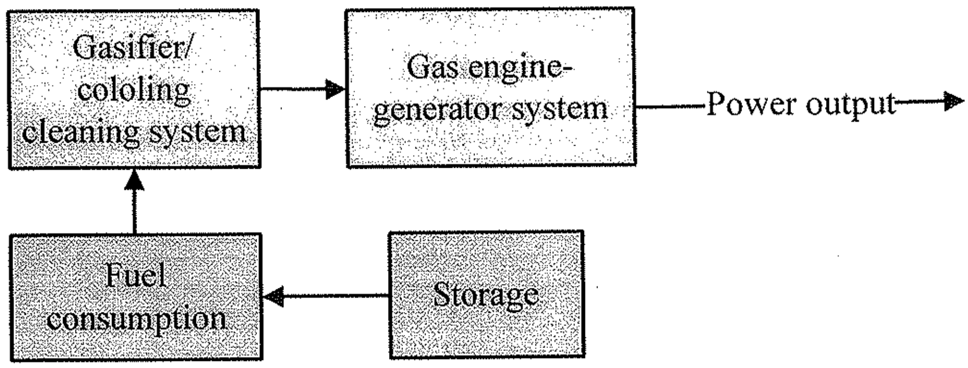


Figure 17 Flow of energy conversion for biomass storage

The amount of biomass storage, S_b (kg year^{-1}) can be calculated the equation below.

$$\text{Biomass storage, } S_b \text{ (kg year}^{-1}\text{)} = \frac{M_{50\%}}{2.4} \quad (3.36)$$

The warehouse can be calculated from biomass storage divide by bulk density of eucalyptus wood chips as shown in this equation.

$$\text{Warehouse (m}^3\text{)} = S_b/\text{bulk density of Eucalyptus wood chips}$$

Economic condition

The parameters of economic study are the cost of energy (COE), discounted payback period (PB), net present value (NPV) and internal rate of return (IRR). The COE is considered following the new subsidy adder for RE on November 20 of Thai Energy Policy Committee (EPC) under the National Energy Policy Council (NEPC) that approved a significant upgrade of Thailand's Very Small Power Producer (VSPP) regulations [16].

Environmental impacts

The environment impacts evaluation was classified into three parts, namely;

1. Waste water that was classified to physical (pH, Conductivity, Total Dissolved Solid (TDS), Suspended Solid (SS) and Temperature).

The parameters, methods and equipments for environmental evaluation are shown in Table 9.

Table 9 The parameters, methods and equipments for waste water analysis

Parameters	Waste water from wet scrubber Unit	Methods and Equipments
1. pH	pH unit	pH Meter
2. Conductivity	$\mu c\ cm^{-1}$	EC Meter
3. Total dissolved solid	$mg\ L^{-1}$	GF/C
4. Suspended solid	$mg\ L^{-1}$	GF/C
5. Temperature	°C	Thermometer

2. Air pollution

The parameters would be analyzed, namely; carbon monoxide (CO) and hydrocarbon (HC).

3. Sound level

Sound level is measured by level meter (IEC 651 Type 2), measured at 0.5 m from the engine.

Methods and equipments for quantity determination of air pollutions and sound level are shown in Table 10.

Table 10 The parameters, methods and equipments for air pollution and sound level analysis

Parameters	Methods and equipments	Unit
1. CO	Gas analyzer (Extech 407760)	%V/V
2. HC (Hydrocarbon)	Gas analyzer (Extech 407760)	ppm.
3. Sound level	Sound level meter (IEC 651 Type 2), measured at 0.5 m from the engine	dB.(A)

Community

Community was a local administrative organization. This sub-model was supported by secondary data and reasonable social concept for guideline local administrative organization to manage biomass supplied system, BGT and community power to SBGPGS.

Development management model of SBGPGS

1. **Risk assessment**

A continual process of risk assessment should identify potential problems of each factor of SBGPGS and hopefully avoid them.

2. **Risk mitigation**

Because risk is distasteful, we attempt to deal with it through avoidance, reduction, retention and transfer. In some cases, two of these approaches-transfer and retention- are combined to create a fifth technique, risk sharing.

3. **Consideration of the most appropriate alternative**

The most appropriate alternative would be considered for establishment of SBGPGS.