

Economic analysis of biomass gasification for generating electricity in rural areas in Indonesia

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Abstract: The gaseous fuel from biomass gasification might reduce the consumption of diesel fuel by 70%. The investment cost of the whole unit with a capacity of 45 kWe was about IDR 220 million in 2008 comprised of 24% for gasification unit, 54% for diesel engine and electric generator, 22% for transportation of the whole unit from Bandung to the site in South Borneo. The gasification unit was made in local workshop in Bandung, while the diesel-generator was purchased also in a local market. To anticipate the development of biomass based electricity in remote areas, an economic analysis has been made for implementations in 2019. A specific investment cost of 600 USD/kW has been estimated taking account to the escalation and capacity factors. Using a discounted factor of 11% and biomass cost in the range of 0.03-0.07 USD/kg, the production cost of electricity would be in the range of 0.09-0.16 USD/kWh. This production cost was lower than that of diesel engine fueled with full oil commonly implemented in many remote areas in Indonesia at this moment. This production cost was also lower than the *Feed in Tariff* in some regions established by Indonesian government in 2017.

1. Introduction

Biomass has gained much attention as an energy resource in Indonesian following the national energy policy, in which biomass accounts for 5% in the national energy mix [1]. Meanwhile there are large amount of various biomass as renewable energy source in Indonesia. Biomass conversion to electricity particularly for rural area gets much attention at this moment. A common technique for the utilization of biomass to electrical energy is steam power plant. Many palm oil mills and sugar cane factories produce power and heat using this technique with a capacity in the range of 1-3 MW [2].

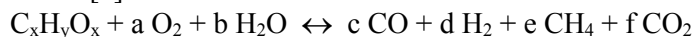
A gasification of biomass may have several advantages over a steam power plant for applications in a rural or remote area, where the capacity is relatively small. This paper deals with economic evaluation and feasibility study on the application of an appropriate technology of biomass gasification to electricity for the near future. The feasibility study was prepared for a project started for operation in 2019. An optimum capacity of this rural electricity was about 500 kWe (kW-electricity). The economic evaluation was based on literature data and our previous experiences on implementation of rural electricity generation units with capacities in the range of 10-100 kWe.

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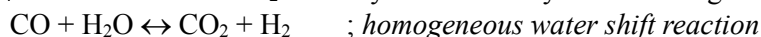


2. Biomass to Electricity System

Gasification process deals with many chemical reactions, and an overall reaction may be represented as follows [3]:



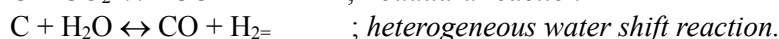
The coefficients of reaction (a, b, c, d, e and f) in the above overall reaction depends on temperature and pressure of the process. The desired combustible gaseous components are H₂, and CO, as well as CH₄. The molar ratio of H₂/CO may be dictated by the following.



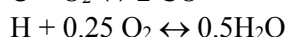
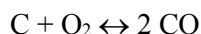
Methane, CH₄ is mainly generated in the pyrolysis, which is a step of gasification process, or probably produced through the following methanation reaction in the presence of a suitable catalyst:



The gasification process is usually operated as auto-thermal process, in which heat for the following endothermic reduction reactions are supplied by oxidation of some parts of biomass.



The exothermic oxidation reactions may be represented with the following reactions:



If air is used as the oxidizing agent, the gaseous product contains significant amount of N₂ gas thus reducing its heating value (see Table 1). This gas is usually known as *producer gas* and it is used as gaseous fuel. If steam or/and O₂ are used, the gaseous product contains high concentrations of H₂ and CO, with a very little amount of N₂, which is called as *synthesis gas* with a heating value up to 10.5 MJ/Nm³ (medium calorific gaseous fuel).

Down draft fixed bed gasifiers have been used in all of our field units with capacities up to 100 kWe. Basically, this type of gasifier is expected to produce a combustible gaseous fuel with a low tar content. Unfortunately for some reasons a small concentration of tar may still present in the gas e.g. due to improper preparation of biomass or improper operation and maintenance.

Table 1. Typical composition of producer gas (our experiences).

No.	Gas composition (mol fraction)	types of biomass		
		Coconut shell	Rubber wood	Rice husk
1.	CO	25%	18%	20%
2.	H ₂	12%	16%	11%
3.	CH ₄	1%	2%	2%
4.	CO ₂	10%	10%	11%
5.	N ₂	52%	54%	56%
6.	Gas Low Heating Value, kJ/Nm ³	4,900	4,600	4,350

A typical set up of a gasification and diesel engine-generator is presented in Figure 1. This unit produced net electricity of about 45 kW distributed to about 60 houses of oil palm farmers. Main components of this unit are:

- down draft fixed bed gasifier fueled with corn cobs with a capacity of about 80 kg/h
- screw-feeder to bring biomass to the top of the gasifier
- water scrubber for gas cooling and tar removal
- filter box filled with locally available filter medium such as coconut husk, saw dust, etc
- start-up blower for sucking gas during the first 15-30 minutes operation
- diesel genset (diesel engine and electric generator) with a rated capacity about 60 kWe

During start-up, low quality gas was drawn from the gasification unit using a start-up blower. The gas was blown through a burner and flared. In this short period, electricity had already been generated using a diesel engine and electric generator set. The electricity was used for running the start-up

blower and other electricity-needs in the power house. As soon as the gas quality better (heating value of at least 3500 kJ/Nm^3 as indicated in flare), the diesel engine could be operated *dual fuel*, and the start-up blower was then stopped. At the end of operation, the diesel engine and generator set was also operated *full oil* again for the the last 15 minutes, while the gasification process was stopped already. The purpose of this operation was purging tar from the internal parts of engine.

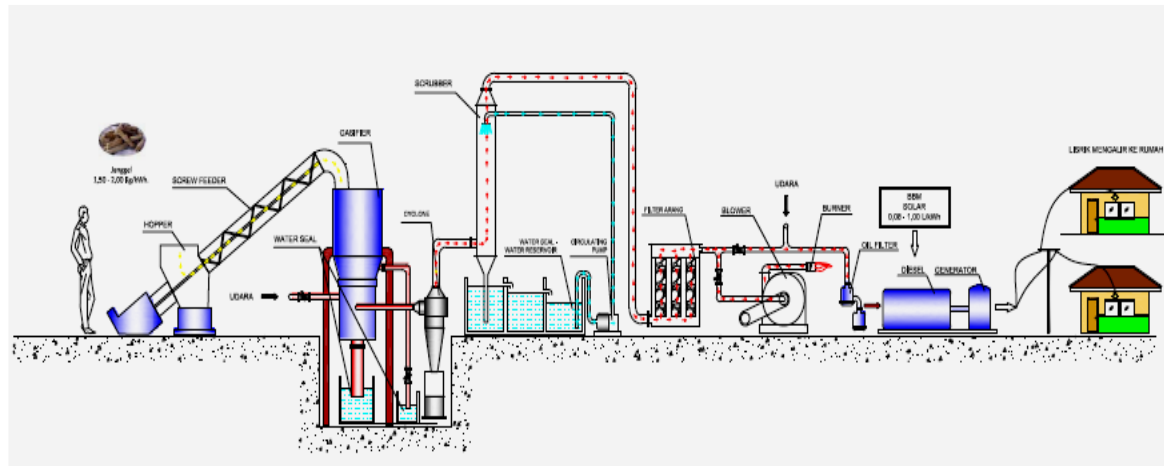


Figure 1. Gasification of corn cobs for rural electricity in Pelaihari, South Kalimantan.

The oil replacement during *dual fuel* operation of the diesel engine was about 70%. In dual fuel operation, fluctuations of gas quality may be compensated automatically with consumptions of diesel fuel. This integrated biomass gasification and diesel engine-generator set consumed about 1.5-2.5 kg dry biomass per 1.0 kWh depending especially on the biomass quality.

Gas engine and diesel engine are basically internal combustion engines. A gas engine is a spark-ignition and requires gaseous fuel with a high methane number. While a diesel engine is compression-ignition and requires fuel with a high cetane number. This moment, gas engines are getting popularity for medium and low calorific gases including producer gas. The price of a gas engine is still higher and the number of manufacturer is limited. On the other hand, diesel engines have already been popular for rural electricity all over the country. Conversion diesel engine into gas engine by some modification with a minimum cost has also been studied [4].

3. Investment

This feasibility study was prepared in 2016 for a project started in operation in 2019 and hence currency values in 2019 are used in the following sections. Capacity of this proposed unit was 500 kWe, which was considered as an optimum based on the availability of biomass at the site. Fixed capital cost was estimated based on our experiences on the 45 kWe gasification unit in South Kalimantan, in 2008 (Figure 1). The total investment for this unit was about IDR 220 million in 2008, and the unit comprised of:

- 24% for gasification unit
- 54% for engine-generator and electrical system
- 22% for transportation from Java to an oil palm plantation close to city of Pelaihari, in South Borneo, including the installation cost at the site.

The investment cost was extrapolated for scaling up using the sixth power law and also corrected for inflation using CEPCI (*Chemical Plant Cost Index*). The investment for 500 kWe biomass gasification coupled with gas or diesel engine was estimated to be USD 250,000 (IDR 3,375 million), or a specific investment cost of about 600 USD/kWe. This investment was much lower than those available in several reports as presented in Figure 2 [5, 6, 7].

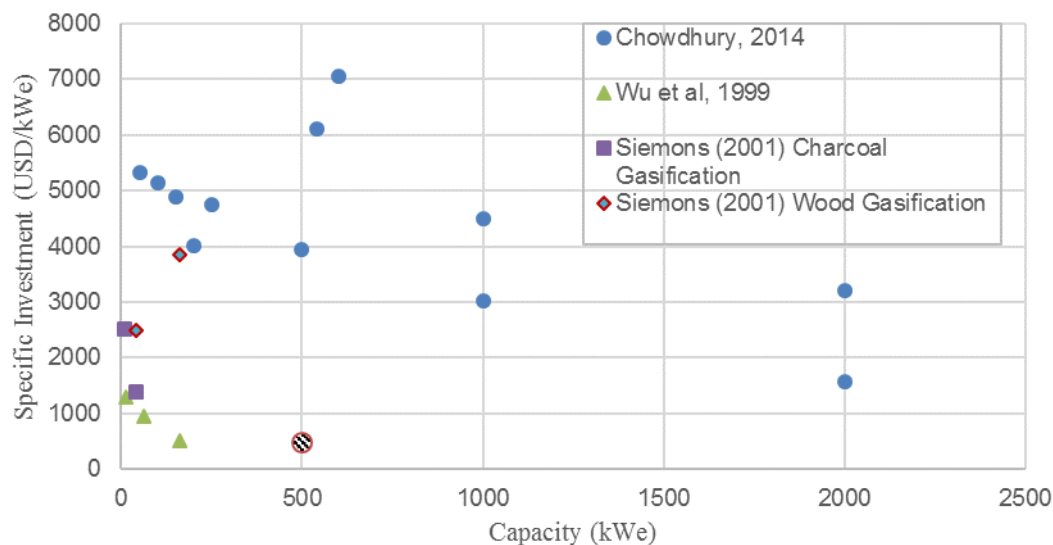


Figure 2. Specific investment for biomass to electricity via gasification [5, 6, 7].

The specific investment cost for biomass to electricity via gasification were in the range of USD 2100-6000/kW. Although there is a relatively low specific investment of USD 1000/kWe in USA was also found [8], which was more or less the same as our experience and as reported in China [8]. A similar value of investment was also found for a fluidized bed gasifier with capacity around 3 MW [9].

The following three configurations have been considered in this economic evaluation (Tabel 2).

- Case A.** A gas engine is used as a primer mover to drive for the electric generator. This system can be operated fully using the producer gas.
- Case B.** A diesel engine is used as a driver for the electric generator. This diesel engine is operated in the *dual fuel*. An oil replacement of 70% was assumed.
- Case C.** A diesel engine is operated fully with diesel liquid fuel as commonly implemented rural or remote areas.

Table 2. Investment cost for 500 kWe gasification system (values in USD).

No.	Components	gasification unit	yes	yes	no	References
		type of engine	gas	diesel	diesel	
1.	Gasification unit: gasifier, biomass feeder, cyclone, gas cleaning system using water scrubber, cooling water system, etc	Case A	47,919	47,919	0	authors' experiences
2.	Gas engine or diesel engine and electric generator, simple power house, and electrical box and wiring in power house		123,696	123,696	123,696	Wu, 1999
3.	Waste water treatment and solid waste handling (from gasification unit)		27,350	27,350	0	Wu, 1999
4.	Miscellaneous costs, such as: transportation of equipments, workshop, etc		49,444	49,444	49,444	authors' experiences
5.	Total Fixed Capital Cost		248,409	248,409	173,140	
6.	Working Capital		32,963	42,296	65,852	estimated
7.	Total Investment		281,372	290,705	238,992	calculated
8.	Specific Fixed Capital Investment (USD/kWe)		497	497	346	
9.	Specific Total Capital Investment (USD/kWe)		563	581	478	

The price of a gas engine was assumed the same as a diesel engine in this study. Fixed bed gasifier and cleaning systems account about 20% of the fixed capital investment. A waste water system also

accounted for a significant portion of the total investment (about 12%). This water scrubber should not be utilized anymore in the near future for the environment reason.

4. Production Cost of Electricity

Economic evaluation was carried out using the LCOE (*Levelized Cost of Electricity*), i.e. the price per unit of the net sold electricity for which the NPV (*Net Present Value*) of an investment is zero [10]. Thus finding LCOE is equivalent to finding the electricity price for a given IRR (*internal rate of return*) of a specified discount factor. The LCOE is less detail than Discounted Cash Flow having the real profitability for the developer [7]. The LCOE is a kind of breakeven price of electricity. If the electricity price is above the LCOE, the project gives good return, because the revenue from electricity is greater than the cost.

The LCOE is calculated using the following equations:

$$\text{LCOE} = \frac{\text{FCI} \cdot \text{CRF} + \text{OC}}{E} = \frac{A}{E} + \frac{\text{OC}}{E} \quad (1)$$

$$\text{CRF} = \left(\frac{r}{1 - (1+r)^{-n}} \right) \quad (2)$$

FCI = Fixed Investment Cost

CRF = Capital Recovery Factor

OC = Operating cost: fixed and variable cost

A = Annualized capital cost

n = life time of equipment

E = net sold electricity

r = interest rate, %/year

n = life time of project, years.

The simplified LCOE can also be used for modeling or policy development. The parameters and basic assumptions for calculation of LCOE are presented in Table 3.

The calculated production cost of electricity (LCOE) for 500 kWe electricity from biomass via gasification is presented in Table 4. Two modes of operation, i.e. 8 or 24 hour/day were evaluated in this study. This first mode of operation has been commonly implemented in rural area, where people use electricity only in the evening and in maybe also in the early morning. The second mode of operation is implemented in more developed areas, where electricity is utilized for various activities such as local offices, clinics, shops and market. Of course, the later mode of operation may be more economically attractive (see Table 4).

Fuel cost was found to be the main component of LCOE. The fuel cost might account for 44%-58% of the LCOE depending on the biomass cost of 0.03-0.06 USD/kg (a mid value was used in Table 4). In Case A (gasification unit coupled with gas engine), the biomass cost was more than a half of LCOE. While in Case C, the cost of diesel fuel was the most affecting parameter in the cost of electricity generation. The effect of the biomass cost on the LCOE in Case A and Case B were examined further (see Figure 3).

Oil palm plantation area would be very attractive for the implementation of the biomass to electricity via gasification. Five 100 kWe demonstration units were installed in the Province of Riau (Sumatra mainland) in 2011 – 2013. The oil palm biomass could be:

- kernel fibre: already collected in palm oil mill, but utilized totally as fuel in mill power plant
- palm kernel shell (PKS): already collected in palm oil mill, but utilized part as fuel in mill power plant
- empty fruit bunches: already collected in palm oil mill, but very poor characteristic for gasification and combustion
- oil palm fronds: left in the plantation, must be collected and pre-treated
- oil palm trunk: biomass generated during replanting every 20 years.

Comparison of LCOE against the *Fit in Tariff* for Sumatra where abundant biomass is available from oil palm plantation are presented in Figure 4.

In the cases of the daily operation mode of 8 hours, the biomass cost should not be more than 0.054 and 0.072 USD/kg for Case A and Case B respectively (Figure 3.a). While for the daily operation of 24 hours, the biomass cost might be as high as 0.08 USD/kg (Figure 3.b).

Table 3. Basic assumptions for economic evaluation (USD 1 = Rp 13,500).

No.	Parameters	Case A		Case B		Case C	
1.	Electricity generation, kW						
a.	Designed capacity	500		500		500	
b.	Sold (net production)	450		450		450	
c.	In house consumption	50		50		50	
2.	Costs of fuel						
a.	Biomass (IDR/kg)	400-800		400-800		400-800	
b.	Diesel fuel (subsidized, IDR/L)			7,000		7,000	
c.	Diesel fuel (not subsidized, IDR/L)	-		10,500		10,500	
3.	Operation time						
a.	Daily (hours/day)	8	24	8	24	8	24
b.	Yearly (days/year)	360	330	360	330	360	330
4.	Specific fuel consumption						
a.	Biomass consumption (kg/kWh)	1.30		1.30		1.30	
b.	Diesel fuel consumption (L/kWh)	-		-		0.29	
c.	Dual fuel operation:						
i).	Diesel fuel consumption (L/kWh)	-		0,09		-	
ii).	Biomass consumption (kg/kWh)	0.90		0,90		-	
5.	Utilities: water cost (IDR/kW produced)	15		15		15	
6.	Number of operators and staffs						
a.	operators (persons)	2	6	2	6	2	6
b.	non-operator staff (persons)	1	3	1	3	1	3
c.	supervisors (persons)	1	1	1	1	1	1
7.	Salaries (1000 IDR/ man-month)						
a.	operators	2,000		2,000		2,000	
b.	non-operator staffs	2,000		2,000		2,000	
c.	supervisors	5,000		5,000		5,000	
8.	Fixed capital investment:						
a.	case of low investment (USD/kWe)	497		497		-	
b.	case of high investment (USD/kWe)	523		523		-	
9.	Maintenance cost (% of fixed capital cost)	6.5%		6.5%		6.5%	
10.	Interest rate	11%		11%		11%	
11.	Capital Recovery Factor (USD/kWe)	0.117		0.117		0.117	
12.	Economic Plant Life, years	20		20		20	
13.	Working capital (% of yearly operating cost)	25%		25%		-	

Based on our experiences, the operation of gasification process required discipline operators and needed intensive maintenance, such as removal of ash from the gasifier, and removal of tar from the gas cleaning system. Automatic operation was possible, but it would increase the investment. Lub-oil of the engine had to be replaced about twice or three times more frequently than the engine normally. These technical aspects were decisive factors affecting the on-stream hours and days, and maintenance cost. So they eventually affected the economic feasibility.

5. Scheme of investment

Since the implementation of the biomass gasification technology requires an additional investment, and its implementation needs demonstration and promotion, the following three scheme has been proposed to extent Case A and Case B.

- Scheme-1: the business entity makes investment on both gasification unit and engine-generator. These are the base case as discussed above.
- Scheme-2: the business entity makes investment on engine-generator only, while the gasification unit is granted by the government or institution.
- Scheme-3; both gasification and engine-generator set were grants. So the business entity manage only the operating cost.

The proposed investment schemes represent one type of subsidy from the government. These scheme made differences in the annualized cost. Cost of electricity generation are presented in Table 5.

Table 4. Production cost of electricity at 500 kW.

No.	Operating time (hours/day)	Case A		Case B		Case C	
		8	24	8	24	8	24
1.a	Biomass (USD 0.045/kg)	0.063	0.063	0.043	0.043	-	-
1.b	Diesel Fuel (0.4 USD/L, Indonesia 2016)	-	-	0.051	0.051	0.163	0.163
2.	Utilities, water treatment, etc (USD/kWh)	0.001	0.001	0.001	0.001	0.001	0.001
3.	Salary of operators and staffs (USD/kWh)	0.008	0.006	0.008	0.006	0.008	0.006
4.	Maintenance (USD/kWh)	0.014	0.005	0.014	0.005	0.009	0.003
5.	Annualized capital cost (USD/kWh)	0.024	0.009	0.024	0.009	0.017	0.006
6.a	LCOE (USD/kWh)	0.110	0.084	0.141	0.115	0.199	0.180
6.b	LCOE (IDR/kWh)	1685	1,134	1904	1553	2430	2430
<i>Feed in Tariff</i> , category of a low voltage grid		USD/kWh (IDR/kWh)					
1.	Riau, Sumatra	0.0862 (1161)					
2.	Jambi, Sumatra	0.0668 (901)					
3.	Bangka Island	0.1161 (1567)					

Source: Indonesian Government Regulation, Ministry of Energy and Mineral Resource 12/2017

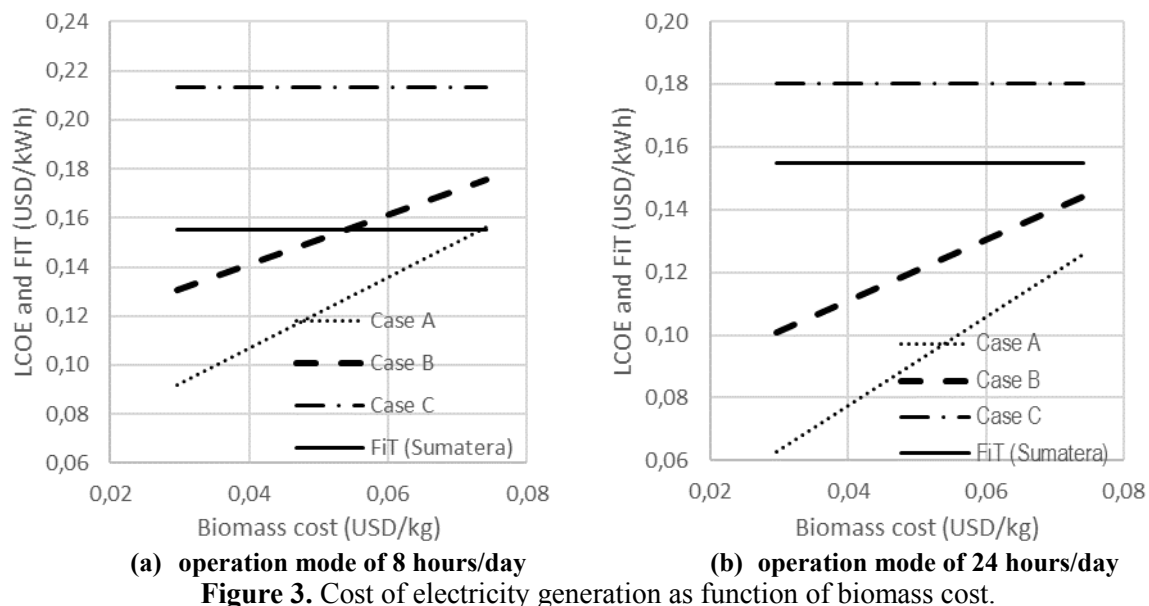


Table 5. Cost of electricity generation at three different scheme of investment.

No.	Parameters	Case A			Case B			C
		A1	A2	A3	B1	B2	B3	
1.	Scheme of investment:							
	a. Gasification Unit	inv.	grant	grant	inv.	grant	grant	-
	b. Engine and Generator	inv.	inv.	grant	inv.	inv.	grant	inv.
2.	LCOE in USD/kWh							
	a. operation mode: 8 h/day	0.110	0.103	0.086	0.141	0.134	0.117	0.199
	b. operation mode: 24 h/day	0.084	0.078	0.075	0.115	0.109	0.106	0.180
3.	LCOE in IDR/kWh							
	a. operation mode: 8 h/day	1,485	1,385	1,155	1,909	1,809	1,579	2,688
	b. operation mode: 24 h/day	1,132	1,052	1,012	1,556	1,476	1,436	2,434

Case B3 was implemented by the Ministry of Energy and Mineral, thorough Directorate of New and Renewable Energy, in 2011 – 2013. Five units of 100 kWe fueled with oil palm fronds were installed in Riau Province, in the main land of Sumatra. These units were designed, manufactured and constructed at the site by a domestic company in Jakarta. Training for operators and supervision for two months were also given.

A unit of 30 kWe fueled with rice husk was installed in Sumba Island in 2014, by the same domestic company as those in Riau. Another unit with a capacity of 1 MW was installed recently, in Sumba, 2016. The later was intended to be fueled with *Caliantra* wood from a pilot project of energy plantation. The electricity system comprised of a fixed bed gasification unit and five gas engine generator sets. In order to ensure tar removal, a refrigerated gas cooling was used. Tar removed the gas stream is dumped in a pond. This electricity generation plant was bought completely from a foreign manufacturer, probably with an expectation to have a reliable operation.

Case B2 is very interesting to be considered, since diesel engine and generator sets have already been popular in many remote places. So the government or funding institutions may contribute only for the investment on gasification unit and addition facilities, including and a little modification of the diesel engine.

6. Conclusions

Economic evaluation for gasification of biomass has been studied based on our field experience and information available in open literatures. An appropriate capacity for this rural electricity was in 100-500 kWe. The investment unit was approximated to be about 600 USD/kWe installed. The biomass cost affected electricity cost significantly. The biomass gasification unit was preferable coupled with a diesel engine to drive an electric generator, rather than with gas engine.

Following to implementing a biomass to electricity, local capacity building should also be developed for instance in creating economic activities for the optimum utilization of electricity. Local officers have to understand the philosophy of new and renewable energy resource in the near future. and understanding the principle of gasification process, and maintenance of engine running with gaseous fuel. The gasification unit may be manufactured in metal workshops in order to reduce the transportation cost, so the design of a gasification unit must be prepared and ready to be used.

Budget for operator training and a certain period of technical monitoring should also be provided in implementation of biomass to electricity. Participation of local agencies was very important in the implementation of the biomass gasification for rural electricity. The local agencies may play important roles, such as establishing management system, environment evaluation, and legal administration. Local academic or technical persons should also be invited for developing technical aspects and and development of economical activities.

Acknowledgements

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