6 GENERAL DISCUSSION

Rapid population expansion increased the demand for food and other necessities. This resulted in the booming of global industrialization for mass-production of goods. However, the anthropocentric views tend to focus on human and their well-being alone (Odum and Odum, 2006). Industrialization and commercialization have become vital factors in determining the standard of living of the society. Consequently this creates a materialistic society that other aspects such as harmonizing civilization and the environment have been considered less important. Recently, more awareness emerges that sustainability of human development become an issue of concern. Generation of waste is considered as one major factor in sustainable development since all human activities produced waste as by-products (World Bank, 1999).

Urbanization occurring throughout the globe resulted with concentrated population within a confined area. This can be translated to the generation of more waste particularly municipal solid waste (MSW). In developed countries with high gross domestic production (GDP), various technologies have been incorporated into the waste management system. Therefore, highly efficient waste management not only prevented detrimental pollution impacts to the environment but also become a solution towards sustainable development for the country. On the contrary, developing and under developed countries are experiencing totally opposite scenario where existing waste management system in the country was not able to cope with the increasing rate and complexity of the waste generated. This resulted with environmental degradation where

land and water bodies become contaminated with various pollutants. Waste management in many developing and under-developed nations is generally practiced in an unsustainable approach and more economy-oriented. Environmental concern is placed much below in the hierarchy of the developing plans. Therefore, this resulted with dilapidation of the environmental quality. World Bank (1999) had reported that improper waste management is one of the three main problems faced by most municipalities in developing and under-developed nations. Malaysia as a rapidly developing country is also experiencing similar situation. The 3% annual increase in MSW generation resulted with the construction of more disposal sites. Current waste existing disposal sites are fast to be filled and normally need to be closed earlier than the original schedule due to unpredicted waste volume. This is happening due to lack of proper and effective waste management planning. Appropriate waste management planning is unachievable due to lack of updated and comprehensive data regarding waste composition and generation in the country. Privatization of waste management in the country which began in 1993 evidently is not improving the waste management system as a whole. The country's waste generation is still increasing and disposal sites are running out of space rapidly. Recycling rate is still at 5% and has not increased significantly while illegal dumping is still at large. These issues indicate the failure of privatization of waste management in improving the existing practice.

The main objective of this study is to collate updated and comprehensive data in order to recommend appropriate waste management system in the country. Selangor is selected as the study area due to its rapid development which represents the future situation of other

states in Malaysia. This study covered the main aspects of waste management in Selangor including waste composition, waste generation, waste disposal options, viability of recycling, composting, refuse-derived fuel (RDF) conversion, impacts of landfill to the environment, the socio-economic aspects, public perception, and modeling of cost-effective technology for future implementation. It is also aimed to provide recommendations to waste managers in order to improve Malaysia's waste management system via a more sustainable approach.

Waste composition in nine non-sanitary landfills in Selangor highly depended on the economic activities within the corresponding area. Similar observation was also reported by Zhu *et al*. (2009) and Rathi (2005) in China and India, respectively. On average, the MSW stream consists of approximately 49± 7% food waste, 15±5% paper, 17±4% plastic, 3±1% metal, 3±2% rubber, 3±1% glass, wood and textile, and others. This depicts the trend observed in many developing countries (World Bank, 1999). It is characterized with high generation of food waste, followed by paper and plastic waste. The high percentage of food waste is mainly due to the lack of alternative route beside its disposal into MSW stream. The largest generators are institutions and commercial centers which contributed 40% of the total food waste. This is followed by the residential sector (37%). Between the areas, urban areas produced the largest percentage (46%). It is probably due to the existence of many food courts and eating centers in urban areas where food wastes are generated in mass. In addition, the 'throw away' habit among Malaysian is also contributing towards the high food waste generation.

Waste generation in individual households in urban areas showed a significant correlation (R^2=0.687) between food waste generation and the increase in income level. On the contrary, opposite scenario was observed among the sub-urbanites (R^2=0.8677) and rural (R^2=0.7921) households where the low income groups tend to generate more food waste than the high income groups. The lower income groups purchase lesser amount of processed food materials that more waste was generated during the food preparation. It is agreeable with findings by Choy *et al*. (2004), and Irina and Chamuri (2004). The 'throw away' habit not only increased the generation of food waste but also increased the disposal of non-consumed food. Expired food products (0.5%), unconsumed precooked food (1.5%) and others are commonly found in the waste generated by individual household. This was probably due to the "cellar-stocking" habit among the consumers to purchase food products in large quantity on monthly or bimonthly basis. This is also contributed by the habit of most Malaysian to purchase goods particularly food items in bulk to get discounted price. Statistical analysis indicated that the generation of non-consumed food increased significantly with the increase in income level, regardless of the level of urbanization. This is agreeable with findings from an online survey conducted among 3,942 respondents (Care2, 2008). The traditional practice of feeding animals with food waste is no longer widely practiced since limited housing space restricted the possibility to rear animals. As a result, food wastes are disposed off into the landfills together with other types of waste.

Plastic at approximately 17% (F.wt) is the second largest type of waste generated. Plastic film i.e. the largest portion contributed 33%. The highest generator is from the urban

areas. The industrial sector is the biggest contributor with approximately 60% of plastic generated. This is generally due to the high plastic utilization by the majority of industries as packaging materials because of its cheap price and easy availably (Najafi *et al*., 2006). Recycling of plastic among industries are lacking that the main portion of this materials is disposed off into the MSW stream.

Based on the statistical analysis, the generation of plastic waste was significantly correlated to the income level (R^2=0.6306) among the urbanites and the rural dwellers (R^2=0.5396). This is likely due to its low market price and the absence of policy in the country that it is abundantly used without any control (Najafi *et al*., 2006; Zabanitou and Kassidi, 2003). Similarly, the generation of polystyrene is also high due to the wide range of its application as packaging material. Significant correlation was derived in rural, sub-urban and urban areas that generation of polystyrene waste increased with increased income. Generally, this is because the higher income groups have bigger purchasing power than the lower income groups resulting in the disposal of more packaging waste. Also, the increased popularity of polystyrene as food packages resulted with more of this material being discarded into the waste stream (Demirbas, 2004; Zabaniotou and Kassidi, 2003). Among the household plastic waste composition in Selangor (average), disposable diapers were highest in percentage (42%). Trend in the disposal of disposable diapers was also significantly correlated with increased income. The higher income groups particularly among the urbanites and the sub-urban community discarded more disposable diapers than the lower income groups. It is generally contributed by the

affordable price of disposable diapers and its convenience. As a result, more of these materials are used and disposed off into the MSW stream.

Paper made up 15% of the total MSW stream, the third largest types of waste generated. Paper waste consisted of newsprint, white paper, mixed paper, corrugated paper, magazine and phonebook. Approximately 78% of the newsprint sourced from the residential sector. Newsprint contributed approximately 14% and a significant correlation was derived (R^2=0.9106) between newsprint disposal and income level where the high income groups has lower percentage of newsprint disposal than the low income group. The high income group has higher affordability to subscribe to various types of newspaper resulting with daily accumulation of the materials. The continuous accumulation of this material make recycling more practical that newsprint is not discarded into the MSW stream. On the contrary, lower income group which purchase newspaper occasionally has no constant accumulation that it is inconvenient to store it for recycling purpose. Also, it is due to the lack of recycling practice. Recycling will be discouraged as a result of unattractive low market price (Woodard *et al*., 2006; Alhumoud, 2005). The generation of corrugated paper is the largest from the commercial sector contributing 47%. This is because commercial sector used packaging materials either for marketing their products or receiving their raw materials. The lack of recycling of this material resulted with its abundance in the waste stream due to its inconvenience and low market price (Grodzińska-Jurczak, 2001). On the contrary, high market price for white paper resulted with its encouraging recycling rate and low percentage in MSW

stream even though paper consumption in Malaysian was high (75kg per capita) (Earth Trend, 2002).

The main source of textile waste in MSW stream is contributed by the industries (67%). This generally is due to the generation of by-products particularly among the textile, furniture and other related manufacturers. In addition, scrap-cloth has also been commonly used among industries to replace paper towels for cleaning purpose. As a result, when the scrap-clothes are beyond cleaning, it is discarded for disposal. Among the households, the generation of textile waste was significantly correlated to the income level. Higher income groups tend to disposed more textile waste than their lower income counterpart. This is probably due to the abundance of textile materials in the market at a price affordable to the high income groups (Ojeda-Benítez *et al*., 2008). Aside from that, trends and fashions are considerably important for the high income group to maintain their reputations and style. Therefore, textile materials were discarded at a faster rate among the high income groups than that of the low income groups. The 'throw-away' attitude was reported as the main reason that various types of materials including textile ended up in the waste stream (Demirbas, 2004; Grodzińska-Jurczak, 2001).

The study also indicated that the MSW stream also contains approximately 3% metal, 3% rubber, 3% glass and 3% wood. Aluminium contributed approximately 1% of the waste received by the landfills. The generation of this material increased significantly (R^2=0.616) with the increase in income level, particularly among the urbanites. This generally resulted due to the affordability of the higher income group to purchase items in high quality packaging i.e. aluminium pack, that more of this waste material is present in

the higher income group's waste stream. Also, aluminium waste generation was lower from the low income group due to the recycling of aluminium materials. The high market price of aluminium items encouraged recycling as it generates an additional source of income particularly for the lower income group (Batool *et al*., 2008; Pappu *et al*., 2007; Damanhuri and Padmi, 2000; Leu and Lin, 1998).

Hazardous waste components in MSW contributed approximately 0.5% of the total waste stream. The generation of hazardous waste in the industries and institutions' waste stream was almost zero. This is because industries and institutions can dispose their hazardous waste at the hazardous waste treatment and disposal facility i.e. Kualiti Alam Pvt. Ltd.. Also, there are existing regulations pertaining to hazardous waste disposal which industrial and institutions need to comply. In the urban and sub-urban areas, the generation of hazardous waste decreased with increasing income level. This can be explained with the fact that the higher income group is more aware of the proper way to discard hazardous waste such as batteries, paint containers, pesticide cans, and others. It is made possible with intensive campaigns organized by NGOs to disseminate information on the danger of improper hazardous waste disposal. In addition, these organizations also provide drop-off centers to collect hazardous wastes. However, both campaigns and drop-off centers are mainly concentrated in urban and sub-urban areas. As a result it did not reach the rural audience that hazardous waste are discarded into the MSW stream (Fauziah and Agamuthu, 2008). Therefore, it is crucial that campaigns are also organized in the rural area to provide the community with sufficient knowledge on hazardous waste and its proper disposal. Also, by creating awareness on the detrimental

effects of improper disposal of hazardous waste, illegal dumping of hazardous waste by irresponsible parties in isolated rural area such as along Bukit Beruntung landfill, can be curbed and stopped.

This study indicated that in most cases, industrial wastes are mainly homogenous. Therefore, the identification of the waste reutilization would enable total conversion of the waste via identified approach. This made reutilization of waste more feasible and cost-effective e.g. the feasibility of converting wastewater sludge from Cognis Oleochemicals (M) Pvt. Ltd. into compost has enabled the company to divert their sludge from landfill disposal via composting (Fauziah and Agamuthu, 2001). Industrial waste conversion into value added products not only boost the reputation of the company but increased the profit-making as well. On the contrary, treatment of domestic waste is more complicated. This is mainly due to its highly heterogenous nature. Thus, it is very important that the options chosen to manage the waste is thoroughly studied prior to its implementations.

The study indicated that high percentage of organic waste in Selangor offer a possibility of bioconversion into value-added products. Among the most common practice is composting, where organic waste undergo degradation by aerobic macro and microorganisms to produce compost. However at the current state, the absence of MSW composting plant in the country make this option non-feasible. Therefore, alternative approach is home-composting. This will enable each waste generator to conduct a small scale composting system to handle the organic waste generated. However, issue of

concern is the ability of the composting system to reach thermophilic phase of 55-70^{o}C. Maintaining high temperature in a composting system is crucial to ensure the elimination of pathogenic microbes from the end-product, as well as, avoiding risk to human health (Domingo and Nadal, 2009). This is normally unachievable in small scale composting as the small volume increased the total surface area allowing more heat to escape to the atmosphere. Therefore, vermi-composting is proposed since thermophilic phase is not necessary for the process to complete. The utilization of worms such as *Eisenia foetida* in home-composting system enables the production of high quality compost. *E. foetida* was reported to have better adaptation in tropical climate (Tripathi and Bhardwaj, 2004). The best vermi-composting combination for household application was kitchen waste (KW) and vermicast (VC). This combination expedited the process where approximately 1kg of food waste can be completely degraded by 80g of worms within 3 weeks. Other combinations such as KW with goat manure, and KW with garden soil required slightly longer period i.e. 4 weeks. Complete conversion of the wastes produced vermicast with soil-like texture (Suthar, 2009; Suthar, 2006).

The simple flowerpot experimental set-up was found to be conducive for vermi-composting where it required minimum maintenance. Pest and loss of moisture can be avoided with the closed system. Escaped worms can be returned by pouring the water collected at the bottom plate back into the vermi-composting set-up. Vermi-composting practice not only reduced the volume of waste for disposal but it also generated high quality organic fertilizer. Various studies had reported that vermicast is regarded as the best supplement to enhance plant growth (Yardim *et al*., 2006; Arancon *et al*., 2005;

Arancon *et al*., 2004). It can also exhibit fertilizer-cum-pesticide character when added with certain types of waste, as well as, converting various types of waste into useful products (Adi and Noor, 2009; Gajalakshmi and Abbasi, 2004). This includes paper, garden waste and others. Also, vermicomposting has been reported to have the highest Practicality Value (2.62) among possible methods to manage Malaysian food waste (Fauziah and Agamuthu, 2009a).

In addition to bioconversion, organic waste can be converted into RDF pallet for energy generation. The study indicated that approximately 86% of the total MSW generated are combustible. Therefore, RDF conversion can be integrated as a method to reduce waste disposal into landfills. The calorific value of waste generated in Selangor averaged at 23,000 kJ/kg. The value is slightly higher than those of other developing countries which ranged from 19,000 to 21,000 kJ/kg (Hansen *et al*., 2007). This is due to the presence of various materials of high calorific value particularly plastic that the average was slightly higher than the typical range of calorific value from other countries (Hansen *et al*, 2007). Food waste was found to have an average calorific value of 18,000 kJ/kg. This generally was due to the presence of high calorific value component such as protein, carbohydrate and fat in the food waste generated. However, the calorific value reduced with the high moisture content retained within the compound. Magrinho and Semiao (2008) had reported that the high moisture content (40-60%) trapped within food waste caused significant reduction in its calorific value. The highest calorific value within MSW components was for plastic (44,000 kJ/kg) followed by mixed waste (27,000 kJ/kg). Plastic of various types comprised of a wide range of polymeric chain and exhibited high

range of calorific value. HDPE gave the highest value (46,000 kJ/kg) followed by plastic film and polystyrene at approximately 40,000 kJ/kg. The low moisture absorption ensures that plastic does not retain moisture with exception of disposable diapers (van Kessel *et al*., 2004). This made plastic a suitable raw material for RDF conversion. On the contrary, even though paper materials are easily combusted, it exhibited contains lower calorific value, ranging from 12,000 kJ/kg to 17,000 kJ/kg. The calorific value of paper is much lower than that of plastic due to its simpler chemical structure which consists mainly of cellulose compound. Among the different types of paper, newsprint has the highest calorific value (17,000 kJ/kg). The inking and reprocessing of paper materials was found to increase the calorific value of paper waste that newsprint has higher value than white paper (Filho *et al*., 2008; Conesa *et al*., 2008; Nas and Bayram, 2008). Corrugated paper has a calorific value of 16,000 kJ/kg which resulted from the compaction process during the manufacturing of corrugated paper (Homlgren and Henning, 2004). However, the calorific value will be reduced drastically if the waste samples are wet due to the presence of high moisture content in the waste stream. Therefore, combusting the waste for disposal via incineration is considered non-economical. As a result RDF conversion of MSW is not feasible and cost-effective without source separation. This is agreeable with the Practicality Value of RDF conversion reported (-0.65). The negative value obtained indicated that this approach is impractical at the current state (Fauziah and Agamuthu, 2009a). RDF conversion is not viable for Malaysian waste since source separation is absent and liquid waste commingled in the solid waste. The disposal of MSW via incineration in Malaysia is not popular due to the fact that Malaysian MSW contains high moisture level that self-

combustion is not possible. Although there are at least five incinerators in Redang Island, Pangkor Island, Tioman Island, Labuan and Langkawi, the constructions are to cater the disposal needs of these islands in Malaysia due to land scarcity. However, the cost of incineration escalates, due to the requirement of fuel injection in every incinerating batch, resulted from the high moisture level in the MSW.

From the study, Malaysian MSW has an average moisture content of 40 to 60% by weight. It depicts a typical waste characteristic from developing nations as observed in China and India (Liu *et al.*, 2008; Sharholy *et al.*, 2008). The high moisture content is mainly due to improper waste collection system that rain water may have trapped in the waste. Also, the typical habit of mixing all waste types including liquid waste into the trash bin enhanced this situation. This increases the moisture content of the MSW. On the other hand, the conductivity of the waste ranged from 4.5 to 6.6 µS/cm while salinity was 0.4 to 1.4 gNa/kg. The salinity of the waste was mainly caused by the presence of salt in Malaysian MSW, particularly in the organic component. However, the salinity level was much lower than those reported by Hicklenton *et al*. (2001). This could be attributed to the 'rinsing' of the waste with surface run-off since the disposal sites lack proper drainage system. The waste was also found to be slightly acidic within pH4.5 to pH6.6. This is due to the rapid degradation of the organic material present in the MSW stream. In addition, the high moisture content and suitable temperature of 28 to 34^{o}C provides a conducive condition for the rapid degradation of putrescible waste. Breakdown of organic component resulted with the generation of organic acid which consequently reduces the pH of the waste (Hao *et al.*, 2008).

The degradation of waste in the landfill resulted with the generation of leachate. The study indicated that the pollution intensity differed from one landfill to the other. This is attributed by different waste composition received by the landfill for disposal and the age of the landfill (Ziyang *et al*., 2009; Sormunen *et al*., 2008; Fauziah *et al*., 2005). Also, different landfill application such as waste compaction, daily cover, spraying of chemicals and others, influenced the quality of leachate produced (Blight, 2005; Őzkaya *et al*., 2005). While pH of the waste collected from households was acidic, the pH of the landfill leachate ranged from slightly acidic (pH6.4) to alkaline (pH8.1). It has a wider range because different landfills undergo different stages of degradation. During acidogenic phase, abundance of organic acids are evident, with leachate of low pH (Kruempelbeck and Ehrig, 1999; Tchobanoglous *et al*., 1993). On the contrary, landfills undergoing methanogenesis phase will produce leachate at pH7.5-9.0 (Jun *et al*., 2009; Tchobanoglous *et al*., 1993). BOD_5 of leachate sampled from the disposal sites in Selangor ranged from as low as 62mg/l to as high as 322mg/l. It is considered too low for an active landfill (Blight, 2005; Tchobanoglous *et al*., 1993). However, this is not the case for the nine landfills in Selangor. The factor which caused the low BOD_5 concentration is the dilution of leachate with surface run-off, since all except one landfill lacked proper leachate collection system. Therefore, leachate generated from the waste cells oozed and accumulated in 'ponds' within the disposal site. It will be diluted with rain water and eventually will be flushed into the nearby river or lake. As a result other pollutants were also diluted. BOD_5 concentration was found to be significantly correlated to the concentration of chloride (ρ= 0.92) and sulfite (ρ= 0.92), total solid (ρ= 0.96) and

colour (ρ= 0.65). The increase in BOD_5 resulted with the increase in chloride concentration with the determination coefficient R^2=0.85. COD level on the other hand averaged at 4313 mg/l. Dilution of leachate with rain and other surface run-off resulted with low COD concentration in most leachate sampled from Selangor landfills. Another factor influencing the concentration of COD, as well as, other parameters is the age of the landfills (Ziyang *et al*., 2009; Blight, 2005; Tchobanoglous *et al*., 1993).

Statistical analysis of the results indicated a correlation between COD and total suspended solid with correlation coefficient ρ= 0.61. High concentration of COD in the leachate will pollute the receptor water bodies and degrade the water quality. Total release of COD from Kundang landfill into Kundang river for example was approximately 28kg/L everyday indicating the seriousness of the pollution (Fauziah and Agamuthu, 2005). On the contrary, the concentrations of metal elements in leachate samples from the nine landfills in Selangor were below the Standard B (EQA 1974) with exception to Cr (144 mg/l) which exceeded 188% of the limit allowed (50 mg/l). However, constant release of the metal elements into the river will cause bioaccumulation and the deterioration of the river water quality. Without proper treatment, this may obliterate the natural ecosystem. Therefore, it is crucial that leachate is treated prior to its release into the water bodies.

Various techniques are applied to treat leachate. Among them are aerated lagoon, semi-aerobic leachate pond, chemical treatments and others. In this study, leachate samples collected from Kundang landfill were remedied via physico-chemicals and biological

treatments. Physico-chemical treatment is applied in order to reduce the toxicity of the leachate while biological treatment is meant to reduce the organic loading. Physico-chemical treatment involved in the study is coagulation and flocculation of the leachate with ferric chloride and alum. Among the two chemicals used, ferric chloride was more efficient in reducing the pollution intensity than alum. The study also indicated that increasing concentration of ferric chloride resulted with higher removal efficiency. The concentrations which ranged from as low as 0.2g/l to as high as 0.8g/l has significant correlation to the removal efficiency of the pollution intensity. This was because at higher concentration of ferric chloride it can bind, react and remove more pollutants in the leachate. This is agreeable with the various published findings on leachate treated with ferric chloride (Zhang and Wang, 2009; Wang *et al*., 2005; Kang *et al*., 2002).

With exception to the removal of total P, ammoniacal- N, and Ni, the removal efficiency of various parameters such as BOD_5, COD, Zn, Cr, and Cu responded in a linear trend. The coefficient of determinations was 0.96, 0.94, 0.95, 0.90, and 0.95, respectively. In addition to the concentration of ferric chloride, pH also influenced pollution removal efficiency in leachate treatment. The study indicated that pollutant removal efficiency by ferric chloride increased at higher acidity. The highest removal efficiency was at pH4. due to the higher affinity of ferric chloride to interact with the pollutants in leachate in acidic condition. As a result, more pollutants were removed. The correlation between pH and the removal efficiency of various pollutants were significant with exception to ammoniacal-N and Li. Primo *et al*., 2008 had reported that pH is very crucial in

improving the efficiency of coagulation and flocculation process. Acidic environment provide more ions to allow flocs to form rapidly (Faust and Aly, 1999).

The study indicated that the application of ferric chloride is not able to remove the pollutants from the leachate totally. This is due to the utilization of ferric chloride at an economical concentration. The use of more concentrated ferric chloride combination will increase the cost and will stimulate other problems such as excess ferric ion. Therefore the study focused mainly on lower concentration of ferric chloride to treat the leachate, as a step to minimize the loading of toxic components in the leachate. This will enable the application of biological treatment where bacterial and fungal cocktails were introduced.

The microbes used in the biological treatment were isolated from leachate, leachate contaminated soil, and waste. The application of the microbial cocktails in an aerobic condition was able to reduce BOD_5 by 40%, 70% COD and 50% of total P. This is because the microbes utilized the chemical components contributing to BOD_5 and COD as their nutrient. Similarly for P, the uptake was important mainly for the growth of the microbes. This is agreeable with various findings where in extreme environment, microbes tend to undergo adaptation to utilize abundant source of nutrient for their metabolism (Sierra-Alvarez, 2009; Zhang *et al*., 2009; Ziagova *et al*., 2007; Isaka *et al*., 2007; Wichitsathian, 2004; Ding *et al*., 2001). Biological treatment of leachate can improve its quality and reduced the pollution intensity at a more economical cost.

The integration of physico-chemical treatment and biological treatment for leachate not only minimized the management cost in the landfill but also enabled a more sustainable treatment system since it utilized lesser chemical. On the contrary, biological treatment has its own disadvantages. Among them is the sensitivity of the system since it involved the use of living organisms particularly microbes. However, this can be overcome with appropriate monitoring of leachate quality and pre-treatment of leachate with physico-chemical treatment.

Besides the generation of leachate, landfills also generated various types of landfill gases. Among the most commonly emitted from disposal sites are CH_4, H_2S and CO_2 with CH_4 contributing 55% of the total landfill gas emission (Agamuthu, 2001). The main concern of landfill gas is CH_4 since each unit of CH_4 can trap 21-23 times more heat than each unit of CO_2. This becomes an alarming situation since it is also a big contributor to global warming and approximately 19% of the total CH_4 in the atmosphere originated from landfills (IPCC, 2008). Since most of the disposal sites in Selangor are non-sanitary landfill, CH_4 generated are passively released to the environment. Thus, it is very crucial that this gas is treated and oxidized prior to its release to the atmosphere. CH_4 oxidation study was conducted with the utilization of various soil materials to enhance the process.

Soil were collected from Panchang Bedena landfill and tested for its ability to promote CH_4 oxidation. Results indicated that the best material which oxidized CH_4 the fastest was soil collected from an active waste cell. This probably was due to the presence of various microbes in the soil as a result of the abundant organic matter in the active waste

cell (Insam and Wett, 2008; Dote, 2002; Huber-Humer *et al*., 2009). Complete CH_4 oxidation was achieved after 218 hours at 20^oC. Since CH_4 oxidation involved microorganism, temperature too played a role in determining the rate. Results indicated that at 35^oC, complete CH_4 oxidation can be achieved within 24 hours. This is because at 30-37^oC, enzymatic activity is at its optimal. Therefore, at 35^oC, microbes can actively oxidize CH_4 to CO_2. At higher (above 40^oC) and lower temperature (below 25^oC) microbial activity was at the minimum due to the inactivation of its metabolic activity (Einola *et al*., 2008; Jugnia *et al*., 2008). As a result, more time is needed to complete the CH_4 oxidation. Another factor which contributed to the rate of CH_4 oxidation is moisture. Extreme moisture level resulted with the attenuation of CH_4 oxidation process (Einola *et al*., 2008; Chen *et al*., 2008). The most optimal moisture level was 5-10% which enabled complete CH_4 oxidation within 192 hours at 20^oC.

Even though remediation such as leachate treatment and CH_4 oxidation can reduce the pollution impacts from disposal sites, the current waste management system in Selangor required major overhaul. Implying to 'prevention is better than cure' concept, the leachate and landfill gas problem can be minimized if an integrated waste management system is introduced.

The waste composition study indicated the largest component of the MSW can be recycled. Annual tonnage of Selangor's MSW included 630,830 tonnes food waste, 166,300 tonnes paper and 133,310 tonnes plastic. It is a typical composition of a rapidly developing country as reported by Zhu *et al.* (2009) and Körner *et al.* (2008). The

composition will eventually evolve to that of a developed country when appropriate integrated waste management is in place (World Bank, 1999). Current waste management practice in Selangor lacks source separation and recycling. As a result, recyclable materials were abundant in the waste stream. If the waste management system is not changed towards the better, it will waste profuse resources ranging from recyclable materials, combustible components and degradables, into landfills. The study indicated that there are various options in diverting these 'valuable' components.

The diversion of compostable waste for composting will eliminate 54% of the total waste generated. Of this approximately 37% will undergo vermi-composting at households scale while the remaining 63% could be channeled to communal composting plants. Meanwhile, less degradable components including wood, rubber and other combustible items can be diverted to incineration. In the future, these portions can be utilized to generate energy for the community or at least to sustain the incinerator. Composting and incineration options will help to reduce landfill gases particularly CH_4. On the other hand, recyclables at 17% of the total waste can be rerouted for recycling. This not only prevents the loss of valuable materials into landfills but will lengthen the landfill's operating period (Fauziah and Agamuthu, 2009). This is crucial due to the increase in land price and difficulty in finding suitable area for landfill siting (Davila *et al.,* 2005; Zeiss and Lefsrud, 1995). The modeling of an integrated waste management in Selangor based on the Government's target of 22% recycling by 2020 using SWPlan calculated that the state will earn annual revenues of RM46 million (USD13.1 milion) from composting and RM7 million (USD2 milion) from recycling. In addition, SWPlan also

indicated that the operating cost of landfill management can be reduced approximately 75% from RM44 million (USD12.6 million) to RM11 million (USD 3.14million). Therefore, it is essential that an integrated waste management is implemented which would be economically benefiting and also be more sustainable. Figure 6.1 illustrates the integrated waste management system proposed for Selangor state based on this study.

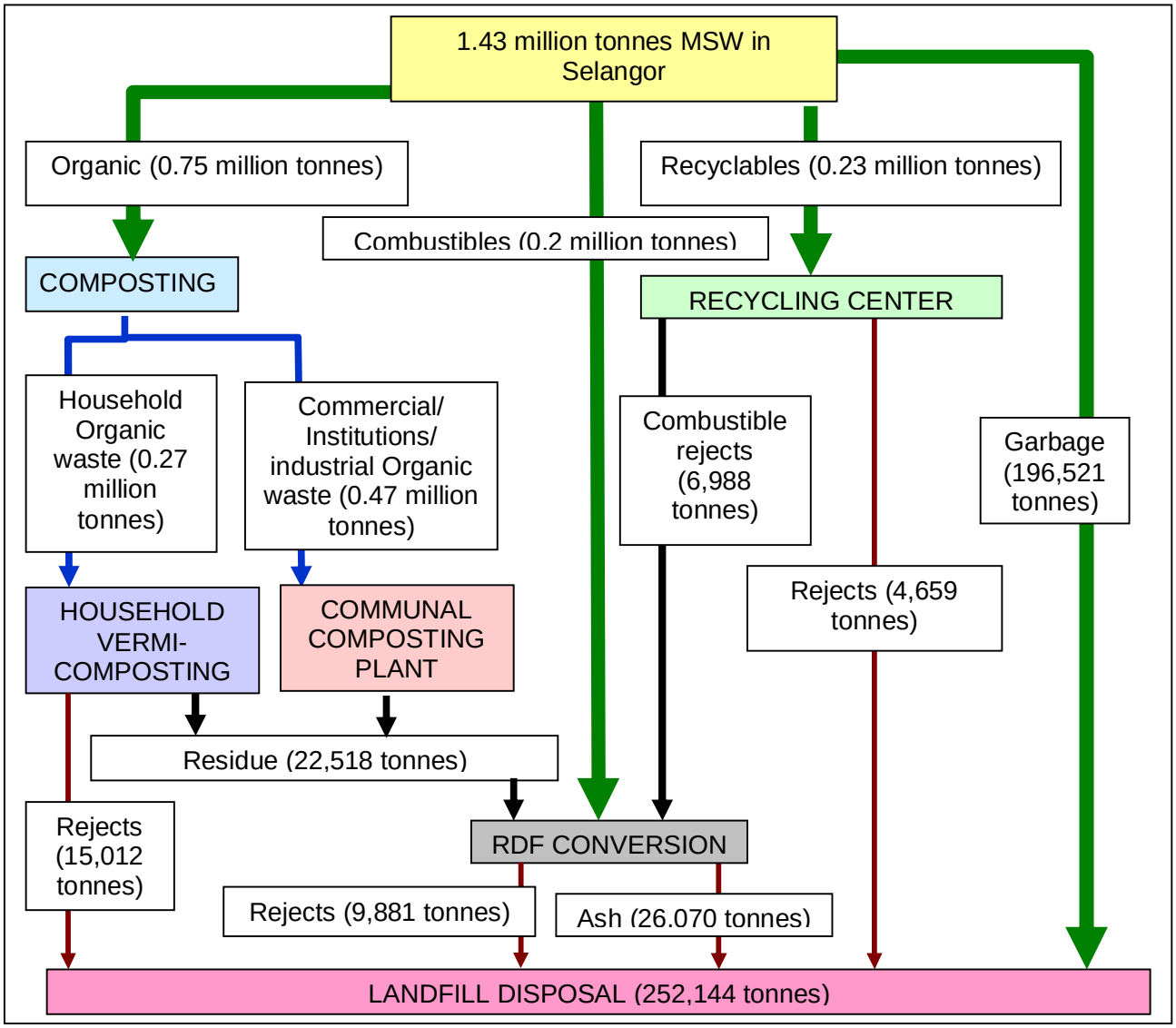

Figure 6.1: Proposed route for integrated waste management system in Selangor (for 1 year).

Annually, a total of 1.43 million tonnes of waste in Selangor which contain at least 86% retrievable materials can be diverted to recycling, organic treatment and RDF conversion. Therefore, approximately 14% of the total wastes are to be landfilled enabling the reduction of 81% from current (95%) MSW sent to landfills. This promises the lengthening of landfill operating period and significant reduction in waste disposal cost. By incorporating composting into the integrated waste management system, it will divert organic components from landfills. It will generate revenues from compost production, as well as, additional income in carbon trading due to the significant reduction of greenhouse gas emissions (IPCC, 2008). RDF conversion will supply alternative energy source besides creating a more competitive market in the energy generating sector. In the other hand, recycling of recyclables will create more job opportunities and enhance economic growth. With full-scale recycling being practice, scavenging activities in landfill will become inconvenient due to the difficulties to find recyclables in the MSW stream. As a result, it will also reduce occupational and health risks at disposal sites. With the idea of landfilling only inert and non-putrescible waste, landfills can be managed more effectively. This will remove the negative perception towards landfill sites among the general public.

The success of an integrated waste management system can only be achieved with full cooperation from all stakeholders. One of the main concerns in improving the waste management system in Selangor is public participation. From the study, knowledge pertaining to waste management in the state is generally high where 76% knew how their MSW is managed. The urban and sub-urban populations have higher knowledge on waste

management issues as compared to the rural community. This probably resulted from the active campaigns by the government and the NGOs in creating environmental awareness. However, it is mainly concentrated in urban cities and the outskirt of the cities. As a consequence, rural dwellers have less exposure to the environmental issues that their knowledge is only limited to those learned from mass media. On the contrary, the majority of the populations knew the responsible party involved to collect their waste. Studies had indicated that people will make the effort to gain knowledge if it will benefit them (Gouveia *et al*., 2004; Myatt *et al*., 2003). In this case, public are aware of their waste collector to ensure that they receive satisfactory waste collection services. Survey conducted indicated that majority of the public is satisfied with the service provided by their waste collectors. Statistical analysis using the Likert scale indicated a score within the efficient level. This was probably due to the fact that waste collection service providers need to ensure the satisfaction of their client to guarantee the renewal of their contract in the future. This is a crucial factor since the government had announced the possibility of contract termination of unsatisfactory waste collectors.

Issue of recycling is still being discussed as most recycling campaigns launched over the year since 1980s is yet to show much result. Recycling rate in the country in general is approximately 5% with Selangor contributing the largest portion. Results from the survey indicated that more than 86% of the public are aware of recycling. This is agreeable with the findings by Irina and Chamuri (2003) and Irra (1999). However, the participation of the public is very low. Robinson and Read (2005) had reported that high awareness on recycling does not necessarily promote high recycling activities among the public.

Among factors which also contributed to this scenario are, lack of consciousness of the benefits of recycling, lack of policy in regards to recycling, lack of recycling facilities available for the public and fluctuating market price of recyclables (Agamuthu *et al*., 2009). Higher recycling rates were reported in Malaysia when recyclables procured high market price (Agamuthu *et al*., 2004). Thus, suitable approach should be implemented to promote recycling among the public if economy drive fails to play its roles. Among other is the implementation of appropriate regulations pertaining to recycling. Solid Waste and Public Cleansing Management (SWPCM) Act 2007 was passed by the Parliament in 2007, but it is yet to be implemented. Survey among the public indicated that the majority (96%) will abide if recycling is made mandatory by law. This indicated the importance of stringent policy and regulation to deal with matters related to environmental problem when awareness and economic gain are unable to generate the appropriate 'push'.

Problem of plastic disposal can also be reduced with the implementation of appropriate regulations. The survey indicated that majority of the public in Selangor knew that plastic is non-degradable and will cause various environmental problem. Significant correlation was derived indicating that awareness of this issue increased with increased education level. However, the public is not very supportive with the idea to impose some charges for plastic bag users as to discourage its usage among the public. This reluctance is obvious since it will impact the economy of the consumer i.e. the public (Gutrich *et al*., 2005). The results of survey indicated that public is more supportive in replacing conventional non-degradable plastic with degradable plastic.

As for reduction of waste generation, pay as you throw (PAYT) system was found to be agreeable by the majority of the public in Selangor. This was probably influenced by the fact that public would want to see some changes in the waste management in the state in general and the country as a whole. Zhang (2000) reported similar findings from survey conducted in China. PAYT which is also addressed in the SWPCM Act 2007 will result in the reduction of waste generation in the country. The reduction is not only due public strategy to minimize waste disposal fees but also as a result of mandatory waste separation. With source separation becoming effective, recycling rate will increase and most of these materials will be diverted from the waste stream meant for disposal. Figure 6.2 illustrates the waste generation projection in Malaysia with and without the implementation of SWPCM Act 2007.

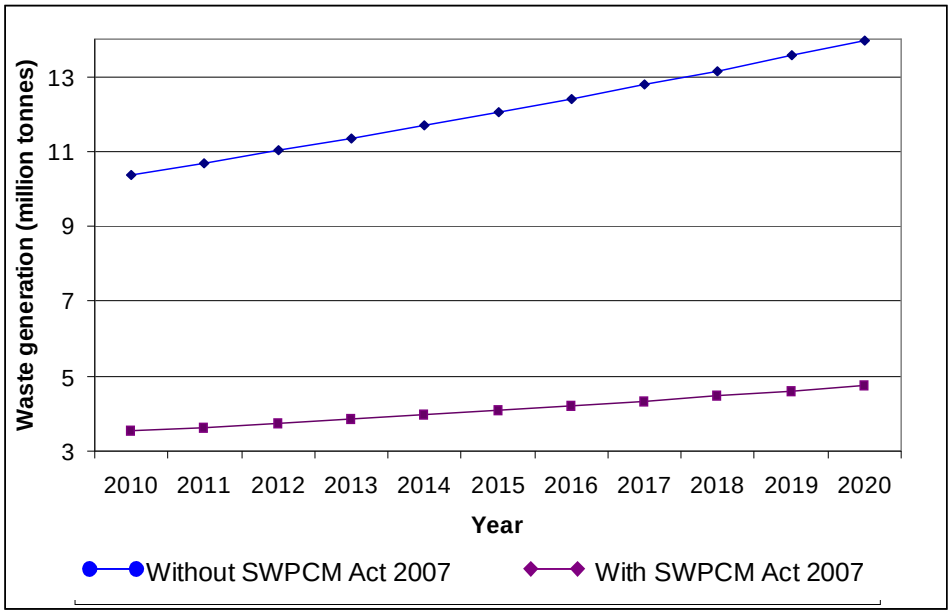

Figure 6.2: Projection of waste generation in Malaysia with and without the implementation of SWPCM Act 2007.

The generation of MSW will exceed 10 million tonnes in 2010 if the current waste management is not improved. It will reach approximately 14 million tonnes in 2020 which would create various environmental issues including the lack of space for MSW disposal. If the composition remained unchanged i.e. approximately 50% organic matter, its risk will be more detrimental to the environment. On the other hand, with the implementation of SWPCM Act 2007, the generation of waste will be drastically reduced. This is achievable since approximately 66% of the total waste consists of valuable materials which can be diverted for composting and recycling. As a result waste management will associate with less financial burden that current expenditure of RM30.8 million (USD 8.8 million) by the National Solid Waste Management Department can be allocated in creating more awareness and improving the waste management system further.

In short, current waste management in Malaysia in general and Selangor in particular can undergo drastic improvement if:

1. Public participation in recycling and source separation be increased. This is possible by creating a community with high environmental awareness and consciousness via extensive and widely covered campaigns, organized by the local councils and NGOs.
2. Provision of more recycling and composting facilities will encourage public participation. Currently 835 recycling stations throughout the country is not sufficient to provide convenience to Malaysian public as a whole since it is located at certain sites only.

3. Appropriate regulations and policies pertaining to MSW management should be implemented. The success of the policy will depend on the acceptance of public. Stringent rules with certain degree of penalty will ensure public cooperation since the main issues of public refusal to participate in recycling is the ‘not bothered’ attitude.

These not only will minimize problems arising from improper waste management but will also benefit the country in the long run in terms of environmental preservation and sustainable development.