ARIV
International Journal of Technology
Paper ID: AIJT12052020 Vol1 Issue 2 2020

A comprehensive investigation of suitable biomass raw materials and biomass conversion technology in Sarawak, Malaysia

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Abstract

Nowadays, reducing pollution, saving mother Earth had become everyone's responsibility. However, the great improvement in technologies leads to large energy demands. Many countries have tried to find renewable energy as their alternative energy source. Biomass has become one of the options of alternative energy sources. It has become a potential alternative source for Sarawak. An investigation has been conducted to ensure the suitableness of building a biomass power plant in Sarawak. A comparison of different biomass conversion technologies and biomass raw materials were made to select the most applicable biomass power plants in Sarawak in this article.

Keywords: *Biomass, power plants, Biomass conversion technologies, advantage and disadvantage of biomass*

Introduction

In this modern civilization, energy source has become a very important issue. Technologies have improved tremendously that human beings cannot live without it and these eventually increase the energy demands. According to Wong (2020), total power generating capacity is needed to increase 7,000 MW by 2025 by Sarawak Energy Bhd (SEB). This is to meet the desired demand of Sarawak Corridor of Renewable Energy (SCORE) phase two development.

According to U.S. Energy Information Administration, the main primary energy sources in Malaysia are Petroleum and other liquids and natural gas which estimated shares of 40% and 36% respectively in 2012 (Biomass Malaysia(2015)). 17% of Malaysia's energy consumption is met by coal. Renewable energy such as Biomass and waste, hydropower contributes 4% and 3% to total consumption respectively. Malaysian government tends to enhance and promote investments in sustainable and renewable energy to keep its economic growth as the country is heavily dependent on natural gas and oil (Biomass Malaysia(2015)).

Despite hydropower, biomass comes as the most potential renewable energy source in Sarawak. According to Sarawak Energy, Sarawak has shown the theoretical potential of biomass energy sources by producing 9,300,000 tons of oil palm fresh fruit bunch and 208,000 tons of paddy per annum. Chowdhury et al., (2018), Tay et al., (2017) and Ahmed et al., (2017) stated that Biomass is the oldest renewable energy source used. Biomass is an energy source based on a large variety of materials such as wood from various sources, agricultural residues, and animal and human waste (Biomass Sarawak (2015)).

The conversion of biomass to electricity can be done through several methods. According to Kashem et al., (2018), Touti et al., (2020) and Ahmed et al., (2019), the most common method used is direct combustion while other methods are gasification, pyrolysis, and anaerobic digestion. Gasification works by heating the biomass at a lower amount of oxygen compared to complete combustion producing biogas. By heating the biomass in the absence of oxygen with high speed, pyrolysis produces bio-oil. Renewable natural gas is produced from anaerobic digestion when organic matter is decomposed by bacteria in the absence of oxygen (Anaerobic Digestion (2015)).

Type of Biomass

Biomass for energy can include a wide range of materials. It is known as the energy that stores within the plants and organic matter. However, biomass can be split into two distinct categories which are waste biomass and energy crops.

Waste Biomass

Waste Biomass is usually the material left over from agricultural and forestry processes, and organic industrial, human and animal wastes. This waste biomass is abundant and can be easily be found.

Agricultural Residues

Agricultural residues encompass a wide variety of types. The agricultural residues can be divided into two divisions which are wet (such as animal slurry) and predominantly dry (such as straw). Khandakar et al., (2019), Kashem et al., (2017) and Kho et al., (2017) stated that Large quantities of agricultural residues are produced annually worldwide. These residues are mostly plough into the soil, or burnt, left to decompose, or grazed by cattle. The residues can be processed into liquid fuels and produce electricity or heat. Through the type of process, the residue will have different content of volatile matter, density, and burning time.

Animal Waste

It is very common in a certain country to use animal wastes as sources of biomass energy. The animal and poultry manures can be burnt to produce electricity and heats. These waste materials can be converted into biogas which can be used to drive engines, generate electricity, burning to provide cooking or water heating through anaerobic digestion (Chowdhury et al., (2019)).

Forestry Residues and Wood Wastes

Forestry residues and wood wastes are the same biomass source. The operation (such as thinning of plantations) generated forestry residues while wood wastes commonly generate waste from processing factories.

Industrial Wastes

There is a lot of waste produces from the industry factories annually. Hong et al., (2018) and Kashem et al., (2016) stated that The food industry is more suitable and can provide biomass energy sources with a large number of residues. The anaerobic process will digest the wastes to produce biogas which can be used as a source of energy.

Energy Crops

Energy crops are grown specifically for use as fuel which gives high output with low inputs. Potential crops were researched, chosen, and grown to enable the maximum outputs given by the desired harvest. According to research from Sarawak Energy in 2013, Sarawak has produced 9,300,000 tons of oil palm fresh fruit bunch and 208,000 tons of paddy per annum. Sarawak shows the potential of biomass energy sources. The oil palm fresh fruit bunch and paddy can be converted to biodiesel through trans esterification which is currently widely practiced (Biomass Sarawak (2015)) and (What is Biomass (2015)). According to Sarawak Energy research oil palm have more potential in electricity production than paddy (Biomass Sarawak (2015)). The total potential electricity produced by the palm oil is 325 MW higher than paddy which proves the potentiality of biomass materials in Sarawak.

Biomass Power Generation Technologies

The biomass resources have the potential to supply more useful energy at the same time reduced the impacts on the environment compared to fossil fuels. Throughout the research from Sarawak Energy, the potential of biomass has stimulated substantial research and development of systems in all aspects. These aspects included growing, harvesting, handling, processing, storing, and converting biomass to energy sources as well as other chemical products. Before using the biomass materials into the power generation, conversion can be done to enhance the potential output of the biomass energy.

Combustion

The most common technology used for energy production from biomass is through combustion. According to Siddique et al., (2017) and Mubarak et al., (2016), to lessen the transportation costs

of the biomass raw materials, the conversion of biomass into fuel with higher energy density is needed to be done first. The biomass is compressing producing dense pellets, cubes, or briquettes with various types of material used. Chowdhury et al., (2019), Tabassum et al., (2016) and Shabrin et al., (2017) stated that in a high-pressure boiler, the biomass is burnt to generate steams which drive the steam turbine. The net power cycle efficiencies for this type of conversion are about 23% to 25% (Dolf Gielen, (2012)).

Besides using the stream turbines, biomass also can use coal together in a coal-fired power plant to produces electricity. According to IRENA, using direct co-firing can be co-fired up to 5-10% of biomass energy while with extensive pre-treatment of the feedstock with minor changes in the handling equipment, 50-80% of biomass energy can be co-fired (Dolf Gielen, (2012)).

Gasification and Pyrolysis

According to the research from IRENA, biomass is degraded into gaseous or liquid form using the heat of combustion. In the presence of oxygen, gasification heated the biomass to produce primarily gaseous fuels. The resulting gas is a mixture of carbon monoxide, water, CO2, char, tar, and hydrogen which can be used in combustion engines, micro-turbines, fuel cells, or gas turbines. Higher electrical efficiencies can be achieved compared to the achievement in a steam turbine (Dolf Gielen, (2012)).

By rapidly heating the biomass in the absence of oxygen, pyrolysis produces a mixture of oils, gases, and solid charcoal. It is similar to gasification systems. According to Kashem et al., (2020), and Nabipour-Afrouzi et al., (2018), at lower temperatures (450°C to 600°C), the partial combustion is stopped and creates a liquid bio-oil, as well as gaseous and solid products. These end products can be used as fuel to generate electricity (Dolf Gielen, (2012)).

Anaerobic Digestion

Simple biogas can be produced through anaerobic digestion by decomposing organic matter in an oxygen-deprived environment. The resulting gas consists mainly of methane and carbon dioxide which is biogas. The clean-up biogas can be used as materials to drive the combustion engines, micro-turbines, gas turbines, fuel cells, and Sterling engines (Dolf Gielen, (2012)).

Comparison between different biomass conversion technologies

Different types of biomass conversion energy will give different efficiencies and costs. Three main thermos-chemical conversions can compare which are combustion, gasification, and pyrolysis. Each type of conversion will have slightly different properties.

By using different types of turbines, fuel cells and engines will provide different levels of efficiency produced. However, not every type of conversion are suitable for every turbines and engine (EAI (2012)). To convert the biomass products into energy, combustion needs a high oxygen supply to burnt the biomass while gasification needs a lesser amount to compare to combustion whereas pyrolysis needs none of the oxygen. Due to the oxidizing agent properties, combustion will have the highest temperature range compare to gasification and pyrolysis. Pyrolysis has the lowest temperature range (Safe et al., (2014), and Shaila et al., (2018),).

By using different turbines and engines in power generation, different efficiency will be obtained. The turbine and engines used in power generation can only be used by a specific type of biomass conversion. The overall efficiencies of 60% to 90% can be obtained by recovering the heat from the gasification process and electrical generation. According to Sheikh et al., (2017), and Kashem et al., (2018), this process is called combined heat and power (CHP). This process can be done by combustion or gasification. From the gasification process and electrical generation equipment, the heat recovery is dropped through a series of applications with each step using a lower temperature. Table 1 shows the efficiency of using different types of turbines and engines (Roos, (2010)).

Table 1 Efficiency of using different types of turbines and engines

Turbine and Engines Used	**Type of Biomass conversion**	**Efficiency**
Biomass-fired steam turbine	Combustion	20% - 25%
Syngas-fueled engines and turbines	Gasification or Pyrolysis	30% - 40%
Using Combined Heat and Power	Combustion or Gasification	60% - 90%

Biomass Power Plants

Biomass power plants convert the biomass to produce electricity and distribute it to the consumers. Most of the biomass power plants use direct-fired combustion systems to produce electricity in which the biomass is burned directly to produce high-pressure steam to drives a turbine generator. Due to the massive increment of the total energy efficiency at about 80% compared to the standard biomass systems with efficiencies at about 20%, some power plants also use combined heat and power (CHP) systems (Roos, (2010)).

To build a biomass power plant, 15 to 100 acres of empty land is needed for all the facilities. The place for the biomass power plant is usually larger and landscaped. According to U.S. Department of Energy, the biomass electric generation system for a steam cycle is made up of several key components such as fuel storage and handling equipment, Combustor/furnace, Boiler, Pumps, Fans, Steam turbine, Generator, Condenser, Cooling tower, Exhaust/emissions controls, and System controls (automated) (Energy, (2015)).

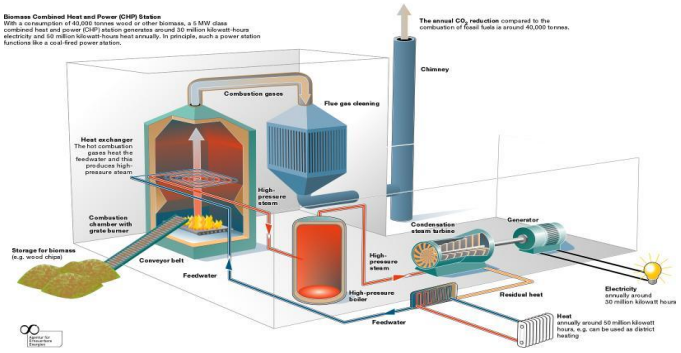

Figure 1: Biomass power generation using a steam turbine

Each of the components has its roles in contributing to biomass electric generation systems. The biomass systems use two types of storage to store the materials, for short-term storage is a bunker or silo while for larger storage is an outside fuel yard. The fuel from the outside storage area is conveyed by an automated control system using some combination of cranes, stackers, reclaimers, front-end loaders, belts, augers, and pneumatic transport (Energy, (2015)). Figure 1 shows the process of biomass power generation using a steam turbine (Bahena, (2015)).

During the direct combustion, the biomass feedstock is fed into a combustor or furnace in which steam is created from the boiler by burning the biomass to heat water in the boiler. Other than direct combustion system, combustible gas can be produced by using some developing technologies to gasify the biomass, while pyrolysis oils can be produced by other technologies which can be replaced with liquid fuels. All the boiler fuel such as wood chips, pellets, sawdust, or bio-oil has the same purpose which is heated up the boiler to produce steam. The steam produce from the boiler will drive a steam turbine or steam engine to run a generator and produce electricity. After that, the condenser of the power plant makes the steam return to its liquid state when the condenser tubes containing the steam is circulated with cooling water around it. Then, the boiler will be heated the condensed water again into steam to run the generator (Biomass Power Plants, (2015)).

Besides that, several numbers of closed-loop cooling systems have been introduced in power plants. According to the U.S Department of Energy, the "closed-loop" cooling systems in the biomass power plants are evaporative wet cooling systems and dry cooling systems. Through evaporative wet cooling systems, the cooling water removed the heat by evaporating some small amount of that water into the atmosphere. Thus, due to water loss to evaporation and the extra amount of water removed from the system (blowdown), additional cooling water is required continuously to maintain dissolved solids levels at suitable levels. Vapor plumes will happen under certain ambient air temperature and humidity conditions as the evaporated water condense rapidly to a liquid through the cooling system generator (Biomass Power Plants, (2015)).

Another closed-loop system is the dry cooling systems that cool the water through convection. However, this system is not suitable for monsoons country such as Malaysia. This system is efficient in winter months but less efficient in hot weather as the electricity demand in hot weather is in the highest state. The overall performance of the plant is affected by dry cooling systems with a penalty of 25% reduction for the hottest hour in power production and 10% of annualized power reduction generator (Biomass Power Plants, (2015)).

The exhaust systems in the power plant act as the ventilation to ventilate the by-products from the combustion to the environment. This ventilation controls included are cyclone or multi-cyclone, a baghouse, or an electrostatic precipitator (Energy, (2015)).

Potential Biomass in Sarawak

Nowadays, Sarawak becomes the last dividing line of oil palm development in Malaysia. According to research from Sarawak Energy, Sarawak has increased its oil palm planted area to 4.49 million hectares in 2008, which is 23.6% compared to 2.63 million tons in 2005. This leads to the increment to 43% which is 8.88 million tons of production of fresh fruit bunch in 2008 from 6.20 million tons in 2005. Table 4 shows the crude palm oil and palm kernel from the fresh fruit bunch (FFB) as well as the by-products such as fiber, shell, empty fruit bunch (EFB). These residues act as the main energy resources for the conversion to useful energies such as electricity, steam, and heat [3].

The most suitable conversion technologies for Sarawak

From the comparison results, combustion conversion is more suitable for Sarawak. Due to the massive amount of palm oil produced in Sarawak, the energy crops can be used as biomass fuels for power generation. In table 2, the raw materials (energy crops) are only suitable for biomass combustion conversion. Besides, by using combine heat and power (CHP), combustion conversion can give 90% maximum efficiency which is a huge range from the other methods. Although gasification can give the same efficiency, combustion conversion is chosen due to the raw materials available in Sarawak.

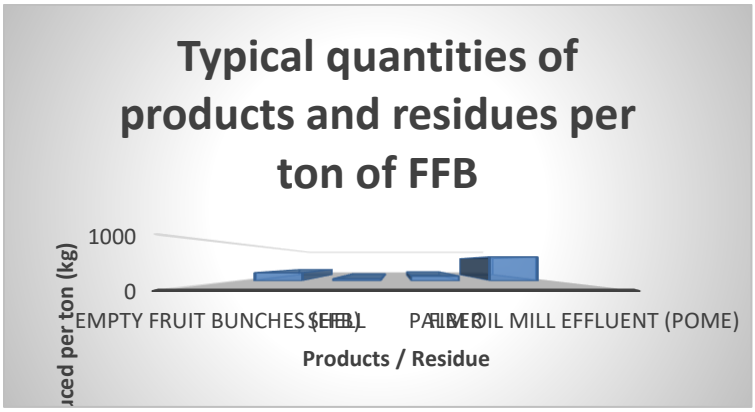

Figure 2: typical quantities of products and residues per ton of FFB

Figure 3 is derived from SarawakEnergy research [3]. From figure 3, palm oil mill effluent (POME) has the highest productivity among the residue materials while empty fruit bunches (EFB) come second-highest follow by fiber and shell. These residue materials can be used as biomass fuel to generate electricity. Although POME has the highest productivity among the residue materials, it does not produce the highest potential electricity generation. EFB has the highest potential electricity generation which is 125 MW compare to POME which has only 40MW.

The potentiality of power generation from palm oil residue has been analyzed in 2008 [3]. The whole palm oil seed produced 3,763,507 MJ of energy.

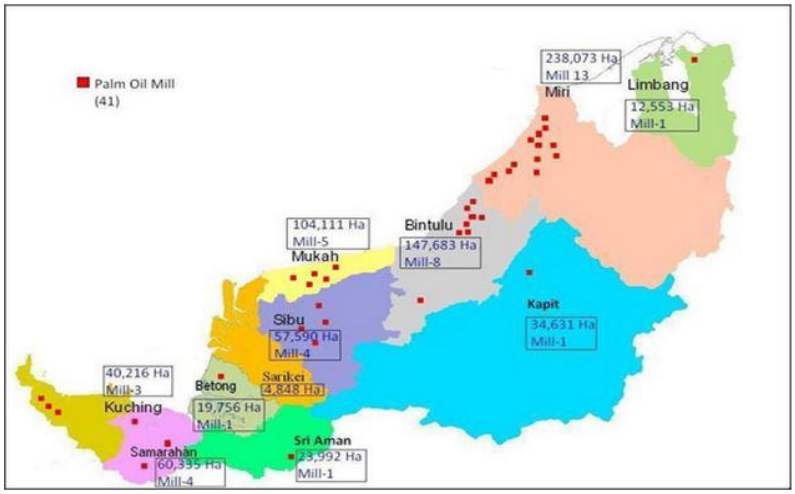

Figure 3: Distribution of palm oil mills in Sarawak

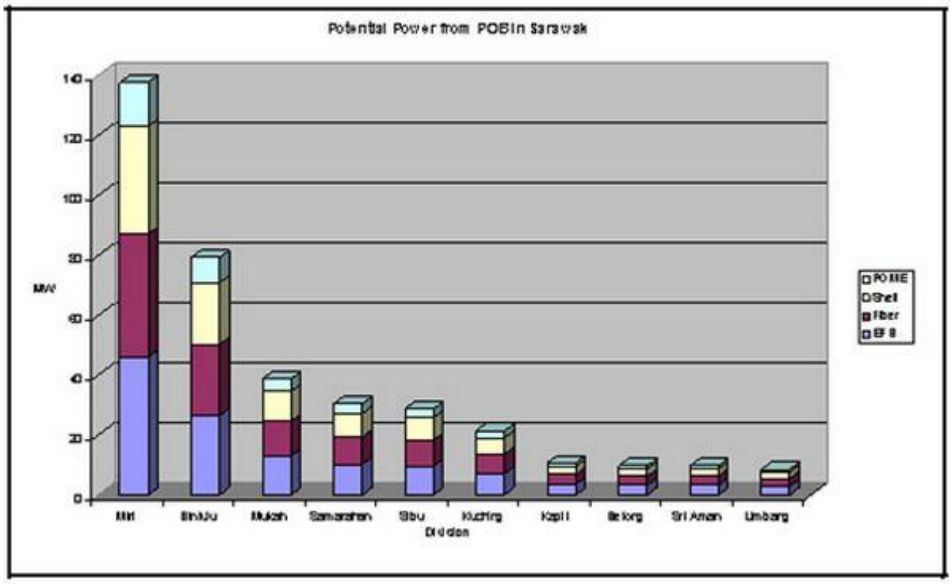

Figure 4: Graph of potential power in Sarawak

Figure 3 shows the distribution of palm oil mills in Sarawak in 2008 [3]. Figure 3, shows that Miri has the largest palm oil mills which have an area of 238,073 Ha. The palm oil mills of Miri are about 25% of the overall palm oil mills in Sarawak. Hence, Miri becomes the most suitable place to build a biomass power plant. With the graph shown in figure 4, Miri has the highest potential power compare to other regions [3]. The higher the amount of palm oil mills, the higher the potential power will be. This is because the power plants need materials to be able to produce electricity.

Fuels for Biomass power generation in Sarawak

In Figure 4, EFB and POME are not being deployed for power generation. These two raw materials have the potential to become a fuel source for renewable (RE) power generation. However, only empty fruit bunches (EFB) are supported. This is because EFB has more potential power generation than POME. Another reason is that only a small percentage of EFB will be returned to the plantation for soil desertification while POME released CH4 to the atmosphere [3].

From the calculation of Sarawak Energy, a calorific value of 6028 kJ/kg is produced by EFB at 65% moisture content. 1 ton of EFB will produce heat content of = 6,028 × 1,000 kJ = 6,028,000 kJ. A Rankine efficiency of 39.8% is given when steam is generated at 42 bar absolute (bara) with a high temperature of 500 ºC by a boiler and a pressure range between 42 bara and 0.035 bara is operated in a condensing turbine [3].

According to the analysis from Sarawak Energy, the total thermal efficiency is about 25% for power output. Hence, with 65% moisture, 1 ton of EFB will deliver 1,507,000 kJ of energy. Hence, **1,507,000 kJ = 1,507,000 / 3,600 kWh = 418.6 kWh**

This unit shows the potential of EFB as a biomass energy resource. Although the quantities of EFB produced in FFB are lesser than POME, the potential power generation produced by EFB is higher than POME which becomes the main reason for choosing EFB as the primary option for biomass energy resource. As the second-highest productivity in the residue materials also become the reason for EFB being chosen as the biomass energy resource in Sarawak.

Advantages of Biomass Energy

In many ways, biomass shows as a new potential source of energy. Since biomass comes from living sources, these products potentially never run out.

No harmful Emissions

During the production of biomass energy, combustion of the biomass is needed. However, this does not create harmful carbon dioxide emissions. Nowadays, many energy sources tend to control their carbon emissions. These gases will cause global warming as the gases can harm the ozone layer and increase the effects of greenhouse gases (Biomass Energy, (2015)). However, biomass is a part of the carbon cycle which means zero net carbon dioxide emissions affect its use.

Clean Energy

No harmful emissions eventually provide clean energy. Biomass is a part of the carbon cycle. During photosynthesis, the plants will absorb the carbon dioxide from the atmosphere. Then the plants will decay along the times or burnt and eventually release carbon into the atmosphere. The process is repeated. Hence, zero carbon emission occurs as the amount of carbon released from biomass fuel into the atmosphere, and the amount that they extract from it is balance. Due to the carbon cycle, biomass energy is clean energy and does not contribute to global warming (Energy, (2015)).

Abundant and Renewable

Since biomass comes from living sources, and life is cyclical, biomass will never run out. As long as there are living things on earth, biomass will excess. Hence, biomass can be abundant. The biomass can be recycled and renewable as the biomass is a carbon cycle. For example, the crops used for fuel can be grown again with certain (Energy, (2015)).

Reduce Dependency on Fossil Fuels

Using biomass as an alternate source of fuel will reduce the dependency on fossil fuels. Due to the high dependency on fossil fuels in Malaysia, these can reduce the use of fossil fuels and eventually increase the economics of the country as fossil fuels can be export to another country.

Reduce Landfill

To get biomass energy, the biomass has to be burnt down. By burning the biomass, the landfill can be reduced. According to Bioenergy technology ltd, around six million tones of wood are wasted by being sent to landfill in the United Kingdom each year (Advantages of Biomass, (2015)).

Cost-Effective

The energy harnessed from biomass is cheaper than coal and oil. The cost of harnessing the same energy using biomass is 1/3 lesser than using fossil fuels which means this can save 1/3 of the cost used for a power plant.

Disadvantages of Biomass Energy

Besides advantages, Biomass energy also has its disadvantages too.

Expensive

The equipment used for the biomass power plant is much expensive than the regular power plant such as fossil fuels or coal. The feedstock for biomass is expensive to care, feed for comparing to fossil fuels or coal which can be immediately used. This includes the harvesting and storing of different types of biomass (Biomass Energy, (2015)).

Inefficient as Compared to Fossil Fuels

The biodiesel produced from biomass which is Ethanol is inefficient compared to gasoline. Inefficient in the fuel used for the power plant will cause lesser energy produced. This eventually consumes more fuel used for the power plant to harness the energy needed. Apart from that, using ethanol over long term use is harmful to the combustion engines.

Require More Land

Different processes of harnessing energy from biomass require big areas of land especially the combustion of biomass products. For safety propose, the power plant needs to further away from the residential homes. To build a biomass power plant, the above factors have to be considered.

Impact of Biomass Power Plants

In Malaysia, building a biomass power plant will have an impact on social, environmental, and economic. It is important to understand the impacts of biomass power plants in Sarawak to determine whether it is worthy.

Employment

By building a biomass power plant, job opportunities will increases. Workers are needed in the power plants to maintain the efficiency of power generated from the power plants. Besides, palm oil will be highly needed which eventually increases job opportunities in the palm industry. Today, palm industries have employed over 860,000 people in Malaysia (Laan, (2015)).

Palm Oil Price and Food Price

McKendry (2002) stated that when the biomass power plants run, biofuel will be highly demanded. The food prices, especially those using palm oil increased This is because many of the palm oil has been allocated to generate electricity causing a decrease in the food supply.

Potential for Land Grabs

To obtain the biofuel to runs the power plants, further expansion of oil palm plantations will occur in Sarawak. Land development schemes are possible as the natural forest and Native Customary Rights land can be used for oil palm plantations.

GHG Emissions

By using biomass fuels, the greenhouse gases (GHG) emission will reduce. With the decreased usage of fossils fuels or coal, the carbon dioxide emission will decrease. The caloric value for coal is about three times of biomass's caloric value. The more the coal is replaced with biomass; the CO2 emission avoided is larger. This proves that by using biomass fuels will eventually help in reducing GHG release. The table below shows the CO2 reduction with the replacement of fossil.

Deforestation and Change in Land Use

There might be potential for deforestation in Malaysia to get more energy for the power generation by changing it to palm oil plantations. This has become a major concern because it can cause ecological damage and consequently leading to economic and social effects.

Extra Income from fossil fuels

According to U.S. Energy Information Administration, the main primary energy sources in Malaysia are Petroleum and other liquids and natural gas which estimated shares of 40% and 36% respectively in 2012 These fossil fuels can be export to another country for economic purpose. Hence, by using biomass energy, the demands on fossil fuels in Malaysia reduce which means extra fossil fuels can be export to other countries and provide extra income for the country.

Conclusion and Recommendation

By summing up all the research, Sarawak does have the potential to have a Biomass power plant. Due to Malaysia's heavy reliance on oil and natural gas, the government tends to promote investments in renewable energy to sustain its economic growth. Despite hydropower, biomass comes as the most potential renewable energy source in Sarawak. This can be shown by the theoretical potential of biomass energy sources by producing 9,300,000 tons of oil palm fresh fruit bunch and 208,000 tons of paddy per annum. The oil palm fresh bunch gives much more potential energy which becomes the primary choice for biomass materials for power generation.

Through the analysis between different biomass conversion technologies, combustion conversion is more suitable to use in Sarawak. Due to the massive amount of palm oil produced in Sarawak, the energy crops can be used as biomass fuels for power generation. From table 2, the raw materials (energy crops) are only suitable for biomass combustion conversion. Besides, by using combine heat and power (CHP), combustion conversion can give 90% maximum efficiency which is a huge range from the other methods. Although gasification can give the same efficiency, combustion conversion is chosen due to the raw materials available in Sarawak. The amount of carbon dioxide emission in combustion is higher than gasification. These matters can be solved by using the

exhaust system in the power plants. This system acts as ventilation to lessen the harmful gases to the atmosphere.

Besides, the empty fruit bunches (EFB) is supported as a source of fuel for renewable (RE) power generation. This is because EFB has more potential power generation than POME. Although the quantities of EFB produced in FFB are lesser than POME, the potential power generation produced by EFB is higher than POME which becomes the main reason for choosing EFB as the primary option for biomass energy resource. As the second-highest productivity in the residue materials also become the reason for EFB being chosen as the biomass energy resource in Sarawak.

Furthermore, Sarawak has a massive land area to build a power plant. There are many land development schemes available in Sarawak. This greatly solves the problems for the land required for power plants to function. However, land grabs will occur since no residential can be allocated near the power plants. The massive amount of land has solved the following problems.
In conclusion, biomass power plants have the potential to become one of the primary renewable energy sources in Sarawak. Building a biomass power plant does have its pros and cons but if the cons are reduced and taken properly. Biomass power plants will provide the massive potential of energy to the people in Sarawak.

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