Energy Efficiency of Biogas Produced from Different Biomass Sources

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Abstract. Malaysia has different sources of biomass like palm oil waste, agricultural waste, cow dung, sewage waste and landfill sites, which can be used to produce biogas and as a source of energy. Depending on the type of biomass, the biogas produced can have different calorific value. At the same time the energy, being used to produce biogas is dependent on transportation distance, means of transportation, conversion techniques and for handling of raw materials and digested residues. An energy systems analysis approach based on literature is applied to calculate the energy efficiency of biogas produced from biomass. Basically, the methodology is comprised of collecting data, proposing locations and estimating the energy input needed to produce biogas and output obtained from the generated biogas. The study showed that palm oil and municipal solid waste is two potential sources of biomass. The energy efficiency of biogas produced from palm oil residues and municipal solid wastes is 1.70 and 3.33 respectively. Municipal solid wastes have the higher energy efficiency due to less transportation distance and electricity consumption. Despite the inherent uncertainties in the calculations, it can be concluded that the energy potential to use biomass for biogas production is a promising alternative.

1. Introduction
Biomass is a name given to any organic matter available on a renewable basis. It can be used to produce biogas in order to reduce dependence on fossil fuels and to achieve environmental benefits. Palm oil wastes, municipal solid wastes, cow dung, sewage waste and landfill sites are the sources of biomass. By anaerobic digestion, the biogas produced can be used for heating, electricity production or as transportation fuel. However, for generating biogas some energy is needed which includes pumping and stirring of biogas reactors, fuels for transporting raw materials and digested residues. The energy efficiency and environmental impact vary with transportation distance, means of transportation, and potential gas production from biomass, conversion techniques and process parameters.

Though Malaysia is endowed with plentiful of natural resources like rubber, palm oil, tin, petroleum and natural gas, but the economic growth based on industrialization, combined with population and urbanization have created an expanding demand for energy[1, 2]. Hence reliable, secure and cost effective energy supply is very much needed. Not only that, efficient utilization of energy sources, diversification of sources and minimization of wastages are also emphasized by government [3]. The two most potential sources of biomass are palm oil residues and municipal solid wastes (MSW). The type and amount of biomass generated from palm oil residues and their heat value is shown in Table 1 and the potential energy from biogas is presented in Table 2 [4-6].

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Table 1. Biomass generated by palm oil mill

| Biomass | Quantity (million tonnes) | Moisture content (%) | Oil content (%) | Heat value (kJ/kg) |
|---------|---------------------------|----------------------|-----------------|------------------|
| FFB     | 18.25                     | 67                   | 5               | 18,883           |
| Fibre   | 11.11                     | 37                   | 5               | 19,114           |
| Shell   | 5.55                      | 12                   | 1               | 20,156           |
| POME    | 53.16                     | 93                   | 1               | 17,044           |

Table 2. Potential Energy from Biogas

| Year | Palm oil production (million tonnes) | Biomass (million tonnes) | POME (million m$^3$) | Biogas (million m$^3$) |
|------|--------------------------------------|--------------------------|----------------------|------------------------|
| 2002 | 13.3                                 | 14.2                     | 45.63                | 1,278                  |
| 2007 | 15.9                                 | 18.5                     | 53.55                | 1,499                  |
| 2010 | 16.9                                 | 19.6                     | 57.42                | 1,607                  |

The solid wastes generated in major urban areas are presented in Table 3 [7] which is increasing rapidly due to increase of urban population. The municipal waste is mainly comprised of domestic and industrial waste [8]. It is estimated that the amount of municipal solid waste (MSW) by the year 2020 will be about 9 million tonnes per year and the amount generated per day is 24,650 tonnes [9].

Table 3. Solid waste generated in major urban areas

| State            | Solid waste (tonne/day) |
|------------------|-------------------------|
|                  | 1998 | 2000 |
| Kuala Lumpur     | 2350 | 2800 |
| Penang           | 1220 | 1400 |
| Johor Bahru      | 450  | 500  |

2. Calculation Methodology

To calculate the energy efficiency three steps were adopted:

- Searching and collecting data for potential biomass in Malaysia
- Propose a location to produce biogas
- Estimation of energy needed to produce biogas and the output energy

The energy recovery is dependent on the volatile solids, fixed carbon content, inert, calorific value, C/N ratio (carbon/nitrogen ratio) and toxicity.

2.1. Palm oil wastes

The location considered for producing biogas from palm oil mill waste is Serting Hilir Mill. The details are provided in Table 4.

The energy needed for transportation is dependent on the distance of source of palm oil wastes and the lorry specification used for transportation. The capacity of each lorry is considered of 4000kg to calculate energy input for transportation. The mileage of lorry and energy consumed for per litre of oil are 7km/litre and 48 MJ/litre respectively [11]. Hence the energy used for transportation is as follow:

\[ \text{Energy use/tonne} = \text{(distance/7 km per litre)} \times \text{(48 MJ/litre)} \div \text{4 tonne} \]  

(1)

Energy needed to produce biogas from palm oil waste and energy obtained from biogas is presented in Table 5, considering Johor Bahru as a source of palm oil wastes.
2.2. Municipal Solid Waste (MSW)

It was observed by a study conducted by Japan International Corporation Agency that 45% of Malaysian

| Table 4. Palm oil Mill location [10] |
|-------------------------------------|
| Location                            | Serting Hilir Mill, Negeri Sembilan |
| Installed capacity                  | 60 T FFB/hour                        |
| Effective working days              | 5 days/week                          |
| Effective working hours             | 20 hours/day                         |
| Electricity from grid (MJ/t)        | 954.47                               |
| Methane composition (%)             | 65                                    |
| Amount of biogas from POME (m³)     | 22,554m³/day                         |
| Calorific value                     | 53,000kcal/m³                        |

| Table 5. Energy ratio for generated biogas from palm oil waste |
|---------------------------------------------------------------|
| Energy input (A)                                              | Energy output(B)                     | Energy ratio |
| (a) Power supply from grid 954.47 MJ/t                        | (Amount of biogas per day* calorific value)*capacity of FEB per day)*methane composition= (22,554m³/day*221.85MJ/m³ 1200t/day)*0.65= 2.71 GJ/t |
| (b) Transportation energy: (372km/7 km per litre)*(48 MJ/litre)+4tonne=637.71 MJ/t | B/A= 1.70 |
| Total energy= energy for transportation+ energy from grid= (a) + (b)= 1.59GJ/t |

MSW consists of food waste [12]. The MSW generation has increased from 5.6 million tonnes to 8.0 million tonnes from year 1997 to 2000 and hence there is an urgent need for a better managed disposal option [13]. In Table 6, the MSW generated in Kuala Lumpur is presented and it will be used as reference to estimate energy efficiency.

| Table 6. MSW generated in Kuala Lumpur [14] |
|---------------------------------------------|
| year                                        | KL population | Solid waste (T/day) | Amount collected |
| 1998                                        | 1,446,803      | 2,257               | 1,900             |
| 2000                                        | 1,787,000      | 3,070               | 2,500             |
| 2005                                        | 2,150,000      | 3,478               | 2,922             |

| Table 7. Energy ratio for generated biogas from MSW |
|-----------------------------------------------------|
| Energy input (A)                                     | Energy output(B)                     | Energy ratio |
| (a) Electricity used: 13.6MJ/t                        | (Amount of biogas per day* calorific value)*methane composition= (200 m³/t*19.15MJ/m³ 0.55= 2.11 GJ/t |
| (b) Transportation energy: 20 MJ/t                   | B/A= 3.33 |
| (c) Handling of raw materials: 0.6 GJ/t             |                                         |
| Total energy= (a) + (b) + (c) = 0.634GJ/t            | 2.11 |

Air Hitam Sanitary Landfill was considered as a location to produce biogas from MSW. The potential landfill gas production is estimated to be 1400 million m³ assuming that one tonne of MSW
is able to produce 200 m$^3$ of landfill gas [15]. The energy input for handling and transportation of raw materials and electricity needed for processing raw materials are 0.6 GJ/tonne, 20MJ/tonne and 13.6 MJ/tonne respectively [16].

Energy needed to produce biogas from MSW and energy obtained from biogas is given in Table 7.

### 3. Results and Analysis

All the possible energy inputs were considered. The electricity needed to operate the biogas plant, the energy for handling raw materials and transportation were considered as input energy. The energy output was taken from the calorific value of biogas produced. The energy efficiency of palm oil waste and MSW is 1.7 and 3.33 respectively. To utilize palm oil residues higher energy was used from grid. Hence alternate use of energy sources and reduction of transportation distance can enhance energy efficiency with palm oil waste. The transportation cost can be substantially reduced if the biogas plant is located within 20 km of biomass sources.

### 4. Conclusions

The two main sources of biomass to produce biogas are palm oil waste and MSW. Palm oil residue is the main contributor to produce biogas, while MSW has higher energy potential. The result presented in this investigation is a reasonable estimate based on Malaysian conditions but not the exact values. The energy efficiency of biogas produced from palm oil waste and MSW are 1.7 and 3.33 respectively. However, it can be concluded that whatever is the source of biogas, in terms of energy efficiency it is a suitable energy option.

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