Prince Mohammad Bin Fahd University

Department of Civil Engineering

Senior Design Project (ASSE III)

Spring 2015/2016

Conceptual MSW Landfill Design and Waste-To-Energy Recovery Potential for Greater Dammam Area

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Acknowledgements

We would like to take this opportunity to show our gratitude towards our supervisor and mentor **Dr. Omar KM Ouda** who has guided us every step of the way and has opened doors to opportunities in our professional careers. We would also like to thank our department chair **Dr. Andi Asiz** for his continued support and flexibility throughout the research process. We would also like to thank **Fasih A. Ahmed** and **Steve Isaac**, who provided us with some aid with editing and formatting. Finally, we would like to express our utmost appreciation to **Courtney Belcher**, who took time off her busy teaching schedule to conduct a comprehensive editing of the final report. Her efforts have made this report into a work of high quality.

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Executive Summary

Saudi Arabia has one of the largest population growth rates in the world, with a current population at almost 29 million. In addition to this, the Kingdom also has an expanding economy driven by the oil and gas industry. Due to this economic development, Saudi residents enjoy a high standard of living, characterized by a culture of excess and oversufficiency. All these factors translate into a high generation of municipal solid waste (MSW) throughout the country. Conventional methods for waste disposal in the country involve the mass landfilling of all generated MSW, with little to no informal recycling efforts. Though Saudi Arabia has an abundance of land, the current waste management system is not sustainable and needs to be improved in order for the country to be able to effectively meet its waste demands in the near future.

The first objective of this study is to evaluate the current waste management system in Saudi Arabia a whole, including the study area. This also includes a review of available waste disposal technologies. The second objective is to gather preliminary data to assess the level of public awareness regarding the issue of local waste management. This data can be used to determine different factors affecting municipal waste services in different parts of the Greater Dammam Area. The third objective is to forecast waste generation in the near future based on current data regarding population, per capita consumption, and waste composition. The final design objective is to forecast landfill surface area requirements as well as the potential for certain methods of energy recovery.

In order to evaluate the current system all the different stages of the system, from waste collection to waste disposal, are examined. This will consist mainly of a literature revew of scholarly works regarding the waste management system in the area well as available waste disposal technologies Public awareness on this issue is evaluated with the use of a survey conducted throughout the study area. The results of this survey are analyzed using IBM SPSS statistical analysis software. The waste generation forecast is done by collecting data on current incoming waste volumes from the municipality. Data regarding the waste composition is used to forecast the generation of each different type of waste. Based on the waste generation forecast the required a conceptual design of volume and surface area requirements for an appropriate landfill cell is produced. Net power generation potential for waste-to-energy approaches of mass burn and mass burn with recycling is calculated to demonstrate the feasibility of alternatives to the current waste management approach.

There are many different waste disposal technologies available in the market today. These include several waste segregation technologies for materials recovery facilities, processes to convert solid waste into thermal or electrical energy, and finally various technologies for the safe disposal of waste in a landfill. Unfortunately, most of these technologies are not being used in the Saudi Arabia, as it still makes use of archaic waste management strategies.

The survey results reflected this fact, as the majority of residents in the country believe that the current waste management system is not satisfactory. It is believed that much more can be done to divert waste away from landfills, and most residents of the area are willing to practice in-house waste segregation if an appropriate government recycling scheme is in place. The majority of residents believe the key to improving waste services is improving public awareness.

The current population of the Greater Dammam Area is around 2.3 million, but is projected to increase up to 5.1 million by the year 2040. Total MSW generation is predicted to increase from the current 1.8 million tons to 4.3 million by 2040. The corresponding landfill surface area requirements for a landfill cell of depth 3m and width 150m is 1.68 sq km. This is expected to increase to up to 3.88 sq km. The net power generation potential for mass burn incineration is around 69MW for current waste volumes, but is expected to increase up to 154MW by 2014. The mass burn with recycling method yield much less power; it has the potential to produce 7MW with current wastes up to about 16MW for projected 2040 waste volumes.

The first design scenario of landfilling without recycling or waste-to-energy shows how critical the MSW challenges would become in the near future if sufficient ways to divert waste are not implemented. Mass landfilling is not a feasible long-term waste management option for the study area. There is a considerable amount of energy that can be produced with the use of the mass burn method of incineration, but this method is known to produce high emissions of toxic materials into the atmosphere. Even with emission control methods, this is not an option the public is easily willing to support. it can be concluded that the best option among the three design scenario methods is mass burn with recycling. The majority of the waste will be recycled and used as raw material in various manufacturing operations, while only residual would end up being incinerated for energy. This approach is economically feasible from both waste management and manufacturing approaches. Furthermore, it is the most environmentally friendly option that the residents of the Greater Dammam Area are likely to cooperate with.

Chapter 1

Introduction

1.1 Introduction

Municipal Solid Waste (MSW) can be characterized as all the solid waste that is generated by commercial or residential buildings. Commonly referred to as “trash” or “garbage,” it consists primarily of food, paper, and plastic waste. All three of these materials can either be recycled or repurposed for other uses, as opposed to being dumped in a landfill. In fact, there are many other applications for MSW that should be considered before dumping. Many countries have created legislation to ensure some of these alternatives are being put to use. More recently, environmental groups and government organizations throughout the world have collaborated to introduce a system of Integrated Solid Waste Management (ISWM). This system ranks all methods of waste use in terms of desirability, with Waste Reduction as the most desirable and Disposal as the least. Introducing technologies for waste-to-energy conversion has created further opportunities, while also presenting its own set of challenges. Only some countries have begun to adopt a comprehensive ISWM system, but more countries are looking to improve in that regard. This research will focus on the waste management in the Greater Dammam Area in the Eastern Province of Saudi Arabia. A study will be conducted on the existing waste management system in the area, looking into possible solutions to improve it.

1.2 Project Design Objectives

The first objective of this study is to evaluate the current waste management system in Saudi Arabia a whole, including the study area. An additional review will be done regarding available waste disposal technologies. The second objective is to gather preliminary data to assess the level of public awareness regarding the issue of local waste management. This data can be used to determine different factors affecting municipal waste services in different parts of the Greater Dammam Area. The third objective is to forecast waste generation in the near future based on current data regarding population, per capita consumption, and waste composition. The final design objective is to forecast landfill surface area requirements as well as the potential for certain methods of energy recovery.

1.3 Project Methodology

The first task is to gather information regarding the current waste management system and how it operates. For this we will observe all the different stages of the system, from waste collection to waste disposal. We will also consider any scholarly works regarding the waste management system in the area. This task also includes conducting a literature review on the different kinds of technology that is available for waste disposal in the market.

The second task is to assess the level of public awareness on the current MSW management system. In order to gain the necessary information, our group has created a survey questionnaire for residents of the Greater Dammam area to fill out. In order to have more variation in the results, we need to have residents from as many different areas as possible fill out the surveys. This will include residents within Khobar, Dammam, and Dhahran as well residents in Abqaiq. The results of this survey will be analyzed using IBM SPSS statistical analysis software, with which we can cross-reference several variables.

The third task is forecast the generation of municipal solid waste for the upcoming 15 years. This will be done by collecting data on current incoming waste volumes from the municipality. Current data regarding the waste composition can be used to forecast the generation of each different type of waste.

The fourth task will begin once the previous three have been completed. Based on the data collected regarding waste volumes we can estimate how much waste will need to be accommodated in a landfill of our own conceptual design, provided all waste is dumped. We will also be looking into the possible net power that can be generated if the waste is mass burned or recycled with incineration of residuals.

1.4 Expected Design Outcomes

Each individual task within the total research project is expected to provide its own independent conclusions as well as contribute toward the overall objective of the study. The literature reviews regarding waste disposal technology will provide our group with a benchmark to evaluate the MSW management system in the Greater Dammam area. It will also be used later when the landfill design process begins; we will be evaluating the potential of some of the energy recovery technology that is mentioned in the literature reviews. The public awareness assessment survey will be used to assess the differences in waste collection services and resident satisfaction between the different districts of our target area. This process can continue to be carried out even beyond the constraints of this project, and the increasing number of completed questionnaires will make the survey data more precise. The waste generation forecast will give us a realistic idea of what waste demands will be like in the near future. This data will determine the volume and surface area requirements of a landfill that services this area. The net power generation from both mass burn and mass burn with recycling scenarios will give us an idea about the feasibility of waste-to-energy as an alternative to mass landfilling.

Chapter 2

Literature Review

2.1 Waste Disposal Technologies

According to Integrated Solid Waste Management (ISWM) standards, the two most desirable methods of waste management are reduction and reusing. These are practices that primarily concern the manufacturers of products and the consumers who purchase and use them (US EPA, 2002). Better product design can be used to create goods that provide the same quality while using fewer materials. Additionally, improving the manufacturing process itself can significantly reduce the amount of waste material being generated during production. Resource depletion can also be the responsibility of individual households. Ideally, a household should only buy as much of a product as what will be used, as the remainder will then have to be discarded as waste. This is especially true for food products that contain organic matter, which have a much smaller life-expectancy than inorganic materials (UNEP, 2005). Moving down the waste management hierarchy, the reuse of products is entirely in the hands of the consumers. Many products, particularly packaging containers and boxes, can be used over and over again until they are damaged or broken. Additionally, there are products such as rechargeable batteries that are specifically designed for reuse. Consumers are encouraged to purchase such products and be proactive in the reuse of materials in order to divert them away from waste streams as much as possible (Masters & Ela, 2014).

Reduction and reuse are the most preferred options in ISWM programs precisely because they are the two steps that we can take to reduce waste before it even becomes waste. These are practices that need to be implemented by producers and consumers; they are not in the hands the waste management agencies. Once materials have become part of the waste stream, they are then in the hands of the agencies responsible for waste management (usually the municipal governments).

The next most significant component of ISWM after reduction and reuse is the recovery of materials for recycling and composting (Masters & Ela, 2014). Organic materials such as food waste and yard trimmings can be decomposed and turned into compost, which can act as fertilizer for various horticultural and agricultural purposes. Alternatively, these organic materials can be used to produce energy in the form of biogas in specialized landfills (Masters & Ela, 2014). These processes will be discussed further in a later section dedicated to bioreactor landfills.

2.1.1 Material Recovery Facilities (MRF)

While the organic matter in solid waste naturally decomposes, the majority of inorganic materials remains intact and decays very slowly, if at all. Materials such as polymers and metals do not decompose and instead are dissolved into leachate, and can be very hazardous to surrounding groundwater if the leachate manages to permeate out of the landfill (Masters & Ela, 2014). These materials are also highly recyclable, and can easily be repurposed towards different manufacturing processes if they are recovered. The recycling of inorganic materials, therefore, manages to solve two problems at once. Firstly, these harmful materials are diverted away from the waste stream and prevented from causing possible harm to the environment. Secondly, the recovered materials can help manufacturers curb the cost of producing (in the case of polymers) or extracting (in the case of metals) them from ores (UNEP, 2005).

There are two types of Materials Recovery Facilities (MRFs); clean MRF and mixed, or “dirty”, MRF. A clean MRF is designed to accept recyclable materials that have been segregated at the source. Recyclable material comes in either single or double streams of relatively homogenous materials. Impurities are removed with the use of manual sorting, with the help of a large and organized labor force. Clean MRFs can only be implemented in areas where public awareness of recycling practices is relatively high. The residents of these areas practice in-house waste segregation, which can greatly reduce the amount of effort required to recycle on large scales.

A mixed MRF facility is one that accepts a mixed stream of waste consisting of all the different types of waste such as organics, plastics, metals, and glass all in one single stream. Different mechanical processes are then used to sort recyclable materials out of this mixed waste stream. Mixed MRFs therefore employ much more sophisticated technology and machinery in the segregation processes.

2.1.2 Waste Segregation Technologies

The key challenge to the recovery of these materials is in its segregation. Since the majority of MSW is discarded and collected as a whole, there is a huge mix of different materials of all shapes and sizes that enters the waste streams (Masters & Ela, 2014). In order to effectively recover the materials in a way that they can actually be used in recycling, they need to be completely segregated. Source segregation of recyclable products is not very common in most countries, so it is important for Materials Recovery Facilities (MRFs) to have the sufficient segregation technology to separate different types of plastics, metals, rubbers and other materials (Masters & Ela, 2014). Some of the most common and effective technologies for waste segregation are discussed below.

i. Trommel Separators/Drum Screens

A Trommel separator, sometimes referred to as a rotating screen, utilizes a continuous tumbling action to separate materials in terms of their particle size. The basic apparatus of a Trommel screen consists of a cylindrical drum made of either mesh screens or perforated plates of specific particle size with an input and output feed on either side. The drum is either elevated at an angle at the input end so that material naturally moves towards the output end due to gravity, or it is fitted with an internal screw that pushes the material along the drum toward the output end. As the waste stream moves through the drum, all materials smaller than the screen openings is able to drop through while larger particles remain inside until they pass through the output end (Sass, 2015). Trommel separators of various different screen sizes can be used in conjunction with one another to separate waste materials in terms of decreasing or increasing particle size. Some of the practical applications of rotating screens in MSW sorting include segregating finer organic compounds used for composting from larger particles used for biofuels (Brentwood, 2016). Another useful application is the separation of metals from incinerated waste; the finer ash falls through the screens leaving the remaining metals that can be recycled (McLanahan, 2016).

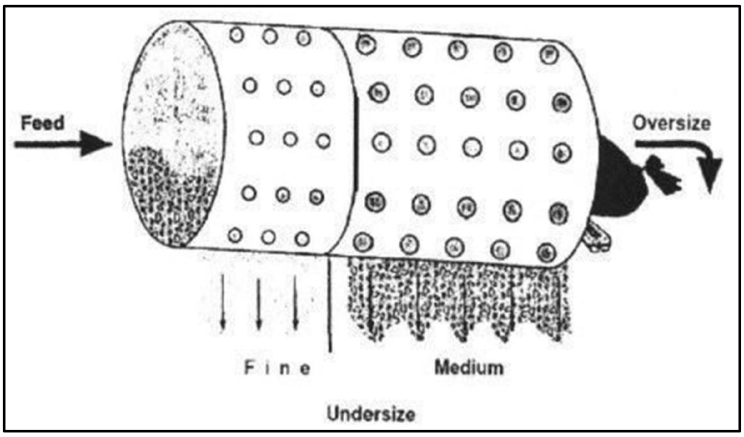


Fig. 2.1 – Basic Trommel Screen Design (Brentwood, 2016)

ii. Eddy Current Separator

Eddy Current Separators are advanced metal separation systems that are used to separate non-ferrous metals such as copper, zinc and aluminum from non-metallic materials in a solid a waste stream (Sass, 2015). As the name suggest, these sorting units make use of powerful magnetic fields known as eddy currents to perform the sorting. These sorting units can only be used once all ferrous metals have been removed using some form of magnetic separation. This is because ferrous metals become dangerously hot when exposed to an eddy current field (Master Magnets Ltd, 2016). The eddy current separator unit consists of a conveyor belt that carries a thin stream of mixed waste material from an input feed. At the opposite end of the belt is a magnetic rotor that produces the eddy current field. There are two separate collection bins for the separated materials; one directly below the end of the conveyor belt and one with its opening at a distance from end. As the waste moves toward the end of the conveyor belt, the magnetic rotor induces a field that repulses the ferrous metals and causes them to “jump” forward as they exit the conveyor belt. Non-ferrous materials simply fall of the conveyor belt into the first collection bin while the ferrous metals are collected in the second bin (Master Magnets Ltd, 2016).

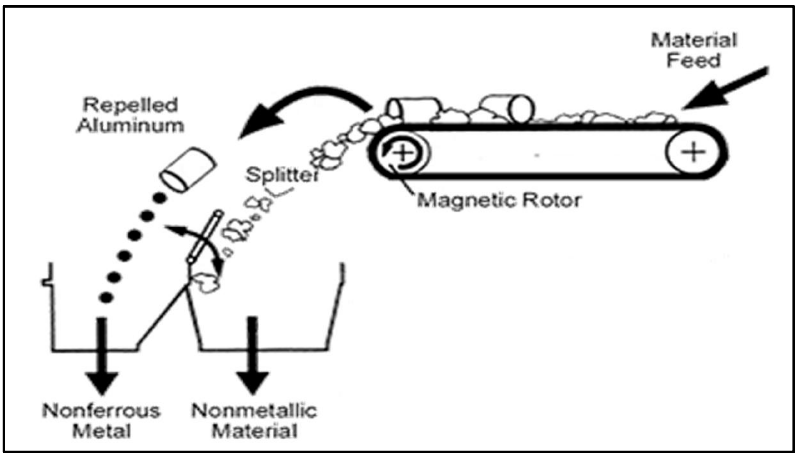


Fig. 2.2 – Basic Eddy Current Separator Unit (Master Magnets, 2016)

A more advanced setup of the Eddy Current separator unit can be assembled with magnetic separators put in place to remove ferrous metals. This allows for a mixed waste stream containing ferrous and non-ferrous metals as well non-metallic materials all to be efficiently separated in one single process. This would greatly increase the device's productivity, allowing for more waste to be effectively segregated in a shorter period of time (Master Magnets Ltd, 2016).

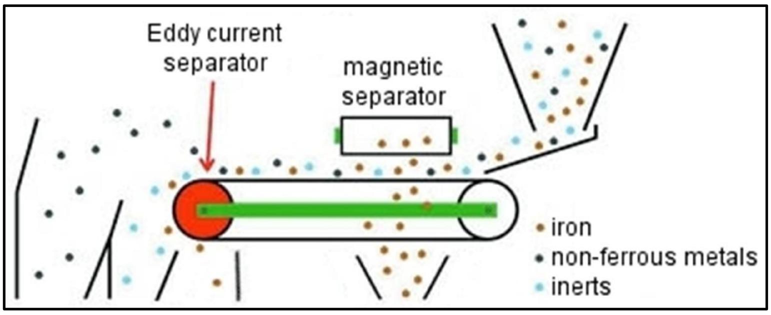


Fig. 2.3 – Eddy Current Separator with Magnetic Separator for Ferrous Metals (Master Magnets, 2016)

<u>iii. Sensor-based Sorting</u>

The aforementioned methods of waste sorting are very effective for the sorting applications that they are specifically designed for, but can only be used within those constraints. This is especially true for Trommel/Drum Screen separation. It is one of the most efficacious methods of categorizing waste in terms of particle size, but that in itself does not have very many practical applications in waste management unless all the waste that is being sorted is of the same material (McLanahan, 2016). Otherwise, drum screen separation is only useful in conjunction with other technologies. One such application would be using drum screens to separate waste streams into different ranges of particle size that can subsequently be fed into other sorting systems designed for those particular particle size ranges (Brentwood, 2016).

Magnetic sorting, on the other hand, is an indispensable technology in waste management, and its application helps to solve multiple major issues at the same time (Master Magnets Ltd, 2016). Firstly, metals contribute to the largest amount of pollutants in MSW and, therefore, need be diverted away from landfills as much as possible. Secondly, metals are much easier to recycle than other materials because of existing ore refining technologies. The cost of extracting metals from raw ore in many cases can exceed extracting from waste streams, giving many industries an economic incentive to promote recycling (Kleine, Wotruba, & Robben, 2011). However, the limitation of magnetic sorting is that it can only be used in applications involving the separation of metals from different waste streams. In Saudi Arabia, metals make up less than 10% of total MSW, which comprises primarily of organics, paper, and plastics in descending order (Aga, Ouda, & Raza, 2014).

In order to effectively segregate different types plastic and paper wastes, different methods of sensor-based sorting have been developed. “Sensor-based sorting” can refer to all applications where individual particles are detected and identified using some sort of sensor technology and rejected from the product stream with the use of mechanical, pneumatic, or hydraulic processes (Kleine, Wotruba, & Robben, 2011). While the different methods of sensor-based sorting focus on different characteristics of materials, they follow the same fundamental principle in each case. The major prerequisite for establishing such technology is the availability of a sensor that is able to detect one or more quantifiable properties of materials in a selected waste stream. The parameters of this property must be identified for the specific materials that need to be separated from the rest of the waste stream (Kleine, Wotruba, & Robben, 2011).

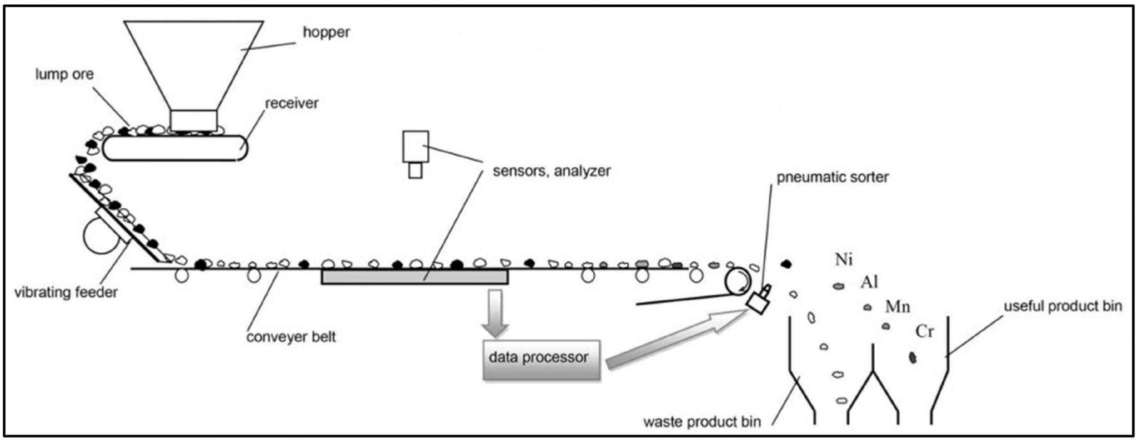


Fig. 2.4 – Generic Sensor-Based Sorting System (Kleine et al, 2011)

Sensor-based sorting can be divided into five sub-processes: material conditioning, material presentation, material detection, data processing, and material separation. Material conditioning refers to all the processes that are used in preparing the material for sensor detection, which consists mainly of screening and cleaning of the feed material (Kleine, Wotruba, & Robben, 2011). This sub-process is significant because all optical sensor technology requires the material to be clean for its optical characteristics to be properly detected. Material presentation refers to way material is arranged for the sensor to detect it. Its goal is to arrange it in a way that provides maximum area for detection, while still keeping individual particles isolated from each other (Kleine, Wotruba, & Robben, 2011). Sensor-based sorters either use conveyor belts or free-fall chutes to move the feed material through the system. Proper material presentation is done with the use of a vibrating feeder that spreads out particles along a conveyor belt before they go into the conveyor or chute for detection. Particles in a belt sorting system are detected horizontally as they travel past the sensor on the conveyor, whereas particles in a chute sorting system are detected vertically as they travel past the sensor during free fall (Kleine, Wotruba, & Robben, 2011). Once the sensor detects the relevant property the data is processed by a computer program. The parameters of this property for various materials are already fed into the program from before, and those parameters are used to identify each individual particle. A decision is then made on whether to accept or reject that particle, based on conditions specified by the in the program. The data is transmitted to a high-speed ejection unit that diverts rejected particles away from the product stream. Most modern ejection units make use of pressurized air jets that shoot selected particles with precision to divert them to a secondary collection stream (Mogensen, 2016).

a) X-Ray Sorting

One of the most prominent methods of sensor-based sorting that has numerous practical applications is the use of x-ray sensors to detect critical properties of materials. One of the great advantages of x-ray sensors is that they can detect materials irrespective of their surface (Tomra, 2016). Materials passing through the x-ray sorting device are exposed to x-ray radiation ranging from 80 to 160 KeV. This radiation passes through the material and hits an x-ray sensor, which measures how much radiation was absorbed by the material. Each element in the periodic table absorbs a different amount of radiation, based on its atomic density (Tomra, 2016). Powerful, high-speed computer software in the sorting device is able to calculate the atomic density of the material based on the amount of radiation absorbed. The material is then identified based on its density and a decision is made on which output stream it will be diverted toward (Mogensen, 2016).

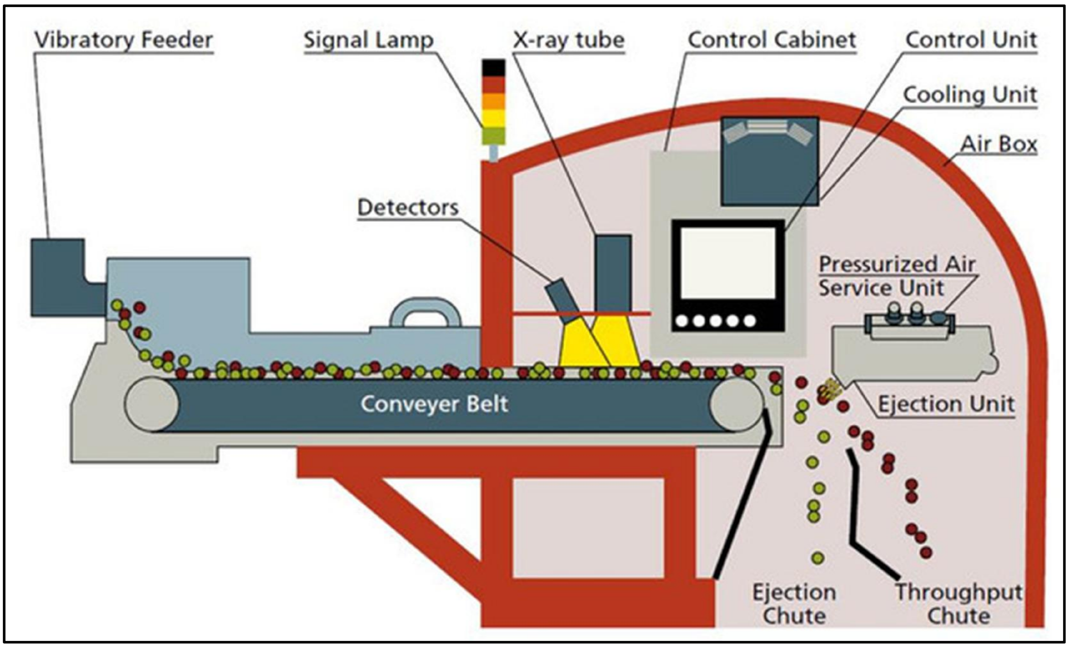


Fig. **2.5 – Typical X-Ray Sorting Device (Steinert, 2016)**

X-ray sensor technology is extremely versatile and can be used to detect and identify more parameters than just material density. X-ray transmission (XRT) can be used to detect the presence of components containing halogens or organic material, composite materials and can also be used to detect internal adhesions in a material (Steinert, 2016). These parameters can be used to separate light and heavy metals, Polyethylene (PET) from other plastics, scrap wood from stone, aluminum castings from wrought alloy, or to isolate materials containing any particular compound or element from a mixed stream (Steinert, 2016).

Alternatively, x-ray fluorescence (XRF) can also be used to distinguish between ores, alloys, and metals based on their surfaces and elemental composition. Materials are run through a low-energy x-ray field, where each element gives off a different amount of energy in response to the radiation. Based on the specific energy emitted by the material, the elemental composition of the material can be determined. This particular method has various applications in mining operations, but is also very useful the recovery of industrial and precious metals from waste (Steinert, 2016).

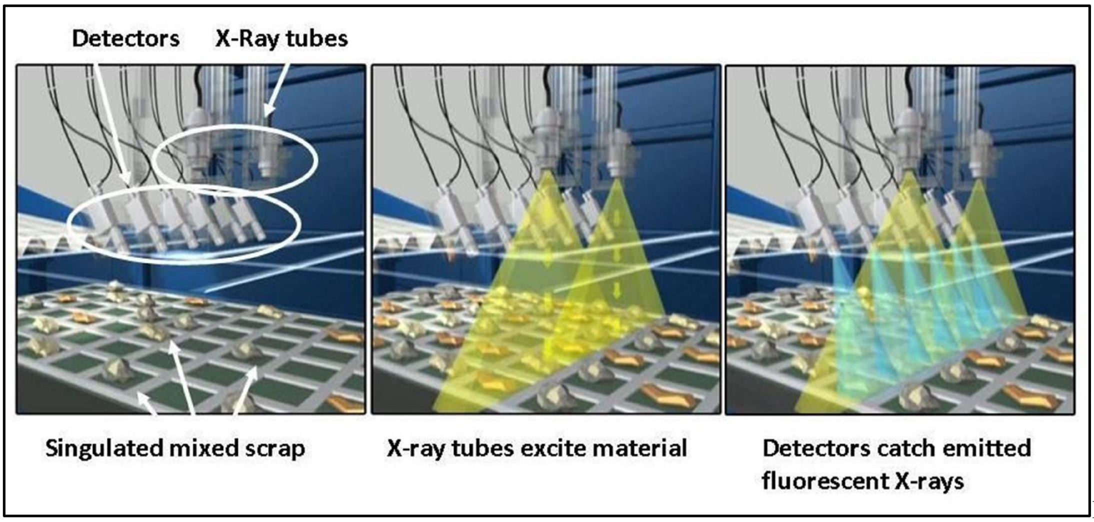


Fig. **2.6 – X-Ray Florescence Technology (Mogensen, 2016)**

X-ray sorting technology can be used to purify material fractions by sorting out unwanted materials. For example, a more valuable and clean fraction of light metals like aluminum can be achieved by sorting out heavier metals like copper, zinc, and lead (Mogensen, 2016). The same principle can be applied to separate glass fragments with different lead compositions. Advanced applications of x-ray sorting technology include sorting out non-combustibles from Refuse-Derived Fuel (RDF) streams and removing organic material from mixed waste for use in composting and bioreactor landfills (Mogensen, 2016).

b) Near-Infrared (NIR) Sorting

Another sophisticated sensor-based sorting technology is Near-Infrared (NIR) Sorting. Unlike x-ray sensor technology, NIR technology is dependent on the surface of the material in identifying it. This means that it identifies materials based on the way that they reflect light (Sass, 2015). Infrared imaging is also referred to as thermal imaging, because it shows the thermal patterns emitted from, or reflected off of a target. Near-infrared spectroscopy for waste sorting is based on the analysis of a reflection spectrum whose signature reveals the structure of molecules within a material. Because of this, near-infrared spectroscopy can be very useful in analyzing bulk material with little sample preparation (Plastics Forming Enterprises, LLC, 2011).

A typical NIR sorting apparatus is very similar in components to most x-ray sorters (Kleine, Wotruba, & Robben, 2011). The mixed waste stream enters the system through a vibrating feeder, which spreads out individual particles evenly throughout the conveyor belt. The material passes through the NIR spectrometric scanner and is identified with the use of complex mathematical algorithms. The program then uses the preset criteria to decide whether to accept each individual particle into the product stream or divert into a secondary collection stream (Steinert, 2016).

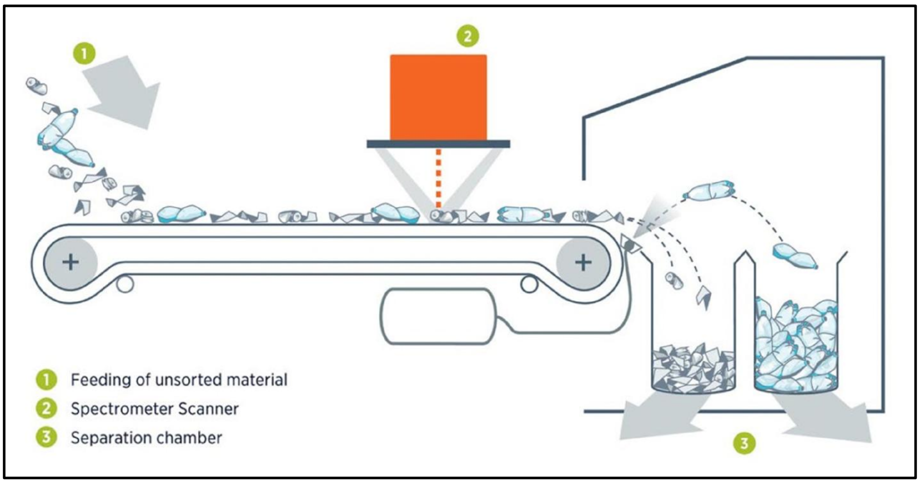


Fig. 2.7 – Typical Spectroscopic Sorting System (Tomra, 2016)

The Near Infrared (NIR) region of electromagnetic radiation covers wavelengths ranging from 700 to 2500 nm (Masoumi, Safavi, & Khani, 2012). The NIR spectra of different polymers are distinct from one another. This makes NIR spectroscopy ideal for plastic identification and sorting. The basis for quantitative analysis of spectroscopy is the Beer–Lambert law (Masoumi, Safavi, & Khani, 2012). The Beer-Lambert law states that absorbance is directly proportional to the thickness of a material and can be expressed in the following equation:

$$A_{(\lambda)} = Ln(I_{0(\lambda)} / I_{1(\lambda)}) = Ln(1/T) = abc$$

$A_{(\lambda)}$ = Absorbance at a particular wavelength λ

$I_{0(\lambda)}$ = intensity of light incident to the sample

$I_{1(\lambda)}$ = intensity of passing light

a = molar absorptivity of the absorber

b = distance the light travels through the sample (the path length or sample thickness)

c = concentration of absorbing species in the sample

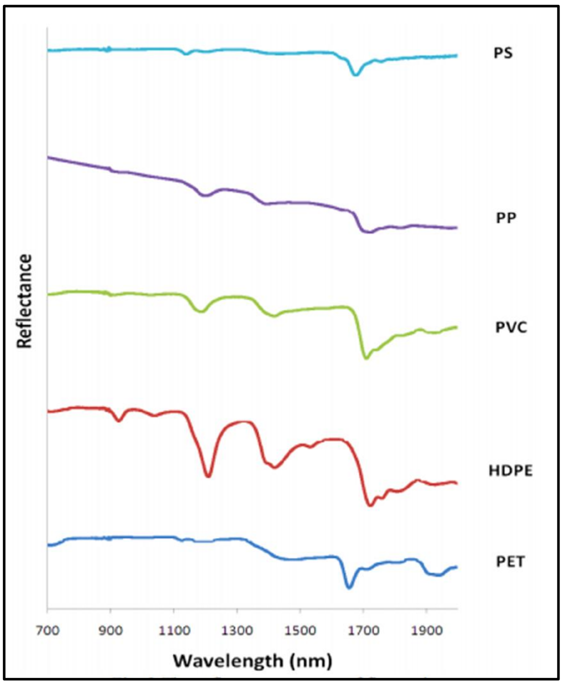


Fig. 2.8 – Reflectance Spectra of Five Different Polymer Types (Masoumi et al, 2012)

By mapping the reflectance of different materials in relation to the NIR wavelength, we can observe a unique "spectral structure" that can be used to identify the material in an NIR sorting facility (Masoumi, Safavi, & Khani, 2012). In addition to separating particles with different molecular structures, NIR sorting can also be used to segregate different colors within the same material. Since different colors absorb different amounts of NIR radiation, the minute differences in their corresponding reflectance can be used to easily detect and sort them (Mattley, 2016).

NIR spectroscopy is a very sophisticated method of material analysis and can be used in a huge number of different applications, but it still has its limitations. Because it relies on a material's absorption of NIR radiation, it only works for materials with reflectance spectra that can be mapped and distinctly classified (Masoumi, Safavi, & Khani, 2012). Dark colors absorb a much larger amount of radiation than lighter ones. Consequently, they have a limited reflectance. The data gathered using NIR methods on very dark colors is not sufficient enough to obtain a spectral structure for classification (Mattley, 2016). Furthermore, glass and metal do not react to NIR radiation the same way that plastics do, their molecular structure does not vibrate when exposed to such radiation. Therefore, NIR sorting is the most effective and efficient way to sort different types of plastics, but cannot be used in the separation of glass and metals (Plastics Forming Enterprises, LLC, 2011).

iv. Parameters for Waste Sorting Analysis

With so many different methods of waste segregation available, it is important to define certain parameters based on which they can be compared. The different sorting methods are usually used to segregate different kinds of materials, so the physical or chemical properties of the input and output streams are irrelevant. The weight, density, or chemical composition of the overall waste stream will vary from material to material and some methods are only used for a small range of waste types (WRAP, 2010). As a result, proper analysis of a particular sorting technology is done by monitoring its effectiveness in isolating a particular desired material from a mixed waste stream. Proper monitoring of a waste sorting system requires compositional analysis of both the input and output streams. The proper way to conduct compositional analysis is to divide all the waste in terms of waste type and weigh the different types separately. The fraction of the weight that the target material comprises of the total weight gives you the percentage composition of that material in the input feed. The different parameters are calculated using the data from the compositional analyses in the input and output feeds (WRAP, 2010).

a) Product Purity Analysis

Purity can be defined as the percentage of the target material within a product output fraction. The data for computing purity comes from the compositional analysis. The target materials in the product output fraction should be split into the same categories as the input feed material. Compositional analysis is used to determine the percentage composition of the target material in the output fraction. For example, if compositional analysis of a 10-ton PET product fraction shows it contains 9.5 tons of PET then the product has 95% purity (WRAP, 2010).

b) B. Yield

Yield refers to the percentage of target material recovered from the input feed stream and put in toward the target product stream. Yield can be calculated for an entire facility or for individual sorting units. Yield is calculated for each material component as follows:

$$Yield = \frac{Quantity\ of\ Total\ Material\ in\ Output\ Fraction}{Quantity\ of\ Target\ Material\ in\ Input\ Fraction} \times (100\%)$$

(Masters & Ela, 2014)

For example, if 10 tons of feed material is processed per day with a HDPE composition of 50% (5 tons) and 4 tons of HDPE product is produced the daily yield would be calculated as follows:

$$Yield = \frac{4.0}{5.0} = 0.8 \times (100\%) = 80\%$$

It is important to note that yield and purity need to be used together in order to gain a full understanding of the process. It is possible to achieve a yield of over 100% because it is based on the entire product fraction, not just the target material. If a process has a high yield and low purity it means that the system has incorrectly ejected non-target material into the product stream, increasing its volume but decreasing its purity (Kleine, Wotruba, & Robben, 2011). A low yield and high purity means the system has been unable to identify the entirety of the target material and therefore it is not ejected. Ideally, you would want a high yield and high product purity, which would imply that the system is correctly identifying target material and removing it while also minimizing the ejection of non-target material into the product stream (WRAP, 2010).

c) Separation Efficiency

Separation efficiency measures how effective system is at sorting. It can be defined as the percentage of the target material being correctly separated into the desired product stream by the sorting mechanism. An efficiency of above 90% is considered to be very good, between 80-90% is good, between 70-80% is acceptable, while efficiency below 70% indicates a poor waste segregation system (WRAP, 2010). Separation efficiency can be calculated with the following equation:

$$Efficiency = \frac{Quantity\ of\ Target\ Material\ in\ Output\ Fraction}{Quantity\ of\ Target\ Material\ in\ Input\ Fraction} \times (100\%)$$

(Masters & Ela, 2014)

For example, if 10 tons of mixed waste is fed through a sorting mechanism and the PET composition is 30% (3 tons). The sorting system is programmed to positively remove PET for output, which produces 2.5 tons of PET product with a purity of 96% (2.4 tons). The efficiency will be calculated as follows:

$$Efficiency = \frac{2.4\ tons}{3\ tons} = 0.8\ \times (100\%) = 80\%$$

Generally, the more efficient a sorting system is the more desirable it is for use in materials recovery facilities (MRFs) (WRAP, 2010). However, there may be other factors that influence whether a particular technology is implemented at a facility. The foremost among those is the type of waste that needs to be segregated. Even though NIR sorting provides the best efficiency and product purity, its use is only confined to polymers (Mattley, 2016). Other factors include operational and maintenance costs. Another issue that can affect many facilities, particularly in the developing world, is the unavailability of certain technologies. Not all manufacturers have agencies in all countries, so certain equipment may not be accessible to all would-be consumers (Kleine, Wotruba, & Robben, 2011).

2.1.3 Waste-To-Energy Technologies

The energy sector in almost all countries is constantly facing increasing energy demands. In addition to this, most established methods for thermal and electrical energy generation consist mostly of the burning of fossil fuels such as coal and natural gas. These practices have been coming under increasing scrutiny due to the many adverse effects they have on the environment and human health. This situation has greatly increased global demand for alternative, renewable energy sources. Waste-To-Energy (WTE) provides a cost effective solution to both energy demand and the issue of exponentially increasing MSW disposal demands. (Ouda et al, 2016)

Waste to Energy uses three primary processes:

1) Thermochemical Technologies

Using high temperatures waste feedstock is transformed into energy that would take the form of electricity, heat and Value-Added Products (VAP). There are three available technologies within the thermochemical process: pyrolysis, gasification, and incineration

2) Biochemical technologies

Organic waste is transformed into energy that would either take the form of liquid or gaseous fuels by using biological agents. The created bio products can be further treated and used in agriculture, cosmetics, cardboards etc. The technologies of biomethanation and fermentation are used during the biochemical process.

3) Physicochemical Technologies

Physicochemical technologies use chemical agents to transform organic waste into energy that would primarily take the form of liquid fuels. The most recognized physicochemical conversion technology is transesterification.

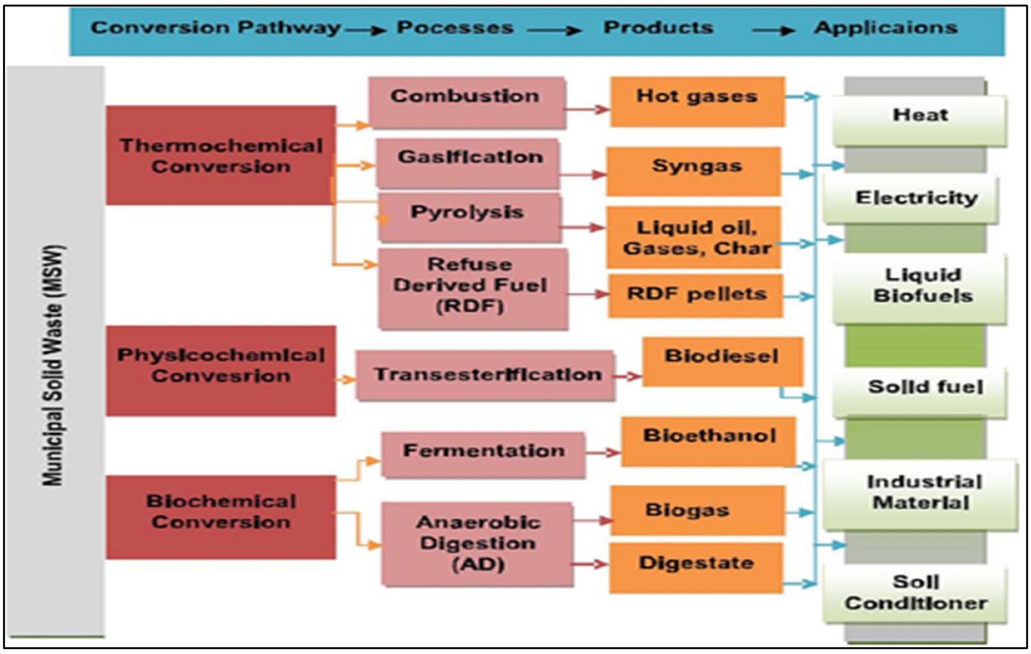


Fig 2.9 – Three Primary Waste to Energy Processes (Ouda et al, 2016)

Considering these methods for converting waste into energy, there are essentially five kinds of Wastes-to-Energy technology that are broadly used and implemented for MSW management: incineration with energy recovery; gasification; plasma arc gasification; refused derived fuel; and Biomethanation.

a) Incineration

One of the most essential parts of MSW management in numerous countries around the world is incineration (Ouda et al, 2016). Incineration is a waste treating method that includes the combustion of organic contained in waste materials. In pursue of defining incineration and other high temperature waste treatment systems the term Thermal treatment is used. Incineration of waste materials turns the waste into ash, gas, and heat. Ash is often formed by the inorganic parts of the waste. The combustion gasses must be cleansed of gaseous and particulate contaminants before they are dispersed into the air. In certain scenarios, the heat generated by incineration can be used to produce electric power. Incineration with energy recovery is the energy product from incineration at high temperatures while combustible gas is often the principal energy product from gasification. Incineration and gasification may also produce power without energy and materials recovery.

Incinerators reduce the solid mass of the original waste by 80–85% and the volume by 95–96% however; this is dependent on the composition and degree of recovery of materials such as metals from the ash for recycling (Ouda et al, 2016). Implying that although incineration may seem insufficient to follow landfills, it significantly decreases the required volume for disposal. Trash trucks usually minimize the mass of waste in a built-in compressor before transporting to the incinerator. At the landfills, the volume of the uncompressed waste can be decreased by nearly 70% over utilizing a permanent steel compressor, although with a significant energy charge. In several countries, simpler waste compaction is the current practiced system for compaction at landfills.

The process efficiency of incineration is 25–30% (Ouda et al, 2016). The end product of incineration is hot combusted gasses, mainly composed of nitrogen(N_2), carbon dioxide (CO_2), flue gas, oxygen (O_2) and noncombustible materials (Ouda et al, 2016).

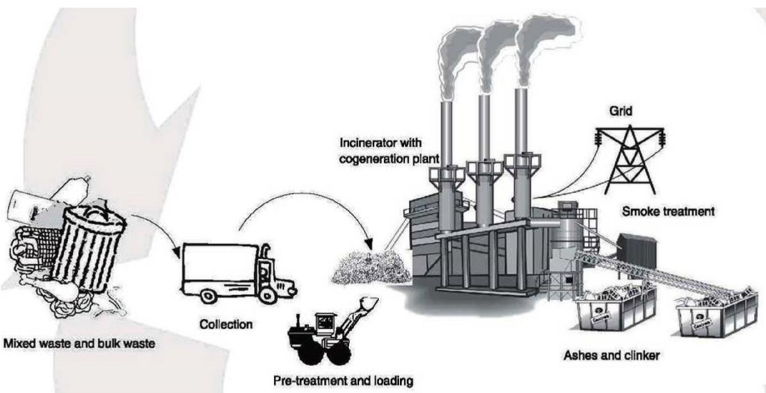


Fig. 2.10 – Typical Mass Burn Incineration Process (UNEP, 2005)

b) Pyrolysis

This procedure recuperates 80% of the stowed energy in carbonaceous waste to liquid fuel and char (Ouda et al, 2016). Diverse sorts of reactors have been used for the pyrolysis. In a usual two-stage Pyrolysis reactor, the primary chamber works at low temperature and the second chamber keeps functioning at a high temperature, where the complete burning of feedstock materializes. The produced substances can then be utilized as a part of energy applications after separation and collaborating with gasoline fuel. Pyrolysis is thought to be financially profitable on massive a scale that minimizes ecological concerns mainly in waste minimization, carbon sequestration, soil correction, energy/heat supply, and (VAP). However, the metal tubes utilized as a part of this procedure are often corroded given their repeated use, and their substitution frequently decreases the process's general productivity.

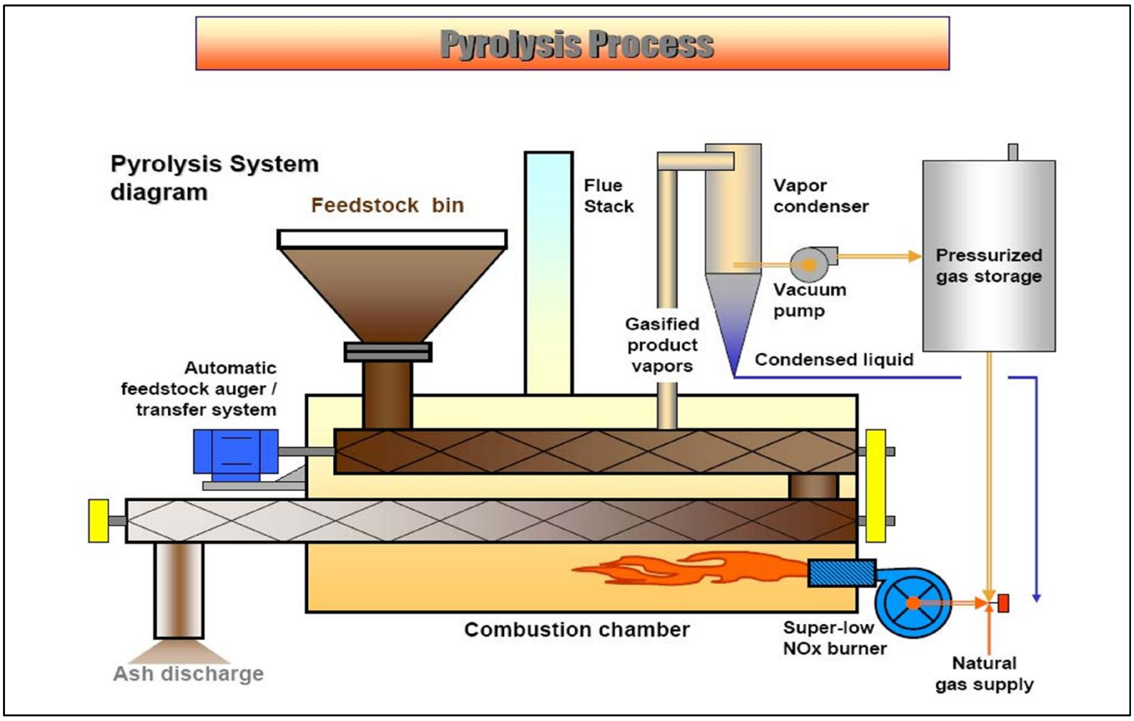
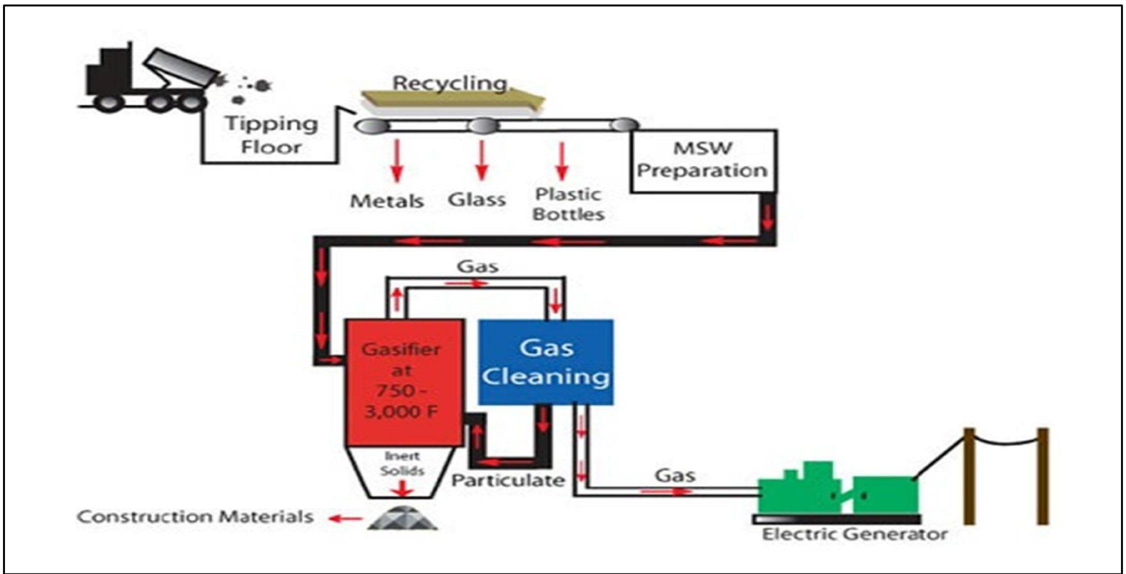


Fig 2.11 – Typical Pyrolysis Process (WTE International, 2016)

c) Gasification

Gasification is an aberrant ignition, where an exothermic response materializes in the reactor when carbon reacts with O2 and produce energy to drive the response. Temperature, pressure, and O2 applications are the principle parameters that influence the gasification process. The produced syngas or synthesis gas is a blend of carbon monoxide (CO), hydrogen (H2) and CO2 that can directly be utilized as a part of a gas turbine for power generation. There are numerous reactor strategies reasonable for gasification with a general effectiveness of around 17%. The net energy production capability of the procedure is assessed somewhere around 20 and 26 kW/ton of MSW. Besides, the process can decrease the waste volume somewhere around half and 90% and can spare 1.9–3.8 MW per ton of waste at the point when contrasted with landfill disposal.



2.12 – Process of Gasification (Alt Energy, 2016)

d) Plasma Arc Gasification

Plasma arc gasification changes over the waste and organic materials into syngas or synthesis gas and solid slag utilizing plasma generated by an electrically driven plasma torch. The nature of waste disintegration through plasma relies on plasma thickness and its temperature. The fourth condition of matter with hot ionized gasses created by electrical release at high temperature (2000-5000 °C) is known as Plasma. Plasma arc gasification for Municipal solid waste is most particular. The working expense for this innovation was observed to be similar with other WTE developments.

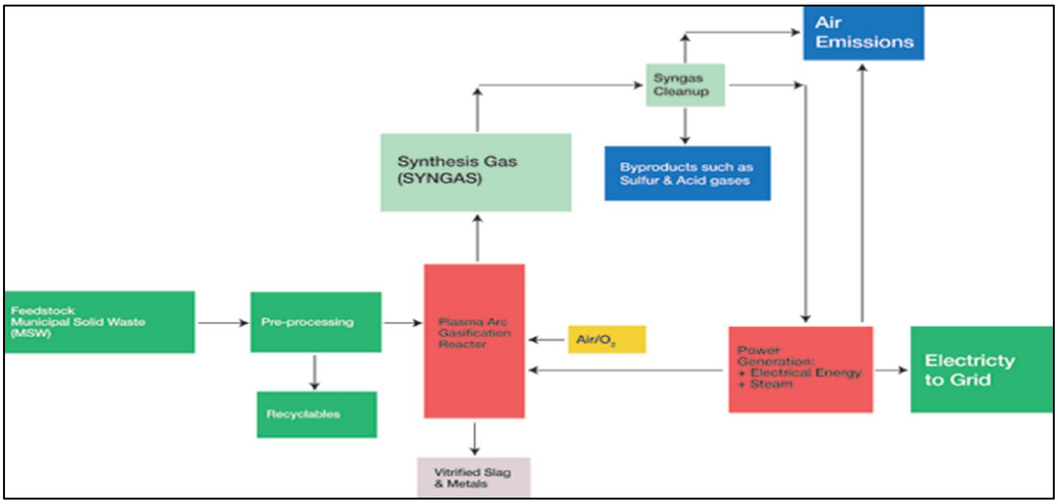


Fig. 2.13 – Plasma Arc Gasification Process (Alt Energy, 2016)

e) Refuse Derived Fuel (RDF)

RDF creates an alternative fuel for power generating facilities, which require coal fuel to operate. This technology includes several stages that consist of size reduction and its separation, crushing, drying furthermore, palletization. The waste utilized as a part of RDF largely contains cardboard, paper, different plastic streams, glass, metallic and nonmetallic material, etc.

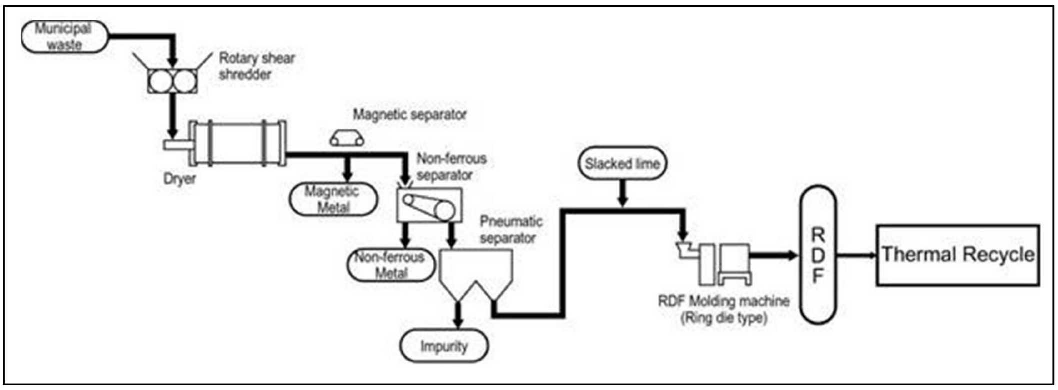


Fig. 2.14 – Typical RDF Process (Hitachi, 2016)

f) Biomethanation

Biomethanation is the anaerobic change of organic materials into energy and organic manure. This process substrate includes industrial, slaughtering, agricultural, vegetable market, as well as restaurant waste. Hydrolysis is the initial stage of Biomethanation, which transforms complex organic materials like carbohydrates, proteins, and fats into dissolvable organic materials for example: sugars, amino, and fatty acids. The second phase of the procedure is fermentation, which further separates the organic molecules into acetic acid, H_2 and CO_2. Methanogenesis is the final stage which makes methane (CH_4) from acetic acid and H_2. Around 25–30% is the efficiency of this technology (Ouda et al, 2016).

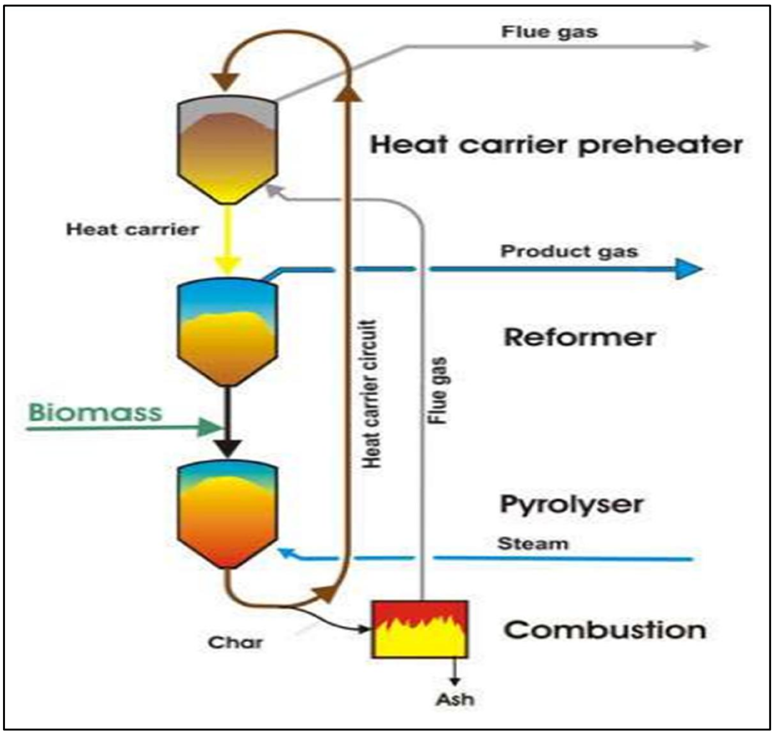


Fig. 2.15 – Typical Biomethanation Process (UNEP, 2005)

	Merits	Demerits
Incineration	• Volume reduction upto 80% • Mass reduction upto 70% • Can take larger waste amounts • Quick treatment	• Air and waterborne pollution • Cancer forming chemical (dioxins) production • High investment • Social opposition • Solid waste (slag) production
Refuse derived fuel (RDF)	• Waste stabilization • Waste sterilization • Waste size reduction • RDF pellets have high calorific value	• Air pollution from power plants where RDF is used • Ash formation and handling in power plant with RDF • High net unit cost per ton • Land acquisition
Biomethanation	• Low solid production • High rate anaerobic composting with energy • Nutrient rich digestate as an organic fertilizer • Cost effective technology	• Contain impurities • Non attractive at large scale • Susceptibility to shocks and overloads • Space requirements
Pyrolysis	• Recovers upto 80% energy from waste • Reduces land requirements • Products have higher calorific values • Liquid products separation in vapor phase • Reduction of MSW volume upto 50-90%	• Liquid products have low yields • Pyrolytic water production from organic matter • Coke production from liquid products • Byproducts cleaning • Corrosion of metal tubes used in pyrolysis • High operating and maintenance cost
Plasma arc gasification	• No greenhouse gas (GHG) emission • Any waste substrate can be used • Technology can be easily expanded	• High operating and capital cost due to high energy requirements
Landfilling	• Least cost/cheap option • If gas is captured and recovered, can be a source of power generation and heat • No skilled labor requirements • Marshy land can be converted into useful land • Natural resources are returned to soil	• surface runoff during rains • Soil and groundwater contamination • High transportation costs • Expensive leachate treatment • Significant GHG emissions, if biogas is not captured and recorded. • Landfill area requirements • Odor problems

Fig. 2.16 – Comparative Analysis of WTE Processes (Ouda, et al, 2016)

2.1.4 Landfill Cells

The oldest and most commonly used method of solid waste management is the use of landfills. While it is often the simplest and least expensive method of disposal, it has many disadvantages that make it an unattractive choice for modern-day waste management (UNEP, 2005). The potentially hazardous effects of landfilling on the environment make it the least desirable option in integrated solid waste management (ISWM). Traditional landfill methods consist of simply digging out a large ditch, burying waste inside it and then covering it up. Slowly, the waste would decompose naturally over the course of about 30 years (Masters & Ela, 2014). There are three by-products of that decomposition, however, that are known to have adverse effects on the surrounding environment.

The first of these by-products, Leachate, consists of various liquids that absorb soluble parts of decomposing waste as they flow to the bottom of the landfill. These solutes can also include various toxins and metals. If leachate flows through the bottom of the landfill and infiltrates nearby groundwater, the water will become contaminated and will likely result in health issues for all organisms that consume it (Masters & Ela, 2014). Methane is a greenhouse gas that is produced during waste decomposition. The buildup of methane inside the covered landfill can cause explosions. Furthermore, methane that escapes into the atmosphere contributes toward the greenhouse effect. According to the US EPA, about 18% of US methane emissions are from landfills (US EPA, 2002). The process of waste decomposition also produces various different types of volatile organic compounds (VOCs), some of which (such as hydrogen sulfide and hyponitrite) are highly dangerous to human health. Due to their low concentrations, most harmful VOCs are known to cause health problems over a large period of exposure. Some VOCs can be dissolved into leachate and pollute groundwater and surrounding soil if not contained properly (Masters & Ela, 2014).

In order to combat these challenges, most developed countries have moved on from traditional landfill dumpsites to the modern landfill cell. The landfill cell is a complex, precisely constructed chamber which is designed to isolate the stored waste from the surrounding environment (Masters & Ela, 2014). The entire structure made of compacted clay with very low permeability. The clay is then covered with polyethylene liner and geotextile matting, which further increases the landfill cell's waterproofing ability. Piping for a leachate collection system is then placed above the liners, with a thick layer of gravel placed above that. The leachate is partially filtered as it runs through the gravel layer into the drainage system. It is then pumped out of the ground and placed in a pond or lagoon, where it can undergo treatment away from the groundwater. There are exhaust pipes located throughout the usable area of the landfill cell that extract methane fumes that are given off by the decomposing waste. These small quantities of methane can be combusted and converted into electricity that can be used to power the entire landfill system. A final safety measure is taken in the form of monitoring wells, which are placed in the surrounding groundwater aquifers. These wells are used to supervise the condition of nearby groundwater and detect any possible contamination that may occur (Masters & Ela, 2014).

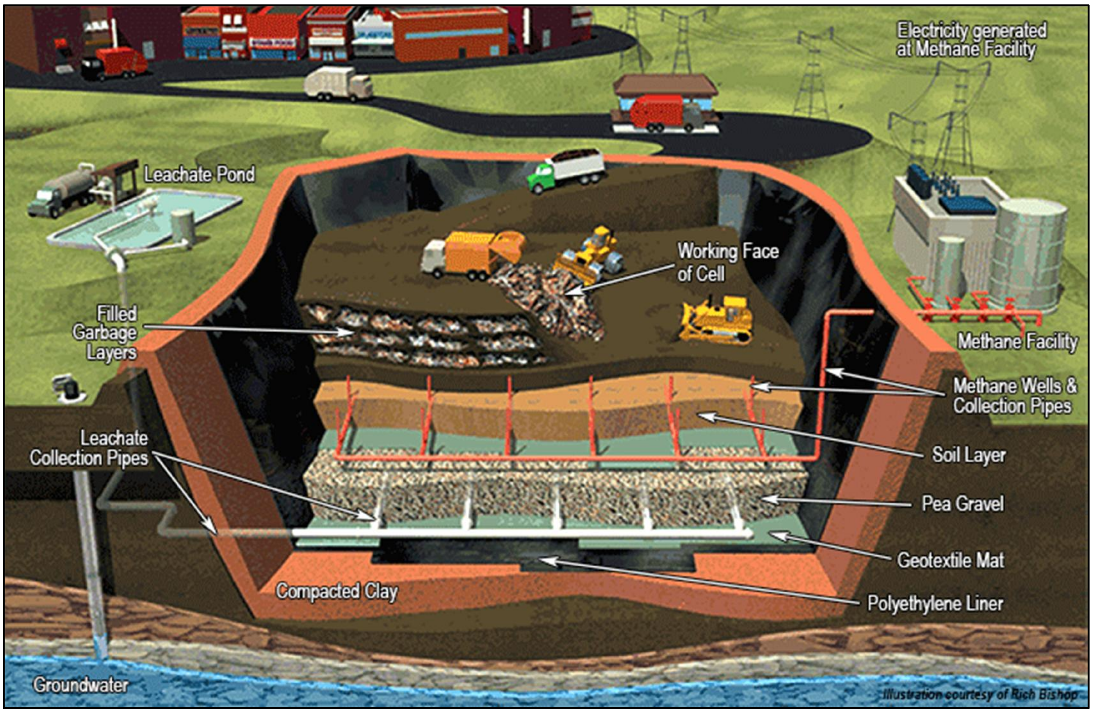


Fig. 2.17 – Typical Landfill Cell Design (UNEP, 2005)

While this landfill cell design has many benefits over the traditional landfill dumpsite, it still has very similar limitations. Most importantly, the rate of waste decomposition is very slow compared to the rate at which waste is being produced and dumped. As a result, landfills tend to run out of space very quickly (UNEP, 2005). The most commonly used method to improve landfill capacity is waste compaction. Waste is compacted during various stages in its life cycle. The first compaction is usually carried out upon collection. The most advanced garbage collection trucks have a mechanism to compress waste before it is stored (Japan Environmental Sanitation Center, 2012). This also allows the maximum amount of waste to be transported at one time, decreasing the cost and emissions associated with waste transport. To further reduce cost and emissions, a municipality can make use of waste transfer stations if the disposal site is reasonably far away from the collection areas (Japan Environmental Sanitation Center, 2012).

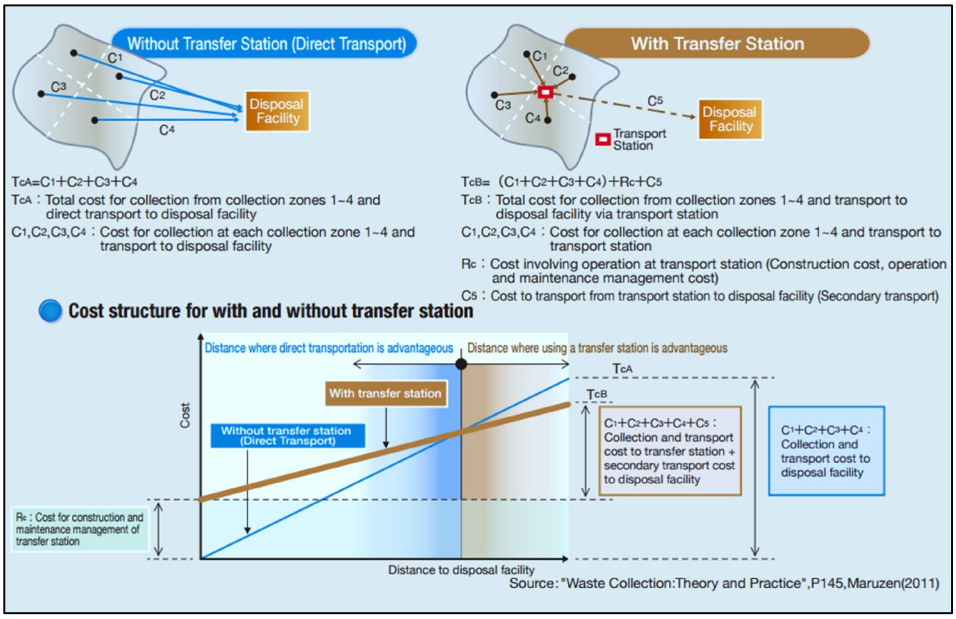


Fig. 2.18 – Cost Structure With and Without Transfer Station (Maruzen, 2011)

Over the last 30 years, a new way of thinking has developed regarding the management of solid wastes. Waste has traditionally been viewed as the residue of economic activity, or surplus materials that are the collateral damage of human development. In recent years, due to the above mentioned limitations of landfills, people have begun to view waste as yet another resource that can be used for economic and social development (Cheng & Hu, 2010). The concept of integrated solid waste management (ISWM) has been very influential in the development of this approach, putting more emphasis on reduction, reusing, and recycling. These have become established practices in most parts of the developed world, but the majority of waste is still not managed with this approach (US EPA, 2002). This is because the majority of MSW does not consist of recyclable materials. According to studies conducted by the King Saud University, more than one-third of MSW in Saudi Arabia is biodegradable organic waste that comes primarily from food (Aga, Ouda, & Raza, 2014). As a result, there is immense scope for technologies that deal with putting this biodegradable waste to good use. The most economically feasible options are either to make compost for agriculture or to use one of the various methods of energy recovery (Nizami, Ouda, Shahzad, & Ismail, 2015).

2.2 Current Waste Management System in Saudi Arabia

This section will focus on the current municipal solid waste management infrastructure in the Kingdom. A review of Saudi Arabia as a whole as well as a few individual cities will be conducted, look at current waste generation and how each municipality manages the incoming waste.

Saudi Arabia's population has increased from 7 million in 1970 to 27 million in 2010, over a period of just 40 years. The population growth rate based on the historical trend is 3.4 % per year. This increase in population growth, in conjunction with an increased the standard of living in the country has resulted in a huge increase in municipal solid waste generation. Moreover, the capability of more purchasing power can lead to more consumption, which results in more waste generation. Consequently, the high gross domestic product in Saudi Arabia could be the reason behind a culture that promotes waste.

Fig 2.19 – Map of Saudi Arabia (Google Maps)

2.2.1 Waste Generation

Saudi Arabia is the largest country in the Arabian Gulf, comprising of about 80 percent of the total land area of the Arabian Peninsula. The total land area of Saudi Arabia is an estimated 2.15 million square kilometers. While the majority of this area is a desert, about 40 percent of this area consists of rangeland and 1 percent is made up of forests. The major cities generate roughly 9 million metric tons of municipal solid waste per year, while Saudi Arabia as a whole has generated an average of around 14 million tons annually until the year of 2010, which averages about 1.4 kg/capita/day (Ouda et al, 2014). By the year 2015, that average of waste generation levels has reached up to 15 million tons annually, or around 1.8 kg/capita/day.

2.2.2 Waste Composition

The majority of about 50% of total municipal solid waste in Saudi consists of organic (food) materials, while papers and plastics comprise about 12.5% and 11% respectively (Ouda et al, 2013). The table below shows overall solid waste composition in Saudi Arabia:

Waste	Percentage
organic food, agriculture, garden waste	50%
Papers, cardboard	12.5%
Plastics	11%
Glass	6.3%
Metals	3.2%
Wood	4.8%
Other types of waste	9.4%

Table 2.1 – Estimated Composition of MSW in Saudi Arabia (Ouda et al, 2013)

It can be observed from the above table that the largest percentage of waste in Saudi Arabia is organic waste. The high content of organic waste reflects the culture of this region, where discarding and wasting food is very common. It also means that the MSW in Saudi Arabia has good potential for biological waste-to-energy processes (Ouda, 2013).

2.2.3 Current Waste Management System

The local municipalities of each region are responsible for management of solid waste In Saudi Arabia, the municipal solid waste is collected from different bins and households and sent to a dump site or a landfill. There are inadequate technologies currently present in the existing waste management infrastructure to produce any sort of monetary benefit from the waste that is collected from different zones in the cities. This is due to weak waste management, waste disposal facilities, and absence of tipping fees. Solid waste generation can be subdivided into residential and nonresidential, depending on its source. Residential wastes are generally considered to be household-type wastes, whereas nonresidential includes commercial, light industrial and other wastes (Ouda, 2013). Wastes generated by residential households are usually calculated in pounds (kilograms) per capita per day. This measurement is suitable for gross estimates for use in sizing disposal facilities and resource recovery operations but is not appropriate for the design of collection systems. Collection systems are more appropriately designed utilizing the annual average weight (pounds) per household (or stop) per week (PPHW). Estimates for household waste generation should be based on actual measurement. This means actually counting the residences on residential routes and weighing the refuse collected (Ouda, 2013).

The high quantity of waste generated throughout Saudi Arabian cities is causing environmental and health issues that are worsening at an alarming rate. The concern is furthered by the fact that the national, regional, and local municipalities actively delay instituting sustainable, long-term solutions in favor of short-term responses.

2.2.4 Conclusions

The low cost of landfill operations in the Kingdom makes the MSW recycling programs implementation unachievable at this time being. Talking about most of the technologies, and methods used in waste management recycling in Saudi Arabia, the only source and scale of recycling systems in the country is only trash sorters collection of metals, cardboards from garbage containers. In general, incineration, and gasification are most of the technologies used in waste to energy in most parts of the world. The government of Saudi Arabia currently is planning for the development of various WTE facilities throughout the Kingdom, which would require significant cooperation from the local communities.

Chapter 3

Public Awareness Assessment Survey

3.1 - Introduction

Municipal solid waste management (MSW) can be characterized as all the solid waste that is generated by commercial or residential buildings. Most conventional methods of solid waste disposal are to use up the precious lands and cause harm to the environment. Integrated solid waste management (ISWM) ranks all the methods of waste management in terms of desirability, ranging from waste reduction as most desirable to disposal as the last resort. The study will investigate the waste management system of the greater Dammam area in order to assess where it stands when compared to global ISWM standards. Unfortunately, Saudi Arabia has been trying to follow ISWM but due to bad management, this act could not get any closer to the best practices, since they have huge empty lands, they dump all the waste into the landfill which is bad not only because they don't follow ISWM but also because of the smell that the landfill creates. Segment 1 of this study is to conduct a survey to assess the level of public awareness on the issue and gather feedback from local residents on how to solve it. This survey will be used to determine local resident's willingness to apply integrated solid waste management practices in daily life. Segment 2 is to gather all the data from the survey questionnaires and insert the data in to SPSS, which helps us generate charts and tables with accurate percentages.

3.2 - Objectives

The first objective of the survey is to assess the level of public awareness regarding the current municipal solid waste management system in the study area. The second objective is to obtain feedback to determine the general public opinion concerning the issue of waste management.

3.3 - Methodology

The first task is to assess the level of public awareness on the current MSW management system. In order to gain the necessary information, our group has created a survey questionnaire, which consists of 40 questions, in which 36 questions are completely related to waste and other 4 questions are personal questions, for residents of the Greater Dammam area to fill out. In order to have more variation in the results, we need to have residents from as many different areas as possible fill out the surveys. This will include residents within Khobar, Dammam, and Dhahran as well as residents in Abqaiq. Since we wanted to conduct the questionnaires all over the greater Dammam area, we visited the above mentioned cities one after another to get the surveys done, and we also used social media to send the surveys out to people who were eligible to answer. In addition, we emailed the surveys to various employers, requesting them to fill out and pass on the surveys to their different departments. Moreover, we visited the most visited city malls to get opinions of randomly selected individuals. The questionnaire is specifically designed to gauge the general public's knowledge regarding integrated solid waste management methods, and to measure the extent to which people believe those methods are practiced within the greater Dammam area. The public opinion section focuses on overall satisfaction with current municipal solid waste management collection and disposal services, possible ways to improve them, and willingness to actively participate in integrated solid waste management practices. Selected personal information is also documented in order to characterize the data, and determine some of the variables that may influence public opinion. All survey data has been recorded and analyzed with the use of IBM SPSS statistics, and charts have been prepared for the response results for the most significant questions in the survey.

3.4 - Sample Characteristics

Age Group	Participants	%
<30	137	27.3
30-39	158	31.5
40-49	97	19.4
50-60	70	14
>60	28	5.6
Unspecified	11	2.2
Total	501	

Table 3.1 – Sample Characteristics in terms of Age

Education Level	Participants	%
High School	68	13.6
Diploma	57	11.4
Bachelors	258	51.5
Masters	94	18.8
PhD	13	2.6
Unspecified	11	2.2
Total	501	

Table 3.2 – Sample Characteristics in terms of Education Level

3.5 - Results and Discussions

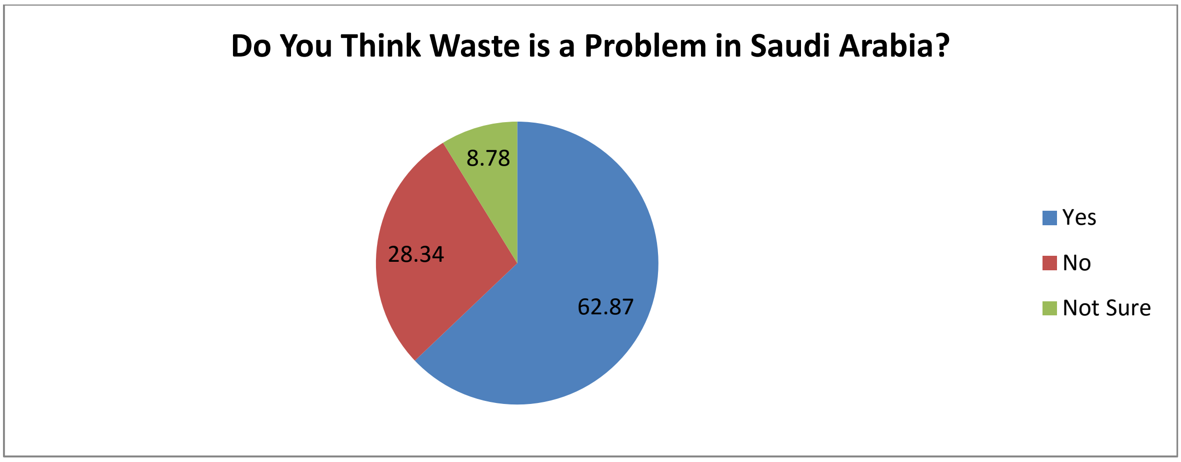


Fig. 3.1 – Responses for Survey Question #1

A decent majority of almost 63% believes that waste is a problem in Saudi Arabia, but a few disagree. This shows that there is sufficient awareness regarding current practices.

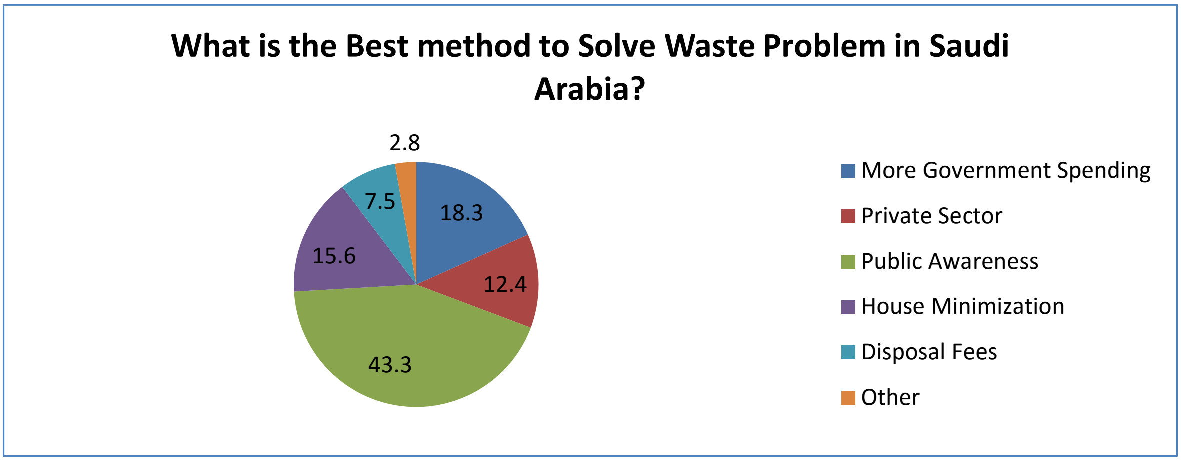


Fig. 3.2 – Responses for Survey Question #2

Most people chose public awareness as the best way to solve the waste problem in Saudi Arabia. In contrast, a significant percentage (18.3%) indicated that the government should be the one spending money to solve the waste problems.

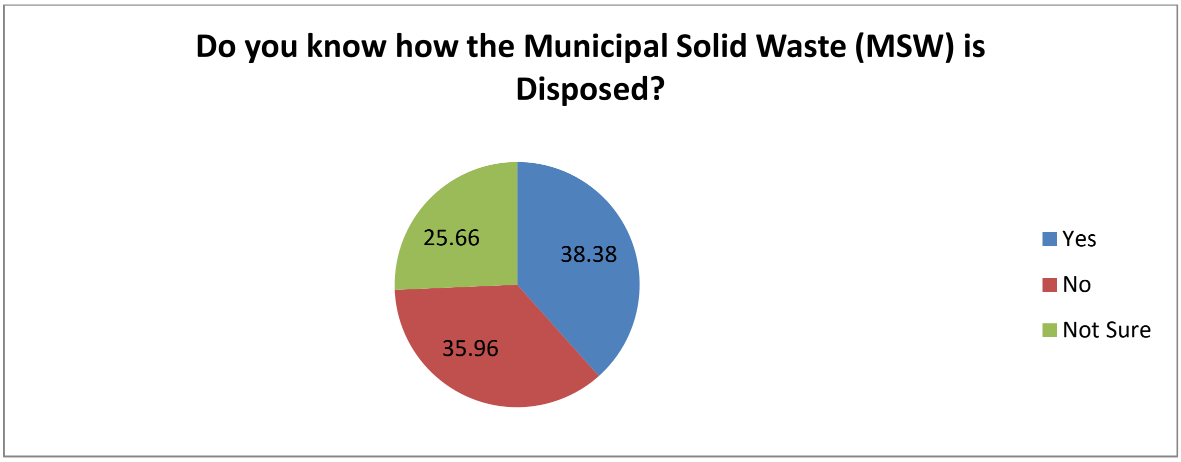


Fig. 3.3 – Responses for Survey Question #3

A surprising 60.8% of people either were not sure or had no idea regarding how municipal solid waste is currently disposed of in this region. This either comes down to the municipality failing to keep the public properly informed or the general public being apathetic in regards to waste management.

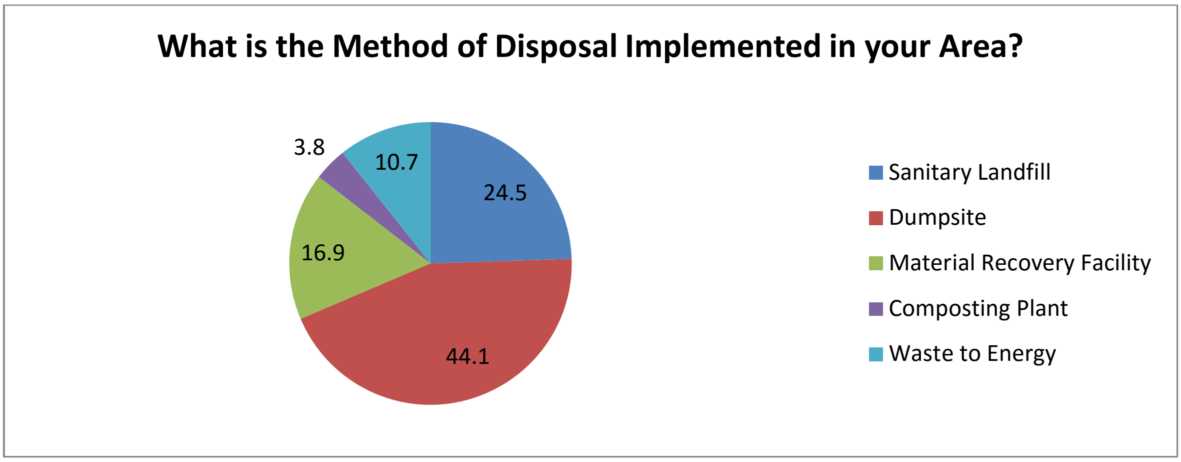


Fig. 3.4 - Responses for Survey Question #4

The above chart clearly shows how the current MSW management is disposing of the garbage at a dumpsite. 44.1% of the study group is disposed of in this way.

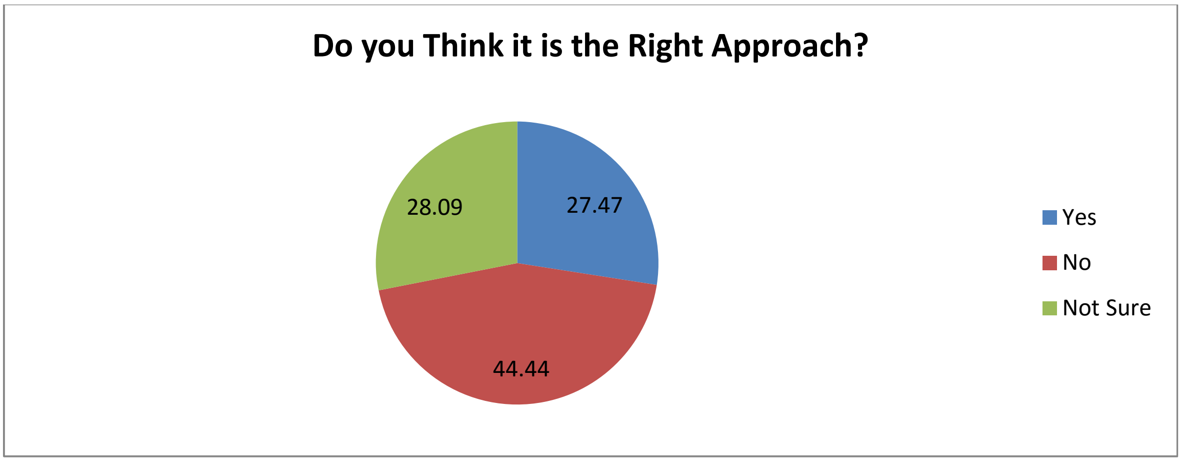


Fig. 3.5 - Responses for Survey Question #5

45.4% of the survey sample believed that dumping all the waste into the landfill is not the right approach, while about 27.5% were satisfied with the current waste management methods. An additional 28% did not have enough knowledge about ideal waste management practices to be able to properly judge whether it is the right approach or not.

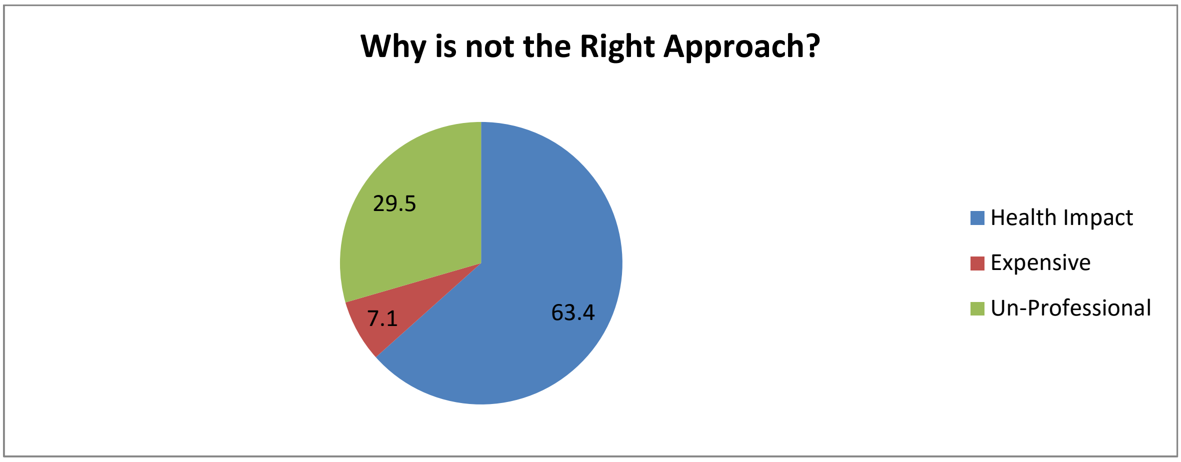


Fig.3.6 - Responses for Survey Question #6

Negative impacts on human and environmental health is the major reason why almost 64% of the public said dumping all the waste into the dumpsite is not the right approach, and almost 30% said dumping waste is a very unprofessional practice.

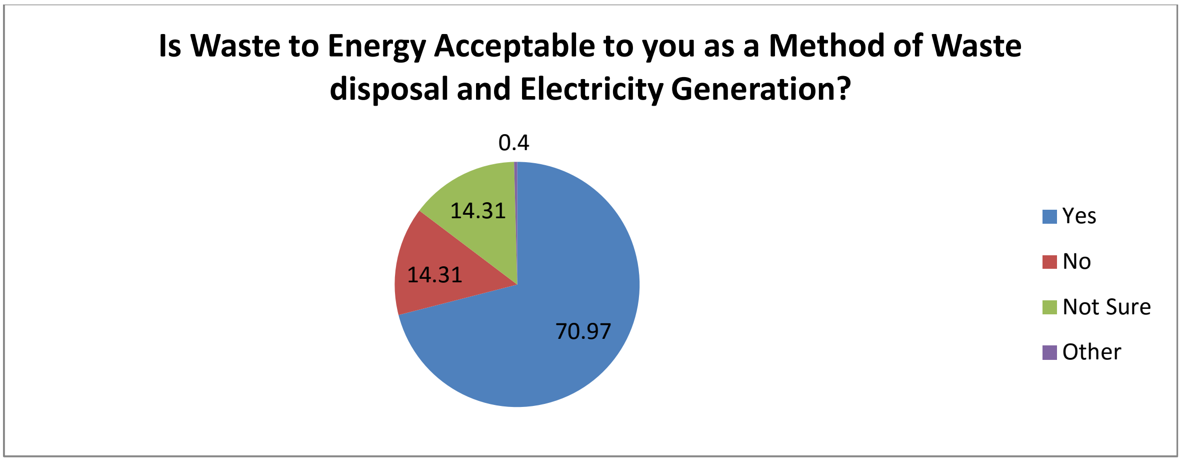


Fig. 3.7 - Responses for Survey Question #7

Almost 71% of the study group reacted positively to the method of converting waste into energy, and only a 15% did not view this method as acceptable.

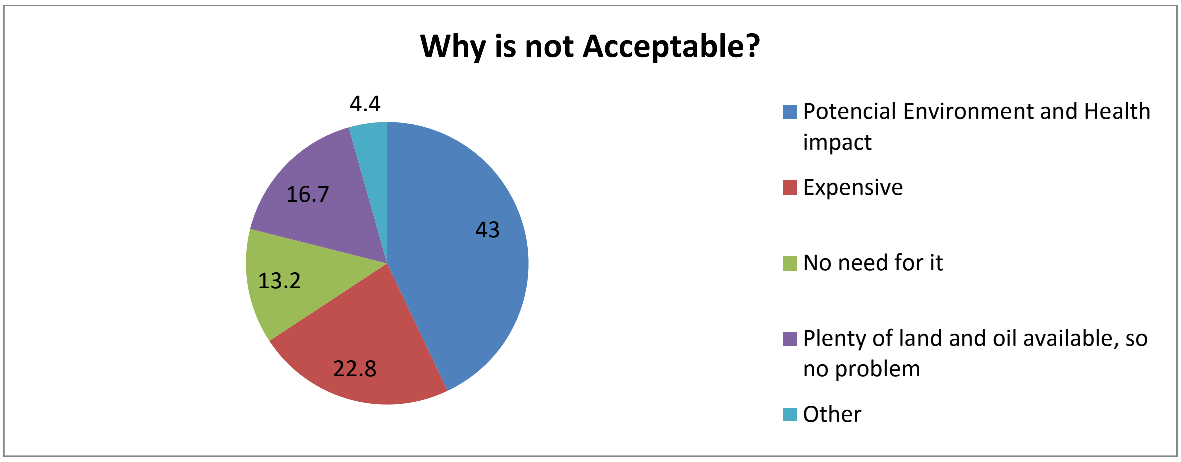


Fig. 3.8 - Responses for Survey Question #8

43% of the respondents asserted that converting waste into energy would negatively impact the environment, almost 23% said it would be expensive to use this procedure, and 13% said there is no need to convert waste into energy; the remaining percentage believed that Saudi Arabia has plenty of land to continue dumping the waste without any issues.

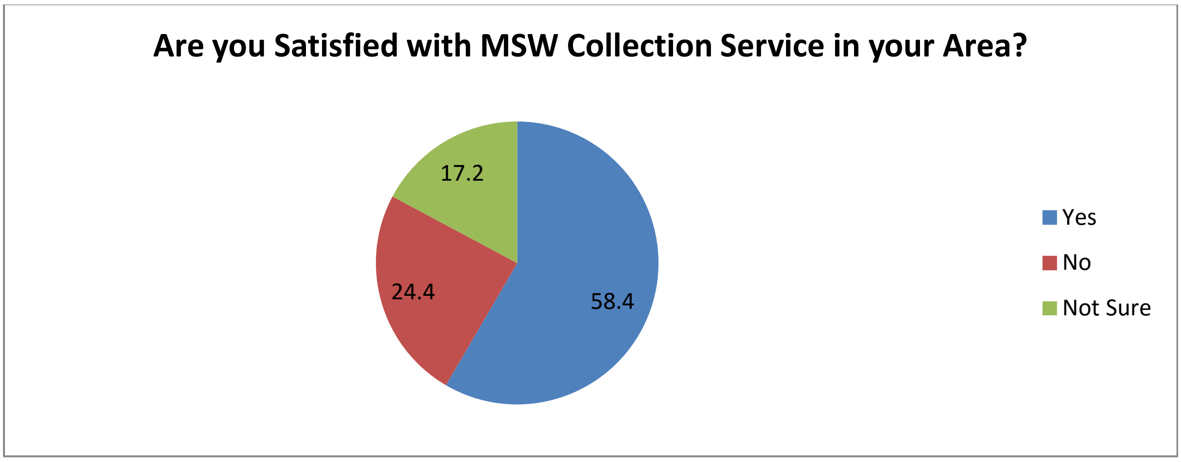


Fig. 3.9 - Responses for Survey Question #9

Almost 59% of the public is satisfied with municipal solid waste collection in their area, while almost 25% are not happy with the local services.

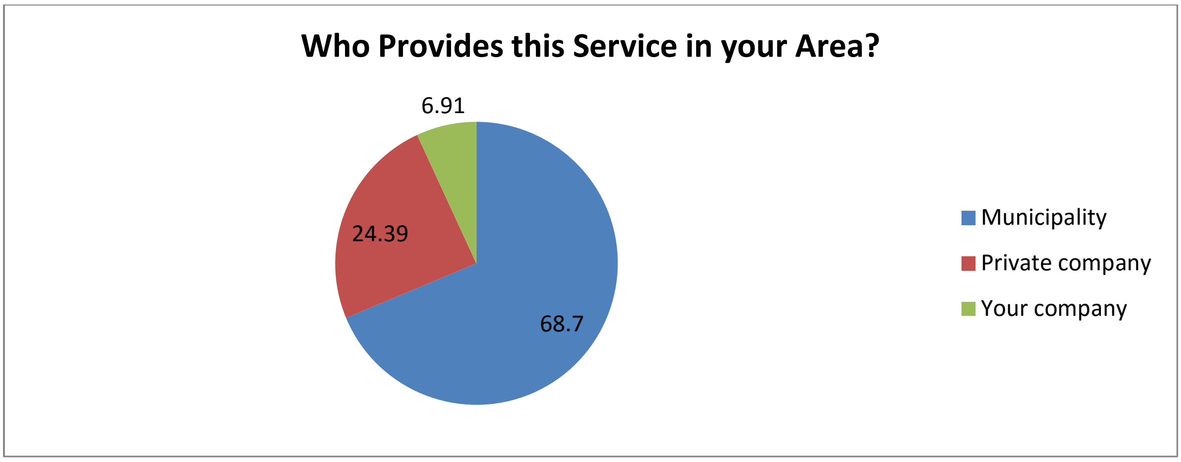


Fig. 3.10 - Responses for Survey Question #10

The local municipality is the main provider of collection services, but private companies manage almost a fourth of waste collection.

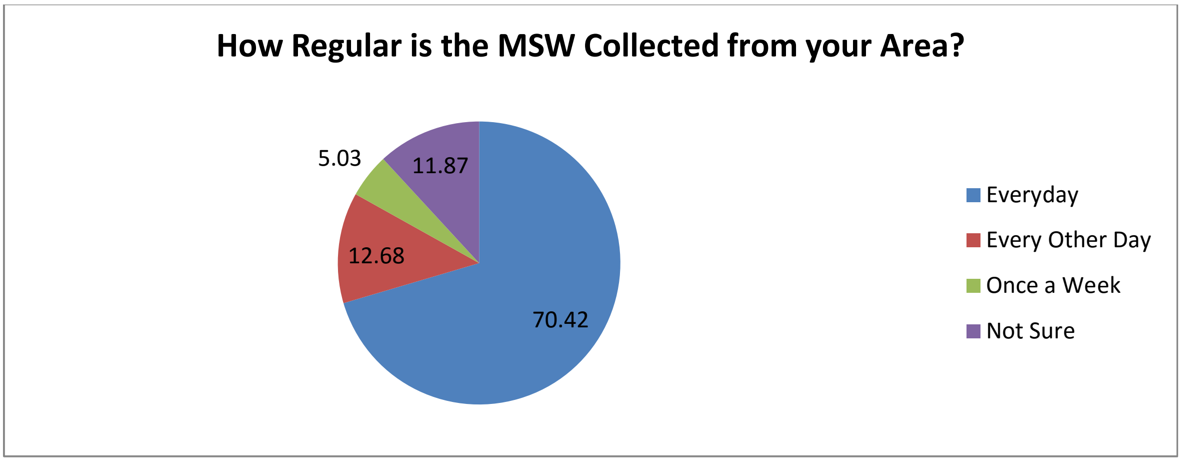


Fig. 3.11 - Responses for Survey Question #11

Everyday collection is usually the reason for a local resident to be satisfied, and 71% of the residents MSW is being collected every day. This shows that the majority of respondents are satisfied with the frequency of MSW collection.

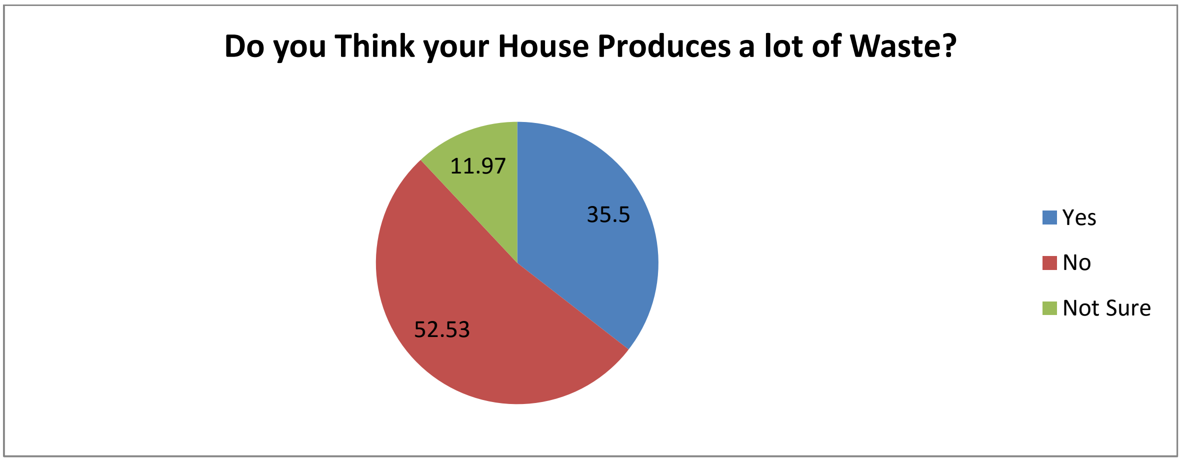


Fig. 3.12 - Responses for Survey Question #12

Food is a major content in waste, but our survey showed us that almost 53% of the local residents do not believe that their household produces an excessive amount of waste.

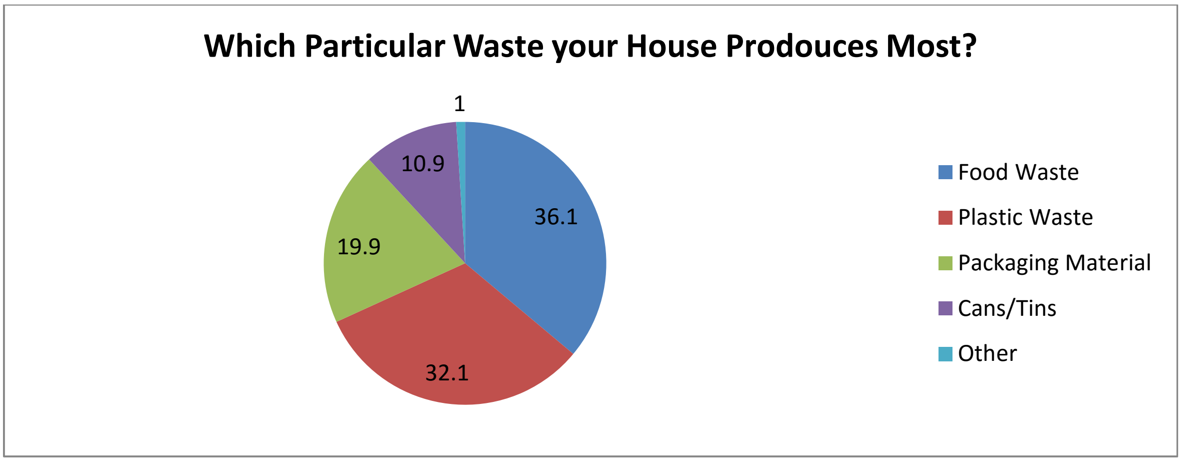


Fig. 3.13 - Responses for Survey Question #13

Our survey showed that waste is mostly comprised of food, as 36% of the residents produce pure food waste. The remaining waste is comprised of 32% plastic waste, 19.9% packaging wastes, 10.9% cans/tins, and 1% of other materials.

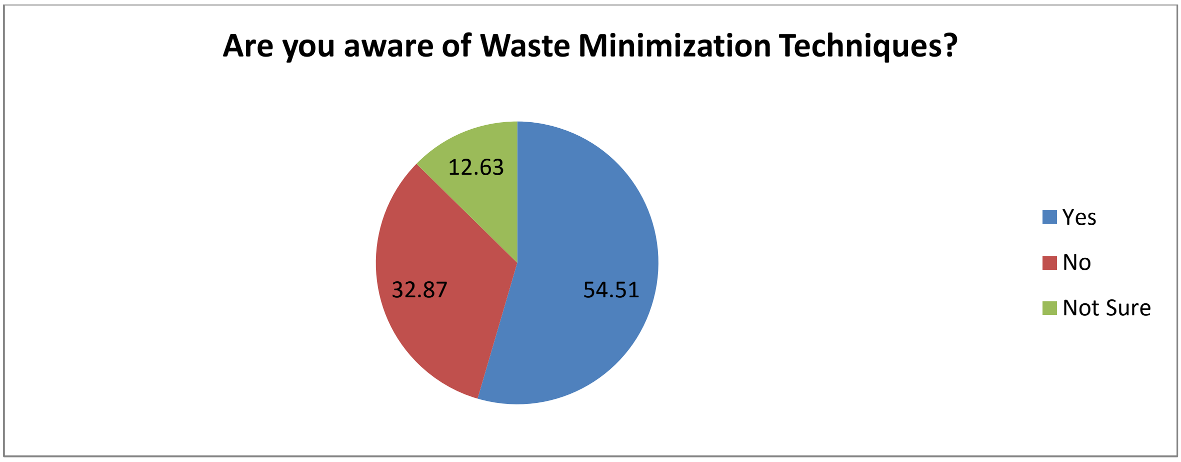


Fig. 3.14 - Responses for Survey Question #14

Surprisingly a 55% of the study group knew of some techniques to minimize the waste produced by their households, but a shocking 32.9% did not know of any waste minimization techniques.

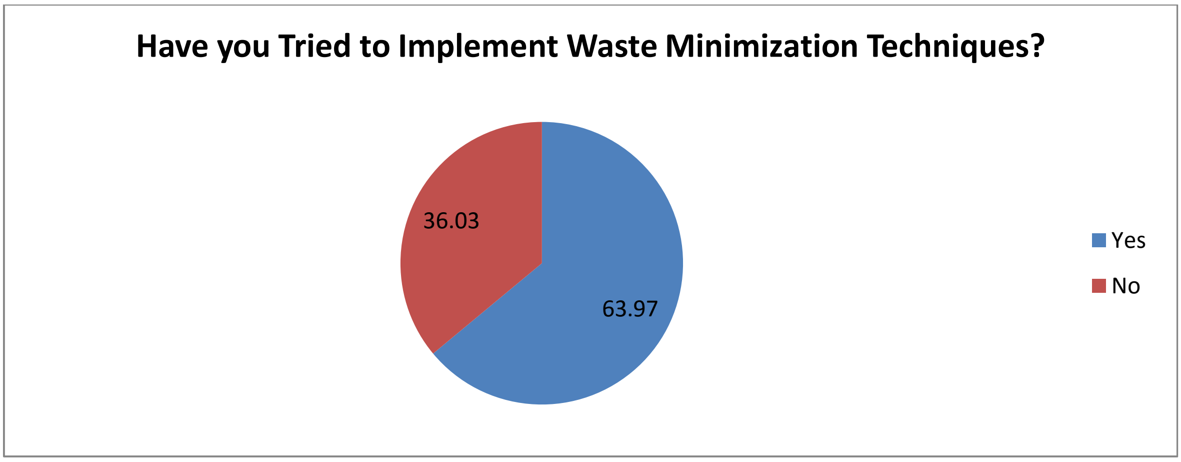


Fig. 3.15 - Responses for Survey Question #15

A 64% of the study group actually tries to minimize their household waste due to the awareness of the waste minimization techniques, but the rest of the group did not attempt apply any waste minimization techniques.

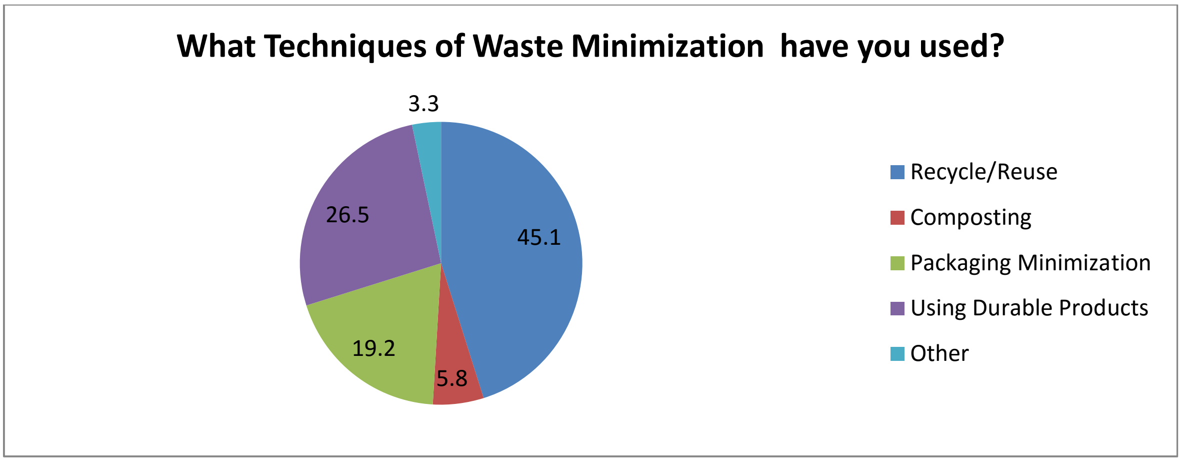


Fig. 3.16 - Responses for Survey Question #16

45% of the residents chose to recycle or reuse as a waste minimization method, almost 27% chose using durable products, almost 20% chose to minimize their packaged products, and the rest chose composting and other methods for their households.

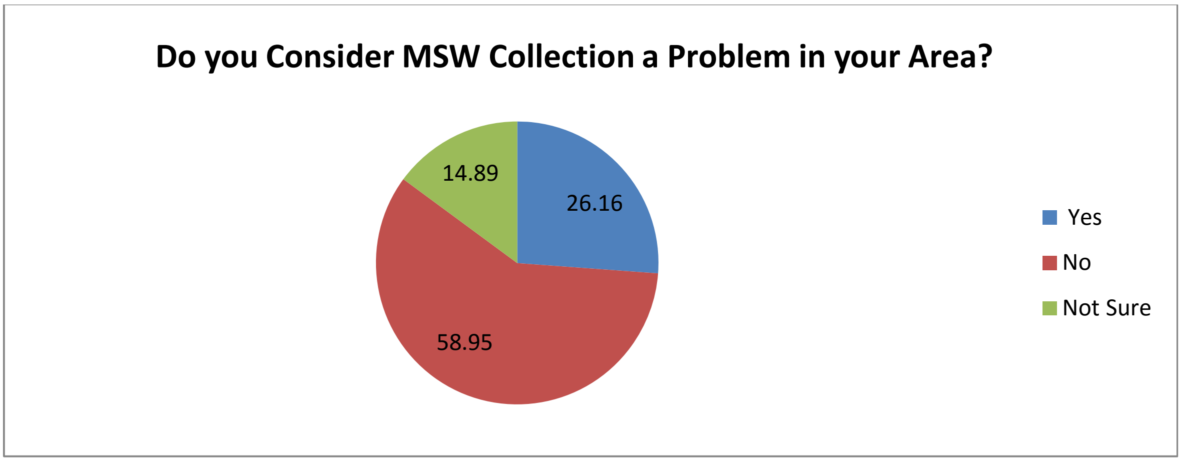


Fig. 3.17 - Responses for Survey Question #17

According to the survey, 59% of respondents are happy with their MSW collection in their area, so they do not consider collection a problem. In contrast, 26% percent are not happy with the collection due to waste not being collected every day.

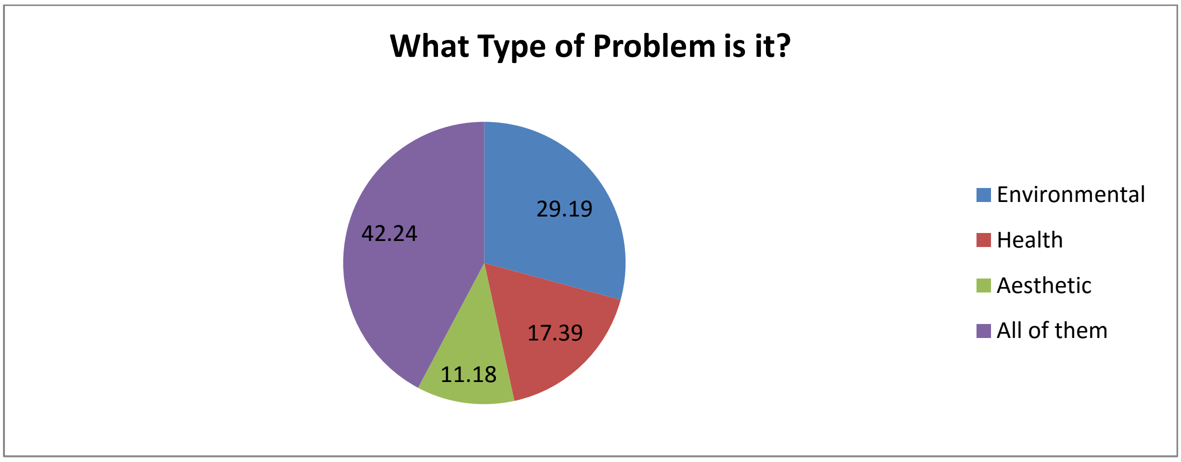


Fig. 3.18 - Responses for Survey Question #18

A choice was provided to the residents to choose among environmental problems, health problems or aesthetic problems. In response to these options, 42% of the study group asserted that the problem not only one issue but a combination of all of them.

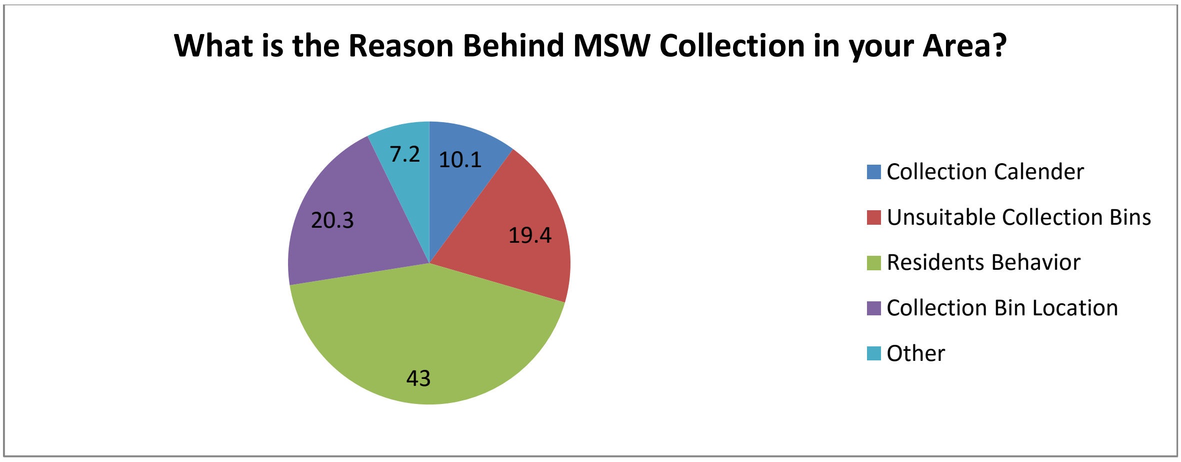


Fig. 3.19 - Responses for Survey Question #19

43% of the residents said they believe that the problems can be solved if residents improve their behavior regarding waste organization. Almost 20% pointed out unsuitable collection bins as the cause of most problems. About 21% said changing the bin location would help. Lastly, a few othera believed that the collection timings cause issues such as traffic problems.

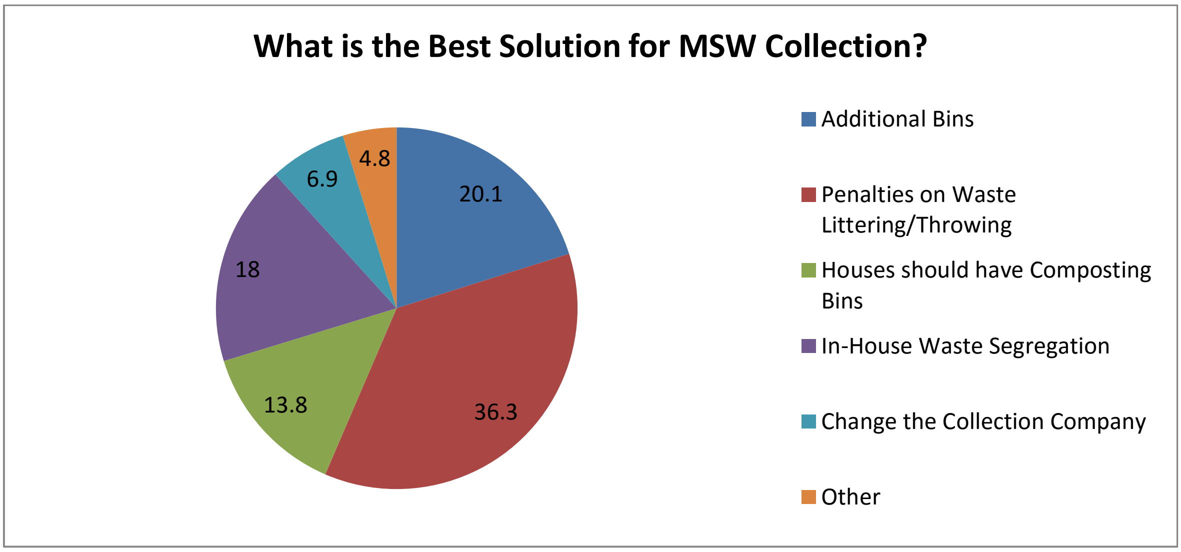


Fig. 3.20 - Responses for Survey Question #20

The majority of respondents (36.3%) demanded that penalties should be placed on littering, 20% requested to be provided with additional bins on the street so the waste does not spill out, and 18% believed if house segregation is being done then collection would be easier for the companies. Changing the collection company was also a suggested solution by almost 7% of respondents.

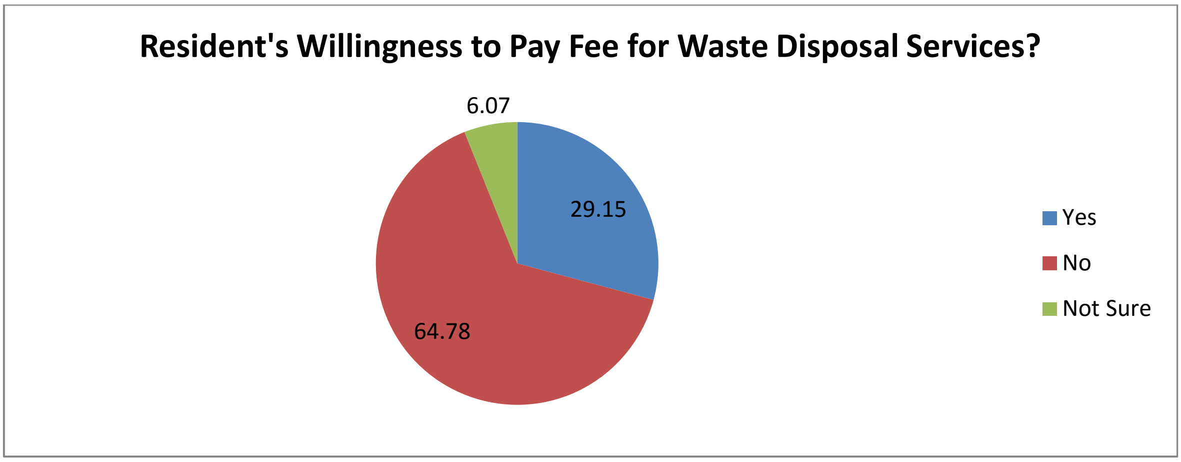


Fig. 3.21 - Responses for Survey Question #21

A significant goal of our survey was to get information from the residents if they were willing to pay for the disposal services provided by the municipality or by the private sector, shockingly almost 65% of the residents are not willing to pay for any waste disposal services.

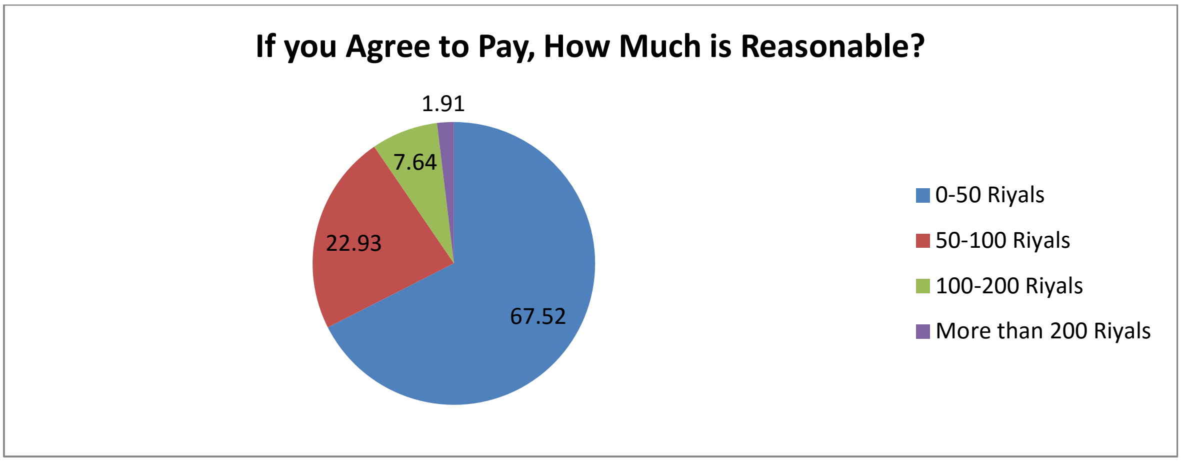


Fig. 3.22 - Responses for Survey Question #22

Among the residents who believe implementing fees for disposal services might help their cities to improve their waste issues, almost 68% of the survey population believes up to SR50 monthly is a reasonable amount to be paid for the services. Some were even willing to pay up to SR100 monthly, while only a small portion was willing to pay any more than that.

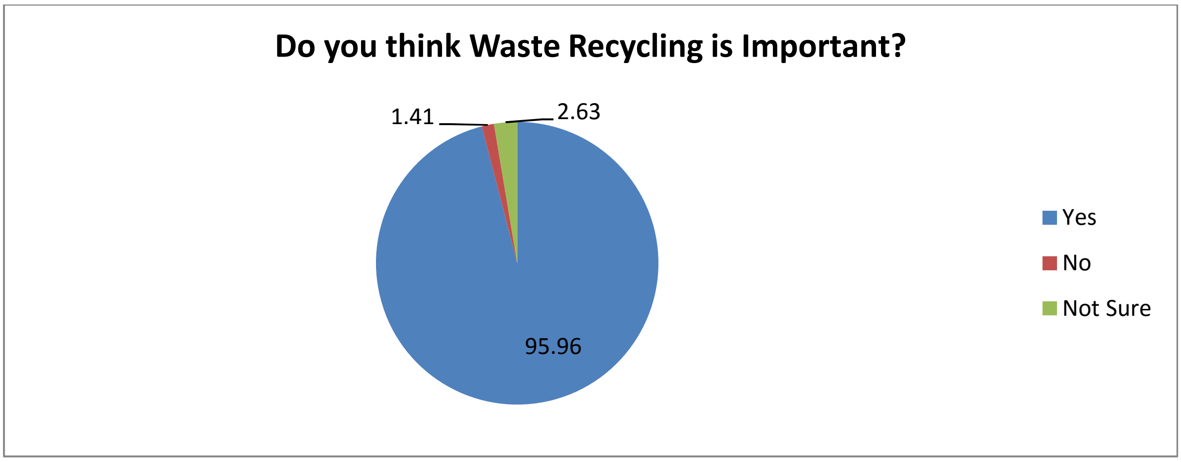


Fig. 3.23 - Responses for Survey Question #23

Almost 96% of the study group said waste recycling is very important and only a 4% were mixed between no recycling and do not know.

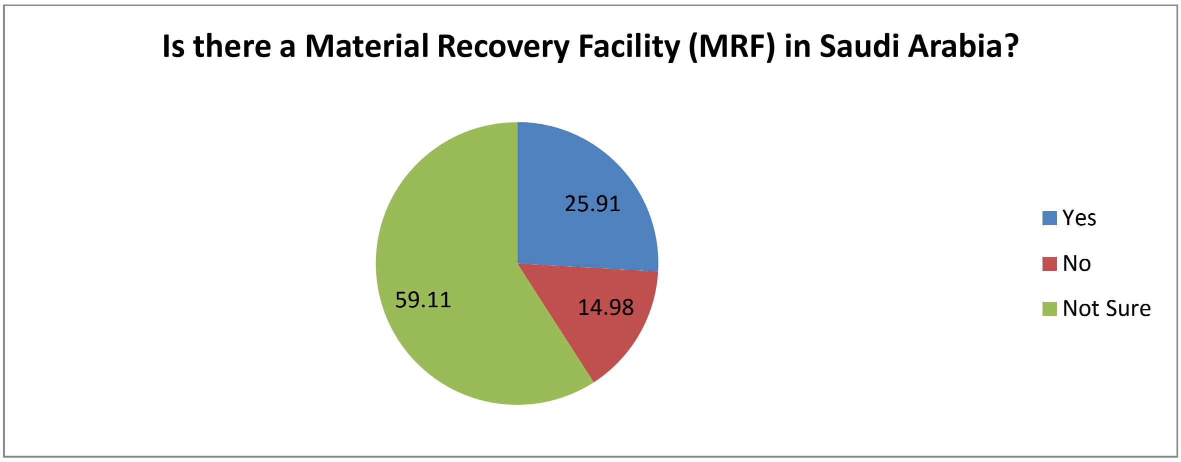


Fig. 3.24 - Responses for Survey Question #24

A majority of the study group said that they do not know if a material recovery facility exists in Saudi Arabia, which was not shocking to us due to the unawareness among the people related to environment.

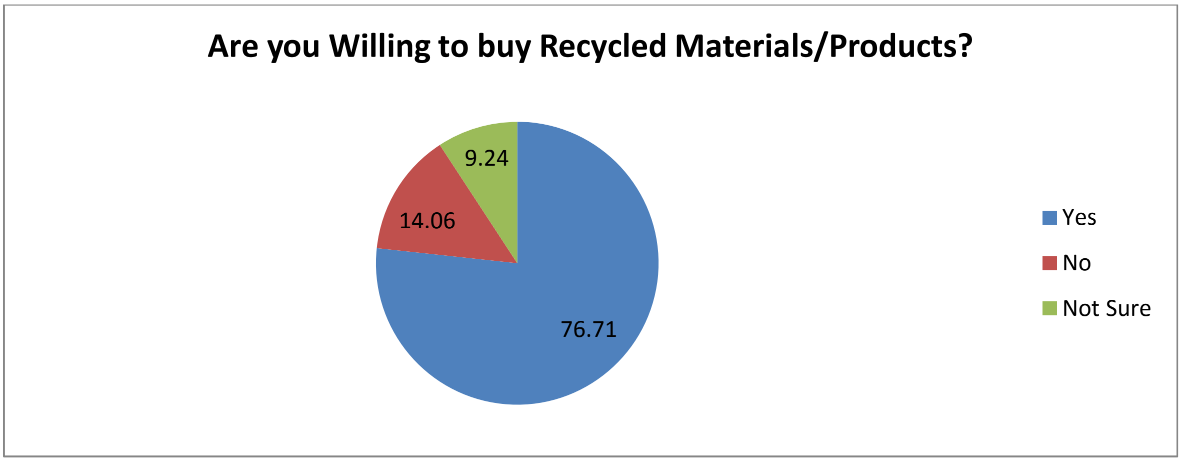


Fig. 3.25 - Responses for Survey Question #25

Using recycled products or materials was shocking to our study group but almost 77% of the residents did agree to purchase recycled materials or products and only a few disagreed.

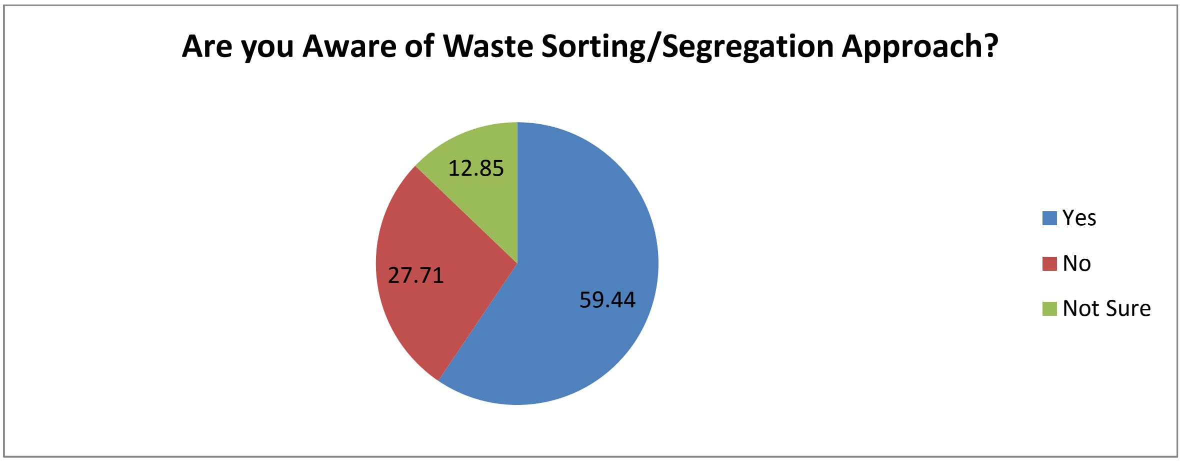


Fig. 3.26 - Responses for Survey Question #26

Almost 60% of the study group were aware and segregated their wastes into food, plastic, cans/tins and others according to their own household routines and many do not segregate.

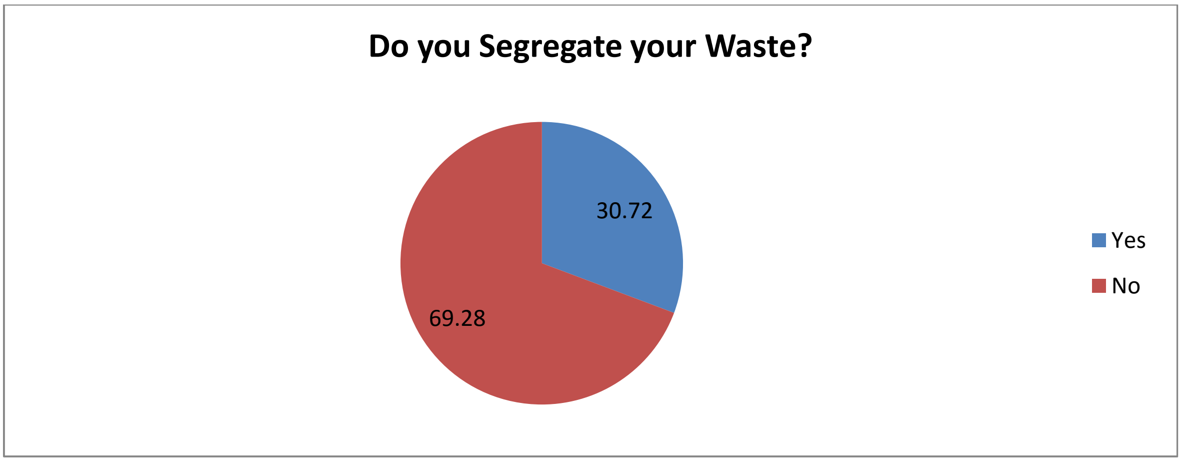


Fig. 3.27 - Responses for Survey Question #27

As per the previous question, majorities do segregate their trash into plastics for recycling purposes.

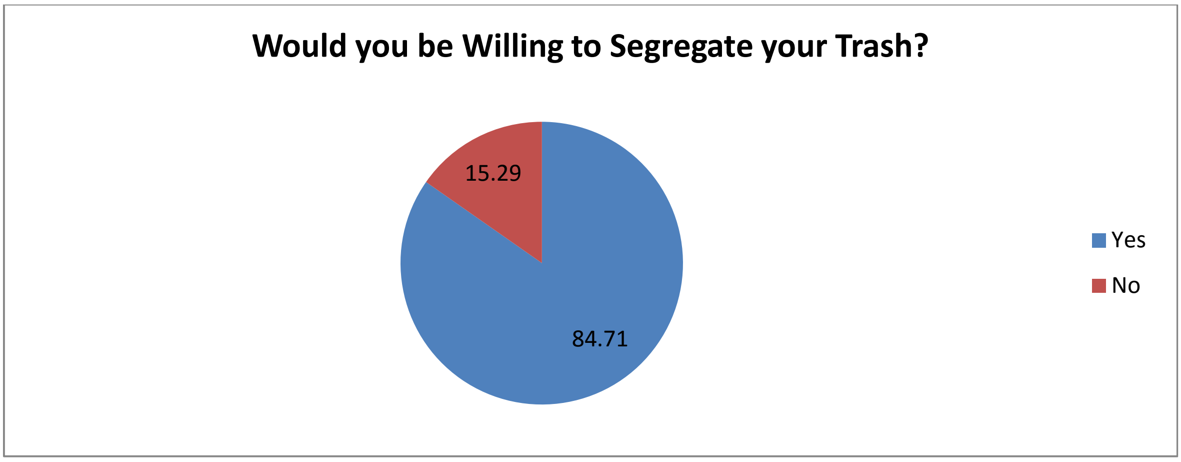


Fig. 3.28 - Responses for Survey Question #28

The residents who were aware of in-house waste sorting were already applying it in their houses but the good news for us was that the residents who were unaware of in-house sorting techniques were also willing to practice this in their houses, which ended up to become a total of 85% of the residents to practice in their houses.

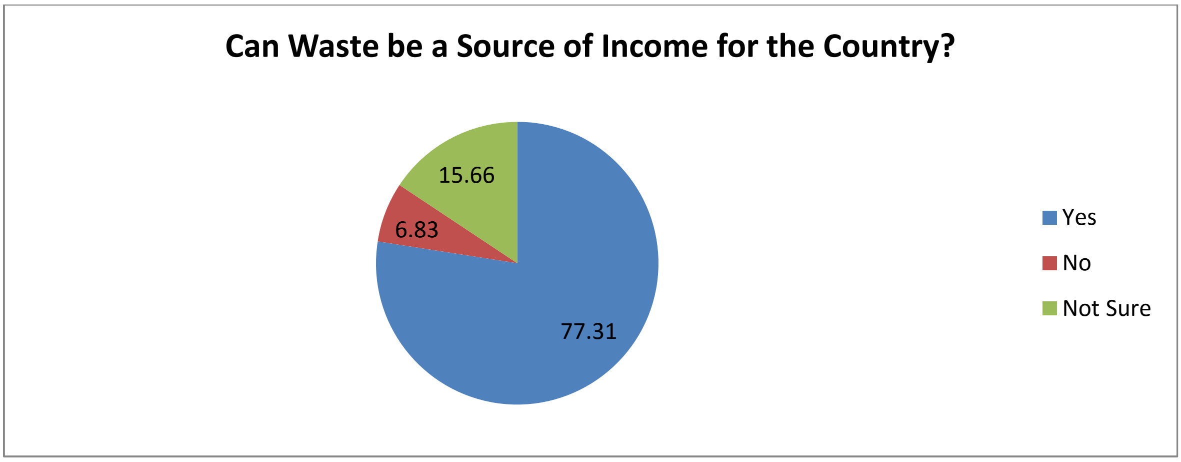


Fig. 3.29 - Responses for Survey Question #29

Almost 78% do believe that waste can be a source of income for the country, almost 16% do not know and few disagree to the idea of source of income.

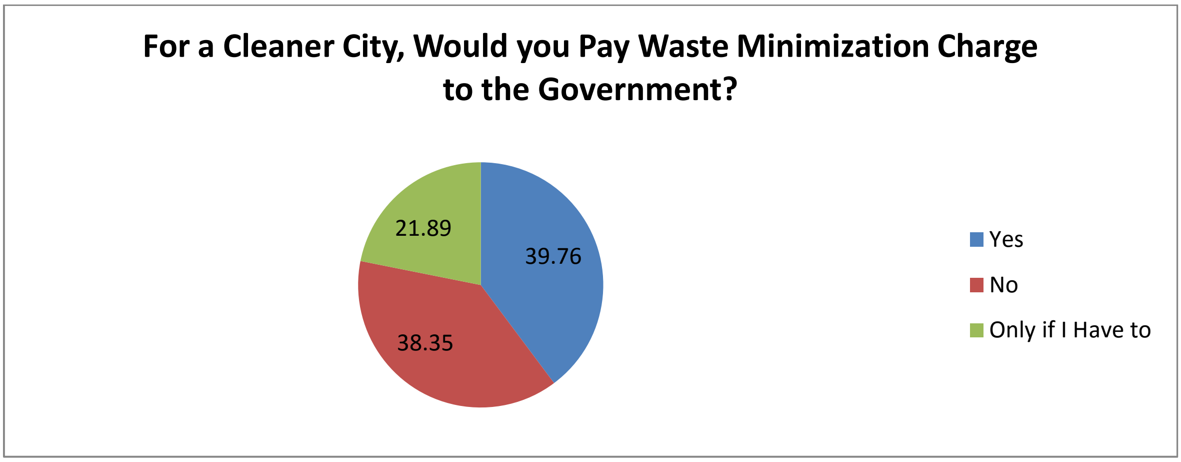


Fig. 3.30 - Responses for Survey Question #30

Almost 40% of the public were ready to pay for the waste minimization charges to the government for cleaner cities but a huge percentage of almost 39% disagreed to pay.

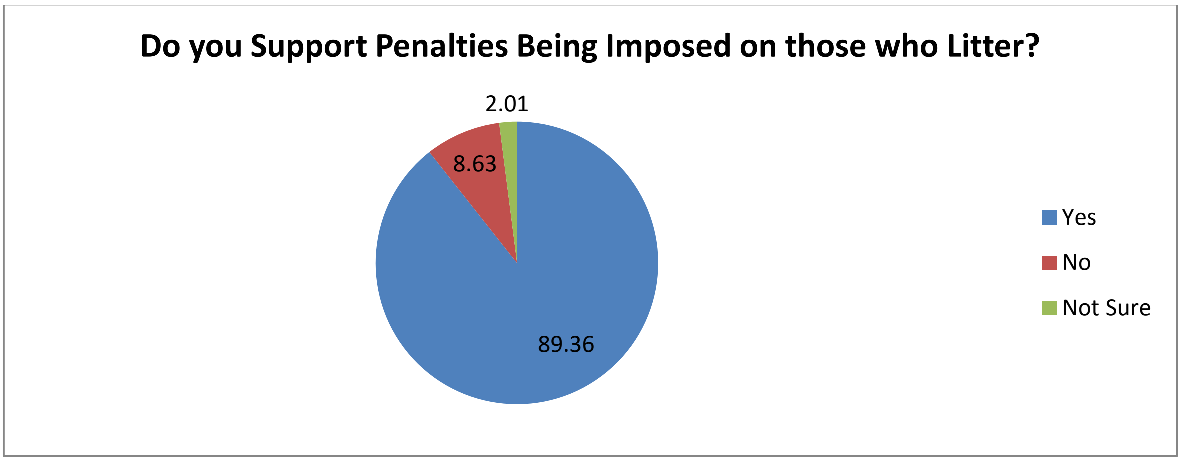


Fig. 3.31 - Responses for Survey Question #31

Almost 90% of the locals do support penalties on the people who disregard the laws and throw the waste of the streets but a small number disagrees.

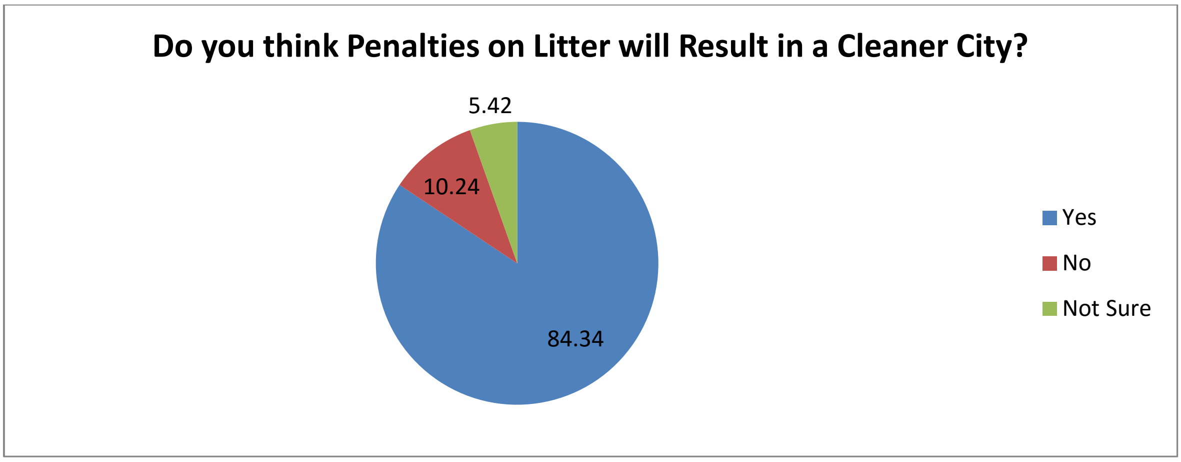


Fig. 3.32 - Responses for Survey Question #32

Penalties being imposed on littering will help the city to be cleaner was widely accepted by the residents where as only a 10% did not support the idea.

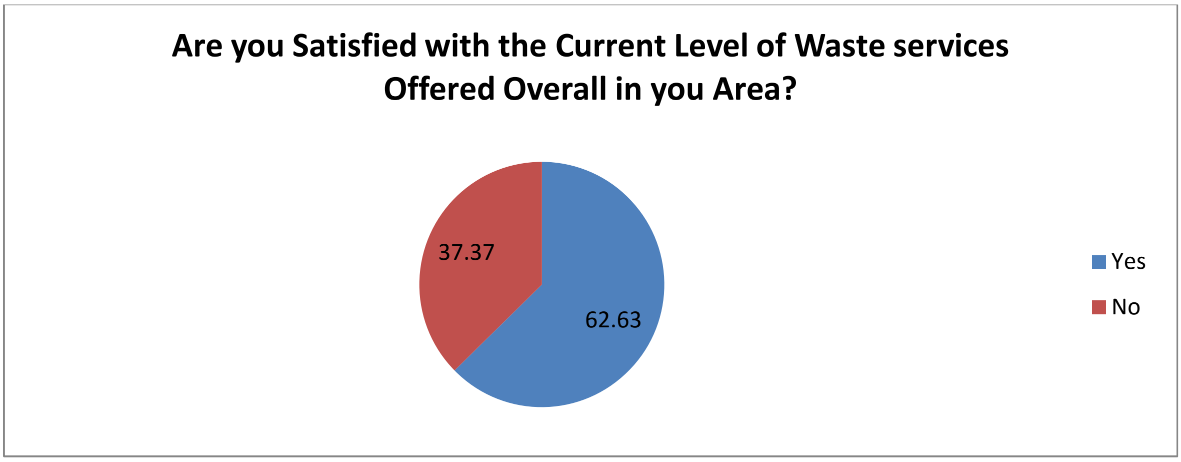


Fig. 3.33 - Responses for Survey Question #33

Almost 63% were satisfied with the current level of waste management services offered overall in your area but on the other hand a 40% also disagrees with the satisfaction.

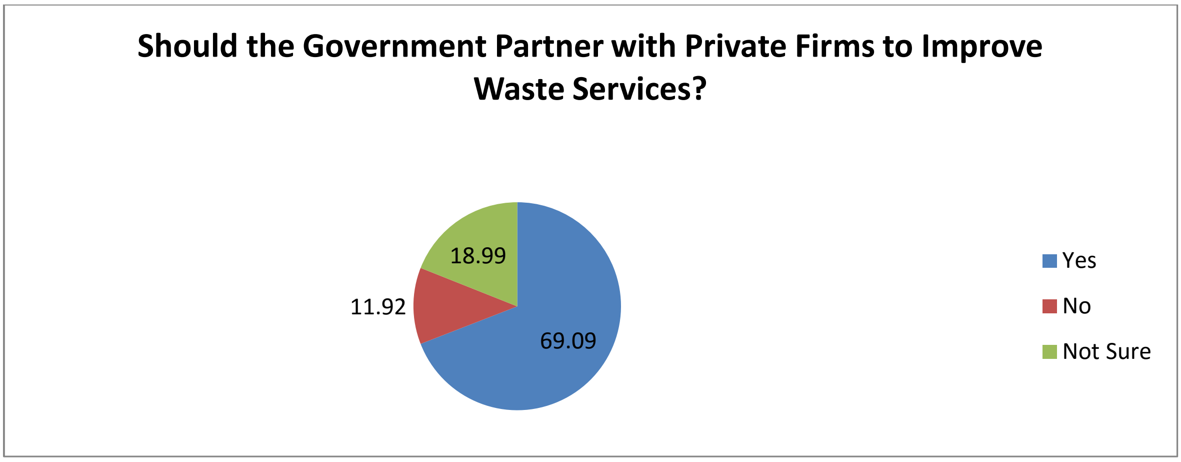


Fig. 3.34 - Responses for Survey Question #34

Due to the unsatisfactory of the collection system, a sum of 70% of the residents believes that government should partner up with the private firms to have cleaner cities.

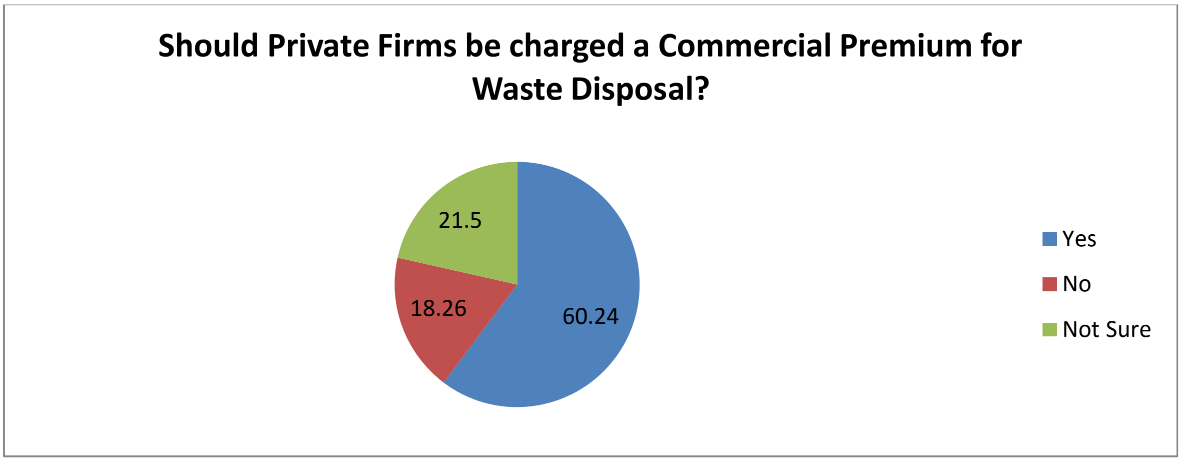


Fig. 3.35 - Responses for Survey Question #35

Almost 60% of the residents believe that private firms should be charged a commercial premium for disposal, many do not know about this and some disagree.

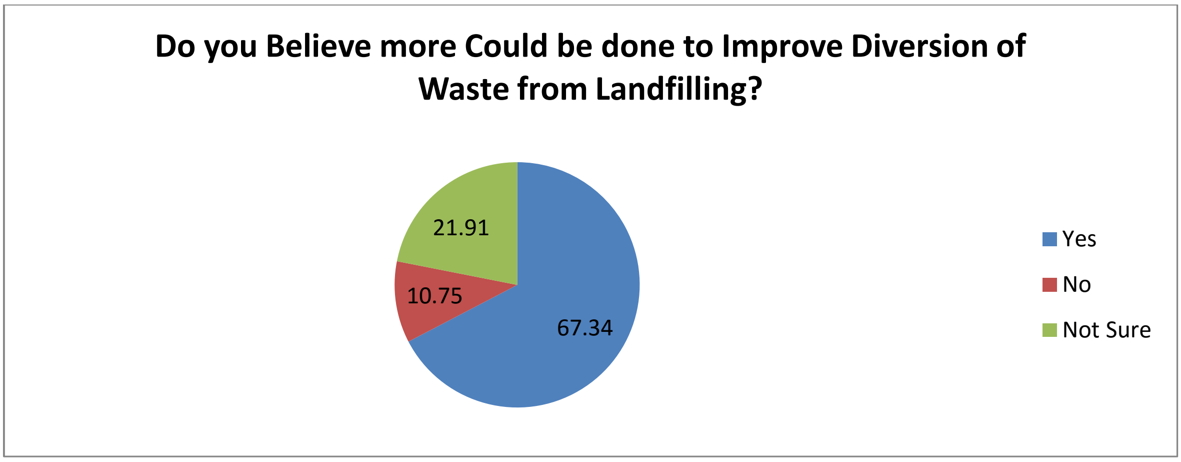


Fig. 3.36 - Responses for Survey Question #36

When asked whether more can be done improve the diversion of waste away from landfills, a majority of about 67% of survey participants responded positively. Only about 11% believed nothing more could be done, while about 22% of the sample population had no input regarding this issue.

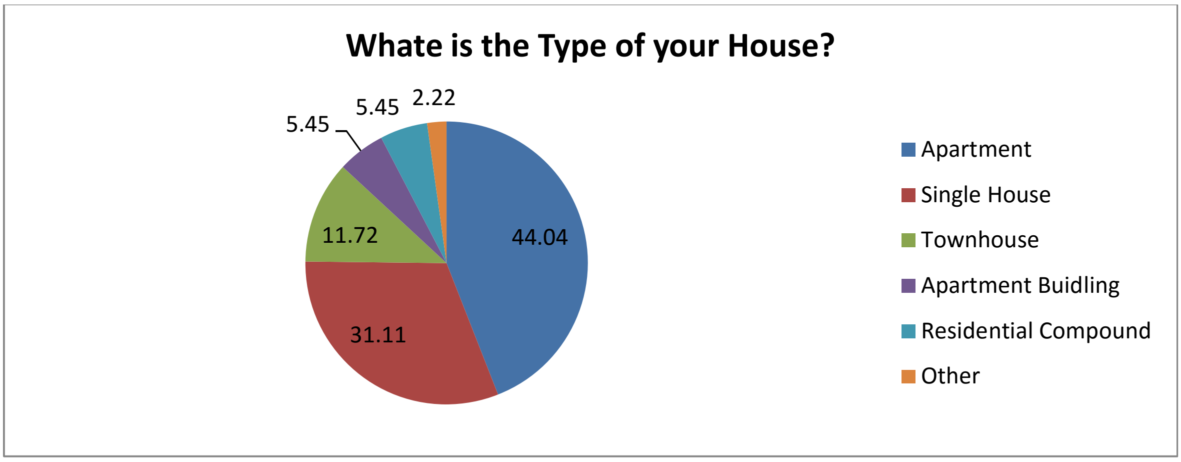


Fig. 3.37 - Responses for Survey Question #37

According to the above responses, most participants live in apartments or single houses. These account for 75% of participants. The remaining participants live in townhouses, privately owned sections of apartment buildings, residential compounds, or other.

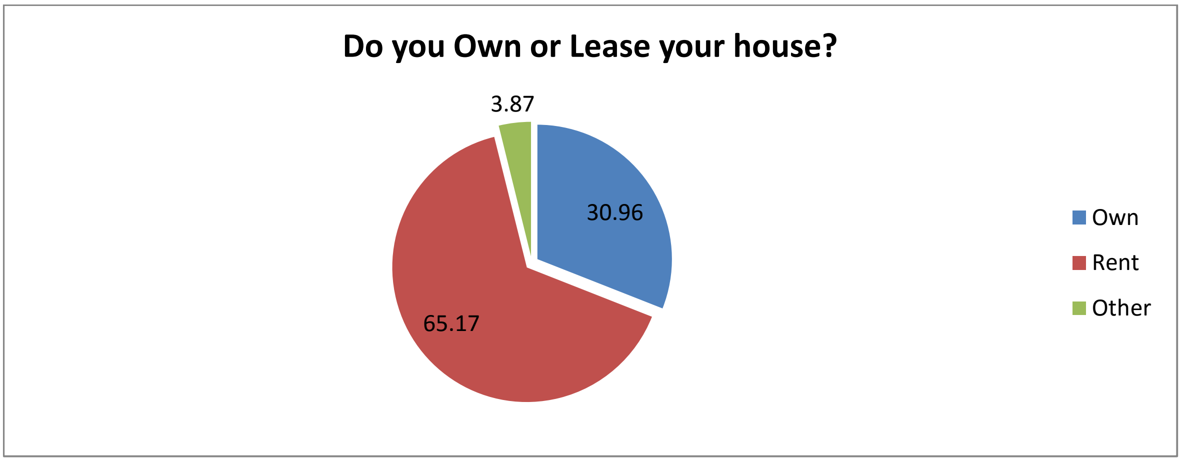


Fig. 3.38 - Responses for Survey Question #38

Our survey results show that 65.17% of our study group rented their residences, while almost 31% owned their houses, and the rest paid annual installments.

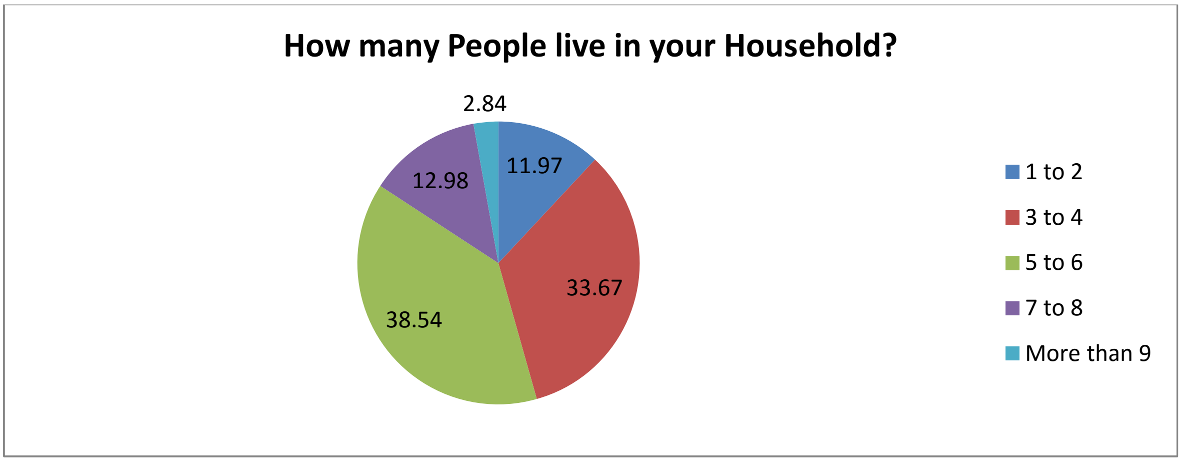


Fig. 3.39 - Responses for Survey Question #39

It was very important for us to know how many people lived in each household. The majority of the residents reported having 5-6 members in each house, while 34% of the residents reported having 3-4 people living in their houses, and smaller percentages had bigger families with 7-9 household members.

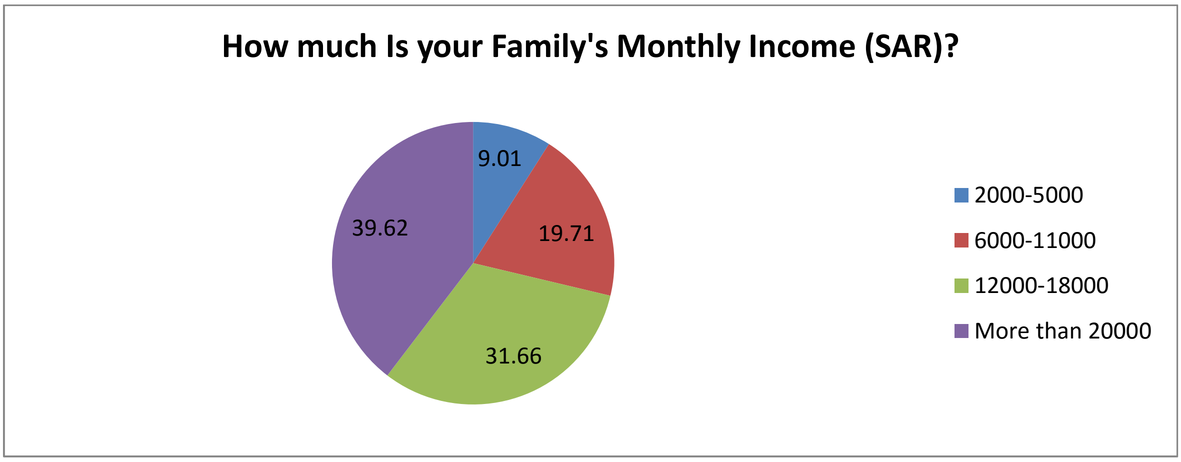


Fig. 3.40 - Responses for Survey Question #40

Many people did not share their family's monthly income due to personal reasons, but we received financial information from some participants. Almost 40% of the families that were included in our study group reported earning more than 20,000 SAR/month, and almost 32% of the families reported earning 12,000-18,000 SAR/month. About 29% reported earning from 2,000-11,000 SAR/month.

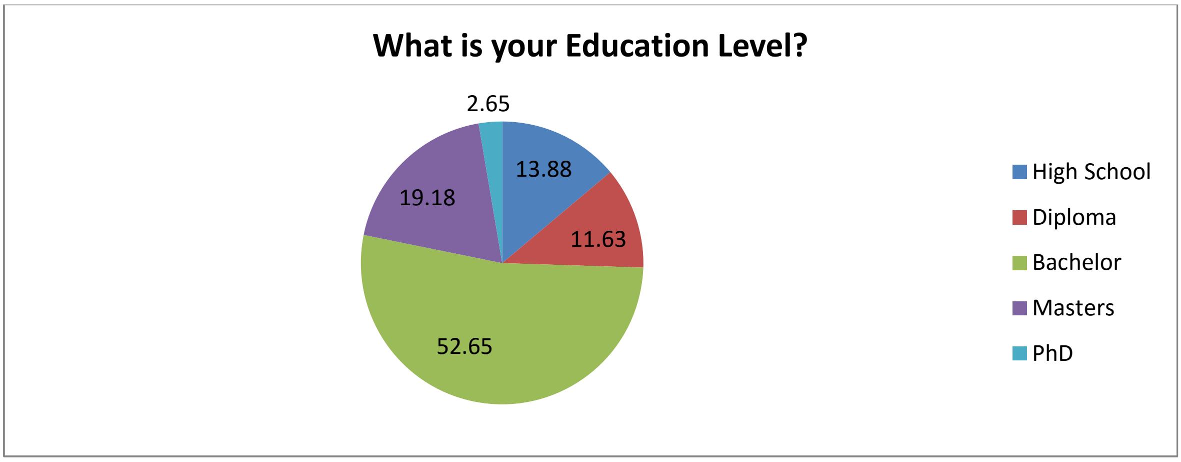


Fig. 3.41 - Responses for Survey Question #41

The largest percent of our study group (52.65%) was found to have at least a bachelor's degree. Almost 20% of them had completed their master's degrees, almost 14% had only completed high school, 11.63% only had diplomas related to their fields, and almost 3% held post doctorate degrees.

Conclusion

The results of the Public Awareness Assessment Survey show that while the general public is not fully informed on waste practices in the area, there is enough awareness for people to understand the implications of continuing to ignore alternatives to land filling. Most survey participants believe the waste collection system can be further improved with increased cooperation from the residents themselves. Currently, waste services are provided for free by the municipality and though residents are not willing to pay for waste services, they show a clear inclination towards practicing ISWM methods at home. Public awareness of waste reduction methods is high, as residents actively attempt to reduce in-house waste generation. A comprehensive government program for recycling, which would include in-house waste sorting, would likely receive strong support from the local population.

Chapter 4

Waste Generation Forecast

4.1 - Introduction

Saudi Arabia has been witnessing rapid industrialization, high population growth rate and fast urbanization, which have resulted in increased levels of pollution and waste. Solid waste management is becoming a big challenge for the government and local bodies with each passing day. With a population of around 29 million, Saudi Arabia generates more than 15 million tons of solid waste per year. The per capita waste generation is estimated at 1.5 to 1.8 kg per person per day (Zafar, 2015).

The increase in population is expected to grow annually due to the following factors: migration from rural to urban areas and an influx of expatriate workers. The Greater Dammam Area is considered an area of industry due to the large amount of crude oils it holds, as well as the fact that it is home to many of the major industrial companies found in Saudi Arabia. When the population increases, the amount of waste is expected to increase as well. Along with these increases, the potential energy that can be generated from waste production would most likely be electricity from methane Gas, which will be estimated from MSW. If current waste management practices are followed, waste will be collected and dumped in landfill sites (Ouda, 2013). These factors will put a challenge before the MSW of the Greater Dammam Area to deal with increased waste production and find ways to convert it into energy.

4.2 – Objectives and Methodology

The Greater Dammam Area is expected to face a major problem of MSW due to the enormous quantity of Municipal Solid Waste produced each year. The population in the region was 2.3 million in 2015, which due to the population growth rate of Saudi Arabia, the number of people living in the Greater Dammam Area is expected to increase by 3.4% each year. (scenario1). The trend of population growth in Saudi Arabia is the above mentioned 3.4%, as calculated below. The population of the Eastern Province was measured in 2005 as 3,360,157 and in 2014 as 4,106,000. Based on these numbers, the growth rate was calculated to equal 2.2%. (Scenario2). The Eastern Province growth rate for (scenario 2) is computed by an equation defined as:

$$I = \sqrt[T]{currentpopulation/pastpopulation} - 1$$

$$\sqrt[9]{4,106,000/3,360,157} - 1 = 2.2340_{\%}$$

Due to a different growth rate, the research will be conducted in different scenarios; the first one will be calculated with a population growth rate of 3.4 % and the second one with a population growth rate of 2.23 %.

The year 2015 was chosen as the starting year for forecasting. The MSW production rate was assumed to be 2.02kg/person/day for the year of 2015. The population growth is projected to maintain its historical trend of 3.4% for a year up to the year 2040[Ouda et.al., 2013](scenario1) and also with the growth rate of Eastern Province 2.22 % up to the year 2040 (scenario2). According to the forecasting year 2015 the values been calculated for Greater Dammam Area City by Exponential Growth equation. Exponential Growth occurs in any situation where the increase in some quantity is proportional to the currently present.

The average per capita calculation for the year 2015:

$$Percapita = \frac{Totalofwastes}{Totalofpopulation}$$

(Masters & Ela, 2014)

$$PerCapita = \frac{1878.9 \times 10^3}{2.3 \times 10^6} = 0.816 Tons/Person/Year$$

$$= 740.2 kg/person/year$$

$$= 2.02 kg/person/day$$

The Exponential Growth Equation defined as:

$$Nt = N(1+r)^t$$

Nt = Amount after t years

N = Initial Amount

r = Growth rate

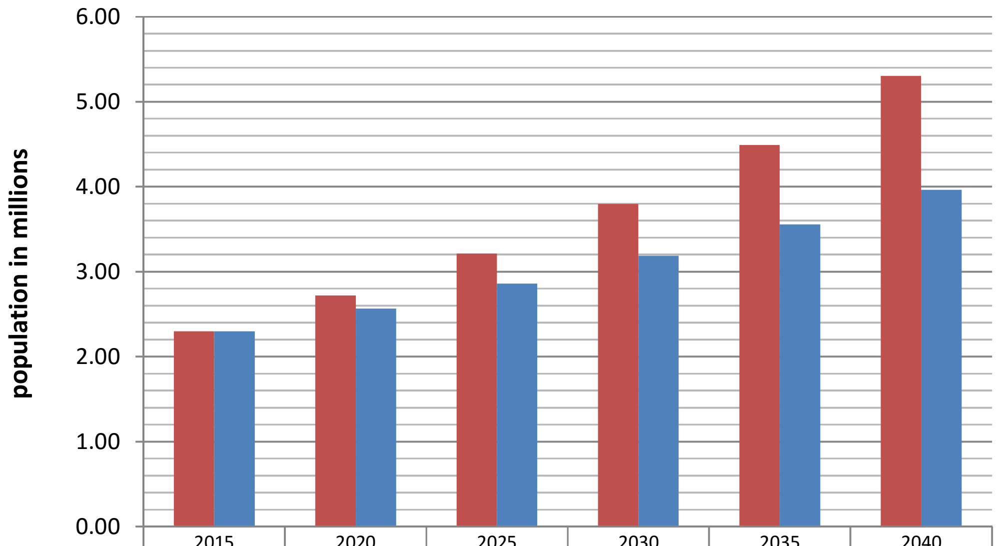
(Masters & Ela, 2014)

The initial amount is equal to 1,878,885.09 tons. There is two growth rate has been calculated into this equation, one as the historical trend of population growth rate in Saudi Arabia which its equal to 3.4 % and the other one for Eastern Province growth rate from 2005 to 2014 which its equal to 2.2 %. Moreover, t represents the number of years where the forecasting quantity needs.

This equation has been used for calculating all the prediction data up to the year 2040 for different scenarios as it will show in the figures.

4.3 – Results and Discussion

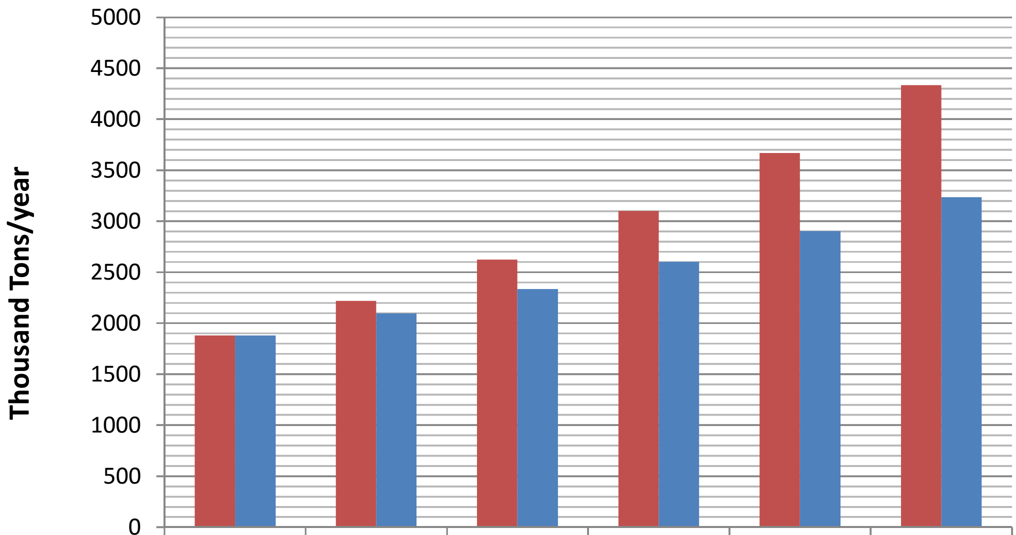
The population of Greater Dammam Area assumed to be 2.3 Million in 2015 as it is shown in (Fig. 4.1) Due to the increase in population in Saudi Arabia which the population growth rate of Saudi Arabia is 3.4%. The population expected to start growing at the same rate up to the year 2040 which it will reach up to 5.3 Million (scenario 1). For (scenario 2) people living in Greater Dammam with Growth rate of 2.2 %, the population of Greater Dammam Area expected to reach up to 3.9 million.



	2015	2020	2025	2030	2035	2040
Greater Dammam Area (scenario 1)	2.30	2.72	3.21	3.80	4.49	5.31
Greater Dammam Area (scenario 2)	2.30	2.56	2.86	3.19	3.55	3.96

Fig. 4.1 – Population Forcast 2015-2040

Greater Dammam Area currently generates 1878.9 Thousand tons in 2015 (Fig 4.2). Due to the increase in population the Municipal solid waste expected to grow at the same rate which up to the year 2040 the MSW expected to reach 4334.3 thousand tons of MSW, for (Scenario 2) The expected to reach up to 3237.2 Thousand tons. Due to this vast quantity, MSW should have to be managed properly otherwise there will be an environmental consequence that may harm Greater Dammam Area and become high quantity of MSW in Saudi Arabia.



	2015	2020	2025	2030	2035	2040
Greater Dammam Area (Scenario 1)	1878.9	2220.8	2624.9	3102.5	3667	4334.3
Greater Dammam Area (Scenario 2)	1878.9	2094.9	2335.7	2604.2	2903.5	3237.2

Fig. 4.2 - MSW Generation Forecast 2015 - 2040

"Populations, urbanization growth, the rise in the standards of living have all dramatically accelerated the MSW generation in City" [Minghau and Xiumin, 2009; Guerrero et.al., 2013]. The Increasing of population will increase the Recycled materials dramatically. Due to the practice of Greater Dammam Area, collect and dump in Site, The Percentage expected to be more of recycled materials year by year. MSW consist of many recycled materials dumped into The Dumb sites as it is shown in (fig. 4.3). With these materials, energy can be extracted and estimated for Methane Gas generation and more of WTE (Waste to Energy) Technologies.

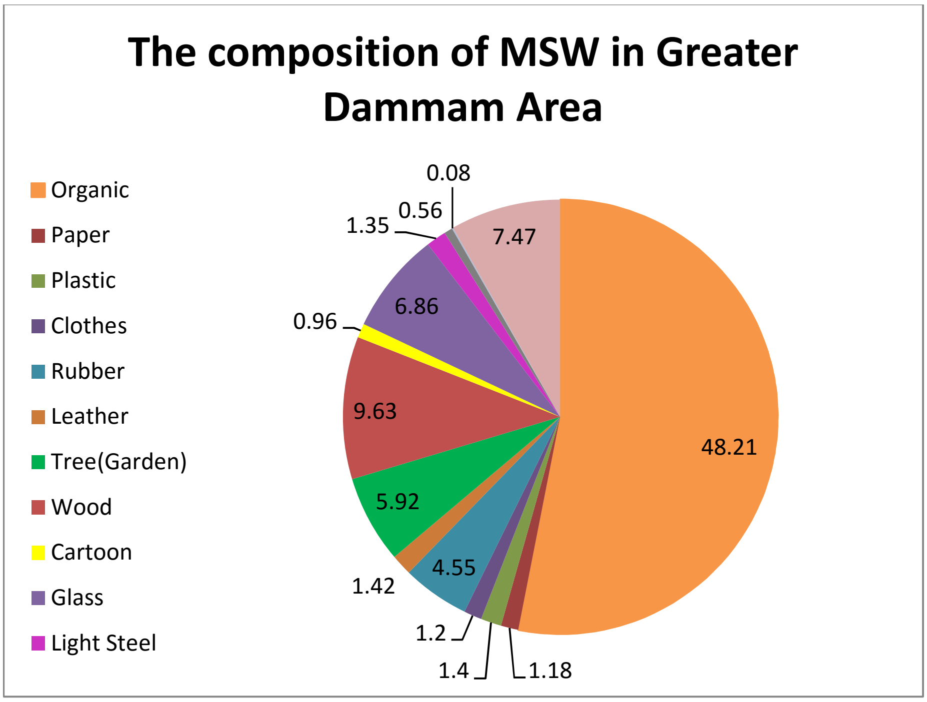


Fig. 4.3 - The composition of MSW in Greater Dammam Area 2015

Due to Figure 4, the Organic waste has a higher percentage of the other recycling materials, 48% disposed into the landfill. The amount of household is equal to 20,974,111 kg in 2015. Wastes in Greater Dammam Area, mostly are coming from houses, which in this figure 4 represent the percentage of it and the huge amount of household in kg. This number expected to increase dramatically next years. The amount of Organic wastes per year expected to reach up to 49 million for (Scenario 1) and for (scenario 2) expected to increase to 36 million up to the year of 2040. Which both number consider as an enormous amount of household as it represents precisely in (Fig. 4.4). The Average per capita for Organic waste in the year 2015 estimated to be equal 1.26 kg/ person/ year

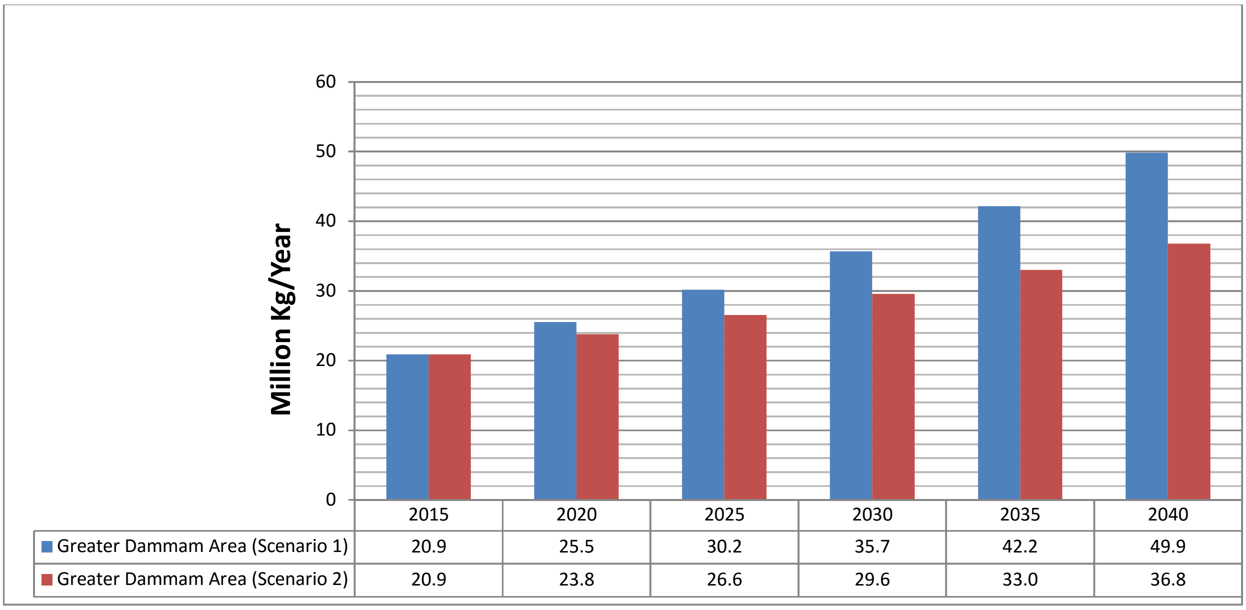
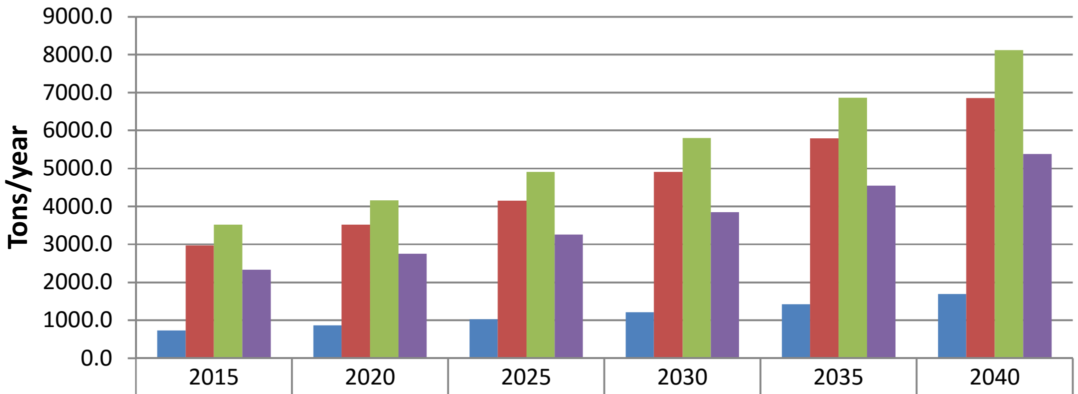


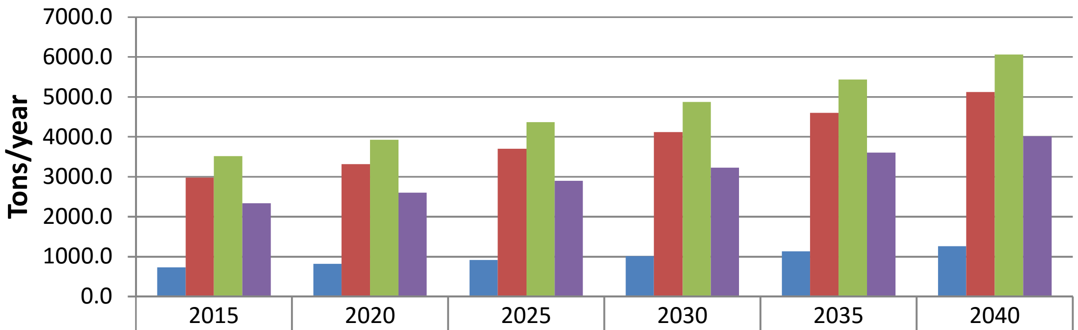
Fig. 4.4 - Organic Waste Forecast 2015-2040

The recycled materials in 2015 due to (Scenario 1) presented in (Fig. 4.5) and for (Scenario 2) shown in (Fig. 4.6). Recycled materials expected to grow at the rate of 3.4 % up to the year 2040 (Fig. 4.5) and expected to increase with the growth rate of 2.2% up to the year 2040 (Fig. 4.6). Due to these massive quantities of materials, its play an important factor of not be disposing into the landfill and can be recycled or can energy be extracted to minimize the amount disposing of and use it by some of the waste to energy technologies.



	2015	2020	2025	2030	2035	2040
Paper	732.4	865.6	1023.1	1209.3	1429.4	1689.4
Plastic	2972.3	3513.1	4152.4	4908.0	5801.0	6856.6
Glass	3517.5	4157.5	4914.0	5808.2	6865.1	8114.2
Rubber	2330.8	2754.9	3256.1	3848.6	4548.9	5376.6

Fig. 4.5 – Recycled Materials Forecast 2015-2040 (Scenario 1)



	2015	2020	2025	2030	2035	2040
Paper	732.4	816.6	910.4	1015.1	1131.7	1261.8
Plastic	2972.3	3314.0	3694.9	4119.6	4593.1	5121.1
Glass	3517.5	3921.8	4372.6	4875.3	5435.7	6060.5
Rubber	2330.8	2598.7	2897.4	3230.4	3601.8	4015.8

Fig. 4.6 – Recycled Materials Forecast 2015-2040 (Scenario 2)

4.4 - Conclusions

The MSW practices in Greater Dammam Area are simple: collect and dump. In This research assessed to Waste generation forecast to predict MSW Quantity up to the year 2040. Different scenarios of forecasting, each one represents future situations of Greater Dammam Area. As a result of these conditions an expectation of big increase of population in Greater Dammam Area, which expected to causes a high of MSW Generation year by year and larger waste per person...

There will be an increase yearly of recycled materials which the materials can be a source of energy by using different technologies that the energy can signify extracted. The central idea of this, the government should consider these materials as last option disposed into the dumpsites.

Chapter 5

Conceptual Design of Landfill Cell

The first design scenario that has been considered is by applying the current waste management effort, which consists of mass landfilling of all MSW produced up to the year 2040. This approach will not make use of any recycling, composting, or energy recovery procedures and instead the entire bulk of the collected waste will be disposed in landfill cells. The conceptual design of the landfill is based on the forecasted weights of waste generation, which are used to estimate the volume and surface area requirements of the landfill for each year. The shape of landfill cross section is trapezoidal, in order to make it structurally stable, with the sides being at an angle of 45°. The height of yearly lift is assumed to be 3m (10ft) and the top width is assumed to be 150m (500ft), as shown in the below figure. Additionally, about 20% of the cell volume is used for covers and lining.

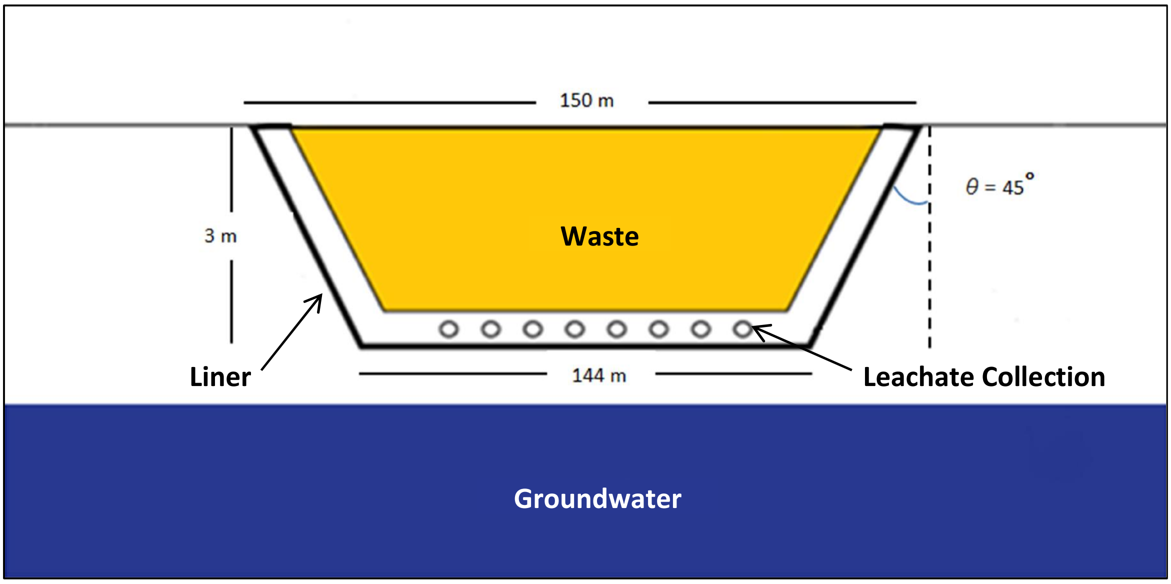


Fig. 5.1 – Schematic Cross Section of Landfill Cell (edited from Laramie, 2014)

The calculations for landfill volume requirements assume the landfill density to be at an industry standard of 1000 lb/cubic yd (593.276 kg/m^3) and are done using the following equation:

$$V_{MSW}\ (m^3) = \frac{Per\ Capita\ Waste\ Generation\ \left(\frac{kg}{capita - day}\right) \times 365 \left(\frac{day}{yr}\right)}{593.276\ \left(\frac{kg}{m^3}\right)}$$

Since only 80% of the cell will consist of landfill the volume needs to be adjusted accordingly:

$$V_{cell} = \frac{V_{MSW}}{0.8}$$

For the calculations on required landfill surface area, the formula for volume of a trapezoidal prism is used, which takes an average width as the mean of the top and bottom widths. This average width is then used to calculate the surface area required for the landfill in the following equation:

$$Surface\ Area\ (sq\ km) = \frac{V_{cell}(m^3) \times 10^{-6} \left(\frac{sq\ km}{sq\ m}\right)}{3m}$$

The actual landfill will require additional surface area for methane and groundwater monitoring systems as well as for service roads. For this reason we have estimated that only 80% of total landfill area will be occupied by the landfill cell. Hence we will need to adjust the calculations to allow for a more accurate assumption on required total landfill space. The total required surface area for the entire landfill can be calculated using the following equation:

$$Surace\ Area_{cell} = \frac{Surface\ Area_{cell}}{0.8}$$

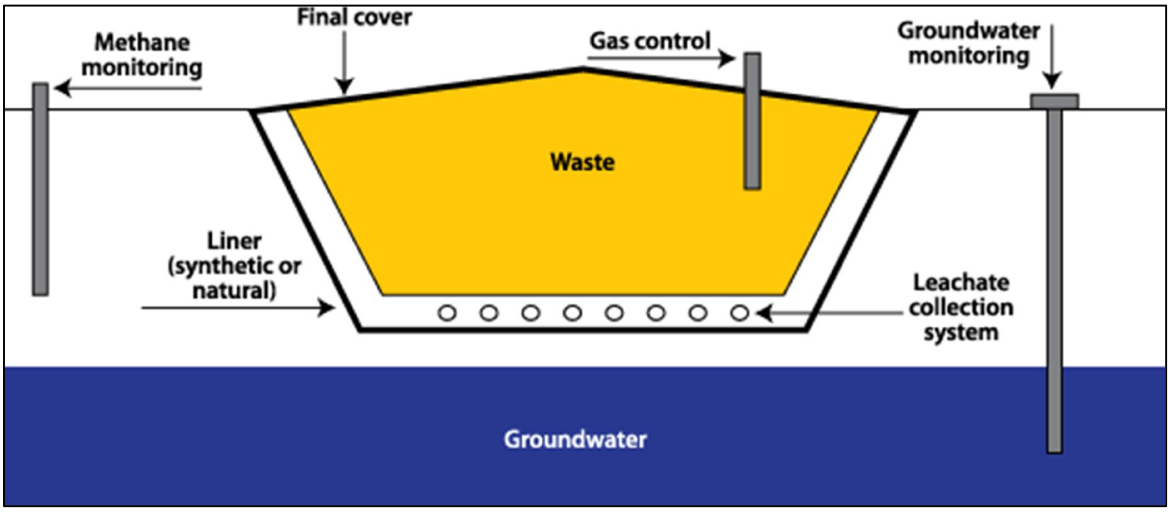
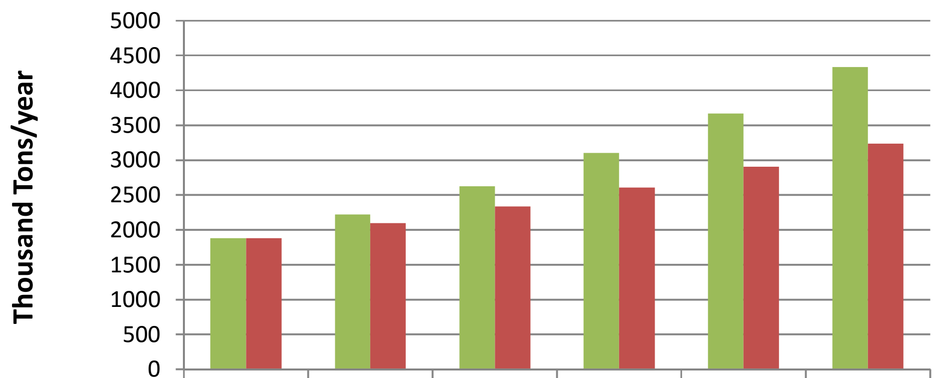


Fig 5.2 – Total Landfill Area Will Include Adjust for Additional Features (Laramie, 2014)

The waste generation has been forecasted from the year 2015 up to the year 2040 based on two different scenarios of population growth rate. Scenario 1 uses the overall historical trend for Saudi Arabia with a growth of 3.4%, whereas Scenario 2 uses the change in population over the last five years to yield a growth rate of 2.2%. The results for forecasted waste generation are shown in the following figure.



	2015	2020	2025	2030	2035	2040
Greater Dammam Area (Scenario 1)	1878.9	2220.8	2624.9	3102.5	3667	4334.3
Greater Dammam Area (Scenario 2)	1878.9	2094.9	2335.7	2604.2	2903.5	3237.2

Fig. 5.3 – Waste Generation Forecast For Every 5 Years up to 2040

The corresponding results for landfill volume requirements depict an exponentially increasing demand for waste volume requirements. Beginning with about 3.9 million cubic meters in 2015, the demand increases to 9.1 million cubic meters for the year 2040 for Scenario 1. The results for Scenario 2 are smaller due to the difference in growth rate, but still show a demand of about 6.8 million cubic meters by 2040. The resulting surface area requirements begin with 1.68 sq km for the year 2015. The demand increases up to 3.88 sq km and 2.90 sq km for scenarios 1 and 2 respectively.

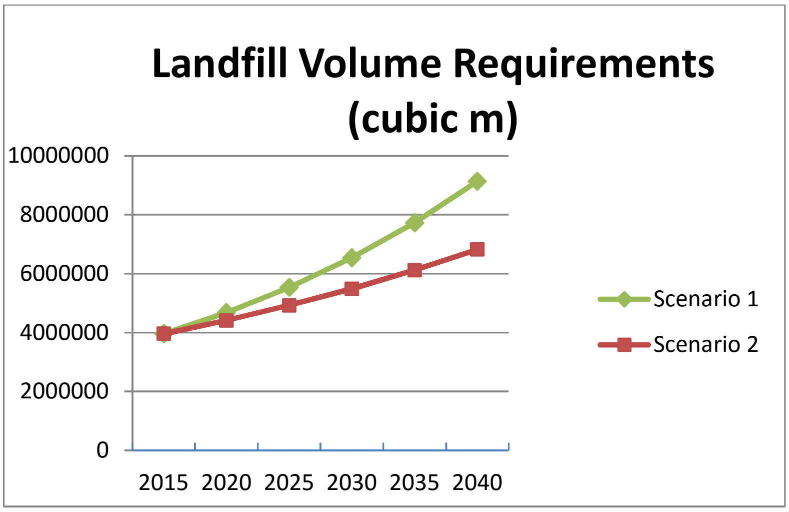


Fig. 5.4 – Landfill Volume Requirement Forecast (2015 – 2040)

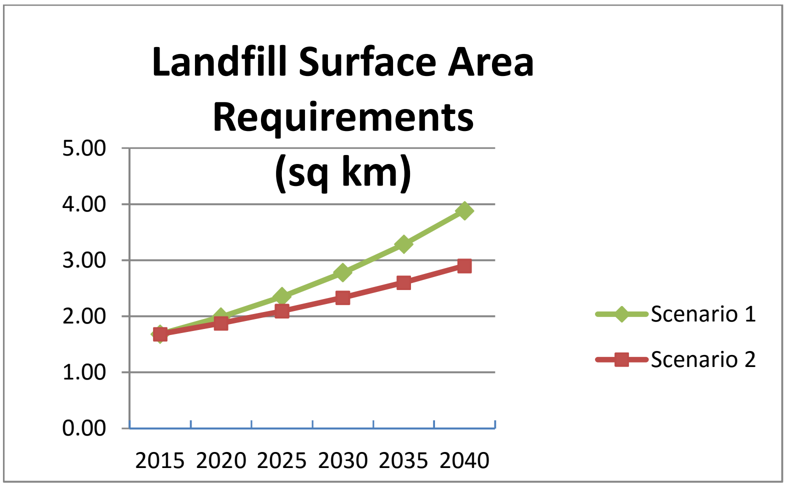


Fig. 5.5 – Landfill Surface Area Requirement s Forecast (2015 – 2040)

Chapter 6

Net Power Generation Potential (Mass Burn and Mass Burn w/Recycling)

6.1 – Introduction

In order to evaluate the energy generation potential from MSW, waste composition in the Greater Dammam Area is used to calculate the lower heating value of the waste by considering the dry solid waste without moisture content. For total mass burn process the average value of the total waste is considered as a lower heating value while for incineration with recycling all types of waste that could be recycled are not include in the calculations. The calculation for mass burn and mass burn with recycling are calculated based on these three equations. Energy recovery potential (GWhr/day), Power generation potential (MW) and Net generation potential (MW).

$$Energy\ Recovery\ Potential\ \left(\frac{GWhr}{day}\right) = \frac{\left(Dry\ waste\left(\frac{tones}{day}\right) \cdot LHV\ of\ waste\left(\frac{kWhr}{kg}\right)\right)}{1000}$$

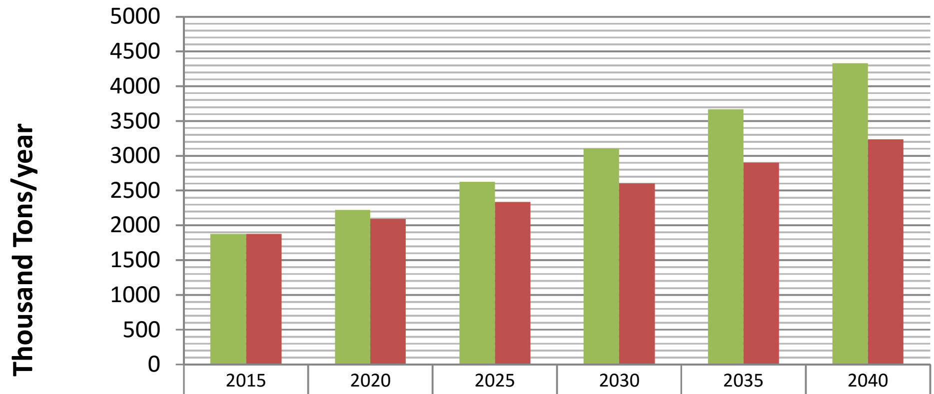
$$Power\ Generation\ Potential\ (MW) = \frac{\left(Dry\ waste\left(\frac{kg}{s}\right) \cdot LHV\ of\ waste\left(\frac{kW}{kg}\right)\right)}{1000}$$

$$Net\ Power\ Generation\ Potential\ (MW) = \eta * Power\ Generation\ Potentital$$

Where η is the efficiency of the process. Efficiency for incineration is taken as 25% (Masters & Ela, 2014)

6.2 – Result and discussion

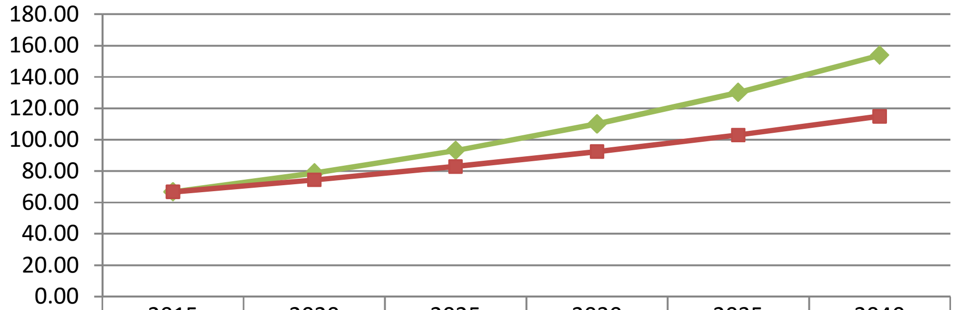
Two processes for WTE for two different scenarios depend on the growth rate of the population in the Greater Dammam area. For the first scenario, the historical trend of growth rate in Saudi Arabia is 3.4% and the second one is the growth rate of the Eastern province alone, which is equal to 2.2%. Based on these two scenarios, the waste management methods were developed and analyzed, including complete incineration and incineration with recycling. The forecast results for waste generation for both scenarios of the Greater Dammam Area are presented in (fig. 6.1):



	2015	2020	2025	2030	2035	2040
Greater Dammam Area (Scenario 1)	1878.9	2220.8	2624.9	3102.5	3667	4334.3
Greater Dammam Area (Scenario 2)	1878.9	2094.9	2335.7	2604.2	2903.5	3237.2

Fig. 6.1 – Waste Generation Forecast from 2015 - 2040

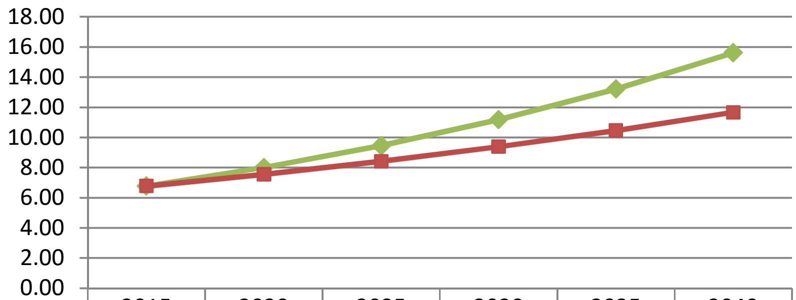
(Fig 6.2) shows two different scenarios for the total Mass burn. for Scenario 1, it has a potential to generate 68.9 MW from 2.2 million tons million tons were to generate up to the year 2016 , this number expected to increase due to increasing of waste generation yearly which expected to reach 153.8 form 4.3 million tons expected form waste generation forecast up to the year 2040. for Scenario 2, it has potential to generate 68.1 from 2 million tons for the year 2016 which these expected to get increasing year by year which it will reach to 114.88 MW from 3.2 million tons of waste up to the year 2040. The cumulative of mass burn generation from 2015 to 2040 is equal to 2716.6 MW.



	2015	2020	2025	2030	2035	2040
Scenario 1	66.68	78.81	93.15	110.10	130.13	153.81
Scenario 2	66.68	74.34	82.89	92.41	103.04	114.88

Fig. 6.2 – Total Mass Burn Generation Potential From 2015 - 2040

While in mass burn with recycling in (Fig 6.3), scenario 1 shows a potential to produce about 7 MW in the year 2016 and 15.62MW up to the year 2040. For scenario 2 mass burn with recycling produce in 2016 6.9 MW and 11.7 Mw up to the year 2040. The calculation was performed from excluding the recycling materials which it is plastic, rubber, Metals. The cumulative of mass burn with recycling generation from 2015 up to the year 2040 is equal to 2305.9 MW.



	2015	2020	2025	2030	2035	2040
Scenario 1	6.77	8.00	9.46	11.18	13.21	15.62
Scenario 2	6.77	7.55	8.42	9.38	10.46	11.67

Fig. 6.3 – Mass Burn with Recycling Net Power Generation Potential From 2015 - 2040

Chapter 7

Conclusions and Recommendations

7.1 Conclusions

The results of the Public Awareness Assessment Survey show that while the general public is not fully informed on waste practices in the area, there is enough awareness for people to understand the implications of continuing to ignore alternatives to landfilling. Most survey participants believe the waste collection system can be further improved with increased cooperation from the residents themselves. Currently, waste services are provided for free by the municipality and though residents are not willing to pay for waste services, they show a clear inclination towards practicing ISWM methods at home. Public awareness of waste reduction methods is high, as residents actively attempt to reduce in-house waste generation. A comprehensive government program for recycling, which would include in-house waste sorting, would likely receive strong support from the local population.

The necessary technologies needed to implement a strong recycling infrastructure include various waste segregation systems. Different systems are used to segregate waste of different types, with sensor-based sorting being the most state-of-the-art technology available today. In addition to recycling as a method to divert waste away from landfill, there are many methods to convert MSW into electrical or thermal energy. This approach accomplishes two goals at the same time; reduction in waste volumes and the availability of a renewable alternative to conventional energy generation methods. The most basic method of waste-to-energy is mass burn incineration, which can also be used in conjunction with recycling efforts.

The first design scenario of landfilling without recycling or waste-to-energy shows how critical the MSW challenges would become in the near future if sufficient ways to divert waste are not implemented. The exponentially increasing demands for landfill volume and surface area will become too severe even for a region with an abundance of open land. The current preference for landfilling will cease to be an economically feasible option for the government within the next couple of decades.

There is a considerable amount of energy that can be produced with the use of the mass burn method of incineration, making it a much more economically feasible alternative to landfilling. However, while mass burn incineration is economically beneficial, it is not the most environmentally option. The reduction in MSW volume and consequent energy production comes at the cost of high emissions of toxic materials into the atmosphere. Even with state-of-the-art emission control systems in place, there will still be a significant amount of air pollution being generated. Furthermore, mass burn method incinerates waste that could be recycled instead.

With this in mind it can be concluded that the best option among the three design scenario methods is mass burn with recycling. Mass burn with recycling only incinerates waste that cannot be recycled, and therefore would inevitably end up in a landfill as residuals. The majority of the waste will be recycled and used as raw material in various manufacturing operations. The main advantage of recycling is that helps reduce the amount of new materials and resources that are being used and therefore helps achieve the most desirable waste management strategy in ISWM, which is source reduction. Reintroducing waste materials into the production stream greatly increases the life cycle of raw materials. In some cases, a material can be used indefinitely provided it can be effectively segregated and repurposed. The power that is generated in mass burn with recycling is much less, but can still be put to use to power the waste-to-energy facility itself. Mass burn with recycling provides an environmentally friendly alternative to landfilling. The large public support for potential recycling operations further establishes it as a realistic option for MSW management in the Greater Dammam Area.

7.2 Recommendations for Further Studies

The survey that was conducted in the beginning of this study can be applied to a larger population sample in order to get more precise results. Feedback from additional 500-1000 residents would significantly improve how well the feedback from the sample reflects the overall population of the Greater Dammam Area.

While this study establishes the Mass Burn w/Recycling approach as the most environmentally friendly option among the three, it does not suggest that it would be the most economically feasible option. Further studies to compare the economic feasibility of each approach can be conducted in order to draw more definitive conclusions on which options can realistically be implemented in the study area.

There are many other waste-to-energy processes in addition to the ones analyzed in this study, such as gasification and pyrolysis. Additional studies on the power generation potential of these other processes could yield an even better alternative that would specifically suit the waste volumes and compositions in the study area.

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Appendix I

Public Awareness Assessment Survey Copy

Prince Mohammed University

College of Engineering

Municipal Solid Waste Management Survey

This Questionnaire is an integrated part of academic research project at Department of Civil Engineering at Prince Mohammed University (PMU). The Questionnaire aims to assess public awareness about municipal solid waste (MSW) management challenges in Saudi Arabia. The gathered data will be used for Academic purpose only. For further Information about questionnaire, please do not hesitate to contact Dr. Omar Ouda at oouda@pmu.edu.sa. Your help and cooperation is highly appreciated.

1. **Do you think waste is a problem in Saudi Arabia?**
   ☐ Yes ☐ No ☐ I don't know

2. **If yes, what is the best method to solve this problem?**
   ☐ More government spending ☐ Privatization of Waste sector ☐ Improve Public awareness
   ☐ In-house waste minimization ☐ Implementing Fees for waste disposal
   ☐ Other, please specify:____

3. **Do you know how the municipal solid waste (MSW) is disposed?**
   ☐ Yes ☐ No ☐ I am not sure

4. **If yes, what is the method of disposal implemented in your area?**
   ☐ Sanitary landfill ☐ Dumpsite ☐ Material recovery facility (MRF)
   ☐ Compositing plant ☐ Waste to Energy

5. **Do you think it is the right approach?**
   ☐ Yes ☐ No ☐ I am not sure

6. **If No, why?**
   ☐ Environmental and health impact ☐ Expensive ☐ un-professional system

7. **Is waste-to-energy acceptable to you as a method of waste disposal and electricity generation?**
   ☐ Yes ☐ No ☐ I am not sure
   ☐ Other, please specify:____________________________________

8. **If No, why is it not acceptable?**
   ☐ Potential environmental and health impact ☐ Expensive ☐ No need for it
   ☐ Plenty of land and oil available, so no problem ☐ Other, please specify:_________________________

9. **Are you satisfied with MSW collection service in your area?**
   ☐ Yes ☐ No ☐ I am not sure

10. **Who provides this service in your area?**
   ☐ Municipality/Amman ☐ Private Company (Name :________________) ☐ Your Company

11. How regular is the MSW collected from your area?
☐ Everyday ☐ Every other day ☐ Once a week ☐ I don't know

12. Do you think your house produce a lot of waste?
☐ Yes ☐ No ☐ I am not sure

13. Which particular waste your house produced most?
☐ Food waste ☐ Plastic waste ☐ Packaging material ☐ Cans/Tins
☐ Other, Specify:______________________________

14. Are you aware of waste minimization techniques?
☐ Yes ☐ No ☐ I am not sure

15. If yes, have you tried to minimize to use in your house?
☐ Yes ☐ No

16. If yes, what methods of waste minimization have you used? (check all that apply)
☐ Recycle/reuse ☐ Composting ☐ Packaging minimization ☐ Using durable products
☐ Other, Specify:______________________________

17. Do you consider MSW collection a problem in your area?
☐ Yes ☐ No ☐ I am not sure

18. If yes, what type of problem is it?
☐ Environmental ☐ Health ☐ Aesthetic ☐ All of them

19. What is the reason behind this problem?
☐ Collection calendar ☐ Unsuitable collection bins ☐ Residents' behavior ☐ Collection bin location

☐ Other, Please specify:______________________________

20. What do you think is the best solution? (You may check more than one)
☐ Additional bins ☐ Penalties on waste littering/throwing ☐ Houses should have composting bins
☐ In-house waste segregation ☐ Change the collection company
☐ Other, please specify: ______________________________

21. Currently, waste services are provided for free, do you think residents should pay for waste disposal service?
☐ Yes ☐ No ☐ I don't know

22. If yes, how much is a reasonable fees per month?
☐ 0 to 50 Riyal ☐ 50 to 100 Riyal ☐ 100 to 200 Riyal ☐ more than 200 Riyal

23. Do you think waste recycling is important?
☐ Yes ☐ No ☐ I don't know

24. Is there a Materials Recovery Facility (MRF) in Saudi Arabia?
☐ Yes ☐ No ☐ I don't know

25. Are you willing to buy recycled materials/products?
☐ Yes ☐ No ☐ I don't know

26. Are you aware of waste sorting/segregation approach?
☐ Yes ☐ No ☐ I don't know

27. Do you segregate your trash to plastics, tin, cardboard and organic (food) prior to disposal?
☐ Yes ☐ No

28. Would you be willing to segregate your trash based on the above prior to disposal?
☐ Yes ☐ No

29. Can waste be a source of income for the country?
☐ Yes ☐ No ☐ I don't know

30. Would you be willing to pay a waste minimization charge to the government for a cleaner city?
☐ Yes ☐ No ☐ only if I have to

31. Do you support penalties being imposed on those who throw the waste on the streets?
☐ Yes ☐ No ☐ I don't know

32. Do you think penalties being imposed on littering/throwing will result in a cleaner city?
☐ Yes ☐ No ☐ I don't know

33. Are you satisfied with the current level of waste management services offered overall in your area?
☐ Yes ☐ No

34. Do you think the government should partner up with private firms to improve waste collection services in your area?

☐ Yes ☐ No ☐ I don't know

35. Should private firms be charged a commercial premium for waste disposal?
☐ Yes ☐ No ☐ I don't know

36. Do you believe more could be done to improve diversion of waste from landfilling?
☐ Yes ☐ No ☐ I don't know

37. What is the type of your house?
☐Apartment ☐Single house ☐Townhouse ☐Apartment building (How many units:)

☐ Residential Compound ☐Other, please specify: ________________

38. Do you own or rent your house?
☐Own ☐ Rent ☐Other, please specify: __________________

39. **How many people live in your household?**
☐ 1-2 ☐ 3-4 ☐ 5-6 ☐ 7-8 and more ☐ 9 and more

40. How much is the family's monthly income? (SAR)
☐2,000 – 5,000 ☐6,000 – 11,000 ☐12,000 – 18,000 ☐More than 20,000

41. What is your education level?
☐High school ☐Diploma ☐Bachelor ☐Masters ☐PhD

42. Extra Information:

Occupation	
Age	
City	
District	

Thank you very much for your time….