Waste to Energy in Malaysia

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1. Introduction

Inevitably, energy plays a vital role on our social life and fossil fuel forms of energy meet the most part of our energy demand. Fossil fuels are exhaustible whereas global energy demand is increasing. Furthermore, they pose significant and principal adverse impacts on environment and public health. As a consequence, societies are seeking alternatives to substitute the fossil fuel consumption. The issue of utilizing agriculture waste to produce energy has always been the matter of debate for the societies.

Biomass is one of the renewable energy that resolves the detrimental environmental impacts and other problems of fossil fuel form of energy. It is commonly available in the form of agriculture waste as well as other wastes such as industrial and municipal solid wastes. Bioenergy generated from anaerobic digestion of biomass such as biogas, is a promising source of energy to produce heat, electricity and hydrogen for fuel cells or to use as vehicle fuel [1].

Due to the tropical hot and humid climate of Malaysia, it is considered as the leader of producer and exporter of palm oil in the world. Consequently, the primary agriculture source for implementing waste-to-energy is palm oil biomass wastes. Biogas production and incineration are the most common techniques for production and recovery energy from palm oil biomass wastes. Animal manures also can be considered for agriculture waste-to-energy implementation.

Biogas is an environmental friendly mixture of gases, mainly methane and carbon dioxide produced by anaerobic digestion of organic matter such as agriculture wastes, municipal solid wastes and industrial wastes. Generally, fermentation of agriculture wastes alone contributes to low content of biogas product. Consequently, co-fermentation of agriculture wastes alongside non-agriculture wastes is utilized for biogas production.

Waste to Energy (WTE) involves any waste treatment process to convert non-recyclable waste materials into useable energy through a variety of processes, including combustion, gasification, pyrolization, anaerobic digestion, and landfill gas (LFG) recovery. Due to the huge amount of the municipal solid waste (MSW) produced daily in urban areas, the attentions are focused on MSW processing as the feedstock to such technologies. The most common and widely used MSW-to-energy technologies are incineration in a combined heat and power plant (CHP) and controlled landfill to capture methane from waste (LFG).

It has been proven that the higher advancement in economics, the higher the amount of MSW produced. With appropriate MSW treatment it would provide an attractive investment since its fuel received almost for free contrary to other feedstock utilized for energy generation, thus maximizes the revenue margin for the WTE plant operators [2]. However the increasing rate of the environmental consciousness as well as certain financial and technical parameters have made blockage in the way of these technologies to spread rapidly. The reality is, although WTE technologies employing MSW as their feed-in materials are well developed but the disconformity of the MSW composition, the complexity of the treatment facilities, and the pollutant emissions still express considerable issues for these technologies. Soaring population, increasing urbanization and economic promotion are significantly altering the urban solid waste regarding generation rates, waste composition and process technologies. In regard to the waste composition, there would be transmit towards an increased percentage of plastic and paper in the whole waste combination mainly in the high-income countries [3].

Malaysia has been proven as a fast emerging economy country and its future of energy generation and sustainable development is at the center of attentions. It has been estimated that each 1% growth in its GDP to be along with 1.2–1.5% increase in energy demand [4]. Extraction energy from waste reduces the rate of current landfill usage and simultaneously decreases greenhouse gas emissions, as the produced energy might be a replacement to equivalent sum of energy from fossil fuels. This work discusses WTE technologies in Malaysia by considering the energy potentials of the landfill sites and incineration plants as the most common effective waste management in Malaysia.

This paper is carried out to investigate the potential of conversion wastes to energy in Malaysia, namely municipal solid waste (MSW), agriculture waste and industrial waste.

2. Municipal Solid Waste (MSW) to Energy

2.1 Malaysian MSW characterization and rate

The amount of waste and its composition varies for different urban and rural areas of a country and it is a function of size, socioeconomic, cultural, environmental awareness and level of the 3R's (reduce, reuse and recycle) practiced. A study of waste generation projects 3% of annual increase for Malaysia [5]. The average composition of Malaysian MSW consists of about 45% food, 24% plastic, 7% paper materials, 6% iron, 4% wood, and 3% glass and the remaining percentage belongs to others [6] thus, remarkable amounts of Malaysia MSW is recyclable. The moisture level of Malaysian MSW is in the range of 52-66% that reduces their calorific value [7].

Table 1 Municipal solid waste generation in Malaysia by state with annual increment of 3 % [8]

States	Estimates Solid Waste Generation								
	2012	2013	2014	2015	2016	2017	2018	2019	2020
West Malaysia									
Johor	2891.5	2970.0	3048.5	3127.0	3205.5	3284.0	3362.5	3441.0	3519.5
Kedah	1998.6	2052.9	2107.1	2161.4	2215.6	2269.9	2324.1	2378.4	2432.6
Kelantan	1549.8	1591.9	1634.0	1676.1	1718.2	1760.3	1802.4	1844.5	1886.6
Melaka	773.9	794.9	815.9	836.9	857.9	878.9	899.9	920.9	941.9
Negeri Sembilan	1138.6	1169.5	1200.4	1231.3	1262.2	1293.1	1324.0	1354.9	1385.8
Pahang	1439.7	1478.8	1517.9	1557.0	1596.1	1635.2	1674.3	1713.4	1752.5
Perak	2297.0	2359.3	2421.7	2484.0	2546.4	2608.7	2671.1	2733.4	2795.8
Perlis	294.1	302.1	310.1	318.1	326.1	334.1	342.1	350.1	358.1
Pulau Pinang	1636.0	1680.4	1724.9	1769.3	1813.8	1858.2	1902.7	1974.1	1991.6
Selangor	4251.4	4366.8	4482.2	4597.6	4713.0	4828.4	4943.8	5059.2	5174.6
Terengganu	1327.8	1363.9	1400.0	1436.1	1472.2	1508.3	1544.4	1580.5	1616.6
Kuala Lumpur	3953.8	4061.1	4168.4	4275.7	4383.0	4490.3	4597.6	4704.9	4812.2
WP Labuan	96.7	99.3	102.0	104.6	107.3	109.9	112.6	115.2	117.9
Total	23648.9	24291.0	24933.1	25575.2	26217.3	26859.4	27501.5	28143.6	28785.7
East Malaysia									
Sabah	3435.0	3528.2	3621.5	3714.7	3808.0	3901.2	3994.5	4087.7	4181.0
Sarawak	2628.0	2699.3	2770.7	2842.0	2913.4	2984.7	3056.1	3127.4	3198.8
Total	6062.9	6227.5	6392.1	6556.7	6721.3	6885.9	7050.5	7215.1	7379.7
Grand total	29711.8	30518.5	31325.2	32131.9	32938.6	33745.3	34552.0	35358.7	36165.4

Table 1 shows municipal solid waste generation in Malaysia by state from 2012 to 2020. According to the table, total daily generation of MSW in Malaysia was 29,711 tons/day in

2012, 30,518 tons/day in 2013 and may range for different areas e.g., from 45 tons/day in Klang to 3000 tons/day in Kuala Lumpur. It also predicts overall of 36,165 tons/day of waste in the whole country by the year 2020 while an average of 70% of the total generated waste is collected in the country [8] and only 1-5% is estimated to be recycled currently [7].

2.2 landfilling in Malaysia

Landfill is the most common and least expensive method of waste disposal in the world but the least desirable option as well. To date, over 80 % of the collected MSW has been landfilled as it is the major disposal technique in Malaysia; however, this method has become challenging to cover the increasing rate of MSW generation in Malaysia since, the current landfills are reaching their capacity limits also due to land scarcity it is difficult to establish new sites [9]. CH4 and CO2 form the major landfill gases (LFG) with relative amounts of 55–60% by volume, respectively. Composition of the waste, availability of biodegradable organic materials, age of the waste, moisture content, pH and temperature are the main parameters that affect methane generation in landfill. For Malaysia it has been estimated 370,000 tons of methane emission for the year 2020, which is equivalent to 2.6 * 109 kWh of electricity generation [10].

In regard to the number of landfill sites in Malaysia, in 2001 there were 155 landfills in operation. The number increased to 161 in 2002 and 176 by 2007. Presently there are 176 operational and 114 non-operational landfill sites [11] while methane recovery is implemented only in five of the active sites which only one of them is located in west Malaysia (Sarawak). The Pulau Burung facility with the greatest amount of MSW disposal of 19,050,000 tons, recovers 45,538 tons CO2eq and the Bukit Tagar facility has the highest methane recovery potential of 219,625 tons CO2eq with 2850,000 tons of waste deposited so far [12].

While landfill is the most widely used method in Malaysia but it must be precisely engineered for any particular district in order to control the emissions, which are harmful to the environment. Over 80% of the collected Malaysian MSW is landfilled whereas most of the sites are open dumpsites, unsanitary and over-loaded in capacity [13]. To tackle the issues the sites must be upgraded to sanitary status and collect the generated LFG for recovery.

In 2012, the Ministry of Housing and Local Government of Malaysia reported altogether 165 operational landfills that servicing 95 % of Malaysian total waste disposal with only 8 of them sanitary [14]. Another study in 2013 [15], reports total of 14 sanitary landfills that 10 are located in west Malaysia and four in Sarawak (an eastern state). All these statistics represent that 10 % of the total operational landfill sites in the country are of sanitary status.

2.3 Incineration in Malaysia

Waste incineration technologies are categorized as Combustion, Pyrolysis, Gasification, Plasma decomposition and Detonation. In general, incineration involves burning waste to boil water, which to run steam generators to produce electricity and/or heat to contribute in our energy needs. One problem associated with incineration is the potential pollutants that are dispersed into the atmosphere by the exhaust gases from the boiler(s).

Due to the issues associated with landfilling, the Malaysian government dedicated a special committee from the cabinet ordering them to propose a holistic waste management frame for the country particularly for populated areas and the committee proposed to place emphasis on development of incineration facilities to contribute in tackling the problems [16].

First, small-scale facilities introduced to Malaysia in 1996 to be implemented in the popular Malaysian tourist islands namely, Langkawi, Labuan, Pangkor, and Tioman to manage their waste disposal. These facilities normally involve three systems i.e., Incineration, Scrubber and Shredder. Tioman Island's facility consists of two 3-ton-capacity incinerators and as reported in 2001, they incinerated an overall of 3221 tons of MSW throughout the year [17]. In these islands, none of the facilities are capable to recover the energy from combustion except for the one operating in Langkawi Island, which has the capacity of generating 1 MW of electricity [18].

The most comprehensive incineration plant in Malaysia belongs to Core Competencies Sdn Bhd (CCSB) Company established in 2008 that is located in Semenyih, Selangor and operates based on refuse-derived fuel (RDF) technology which requires more pre-processing steps prior to the actual incineration and involves four major processing steps, namely, physical separation of incombustible materials, reduce moisture, decrease size and palletizing (to ensure size homogeneity). The power plant is comprised of a single 8.9-MW extraction condensing turbine generator and a 55-ton steam generator. Its boiler operates at load of 46-ton/hour and delivers 38 tons of steam to the turbine and 8 tons to the process plant at 338 lb./in2 absolute pressure through a pressure-reducing valve to generate hot air for the waste-drying step by secondary heat exchanger [19]. Its actual capacity is 1000 tons of MSW/day and 8.9 MW of electricity generation and it is currently operating on 70% of its actual capacity and exports approximately 5MW electricity to the grid.

The major problem associated with the Malaysian is the high level of moisture, which reduces the calorific value as it was found to be in the range of 1500 and 2600 kcal/kg [20]. In 2008, it was reported that the use of small-scale incinerators operating in the tourist islands were discontinued due to poor maintenance servicing and the high cost of their operation imposed by the high moisture of the waste since, moisture increases fuel costs [9]. But again in 2012, it was reported that they became active based on the volume of waste generated.

As result, it is a challenging issue to adopt an incineration technology that is able to operate with low calorific feed-in materials economically and the situation becomes worse when there is an alternative technique without such complexities i.e. landfilling but, it must be taken into account although the landfill method is cheaper but for long term period experts claim that landfill technique emits more CO2 while incineration along with recycling and energy recovery systems, reduces the emissions while saving cost of energy generation by reducing fossil fuels share [10].

Waste sorting at source can be considered as an relief to make incineration affordable in Malaysia. With proper sorting at source i.e., separating materials that hold good heating values (RDF), the moisture content of the waste will significantly drop and the calorific value enhances. Other challenge faced by the incineration industry is to meet the very stringent emission standards to not only minimize their impacts to the environment but also to ensure the public that such technology is not going to affect their health. One instance has been the controversial Broga incinerator project in Malaysia [21]. It was about to be built but due to high public outcries/complains and the large investment needed (USD400 million) subsequently, the project was discarded [4]. In 2007, the Prime Minister of Malaysia (chair of cabinet committee on solid waste management) stated that incineration plants would be built in the near future, regardless of public opposition [22].

3. Agriculture Waste to Energy

Anaerobic digestion is a technology by which microorganisms break down biodegradable material in the absence of oxygen. Anaerobic digestion of agriculture wastes (crops and manure) is implemented widely for waste management, energy production, energy recovery and reducing greenhouse gas emission and pollution [23]. Furthermore, agriculture wastes are used for composting, improving soil quality and animal fodder [24].

3.1 Animal Manures

Animal manures used for energy generation in Malaysia are mainly pig, poultry and cow. Gasification of animal manures to produce ethanol and methanol requires expensive technologies and machineries [4]. CH_4 is produced by anaerobic digestion of animal manures whereas N_2O is produced by nitrification and denitrification of the organic nitrogen in livestock manure and urine. Anaerobic digestion occurs in liquid from or slurry in lagoons, tanks and pits. Leaving animal manures in solid forms in land areas leads to harmful environmental effects. They can pollute lands and waters as well as endangering public health. Moreover, due to the fact that there are so many animal manures in the land, distribution of manures in the land is not possible. Manure management, improving land, improving diets for animals, production of methane from manures contribute to resolving adverse environmental effects of spreading manures on the land [25].

3.2 Agriculture Crop Wastes

Malaysia is located in the equatorial region, and has a tropical rainforest climate and it is being hot and humid throughout the year. Oil palm grows significantly in the areas of tropical climate. Consequently, Malaysia is the leading producer and exporter of palm oil in the world. It is reported that the total palm oil plantation area in Malaysia was 4.98 Mha in 2011[26].

The mass ratio of palm oil to dry biomass production is about 1 kg to 4 kg, excluding palm oil mill effluent (POME) [27]. Palm oil mill effluent is a wastewater generated during palm oil mill processes and contains extremely polluting characteristics. Table 2 demonstrates the amount of palm oil biomass available in 2011.

The total palm oil biomass is approximately 87 Megaton which has total energy potential of 37 Million Tons of Oil equivalent. Although palm fronds, palm trunks and palm kernel cake are excluded in Table 2, they are also considered as palm oil biomass wastes and contribute to energy utilization. Palm kernel cake is obtained from palm kernel when oil has been removed from the kernel [28].

Table 2 The amount of biomass available as of 2010 in Malaysia [27]

Biomass available From palm oil industry	Quantity (Mt/y)	Net calorific value (MJ/t)	Potential energy (MTOE[1]/y)
Dry biomass			
Empty Fruit Bunch (EFB)	21.27	18795	9.55
Mesocarp fibre	10.8	19055	4.92
Palm kernel shell	4.98	20093	2.39
Palm Oil Mill Effluent (POME)	49.85	16992	20.23
Total	86.90		37.09

[1] 1 MTOE (Million Tons of Oil Equivalent)= 41868×10^6 MJ

Approximately, for 1 tons of crude palm oil generated from fresh fruit bunches (FFB), different amount of dry palm oil biomass wastes can be collected, namely

- Palm fronds (6 tons)
- Empty Fruit Bunch (5 tons)
- Palm trunks (1 ton)
- Mesocarp fibre (1 ton)
- Palm kernel shell (500 kg)
- Palm kernel cake (250 kg)

And 100 tons of palm oil mill effluent (POME) [29].

Generally, in palm oil mill industry, Mesocarp fibre and Palm kernel shell are used as boiler fuel for electricity and steam generation for the internal combustion processes. Empty Fruit Bunch (EFB) waste is less used as fuel for energy generation compared to other palm oil wastes due to its high moisture content. It is usually used for improving soil condition and composting [30]. Palm Oil Mill Effluent (POME) can be processed to generate methane or biogas. Other palm oil wastes as well as EFB are either incinerated for energy recovery and mulching or dumped in open landfills [27, 28].

Other main agriculture crop residues which can be used for Malaysia waste to energy conversion, especially biogas are rubber, cocoa, rice husks and coconut. cassava, corns, corn straws, paddy straws and sugarcane can also be implemented as biomass energy [31].

4. Industrial Waste to Energy

Any material that is considered not to be useful inside industries' manufacturing process is considered as Industrial waste. The environmental concerns around industrial waste have always been a matter of controversy. Waste treatment, water waste treatment and sewage treatment are some of the solutions prepared for environment. Regulations and standards are created around the world to manage and reduce industrial waste and its impacts on environment.[32]

4.1. Thermal Conversion

Incineration, pyrolysis and gasification are the techniques which are included in waste's thermal conversions. The production of various by products which have subjected to various energy and resource recovery techniques for treatment is the result[33].

Incineration is the most common waste to energy implementation, which is the combustion of organic waste material with recovery of the released energy. The differences between modern and old incineration plants are significantly considerable, while the previous one's recovered neither materials nor energy. The amount of volume reduction in modern incinerators has reached to 96 percent of original waste. Although the emissions of incineration are relatively low, strict emission standards for nitrogen oxides, sulphur dioxide, dioxin and heavy metals are implemented among most of the countries new incineration plants. However, due to new implemented methods, the amount of emission is less significant than previous. Management of residues like toxic fly ash and incinerator bottom ash is one of the other concerns. Although there is some argues about incineration affects the motivation to recycle, European countries recycle up to 70 % and for avoiding landfill, incinerate their residual wastes[34].

As the incinerators have 14 to 28 % of efficiency in electricity generation, the remained heat can be used for heat recovery or district heating as a cogeneration plant with more than 80 % efficiency.

Inevitably, more small and large incinerators will be utilized in Malaysia as it has been mentioned by Prime minister. In 2007, the government announced an Act which permits solid waste management by Federal government [10]. One of the most important concerns of this Act was 3R's sustainability (Reduce, Reuse and Recycle). As a result, it might cause to better future acceptance of incineration in future and have a positive sustainable effect by the means of recycling and waste to energy. Due to incineration costs, some waste management scenarios proposed by combination of recycling, biological treatment, landfill and incineration within Malaysia [35].

The Gasification process is to convert carbonaceous organic or fossil based material to carbon monoxide, hydrogen and carbon dioxide. The process is reacting in high temperatures (more than 700 °C) in presence of oxygen without combustion. The product gas is called syngas which is a fuel and the generated power from combustion of this fuel is considered as renewable energy source while the primary feed of the process were biomass[36].

The most significant benefit of gasification is that due to the higher combustion temperature, burning the syngas is more efficient than burning the original fuel, and also the process can be implemented on biodegradable waste.

Some of the advantages of gasification over incineration are[37]:

- ✓ The filtering of flue gas is much easier do to less amount of gas in compare to combustion gases.
- ✓ The fuel has potential to generate electricity through engines and gas turbines which is more affordable for companies than steam cycle and incineration plant.
- ✓ Syngas can be used to produce other synthetic fuels by gas to liquids chemical and processing.

One of the most important challenges on waste gasification technologies is about reaching an acceptable electric efficiency which is influenced by the consumption of waste processing, pure oxygen and filtering. The other concern is about keeping the plant running longer and not interrupted for cleaning and services.

4.2. Biochemical Conversion

Biomass which is natural material has a lot of efficient biochemical processes in nature to get its' material broke down and decomposed. The bacteria's enzymes or other microorganisms do the job of decomposition. Anaerobic digestion, fermentation and composting are some of the methods to implement in biochemical conversion.

Palm oil mill effluent (POME) is the discharged waste water from the palm oil extraction process facility. The huge amount of methane gas which has high Global Warming Potential (GWP) in comparison to other gasses from the anaerobic process is considerable. By using the produced methane as fuel for producing power and heat in cogeneration plants, it can be solved.

Waste water treatment facilities are one of the most significant components in Palm oil industry. Anaerobic process is the most efficient process with respect to large amount of POME produced in the crude palm oil production facilities and the chemical and physical properties of POME[38].

Large amount of biomass in Malaysia comes from agriculture and the processing industry with high energy extraction potential. Some of these plantations are palm oil, rubber, cocoa, wood and pepper which are under supervision of Ministry of Primary industry and Commodities of Malaysia. High amount of these plantations and the year by year increasing statistics show the high potential of electricity generation from biomass residues [39].

Malaysia Palm Oil Board has the supervision Palm Oil industry in Malaysia which is the second producer of it after Indonesia. In 2009, 39% of world production was from Malaysia[40]. This cause the country to produce a significantly large amount of palm oil related waste either in plantations and mills[41]. Although palm oil waste as a biomass has a very good potential to be used as an energy source, most of the power plants implemented steam turbine and just a few of them inside this industry use the waste to generate electricity. Among more than 500 mills in palm oil industry, only 10 of them are using their waste as fuel to generate power[42].

Malaysian wood industry also has the potential of energy extraction from biomass. There is only five cogeneration plants which are used wood waste and generate from 900 kW to 10 MW of electricity. These plants are considerable but there are not enough in compare to high amount and variety of wood production in Malaysia[43].

5. Conclusion

Malaysia is one of the countries in the world that significantly implements agriculture wastes to energy conversion technologies in order to develop sustainability. On account of climate conditions of Malaysia, the main agriculture source for energy production is palm oil biomass wastes. However, animal manures and other agriculture crops can also be processed for energy production. Agriculture waste-to-energy technologies include fermentation of agriculture wastes for biogas production and energy recovery by incineration.

Malaysia as a rapidly growing economic due to its increasing energy needs, soaring population, ascending waste generation and environmental concerns, is trying to alter its current energy mix to a new concept in which renewable and sustainable energy sources have much more contribution in. Attaining such goal helps to the sustainable development of the country as well as reduces their impact on the planet. Appropriate waste management techniques/technologies e.g. WTE, could help attaining such goals effectively. Currently, both LFG and incineration plants as the most common WTE methods are at different stage of development. The most practiced one is landfill while only a few are engineered properly to provide sanitary waste disposal and offer methane capture. On the other sides, there are only a few incineration plants operating in Malaysia and only one of them is capable to recover energy (electricity) from MSW and industrial waste in an economically viable way.

Considering that the current dominant disposal method is landfill so, LFG would provide an effective measure to reduce overall greenhouse gas emissions from landfills as well as dependency on fossil fuels. This becomes more desirable from financial point of view since upgrading current landfill sites tin terms of making them capable for methane capturing requires less capital investment comparing with that of a standard incineration plant with energy recovery system. To achieve higher pace toward sustainability, employing large-scale incineration plants with proper design and technologies to meet the special characteristics of Malaysian MSW is inevitable and the case attains more attention as landfill sites are becoming difficult to develop due to land scarcity. Financial viability, efficiency and air pollution of incineration plants must be studied holistically particularly for Malaysia due to its humid climate. One important parameter to increase incineration plants efficiency is waste sorting at source that requires upgrading the level of people's awareness and change in their attitude toward the environment.

In the future, with combination LFG and the recovered energy form incineration plants, the cleaner and cheaper energy can be at reach that will reduce environmental pollution and results in job opportunities for the local population while at the same time there will be less impact to the environment and upgrade in public health.

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