Handbook

Municipal Solid Waste and Plastic Waste Management

Preface

In 2019, the amount of solid waste grew by around 3% year-on-year and, thus, Thailand banned plastic bags at shopping stores. In 2020, the COVID-19 pandemic forced people to use online shopping and food ordering as anti-COVID-19 measures. The new normal led to a substantial amount of solid waste, in particular plastic waste. Furthermore, solid waste collection in Thailand is a random operation instead of sorting, and plastic waste is undegradable. As such, landfill stations face a large amount of impending plastic waste and fall short of solid waste management capacity in a timely manner.

Faculty of Environment, Kasetsart University and Indorama Ventures have jointly produced the "Municipal Solid Waste Sorting and Plastic Waste Management" guideline to disseminate solid waste sorting know-how and suggestion for managing each type of solid waste, especially plastic waste in a circular economy. The handbook aspires to reinforce the use of plastic waste stemming from solid waste sorting. The ultimate goal is to cut solid waste that are relocated to landfill stations and, more importantly, lower the demand for virgin plastic.

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Editors

Content

Municipal solid waste

and a proper management

Municipal solid waste or MSW is referred to solid waste responsible for everyday activities in municipalities. According to its sources, the types can be classified, such as communities, educational institutes, commercial bodies, construction sites and industrial plants, etc. Table 1 below illustrates the characteristics of solid waste based on the sources of origin.

Table 1. Solid waste as classified by sources

Sources	Agents	Components
Residences, communities	Houses and condominiums	Food waste, paper, plastic, leather, textile, wood, glass, metal, ash, electronic items, batteries
Industry	Power plants, construction sites, factories	Food waste, packages, construction materials, ash and hazardous waste
Business, trade, institutes	Hotels, shopping malls, restaurants, offices	Paper, plastic, cardboard, wood, food waste, glass, metal, hazardous waste
Agriculture	Gardens, farms, livestock	Leaves, branches, droppings, hazardous waste, insecticides

Source : An adaptation from Luque. R and J.G. Speight (2015)

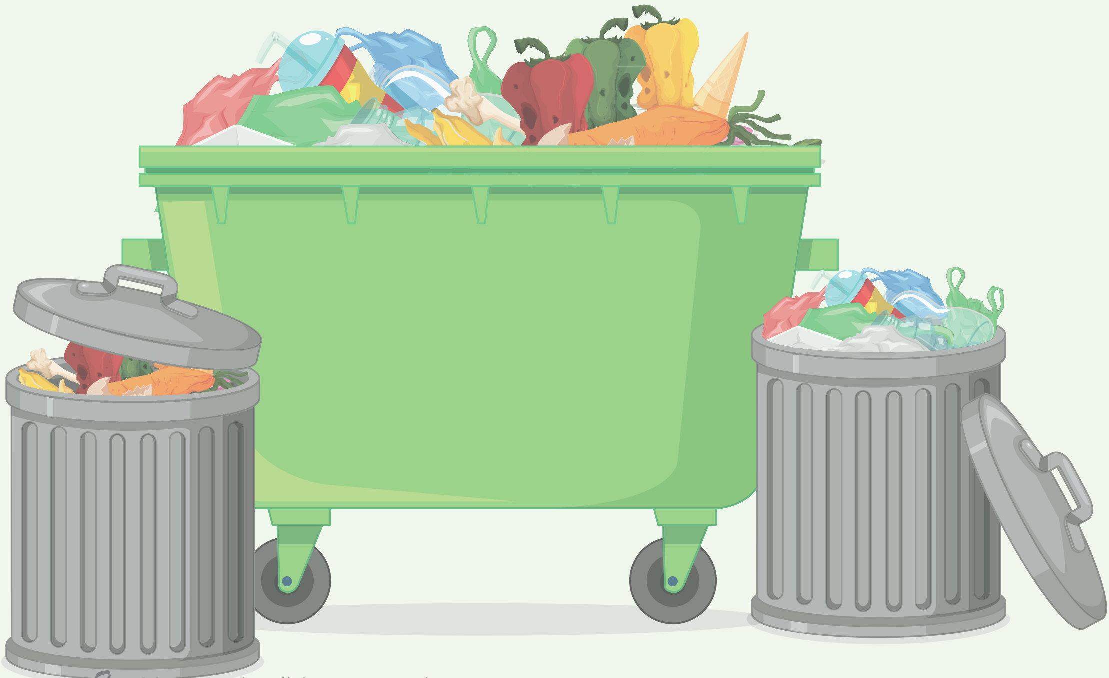
These are four types of solid waste in general :

1) Organic solid waste - biodegradable objects, i.e. food waste, vegetable and fruit wastes and leaves;

2) Recyclable solid waste - waste that can be recycled and cost-effective, i.e. glass, PET plastic bottles, paper, aluminium cans and metal;

3) General waste - items outside the first two groups which are unlikely biodegradable or not cost-effectively recyclable, i.e., instant noodle packets or coffee sachets;

4) Hazardous waste - waste that contains elements or contaminated with dangerous components. Hazardous objects include reactive substances, igniters, oxidizers, toxins, infectious agents, corrosives, radioactive, genetic modifiers, and other materials leading to environmental impacts.



In parallel to the four groups above, the Ministry of Interior, therefore, issued the Notification of Solid Waste Management 2017 (B.E. 2560). It is divided based on the colours of trash bins green for organic waste, yellow for recyclable waste, blue for general waste, and orange for municipal hazardous waste; such as batteries and light bulbs (Figure 1).

Figure 1. Trash bins and disposal samples as per waste classification

Thailand's current solid waste circumstances and management

The amount of solid waste in Thailand tends to grow as a population, and daily life activities expand. In 2019, the quantity was reported at 28.7 million tons, a 3-percent rise from the previous year. The reasons involved larger urbanization, a higher number of non-registered populations identified as alien workers, tourism promotion and changed consumer behavior that shifted toward online shopping and food delivery, resulting in an increase in solid waste.

However, the trend of solid waste disposal by reuse management is remarkable. For instance, recycling and fertilization accounted for 12.6 million tons (43.9%), 11-percent rise as opposed to 2018 (Ministry of Natural Resources and Environment, 2020), as shown in Figure 2.

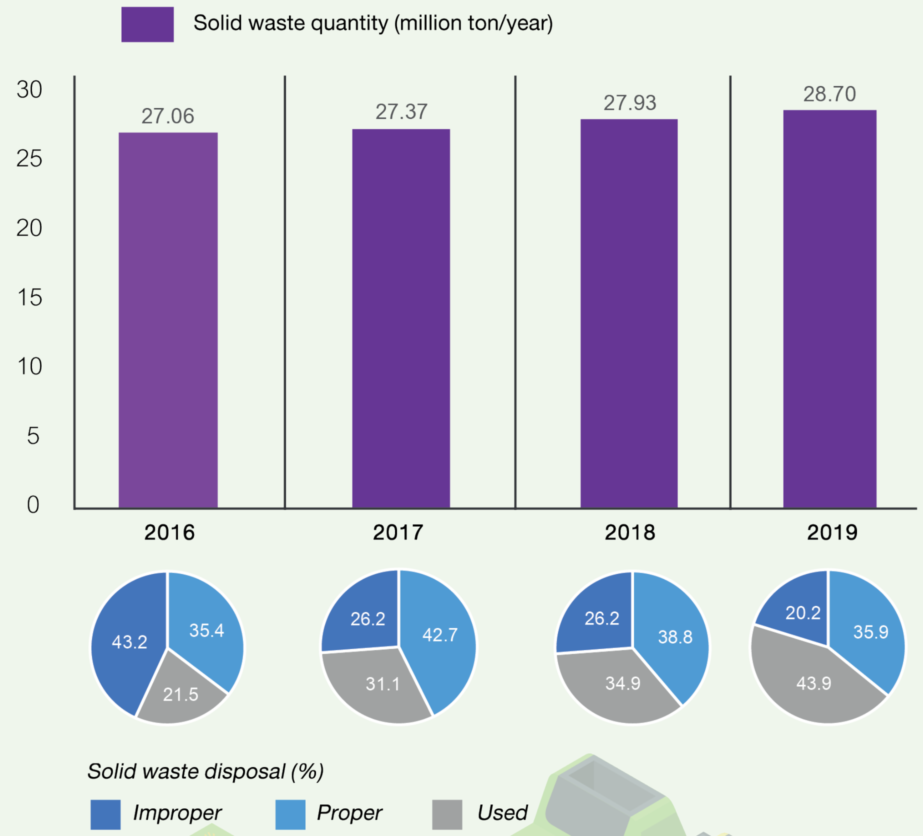


Figure 2. Solid Waste Quantity and Proportion of Used, Improperly and Properly Disposed Wastes between 2016 and 2019

The campaign of solid waste segregation succeeded in proper solid waste management and led to correct recycling. According to Suma et al. (2019), the components of solid waste in Mae Salong Nok sub-district, Mae Fa Luang District, Chiang Rai include organic (42.79%), recyclable (26.53%) and hazardous (1.49%) as illustrated in Figure 3.

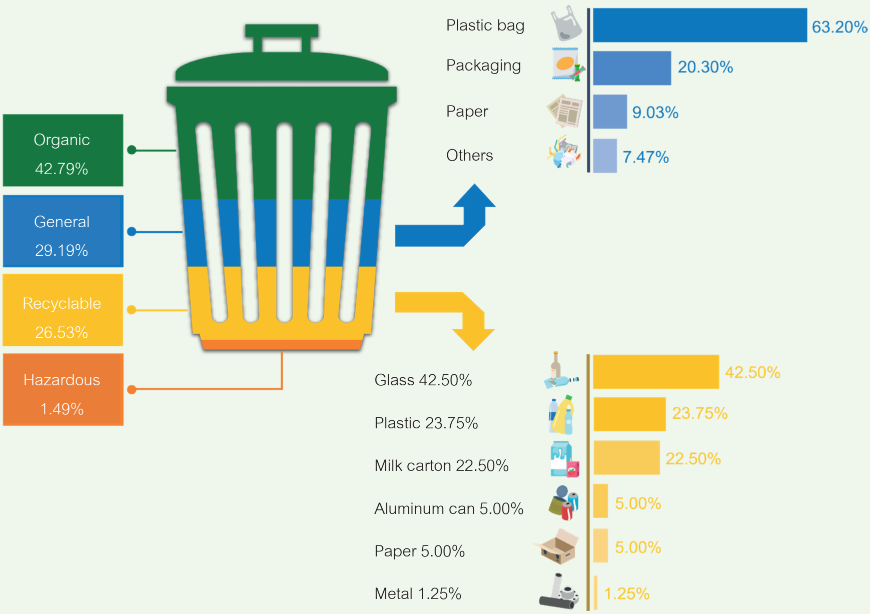


Figure 3. Components of municipal solid waste in Mae Salong Nok, Chiang Rai

Source: Suma et al., 2019

Recyclable solid waste in Mae Salong Nok sub-district encompasses glass, plastic, milk cartons, aluminium cans, paper and metal. The above information suggests that proper waste segregation makes possible the organic waste composting for soil amendment agent, the re-use of recyclable trash and correct disposal of hazardous waste. As such, the quantity of waste in sanitary landfill stations has fallen to 29.19%.

In the past, lack of segregation at the first stage resulted in random dumping of assorted trash. Partially-recyclable parts were left behind in waste bins and thwarted the practice of re-use before disposal. In addition, throwaway plastic bags were used only once. For this reason, the quantity of solid waste transferred to landfill stations was substantial and led to a shortage of areas to operate the disposal process.

Consequently, the government is currently dissuading plastic bags while promoting re-use and recycling. These schemes are common in the circular economy's solid waste management. They bolster the optimal efficiency of resource use, pollution reduction and maximize the potential of solid waste use as per the National Solid Waste Management Master Plan 2016 – 2021. Inconsistent with this policy, Thailand is gearing towards the zero-waste society under the 3Rs notion, namely, Reduce, Reuse and Recycle (Office of Permanent-Secretary, Ministry of Natural Resources and Environment, 2017).

Proper segregation cuts waste amount at the places of origin, maximizes solid waste, and facilitates waste management in the next stage by relying on suitable technologies. As a result, the waste volume sent to landfill stations decreases, as shown in Figure 4.

Figure 4. The current solid waste management flowchart in Circular Economy

In 2019, the government promoted plastic bag reduction. Examples included the limitation and the ban of single-use plastic products, No Plastic Bag campaign at shopping malls, cloth or plastic bag reusing campaign and Bring Your Own Container campaign. These actions brought about lower plastic solid waste (as per Reduction and Reuse). Furthermore, public cooperation in plastic bottle sorting, most of which were PET (Polyethylene Terephthalate), helped increase the volume of recycled PET bottles in the industry. On the contrary, solid waste at sanitary landfill stations was on the decline.

In pre-disposal recyclable waste management, it is advisable to clean the waste to avoid unfavorable smell posed by decomposition and facilitate recycling later. For instance, Japanese ensure that food containers are rinsed with water and let dry before putting in recycling bins. Similarly, Thais clean and dry milk or juice cartons and put in drop boxes for a recycling purpose. In Sweden, waste recycling machines are available, especially for PET and aluminium products, and people obtain food coupon in return.

In Thailand, buying recyclable waste is common with varying prices from days to days. For example, aluminium cans, HDPE (opaque) and PET (clear) water bottles were traded at 26, 5 and 5 baht respectively per kilogram on 26th September 2020 (Figure 5).

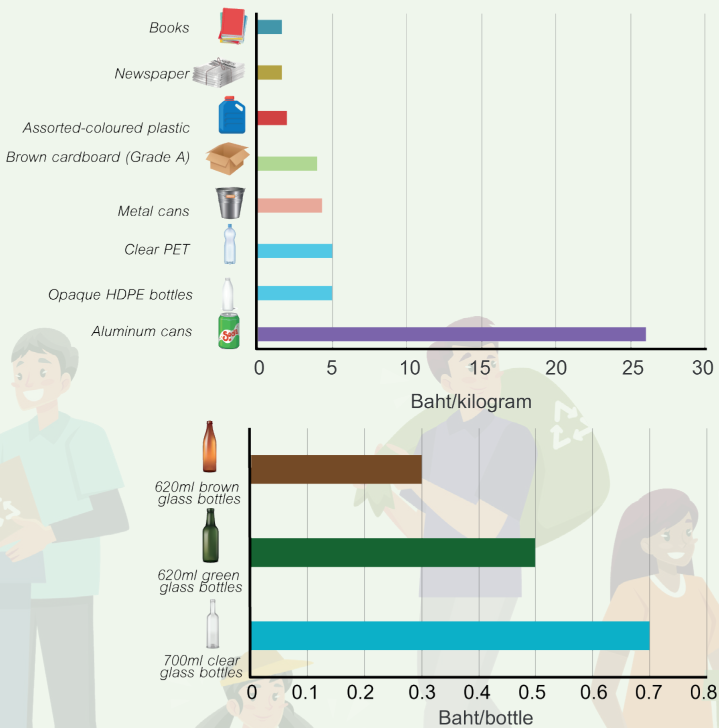


Figure 5. Selected recyclable waste prices traded on 26th September, 2020

Source: Wongpanit (2020)

The management of waste randomly dumped without segregation at the place of origin must be done by waste sorting machines, resulting in more processes and higher costs. Below are waste sorting machines which vary according to waste characteristics:

- Size screening can be achieved using sieves, of which openings are proportional to the desired waste.
- Air screening concerns water or air use to sort out waste based on density, such as an air classifier that separates paper from a glass.
- Waste density intensification involves pressing plastic bottles into bales after sorting, leading to lower cost and easier transportation.
- Metal property-based sorting is carried out by a magnetic separator or eddy current to keep out aluminum cans.

Here is how to sort recyclable items from waste. To begin with, human laborers sort massive objects into groups. Waste separators are used in the second step to classify trash by size and keep cardboard out for reuse. Thirdly, ballistic separators sort out and shake objects with different shapes. That is, tube-shaped objects (3D) such as plastic bottles, glasses, aluminium and metal cans are divided from sheet-like waste such as paper. Subsequently, paper is compressed into bales for the next step. Magnetic separators sort metal objects and eddy current machines select only aluminium cans from other waste. Similarly, paper is separated from glass by air classifiers that work by dealing with differences in density. Plastic waste is picked by optical sorters. In the final stage, sorted items are compressed in bales for easier transportation (Figure 6).

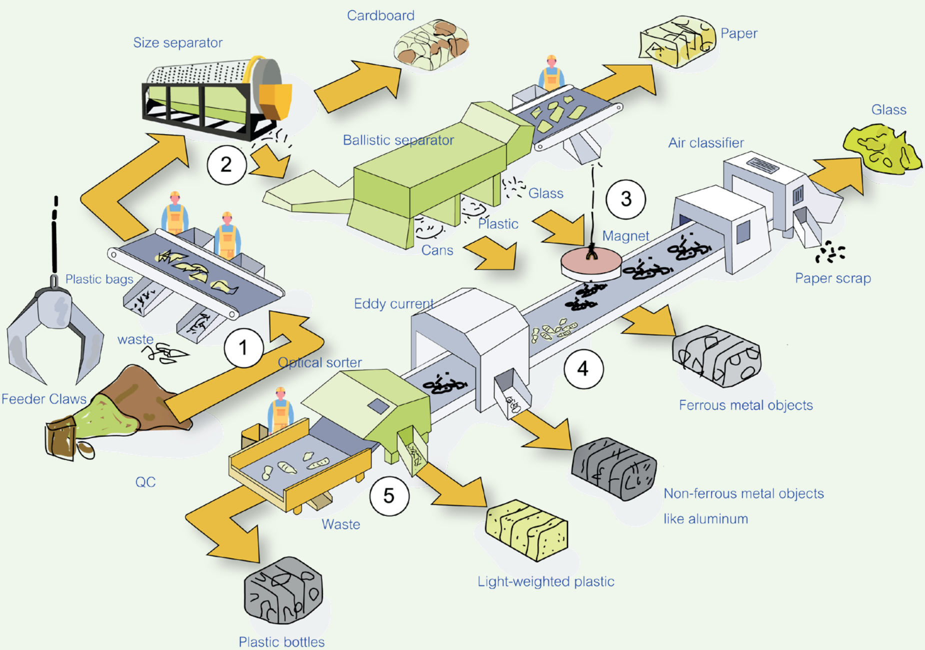


Figure 6. Recyclable waste classification by machines at sorting stations

Source: Adaptation from SUEZ (n.d.)

Proper waste
management technologies

The municipal solid waste components lay as a primary input in management guidance planning and suitable technology selection (as seen in solid waste sampling and waste component analysis in Appendix 1). Figure 7 suggests the three methods of solid waste management in line with components' properties.

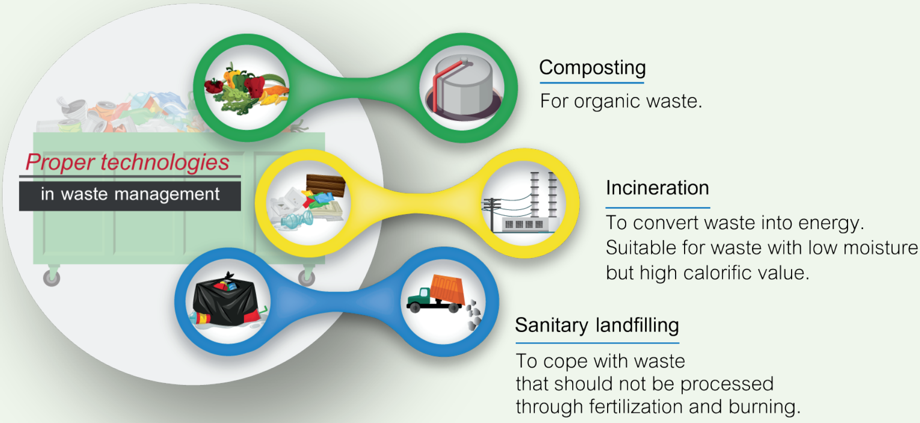


Figure 7. How to properly manage solid waste

Composting

Food waste is an organic waste which could be degraded by microorganisms, making composting an ideal option to handle this waste. There are two types of composting based on treatment purposes and types of microorganism, namely, an aerobic method that aims to produce compost; an anaerobic way in which byproduct is biogas that can be used as auxiliary fuel.

The Table 2 suggests the ideal conditions for aerobic composting and the Figure 8 provides the guidance of providing oxygen air to fertilizer which can be achieved by windrow method; while Figure 9 demonstrates the aerated static pile method which provides air circulation at the base of the fertilizer pile. As an eco-friendly scheme, organic waste composting returns carbon into the environment and downsizes the volume of solid waste delivered to landfill stations.

Table 2. Ideal organic waste composting for compost production

Factors	Suggested Ranges
Carbon to nitrogen ratio	25-35:1
Moisture content	40-60%
Aeration	10-30%
pH value	Rather neutral
Particle size	10-50 millimeters

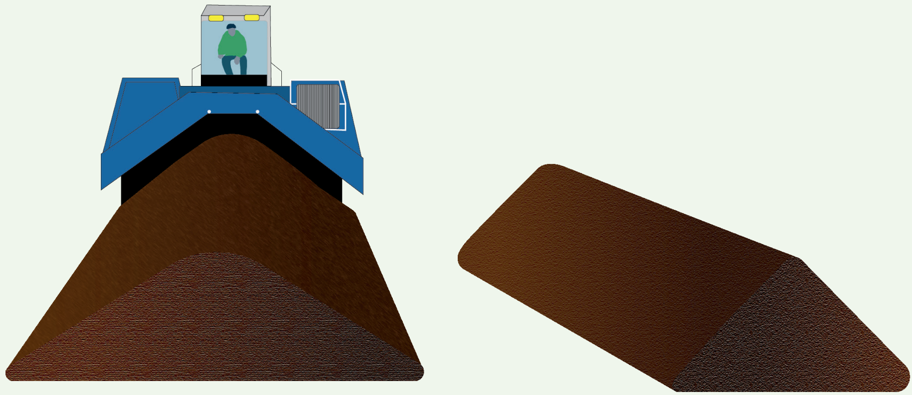


Figure 8. Aerobic windrow composting for organic waste

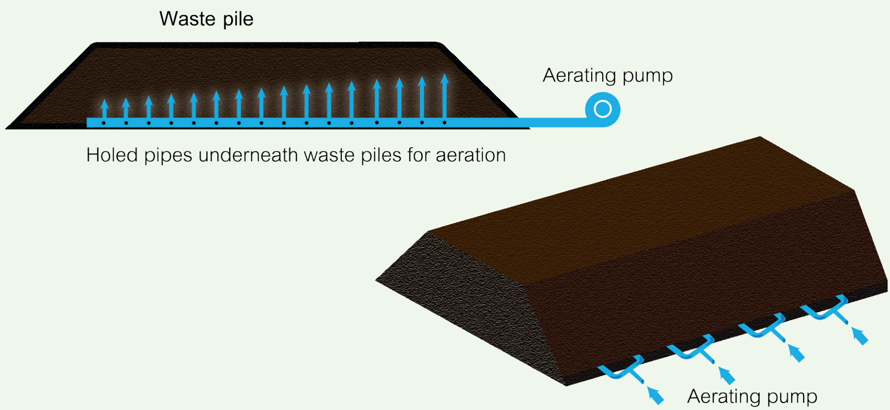


Figure 9. Aerated static pile composting

Incineration

The solid wastes that cannot undergo recycling or compost, namely, packaging plastic scraps, clothes, wood and rubber, have high calorific values and are combustible. They perfectly fit for use as refused derived fuel or RDFs as shown in Figure 10.

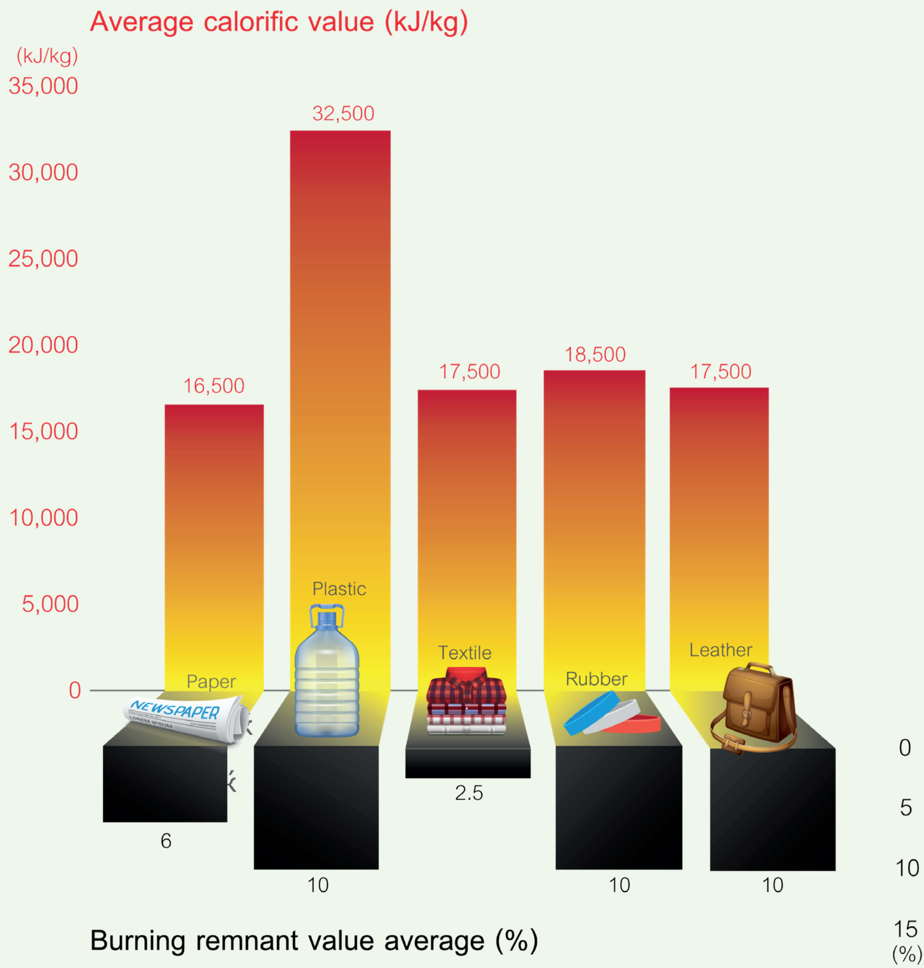


Figure 10. Calorific value and burning remnant of various municipal solid wastes

Source: Adaptation from Tchobanoglous et al. (1993)

Table 4 provides the ideal characteristics of waste fuel, and figure 11 shows the burning calorific value that is conducive to electricity generation. There are three methods of solid waste burnings according to the different levels of aeration in the system (Figure 12).

Table 4. The ideal fuel characteristics

Characteristics	Units	Values
Physical properties		
Net calorific value	Megajoule/ kilogram	Not less than 6.5
Moisture content	-	Not more than 40% by weight
Bulk density	Kilogram/cubic meter	Not less than 100
Chemical properties		
Chlorine content (Cl2)	Percent dry matter basis	Not more than 0.8% by dry weight
Ash content	Percent dry matter basis	Not more than 50% by dry weight
Mercury density/ content (Hg)	Milligram/ megajoule (median value)	Not more than 0.06
Cadmium density/ content (Cd)	Milligram/ megajoule (median value)	Not more than 7.5
Density/content of other metals including Antimony (Sb), Arsenic (As), Lead (Pb), Chromium (Cr), Cobalt (Co), Copper (Cu), Manganese (Mn), Nickel (Ni) and Vanadium (V)	Milligram/ megajoule (median value)	Not more than 190

Source : Notification of Pollution Control Department (2018)

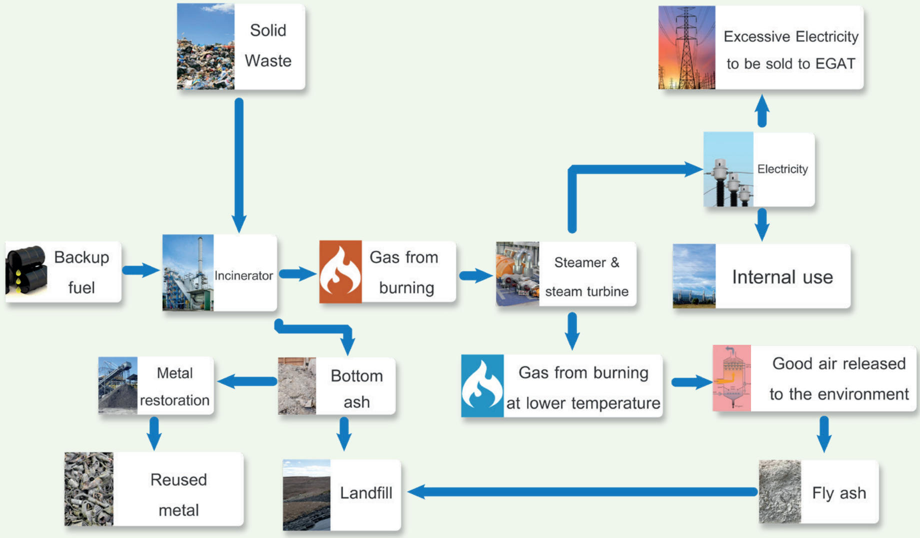
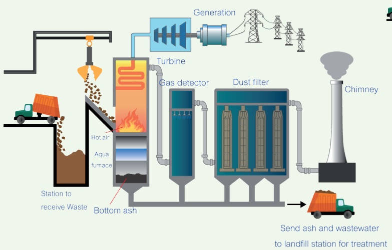
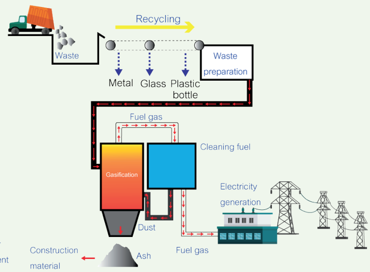


Figure 11. Solid waste incineration and burning-induced electricity generation



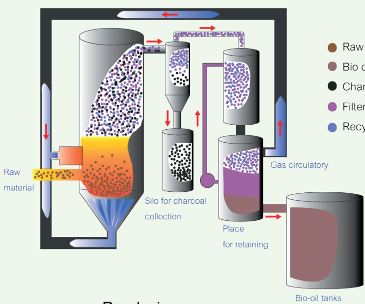
Incineration :

Complete burning



Gasification :

Partial aeration



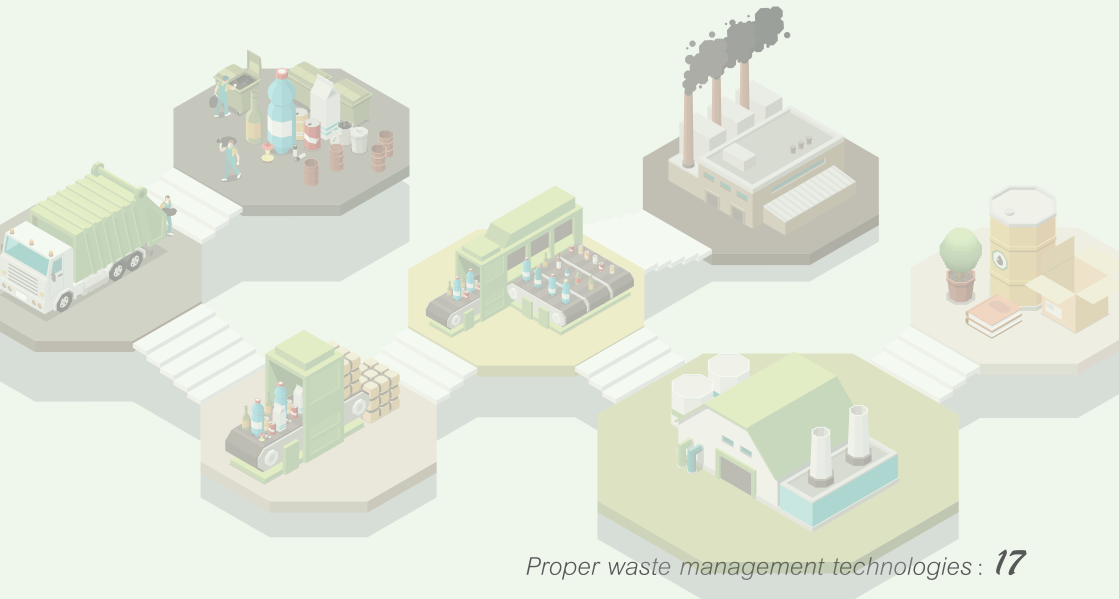
Pyrolysis :

Anaerobic burning

Figure 12. Three types of solid waste incineration

The following two cases are taken as examples. The incinerator in Phuket has a daily disposal capacity of 700 tons and generates 10 megawatts of electricity. Also, a city named Biscay in Spain encountered a shortage of landfill spaces and electricity. Therefore, in 2020, it aimed to achieve 50% of waste recycling through education and strict enforcement of waste segregation. Other unrecyclable wastes would be incinerated, in line with the EU's circular economy. Besides, the Zabalgarbi power plant, with the disposal capacity of 30 tons of solid waste per hour, was constructed (Prachachat Turakij, 2019).

In aspiration to cope with non-segregation in which organic waste is mixed with general items, MBT or mechanical a biological treatment is introduced to cut the amount of solid waste to be landfilled. Firstly, municipal solid waste pretreatment is carried out manually to pick out large recyclable wastes. Subsequently, solid wastes are mechanically reduced in size. The organic waste will then be composted using biological method for fertilizer and sieved to release diminutive particles. The larger items stuck on the sieve, mostly non-degradable plastic, would be used for waste fuel generation or landfilled (Figure 13).



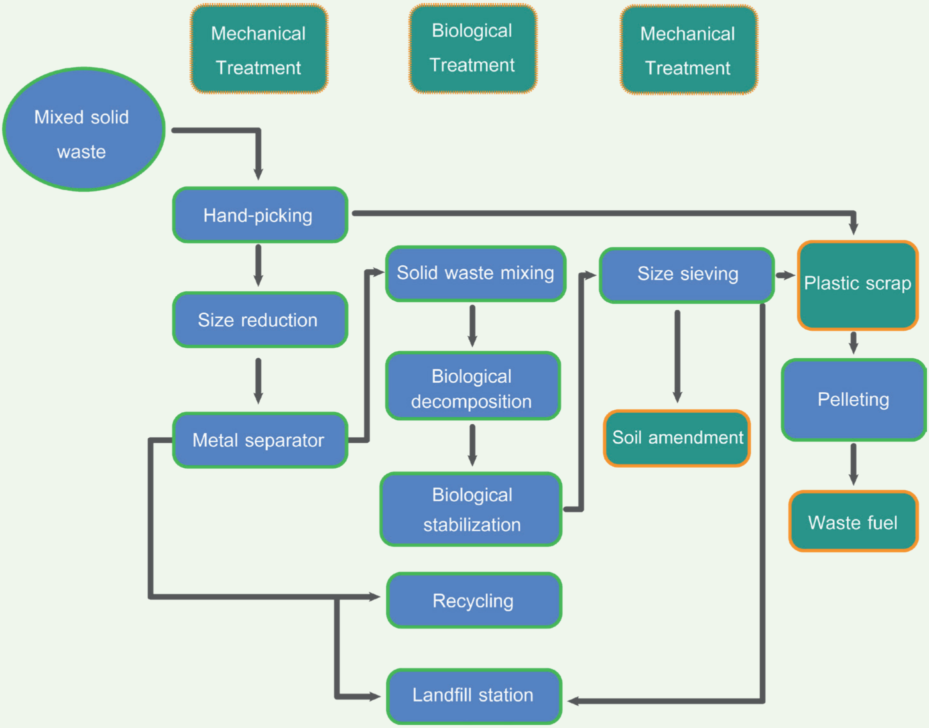


Figure 13. A sample of mechanical biological treatment of municipal solid waste

In Thailand, municipal solid waste plants' mechanical biological treatment is situated in Phitsanulok, Rayong and Bangkok's On Nut Solid Waste Disposal Center. In Rayong, technology for biofertilizer production and electricity generation is put in place (Figure 14).

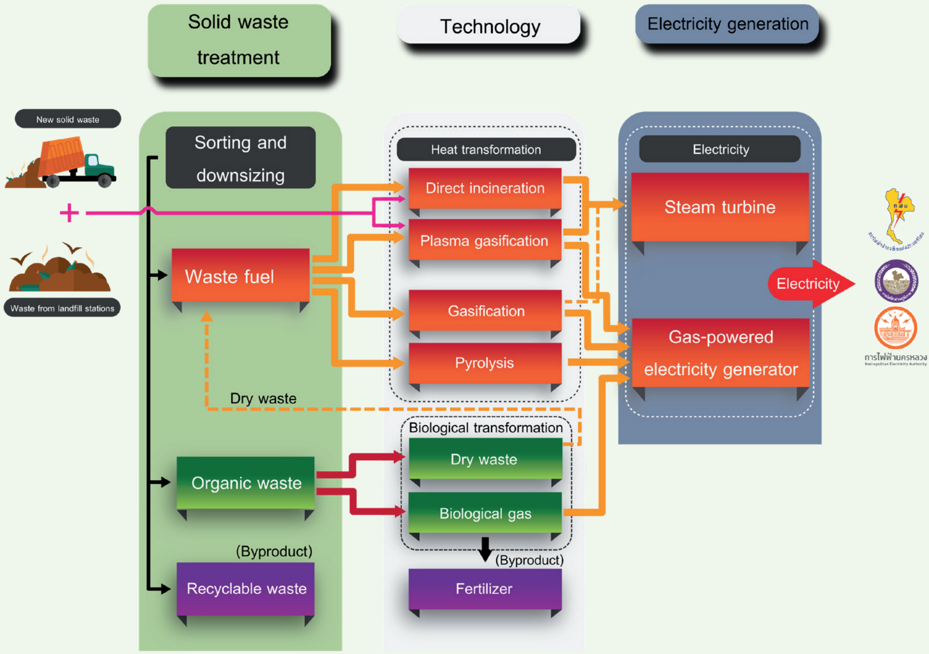


Figure 14. Biological fertilizer production and electricity generation stemming from solid waste treatment through a combination of mechanical and biological methods

Source : Global Power Synergy Public Company Limited (2017)

Sanitary Landfill

The final solid waste management step is landfilling. Conventional methods fail to implement first-stage segregation, culminate in excessive solid waste at landfill sites, and limited venues cannot adequately cope with solid waste. Nowadays, reduction, reuse, recycling and other usages are promoted to reduce solid waste volume at landfill sites.

Sanitary landfill management involves the following steps. To begin with, solid waste is weighted to determine the total volume. Since sanitary solid waste landfill is operated under anaerobic conditions, organic wastes that are decomposed by microorganism produce biochemical reactions during the landfill process, resulting in polluted leachate and biogas. As a result, sanitary solid waste landfill resorts to a bottom foundation laying, a collection system, wastewater and biogas treatment and exploitation systems; and an environmental impact follow-up to ensure community safety and lesser setback the environment (Figure 15).

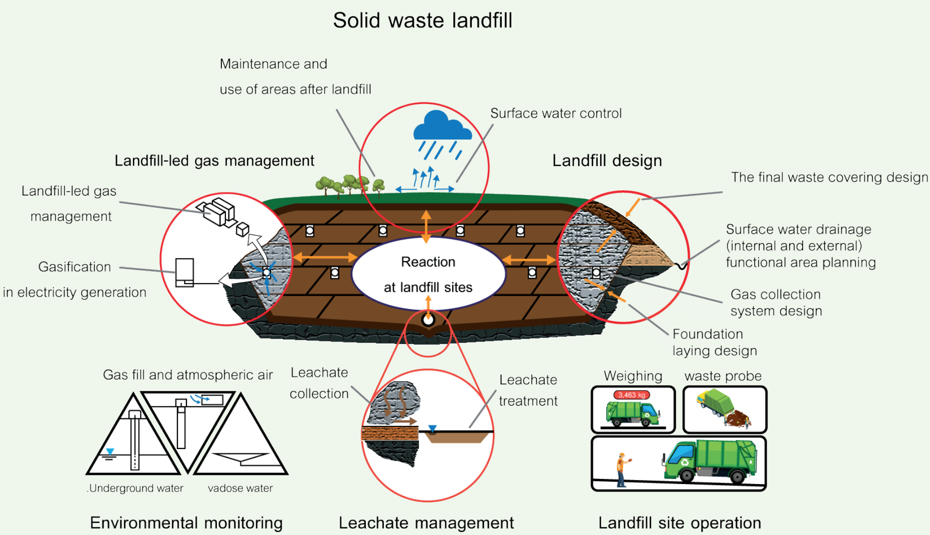


Figure 15. Sanitary solid waste landfill operation and processes

Source : Adaptation from Tchobanoglous, et al. (1993)

Plastic

and plastic recycling

Plastic is a significant material these days as its uses are parallel to those of organic materials and widely accepted in functions. In general, its properties include remarkable stability in a normal condition, difficulty in decomposition, great functions as an electricity and heat insulator, softening and fusibility when exposed to heat. As such, plastic can be variously transformed into shapes and light in weight.

Due to its low production cost, plastic exerts a huge role in everyday life and continually grows in usage demand. Consequently, an enormous amount of plastic waste is produced, jeopardizing the environment by its mismanagement. The most common trash include plastic bags, followed by straws, bottle lids and food containers. Being non-degradable and synthetic substance, plastic may take hundreds of years to decompose. Without proper measures, plastic trashes may deteriorate soil and water quality, together with human health. In addition, improper plastic burning in unapproved incinerators entails carbon dioxide (CO2) emission and other toxic gases that lead to global warming.

A History of Plastic

The word plastic derives from the Greek πλαστικός (plastikas), meaning “capable of being shaped or molded”. Most plastics are produced from chemical synthesis reaction, and 90% of raw materials are petrochemical products, i.e., crude and natural gas. In early days before plastic was invented, human utilized liquid rubber from the trees to make containers, shoes, water bowls, to name but a few.

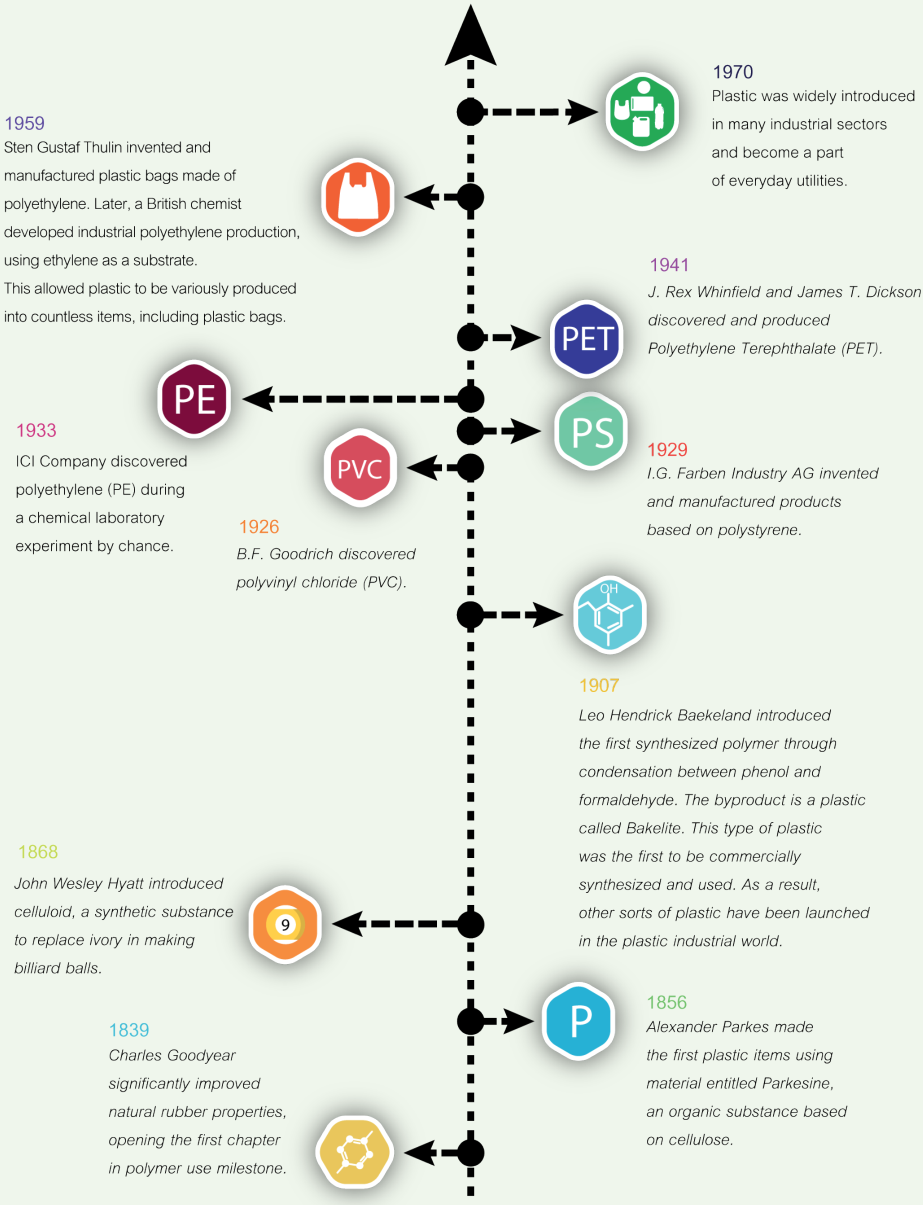


Figure 16. A history of plastic

According to the evolution in Figure 16, plastic was firstly known in 1839 when Charles Goodyear, an American inventor, discovered an effective way to overhaul natural rubber properties through sulfur adding and heat introduction. The method is called vulcanization and has been in use until now. His endeavor gave birth to the significant development of polymer utilization.

In 1856, Alexander Parkes officially produced plastic for the first time. He discovered the cellulose-led organic substance called Parkesine which could be molded once heated and retained its shape when cooled. In 1970, a Belgium-born American chemist, Leo Hendrick Baekeland, succeeded in debuting the first synthetic polymer when phenol and formaldehyde condensation was carried out. Thus Bakelite was produced and regarded as the world’s first synthetic plastic. A wide range of plastic materials have been around to accommodate countless uses. From 1970 onwards, plastic has been remarkably useful in several industrial areas and produced as daily merchandises, resulting in an annual 300 million tons in plastic production.

Types of plastic

According to Figure 17, there are two types of plastic categorized by thermal properties, as shown below:

1. Thermoplastic is the most common plastic in terms of use. When exposed to heat, it becomes molded and stable when cooled. It can retain its shape or be reshaped for various demands without losing the original properties. It fits the molding of items across types via basic methods, ranging from injection to extrusion and thread spinning.

2. Thermosetting plastics are characterized by low contraction and great resistance to temperature, pressure and chemical reaction. So, stains and spots are rare. This plastic efficiently maintains its shape after undergoing heat or pressure for once. When cooled, its form can no longer change.

Facing excessive heat, it gets cracked and burns into black ash. This type of plastic needs longer setting time than thermoplastic and may require post mold finishing.

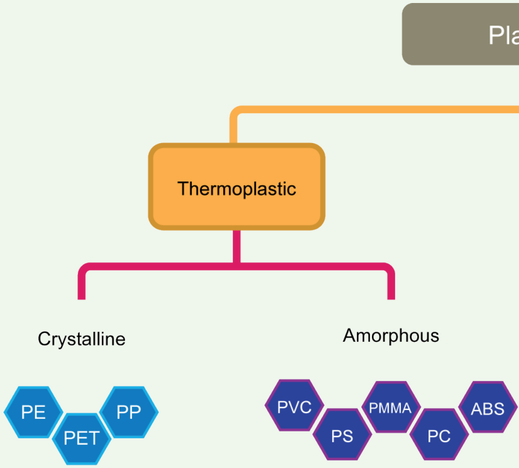


Figure 17. Types of plastic

Table 5. Differences in thermoplastic and thermosetting plastic

Thermoplastic	Thermosetting plastic
1. Thread or semi-polymer	1. Linked or chain polymer
2. Softens or melts upon heat	2. Solidifies upon heat
3. Needs to cool down before removal from a mould to avoid disfigure	3. No cooling before removal from a mould is needed
4. Causes no polymerization reaction in a mould	4. Causes polymerization reaction in a mould
5. Recyclable by molding and reshaping	5. Non-recyclable

Types of plastic by thermo-properties

1 Thermoplastic features long-chain molecules and contains two types of molecule forming (as per Figure 20). Each holds different physical properties, heat resistance and conductivity, as follows:

1.1 Partial crystalline thermoplastic or crystalline – in this category, molecule forming is systematic and close to one another, making this type of plastic strong and heat-resistant; however, the plastic will appear opaque. Below are samples of crystalline.

1.1.1 Polyethylene or PE – with a low melting point and inefficient heat resistance, the plastic is clear, viscous and highly flexible. PE is a component of plastic forming process to create either soft or hard plastic products. Its three levels of density include low (LDPE), medium (MDPE); and high (HDPE).

1.1.2 Polyethylene terephthalate or PET – the colorless, hard, highly-crystalline thermoplastic offers strength, flexibility and good impact resistance, as well as gas-impermeable property and low rate of decomposition. As the only 100% recyclable plastic material, PET is common in packaging production; ranging from water bottles, films, vegetable oil bottles and synthetic threads to plastic bottles and containing packages.

1.1.3 Polypropylene or PP – this low-density type offers an easy forming capability that is sparse and light in weight. It is strong, viscous, chemical resistant, mildly durable, and less heat resistant compared to PE. It's used to produce straws, food bags, and food containers since these food-grade plastic pellets are safe for food packaging and protection against humidity. However, the plastic is ineffective in a low-temperature environment, so it is not ideal for frozen food packaging and use as bonding materials at joints.

1.2 Amorphous thermoplastic – the plastic has a disorganized molecular structure with a long bond distance between molecules. Thus, it has a lower strength and heat resistance. However, it has better clarity compared to crystalline plastic. Below is the list of amorphous thermoplastic.

1.2.1 Polyvinyl chloride or PVC – it is hard, fragile, clear, colourless, chemical resistant, and effortlessly soluble upon heat. Therefore, it is indispensable to include additives to improve heat resistance. PVC is commonly used to produce pipe joint, water pipe, door frame, window frame, artificial leather, hose, car seat, raincoat and insulated wire.

1.2.2 Polystyrene or PS - this plastic is made of styrene monomer. It is hard, clear, fragile, easily broken and not impact resistant. However, it is acid and base resistant. It is mostly served as material for components of refrigerator, car and electronic devices, office supplies, plastic rulers, pen bodies, trash bins and plastic bottles.

1.2.3 Polymethyl methacrylate or PMMA – it is also known as acrylic. The plastic is eminent for viscosity, tensile strength, toughness, high resistance to UV and glass-like clearness and lighter weight. For this reason, acrylic is an outstanding substitute of glass across industries and an ideal material for the production of plastic covers for automobile headlights and taillights, dial screens, lens, lamps, store signs and advertisement signs.

1.2.4 Polycarbonate or PC – this engineering plastic is of great strength and durability and widely used across industrial sectors. PC is really hard, transparent, viscous, resistant to acid but not base, resistant to retaining force and impact, and able to withstand heat up to 140oC. PC is an expensive material which is perfect for construction, bullet-proof windows, components of electronic appliances, electronic devices, battery parts, electrical fuse covers and baby milk bottles.

1.2.5 Acrylonitrile–butadiene-styrene or ABS – this polymer is highly resistant to impact and chemical substance. It is viscous, transparent, yet opaque. It is common in the manufacture of items dedicated to outdoor and decorative purposes, such as electric parts, automobile components, sports equipment, gas pipes, case or cover materials, telephones, computer keyboards, computers, cell phones, toys such as Lego, dishes, bowls, fan structures, racing helmets and power switches.

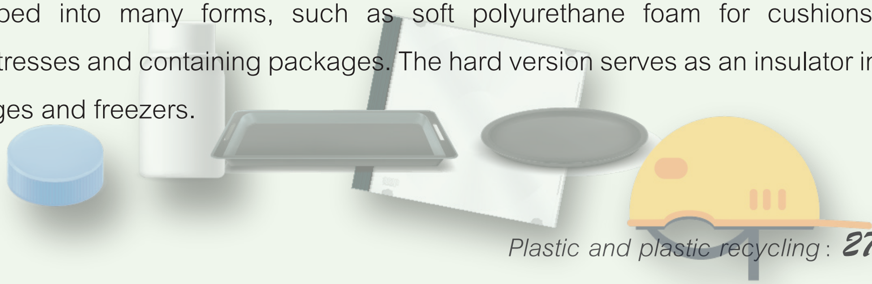
2. Thermosetting plastics – this randomly-ordered structure plastic offers the ability of durable form but can be only once molded; it is unable to return to the previous form after receiving heat, pressure and chemical reaction (higher than 200°C in general). After being exposed to the second high heat, this plastic becomes deteriorated and decomposes since the heat has destroyed its molecular structure. Examples of this type are listed below:

2.1 Phenol formaldehyde or PF – this highly strong and inflexible plastic doesn’t melt or becomes soluble in any solvents and withstands heat up to 200^{O}C. Its common functions are frying panhandles, automobile distributor caps and chemical trays.

2.2 Melamine-formaldehyde or MF – this highly strong plastic withstands heat up to 110^{O}C and is a common material for plastic dishes, furniture and countertop materials.

2.3 Urea-formaldehyde or UF – with the strength comparable to that of melamine-formaldehyde, it is usually produced as switches and plugs.

2.4 Polyurethane or PUR – this hard plastic can be shaped into many forms, such as soft polyurethane foam for cushions, mattresses and containing packages. The hard version serves as an insulator in fridges and freezers.



Plastic Recycling

The central part of plastic consumption is that consumers often throw away plastic, even so, various plastic types are recyclable. This is especially true for thermoplastic which can be reshaped through grinding and heat-induced melting. These two techniques offer benefits through waste; nonetheless, plastic may undergo degradation from repeat recycling. As such, recycled plastic should be added with an appropriate amount of plastic particles during production. In the case of some plastic products that require special properties, cleanliness and contamination shall be heavily monitored. However, recycled plastic has limited usage as it can be distorted and disfigured upon high heat or temperature.

According to figure 18, recycled plastic is divided into 7 types. The Society of the Plastic Industry Inc. of the United States of America provides the standard symbols for recyclable plastic in daily functions. The signage sports three arrows facing the same direction in a triangle, or a mobius loop. It indicates that the product is recyclable or made from recycled materials. The number at the center of the triangle and the roman alphabets under the triangle base denotes the classification of recyclable plastic types.

7 Types of Plastic

Segregate recyclable plastic before disposal.

Symbol	Polymer Name	Product Examples	Properties
1 PETE	Polyethylene Terephthalate	Water and vegetable oil bottles	Transparent and dense polymer. It resists impact and performs well to prevent gas permeability.
2 HDPE	High-density Polyethylene	Shampoo bottles, plastic bags, trash bins	Highly-density plastic offers prominent strength but is less transparent than polyethylene. It is less dense, resistant to acid and base, and effective in moisture permeability prevention.
3 PVC	Polyvinyl Chloride	Water pipes, wire insulators	This highly-strong material allows for a mild penetration of steam and air but a great prevention of oil permeability.
4 LDPE	Low-density Polyethylene	Plastic bags, frozen food bags	It is transparent with high volume but low density.
5 PP	Polypropylene	Bottle caps, medicine bottles	It is the lightest of all plastic types, but strong and resistant to impact and high heat.
6 PS	Polystyrene	Bowls, dishes and CD cases	Transparent and fragile, but great resistant to acid and base. It can be easily formed into shapes and allows for a mild permeability of moisture and air.
7 OTHER	Others	Pens, feeding bottles, safety helmets	There are many plastic types that can be recycled. The plastic other than the 6 above types are grouped into this type.

Sorting Recommendation

- Sort by types based on the symbol on packages
- Rinse with a splash of water
- Don't throw cigarette butts or litter into bottles
- Separate a bottle and a lid as they are not the same kind of plastic.

Figure 18. Types of recyclable plastic to be segregated before disposal

Plastic Recycling Processes

Plastic recycling is a process of recovering and reprocessing plastic waste into functional and useful products. Recycling can reduce the amount of chief raw materials in a virgin plastic manufacturing process, and minimize hazardous waste during the process. Finished products of recycled plastics offer different functionality from the original ones. For example, plastic bottles are melted and molded into containers.

Please bear in mind that plastic segregation is the first and significant step in recycling. As plastic has a different weight and highly-complex molecular structure, mixing types of plastic is not feasible. There are 4 key types of plastic recycling (as shown in figure 19).

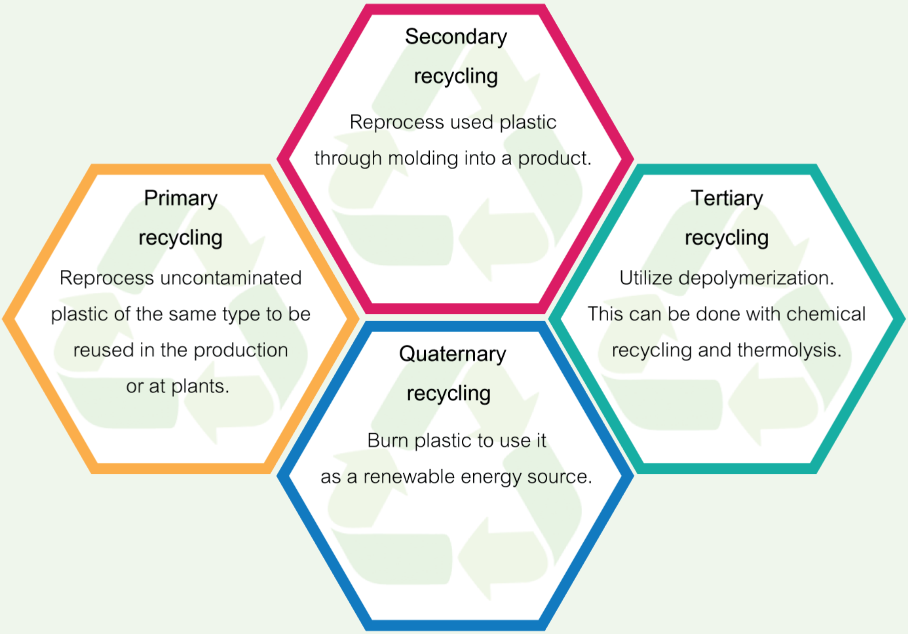


Figure 19. 4 types of plastic recycling

1 Primary recycling – this reuses uncontaminated bottles or plastic material of the same type, which are produced in a production or molding process, at a plant. This process can be completed using only one type of material or adding appropriate amounts of new plastic particles.

2 Secondary recycling – also known as a molding process. Used plastic will be cleaned, ground, melted, and reshaped to create a new plastic product. This recycling process can be done by various methods as detailed below.

2.1 Mechanical recycling – plastic is sorted by types and colors, rinsed until clean, and then ground and melted into a recycled plastic resin, which is ready to either be used in the next production or mixed with new resin to ensure the desired property in a molding stage.

2.2 Chemical modification – the resin of recycled plastic is processed to have a quality as close as new resin. This can be applied to both single and mixed resin. For the former, chemical addition or irradiation methods will be used. In the case of the latter, a compatibilizer is required for blending.

2.3 Co-extrusion and co-injection molding – this option is suitable for the production of food packages. Products processed with this method contain several layers, similar to a sandwich. The outer layers will be made of new plastic, making them highly resistant to tensile and scratch, while the middle layer is recycled plastic.

3 Tertiary recycling has two categories, as follows:

3.1 Chemical recycling – it involves depolymerization that yields monomer or oligomer. Through purification based on refining and crystallization, the end result is a high-quality substrate. This method is often used for PET recycling.

3.2 Thermolysis – heat is introduced to break plastic structure. This technique can be achieved with these 3 methods as follows:

(1) Pyrolysis – depolymerization is achieved through an oxygen-free thermal action. Through condensation, a liquid substance called synthetic crude oil, which can be supplied to the refining plants is produced. Simultaneously, the remaining materials that do not undergo condensation will be utilized as fuel to provide heat during a process.

(2) Gasification – depolymerization is achieved through a thermal action using limited oxygen to facilitate a reaction; this process utilizes higher temperature compared to pyrolysis. This results in syngas, consisting of carbon monoxide and hydrogen. This gas can be used as a direct source of fuel. However, its value can be increased by 2-3 times if it's processed through gas separation.

(3) Hydrogenation – the technique is developed based on crude oil refining catalytic method. Depolymerization uses a thermal process. The material will be introduced to excessive hydrogen at a pressure higher than 100 bar until the cracking and complete hydrogenation are achieved. This method mostly yields liquid fuel such as gasoline or diesel.

Thermolysis is more beneficial and cost-effective than chemical recycling since it is capable of processing plastic waste mixed with non-plastic contaminants. On the contrary, chemical recycling requires relatively clean plastic, can withstand low contamination and contributes to high preparation cost. However, thermolysis still requires cleaning or size screening.

4 Quaternary recycling – plastic can be burned as alternative fuel. The calorific value of plastics is between 22-46 MJ/kg, similar to coal (29 MJ/kg). This is conducive to wet waste burning and, thus, ensures a lower volume of fuel required in waste burning.

Plastic Types and Recycling

All plastic types are recyclable, except those with limitation such as PVC, melamine, light plastic with difficulty in the collection, or those made of mixed plastics, making them non-ideal for recycling. Most recyclable plastics are listed below;

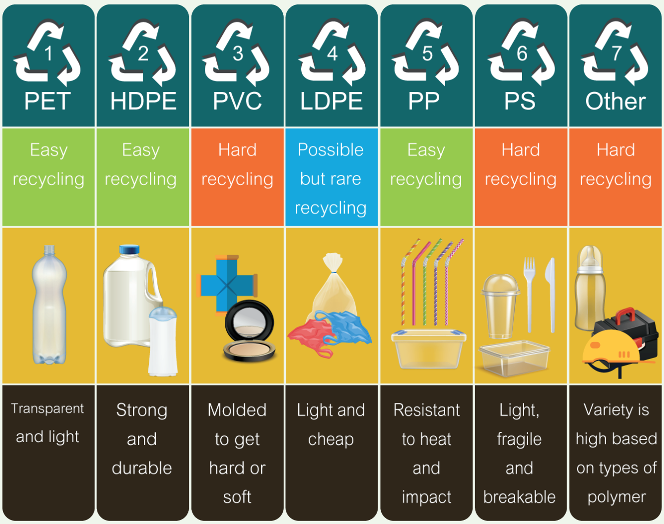


Figure 20. Types of plastic common in recycling process

As mentioned above, plastic recycling processes are vital to maximize resource utilization. The cycle starts from raw material management and production to fuel generation as clearly depicted in figure 21.

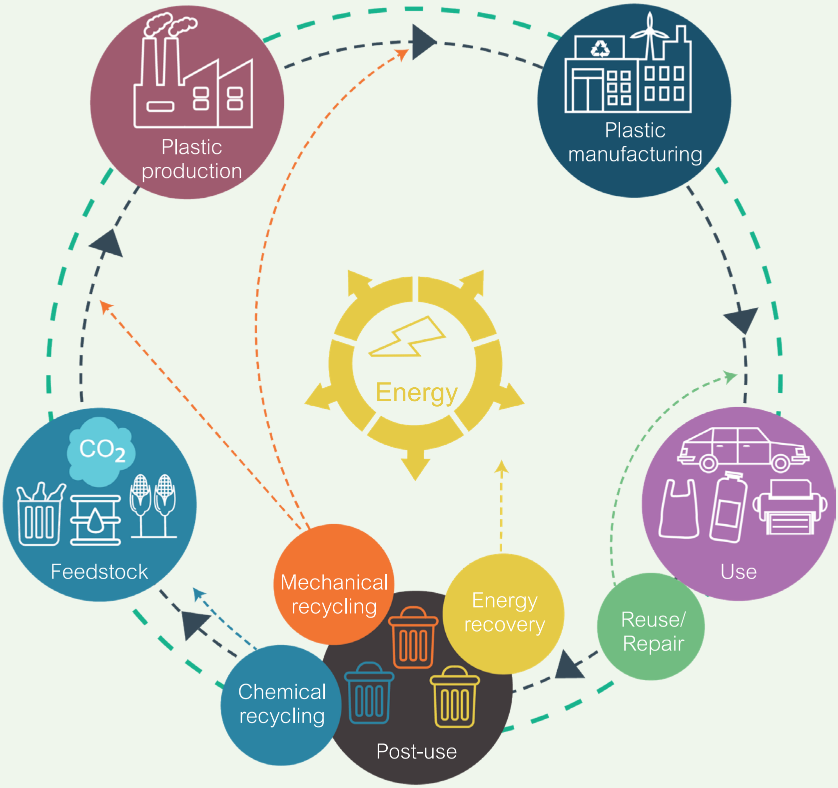


Figure 21. The Life Cycle of Plastics

Source : Woldemar (2019)

Currently, 1.5l PET bottle weighs 26.8 grams, less than the previous version. This resulted from the improved efficiency in material utilization which also helped reducing the volume of materials by 66% in the past 5 years. As a result, a single truck can transport more products and significantly reduces fuel consumption and emission (Stadler, 2020).

Recycling Processes

Plastic recycling consists of steps as follows.

1 Inspection – the first step is to screen and separate contaminants in plastic waste such as rocks, glass and unrecyclable plastic.

2 Chopping and washing – the second step is to clean plastic.

3 Floatation tank – since each plastic type has a different density, some plastic types such as PS, PVC, PET and ABS will sink, while PP, HDPE and LDPE will float. This proves to be a simple method for classification as displayed in figure 22.

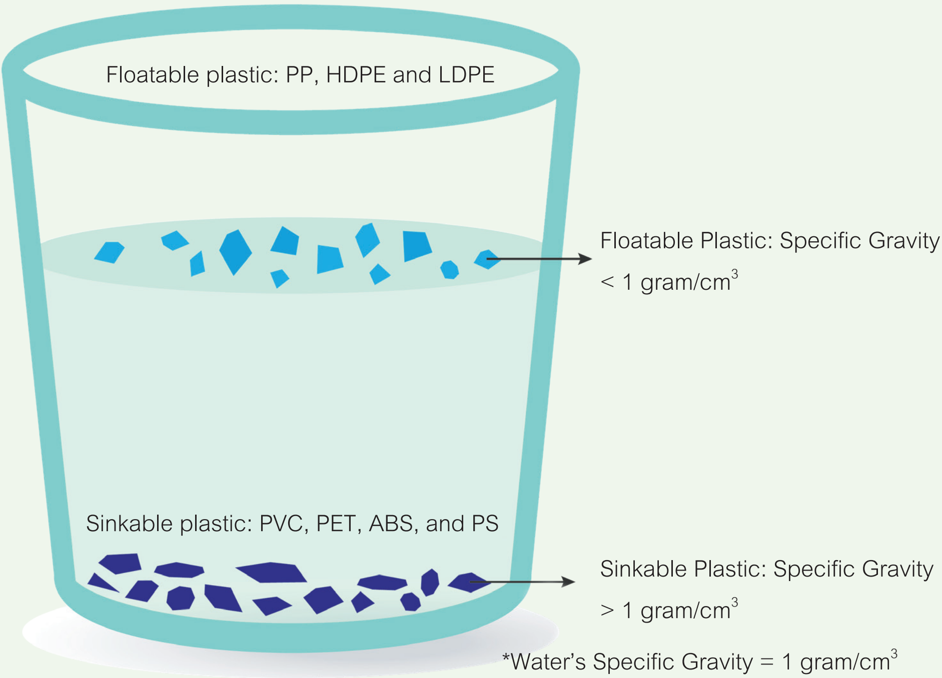


Figure 22. Plastic classification by floatation

Source: S. Serranti & G. Bonifazi (2019)

4 Drying – dry the plastic segregated from the previous step by a tumble dryer.

5 Thermal and pressure are melting – an extruder inserts heat into the plastic. Temperature and pressure vary depending on plastic types due to different melting points.

6 Filtering – melted plastic is finely filtered to eliminate contaminants, and fed to an extrusion to form the plastic threads.

7 Pelletizing or granulation – cool down plastic threads by soaking in water, break them into small grains, and feed into plastic production plants for molding.

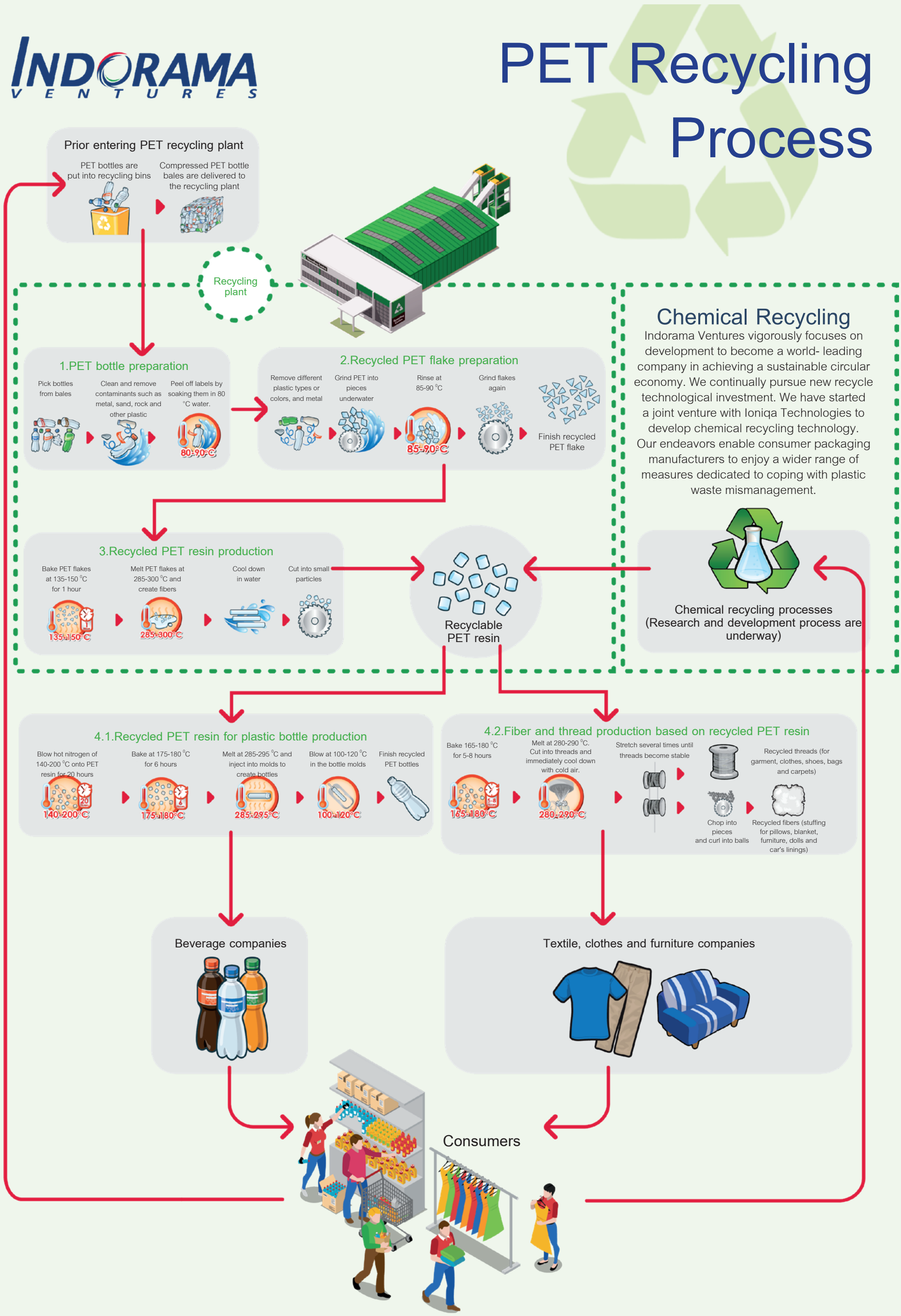


Figure 23. Plastic recycling processes by Indorama Ventures Public Company Limited

A new perspective on plastic recycling

Most people may think that plastic is the main cause of environmental degradation. However, plastic presents numerous benefits. Compared to alternative materials, plastic exerts less environmental impacts; for example, between life cycles of plastic bags and that of paper bags, it's found that the plastic bags emit less air pollution, and require much less energy and clean water. According to Figure 24, at the same production volume, the paper bags trigger 6 times more air pollution and 2.5 times more energy, while consuming 16.1 times more clean water.

From this information, it can be argued in detail that the productions of plastic bags and paper bags consume natural resources. Plastic originates from natural gases or crude oil, while paper is made from trees' cellulose fibers. The materials are secured and processed through production processes, and then pass on to the consumers in the form of products. Finally, they are discarded and later collected for recycling. In these processes, pollution emissions (greenhouse gases for this instance), energy consumption, and clean water consumption are required. Considering the carbon emission levels of all packaging types, plastic products account for only 5% of total natural gases and petroleum in Thailand. Therefore, plastic is not the main cause of the decrease in natural gas and petroleum compared to other activities.

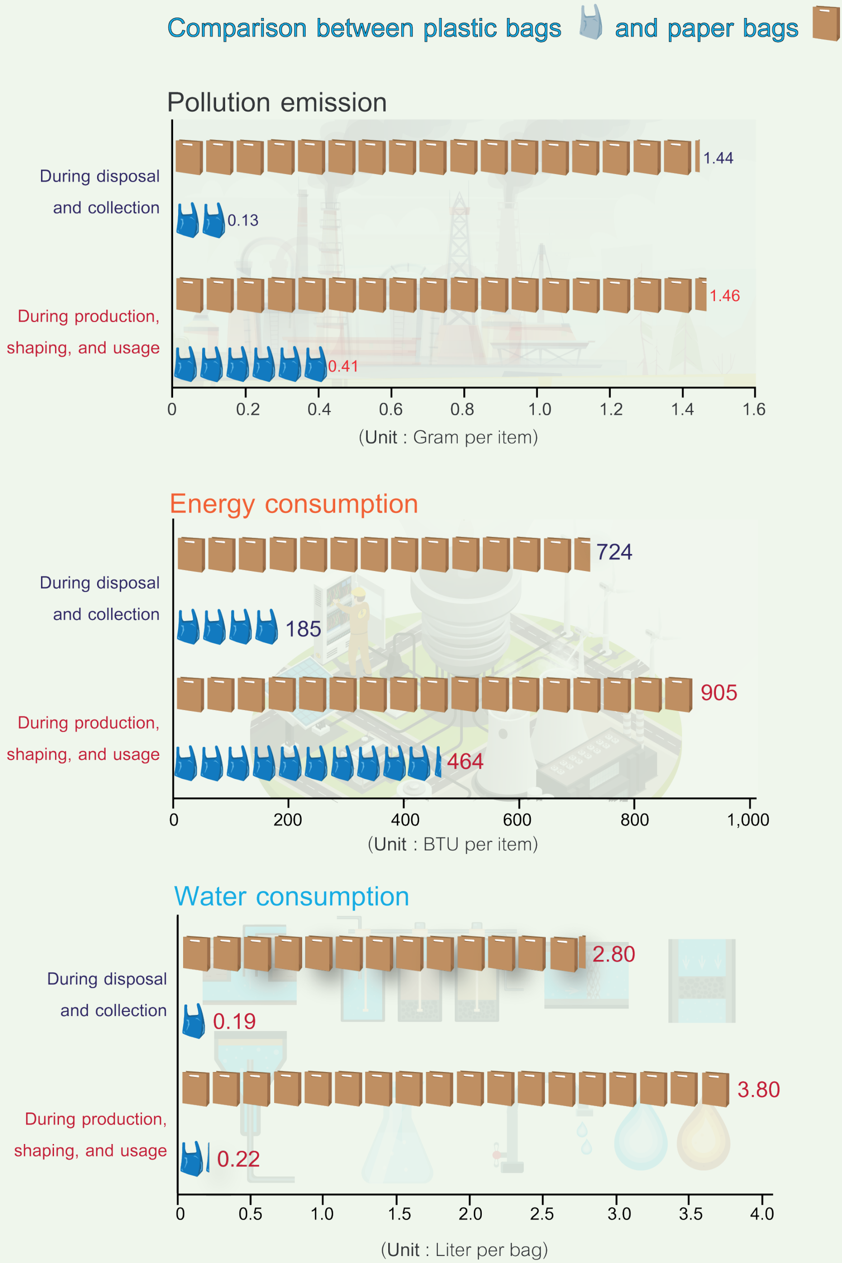


Figure 24. Comparison between plastic bags and paper bags

Source: Franklin Associates, A Division of Eastern Research Group (ERG)

According to the study of greenhouse gas emissions on the Life Cycle Assessment of packaging materials (Voulvouslis N et al., 2019), every beverage packaging, whether it is made from plastic or other materials, causes an environmental impact. However, in terms of the 500 ml of beverage packaging, the plastic bottle production has less greenhouse gas emission than the liquid fiberboard, steel cans, aluminium cans, and glass bottles as shown in Figure 25.

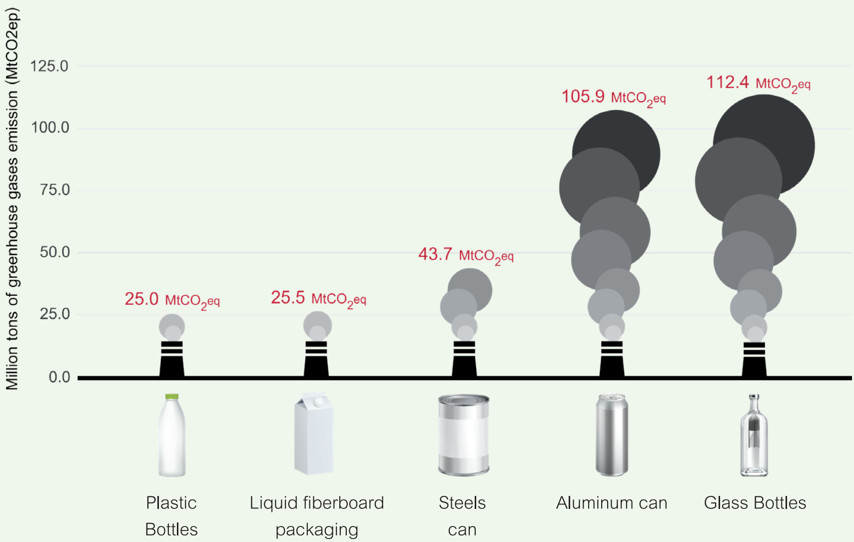


Figure 25. Greenhouse gas emission from production of 500 ml beverage packaging using different materials

Source: Voulvouslis N et al. (2019)

Circular economy

and plastic industry

A circular economy is a business model focusing on waste management after consumption; it's different from take-make-use-dispose model, a linear economy that revolves around production and consumption and causes enormous waste. It also promotes resource efficiency and supply of the used products into the manufacturing process (make –use-return-model). As a result, the balance in business, quality of life, and the sustainable future are encouraged.

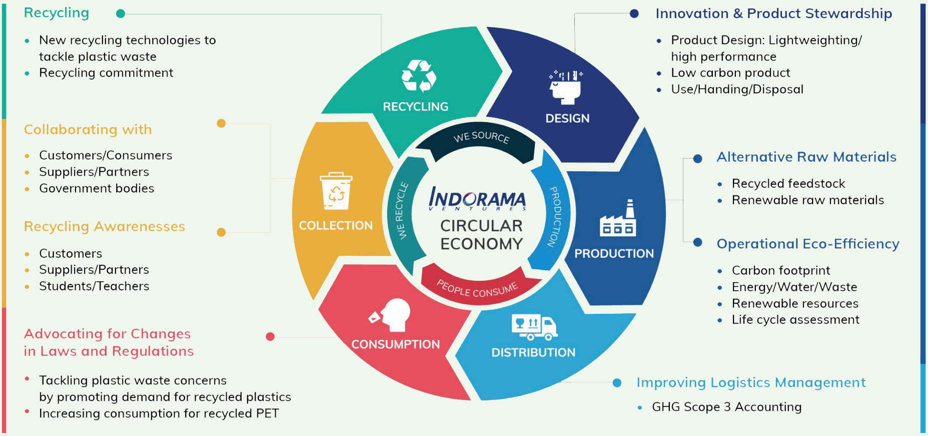


Figure 26. Circular economy

Source: Indorama Ventures Public Company Limited

Implementation of a circular economy for waste management must start with a design which uses the least resources in a production process, provides the most value for customers, or can be reused as much as possible. To achieve maximum usage and effective reuse, the user is required to systematically sort and store items. However, if it cannot be reused, it should at least be used as fuel. These ideas shall lead to the rising trend of the circular economy model used in many industries. Manufacturers use leftover materials to add more value to their products through design, as well as recycling used products and redesigning products to be eco-friendly from the beginning of production.

Plastic recycling
by circular economy

Many countries have suitably implemented the circular economy model according to the context of their countries and organizations. The plastic industry is one of the industries that apply the circular economy model to reduce environmental complications sustainably. Using only the take-make-use-dispose model without waste management or disposal will rapidly double waste when there is plastic waste. Therefore, plastic waste is considered a global issue which needs to be tackled seriously.

However, the European Union has established the new regulation stating that beverage bottles must consist of 25% recycled plastics by 2025 and 30% by 2030. The regulation, coupled with changing consumer behaviors will facilitate a rapid increase in plastic recycling rate (Stadler, 2020).

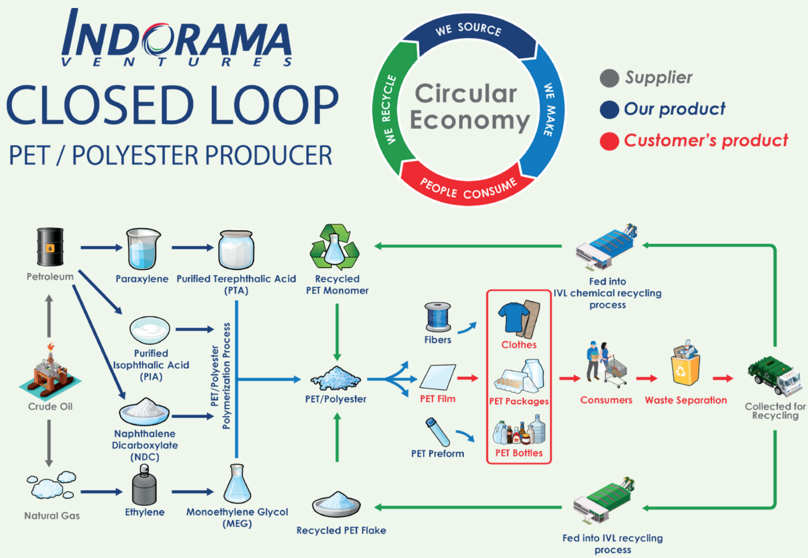


Figure 27. Plastic recycling by circular economy

Source: Indorama Ventures Public Company Limited

The United Nations (UN) elevated the mismanagement of plastic as the global challenge as specified in the sustainable development goals (SDGs) which were recognized by 193 member states in September 2015. The SDGs consists of numerous goals regarding resource and waste management, especially 17 goals regarding sustainable consumption and production (SDG 12) and conservation and sustainable use of seas and marine resources (SDG 14) which closely relate to plastic waste and plastics in general. In 2016, UNEA-2 rectified the resolution No. 2/11 to request consideration regarding plastic waste and recycling issues.

Currently, the government is preparing to pursue sustainable development goals under an agreement of the ASEAN-UN Plan of Action 2016 – 2020 by making a strategic plan to propel the country towards sustainable development in economic, social and environmental aspects. The Ministry of Industry has an important role in establishing the policies for the plastic industry. These policies aim to facilitate the transition of production structure into the circular economy model to decrease environmental impact while increasing economic value and encouraging businesses to make innovative products from waste or leftover materials in the country.

In the current situation, the report of the Plastics Institute of Thailand found that Thailand generates plastic waste for 2,000,000 tons per year, but only a quarter of the total waste is properly recycled. Due to a lack of waste management and systematic recycling measures at the moment, clean plastic waste is insufficient, which results in high recycling cost and low economic value. In addition, small entrepreneurs' production technology is still underdeveloped, lacks a standard, and remains outside the system where the government can provide support. Thus, each sector must cooperate to discuss a win-win solution. As Thailand has announced that the import of plastic waste will be banned by 2021, this is the best opportunity to review and create a national waste management plan for the optimal benefits. According to the 20-year national strategy regarding the plastic waste action plan, the 7 types of single-use plastics will be banned by 2025 (Figure 28).

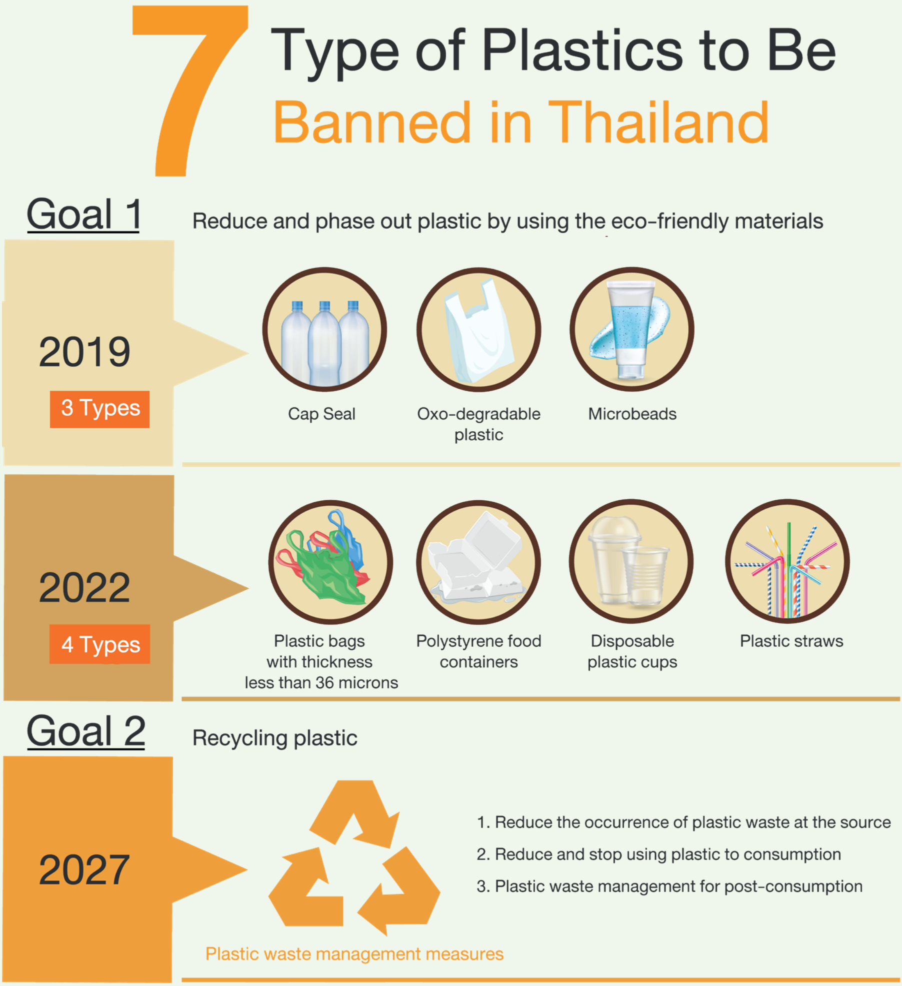


Figure 28. The 7 plastic types to be banned in Thailand

Source : Pollution Control Department

This measure improves the waste management by applying a circular economy system. This is considered as a starting point for the plastic industry which encourages the entrepreneurs to innovate long-lasting or fully recyclable plastic products that can be reused for maximum benefits.

Last notes

Unavoidably, daily activities are the source of solid waste, particularly an increase in packaging waste, although manufacturers are trying to replace plastic with biodegradable materials or recycled plastic for packaging. To solve this issue, proper packaging management is essential. Problematic behaviors, such as littering on roads and public spaces, should also be addressed. Waste disposal in correct bins allows waste to be properly treated. This action is especially crucial for plastic waste which can be recycled into plastic resin pellets or transformed into energy through established technology.

Recycling is an action in which deteriorated, broken, malfunctioning materials undergo a transformation process to return to an original form. It is intended to partially, rather than fully, use new material. For instance, plastic bottles that are thrown away are turned into new ones. Meanwhile, upcycle promotes a higher value of old material by processing into new material for usage in a new form. Recycle and upcycle still require energy and chemical substance in the process even though used material are restored.

In general, upcycle is similar to recycle. However, methods and purposes are different in terms of solid waste management. The same benefit is to promote a cycle of waste. Both of them are suitable waste managements for Thailand. According to Figure 29, recycle and upcycle relating to PET bottles present a variety of products.

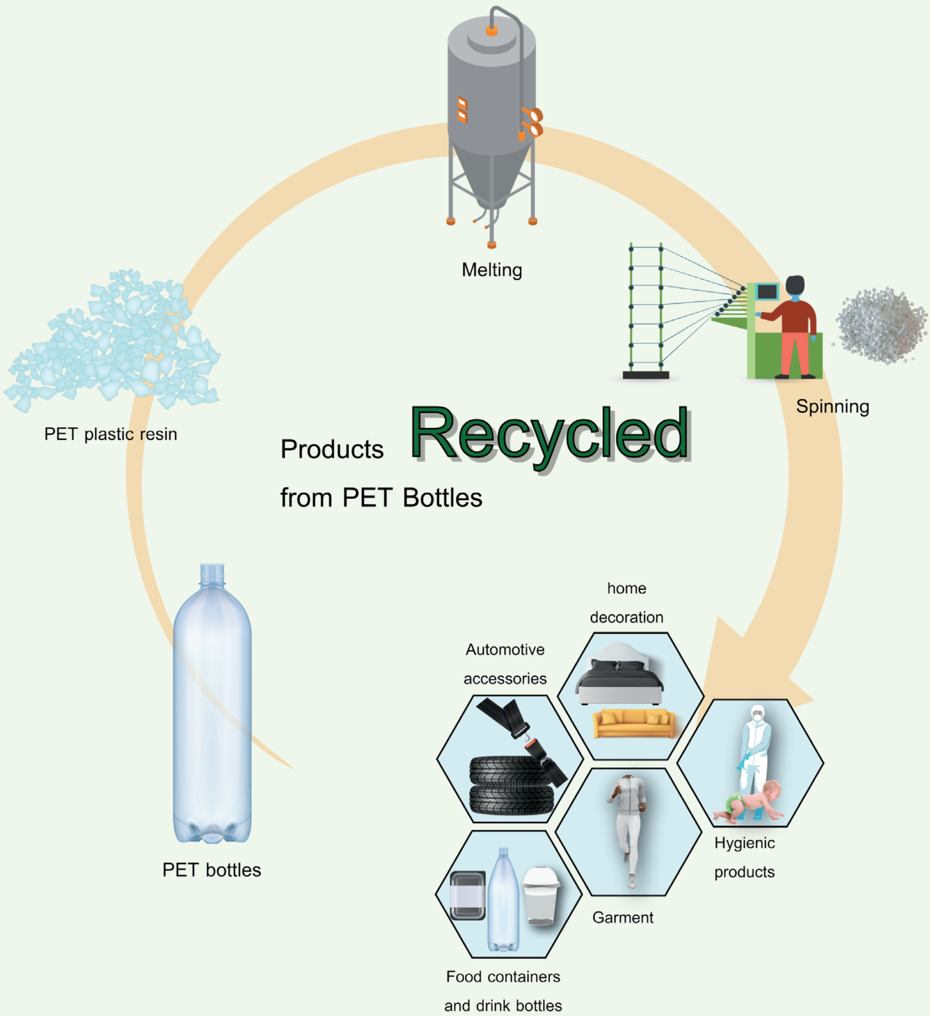


Figure 29. Products recycled and upcycled from PET bottles

Recycle and upcycle processes are efficient tools to manage solid waste problems. If waste is treated correctly from the sorting process and reutilized, the 4 significant benefits will be achieved, as illustrated in Figure 30.

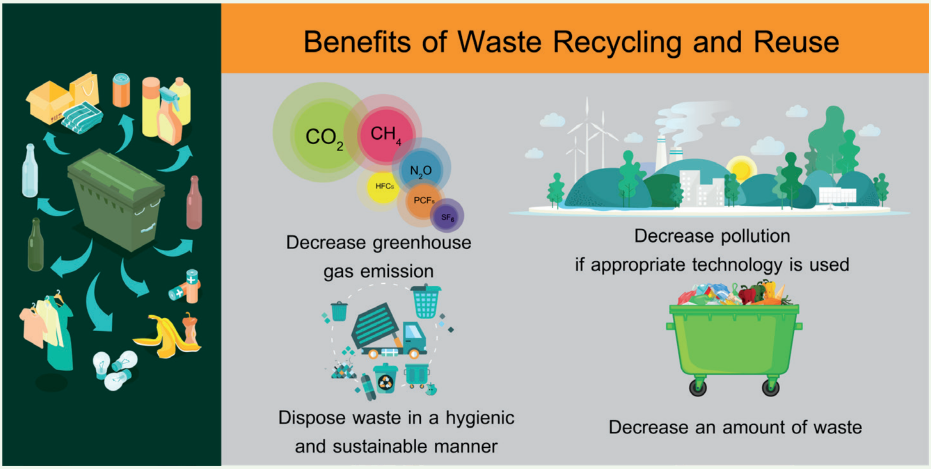


Figure 30. Benefits of waste reuse

Lastly, recycling and upcycling can efficiently cope with solid waste management and lead to less waste disposal burden at the last stage by restoring waste into a cycle. However, all of these may not be adequate in tackling environmental complication. The optimal solutions are to create less waste, environmental issues and usage of green products which can be reused into the environment. Most importantly, people should properly dispose of garbage in a correct bin for simple, energy-efficient disposal and less environmental impact.

Test

1 Match the following waste with its types and disposal technology

2 Match the following waste types with their recycled and upcycled products

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Appendix :

Solid waste composition analysis

Objective

To study the physical composition of waste from the selected source

Principle

Municipal solid waste from various sources has different composition, which shall be useful information for predicting waste management approaches in the next step. Composition of waste can be divided into:

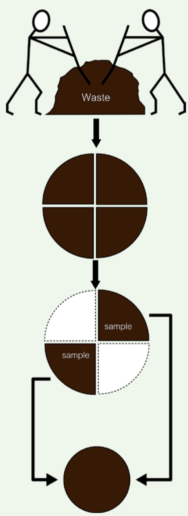
- Leftover food, vegetable, fruit
- Paper
- Plastic and foam
- Rubber
- Leather
- Textile
- Wood
- Glass
- Metal
- Stone and ceramic
- Hazardous waste, e.g. battery, fluorescent lamp, chemical product
- Others, as seen from the pile

Tools and equipment

1. Rubber textile, plastic tablecloth or sheet for waste sorting
2. Rubber gloves
3. Respirator
4. Aluminum tray or plastic bag
5. Weighing scale
6. Tongs
7. Dryer

Testing Method

1. In case of a large amount of waste, gather the waste and use the quartering method until it weighs approximately 10% of the total waste to get a sampling of the waste in an adequate amount for the next step and the analysis. In case of a low amount of waste, use all the waste for the analysis.



Waste Gathering and the Quartering Method

2. To calculate composition of waste with fresh weight:
   a. Sort waste into different types (Table 1)
   b. Calculate percentage of each waste type using the formula (1)
3. To calculate composition of waste with drying method:
   a. Sort waste into different types
   b. Weigh each waste type
   c. Dry the sampling at 75 °C for 4-5 days until its weight is stable
   d. Weigh each dried waste type
   e. Calculate percentage of each waste type using the dry weight and the formula (1)

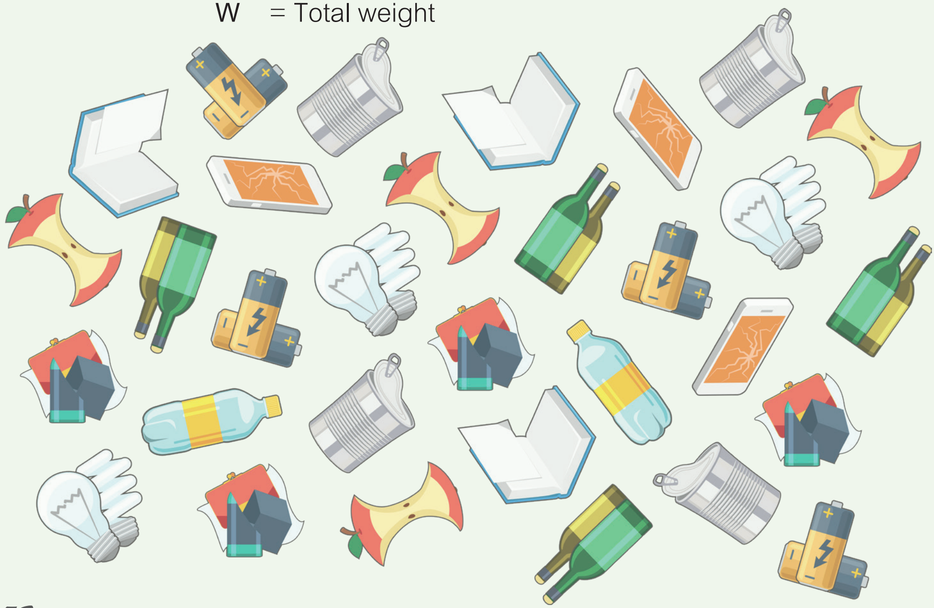
$$Ci = \frac{W_i}{W} 100 \qquad (1)$$

Where:

C_i = Percentage of the type i waste in the pile

W_i = Weight of the type i waste

W = Total weight



Waste Composition Analysis Report

Reporter name..

Date of test...

Analysis Result

Waste source ....

Waste Type	Weight		Percentage (%)	
	Fresh (g)	Dried (g)	Fresh Weight	Dry Weight
Leftover food, vegetable, fruit				
Paper				
Plastic and foam				
Rubber				
Leather				
Textile				
Wood				
Glass				
Metal				
Stone, ceramic				
Hazardous waste				
Others				
Total				

Test keys

1 Please choose the solid waste, type of solid waste, and proper technologies management

2 Please match the type of plastic and the upcycling products