APPENDIX

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APPENDIX A BIOMASS PRODUCTIVITY OF FAST GROWING PLANTS

Table 26 The biomass productivity of SRF that are appropriate for growing in Thailand, E. camaldulensis, L. leucocephala, and A. mangium, is classified by amount of rain of any region in Thailand and the interval of growing [9].

Specific characteristics	Amount of rain (mm. year^{-1})	Biomass productivity is classified to the interval of growing (ton Rai^{-1} year^{-1}) as dry basis				
		1 × 1 m^2	1 × 2 m^2	2 × 2 m^2	2 × 3 m^2	4 × 4 m^2
E. camaldulensis	800-1,000	1.862	1.478	1.374	1.270	1.071
	1,000-1,200	2.385	2.046	1.901	1.882	1.636
	>1,200	3.401	2.723	2.564	2.282	2.088
A. mangium	<1,200	2.751	2.511	2.391	2.270	1.724
	1,200-1,500	3.075	2.751	2.691	2.631	2.598
	>1,500	3.867	3.582	3.297	3.132	3.075
L. leucocephala	800-1,000	2.204	1.259	1.173	0.877	0.580
	1,000-1,200	3.773	1.986	1.658	1.329	1.000
	>1,200	4.430	2.705	2.142	1.821	1.500

APPENDIX B QUALIFYING AND ACCEPTABLE PERFORMANCE LEVELS OF BGPGS BY WOODY BIOMASS

The qualifying and acceptable performance levels, shown in Table 27, follow the test procedures, methodology and protocols-Test procedure no II of ministry of non-conventional energy sources (MNES); April 2000 and American Society for Testing Materials (ASTM) standards methods [18, 71].

Table 27 **Qualifying and acceptable performance levels for commercial standard.**

Qualifying	Acceptable performance levels
1. Gasification efficiency (woody biomass)	NLT* 70% (cool gas)
2. Maximum permissible level of tar content of gas	100 mg Nm^{-3}
3. Maximum permissible level of particulate content of gas	50 mg Nm^{-3}
4. Total tar and particulate content of gas	150 mg Nm^{-3}
5. Specific biomass consumption (woody biomass)	NMT* 1.8 kg kWh^{-1}
6. Overall system efficiency at rate load (woody biomass and electrical applications)	NLT 20%

NLT* - Not less than and NMT* - Not more than

APPENDIX C ENERGY CONSUMPTION PER DAY OF MEN AND WOMEN

Table 28 The average energy consumption per day of the men and women that the ages are between 20 to 60 years, height are between 5 to 6 feet, and weight are between 40 to 80 kg [50, 51, 52].

Sex	Age	Height 5 (Feet)					Height 6 (Feet)					Average (kcal day^{-1})
		Weight (kg)					Weight (kg)					
		40	50	60	70	80	40	50	60	70	80	
male	20	2,541	2,643	2,745	2,847	2,950	2,792	2,894	2,997	3,099	3,201	**2,612**
	25	2,484	2,587	2,689	2,791	2,894	2,736	2,838	2,940	3,043	3,145	**2,561**
	30	2,428	2,531	2,633	2,735	2,838	2,680	2,782	2,884	2,987	3,089	**2,511**
	35	2,372	2,475	2,577	2,679	2,781	2,624	2,726	2,828	2,931	3,033	**2,460**
	40	2,316	2,418	2,521	2,623	2,725	2,568	2,670	2,772	2,874	2,977	**2,409**
	45	2,260	2,362	2,465	2,567	2,669	2,511	2,614	2,716	2,818	2,921	**2,359**
	50	2,204	2,306	2,409	2,511	2,613	2,455	2,558	2,660	2,762	2,865	**2,308**
	55	2,148	2,250	2,352	2,455	2,557	2,399	2,502	2,604	2,706	2,808	**2,258**
	60	2,092	2,194	2,296	2,399	2,501	2,343	2,445	2,548	2,650	2,752	**2,207**
Average		**2,316**	**2,418**	**2,521**	**2,623**	**2,725**	**2,568**	**2,670**	**2,772**	**2,874**	**2,977**	**2,646**
Female	20	1,681	1,753	1,826	1,899	1,971	1,774	1,847	1,919	1,992	2,064	**1,704**
	25	1,642	1,715	1,787	1,860	1,932	1,735	1,808	1,880	1,953	2,026	**1,669**
	30	1,603	1,676	1,749	1,821	1,894	1,696	1,769	1,842	1,914	1,987	**1,635**
	35	1,565	1,637	1,710	1,782	1,855	1,658	1,730	1,803	1,875	1,948	**1,600**
	40	1,526	1,598	1,671	1,744	1,816	1,619	1,691	1,764	1,837	1,909	**1,565**
	45	1,487	1,560	1,632	1,705	1,777	1,580	1,653	1,725	1,798	1,870	**1,530**

Table 28 (Cont.)

Sex	Age	Height 5 (Feet)					Height 6 (Feet)					Average (kcal day^{-1})
		Weight (kg)					Weight (kg)					
		40	50	60	70	80	40	50	60	70	80	
	50	1,448	1,521	1,593	1,666	1,739	1,541	1,614	1,686	1,759	1,832	1,495
	55	1,409	1,482	1,555	1,627	1,700	1,502	1,575	1,648	1,720	1,793	1,461
	60	1,371	1,443	1,516	1,588	1,661	1,464	1,536	1,609	1,682	1,754	1,426
Average		1,526	1,598	1,671	1,744	1,816	1,619	1,691	1,764	1,837	1,909	1,717
Total Average		1,921	2,008	2,096	2,183	2,271	2,093	2,181	2,268	2,356	2,443	2,182

APPENDIX D MEASUREMENT SYSTEMS

The measured parameters included the following:

1. Gas composition analysis

Gas analyzers were used to measure the composition of the producer gas at real time. They indicated directly and continuously the composition of the gas. One of them measured volume percentage of CO. The another measured volume percentage of CO_2, CH_4 and H_2. To analyze gas compositions, gas was passed through the gas analyzers after reaching steady state for a particular operation condition. The producer gas would be detected again by Gas Chromatography in laboratory for reliable analysis. Producer gas samples were collected by gas sampling bag (Tedlar® bags) and analyzed by using gas chromatography (GC-2014 SHIMADZU GAS CHROMATOGRAPH).

The chromatography consisted of two columns; Molecular sieve and Porapack N as stationary media and Argon as carrier gas. Chromatography used Thermal conductivity Detector (TCD) as the detector. Gas analyzer, GC, gas sampling bag and tight syringe for injection gas sample are shown in Figure 33 and Figure 34, respectively.

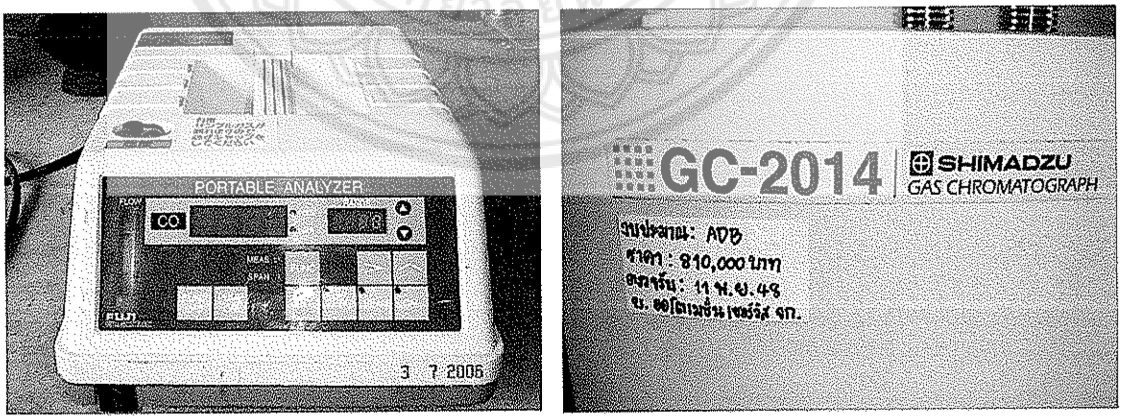

Figure 33 Gas composition analsis by gas analyzer (Left) and GC (Right)

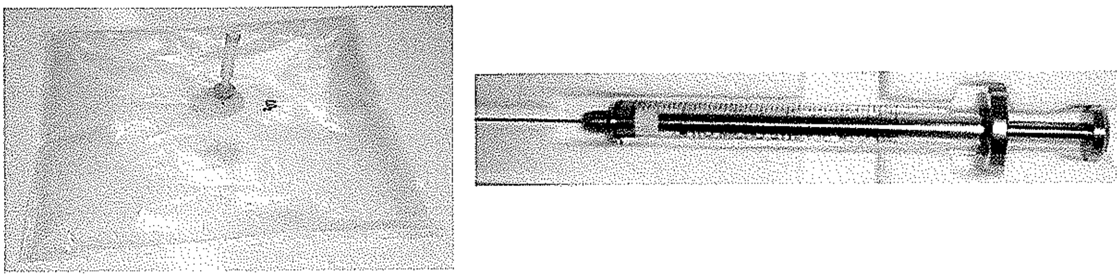

Figure 34 Gas sampling bag (Left) and tight syringe for injection gas sample (Right)

2. Tar measurement

Tar was the main unwanted constituent in the producer gas. Total tar and particulate were measured by NIOSH Method No. 0500, 0600 (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. gravimetric method with polyvinyl chloride (PVC) filter pore size 5 µ. The total tar and particulate measurement can be seen in Figure 35.

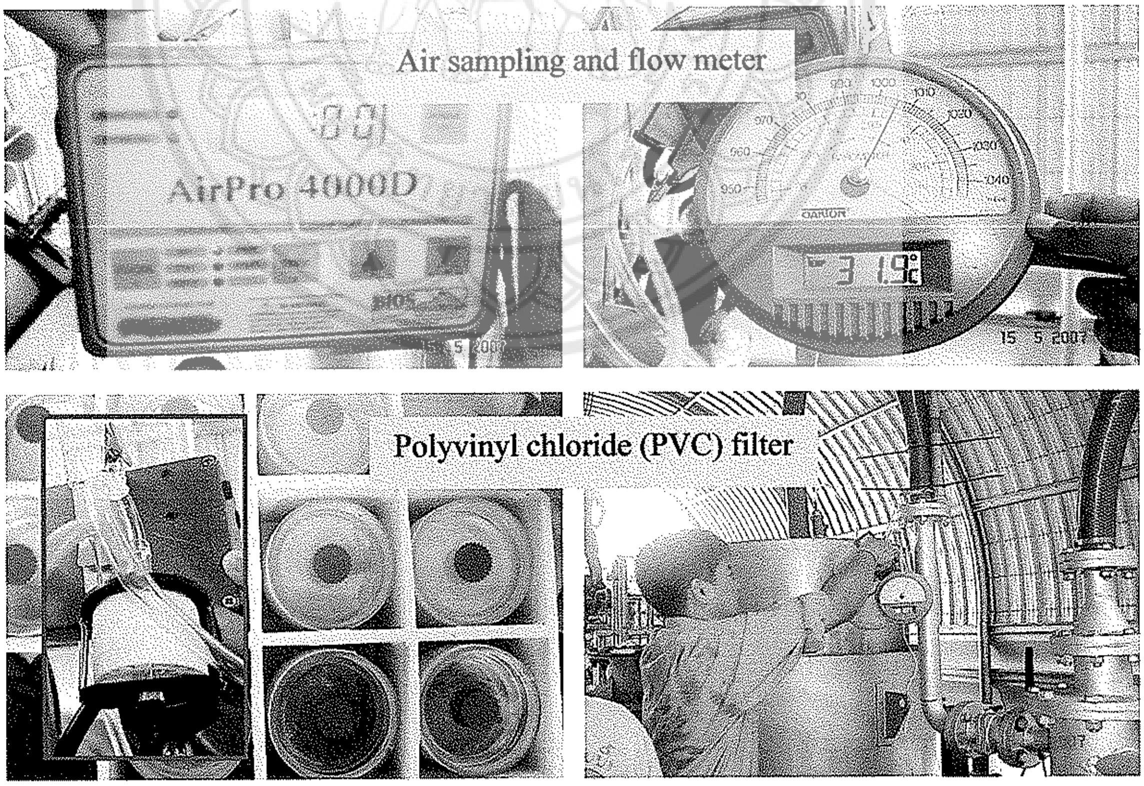

Figure 35 The total tar and particulate measurement

3. Measurement temperature

Chromel-Alumel (K-type) thermocouples were used to measure temperatures at different points of the experimental set-up. These thermocouples were connected to a digital temperature indicator and a selector switch to indicate the temperature. The highest temperature that can be measured by this type of thermocouple is 1,200°C. Figure 36 shows the instruments used in the measurement of temperature.

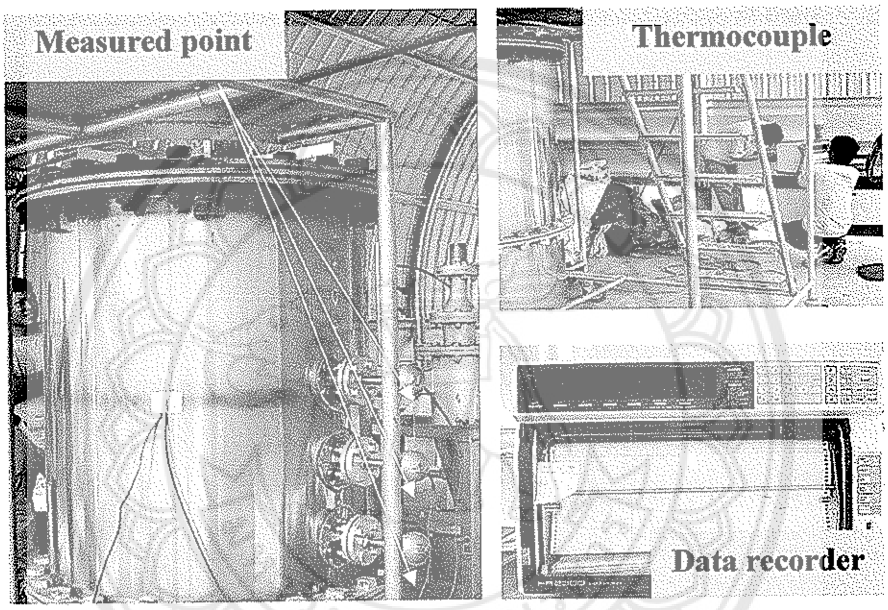

Figure 36 The measurement of temperature

4. Air flow rate measurement

The amount of air supplied to a gasifier has a great influence on producer and amount of producer gas supplied to engine. An air flow meter can be seen in Figure 37.

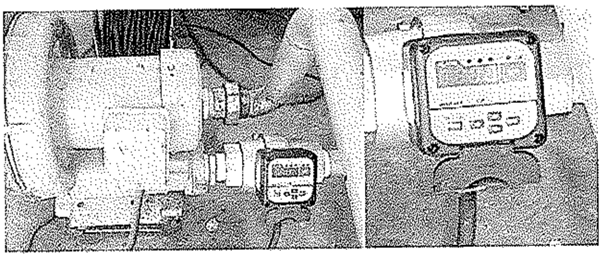

Figure 37 The air flow rate meter for supplying air to a gasifier

5. Biomass fuel

The biomass fuel in this experiment was wood. The properties of feedstock e.g. moisture content, size, composition of the feedstock etc. had great influence on the expected gas composition.

Eucalyptus residuals were the main fuel in this experiment. Eucalyptus residuals from sawmill were taken and cut into chips of nearly cubic shape with sizes range from $2\times2\times5$ to $4\times4\times7$ cm^3, then air dried by means of a solar dryer available and stored in plastic bags as shown in Figure 38. Eucalyptus wood chips required the moisture content range from 10 % to 20 %.

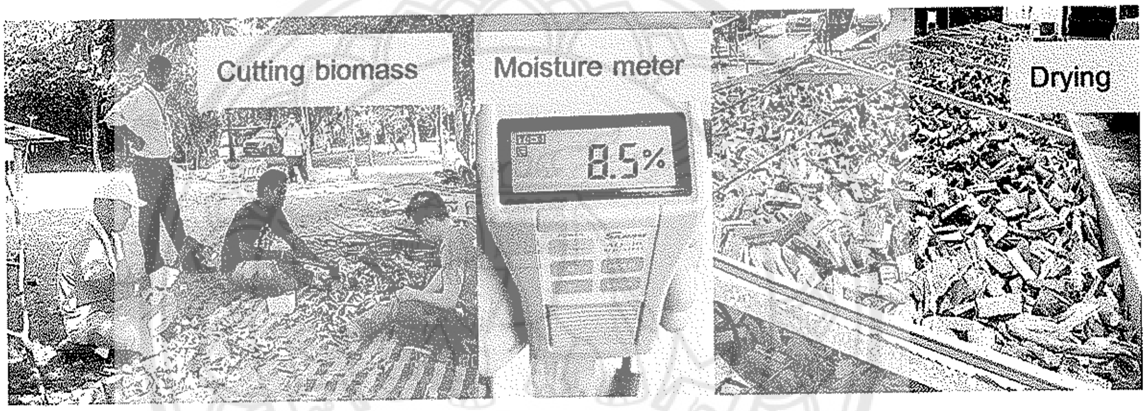

Figure 38 Eucalyptus residuals being cut and dried before feeding the BGPGS

Eucalyptus residuals were specific wood chips for determining technical performance of the 25 kW$_e$ BGPGS.

6. Load testing

The maximum output power at full load of the BGPGS in this study was measured by dummy load. The maximum load testing were shown in Figure 39.

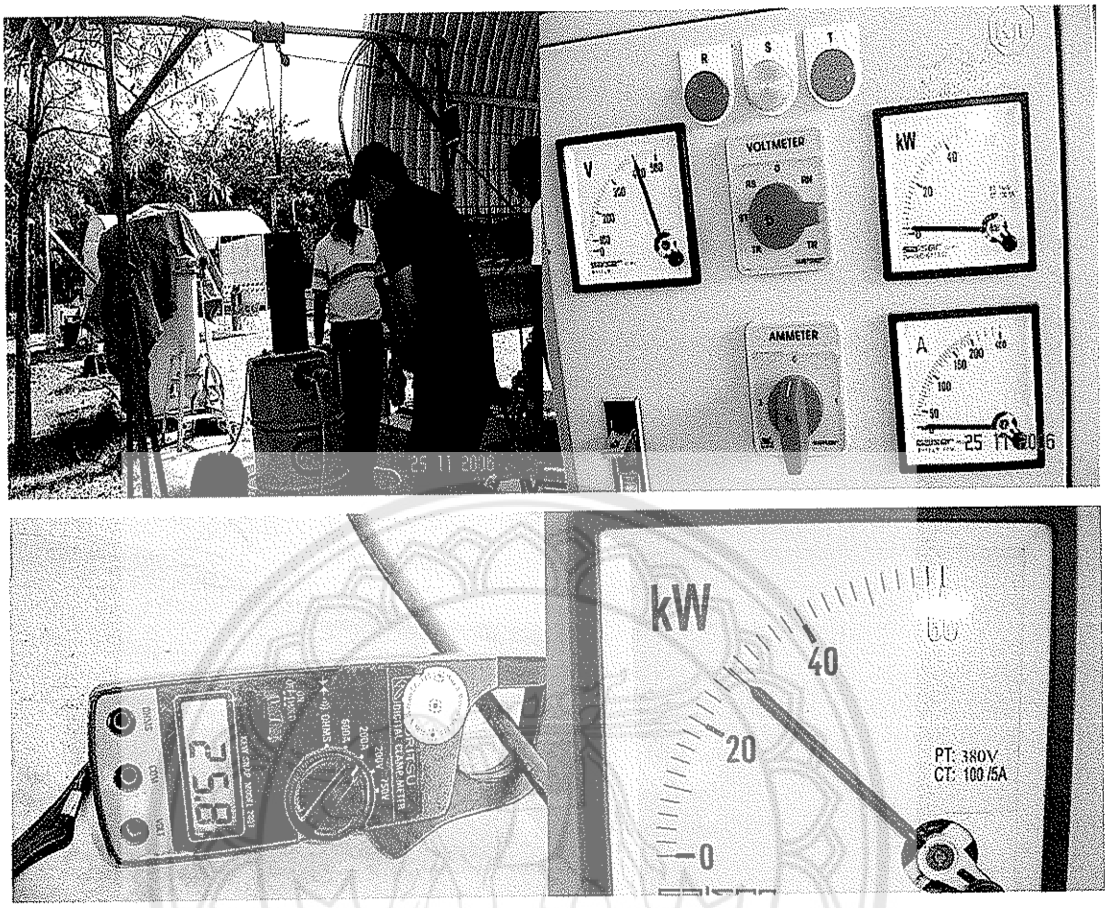

Figure 39 The maximum output power testing at full load of the BGPGS on only producer gas

APPENDIX E PERFORMANCES AND COSTS ESTIMATION

Although the potential of bio-energy utilization was widely agreed upon, key problems regarding the use of biomass were the limited availability in term of time owing to biomass seasonality and the scattered geographical distribution over the territory that make the collection, transportation, and storage operations complex and expensive. These critical logistic aspects strongly affected the economic and energy performance of bio-energy conversion systems.

With this in mind, a system analysis was presented in order to investigate the economical feasibility of biomass utilization for direct production of electric energy through gasification processes, considering the technical, organizable, and logistic issues related to the overall bio-energy chain.

This study aimed to evaluate biomass utilization for direct production of electric energy by means of gasification-conversion processes of BGPGS, taking into account total capital investments, revenues from energy sale and total operating cost and also included a detailed evaluation of logistic costs. Moreover, in order to evaluate the impact of logistics on the bio-energy plants, the effects of main logistic variables such as specific vehicle transport costs, vehicle capacity, specific purchased biomass costs and distribution density have been examined.

1. Plant configuration

As mention above, BGPGS has been selected for the following analysis which represented typical plant architecture for power generation, downdraft gasification, followed by gas engine power generation.

2. Plant performance evaluation

The result of the technical performance of the BGPGS revealed that the overall efficiency of the conversion biomass to energy using the BG system was 10%.

3. Equipment cost evaluation

The reliability of such equipments had been verified by resorting to a comparison between calculated costs and actual cost data obtained from the vendors.

4. The overall economic model

The economic evaluation of analyzed plant configuration had been carried out on the basis of total capital investment, TCI (baht), total operating cost, TOC (baht year^{-1}), benefits from sale of produced electric energy, B (baht year^{-1}) and environmental benefit, EB (baht year^{-1}). In this way, the parameters of economic performance used for explanation consisted of cost of energy (COE), payback period (PB), net present value (NPV) and internal rate of return (IRR). Moreover, TCI costs had been evaluated as the sum of all plant section costs including power generation costs, biomass storage-dryer costs, ash storage cost, electrical equipment costs, waste water treatment costs and direct installation costs. Total investment cost (IC) had been calculated as the sum of IC costs of pieces of equipment which were power generation, biomass storage-dryer, ash storage, and electrical equipment. In addition, waste water treatment costs had been estimated by resorting, as shown in Table 17, resulting from interpolation of experiment and literature data. Finally, direct installation costs had been calculated as a percentage of total IC costs. Numerical values for such percentages had been derived from literature data [55, 75, 76, 77]. All the considered items of cost utilized for TCI costs estimation has been summarized in Table 29.

Table 29 The investment cost of equipment pieces and waste water treatment

Investment Cost (plant section)	Sum (baht)	Investment Cost (plant section)	Sum (baht)
Power generation	**1,318,000**	Electrical cost	**23,000**
Gasifier	380,000	Electrical equipments	3,000
Cooling/cleaning system	380,000	Wood chip machine	20,000
Gas engine + alternator	500,000		
Fans (2 units)	40,000		
Pump	18,000		
Biomass storage-dryer	**72,000**	Waste water treatment	**85,000**
Biomass storage $10\times10\times10$ m^3	50,000		
Biomass handling	2,000		
dryer	20,000		
Ash storage	**5,000**		
Total investment cost		**A = 1,503,000 (baht)**	

Total operation costs had been determined as the sum of operating labour cost, ash land-filling costs, purchased biomass cost, biomass transportation costs, and maintenance costs, as listed in Table 32.

In particular, operating labour costs, L (baht $year^{-1}$) had been computed in function of the employed personnel average fee, C_p fixed to 60,000 baht $unit^{-1}$ $year^{-1}$ [64], and the number, N of total annual working personnel, assumed variable with the plant size and calculated considering 3 shifts in rotation. Therefore, the adopted equation for operating labour costs evaluation is the following:

$$L = C_p \times N \tag{1}$$

In this study, N of total annual working personnel was assumed as 8 persons, considering 6 persons for feeding biomass and running BGPGS of 3 shifts in rotation and 2 persons for drying and cutting biomass. Therefore, the operating labour cost is 480,000 baht year^{-1}.

Table 30 Components of capital investment costs evaluation [55, 75, 76, 77].

Cost component	Factor
Total IC cost	A
Direct installation cost	B = 0.30A
Vehicle costs (Second hand) (baht unit^{-1})	C
Tricycle	15,000
Motor tricycle	30,000
Pickup truck	300,000
Truck	1,000,000
Total capital investment cost	**TCI =A+B+C**
Tricycle	1,968,900
Motor tricycle	1,983,900
Pickup truck	2,253,900
Truck	2,953,900

มหาวิทยาลัยนเรศวร

Ash land-filling costs, AL (baht year^{-1}) had been calculated assuming ash land-filling fee of 300 baht per month; therefore, ash land-filling costs was about 3,600 baht year^{-1}.

Purchased biomass costs, PB (baht year^{-1}) had been determined in function of the annual biomass consumption, M (t year^{-1}) and the specific purchased biomass cost, C_B (baht t^{-1}) as follows:

$$PB = C_B \times M \tag{2}$$

Considering experimental data, specific purchased biomass cost was assumed as 500 baht t^{-1} of Eucalyptus wood and biomass consumption rate at 50% wet weight was 521 t $year^{-1}$; therefore, purchased biomass cost was 260,500 baht $year^{-1}$.

While, biomass transportation costs, TB (baht $year^{-1}$) had been evaluated as the sum of vehicles costs, V (baht $year^{-1}$) and transportation personnel costs, TP (baht $year^{-1}$)

$$TB = V + TP \tag{3}$$

More specifically, vehicle costs were function of total annual traveled distance, TD (km $year^{-1}$) and the specific vehicle transport cost, C_{VT} (baht km^{-1}), as follows:

$$V = TD \times C_{VT} \tag{4}$$

Where TD was calculated as the number of travels required to transport the total amount of biomass consumption, M by resorting to vehicle having a capacity, VC (t $vehicle^{-1}$), times the average round trip transportation distance, computed assuming that the average distance was of square root of r^2 combined to $\left(\frac{r}{2}\right)^2$ of the catchment square area necessary to produce the amount of biomass feeding the plant, starting from a uniform biomass distribution density, D_{BD} (t km^{-2} $year^{-1}$)

As far as transportation personnel costs, TP (baht $year^{-1}$) was concerned with a transport operations employed personnel fee, C_{TP} equal to 60,000 baht $unit^{-1}$ $year^{-1}$ had been assumed, and a number of operators employed in transport operations, n_T (unit) proportional to the number of required travels had been considered; so the adopted equation for TP evaluation is

$$TP = C_{TP} \times n_T \tag{5}$$

Biomass transportation costs, TB (baht year^{-1}), vehicle costs, V (baht year^{-1}) and transportation personnel costs, TP (baht year^{-1}) can be seen in Table 31, considering specific vehicles of tricycle, motor tricycle, pickup truck and truck.

Table 31 Biomass transportation costs, TB (baht year^{-1}), vehicle costs, V (baht year^{-1}) and transportation personnel costs, TP (baht year^{-1}) considering to specific vehicles of tricycle, motor tricycle, pickup truck and truck.

Specific vehicles	TD (km year^{-1})	C_{VT} (baht km^{-1})	V (baht year^{-1})	C_{TP} (baht unit^{-1} year^{-1})	n_T (person)	TP (baht year^{-1})	TB (baht year^{-1})
Tricycle	890	15.48	13,777	60,000	non	0	13,777
Motor tricycle	890	0.88	783	60,000	1	60,000	60,783
Pickup truck	160	2.89	462	60,000	1	60,000	60,462
Truck	42	11.46	486	60,000	1	60,000	60,486

Finally, maintenance costs, MAN (baht year^{-1}) had been calculated as a percentage of TCI using the factors given in Table 32. Numerical values for such percentages had been derived from literature data [55, 75, 76, 77]. In particular, referring to maintenance costs estimation, given the low maturity of biomass systems with respect to biomass gasification power generation system.

Benefits from sale of produced electric energy had been evaluated as

$$B = (P_o \times OH \times EP) + EB \qquad (6)$$

Where OH (h year^{-1}) were the plants annual operating hours, assumed as 7,008 h year^{-1}, EP (baht kWh^{-1}) was the current market price of produced electricity, with government subsidies, while P_o represents the percentage of the net electric energy plant output P_o that was effectively available for sale, assumed as 90% of P_o in order to take into account the energy needs of auxiliary pieces of equipment. Power output was 175,200 kWh year^{-1} with 80% power plant capacity but internal energy consumption of BGPGS in this study that consists of 2 fans of 0.5 HP and 0.75 HP, water pump of 1.00 HP and cutting machine 1,050 W was around 17,520 kWh year^{-1}. Therefore, total power output that could be sold is 157,680 kWh year^{-1}.

Table 32 Components of total operating and maintenance costs evaluation

Cost component	Factor	Cost
Operating labour	L	480,000 (baht year^{-1})
Ash land-filling fee	AL	3,600 (baht year^{-1})
Purchased biomass cost	PB	260,500 (baht year^{-1})
Biomass transport cost	TB	
Maintenance cost	MAN = 0.03TCI	
Total operating cost (TOC)	TOC=L+AL+PB+TB+MAN	-
Tricycle	41% of TCI	816,944
Motor tricycle	44% of TCI	864,400
Pickup truck	39% of TCI	872,179
Truck	30% of TCI	893,203