Organising Waste Management in Marsabit County

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ABSTRACT

This Bachelor's Thesis was commissioned by HAMK Sheet Metal Center, and is a part of HAMK's contribution to the project of Sustainable Housing in Marsabit County, Kenya. The aim of the thesis was to create a technical plan for the implementation of a sustainable and low-tech waste management system that can be executed in hot and arid climatic conditions of Marsabit.

The thesis consists of detailed descriptions of a number of small- and big-scale solutions along with a set of policies and strategies that should be implemented in order to ensure effective waste management.

As a result of the thesis recommendations are provided on how to utilize the described techniques in tandem to achieve better efficiency of the waste management system.

Keywords sustainability, waste management, development

Pages 52 pages including appendices 8 pages

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Appendices

1 INTRODUCTION

The main goal of this Bachelor's thesis is to explore issues related to waste management in the developing countries in general and the Marsabit County of Kenya in particular. The methods that are discussed here have been carefully selected to fit a narrow range of criteria suitable for financially destitute countries with hot and arid climate. The criteria limit the possible solutions to ones that are sustainable, low cost, can be established by the local supply means, target the environmental advantages of the areas and compensate for their weaknesses. In most cases that means using renewable energy sources and energy efficient technologies.

The Marsabit County population rate is expected to considerably increase in size, therefore leading to a respective rise in produced waste. This means that waste management will be an ongoing and serious issue for years to come. It has to be handled in the most efficient and locally appropriate manner to minimize the risk of aggravating existing environmental problems and endangering the health of the population.

This thesis will provide information on hazards of inadequate waste management, organization of a small scale and a large-scale waste management system, developing small-scale sustainable waste management habits, waste prevention techniques and waste reuse.

2 PROJECT BACKGROUND

The County of Marsabit, located in a hot and arid northern region of Kenya, is one of the most underdeveloped regions in the country, where water and energy are precious resources. Population has more than doubled in the last 10 years and urban population has increased from 13% in 1999 to 22% in 2009 (National Census 2009) or 70,868. This is expected to increase to 99,869 in 2017. (Goverment of the Marsabit County, 2016)

Water is a scarce resource, mainly sourced from boreholes, although many households harvest rainwater in the rainy season. There are no sewer or solid waste collection systems in urban areas, although the county is planning to set up a controlled landfill to dispose of the garbage. (Goverment of the Marsabit County, 2016)

There is a great potential to reduce the ecological footprint of the populace through waste recycling. With new investors being attracted by the county this is a promising business opportunity that will be beneficial for both local economy and environment. (Goverment of the Marsabit County, 2016)

The requirements set by the government of Marsabit oblige the waste management system to promote sustainability, energy efficiency, resource conservation, population health and well-being of the environment.

3 INTRODUCTION TO WASTE

3.1 What is waste and non-waste

In the Marsabit County context we will be dealing with household and industrial (derived mostly from construction, transportation, agriculture and commerce) waste. The waste is generally non-toxic and solid, organic or non-organic, with high recyclability prospect. (HAMK, 2017)

Waste is defined as an object the holder discards, intends to discard or is required to discard (European Commission Directorate-General Environment, 2012). The visualization of legal definition of waste can be seen in Figure 1.

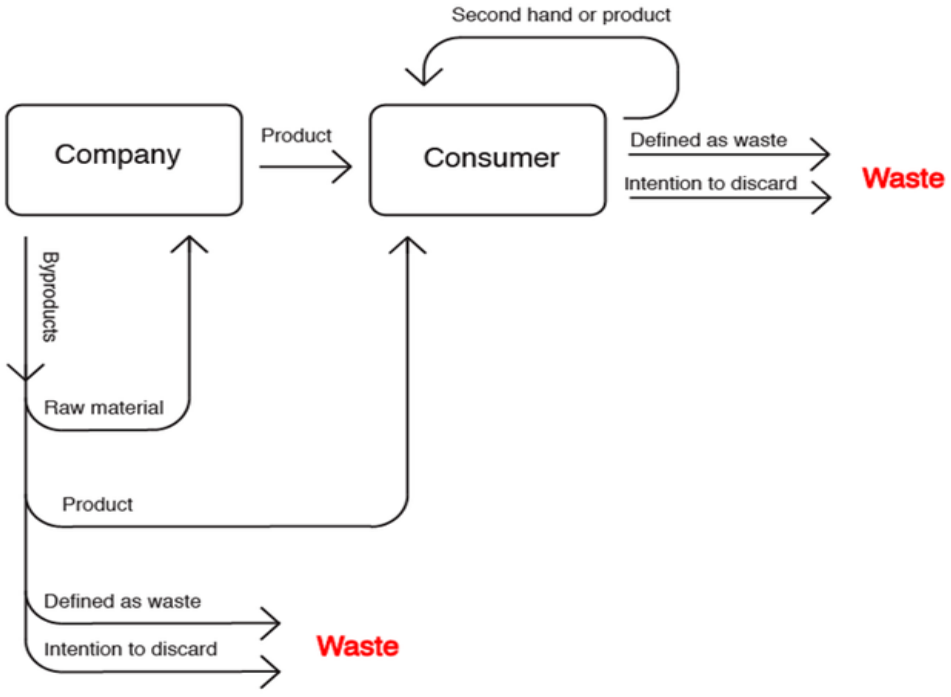

Figure 1. Illustration of EU legal definition of waste (European Commission Directorate-General Environment, 2012)

The Waste Framework Directive clearly states the difference between 'waste' and 'by-product'. By-products can be applied to the creation of new products or re-used in some other way. Waste, however, is any material that has been set up for final disposal. (European Commission Directorate-General Environment, 2012)

The definition of waste varies individually. One person might know what to do with a particular material, and will therefore perceive it as something valuable, whereas someone else might not know any applications for the same resource, and will willingly discard it. (Pongrácz, 2002)

Waste can be converted to non-waste if it is assigned a new role or purpose. Therefore, it is merely a matter of perception. The state or structure of waste can be manipulated to enable it to perform some purpose (Pongrácz, 2002). The algorithm in Appendix 1 can be used to define whether an object is actually waste, or whether an application or a new owner can be found.

3.2 **Waste types**

According to the Marsabit waste baseline survey (HAMK, 2017) and Municipal waste management systems for domestic use report (H.Jouharaa, 2017) that one household of about 3-5 people produces about 1-2 litres of organic kitchen waste per day. In the big picture, nearly half of the waste in Kenya has recyclable/reusable potential, which can clearly be seen in Figure 2.

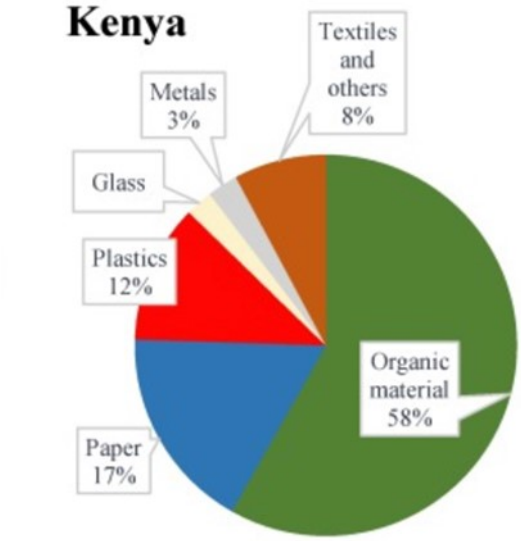

Figure 2. Kenyan Waste chart (H.Jouharaa, 2017)

Plastic attributes for 12% of the total waste, water bottles being one of the most commonly disposed articles. Metal and glass waste is not typical for Marsabit. Due to socio-economic context, metal and glass are considered valuable resources and are reapplied most efficiently most often.

3.3 Waste management hierarchy

Waste management hierarchy visualized in Figure 3 is a widely accepted list of preferred waste management options.

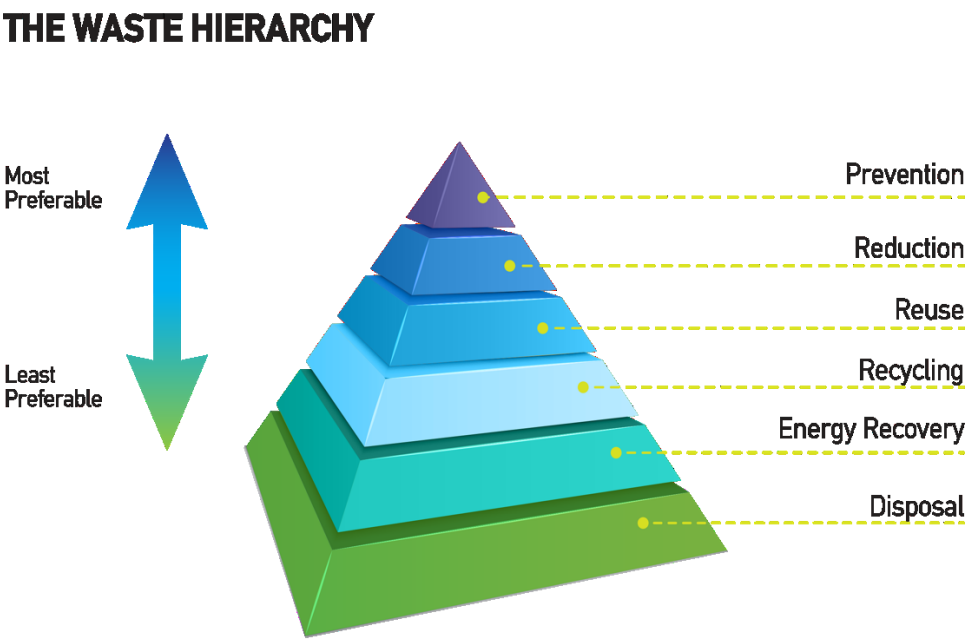

Figure 3. The waste management pyramid (Rethink.com, 2015)

The tip of the pyramid, and therefore the biggest preference, is given to waste prevention. The intention is to show that a sustainable waste management strategy mostly uses minimization techniques, and only recovers and disposes of waste that cannot be avoided. (Pongrácz, 2002)

3.4 Marsabit energy situation

A municipal waste management system can present considerable opportunities for energy recovery and electricity production. In Marsabit, however, electricity accounts for only 9% of the total energy use, with wood (69%) and petroleum (22%) being the main energy sources for the local population. Over 85% of Marsabit residents rely on natural fuels, since electrical grid has a very modest area of coverage (only 23% of the population have access to electricity connections) and electricity can be supplied irregularly, making it an unreliable source of energy. Even though the electricity sector is estimated to expand progressively and the government is striving to develop it, using waste to produce electricity in a centralised manner appears to be a strategy best left for the future due to the low level of local demand. (Marsabit County Government, 2015)

4 WASTE AS A PROBLEM

Waste represents a large loss of resources both in the form of materials and energy. Quantities of waste can be seen as an indicator of the material efficiency of society. However, while waste quantities alone are a measure of resource loss, the environmental impact of waste cannot be contributed by quantity alone. Dangerous substances contained in waste can have a very negative impact on the environment. (Pongrácz, 2002)

The problem of waste in the developing countries is widely known, and is expected to worsen in the observable future due to the rapid population growth. In poor economic conditions where the insufficiency of funds prevents governments from creating a proper waste management system, the garbage problem is just left mostly unattended, with only about 30-60% of the total amount of waste being collected (UN HABITAT, 2010, pp. 14-15).

The lack of organised means of controlling solid waste, irregular garbage collection, insufficient enforcement of waste-related legislations, uncontrolled dumping - these are just a few of the problems that waste management sectors in the developing regions have to deal with. As the result, garbage tends to accumulate in waterways and on land, creating a spectre of profound environmental, ecological and social problems. (MIiller, 2010)

The character of the problem ensuing from waste mismanagement depends on various factors, such as the physical characteristics of waste and the local geography (The World Bank, 1995). For instance, in some communities where sanitation infrastructure is inadequate, the municipal waste gets intermingled with biological human waste, which increases its critical character. The fact that developing countries are used as illegal dumpsites for exported toxic waste only further intensifies the problem. (UN HABITAT, 2010, pp. 14-15)

4.1 **Environmental impacts**

Environmental degradation that comes as the result of inadequate waste management practices can have various manifestations. Open burning in dumpsites releases particulates as black carbon and persistent organic pollutants, which bioaccumulate in the food chain. (Courtois, 2012) Contamination of surface and ground water with leachate decreases the overall quality of water, makes it unsuitable for consumption and increases municipal treatment costs. Soil contamination through direct contact with waste or leachate leads to stunted vegetation growth and wildlife deterioration, thus decreasing the favourability of living conditions of the contaminated area. The same can be said about air pollution through waste burning/landfill gas emitting, increase in pest and rodent populations and magnified wildfire probability. (S. Buso, 2015)

4.2 **Economic impacts**

Economic repercussions of waste overflow may not be as obvious as environmental and social ones, but they are present nonetheless, and they take a heavy toll on the government dealing with them. Decrease in waste quantities would mean minimisation of greenhouse gas emission and subsequent adherence to the UN Sustainable Development Goals. More efficient resource utilisation would mean lesser economic losses as well as demand on non-renewable natural resources and diminished environmental impacts of the extraction, harvesting and processing of them. Besides, developing a sustainable and comprehensive waste management system can encourage economic development through job creation, more economic budget use and increase in land value. (WRAP.ORG, 2019) In low-income countries, the solid waste market provides up to 5% of urban jobs (Courtois, 2012).

4.3 **Social impacts**

Health deterioration is the most notable and destructive impact of waste on the local community. Waste mismanagement has been linked to higher rates of cancer and respiratory diseases, as well as dermal conditions such as eczema. Children are especially susceptible to these hazards, since they have a higher rate of breathing than adults and thinner layer of skin among other physiological disadvantages. (UN HABITAT, 2010, pp. 14-15) These diseases decrease the quality and expectancy of peoples' lives, as well as diminish the productive output of the population, therefore undermining the functioning of the society. Sickness, combined with an overall marginal environment of poverty, leads to stigmatization of certain groups of the society and social stratification. Besides, the presence of waste on the streets has been linked to lower levels of child literacy. School kids in Africa were observed to skip school to scavenge the landfills in search of valuables for sale, which led to subsequent rise of crime rates in subsequent years. (S. Buso, 2015)

Growing up in such problematic environment has been linked to a general disregard of sanitary and waste management practices in children. These issues create a vicious cycle of harmful habits and facilitate a sense of insecurity, therefore decreasing the quality of social interactions and undermining the local culture. (Owusu, 2010)

5 **BIG-SCALE WASTE MANAGEMENT SOLUTIONS**

This section of the thesis will explore the possible ways of managing waste on a municipal-scale level.

5.1 **Waste-to-product**

Recyclable plastics accounts for 12% of Kenyan waste. The Marsabit Waste Baseline Survey (HAMK, 2017) shows that most of this plastic is either given to the municipal waste collection systems or simply burnt. Disposing of plastic in such ways is not energy-efficient and does not contribute to mitigating the environmental footprint of the populace. Being a synthetic polymer, plastic is malleable and can be melted and moulded numerous times. Plastics can be given a wide array of properties and have a near limitless number of possible applications.

On the other hand, the Marsabit County's population is expected to increase significantly (Goverment of the Marsabit County, 2016), so the need for new housing units is very pressing. It would be possible to address both the recycling and the housing issues simultaneously if plastics was to be used as a building material.

5.1.1 Hot moulding method

Hot moulding method requires a certain amount of machinery and entails energy expenditures. However, the result is very durable and can be customized in a wide variety of ways.

As the base for this method, a working scheme (Precious Plastic, 2013) designed by Precious Plastic© will be utilized. Precious Plastic© is an open-source project the goal of which is to boost plastic recycling worldwide. It was started in 2013 and by now, hundreds of people around the world have joined the project, built the machines and started recycling plastic waste.

Generally plastics can be divided into two categories: thermoset and thermoplastic. Thermoplastics soften when heated and become more fluid as additional heat is applied, whereas thermoset plastics contain polymers that cross-link together during the curing process to form an irreversible chemical bond. This characteristic allows thermoplastics to be remolded and recycled without negatively affecting the material's physical properties (Modorplastics.com, 2017). This solution is feasible only in regard to thermoplastics.

Thermoplastics in turn are divided into many different categories depending on their structure and properties. Different plastics can be recognized by their name and number that are typically printed or embossed somewhere in the product, normally within the recycling sign. (Preciousplastic.com, 2013) Plastic resin identification chart can be found in Appendix 2.

Knowing what plastic type you are dealing with is crucial. Depending on the type, plastics will have different melting points, so different correct

temperatures should be applied. This will ensure a smooth recycling process. (PreciousPlastic, 2018)

Different plastic types should never be mixed together during recycling as this will make them unsuitable for the process. Mixing plastics would end their cycle. Moreover, when different types of plastics are melted together, they tend to phase-separate, like oil and water, and set in layers resulting in structural weakness and lower quality products. (PreciousPlastic, 2018)

The first step of plastics recycling is collection and sorting. Agreements should be made to ensure a constant supply of plastics, either with a private contractor or a municipality. It may also be possible to purchase already collected and separated waste for some additional fee. That would make the recycling manufacture more compact in space and would require less manual labor. However, if it is not possible, or cost-effective, plastics can be separated on-site, by means of manual labour. (PreciousPlastic, 2018)

Sorting is done by checking the product's SPI resin identification code mentioned before and assigning the item to the corresponding heap of plastics. Products that don't have the SPI code (due to it never being there in the first place or getting eroded with time) should be put in a separate heap and either be identified by alternative means later, or recycled in some other way, according to what is shown in Figure 4. Often there are specific types of plastics assigned to a specific line of products, and therefore they don't require any sort of marking. For example, water bottles are made from PET, CD cases from PS, jerrycans from HDPE etc. It is important to know these criteria in order to be able to distinguish which type of plastic is being handled. (PreciousPlastic, 2018)

floats on:	alcohol	vegetable oil	water	glycerin
PET	no	no	no	no
HDPE	no	no	yes	yes
PVC	no	no	no	no
LDPE	yes	no	yes	yes
PP	yes	yes	yes	yes
PS	no	no	no	yes

Figure 4. Plastic identification means (PreciousPlastic, 2018)

The next step is shredding. At this stage, bigger plastic objects are chopped into small granulate to reduce their size and allow for proper washing and efficient storage shown in Figure 5. At this stage they can also be separated by colour, if necessary. (PreciousPlastic, 2018)

Figure 5. Shredding process (Molok, 2013)

The final product should look similar to the one shown in Figure 6.

Figure 6. Shredded material example (Molok, 2013)

Plastic needs to be cleaned from dust, dirt and other impurities, as these can result in extra maintenance, breakdowns, production problems and decrease in the overall quality of produce. The most efficient way is to wash plastics after shredding using a basic filtering system: plastic flakes are placed on a mesh, similar to one shown in Figure 7, and immersed in water. They are then thoroughhly stirred 5-10 times and taken out. After the procedure the material should be placed on a drying plate for a few

hours to allow for water evaporation. It is important that the plastic is dry before being melted. (PreciousPlastic, 2018)

Figure 7. An example of a sieve (Realmensow.co.uk, 2013)

Once the plastic is dry it can be conveniently stored. Ideally, storing should be done in stackable buckets, strong and transparent so the colour and nature of the plastic can be easily seen. The SPI coding should be minded when storing the plastics using respectful markings, as shown in Figure 8. For example, if PS plastic has been sorted, shredded and eventually washed, it is essential that it is put in a bucket with the PS code sticker so that different plastics don't get mixed up. (PreciousPlastic, 2018)

Figure 8. Storing example (PreciousPlastic, 2018)

The first step is to determine what temperature is needed to melt the plastic. Most of the time this depends on the type of plastic type being handled and the room temperature at which recycling is performed (e.g. if it is windy the heat will disperse faster). Unfortunately, plastic is often mixed with additives, pigments and fillers that transform its chemical and physical composition affecting the final melting temperature. If sometimes the recommended melting temperature does not achieve the needed molten state, it should be gradually adjusted up or down until the desired result is achieved.

All plastics have a melting zone, which is a temperature window between which they melt (e.g. 130 to 171 °C), beyond those limits plastics will begin to burn, which should never be allowed to happen. Fumes from burning plastic are highly toxic and can cause serious health issues. During recycling it is not recommended to burn plastic, as the finished products will be damaged or lower in quality. (PreciousPlastic, 2018)

In order to establish the production process, at least two machines need to be assembled: a shredder and a compression machine which are presented in Figure 9 and Figure 10.

Figure 9. Compressor prototype (PreciousPlastic, 2018)

Figure 10. Shredder prototype (PreciousPlastic, 2018)

A shredder enables bigger plastic objects to be chopped into smaller flakes that are easier to store, wash and feed to the other machine. The shredder helps the process to be more efficient and fast as shredded plastic is easier to work with and melts readily. At the same time a compressor is needed to heat and apply pressure to the plastic, and since these are the two only conditions needed for the recycling process to occur they are both crucial. Depending on the type of the machine assembled and the final production purpose, the compressor either injects molten plastic into a mould or heats and pressurizes it in the mould directly. Thus, different lines of production can be run and different products fabricated creating a variety of products shown in Figure 11. (PreciousPlastic, 2018)

Figure 11. Finished product example (Precious Plastic, 2013)

Moulds have to be able to withstand heat and pressure. Metal is proven to be the best material for such a purpose. (PreciousPlastic, 2018)

The cost of assembly is estimated to be around 300 euros (based on year 2015 value) for both machines. However, the machines are designed to be made from scratch, so most of the materials needed can either be found on a landfill or purchased second-hand, so the overall cost for both units can be easily mitigated to 100 euros and less. (PreciousPlastic, 2018)

Detailed blueprints, cost calculations, customization options and manuals for all units can be found on the Precious Plastic© project's web-site in the 'Download' section (PreciousPlastic, 2018). However, this is just one possible way of creating these machines, other designs and functions can be implemented. It is strongly encouraged that the maker customizes these machines to their personal needs and realia, to increase productivity and efficiency.

5.1.2 Cold moulding method

Cold moulding method, compared to hot moulding method) requires lower energy expenditure and fewer pieces of machinery to produce a product out of plastic waste. The upside of this method is that plastic doesn't require sorting, and can be used regardless of its recyclability status (since it only undergoes mechanical treatment). However, it does require a binder (such as tar, bitumen or other resinous substance) to hold the components together, and the selection of products that can be made with this method is more narrow.

The process partially copies the sequence mentioned in the Hot moulding method section. Plastic is thoroughly separated from organic matter, dried, and then shredded with a machine, just like described below. After that, the grinded material is mixed with an organic resinous or non-organic mineral binder. While the mixture is workable, it is poured into moulds of desired shape and is left to harden.

This method can be used to create, among other things, cheap asphalt-like floor and road pavements for areas not intended for frequent public use. An example of such application can be found in Figure 12.

Figure 12. Pavement example (Pinterest, n.d.)

5.1.3 Benefits and prospects of moulding techniques

Both these methods can be used either as ready-made private business ideas, or governmental environment-friendly tactics for dealing with plastic waste. Opportunities are limitless, anything from kitchen utensils to house building blocks can be produced, as shown in Figure 13. This technology is ideal for creating non-load bearing walls, sound and retaining walls, privacy fencing, thermal insulation etc. (ByFusion, 2019)

It might be possible to solve the need for cheap housing units in Marsabit through the introduction of these technologies to the local society. More so, it can be done in a way that would enhance the ecological situation in the area by diminishing the rate of environmental waste pollution, which will have a positive impact on the populace health, economic prosperity of the region and wildlife wellbeing.

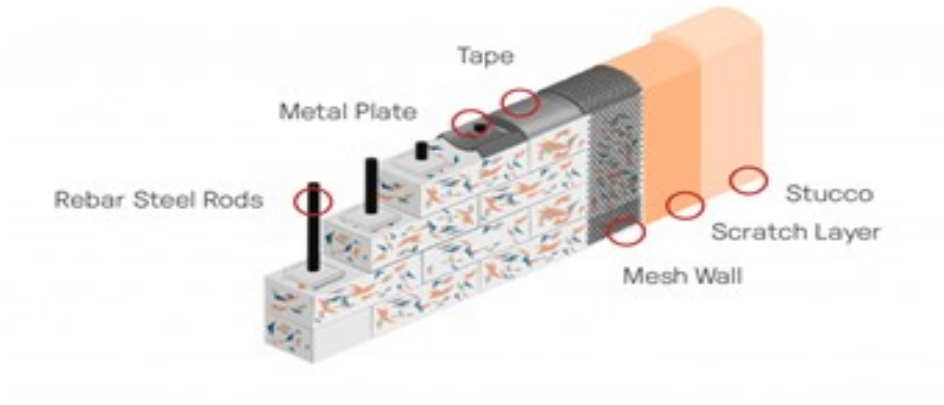

Figure 13. Plastic walls assembly (ByFusion, 2019)

5.2 **Landfilling**

With a limited budget, building a landfill is suggested. A landfill, however, may create many problems and is harmful to the environment. It is the least preferred waste management option, and therefore landfilling should only be done when no energy/material recovery is possible. Ideally, recycling and incineration is done before the final dumping, but due to the poor economic conditions of Marsabit these systems cannot be implemented in a centralized manner at the moment. Nonetheless, they should be established in the observable future, to preserve environmental soundness of the region.

A landfill's most notable negative impacts are:

-Air pollution (dust and bad odor)
-Pest population increase
-Noise pollution
-Surrounding soil erosion and nearby surface and underground water sources pollution
-Harmful gasses emission, such as is methane (CH4), which is 21 times stronger than carbon dioxide (CO2) in causing global warming
-Health hazard (e.g. may cause cancer, birth defect, etc.) (J.Lisk, 2007) (EHP, 2000)

A landfill should be far away from a residential area and from any water source (such as lakes or streams). The distance depends on several important factors, such as, the local and national legislation, typical wind direction and accessibility. A deserted area with a minimal amount of plants and other living organisms would be a suitable place for a landfill.

The size of the landfill will be determined by the County (a survey on how much waste 100 families can produced is recommended). The landfill should be dug as deep as possible, depending on the soil property, but not

below the groundwater level, to avoid contamination. A road to travel into and out of the landfill needs to be built sturdy enough to withstand heavy machinery during any season. The bottom of the landfill should be made into V-shaped surfaces with pipes installed as shown in Figure 14. This will help collecting unwanted liquid for further treatment.

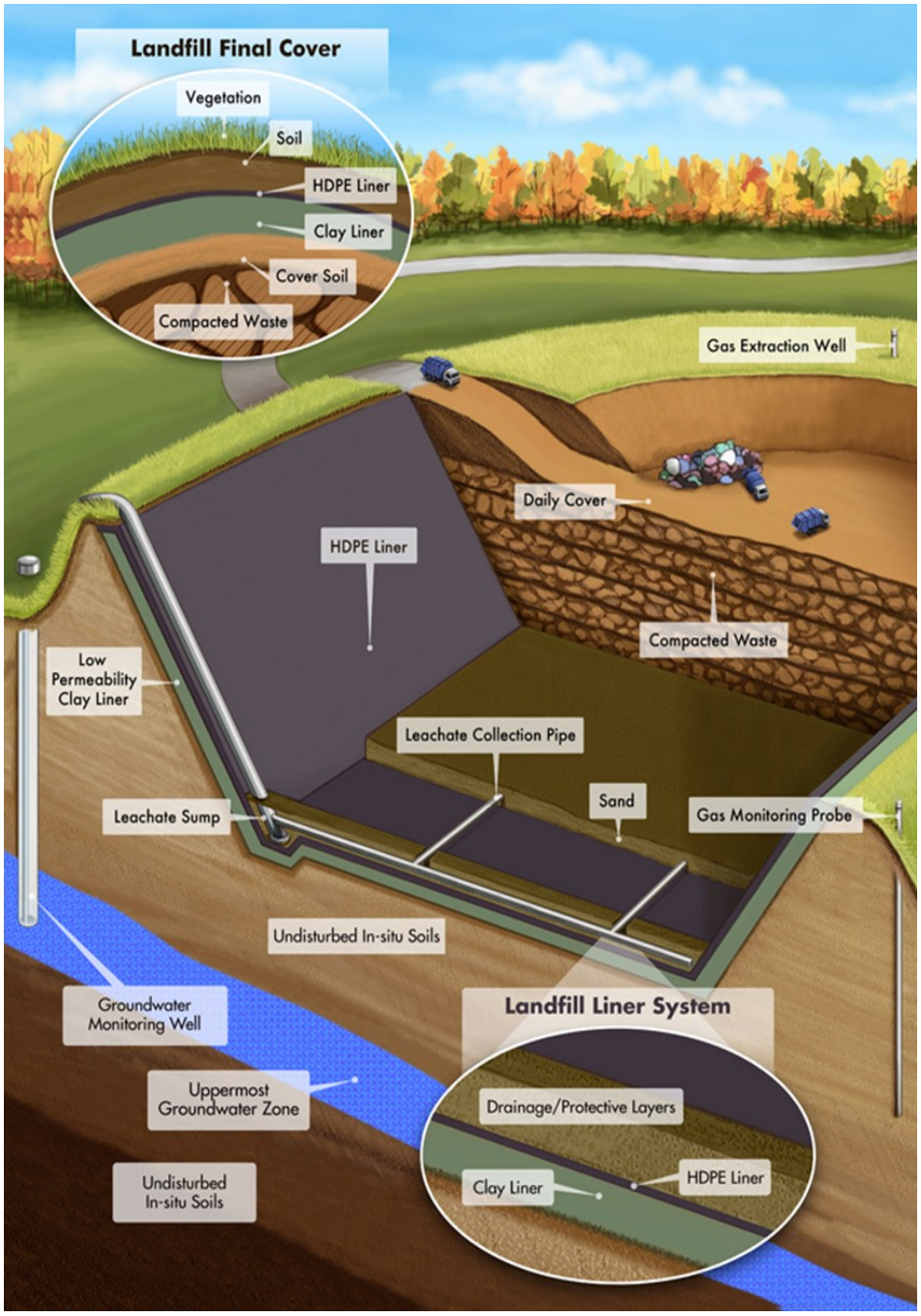

Figure 14. Landfill structure (Arrowheadlandfill.com, 2013)

When the volume of the landfill has been decided upon, containment layers have to be chosen. It is typical for a landfill to have a barrier system aimed at limiting contaminant movement to deeper levels. Such a system includes a leachate collection system meant to control the leachate's

corrosive impact on the underlying liner, and collect and remove it. The leachate collection system is typically comprised of a geotextile filter, a granular layer or geonet, and perforated collection pipes. The liners can differ from a thick natural clay deposit to engineered liner systems involving one or more geomembrane and/or a variety of clay liners. The purpose of a composite liner is to combine the strong sides of two materials, such as geomembranes and clays, each one of which has different hydraulic, physical and endurance properties. (CAEE, 2002)

Leachate, a liquid containing dissolved substances and suspended matter, accumulates at the bottom of the landfill causing a significant threat to surface and groundwater safety. The main sources of leachate are precipitation entering the landfill and moisture contained in waste. Typically, leachate components include high values of NH3 and heavy metals. The substance is highly acidic and has a strong odor. However, these characteristics vary greatly depending on the composition and volume, and the amount of biodegradable matter. All these factors make the process of treating leachate difficult and complex (Safaa M.Raghab, 2013). To minimize the amount of leachate penetrating the groundwater, the permeability of the landfill is reduced with filters, layers etc., and a collection system is installed, which pumps it out of the collection trench and forwards it to treatment facilities. (Abu-Zuid, 2015)

Another natural byproduct of organic material decomposition in landfills is called landfill gas. About half of it is methane, another half is CO2 with some addition of non-methane organic compounds. The gas is extracted from landfills using pipes and wells, which channel the collected gas to a treatment facility where it is processed depending on the need (see Appendix 4 for an example). Ultimately, gas can be used as a source of energy or heat. (EPA, 2018)

If gas and leachate formation are not controlled, incidents may arise, such as fires and explosions, unpleasant odors, landfill settlement, groundwater and air pollution etc. (Abu-Zuid, 2015)

In order to have a long-life landfill that has minimum impact on the environment and human's health, there are certain general rules that have to be abided:

1. **Personnel:** Landfill work is full of hazards, so all personnel must be trained in handling of different types of waste, safety procedures, landfill equipment usage etc. Moreover, all personnel must always wear protective gear while working as shown in Figure 15.
2. **Setting up:** There is a need to set a weight limit to control the amount of incoming waste for ecological reasons.
3. **Weighing standards:** When waste trucks come, the amount of waste needs to be checked, so that the weight limit is not exceeded.

4. **Unloading and load checking:** During unloading, hazardous waste and waste requiring special treatment need to be identified, removed and transported to an appropriate location.
5. **Materials recovery:** When checking the waste, recyclable materials such as paper, cardboard, glass, metal and aluminum need to be recovered.
6. **Spreading and compacting:** Having been carefully checked, waste needs to be compacted as thin as possible, to extend the landfill's operational capacity.
7. **Daily cover:** Every day a new layer of waste needs to be covered by a layer of soil.
8. **Site security:** Security is required to prevent unauthorized entry, for the safety of outsiders, workers and the landfill itself.
9. **Supervision:** All workers on-site must always be supervised. (CalRecycle, 2003)

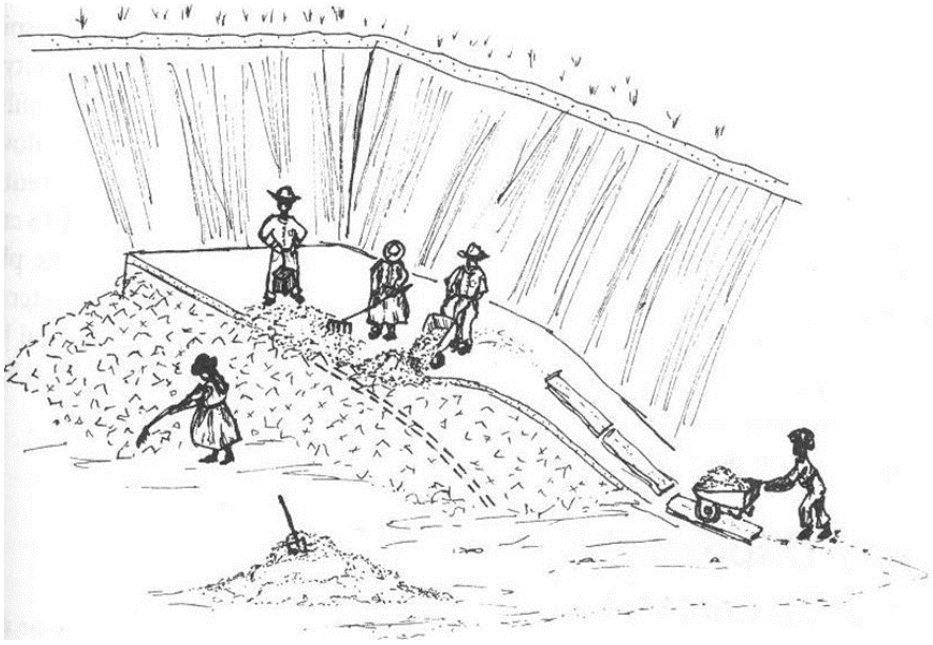

Figure 15. Manual landfill operation (J. Mihelcic, 2009)

5.3 **Separated waste collection system**

The most suitable and cost efficient way to keep the landfill less harmful to the environment and make it last longer is to include waste separation as a common habit of the people in Marsabit. Waste separation means separating biological waste, recyclable/reusable waste (plastic bottles, tin can, carbon boxes, papers) and non-disposable waste (plastic based products).

To help with the separation, trash bins should be placed at the collection points. These bins can be painted with different colors and descriptions about the types of trash that should be thrown in. The bin for paper, plastic

and cans are painted differently; in addition, which type of waste should be left inside is also written on the lid (see Appendix 4 for reference)

Waste separation techniques can be combined with underground waste collection systems such as ones used my Molok company and presented in Figure 16.

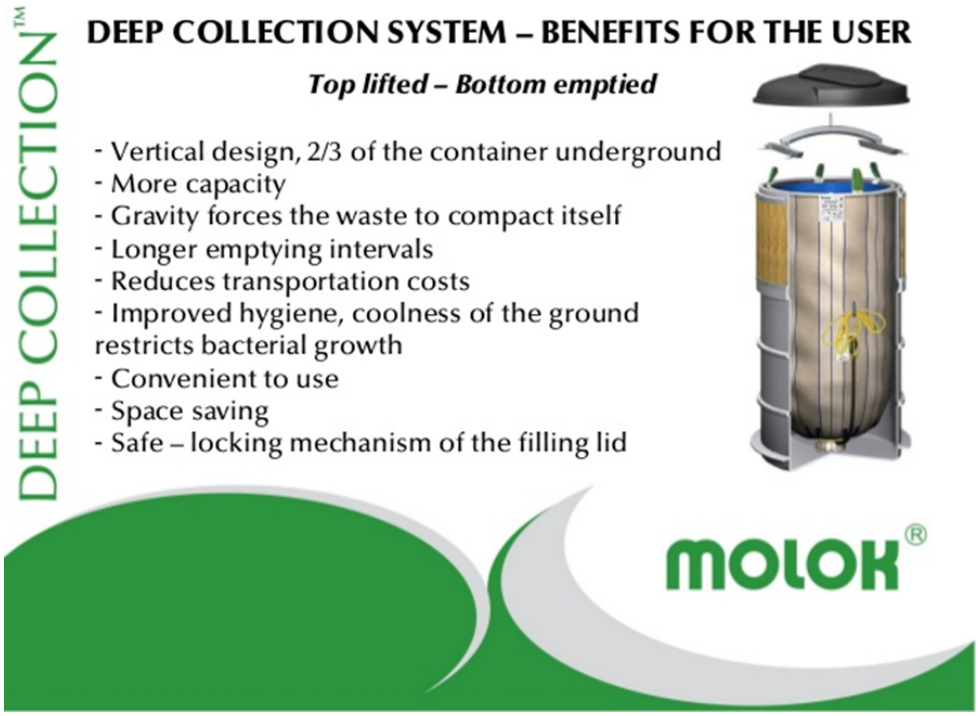

Figure 16. Molok bin cross-section (Molok, 2018)

These bins store waste mostly underground, and allow for a convenient and systematic collection. Generally, they consist of three parts: a hollow well-like bin, removable and durable inner bag and a sealable lid. Depending on the type of waste their size should be varied, to allow for the most efficient collection possible. An example can be found in Figure 17.

Figure 17. Separate underground collection system (Molok, 2018)

Waste separation methodology is suggested as follows:

-Paper, cardboard boxes, cartons
-Glass jar/bottles, tin cans, plastic bottles (broken window or mirror glass is considered residual waste and should not be put in the same bin as glass jar (Lemann, 2008))
-Bio-waste (food residue and other organic waste)
-Hazardous waste

Hazardous waste cannot be mixed with other waste, and requires special treatment procedures mentioned in Chapter 8 of this thesis.

Bins should be placed in a common area and shared between multiple households. Waste bin sizes and frequency of waste collection depend on how many households are sharing the bins. For the first five prototype units, 660L waste bins (1250*720*1330mm)* are recommended for the most common waste (paper, cartons, etc.) and 140L waste bins (480*555*1100mm) for other types of waste (tin cans, bottles, bio-waste, etc.). During the testing time the amount of waste needs to be measured, to determine the adequate frequency of waste collection and create a more suitable waste handling plan for all houses. Usually, for 10 houses, uncommon waste is disposed in 660L bins while common waste will be disposed in 1100L bins (1375*990*1370mm). For 20 houses, waste is disposed in 1100L bins and 1280L bins (1280*1000*1445mm). However, only a practical research based on conditions in Marsabit will be able to tell the exact size of bins needed.

Another advantage that Molok system has to offer is that the collection process is fast and easy. It doesn't require any other equipment aside from a crane-truck (for bigger bins) or an ordinary truck (for manual emptying of smaller bins). Figure 18 shows a photo taken during the collection process.

Figure 18. Emptying the underground waste collectors (Molok, 2014)

The bins' dimensions are displayed respectively: width*depth*height The common areas for the waste bins (collection point) need to be kept 10-15 m from the closest houses, and ease of access for collecting vehicles ensured. Access roads to the collection points must have a minimum width of 5 m; any gates or archways should have a minimum clearance of 3.7m. If turning spaces are required, the road layout should have a 17 m curb-to-curb or 20.3 m wall-to-wall turning circle. (Development Control Team, 2010)

When waste is separated, recyclable waste can be sold, bio-waste can be treated to produce biogas and compost and the remaining non-disposable waste can be moved to the landfill. This way, the volume of landfill waste will be reduced significantly.

6 SMALL-SCALE WASTE MANAGEMENT SOLUTIONS

In this part of the thesis possible ways of handling waste on a single household-scale level will be investigated.

6.1 Household composting

Compost is organic material that can be added to soil to help plants grow. Making compost out of food scraps keeps these materials out of landfills

where they take up space and release methane, a potent greenhouse gas (Eartheasy.com, 2018). Composting is a simple way to add nutrient-rich humus which fuels plant growth and restores vitality to depleted soil. It's also free, easy to make and good for the environment. (USEPA, 2018)

Composting has a wide range of economic and environmental benefits (Eartheasy.com, 2018):

Soil conditioner: With compost, rich humus for growing produce is created. It adds nutrients for plants and helps retain moisture in the soil.

Recycles kitchen and yard waste: Composting can divert a share of household waste away from the garbage can.

Introduces beneficial organisms to the soil: Microscopic organisms in compost help aerate the soil, break down organic material for plant use and ward off plant diseases.

Good for the environment: Composting offers a natural alternative to chemical fertilizers.

Helps waste collectors: Composting alleviates some of the load on the local Waste Management system, therefore allowing it to function more properly and under less stress.

Reduces landfill waste: Composting decreases the amount of waste that ends up being dumped on the landfill and reduces methane emissions from landfills thus lowering their carbon footprint.

Business potential: Upon creation, compost can be sold or exchanged, if the owner doesn't need it.

Composting requires three basic ingredients:

Browns - carbon-rich matter i.e. branches, stems, dried leaves, peels, bits of wood, bark dust or sawdust pellets, shredded brown paper bags, corn stalks, coffee filters, egg shells, straw, wood ash give compost its light, fluffy body.

Greens - nitrogen or protein-rich matter i.e. manures, food scraps, green lawn clippings and green leaves. Provide raw material for making enzymes.

Water - having the right amount of water is important for compost development (Eartheasy.com, 2018)

A healthy compost pile should have much more carbon than nitrogen. On average, one-third green and two-thirds brown materials are used. The 'fluffiness' of the brown materials allows oxygen to penetrate and nourish

the microbes that consume the green matter. Too much nitrogen leads to a dense, smelly, slowly decomposing anaerobic product. Good composting hygiene is to cover fresh nitrogen-rich matter, which can release odors if exposed to open air, with carbon-rich matter. (Eartheasy.com, 2018)

Composting process can be divided into the following stages:

1. Creating the pile

   The first layer should be soil, to provide the heap with microorganisms and air. Next, finely shredded brown and green matter should be placed alternately. The pile has to be watered between each layer. Manure can be used to speed up the process of decomposition. Keeping the heap warm and moist is essential for a good rate of progress. (Eartheasy.com, 2018) (Table of materials can be found in Appendix 5)

2. Watering the pile

   Watering is essential for the process to happen. To check the moisture content of the pile a handful of compost is squeezed, and if a few drops of water bead up, the moisture level is about right. If no drops fall, the pile is too dry, and if water trickles out, the pile is too wet. If the heap is too wet or too dry, then the composting process will be inhibited, and certain problems will arise. (Eartheasy.com, 2018)

3. Maintaining the pile

   Every few weeks the pile has to be tossed up with a pitchfork or shovel, to facilitate even aeration and mixing of the matter. Turning will also give an opportunity to assess the moisture level, to make sure it's sufficient.
   Once the compost pile is established, new materials can be added by mixing them in, rather than by stacking them in layers. (Eartheasy.com, 2018)

   When the material at the bottom is dark and rich in color, the compost is ready to use. This usually takes anywhere between two months to two years, depending on many factors. (Eartheasy.com, 2018)

   Some of the things forbidden for composting include meat, bones or fish scraps (attract pests), perennial weeds (can contaminate the soil treated with compost), deceased plants, oil or dairy products. Pet manures in compost should not be added to compost for a fear of developing pathogens and parasite, but herbivore manure is safe to use. Fruits like bananas, peaches and oranges may contain trace amounts of pesticides, and ideally should be kept out of the compost. Sawdust is a good addition to the pile, but it should be scattered in thin layers and then mixed thoroughly to avoid clumping. (Eartheasy.com, 2018)

Urine is an excellent source of nitrogen, and is therefore worth saving as it is very useful for activating the compost (CountryFarm.com, 2015). Light graywater (e.g. water used in cooking or for detergent-free cleaning) can also be used to water compost. However, these substances cannot totally substitute water, and need to be used sparingly.

Different composting materials derived from yards and gardens will decompose at different rates. Leaves and grass clippings are good compost feedstock, but they should be combined with other materials, or dug into the center of the pile and mixed. Making thick layers should be avoided, as they tend to clump together and reduce aeration in the heap, which slows the composting process. (Eartheasy.com, 2018)

If the pile size doesn't change or heat is not generated, then a boost might be needed.
If the pile is dry, water should be added evenly.
If the pile is overly moist, it should be spread in the sun to dry. Adding dry material is also advised. (Eartheasy.com, 2018)

Composting can be conducted on any scale needed, from single-household to municipal. In the context of this project we will review a way to organize composting on the single-household scale.

Household composting has proven itself to be a great way to deal with kitchen waste in developing countries (Practicalaction.org, 2008) and can therefore be implemented in Marsabit. Household composting is cheap, extremely low-maintenance and the output is highly profitable and can even be locally sold. However, the process is time-consuming and requires clean water, which is a scare resource in Marsabit.

Composting requires very little: organic waste, water and a vessel. Vessels can be different, depending on the particularities of local conditions and desired size. For a single-household use, utilizing self-made bins, similar to ones shown in Figure 19, are recommended. The size typically varies from 200 – 300 L. They can be crafted from different materials such as cement/concrete, plastic, metal, etc. Bins are preferred over free-standing piles, because they occupy less space, and are easier for maintenance. Bins also protect compost from weather, reduce odours, and provide better temperature control. (Practical actions)

Figure 19. Different composting bin designs (Practical actions)

A standard bin design should facilitate (Practical actions):

- Easy transportation and installation
- Good aeration (Aeration holes < 1cm diameter would be sufficient, if placed all over the bin's surface)
- Drainage of excess moisture (Porous bottom pad)
- Protection from extreme weather conditions i.e. rain, wind etc (Proper cover or lid)
- Retaining the needed temperature (Dimensions of the bin and material used for constructing)
- Easy adding and mixing of waste (Sufficient height, lid handles)
- Easy removal of compost (Several compost removing doors)
- Keeping away pest like rats, dogs crows etc.
- Durability of the bin (Material used, strength etc)

The bin can be arbitrarily made and customized depending on the maker's financial situation and available resources. Even wood can be used as a building material for the bin; however plywood is not recommended as it deteriorates easily. The preferred bin colour is black, as it absorbs heat, therefore enhancing the decomposition rate. The bin should be big enough to allow the compost to be easily mixed with a shovel or pitchfork, as this saturates the heap with oxygen and speeds the process. It is best to cover the bin, since too much rain will cool the compost and make it too moist. Making openings is vital for a proper aeration of compost. On average, a bin should have around 20-25 holes, evenly distributed on all its sides. It is also advised to attach 'legs' to the bottom surface of the bin, to create some space underneath that will allow air and moisture to circulate freely through holes. (USEPA, 2018)

Such installation would allow household residents to convert their organic waste into a useful resource at no cost. Household composting can divert some of the organic waste produced by the Marsabit community from being landfilled, therefore improving its carbon footprint and allowing the local waste management systems to operate more smoothly. At the same time the ready product can be used for agricultural means or sold to make profit, either option being able to positively impact both the household owner's personal financial condition and local economic situation.

A real-life example of using compost for farming can be found in Bangladesh. Severe annual rains cause the three biggest rivers to spill, which results in floods that erode fertile land and destroy homes. Upon waning of the water, infertile sand plains appear. However, even this soil can be used for agriculture again by using the technique of pit cultivation for pumpkins and other crops.

The method is as follows: holes are dug in the sand, each no more than a meter across, and then filled with compost. See Figure 20 for a visual reference.

Figure 20. Digging process (practicalaction.org, n.d.)

Into these farmers plant seeds from which crops are grown to be eaten, stored or sold to make money (See Appendix 6 for a visual reference). Crops need to be tended and require frequent watering.

In Bangladesh this model was replicated throughout the country, helping alleviate poverty through tens of thousands more people overcoming hunger and increasing their income. The results can be seen in Figure 21.

Figure 21. Pumpkin pit cultivation output (practicalaction.org, n.d.)

6.2 **Suiro hooks**

Wind is a big problem in the area, it allows waste to migrate. A Suiro hook, which is a long sharpened wire hook that can hold a large number of plastic, is a very efficient solution to this problem. Its main purpose is to encourage at-source segregation of recyclable wastes (e.g. soft plastics) to ease the upcoming process of plastic recovery by the municipality. Such hooks can be used to hold a number of used plastic bags together before they are collected for recycling in a way that is shown in Figure 22 and Figure 23. Such a system prevents the bags from being scattered by the wind (Practicalaction.org, 2008). This method of handling this type of inorganic waste is simple and sanitary.

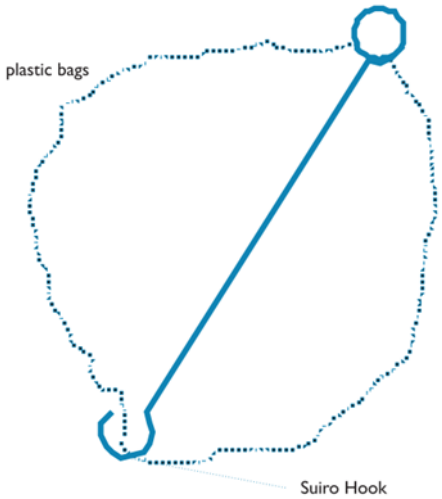

Figure 22. The Suiro hook sketch (Practicalaction.org, 2008)

The Suiro hooks played an important role in promoting the recovery of plastic waste and were included in the program aimed at reducing the generation of plastic waste that was launched by the Nepalese municipalities. Significant environmental improvements have been achieved in Nepal by recovering plastic. The adoption of the hooks helped to reduce the quantities of mixed waste and careless dumping of waste, resulting in better drainage. Aside from reducing the amounts of plastic waste in the urban area, this movement also made the Nepalese people aware of the environmental problems caused by plastics. (Practicalaction.org, 2008)

Figure 23. 'Suiro hook in action' model

Thus, a similar program can be launched in Marsabit. The hooks should be distributed among households by the municipal administration at no cost, to make the populace more likely to participate in the program. People would then hand over the accumulated waste during waste pick-up process, or at waste collection points along with other waste. This program will improve the rate of recycled soft plastic in Marsabit and therefore contribute to building a sustainable waste management system in the county.

6.3 **A burn-barrel**

Traditionally, waste in Marsabit is burned in barrels. This method is the second least-preferred way of dealing with waste, prior only to landfilling.

However, unsupervised burning is common in Marsabit, but it can be extremely dangerous and can lead to serious consequences. Thus, this section of the thesis will cover the right ways of creating and handling a burn-barrel.

Most typically, a burn barrel is a 210 L metal open head drum, minimally modified to burn household trash safely and cleanly, similar to one shown in Figure 24 (elevation blocks should be added underneath). There are holes that should be made on the sides and the bottom of the metal drum (but not many, as this will encourage the degradation process of the metal) to allow for proper air flow during the burning process and drainage of any accidental rainwater. Nevertheless, burning particle matter will also manage to get out through them, so they should be covered with a fine grid. Additionally, the barrel should be set on concrete blocks and the area underneath it kept clear to further improve ventilation and drainage. When the barrel is burning, it should be covered with a burn cover. For the burn cover, a piece of fencing or a metal grate can be used (the same as for ventilation purposes). The protection is needed to capture the burning material inside the barrel and only allow the smoke to get out. When not used, the barrel has to be covered up with a sheet of metal to keep rain water from getting in and prevent rusting. (Piek, n.d.)

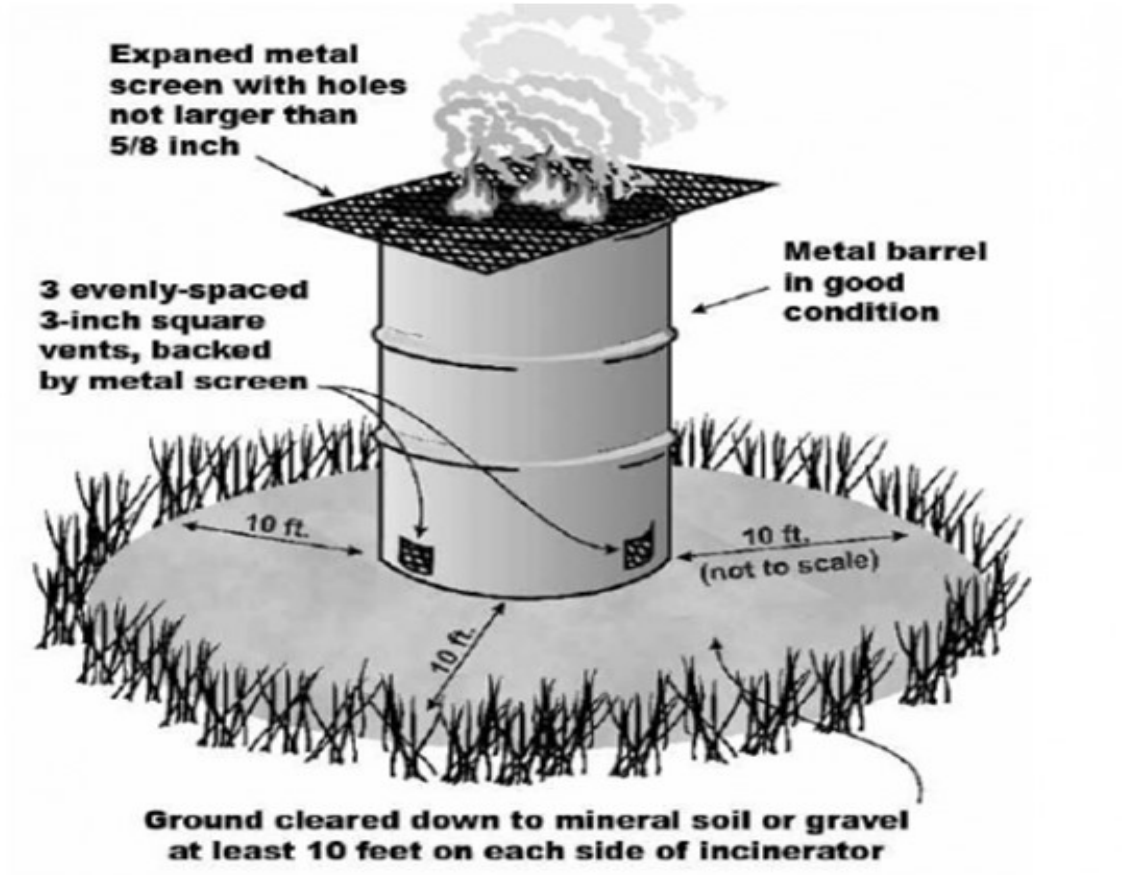

Figure 24. Burn barrel prototype (diydiva.net, n.d.)

It’s important to know what can and cannot be burned.
Items that can be burned include:

-Non-recyclable plastics
-Food wraps
-Non-recyclable paper and cardboard
-Dry twigs and wood

Items that cannot be burned include:

-Toxic waste
-Non-combustible items (e.g. lightbulbs)
-Metal
-Flammable substances
-Rubber
-Painted or treated wood

Any food scraps should be composted, and recyclables recycled, not put in the barrel. Chemicals, paint and other hazardous waste should be properly utilized, along with other non-combustible items such as lightbulbs. (commonsensehome.com, n.d.)

When using the burn barrel, common sense and safety precautions should be minded. Windy days, or hot and dry days when unsupervised burning can lead to a fire, are not suitable for burning. It’s crucial to not burn any aerosol cans as they tend to explode. Also, if too much trash is stuffed in the burn barrel, smoldering and incomplete burning may occur. (commonsensehome.com, n.d.)

After using the barrel for a while, a buildup of ash and small items is likely to appear. It is sensible to wait until the barrel is about ½ full of ash and then empty the burn barrel into a large, heavy-duty trash bag and take it to the trash collecting point. It is dangerous to dump the ash anywhere else as it may contain toxins and trace metal harmful for human health. Additionally, ash is extremely hot, and has to be allowed to cool sufficiently before dumping, for fear of inadvertently causing a fire. (commonsensehome.com, n.d.)

The heat, produced as the result of incineration, could be utilized while keeping in mind that the fumes of burning waste are highly toxic. With due ventilation, burnable waste can be used as an additional fuel source for certain manufacturing processes.

7 WASTE PREVENTION AND MINIMIZATION STRATEGIES

Waste minimization strategies (Chart can be found in Appendix 7) can be used to promote public awareness of waste as an environmental issue and therefore reduce the creation of certain types of waste, whereas waste prevention targets at-source waste production, reduces the amount and toxicity of waste before recycling, composting, energy recovery and landfilling become options. Both tactics aim to increase the efficiency with which products, once created, are used. Waste prevention and waste minimization address the problem most efficiently, as what has not been created doesn't have to be dealt with. (European Commission Directorate-General Environment, 2012)

In this section of the thesis, different improvements of the civic structure will be discussed. These improvements have the potential to diminish the amount of waste created by the society by making an indirect impact on how the waste management process is carried out.

7.1 **Education**

Educating the populace on waste matters plays an important role in creating a sustainable management cycle that would complement to the overall well-being of the regional environment. However, due to low economic development of the area, the educational outcome might be more effective if the studies are not exclusively environment-centered. How would learning to manage the waste benefit us? What positive impact will it make on our everyday lives? These are the questions that genuinely interest the community of Marsabit, so this is where the main emphasis should be placed.

However, aside from personal benefit, there are plenty of aspects that should be covered by such a program. The bare informational minimum should include courses on:

- Waste etiquette and on-site utilization
- Waste hierarchy
- Correct ways of handling hazardous waste
- Municipal rules regarding waste
- Waste re-application
- Waste prevention

7.2 **Commercialization of the recyclables**

Governmental or privately owned businesses that would purchase recyclable material from the populace could be established. Their aim would be to make profit out of unwanted re-usable materials that would otherwise have been either incinerated or disposed of.

To give a feasible business example, here is a description of a project of such orientation:

A paper-processing company is set up to recycle paper and paper-like materials into saleable produce. They have representatives standing near waste collection points in the city, who offer people to turn in their paper-based waste for a modest monetary reward. Later a car goes to collect all the acquired material and then delivers it to a processing facility. There the material is shredded, soaked in water and turned into papier-mâché. The mixture is then used to create kitchen utensils and non-heated cutlery that will be locally distributed and sold.

A monetary reward plays the role of an incentive, to encourage the populace be mindful of their waste and engage people. Being located near a waste-collection point is also critical, as that would both ease the process of disposing of trash (instead of going to one place to get rid of waste and another place to sell it, people will have the opportunity to do both simultaneously) and motivate people to actually bring non-purchasable trash too instead of disposing of it somewhere else, since they are going there anyway.

As the result of such enterprise, both the load on local waste management systems and the environmental impact of human activity would be decreased. This would allow for a smoother operation of waste management services in the county and contribute to the overall well-being of the populace. Another positive side effect would be the enhancement of the local economic situation as more work places will be created and more financial assets will circulate in the economy.

7.3 **Infrastructure and legislation improvement**

For any type of construction, either residential or commercial, a municipality should enforce basic requirements in order to reduce or segregate waste at source. For example, municipalities should consider making provision for measures such as household composting and separate containers for recyclables before approving a construction proposal. This provision should be monitored and penalties enforced if necessary, in order to enforce such requirements. Municipal boards should make this provision a high priority. (Practicalaction.org, 2008)

Also basic civil services such as roads should be enhanced to improve the ease of waste managing for both private and business users. Making the process of transporting waste easy and comfortable would greatly improve the chances of locals recycling it and disposing of waste in the designated areas.

7.4 Involving the local business owners in waste management planning

Local businessmen should be involved in waste management planning because their insights and experience could improve planning for sustainable solid waste management. They should be invited to take part in the annual meetings of municipal boards when waste management issues are being discussed (Practicalaction.org, 2008). By showing the local entrepreneurs the importance of appropriately handling waste and explaining the ways in which recycling can benefit them, it is possible to improve their environmental feedback and create a fruitful cooperation between the municipality and the private sector.

7.5 Harmful substances substitution

Hazardous substance substitution practices reduce dangerous waste and the cost of its disposal, make the workplace and environment safer, and deliver substantial economic benefits with regard to manufacturing costs. The main ideas is to encourage the substitution of dangerous by less dangerous substances where suitable alternatives are available (Croner-i, 2012). Alternatives should be safer, with a lower hazard and risk potential, but still have similar performance as their counterpart, and be economically viable and sustainable. Substituting chemicals also goes beyond finding a drop-in chemical alternative and can include systems, materials, or process changes. However, the concept of substitution must also be included as a part of policy and regulatory measures for the management of chemicals of concern (GreenFacts, 2019). The algorithm of replacement (Chart can be found in Appendix 8) can be used to find a substitute for paints, for example by developing a natural dying solution, or for detergents, by using less potent, natural counterparts.

7.6 Organizing a communal network of waste management

Establishing a sustainable communal system of managing waste and maintaining public areas is another important aspect of dealing with the problem. People in the community should be responsible for dealing with waste that they create. With municipal help, cleaning jobs for unemployed and low-income groups of citizens should be created. Street sweeping and waste collection could be a starting point, but later a more complex network of waste management can be established. Such arrangement would be beneficial for both the community in general (as unemployment and poverty rates would drop) and for people in particular, as then they would have another source of income to support themselves. If taught properly, these people could also increase the level of awareness of waste management importance in the local society. They would be given the task of promoting waste prevention, treatment and collection techniques, thus gradually acquainting the local population with them and making them a typical part of everyday-life.

8 HAZARDOUS WASTE MANAGEMENT

The Resource Conservation and Recovery Act of 1976, defines hazardous waste as “a liquid, solid, sludge, or containerized gas waste substance that due to its quantity, concentration, or chemical properties may cause significant threats to human health or the environment if managed improperly”. This type of waste mostly comes from industrial practices, however households can also produce it.

The following wastes are considered hazardous:

-Any liquid waste: paints, varnish, thinners, automotive fluids, industrial oils and any devices that contain mercury.
-Dangerous waste: explosives, fireworks, gasoline, syringes, medical waste and equipment, pool chemicals and propane cylinders
-All types of battery and certain electronics such as: TVs, computers and accessories, mobile phones and MP3 players
-All types of tire
-Large appliances: fridges, freezers, washers, dryers, etc.
-Construction waste (CSWD, 2016)

Hazardous waste recycling and processing requires more intensive treatment procedures than ordinary waste. Incineration is one of the most simple and affordable techniques for hazardous waste treatment. The government of Marsabit is currently considering establishing an incinerator, mostly to treat medical waste produced daily by the hospital facility of the county. The project is estimated to have a range of positive effects on the environment and society, as it will ensure the safe treatment of biologically and chemically active waste, provide employment opportunities, and be a starting point for subsequent developments in the field of sustainable performance. If implementation proves this project to be successful, it can be duplicated and scaled up in order to treat hazardous municipal waste too. (Marsabit County Government, 2018)

8.1 Construction waste

Considering that the Marsabit population is increasing, construction industry is bound to expand dramatically. Since up to 30% of the materials purchased for the construction projects end up as waste (WRAP, 2019), a massive amount of it will be generated as the result. Because of the huge amounts, this waste cannot be utilized in the same way as the municipal waste, it needs separate landfills and plants to process it. However, there are certain principles that can be followed to manage it more easily.

Just as with municipal waste, reduce-reuse-recycle hierarchy needs to be followed. Reducing the generation of waste through smart procurement

and careful preliminary planning, waste segregation and on-site re-use and leftover auctioning can help to reduce disposal costs dramatically. Consequent recycling or energy recovery from the materials that don't have any application can become very profitable areas for private businesses, too. For example, old concrete can be crushed to make aggregate materials, metal reinforcements can be turned into raw material, reclaimed bricks can be used for landscaping purposes etc. Business potential of construction waste is huge, and it needs to be utilized. Alternatively, some product manufacturers may have recycling schemes through which they will acquire leftover/used materials. (WRAP, 2019)

9 CONCLUSIONS

As indicated by this thesis, waste management practices are very diverse in nature and possible applications. The methods described were selected out of many possible options due to their applicability and particular effectiveness in the climatic and economic conditions of Marsabit. However, even though it is up to the final user to decide which methods are most suitable in practice in their particular setting or situation, the author gives a set of personal recommendations on how to establish an efficient and comprehensive waste management system, should a unified municipal-scale project be required.

9.1 General guidelines on establishing a unified waste management system

Ensuring effective and efficient functioning of a large waste management system requires diligent contributions of each and every household involved, as well as well-stablished and accessible means of transportation. Therefore, individual waste management practices should be encouraged whenever possible (such as plastic reuse, compost production, energy recovery etc.) using the techniques described in this thesis, to diminish the overall quantity of waste and processing required to treat it. Each participant should be taught the basics of adequate waste handling and sorting, as well as ways to individually profit from waste. But most importantly, people need to be taught waste prevention and minimization techniques, since, as was described earlier, they are the most effective ways to combat the problem of waste.

New legislations regarding waste should be collectively chosen and implemented, thus making a unified set of legal rules which everyone would have to follow. The community should be encouraged to self-monitor the compliance with these rules on the basis of civil conscious, rather than any particular authority, as the latter showed to have had no particular impact on the waste situation in the county (Goverment of the Marsabit County, 2016). Again, people's mindset has to be changed, they

need to be shown that waste is not a useless matter, but rather a resource that can positively impact their well-being.

If implemented successfully, such shift in individual attitude may lead to a dramatic reduction of municipal waste quantities. Instead of having to invest into costly and sophisticated industrial units such as waste-to-energy plants or waste sorting stations, the municipality would be able to either use the means of much simpler and cheaper solutions, manual sorting and burying of the unrecyclable waste or subcontracting waste management to a private party that would use waste fractions for business purposes and dispose of the rest in a manner approved by the law. The latter arrangements are especially valuable as they would be extremely beneficial for the local economy, since new workplaces would be created and more financial assets would circulate in the market.

All in all, such hybrid combination of waste management solutions will create a basic circular economy in Marsabit, allowing to preserve as much energy and resources as possible, while promoting sustainability and positively affecting the well-being of the environment, economy and populace.

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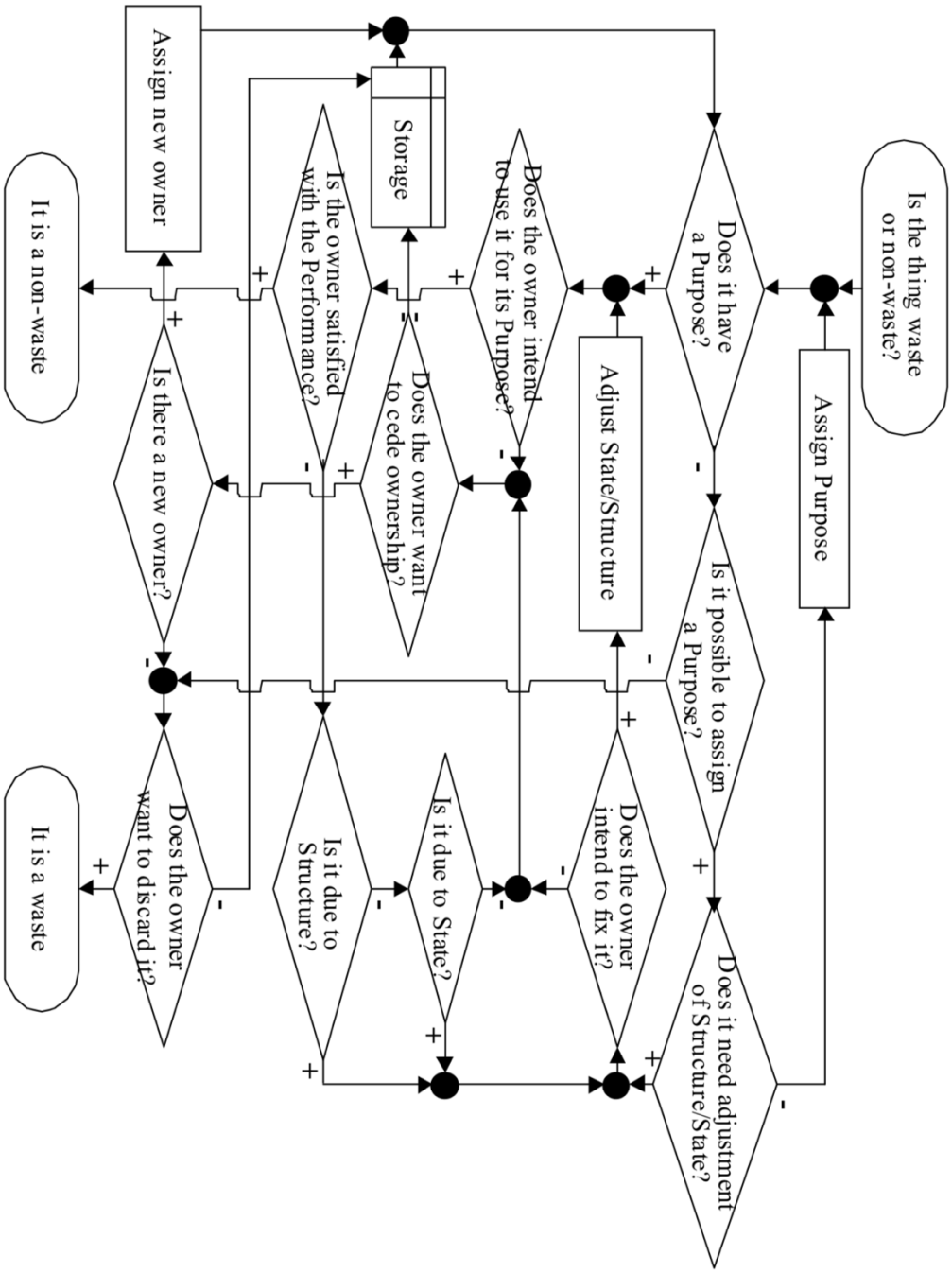
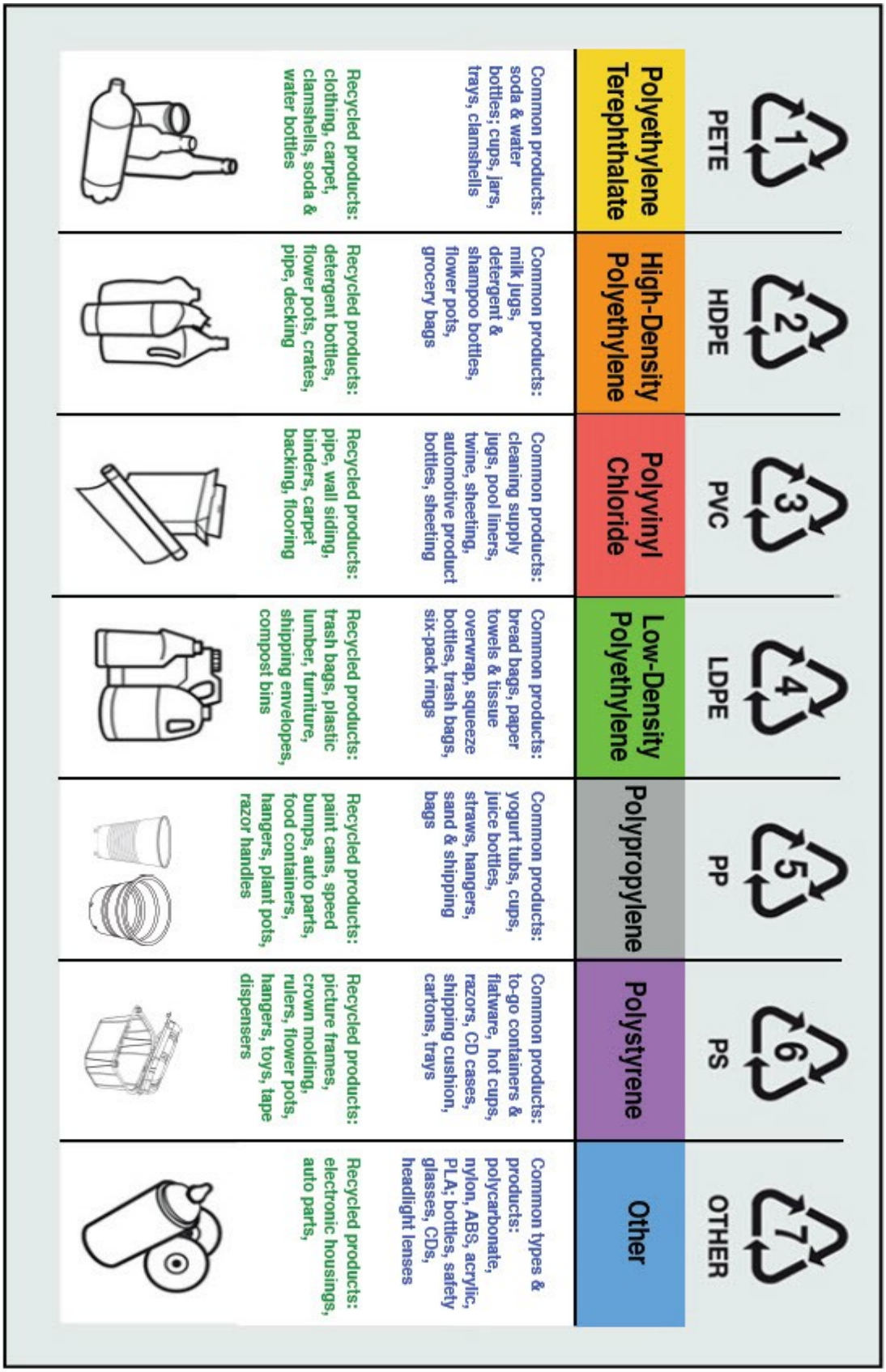
APPENDICES

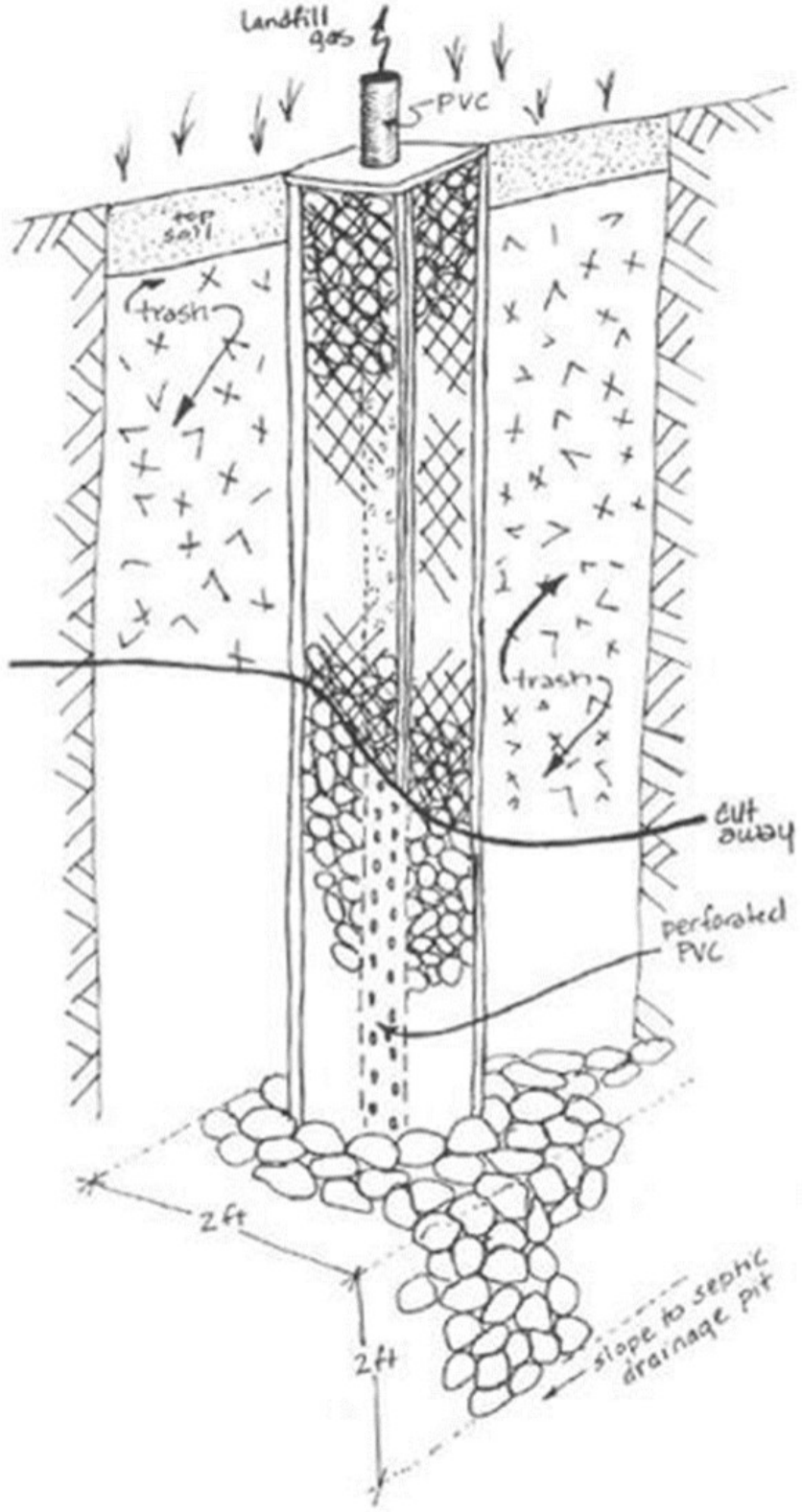
Appendix 1



Appendix 1. Flowchart helping to distinguish waste from non-waste (Pongrácz, 2002)



Appendix 2. Plastic Resin Identification codes (Ethicalhuman.co, 2018)

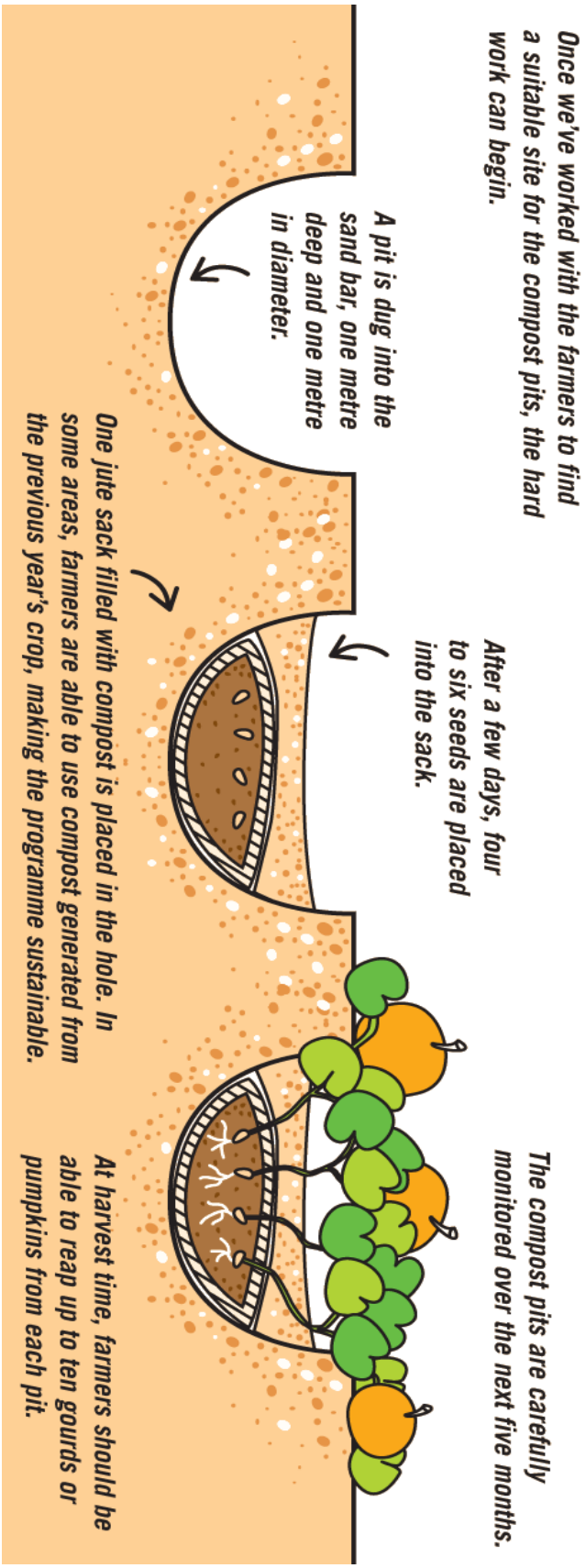


Appendix 3. PVC pipe installed to collect the landfill gas (J. Mihelcic, 2009)

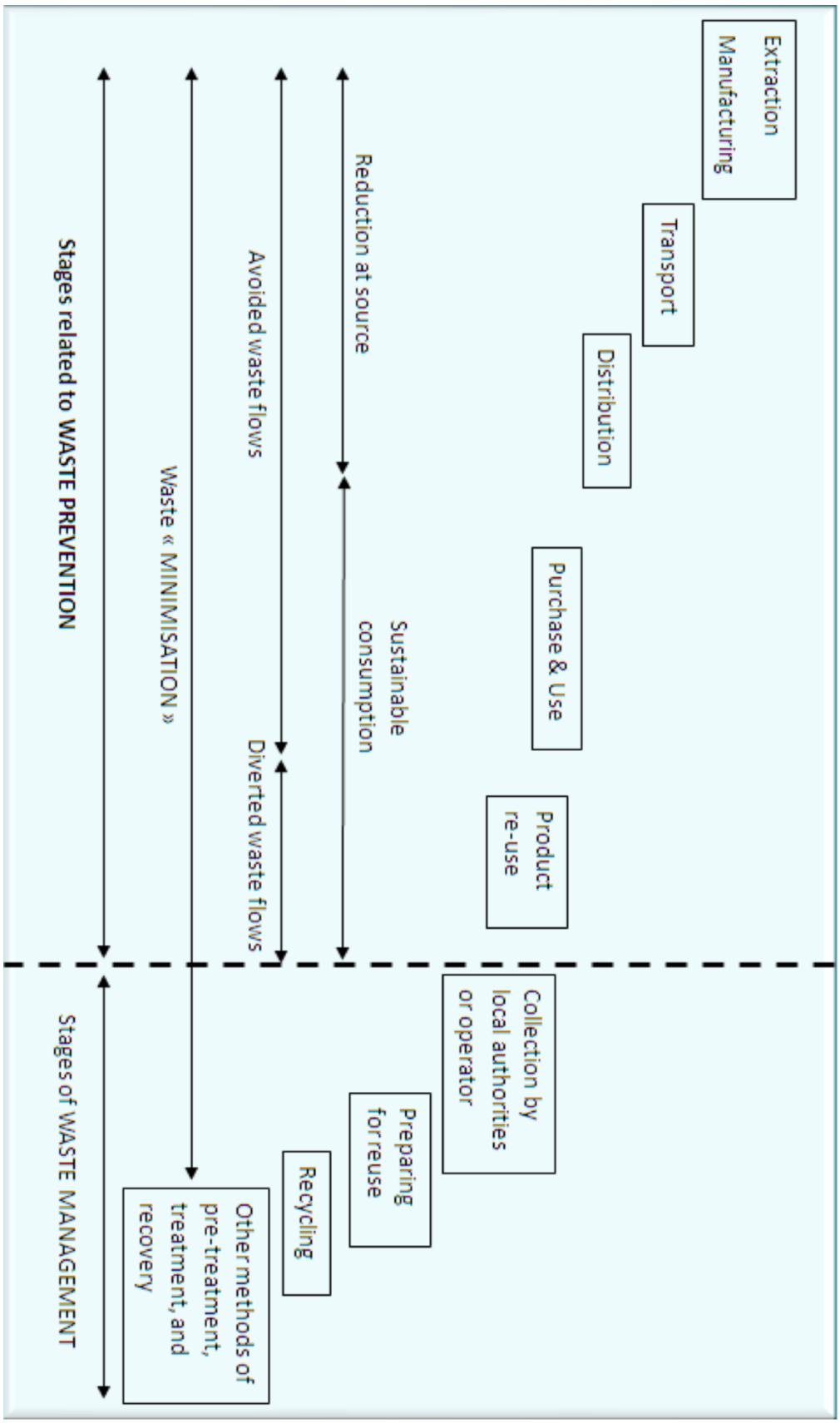
Appendix 4. Separate collection system example (richmondvalley.nsw.gov.au, 2018)

Material	Carbon/Nitrogen	Info
table scraps	Nitrogen	add with dry carbon items
fruit & vegetable scraps	Nitrogen	add with dry carbon items
eggshells	neutral	best when crushed
leaves	Carbon	leaves break down faster when shredded
grass clippings	Nitrogen	add in thin layers so they don't mat into clumps
garden plants	--	use disease-free plants only
lawn & garden weeds	Nitrogen	only use weeds which have not gone to seed
shrub prunings	Carbon	woody prunings are slow to break down
straw or hay	Carbon	straw is best; hay (with seeds) is less ideal
green comfrey leaves	Nitrogen	excellent compost 'activator'
pine needles	Carbon	acidic; use in moderate amounts
flowers, cuttings	Nitrogen	chop up any long woody stems
seaweed and kelp	Nitrogen	apply in thin layers; good source for trace minerals
wood ash	Carbon	only use ash from clean materials; sprinkle lightly
chicken manure	Nitrogen	excellent compost 'activator'
coffee grounds	Nitrogen	filters may also be included
tea leaves	Nitrogen	loose or in bags
newspaper	Carbon	avoid using glossy paper and colored inks
shredded paper	Carbon	avoid using glossy paper and colored inks
cardboard	Carbon	shred material to avoid matting
corn cobs, stalks	Carbon	slow to decompose; best if chopped up
dryer lint	Carbon	best if from natural fibers
sawdust pellets	Carbon	high carbon levels; add in layers to avoid clumping
wood chips / pellets	Carbon	high carbon levels; use sparingly

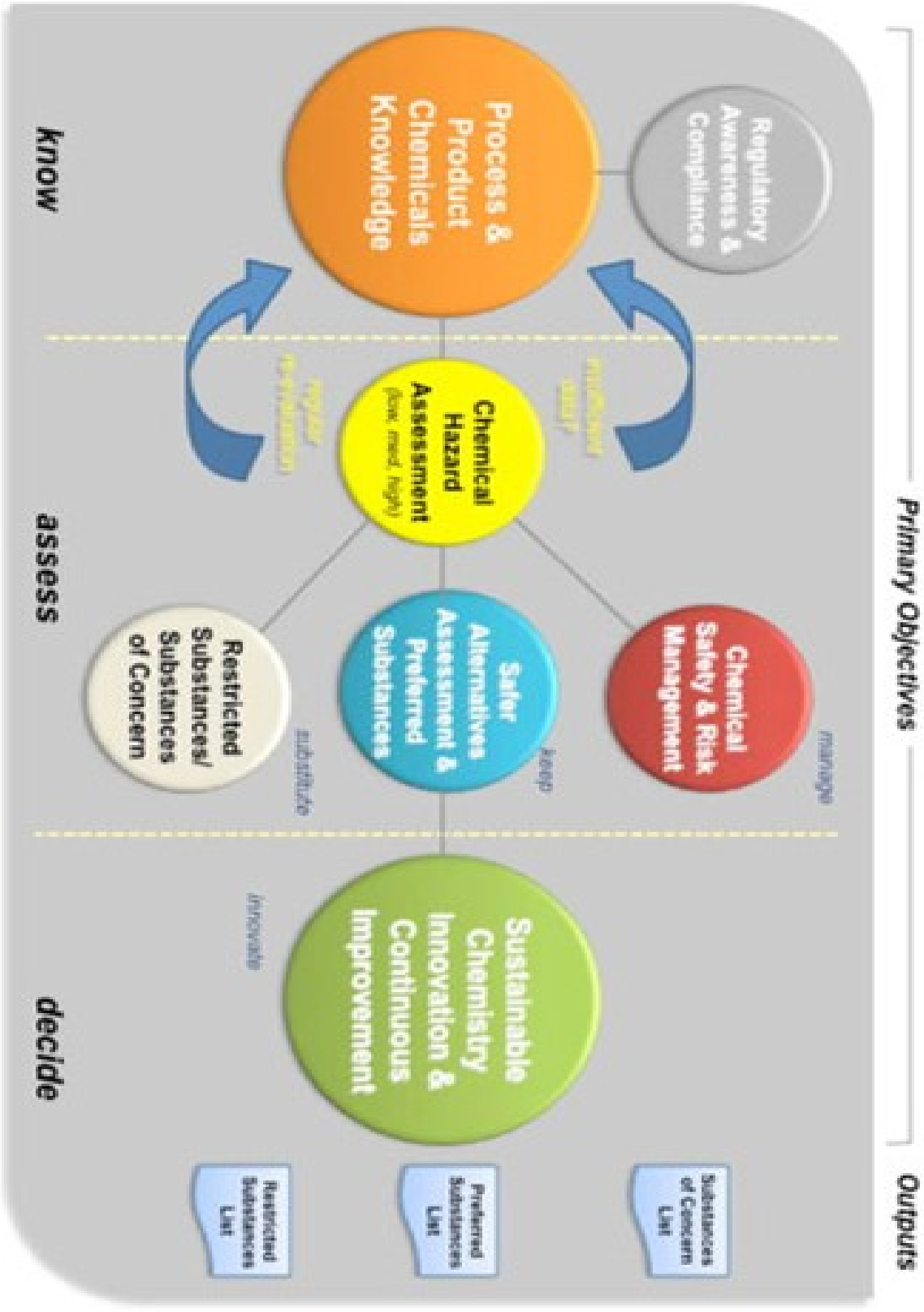
Appendix 5. Composting materials table (Eartheasy.com, 2018)



Appendix 6. Pit cultivation scheme (practicalaction.org, n.d.)



Appendix 7. Waste minimization scheme (European Commission Directorate-General Environment, 2012)



Appendix 8. Substitution algorithm (GreenFacts, 2019)