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Moving from landfill to Integrated Waste Management (IWM) system in Malaysia – Status and proposed strategies

Keng Zi Xiang*, Sumiani Yusoff , & Khadijah Md. Khalid
INPUMA (International Institute of Public Policy and Management)
Level 3, Block C, UM City Campus, University of Malaya, Jalan Tun Ismail, 50480 Kuala Lumpur, Malaysia.
*Corresponding Author: Phone: +603 2617 3038 Fax: +603 2617 3040 E-mail: jaronkeng@um.edu.my

Abstract—**Municipal Solid Waste (MSW) in Malaysia has a high percentage of perishable organic fractions (OF) such as food waste and green waste which account for 60% - 80% of total MSW by weight. Organic Fraction of Municipal Solid Waste (OFMSW) typically food waste contributes to the high moisture content and low calorific value in MSW. These characteristics of MSW are the major obstacles to the introduction of thermal treatment facility. The disposal of OFMSW in landfills creates negative environmental impacts with the high production of landfill gas and leachate as the local climate of high precipitation. The release of methane gas from landfills to the atmosphere and the long hauling distance make waste management sector one of the largest carbon emitter in the country. As an active waste, OFMSW has to be separated at source and undergoes biological treatment for energy and nutrient recovery. The high energy content of OFMSW promises a great potential in biogas recovery especially with the local climate. Therefore, separation at source with a wet – dry basis or the separation of OFMSW at source is the pre-requisite toward achieving an Integrated Waste Management model in Malaysia. The paper discuss the unsustainable MSW disposal in landfill, drawback of thermal treatment of MSW, the vast potential of biological treatment and proposed strategies in moving toward IWM model in Malaysia.**

Keywords-Biological treatment; IWM system; Landfill; OFMSW; Source segregation

I. INTRODUCTION

Municipal Solid Waste (MSW) in Malaysia has a high percentage of perishable organic fractions. Organic Fraction of Municipal Solid Waste (OFMSW) such as food waste and green waste constitute the most (60% - 80%) of our country total waste streams that exclude source segregated dry recyclables (Table 1). The high fraction of organic waste contributes to the high moisture content and low caloric value in our MSW. As an "active" waste, OFMSW is the fundamental cause of pollution in a landfill, i.e., landfill gas (LFG) like methane gas is a significant greenhouse gas while landfill leachate causes pollution on nearby water bodies especially at non-sanitary landfills. In a sanitary landfill, leachate treatment plant (LTP) consumes considerable amount of energy (electricity) and the efficiency of the LFG recovery is considerably low. In Malaysia, the existing mixed MSW with high organic fraction poses a huge hindrance in steering toward an Integrated Waste Management (IWM) system.

TABLE I. MSW COMPOSITION BY SOURCE IN KUALA LUMPUR, 2002 (PERCENTAGE BY WEIGHT)

Waste stream	Residential	Waste sources Commercial	Institutional
Food waste	63.1	76.8	40.6
Mixed papers	6.7	7.6	16.0
Mixed plastics	14.3	9.0	17.2
Textiles	1.7	0.5	0.7
Rubber & leather	0.6	0.3	0.1
Yard waste	6.3	0.9	18.4
Glass	2.1	0.9	1.5
Ferrous waste	2.3	1.4	2.8
Aluminum	0.1	0.1	1.3
Others	2.8	2.5	1.4

To reduce the landfilling of OFMSW, separation at source with a wet-dry basis is the prerequisite step. With high moisture content in MSW, it is not feasible to introduce thermal treatment such as incineration because of the low calorific value of MSW at 6 MJ (Mega Joule)/kg. In EU Member States where incineration is common, the caloric value of mixed municipal waste is normally between 10-12 MJ/kg. In Malaysia, separation of dry recyclable at source is rather common, especially metals (<4% by wt.) and paper products (<10% by wt. except institutional area). The separation of dry recyclable at source can prevent contamination and give quality recyclable which can avoid the application of dirty MRF (Material Recovery Facility). Hence, separation of OFMSW at source serves at the next major enabling factor of the trajectory toward IWM system. This concept of practice will reduce the moisture content of the MSW which brings double benefits – energy and nutrient recovery of OFMSW and increase the feasibility of energy recovery from residual waste. As an active waste, OFMSW is banned from landfilling in certain countries. For example, in Korea, the direct landfilling of raw food wastes has been banned since January 1st, 2005 (Mi-Hyung Kim et al, 2010) and in Europe, Europe Union (EU) policy to reduce the landfilling of Biodegradable Municipal Waste (BMW) under the landfill Directive or more formally Council Directive 1999/31/EC was commenced in year 1999.

II. MATERIALS AND METHODS

The objectives of the study are to discuss the current unsustainable solid waste management in Malaysia, feasibility of both the thermal treatment and biological treatment for MSW especially OFMSW and proposed a strategy in achieving IWM model. The study is based on literature reviews, conference proceedings, interview session, site visit (stakeholders engagement) and an OFMSW source segregation project (Organic Waste Diversion Project in Campus of University of Malaya). Biological treatment is proposed for the disposal of OFMSW to achieve IWM model. The proposed strategy is based on data obtained from project, literature findings and real case experience from local private sector. Facts and figures are derived from interview and site visits to local waste management entities such as landfill operator, waste concessionaires, government agency and private R&D (Research and Development) company as well as the project in UM campus.

III. RESULTS AND DISCUSSION

A. *Landfill: Unsustainable OFMSW disposal method*

Landfill is the most economical and hence most common MSW disposal method in Malaysia. Nationwide, there are 176 operating landfills but only 11 of them are sanitary landfills with 7 in Peninsula Malaysia, 1 in Sabah and 3 in Sarawak (Table 2). Besides the operating landfills, there are 114 closed landfills in the country which required post closure treatment and management for at least 30 years[1]. The total capacity of MSW disposed in the current 176 operating landfills is 20,515 mt (metric tonne)/day and the total size of operating landfills is 2,528.2 ha. In total, the size of operating and closed landfills is 3,446.2 ha, which is 0.01% of Malaysia total land area (Nagapan, 2012; JPSPN, 2010).

TABLE II. NUMBER OF OPERATING AND CLOSED LANDFILLS IN MALAYSIA, 2010

	Closed landfills	Operating landfills	Operating sanitary landfills
Peninsula Malaysia	101	103	7
Sabah	1	18	1
Sarawak	12	55	3
Total	114	176	11

With the local climate of high precipitation (annual average of 2,540 mm at Peninsula and 4,420 mm at Sabah and Sarawak) , the cost of operation and maintenance of a sanitary landfill is adversely affected with the high production of landfill leachate. For example, Jeram Sanitary Landfill (JSL) with a daily capacity of 2,100 mt/day produces about 380-400 m3 of leachate. The electricity consumption of the operation of leachate treatment plant (LTP) with 20 aerators with 16 kWh each amounts to RM 40,000 - 50,000 per month (Zhafran, Worldwide Landfill, 2010). The LFG production rate is 270 m3/hour on an area of 14,400 m2 with 9 gas wells (Imran, Worldwide Landfill, 2010). Of all the operating and closed landfills, the Government with the assistance of (JICA Japan International Cooperation Agency) has identified 16 critical sites situated near water intake points or the sea in 2004 and ordered their closure in 2006. One is the non-sanitary landfill near Sungai Kembong that caused the Sungai Semenyih water treatment plant to be closed temporarily due to high levels of ammonia in September 2010.

Besides, another issue with landfill is the distance from the point of MSW generation. With the urban sprawl and rise of land value surrounding urban area, landfills have to shifted further away from the waste source and hence not fulfilling the proximity principle. For example, in Kuala Lumpur (KL), Taman Beringin non-sanitary landfill became the sole operating landfill from 1996-2004 following the closure of 5 other landfills at Jinjang Utara (1996), Brickfields, Sg. Besi (1995), Paka 1 (1994), Paka 2 (1994) and Sri Petaling (1991). The closure of Taman Beringin landfill in 2004 led to the construction of Bukit Tagar Sanitary Landfill (BTSL), the biggest landfill in Malaysia with a size of 700 ha. However, the distance of BTSL to KL city centre (Figure 1) is about 70 kilometers (km). A transfer station was built at Jinjang Utara to receive all the MSW from KL and send to BTSL with garbage truck capacity of 18 mt. This proximity issue happens to another sanitary landfill, JSL, which began operation in 2007 and located at Jeram, Selangor. JSL receives MSW from five major municipalities (MPAJ, MBSA, MPK, MPSJ and MBPJ) which distances range from 30 km – 70 km (Imran, Worldwide Landfill, 2010).

The long hauling distance incurs high transportation cost and increase the carbon emission from the burning of fossil fuel (diesel). With the development of more sanitary landfills with location further from MSW sources compared with existing non-sanitary landfills, the reduction of pollution levels from landfills will be offset (in term of environmental impact) with the increase in carbon emission results from the unsustainable energy consumption in the hauling process. Under the National Strategic

Figure 1. Distance of KLCC-BTSL (70km) and MPSJ-JSL (50km)

Plan for Solid Waste Management, the priorities are building and upgrading more sanitary landfills as well as introducing intermediate treatment facility. The total number of facilities and equipments required under the Plan period of 2004-2020 are sanitary landfills (22), transfer station (45), integrated MRF (7), thermal treatment plant (6), collection vehicles (8500) and transfer haul vehicle (1200). Based on the Plan, the distances of the proposed sanitary landfill to the waste sources are ranging from 15-80km, which is no sustainable in the context of fossil fuel consumption.

B. Drawback of thermal treatment of MSW in Malaysia

Incineration or "mass burning" is the next common MSW disposal method globally. Incineration has become one of the most expensive waste treatment facilities with sophisticated burning mechanism and advancement of emission control technology. Besides incineration, other thermal treatment technology such as pyrolysis and gasification are typically operated in small scale plants. Incineration can reduce the mass of MSW to less than 10% and hence increase the lifespan of landfills. However, with a high percentage of OFMSW i.e. high moisture content, incineration is not an economically viable waste treatment option.

For a case study, Pollution Engineering Sdn Bhd (PESB) had fabricated a 12 mt/day incinerator with capital expenditure (capex) of RM 9-10 million and operated for 2 years in Kuantan Municipal Council for R&D purpose in year 2004. It was found that it required about 120 Litres (L) of diesel to incinerate 1 mt of MSW from Kuantan. Hence, the operational expenditure (opex) is easily more than RM 300/mt as the fuel (diesel) alone cost more than RM 200/mt with the current market price of diesel of RM 1.75/L. However, 5 small-scale incinerators of rotary kiln type were in placed in 5 tourism spots: Pulau Langkawi (100 mt/day), Pulau Labuan (60 mt/day), Cameron Highlands (40 mt/day), Pulau Pangkor (20 mt/day) and Pulau Tioman (10 mt/day). The incinerators use autogenous combustion technology (ACT), which involves the usage of a rotary kiln and an air-injection system to ensure continuous combustion. These incinerators are designed by XCN Technology Sdn Bhd and the operation may begin in 2011. The primary purpose of the introduction of incinerators at tourism spots is to divert waste from the landfill as the scarcity of land in island and highland area.

A 700mt/day capacity RRC/RDF-WTE (Resource Recovery Centre/Refuse Derived Fuel and Waste-To-Energy) plant was established in 2004 at Semenyih, Selangor and it receives the MSW from Kajang Municipal Council (MPKj). The plant employs mechanical and thermal process. Mechanical process includes the recovery of dry recyclables (rotary screen, magnetic separation, air classifier and visual inspection) and densification (shredding and pelletizing) of combustible materials to RDF. Thermal process refers to the drying (primary and secondary) and combustion of RDF. The power plant for the RDF combustion is producing 8.9 MW of electricity where 5.5 MW is sold to the National Power Grid and the rest are utilized internally while the heat generated from the boiler is used for the drying process which intends to lower the moisture content of residual waste for more efficient combustion. The residue materials consisting of some inert and non-recyclables, bottom ash and fly ash are disposed at a sanitary landfill.

The feasibility of the entire energy and material recovery will increase significantly if IWM system is introduced. Energy recovered from the anaerobic digestion (AD) of OFMSW (assume ~40% by wt. of total MSW) is comparable with the energy recovered from RDF plant based on the assumption that biogas production from food waste is 120-150 m^3/mt (Chin Kiat, 2010) and the calorific value of biogas is 21 MJ (Mega Joule)/m^3. Hence, the electricity generation from OFMSW is predicted as 700-875 kWh/mt (1 kWh is 3.6 MJ) based on the biogas production from the AD plant of PESB. Assume the capacity of OFMSW as 300 mt/day; the electricity generation capacity is 210-263 MWh per day or 8.75-11 MW per day.

With the OFMSW diverted from the MSW, the calorific value of the (Sivapalan et al, 2002) resulting residual waste will increase with the reduction in its moisture content. MSW with low moisture content will increase the feasibility of thermal treatment as well as reduce the emission (leachate and LFG) from landfill. Besides, the application of AD for food waste management has a GWP (Global Warming Potential) of -

162 or -215 $kgCO_2e$/mt of food waste, compared to other treatment options such as composting (-14 $kgCO_2e$/mt), incineration with energy recovery (+13 $kgCO_2e$/mt) and landfill with LFG collection system (+743 $kgCO_2e$/mt). This preliminary assumption shows the importance of integrated waste management with segregation at source.

C. Significant and potential of biological treatment

Diverting OFMSW from landfill is a predominant step in striving toward IWM system as the move to promote energy and material recovery, pollution prevention and carbon (methane gas) emission reduction. In Europe, Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste sets, as a policy target, the phased reduction of BMW going to landfill. By 2006, EU Member States are restricted to landfilling a maximum of 75% of the total amount by weight of BMW produced in 1995 and this target increases to 50 % in 2009 and 35% in 2016. In member state, to achieve the target, monetary instrument especially landfill tax was introduced to increase the gate fee (tipping fee) of landfill; hence to encourage the disposal of MSW in other treatment facilities such as composting, anaerobic digestion, MBT (Mechanical Biological Treatment), MRF, etc. For example, in UK, the median rate of gate fee for landfill is only £22 but the gate fee plus landfill tax had been increased from £45 in 2008 to £70 in 2010[2].

Besides, LATs (Landfill Allowance Trading Scheme) was introduced by the UK government in the 2005 under the Waste and Emissions Trading (WET) Act 2003 to help the country meets its Landfill Directive targets. The scheme will penalize local authorities that exceed their given allowances for landfilling BMW. The implementation of landfill bans and landfill taxes have to coupled with material sorting (e.g. segregation of OFMSW at source) to enable the introduction of any thermal or biological treatment and enhance their viability. A feasibility research of landfill bans by WRAP (Waste and Resource Action Program) shows that climate change benefits and resource efficiency gains are likely to be greatest where landfill bans are coupled with a requirement to sort materials.

Biological treatment is the process of upgrading OFMSW to useful outputs with microorganism either in an aerobic or anaerobic condition. Examples of biological treatment are in-vessel composting, windrow composting, vermicomposting, anaerobic digestion, etc. The high organic content of our MSW provides a great potential in harnessing the biogas from MSW as a form of waste to renewable energy (Amirhossein et al, 2008). Our country current MSW generation is about 22,000 mt per day. If all organic wastes represent 40% or 8,800 mt of the MSW undergo biogas recovery, the minimum capacity of electricity generation is at least 230 MW per day. With the local hot and humid climate condition which greatly facilitates the activity of microorganism, anaerobic digestion is the BAT (Best Available Technology) in tapping biogas from source segregated OFMSW. Besides biogas, the digestate from AD can be further stabilized and turned into quality compost and fertilizer.

Compared to composting, AD provides the extra benefit of biogas recovery that captures methane gas to generate renewable energy. At the moment, there are only a few small scale composting plants (< 1 mt) in Malaysia and there is no big-scale biological treatment facility. Hence, the government has to explore the promising potential of the application of AD as a MSW treatment option as well as an important source of renewable energy. In Europe, the numbers of AD plants for OFMSW treatment has grown from 3 in 1990, to 62 in 2000, to up to more than 170 plants (with capacity of more than 5 million mt/year) that will be installed by the end of 2010. About 15% of the OFMSW is treated biologically in Europe and AD represents about 20-30% of all biological treatment capacity.

D. Trajectory toward IWM (Integrated Waste Management) in Malaysia

The proposed trajectory toward IWM in Malaysia is to diversify the MSW disposal (with treatment) option and prioritize biological treatment. First, the facility installation has to be in placed, followed with effective collection system with strategic planning, effective policy instruments and lastly the sustainability of the entire system. The installation of biological treatment facility (BTF) requires appropriate government policy and incentive, investment, expertise of contractor, consultant and operator and the forming of strategic partnership (Figure 2). In Malaysia, the Solid Waste and Public Cleansing Management (SWPCM) Act 2007 introduced by Ministry of Housing and Local Government is the possible policy to prompt the introduction of BTF. Feed-in Tariff program under the Renewable Energy Act 2011 introduced by KeTTHA (Ministry of Energy, Green Technology and Water) will gain the investors' confidence to invest in MSW treatment technology with energy recovery. BTF installation will be possible with the enabling factors and collaboration from various ministries and other parties.

Next, the supply of quality OFMSW to the BTF requires an effective and viable collection system. All components in a collection system from separation, storage to

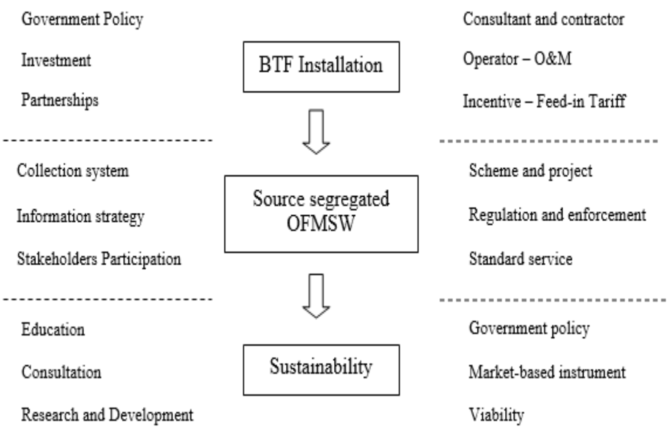

Figure 2. Strategy to initiate biological treatment of OFMSW in Malaysia

transfer and transport have to function correctly and continuously to sustain the operation of the treatment facility. The formulation of a collection system needs a strategic planning that provides a comprehensive outlook of waste stream, waste source and waste flow (Figure 3). Source segregation of OFMSW as the primary step in the collection, play a significant role in the entire system. Government and non-government bodies have to initiate campaign, training, capacity building, education and awareness program to disseminate the information while introduction of scheme, regulation and enforcement for implementation purpose. To promote the diversion of OFMSW to BTF, the introduction of mixed policy instrument (market-based and command & control) such as pay-as-you-throw, landfill restriction and landfill tax are the major driving forces. To ensure the sustainability of the system, continual research and development on technology and consultation on entire system feasibility have to go hand in hand with government policy and education to the public especially the younger generation.

To initiate the operation of a big-scale BTF (> 50 mt/day), the feasibility of acquiring quality OFMSW in a considerable quantity is important to fulfill the economics of scale. Identification of possible waste sources with high OFMSW and introduction of scheme based project are the key factors. OFMSW such as food waste, green waste, animal by-product, livestock manure, sewage sludge can be sourced from market (wholesale, wet, night, morning, agriculture, etc), retailer, eateries (restaurant, food court, etc), hotel, farm, slaughterhouse, sewage treatment plant, recreational park, zoo and institutional area (university, army camp, hospital, etc). The co-digestion of OFMSW may produce a higher yield of biogas. A study of anaerobic co-digestion of kitchen waste and sewage sludge shows that the biogas yield is highest at the ratio of 75% kitchen waste and 25% sewage sludge, compared with 100% of each individual waste, 50% of each and 75% sewage sludge and 25% kitchen waste.

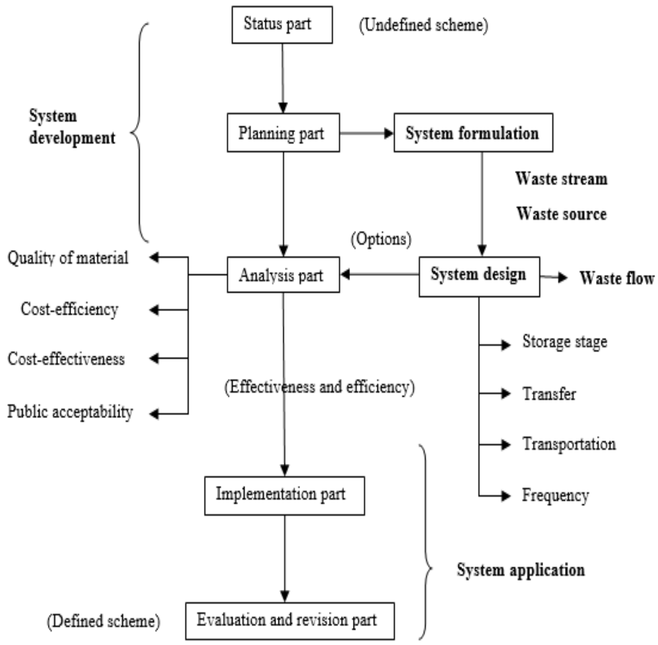

Figure 3. Overview of the formulation of source segregated MSW collection system

The good practice of separation at source (especially on a wet-dry basis) has to be promoted intensively to all sectors and public as it is the fundamental concept in IWM, contrary to the common belief of material recycling which is only part of the solution as only 20-30% (by wt.) of the MSW in Malaysia (in 2010) is recyclable. Thermal and biological treatment or Waste-To-Energy (WTE) is indispensable in an IWM system and source segregation serve as the foundation of effective and efficient material recycling, energy and nutrient recovery. Therefore, the concept of 3Rs (Reduce, Reuse & Recycle) is challenged to become 2Rs+S (Reduce, Reuse & Separate) as the more appropriate and sustainable concept. Another argument for this new concept is the practice of “Reduce” and “Reuse” is within an individual control but not “Recycle”. In fact, our daily practice of recycling is “Separate” the recyclable into paper, plastic, etc; and not “Recycle”.

The proposed source segregation classifies MSW into 6 majors groups (Figure 4): Food waste, garden waste, dry recyclables, residual waste, bulky waste and HHW (Household Hazardous Waste). The perishable fraction (OFMSW) has to undergo biological treatment, dry recyclables are separated for recycling, thermal treatment for residual waste and HHW has to be treated especially e-waste which had been coded SW110 under DOE (Department of Environment). The entire system will work efficiently once separation is fully practiced. The next order of priority in an IWM system is proximity principle which is becoming a prevalent issue in Malaysia with the introduction of more sanitary landfills with long distance from the townships. The establishment of treatment facilities have to fulfil the requirements stipulated by certain authorities e.g. DOE, and proximity principle, which plays a significant role in Type 3 environmental issue – resource consumption and climate change.

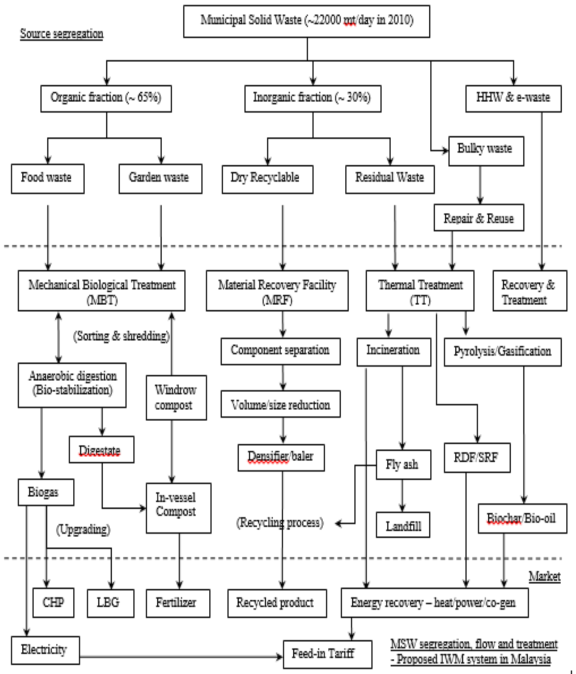

Figure 4. Proposed MSW segregation, flow and treatment for IWM system in Malaysia

To achieve the model of IWM system, it requires the comprehensive perspective of an integrated solution with various functional units from segregation to treatment and final disposal or market with certain elements (concepts) such as proximity principle. The individual element may be varied and flexible to suit the local system, e.g. the different approach in source segregation, collection system and even treatment method. To determine the best available option in the process, substantial study, analysis and consultation are required. In Malaysia, landfill and recycling are the dominant waste disposal/treatment methods. To move forward an IWM system, thermal and biological treatment is inevitable (Figure 5). Hence, proper policy structures have to be in place to develop the sector and ensure its sustainability with appropriate instruments.

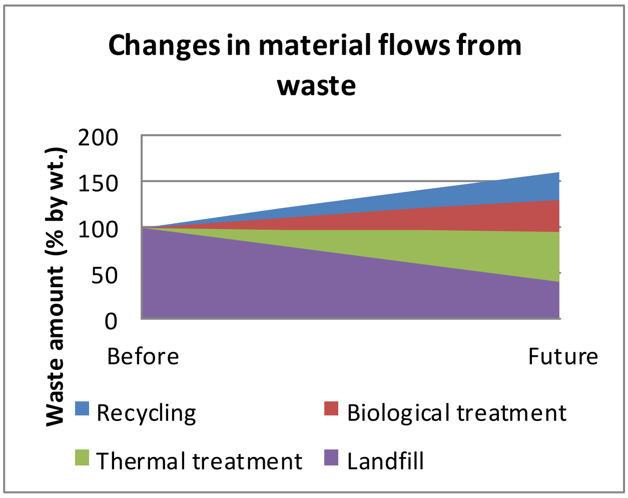

Figure 5. Change of material flows from waste toward IWM system

IV. CONCLUSION

Biological treatment is one of the principal elements in the formation of IWM system. In Malaysia, the inadequacy of biological treatment sector results in MSW of low calorific value which poses a challenge to thermal treatment. Therefore, government has to give due attention to the development of the sector with appropriate policy, effective information, financial incentive and promote state-of-art energy recovery system. The fundamental concept of source segregation, especially with a wet-dry basis, has to be embedded in every individual daily practice in the long run. The establishment of BTF and practice of source segregation are the fundamental strategy in moving the waste management sector toward an IWM model in Malaysia.

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