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TOGETHER, WE'LL SUSTAIN AFRICA'S SEAS.

AFRICAN RESOURCE BOOK:

A GUIDE TO PLASTICS

CHAPTER 2

Plastics from raw material to end-of-life

*Written and compiled by **Annabé Pretorius***
Plastics SA

All plastics undergo a continuous process of value being added (or taken away) in the plastic value chain. The plastic value chain includes the sourcing of raw materials to produce the plastic, the production of plastic monomers and polymers, polymer modification, converting the polymers into plastic products, and then, after being used, their disposal. This chapter briefly explores these steps, particularly the different processing techniques used to convert raw plastic materials into finished products.

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2.1. Abbreviations and acronyms

ABS	acrylonitrile butadiene styrene
DMC	dough moulding compound (prepreg used in unsaturated polyester processing).
EP	epoxies
FRP	fibre reinforced plastics/polyesters
GRP	glass reinforced plastics/polyesters
ISWA	International Solid Waste Association
L	litre
LNG	liquified natural gas
MMt	million metric tonnes
MRF	material recovery facility
MSW	municipal solid waste
PA	polyamide, also called nylon
PC	polycarbonate
PE-HD	high density polyethylene
PE-LD	low density polyethylene
PE-LLD	linear low-density polyethylene
PET	poly(ethylene terephthalate)
PETG	poly(ethylene terephthalate) glycol
PMMA	poly(methyl methacrylate)
PP	polypropylene
PS	polystyrene
PS-HI	high impact polystyrene
PVC	poly(vinyl chloride)
SANRAL	South African National Roads Agency
SMC	sheet moulding compound (prepreg used in unsaturated polyester processing)
UP	unsaturated polyester
UV	ultraviolet light

2.2.

Introduction: Plastics for Africa

A brief history of plastics

In the middle of the 19th century, scientists were investigating modifying natural materials into materials with better processing characteristics. Until then, most products were manufactured from natural substances like wood, metal, ceramics, and paper. It was, however, difficult to mass-produce products from these natural materials. In 1832, Professor Henri Bracconot studied the effect of concentrated nitric acid on cotton and wood fibres (Brittanica n.d.). A few years later, in 1846, Christian Frederick Schonbein, a professor at Basel University, succeeded in creating a substance by adding a mixture of nitric and sulphuric acid to paper. The material formed was a transparent substance, cellulose nitrate, or, as Schonbein called it, gun-cotton. This material had the properties of plastic, but it also had explosive properties, and for this reason, Schonbein is regarded as the founder of the explosives industry.

It was only years later, however, that an English metallurgist, Alexander Parkes, established cellulose nitrate as a commercial plastic. On 12 December 1865, Parkes displayed a collection of small objects made from plasticised cellulose nitrate. Possible uses for this material included *"knife handles, combs, brush backs, shoe soles, floor cloth, whips, walking sticks, umbrella handles, buttons, braces, buckles, bookbinding, chemical taps and pipes, photographic baths, battery cells, fabrics, sheets and other articles for surgical purposes and works of art in general"* (White 1998).

During the years immediately before the Second World War, great emphasis was placed on developing modern plastic materials that could be used in equipment necessary for war.

Germany, in particular, put significant pressure on their scientists to produce these new materials. By 1939, the USA was the world's leading plastics producer with 125 000 tonnes, followed by Germany with 75 000 tonnes. By the end of the Second World War, in 1945, the output had increased enormously. Plastics available at this time included polystyrene, a wide range of vinyl plastics, acrylics, and polyethylene. Synthetic rubbers also developed rapidly during this time.

The development of plastics did not stop after the war, even though the market for these wartime materials largely diminished. Development continued, and today, about 45 different types of plastic polymers are commercially available, partly due to better processing methods and greater possibilities in the manufacture of processing machinery.

Plastics in Africa

Plastics have been mass-produced since the 1950s (Geyer et al. 2017) and introduced to Africa a little later, at the end of that decade (Jambeck et al. 2018). Since then, their use has exploded in different spheres of society, and they serve crucial functions such as the safe distribution of clean water (Stoler et al. 2012). Plastics are now also produced in Africa, albeit at low rates.

As by-products of energy fuels, the global plastics industry largely hinges on the global economic outlook of crude oil, gas, and coal. This is no different in Africa, where the feedstock used to produce plastics primarily originates from oil and liquefied natural gas (LNG). However, coal is a major feedstock in South Africa. Nigeria, Egypt, and Algeria produce approximately 6% of the world's share of natural gas. Other significant gas resources in Africa are in Angola, South Africa, Tanzania, and Mozambique.

There are only three polymer-producing countries in Africa. AE & CI started the first PVC plant in South Africa in 1955. This was followed by a PVC plant established in Egypt in 1987. Today, South Africa produces PE, PP, PET, and PVC, Egypt produces PE, PP, and PVC, and Nigeria produces PE, PP, and PET (Plastics SA 2023; Yahia 2013; World Bank 2020).

Most plastic demand in Africa is met by importing raw materials for manufacturing and manufactured (finished) goods.

Plastic product manufacturing is guided by population growth, the gross domestic demand, and the general economy of a nation. The demand for plastic goods on the continent, consumption, and production is lower than in other parts of the world. In 2021, the per capita consumption of plastics in Africa was 45 kg, while 115 kg in the EU. Consumption between countries varies substantially, though – For example, 2 kg per capita in Côte d'Ivoire in 2018 and 26.7 kg per capita in South Africa in 2021 (Plastics SA 2023). Yet, Africa is considered the second most polluted continent (Jambeck et al. 2015). Although not the largest waste producer per se, African countries – Egypt, Nigeria, South Africa, Algeria, Morocco, and Tanzania – are among the 20 largest contributors to mismanaged plastics waste, in other words, waste that is not disposed of and processed correctly which has the potential to become plastic pollution (Jambeck et al. 2015; Lebreton and Andrady 2019). Despite the difficulties of acquiring accurate and up-to-date estimates from the waste management sector in African countries (Jambeck et al. 2018), it is clear that waste is a persisting challenge (UNEP 2018).

1 See Chapter 1: *Plastics: Their properties and applications* for more on polymers and the different types in use.

2 See also Chapter 3: *Sources, pathways, and drivers of plastic pollution*.

As the need for plastic increases as Africa's population and middle class grow (Cartwright 2016; UNEP 2018), the waste problem is expected to worsen (Lebreton and Andrady 2019). The lack of sufficient waste management infrastructure is the primary driver of increasing waste and pollution, with large proportions of waste ending up in open (unmanaged) dumpsites (UNEP 2018). Waste can be disposed of and processed in various ways, including landfilling and recycling. Some end-of-life options are expensive and require advanced skills and training, which are currently limited in many African countries (UNEP 2018).

Mechanical recycling is the preferred, responsible end-of-life solution in Africa. In the last couple of years, South Africa managed to recycle 22 to 23 % of all locally made products into raw materials for the local manufacture of other products (Plastics SA 2023). There are also mechanical recyclers in Kenya, Nigeria, Mozambique, and other more affluent African countries, as recycling requires fair amounts of private capital investment and local markets for the recyclate. Since Africa recycles only 4% of the waste generated, it has become a dumping ground for waste, particularly hazardous waste, often imported from developed countries. The current situation is a far cry from the African Union's vision that "African cities will be recycling at least 50% of the waste they generate by 2023" (UN 2018). There is little empirical data on recycling in Africa because the collection of recyclables is usually carried out informally at the household level or by the informal sector (Wilson et al. 2009; CSIR 2011; Godfrey et al. 2016). The informal sector (e.g., itinerant buyers and waste pickers) recovers most post-consumer recyclables, such as ferrous metals, plastics, glass, and paper, and supplies them to recycling businesses.

The plastics value chain

Plastics manufacture, use, and eventual disposal – including recycling - are links in the plastics value chain.

The term has since been used in a broader context to include the disposal stage of a product. So, the plastics value chain includes all the activities and stakeholders involved in sourcing the raw materials to produce monomers, production of the polymers (polymerisation), all the activities involved in converting these polymers into finished plastic products, retail, and making the finished products available to consumers, consumption (i.e., use) by the consumers, and, eventually, disposal or the end-of-life stage of that product, including the various waste management options (Figure 2.1).

There is always some form of distribution between each link in the value chain, even if not illustrated for every instance (Figure 2.1). Care must be taken during these specific forms of distribution to avoid material ending up in the environment. The first significant distribution step is where raw material is transported in bulk to plastics processors in shipping containers, road tankers, and bags (small or bulk) by road. Accidents happen, and products may fall off trucks, get stuck on conveyors, or get damaged during distribution, causing environmental spills. The second distribution is where products are transported to retailers or consumers. During this stage, products and packaging can also sustain damage during distribution and spill. The last distribution step is the waste management material flow. Even formal waste management collection has materials that end up in the environment due to irresponsible behaviour or lack of suitable containers or transport. So, distribution between steps in the value chain is an important activity, not only to add value to a product but also to prevent waste from ending up in the environment and becoming pollution.

In this chapter, we briefly introduce the main components of the plastics value chain[4], emphasising the various manufacturing processes used to produce the vast array of plastic consumer goods available today. We conclude this chapter with a brief look at the main ways we process plastic waste in Africa.

The term *value chain* was originally developed for economics, and referred to all the steps of product manufacture and distribution that adds value to a product[3].

3 Harvard Business School Online (https://online.hbs.edu/blog/post/what-is-value-chain-analysis).

4 We spend more time on the value chain in *Chapter 8: An introduction to the circular economy*.

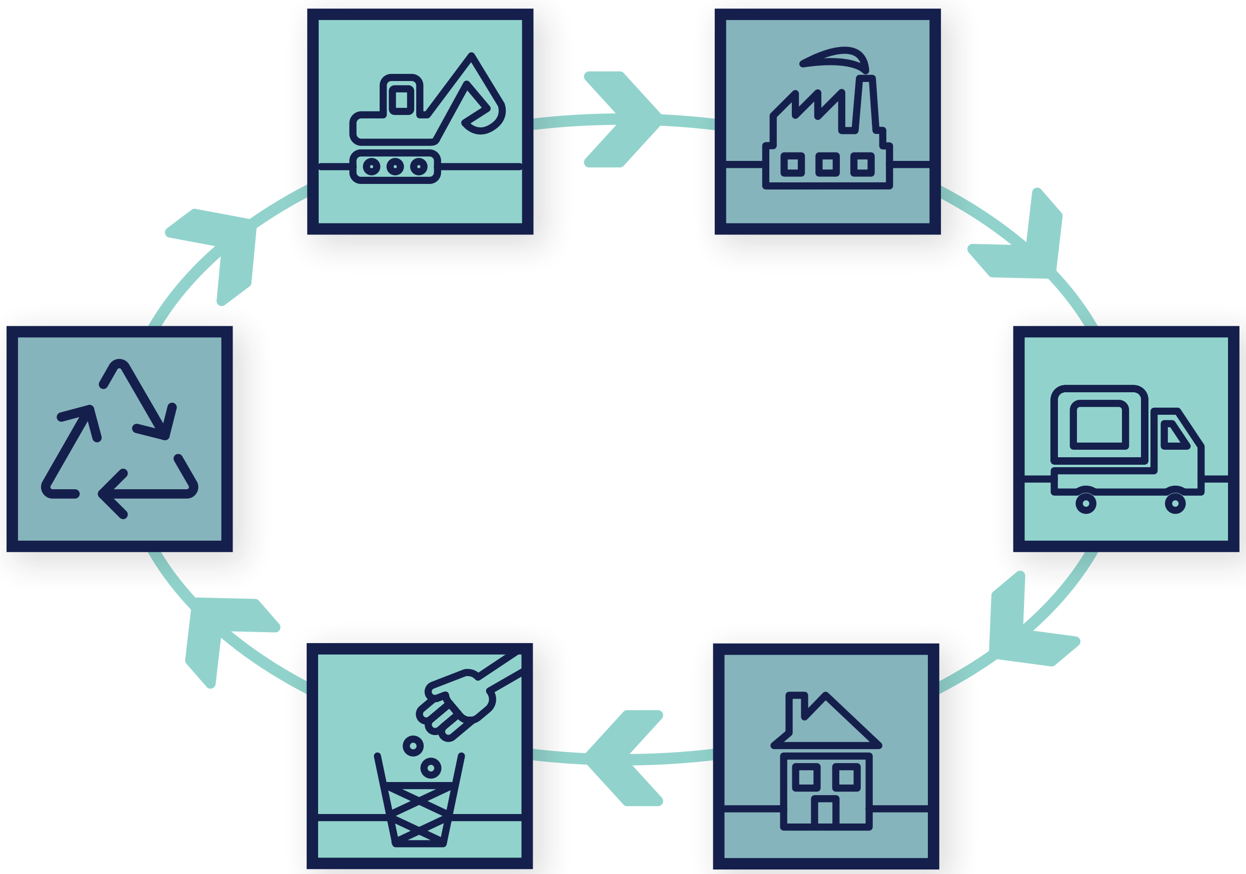


***Figure 2.1**: The plastics value chain.*

2.3.

Producing polymers for plastics

The first steps in the plastics value chain involve extracting the chemicals used to make the raw materials, or basic building blocks, for plastic and producing and preparing polymers.

2.3.1. FROM RAW MATERIAL TO MONOMER TO POLYMER

Plastics, like most synthetic organic materials, originate from fossil fuels, or petrochemicals, such as crude oil, natural gas, and coal[5]. More than a thousand hydrocarbon components can be sourced from crude oil, which are then used to produce a myriad of synthetic chemicals. In Europe, as in the rest of the world, only about 4 to 6% of all oil and gas reserves go towards producing plastics[6], with the rest used for transport, electricity, heating, and other applications. Most of the plastics in use today are derived by the following steps:

- **Raw material extraction** of largely crude oil, natural gas, and coal, resulting in a complex mixture of thousands of compounds.
- **The refining process**, transforms crude oil (the mixture of compounds) into different petroleum products, including the monomers used to produce plastic polymers.

In the refining process, crude oil is heated in a furnace and then sent to the distillation unit, where heavy crude oil is separated into lighter components called fractions (Figure 2.2). Examples of fractions include naphtha, paraffin, diesel, and bitumen used to pave roads. The fractions that come off during distillation are characterised by their boiling points and molecular masses. The fractions differ according to the country of origin of the crude oil.

Monomers, the building blocks of polymers, are derived from naphtha. The naphtha[7] portions can be split into small gaseous, unsaturated hydrocarbon segments during a further cracking process (whereby long complex chains of hydrocarbons are broken down into smaller ones), resulting in the monomer ethylene, among others. Ethylene obtained in this manner is one of the most important raw materials used in the chemical industry, including plastics production[8]. can also be derived from the fractions of natural gas or the residual gas from processing coal.

Most plastics in use today are petrochemically based because of the ease of manufacturing methods involved in processing crude oil. However, the growing demand for limited oil reserves is driving a need for novel plastics from renewable resources, such as waste biomass and animal waste products. A small but growing portion of plastics are biobased. These are produced from renewable products such as carbohydrates, starch, vegetable fats and oils, bacteria, and other biological substances.

5 Some plastics may also be derived from biological material, such as sugar cane, cellulose, or vegetable oil (see *Plastics: Their properties and applications*).

6 See https://www.bpf.co.uk/plastipedia/how-is-plastic-made.aspx.

7 The fractions obtained from naphtha are olefins (ethylene, propylene, butylene) and aromatics which include benzene, toluene, and xylene. Most plastics are produced from these raw materials.

8 Ethylene is the monomer of polyethylene plastics, which is the most commonly available and produced plastic if we ignore plastic fibers, making up 36% of the global market (see Geyer et al. 2017).

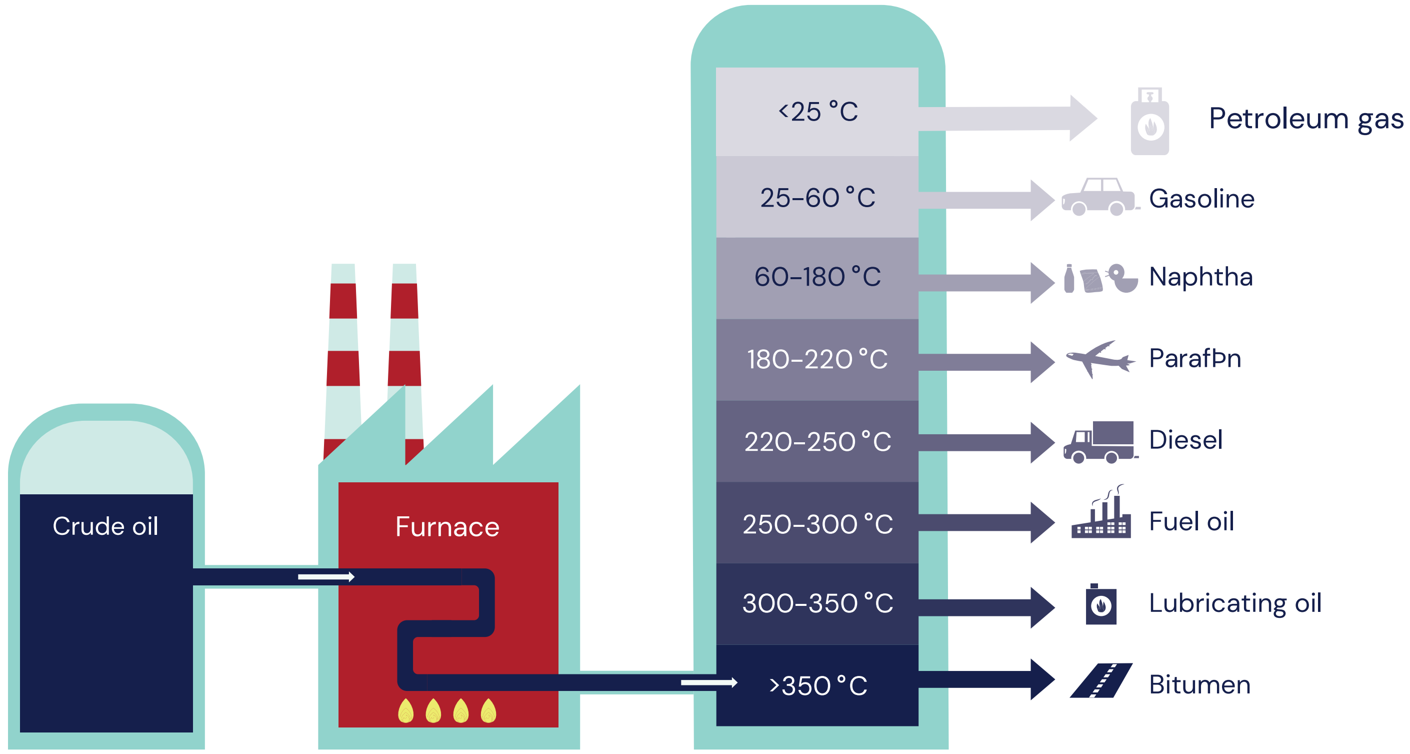


***Figure 2.2**: Schematic representation of fractional distillation of crude oil (Source: British Plastics Federation – https://www.bpf.co.uk/plastipedia/how-is-plastic-made.aspx).*

2.3.2. POLYMERISATION: FROM MONOMER TO POLYMER

Monomers are joined in a process called polymerisation to form the polymers that make up a particular type of plastic.

A. Polymer modification

Usually, plastic polymers can only be processed into new products in their original form with the addition of some processing agents. It may also be necessary to add certain modifying and protective additives to polymers to achieve the desired properties of the final product. Often, polymer producers add all the necessary additives to plastic raw material before it is distributed, and converters can use these without any further changes. For some plastics, though, such as PVC, UP and EP, converters must make their additions on the shop floor to render these polymers usable.

Additives are chemicals added to plastic to incorporate specific properties absent in the (pure) plastic polymers. Modifying additives are used to change the final properties of the polymer (and hence the final plastic product) and include plasticisers, extenders, dyes or pigments, fillers, flame retardants, foaming or blowing agents, and anti-static agents. Protective additives help to protect polymers during the manufacturing process and include lubricants, ultraviolet (UV) absorbers, antioxidants to prevent oxidation (degradation) of polymers, and stabilisers to protect against heat, moisture, UV, and oxygen damage.

B. Formats of raw materials

Additives are added to plastic materials in one of two ways: as a master batch or compound. A **master batch** is a concentrate of additives in a specific base material. For example, the converter will add a small quantity of blue polyethylene master batch to white high-density polyethylene material to make light blue bottles. Alternatively, a **compound** can be prepared. Compounding is the process used to mix the various additives into the plastic matrix (i.e., the polymers) and process the mixture so that the final mix – or compound - is similar in appearance to virgin plastics, i.e., small pellets. Mixing occurs by melting the various substances together, called **melt-blending**, often with an extruder of some type (see Section 2.4 below); pellets are then made of the mixture, ready for use by the converter. In compounding, instead of adding a blue master batch to white polyethylene, for example, the converter could order blue compound in exactly the required shade of blue to manufacture his light blue bottles. Master batch is the preferred and more cost-effective option, though. For some plastics, the converter's equipment is not good enough for consistent blends, and compounding is then the only option, for example, when working with PVC powders, polycarbonate (PC), unsaturated polyesters (UP), and epoxies (EP).

The plastic raw materials, generally with their additives and processing agents already added, are prepared in various formats for distribution to converters (Figure 2.3). As mentioned earlier, most of the thermoplastic materials are supplied as **pellets.** Pellets have cylindrical or lenticular shapes of about 2 to 3mm in diameter or length. In some cases, thermoplastic materials are supplied as a **paste**, e.g., PVC, to manufacture impregnated cloth. Plastics in powder form are used when additives are added to the polymer shortly before processing, e.g., PVC, or where a high melting rate is required, e.g., rotational moulding (see Section 2.4). Solid thermosetting **powders** are supplied with additives already added by the producer.

Thermosetting plastics such as unsaturated polyesters, epoxy, polyurethane, or methacrylate resins are prepared as liquid curable moulding materials called **reaction resins.**

In contrast to moulding materials, semifinished forms are processed by any of the basic production processes, like injection moulding or extrusion (see Section 2.4). They are reformed or reshaped by thermoforming, shaping, or cutting and joining into the final products. **Film** and **sheets** are flexible, flat products that are mainly supplied in rolls either of full width or slit into narrow webs to satisfy demand. **Panels** are thick, flat products supplied in specific sizes. **Blocks** are rectangular or cylindrical semi-finished stock of large cross-section.

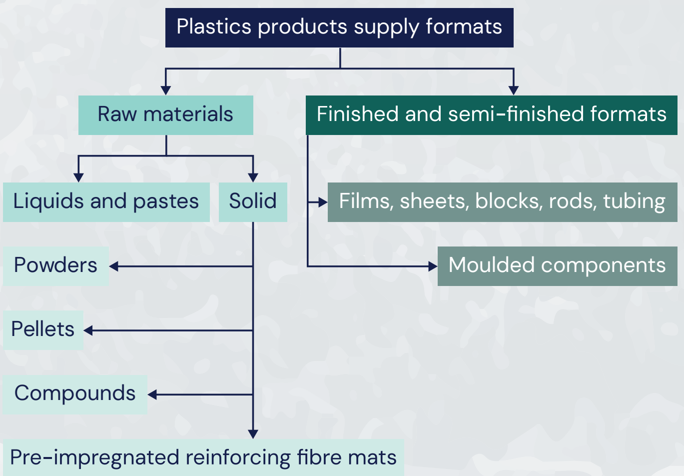


Figure 2.3: The different forms, or formats, of plastic raw materials, as used by the converters.

9 These additives are described in more detail in Chapter 1: *Plastics: Their properties and applications.*

2.4.

Plastics processing

Processing methods have been developed over decades to suit the various materials and enable the producer to manufacture various products.

One of the advantages of plastic polymers is that they can be processed, i.e., converted, to manufacture finished products or semi-finished components quickly, efficiently, and consistently, unlike alternative materials such as metals, which require more processing steps.

Notably, the scrap resulting from plastic processing is expensive, and the converter must, therefore, control and limit the amount of waste produced. Most converters can utilise their waste to manufacture the same or different products or outsource the waste to a service provider for management.

Various processing methods are available, but not all are suitable for all plastic polymers. The thermal properties of the raw material, such as its melting point, its physical nature (i.e., whether it is in a liquid, pellet, or powder format), and the ultimate quantities required, as well as the final product application – or the product produced - all determine the most suitable process. So, thermoplastic and thermosetting plastic products are produced using different methods. In **Chapter 1: *Plastics: Their properties and applications***, we discussed the different groups and types of plastics, their polymer chemistry, characteristics, and intended uses. In this section, we describe the different processing methods used to produce the various types of plastic products. The basic principles of these processing methods are described by Woebcken (1995) and summarised below.

10 Thermoplastics, which include PET, polyethylene, polypropylene, polystyrene, PVC, and engineering plastics, for example nylon, can be repeatedly softened and hardened by heating and cooling, respectively. Thermosetting plastics, such as epoxies and phenoplasts, cannot soften again when heated once they have been formed. See Chapter 1: *Plastics: Their properties and applications* for more on the different groups of plastics.

2.4.1. ROTATIONAL MOULDING

Rotational moulding produces large hollow products from thermoplastics, mainly linear low-density polyethylene (PE-LLD) powder. Products or items with complicated closed or open shapes with volumes of up to 15 000L, diameters of 2m, and lengths of 2.5m and more can be produced using this processing method. Rotational moulding has specific advantages over other manufacturing methods. The equipment and moulds used in rotational moulding are cheaper than blow moulding, especially injection moulding. Rotational moulding is also very suited to produce large articles almost free of stress and with even, adequate wall thicknesses. These properties are essential for producing transport and storage containers, water tanks, septic tanks, and even swimming pools.

Rotational moulding is a simple process (Figure 2.4). A mould that can be heated is filled with the correct amount of moulding powder. As soon as the mould is heated, the powder softens and gels onto the inner walls of the mould. This is followed by a cooling period. During heating and cooling, the mould rotates around two axes to ensure that the heated polymer coats the mould contours evenly. The rotational speed can be up to 30 revolutions per minute. Rotational moulding is performed at normal air pressure (see **extrusion** for comparison).

2.4.2. CALENDERING

Calendering is the shaping of plastic compounds between two or more rolls to form a continuous sheet. The calendering process is especially important for producing plasticised (soft) PVC film and sheets for shower curtains, coated leather-like cloth, tarpaulins, footwear materials, and more. Other thermoplastics that can be processed this way include polypropylene, polystyrene, some styrene copolymers (e.g., ABS), polyethylene grades, polyurethane, and certain polyamide (PA) grades. Because of the high costs involved and the high production rate, this process is used by only a few manufacturers globally.

The calendering process begins with a dry mix of PVC and additives prepared and plasticised into a homogeneous (well-mixed) melt. This softened moulding compound (the plastic) is then transported onto the rolling mill and flattened under heat and pressure (Figure 2.5). A rotating knife cuts off a strip fed continuously into the calender at a particular stage. The calender, or calender train, consists of a series of pairs of (heated) rollers. The gap between two rollers through which the moulding is fed is called a nip. Retaining shoes prevent the moulding compound from running off on the sides of the calender rolls. As the plastic moulding moves between the rollers, it is flattened to a consistent, even thickness.

The newly produced film or sheet can be embossed whilst still soft and warm. Other post-treatments that may be performed include printing, which is done by means of roto-gravure machines; for specific applications, a velvet-like surface can be created for sheets by means of *flocking*, films can be metallised (this takes place under high vacuum), foam backing can be added to sheets, or sheets can be coated for a glossy look, among other things, in a process called lacquering. Thereafter, the film or sheet is cooled over several cooling rolls before its edges are trimmed. Finally, the cold film is wound into large rolls at the end of the calender.

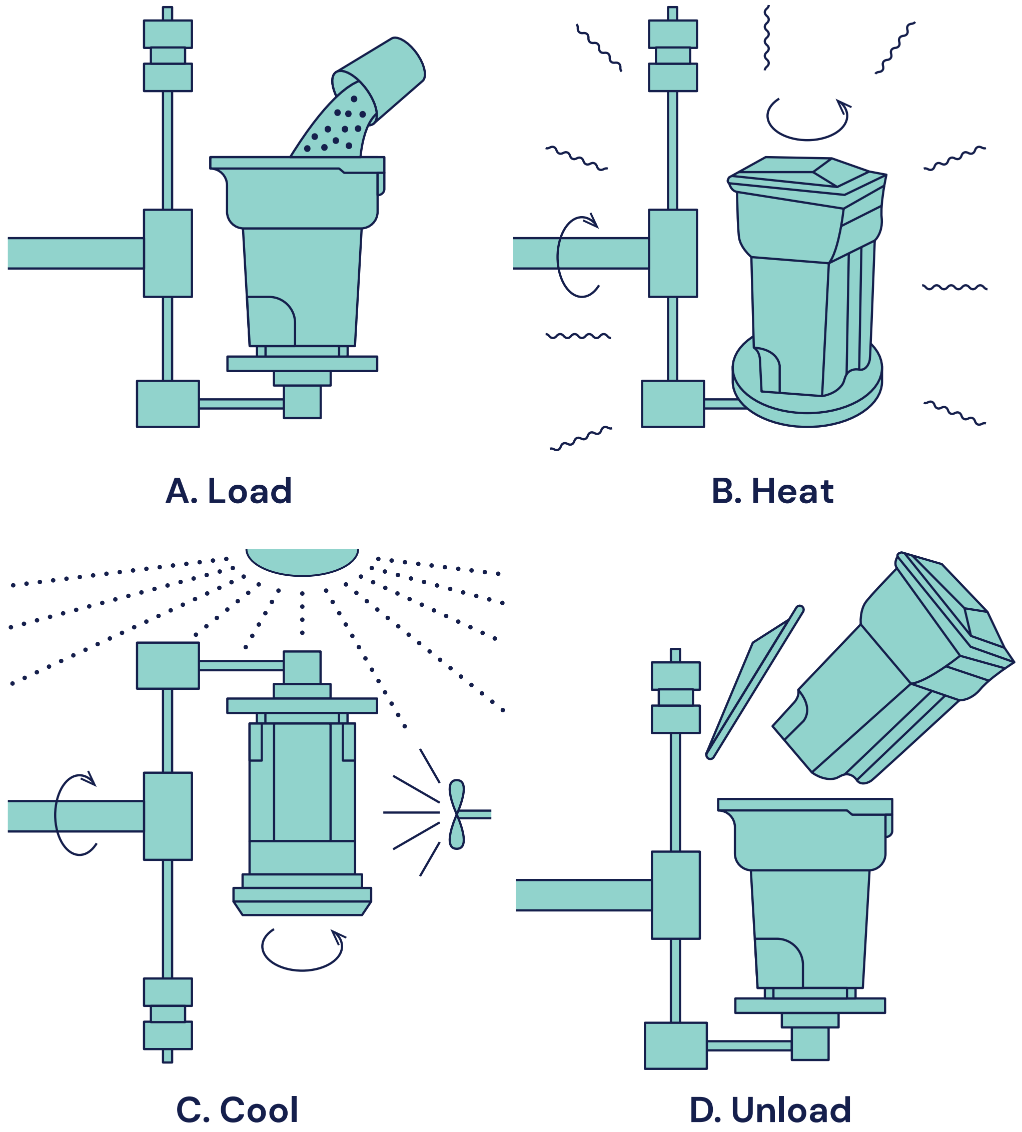


Figure 2.4: *Rotational moulding. The mould rotates around two axes to ensure that the softened polymer coats the mould contours evenly.*

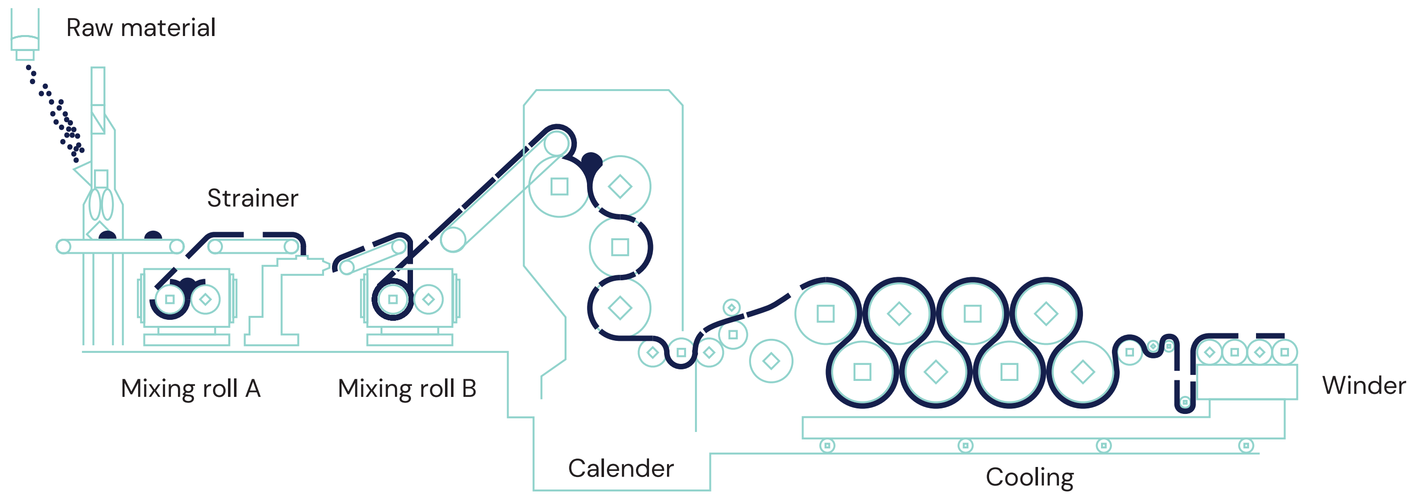


Figure 2.5: *Calendering: Producing sheets and films.*

2.4.3. EXTRUSION

Extrusion is when a thermoplastic material is continuously forced through a die at a constant cross-section, producing long, continuous pieces of plastic of a consistent shape (Figure 2.6A). The die is the part of the extrusion machine that determines the diameter and shape of the final plastic product. The raw material – plastic pellets or powder – is placed in the hopper and fed into the heated extruder barrel. A rotating screw inside the barrel moves the plastic material forward, compressing, melting, homogenising (mixing), and eventually forcing it through the die. The shape of the die and the subsequent auxiliary equipment (the other parts of the extrusion machinery) are determined by the end product, which could be a pipe or profile (that is, a customised shape), film, sheet, or cable. The extrusion process for each of these applications is briefly discussed below.

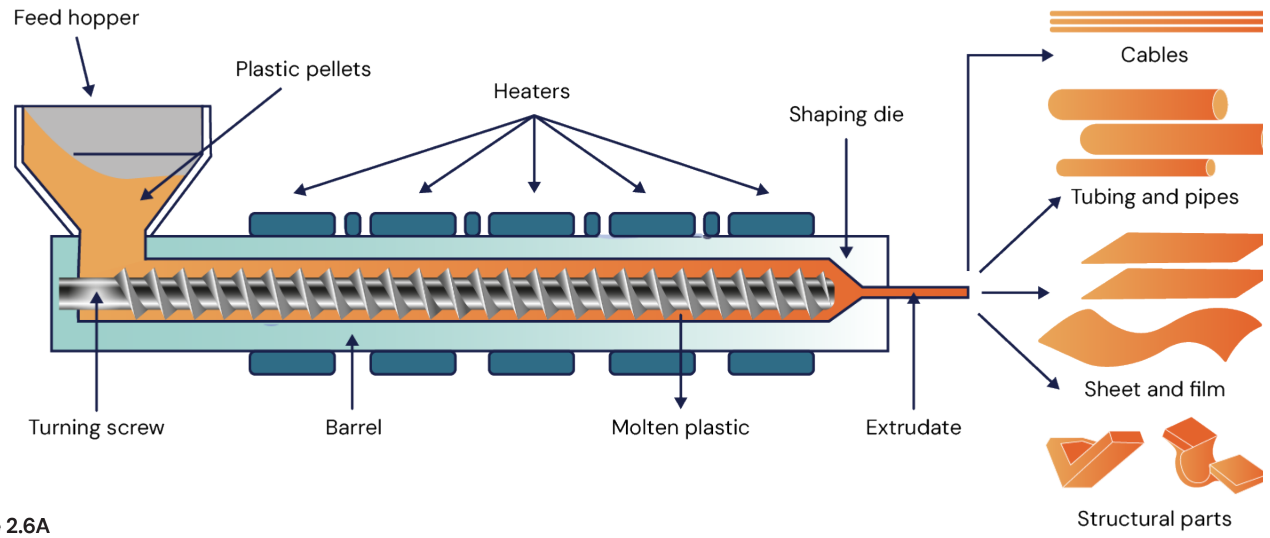


Figure 2.6A

A. Pipe and profile extrusion

To form a pipe, the die gap must be circular or ring-shaped. This is achieved by putting a mandrel in the die opening (Figure 2.6B). The melt is divided by the tip of the mandrel, called the torpedo. A spider or a perforated ring supports the mandrel in the die. The melt flows smoothly around the torpedo through the holes of the spider to the die gap. The die gap is larger than the cross-section of the pipe to allow for shrinkage during cooling. A haul-off unit draws the newly formed plastic pipe - here called the extrudate - from the extruder at a steady rate. Pipes have a standardised outside diameter and are calibrated accordingly. The shape is maintained by cooling off the pipe in water baths or using water sprays. The pipe or profile can be wound up or cut into specific lengths, as required. Some of the plastics used for pipes and profiles are rigid and flexible poly(vinyl chloride) (i.e., PVC-U and PVC-P), high-density polyethylene (PE-HD), polypropylene (PP), nylon (PA), and styrene, ABS.

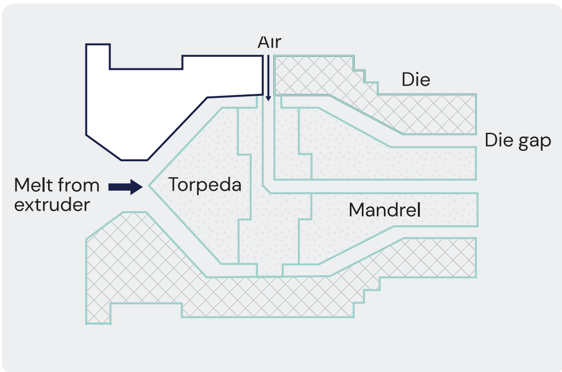


Figure 2.6B

B. Film extrusion

Earlier, we discussed the production of films and sheets using calendering. Films can also be produced through extrusion, specifically, blown film extrusion. Plastics suitable for the manufacture of blown films are low-density polyethylene (PE-LD), linear low-density polyethylene (PE-LLD), high-density polyethylene (PE-HD), PP, PVC, and foamed polystyrene (PS). Products produced include shopping bags, bags for dried food like rice, sugar, etc., sachets for linen and clothing, plastic pockets for your filing system and the initial start of the polystyrene sheeting from which trays would be made.

In blown film extrusion (Figure 2.6C), the melt is forced through a tubular die upwards or downwards in a 90-degree direction. Air is introduced into the tube to form a bubble. The outside of the tube is cooled with cold air. Flattening boards guide the tubular film towards the nip of the nip rolls. (Figure 5c). After the nip rolls, the film is led downwards over guide rollers and is wound up either as a lay-flat tube or slit open along the side as flat sheet film. The film can be used as is or can be converted into bags.

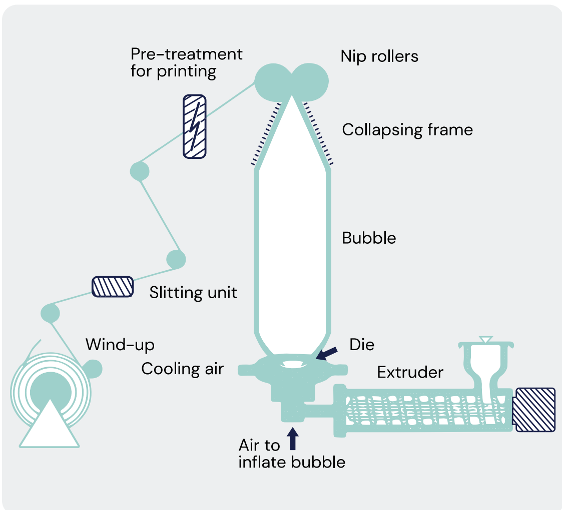


Figure 2.6C

C. Sheet extrusion

Plastic sheets are manufactured in a process called sheet extrusion into thicknesses ranging from 0.8mm to 10mm and are produced mainly from ABS, PMMA (acrylic), PE-HD, PP, PVC, and PS. These sheets are used to produce shower doors, mirrors, skylights, bathtubs, roof sheeting, light covers and numerous thermoformed products (more about this later).

To produce flat sheets, the die spreads the melt laterally (Figure 2.6D). Using a three-roll polishing stack, the soft sheet is calibrated or polished to ensure the sheet is of the correct thickness. The required thickness is obtained by adjusting the gap between the first two rollers of the stack. The sheet winds around one roll until it reaches the second nip, where the final polishing and minor thickness adjustments occur. The second contact roll can be textured to impart a surface finish to the sheet. This could simulate a wood grain, a leather finish or a diamond pattern for improved light diffusion, as seen in light diffusers used as light covers for ceiling lights. The sheet moves towards the haul-off via an air-cooling section from the last roll. The sheet is then cut to size and stacked.

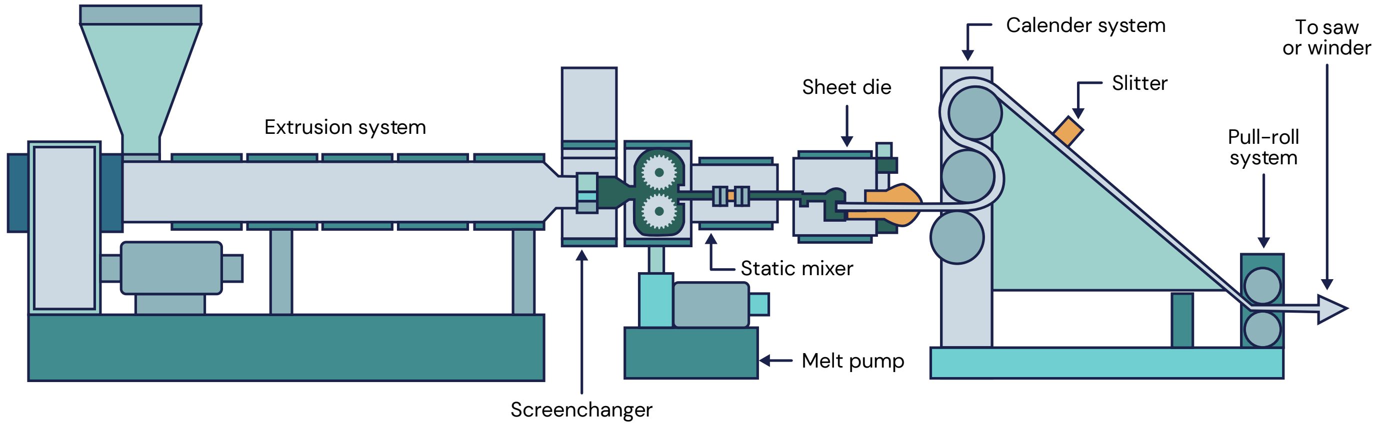


Figure 2.6D

D. Cable extrusion

In some applications, metal or copper wires are coated with plastic using cable extrusion. The plastic coating provides insulation and protection for the cables, typically those used in telecommunication and electrical applications. Ropes, pipes, and tubes are coated similarly. Even rigid materials such as wood, steel, and aluminium can be coated for protection, waterproofing or decoration. In this way, fencing, curtain rails, broomsticks, lead pencils, and decorative strips for the automotive industry are produced. Polyethylene, PP, and PVC are suitable for wire and cable coating.

In cable extrusion, the wire to be coated is pulled through a crosshead die (Figure 2.6E), where it is covered by the melt. Crosshead dies turn the melt 90 degrees and apply an even plastic coating around the bare wire or substrate to be coated. The coating is cooled by moving it through a cooling trough. For high speeds, the cooling trough can be very long. An in-line testing device ensures that the desired wire specifications, such as thickness and concentricity, remain within the set parameters. The coated wires are wound up at the production line's end.

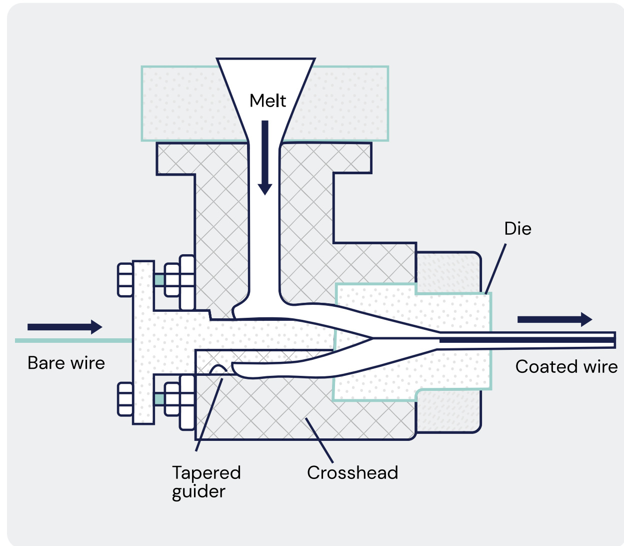


Figure 2.6E

Figure 2.6: *A): The basic extruder used for the production of pipes, cables, sheets, profiles, and films; B) die and mandrel used to extrude pipes; C) film extrusion with tubular die; D) extrusion with three-roller polishing stack used to produce sheets, and E) a crosshead die used in cable extrusion.*

2.4.4. INJECTION MOULDING

Injection moulding involves molten plastic being forced into a mould, where it cools and solidifies. Unlike extrusion, therefore, the shape of the die does not determine the final product; it is the mould. Injection moulding is used to mass-produce detailed, high-precision products, often not requiring additional finishing after production.

The use of plastics for injection moulding is well established, and new applications are continuously being developed. Injection moulding is used extensively in the packaging, toy, electrical, and precision engineering industries. Household appliances, transport containers, furniture and automotive industries, sectors of the machine building industry, the construction industry, and even the aerospace industry all use plastic injection-moulded parts. Depending on the equipment, thermoplastics, thermosets, and elastomers can be processed using injection moulding.

The injection moulding system consists of three broad parts: the injection unit, the mould, and the clamping unit (Figure 2.7). The injection unit, which contains the hopper, barrel, and rotating screw, must melt, transport, and eventually inject a *pre-determined* quantity of plastic into the mould. An electrical heater heats the barrel. The screw is driven forward by an electric or hydraulic motor while also rotating around its axis (an axial movement) by means of a piston in a hydraulic cylinder. The screw injects the melt from the barrel, under pressure, through the nozzle, into the mould cavity.

The mould determines the shape and dimensions of the end product; there are many different injection mould designs. The sprue (in the sprue bush) connects the nozzle and the mould cavity via a network of runners.

The injection mould consists of two parts that are closed before injection takes place: One "half", which includes the sprue bush, remains stationary, while the other "half" is moved by the clamping unit to open and close the mould. The clamping unit is responsible for opening the mould and keeping it closed during the injection process, which means it must assert a *clamping force* larger than the pressure inside the mould cavity. An ejection mechanism in the moving half of the mould ejects the new plastic product (or the moulding) from the mould.

So, the injection moulding process can be described in four stages (Figure 2.7):

1. The rotating screw moves pellets from the hopper through the barrel and to the screw tips.

2. The mould is closed, the injection unit moves towards the mould, and the screw forces the melt into the mould (via the sprue and runners).

3. The moulding (the plastic product) is cooled and solidifies.

4. The mould opens, the new product is ejected by means of the ejector pins, and the screw moves backwards in the barrel.

A multi-cavity mould instead of a single cavity can produce cost savings. The machine produces more products per cycle when using multi-cavity moulds. When designing injection mouldings, the subsequent use of the end product, the material's properties, and the mould's construction must be considered. Post-finishing of the moulding should not be required; the new product ejected from the mould is the *final* product.

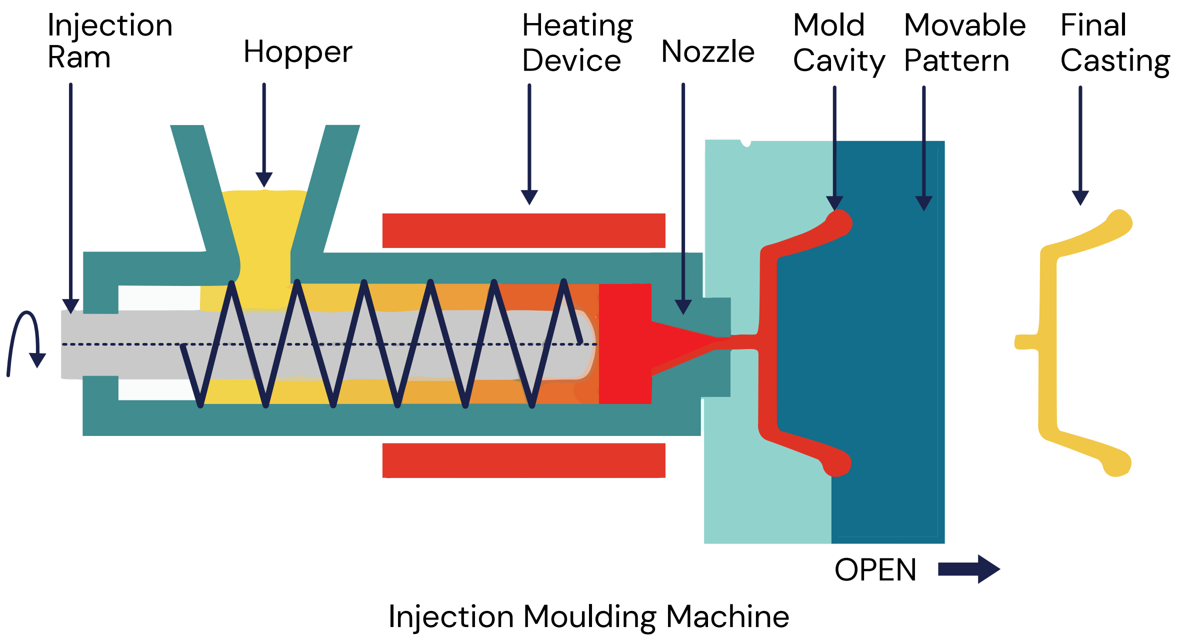


Figure 2.7: *Injection moulding.*

2.4.5. BLOW MOULDING

Hollow containers can be made using several different processes, such as rotational moulding (described earlier), extrusion blow moulding (EBM), and injection blow moulding (IBM). Blow *moulding* is the blowing-up of the heated plastic raw material, called the parison, in a two-piece hollow mould until the parison has accepted the shape of the cavity or mould. Both EBM and IBM use a mould to shape the end product. The two processes differ in how the melt is inserted into the mould. Differences in mould requirements and, consequently, the end products made further distinguish these two processes.

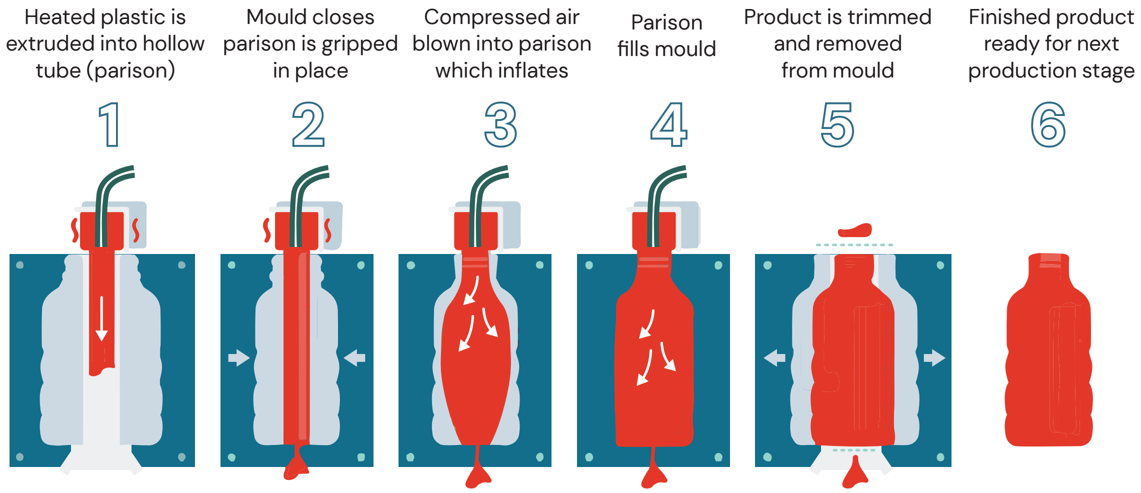


Figure 2.8

A. Extrusion blow moulding (EBM)

Extrusion blow moulding (EM) is used to produce products such as dairy product bottles, hand lotion, shampoo, motor oil, and pesticides. Popular materials for EBM are PE-HD, PP, PVC, and poly(ethylene terephthalate) glycol (PETG).

EBM is a two-stage process (Figure 2.8): Extrusion of a parison from a *down-facing* crosshead die, followed by the moulding of the tube in a blow mould to form a hollow body. The hot parison is shaped into the hollow product by blowing air into the clamped parison in the blow mould. The two halves of the mould are mounted on carrier plates, which form the clamping unit used to open and close the mould. The hot parison is extruded into the space between the two mould halves while the mould is open. Different crosshead dies are used for containers of different sizes and various types of plastic. The clamping unit seals the mould, clamping the parison in position to create a closed shape with only an opening for the blow pin.

A mandrel is used to form bottles and canisters with defined necks. Cold air is blown into the parison via the blow pin at a pressure of 6 to 8 bar, forcing the soft parison into the mould cavity to create the desired shape. The clamping unit keeps the two mould halves closed against this blowing pressure. The cold mould cools and solidifies the parison, after which the clamping unit opens the mould to release the new product.

The pinch-off section at the bottom ends of the product and the excess material at the neck area can be removed after production, either manually or in an automated process. After this, an orderly transfer to other devices, such as bottle testers, printers, labellers, and even filling machines, can take place. In fact, it is possible to produce a bottle such as a hand soap dispenser, label it, fill it with liquid soap and cap it in one continuous production line.

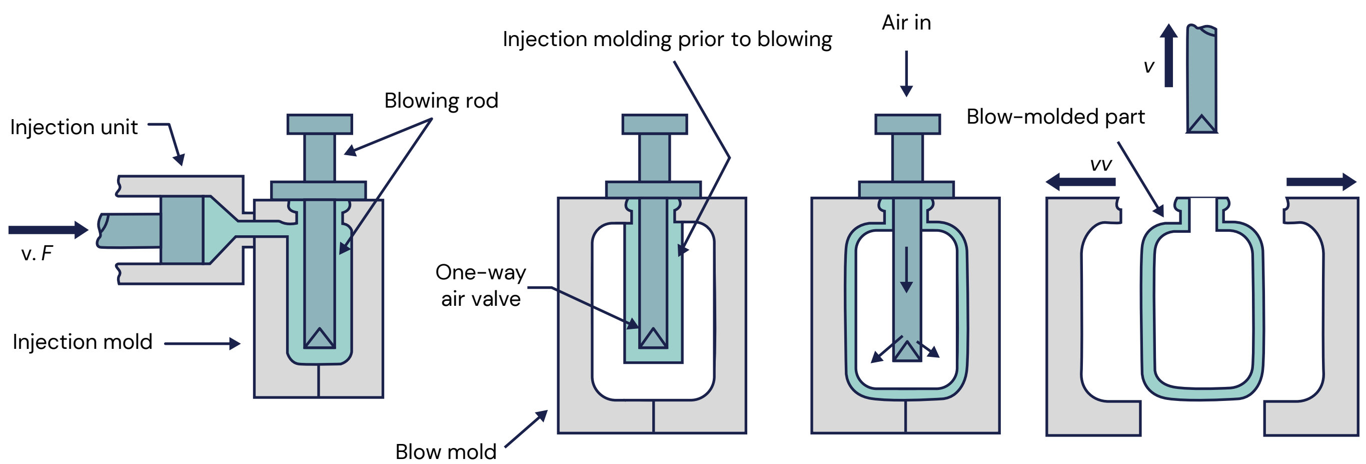


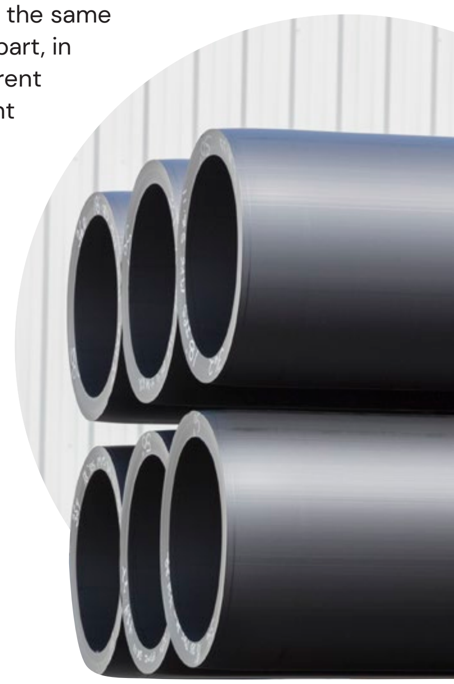
Figure 2.9: *Injection blow moulding (IBM).*

B. Injection blow moulding (IBM)

As the name suggests, injection blow moulding combines injection moulding and blow moulding. The advantage of having both processes is that you get the precision of injection moulding and the shaping possibilities of blow moulding. Production is done without top and bottom waste, as in extrusion blow moulding. Hollow products, mainly bottles, remain seamless at the neck and bottom and exact wall thickness is obtained. The process was developed for poly(ethylene terephthalate) (PET) to accommodate its very low melt viscosity and to facilitate the orientation of the bottle for reduced gas permeability and improved transparency[11]. The process is also used to blow hollow articles from PS, PP, and polyethylene, and is best suited for symmetrical products with even wall thickness. Extrusion blow moulding is better suited where intricate shapes and integral handles are required. An integral handle on a 5L motor oil bottle is only possible in PE-HD in extrusion blow moulding, whereas a 2L edible oil bottle with a handgrip is possible in PET in injection blow moulding.

A simple injection blow moulding machine consists of an injection mould, a blow mould, and a core (Figure 2.9). The injection mould is used to produce the preform, which can be a single cavity or multiple cavities. Molten plastic is injected into the injection mould around the core (or blow pin) to create the preform. The preform on the core is then transported from the injection mould to the blow mould by a core carrier. In the blow mould, the heated preform is blown off the core and into the mould cavity to take the shape of the cavity. After cooling, the newly formed product is released from the mould.

The injection of the preform and the blowing of the hollow product can occur immediately following each other, even in the same machine, or days or weeks apart, in different machines in different places, and even in different countries. If processed only later, the preforms will be reheated and positioned before being blown into the final shape.



2.4.6. THERMOFORMING

Thermoforming is the shaping of a heated thermoplastic sheeting using external forces into a moulding. Thermoforming, therefore, requires sheets formed by calendering or sheet extrusion. Amorphous materials (transparent plastics in their unpigmented form, like PVC or polystyrene) with a wide softening temperature range are ideal for thermoforming, while crystalline materials can be processed but require additional temperature and process controls. ABS, PMMA, PC and PVC sheets are exceptionally well suited for thermoforming automotive components, bathtubs, shower basins, skylights or suitcases. PET, PS-HI, PS-E and PP sheets are used to manufacture thin, low-cost packaging, such as fruit punnets, meat trays, takeaway food packaging and blister packs.

The sheet can be shaped using a vacuum or pressure to force the softened sheet into a mould (Figure 2.10). Variations of the thermoforming process were developed to accommodate the molecular alignment and the wall thickness distribution. Excess plastic is trimmed from the final product, so thermoforming generates a lot of scrap material. These trimmings (or skeletals) are recycled in-house to manufacture new sheeting, reducing the waste generated.

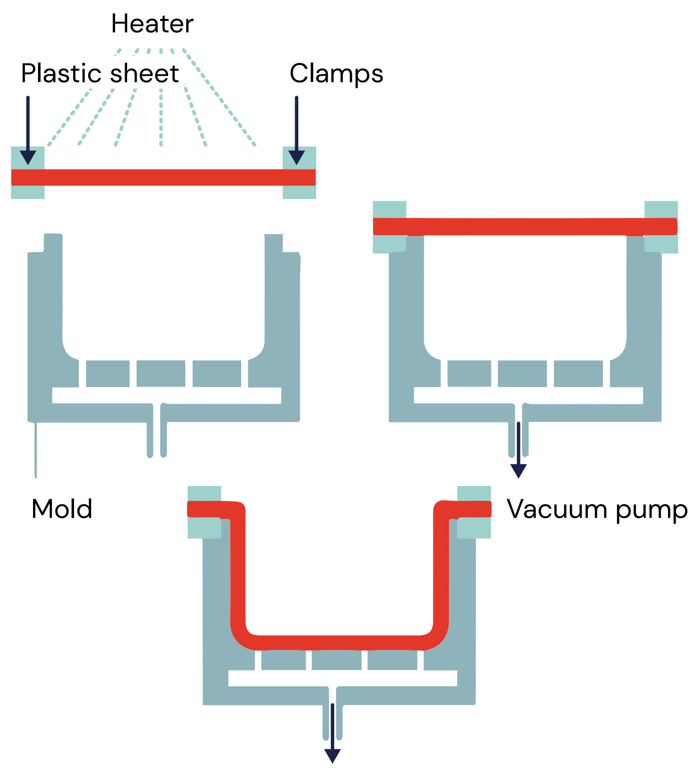


Figure 2.10: *The process of thermoforming.*

11 See Chapter 1: *Plastics: Their properties and applications* for more on the viscosity and orientation of plastics.

2.4.7. THERMOSETTING PROCESSES

A thermoset is formed through the cross-linking of molecular chains at a high temperature, resulting in plastics that cannot be melted again. Therefore, thermoplastics require manufacturing methods that are different from those discussed so far. Specialised processes have been developed to deal with thermosets in their various formats, which include moulding powders, pastes, liquid resins, and prepolymers (see Figure 2.3).

A. Compression moulding

In compression moulding, plastic is processed so that the tableted, pre-heated, or pre-plasticised material is put into an open mould, where it cures under pressure at a high temperature. During the curing time, the long molecules cross-link with one another, and a cured thermoset moulding (the plastic end product) is formed. The process is mainly used to produce electrical fittings, bottle caps, knobs, and handles from phenol formaldehyde (PF), melamine formaldehyde (MF), or urea formaldehyde (UF). Sheet moulding compound (SMC) for structural shapes or dough moulding compound (DMC) products where high strength and high-temperature resistance are required can also be compression moulded (SMC and DMC are prepregs[12] used in unsaturated polyester processing).

Compression moulding of *thermoplastics* is possible. Mouldings produced in this way have low or no orientation, which means the polymers (molecules) are not aligned in any particular direction. This feature makes this process suitable for producing lightweight PE-HD bottle caps for carbonated drinks where high strength is required. Apart from making bottle caps, compression moulding is only sometimes used for thermoplastic applications.

B. Hand Lay-up

Hand lay-up is a manual process that can be used to produce plastic items of any size or complexity, such as bird baths, canopies, artificial rocks, paddle boats and swimming pools. This technique produces a layered or laminated plastic made from unsaturated polyester and some type of reinforcement, normally glass mats. A gel coat (providing colour to the moulding) is applied to the mould, which has been treated with a release agent. During the lamination process, resin and its glass fibre reinforcement are placed alternately on top of each other, with the resin layer as the first layer.

The resin coat is applied with brushes, spatulas, or spray guns. The glass fibre reinforcement must be worked well into the previously applied resin layer while avoiding forming air bubbles using rollers. Hand laminates usually have a thickness of between 2 and 10mm. A final sealing layer of an air-curing resin forms the inner surface of the moulding. Hand lay-up requires skill and experience; the process is simple but not easy.

C. Spray-up

Spray-up moulding is a partly mechanised hand-laminating process useful for small runs, large flat parts, and coating. It is used to make canopies, swimming pools, boats (dinghies), and storage containers. Hand lay-up and spray-up equipment must be cleaned thoroughly to remain fully functional.

12 Prepregs are glass fibers pre-impregnated with resin and are used in some high-volume production methods with unsaturated polyesters (a thermosetting plastics).

D. Filament winding

Filament winding is used to produce pipes and hollow items (Figure 2.11). It is usually mechanised with high accuracy and reproducibility. Glass fibre rovings, i.e., a bundle of fibres or spun threads, are led through a resin soaking trough. After the excess resin has been squeezed out, the glass fibre rovings are wound under tension over a rotating mandrel. Woven materials or mat ribbons can also be wound. Some streetlight poles and chemical storage tanks are produced using filament winding.

Figure 2.11: *Street poles are made using filament winding.*

E. Vacuum Bagging

In vacuum bagging, reinforcement fibres (laminate) and resin are cured – i.e., hardened –under vacuum pressure. The mould is prepared with a release agent, and after the fibre reinforcement has been put in place, the resin is poured into the mould. A rubbery membrane (flexible bag) is stretched over the mould and sealed around the edges. A vacuum is applied between the mould and the membrane using pneumatic or hydraulic force. This allows for the *wetting out* of the fibre reinforcement and the resin, in other words, the spreading out of the resin among the fibres, which helps to join the laminate together, ensuring proper curing of the moulding. Alternatively, the membrane can be pressed against the laminate through pressure. Products manufactured in vacuum bagging include cold rooms and temperature-controlled truck containers.

F. Pultrusion

Fibre-reinforced polyester (FRP) flat or corrugated sheets and profiles are made using pultrusion. For corrugated sheets, the resin is spread on a carrier layer (normally PP or PET film). A glass fibre mat is rolled onto the resin layer, and a top, surfacing fibreglass sheet is rolled onto the glass/resin mat. Shaping occurs between profiled moulding chains and rollers in the gelling and curing zone. For profiles, spun threads or rovings are used as reinforcing elements instead of a glass fibre mat.

2.5.

End-of-life

Each step in the plastic value chain can influence the environmental footprint of a product during its use, or "life", including its end-of-life when that product is disposed of as waste. There are several ways to deal with plastic waste, such as landfilling, incineration, pyrolysis, and gasification. Other end-of-life solutions include reusing a product after repairing or refilling and recycling, which effectively diverts waste from the waste stream. Composting[13] is the appropriate treatment of compostable and biodegradable waste. In Africa, municipal solid waste (MSW), including plastics, is still most commonly disposed of in landfills and uncontrolled, open dumpsites, with some open burning and recycling (Figure 2.12).

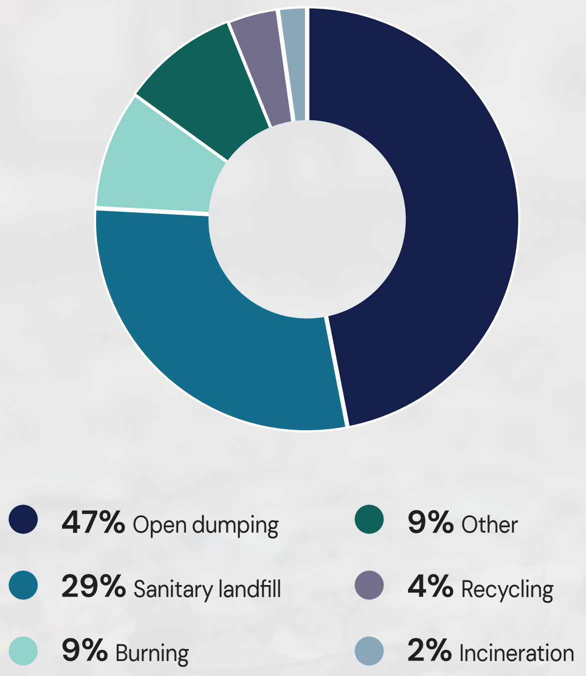


Figure 2.12: Common disposal methods of waste in Africa (Source: UNEP 2018).

Local authorities, i.e., municipalities, are generally responsible for waste management services, which include the collection of waste, sorting of recyclables at transfer stations, and disposal of non-recyclable waste in open dumpsites or landfills; some of these services may be managed by private companies (ISWA 2015; UNEP 2018). Waste management services in Africa are severely under pressure, and they need more technical and financial capacity to deliver efficient services (UNEP 2018). Part of the problem is the sheer amount of (plastic) waste generated, which outpaces the ability of local governments to deliver waste services. It was estimated that Africa produced 19MMt of plastic waste, of which 88.5% was mismanaged, in 2015 (Lebreton and Andrady 2019). A further problem across Africa is the lack of sufficiently trained personnel in the waste sector (Cape Talk 2022a; UNEP 2018). At the same time, public awareness around the safe disposal of hazardous waste, littering and illegal dumping needs to complement well-designed mandatory or voluntary extended producer responsibility in addressing the environmental consequences of waste.

These challenges have implications for end-of-life solutions for plastic, specifically disposal in landfills (and dumpsites) and recycling. For example, the average collection rate of waste in Africa in 2012 was only 55%, although this is expected to improve to an average rate of 69% by 2025 (Scarlet et al. 2015). MSW collection rates vary widely among countries, e.g., 18 to 80% in 2015 (UNEP 2018), and only 58.8% of households in South Africa have access to a regular waste removal service (Stats SA 2019). The lack of efficient service delivery means households must deal with the waste themselves (e.g., with open burning or on open dumpsites), leading to mismanaged waste and pollution.

However, it is not only the responsibility of local waste management service providers or the government to minimise this impact. All stakeholders in the plastics value chain, from raw materials to the finished product, need to consider the impact of a product. They must plan, design, and manufacture products so that there is a workable solution to deal with the waste once that product reaches the end of its useful life. Here, we briefly explore some of the more common ways plastic waste is processed or disposed of in Africa.

13 It is worth pointing out that organic waste is the dominant type of waste generated in Africa (57% of MSW; Hoornweg and Bhada-Tata 2012). Home composting will help to divert a large proportion of household waste from landfill.

14 This is discussed in detail in Chapter 3: Sources, pathways, and drivers of plastic pollution.

15 See also Chapter 8: An introduction to the circular economy.

2.5.1. LANDFILLS

Although not the most preferable method of waste processing (see Chapter 8), landfilling is still one of the more common ways we deal with waste in Africa. Landfilling differs from illegal and open dumping in that waste disposed here is regularly covered by earth. Landfills have better controls to limit the environmental and health impacts of (plastic) waste (Table 2.1). Sanitary landfills, especially, are managed strictly. The amounts and types of waste allowed on site and site access are regulated. Measures to limit the harmful impacts of waste on people and the environment are implemented, which includes a lining to prevent toxic leachate from entering the soil (and possibly the water table). Gas from decomposition is also captured. The covering of waste with soil also helps to limit the spread of pollution.

But even sanitary landfills have their disadvantages. Landfills reduce land value and can not be used for any other purpose than storing waste, at least for the foreseeable future. Wind can blow waste off trucks while being transported to the landfill or when disposed of at the landfill, thus causing pollution. Waste does not really disappear, even though some decomposition occurs (ISWA 2015), but is compacted and buried, therefore taking up more space. We are running out of landfill space (also called landfill airspace). In South Africa, for example, the Robinson Deep landfill site in the city of Johannesburg is estimated to run out of space by 2025 (Cape Talk 2022a), while landfills in Cape Town have airspace only until 2032 unless interventions are implemented (Cape Talk 2022b). Waste can be diverted from landfills by banning the disposal of food waste and other organic (biological) materials, thus necessitating composting, and by increasing the rate of plastic recycling (Cape Talk 2021).

***Table 2.1:** A comparison of different dumping and landfill methods (ISWA 2015).*

Criteria	Open dumpsites	Controlled dumpsites / landfills[16]	Sanitary landfills
Site planning & management	No planning; little / no site preparation. No record keeping of incoming waste.	Some site preparation. Basic record keeping.	Site is carefully selected and prepared. Good record keeping.
Waste	No control of volumes or types of waste.	No/limited control of waste volumes accepted. Only MSW accepted.	Only specific types and volumes of waste accepted. May make provision for special types of waste.
Enclosed	Not fenced	Fenced	Fenced, access control via gate.
Soil cover	No or occasional soil covering of waste.	Regular covering of waste by soil.	Daily covering of waste by soil.
Leachate[16] management	No management	Partial management	Full management (soil covering prevents leachate from seeping into the soil).
Gas management	No management of emitted gas	Partial or no management	Gas is collected from the landfill, which can then be used as a source of energy.
Waste picking	Commonplace	Controlled waste picking	None
Environmental and health impacts[17]	High health and environmental impacts.	Smaller risk for harmful impacts compared to open dumpsites.	Minimum health and environmental impacts.
Cost	Low initial, but high long-term, cost.	Low to moderate initial cost; long term cost is high.	Initial cost high, but moderate over the long term.

There has been a gradual move away from uncontrolled dumping towards regulated landfills across Africa, including sanitary landfills. However, effective landfill management is costly and requires trained professionals to operate them (UNEP 2018). The private sector could play an important role in this regard by managing engineered landfills on behalf of cash-strapped municipalities. But considering the problems associated with even well-managed landfills, it is necessary to look to more sustainable end-of-life solutions that also valorise—create value from—waste.

16 Over time, chemicals – the leachate - leach from waste. These may include toxins from e-waste and plastics.

17 Harmful health and environmental impacts associated with waste dumpsites include diseases, the risk of fire, toxic leachate into the soil, and emissions (such as methane, a greenhouse gas) from decomposition.

2.5.2. RECYCLING

Recycling of plastics is one method for reducing environmental impact and resource depletion. Recycling is the process of transforming used products or parts thereof back into basic building blocks to produce a new product that may be similar to or different from the original. Fundamentally, high recycling rates can allow for a given product service level with lower virgin material inputs than would otherwise be required. Recycling can, therefore, decrease energy and material usage per unit of output, yielding improved eco-efficiency. There are two broad types of recycling: mechanical and chemical recycling.

Mechanical recycling is the most effective way of dealing with a variety of materials and generating a recycled raw material that can be used to manufacture new products. Mechanical recycling involves grinding, washing, separating, drying, regranulating, and compounding. For example, packaging film can be recycled, which means it is cut, washed, and melted into pellets, which are then used to make new refuse bags; in this case, the new product is different from the original product. In closed-loop mechanical recycling, the used product is collected and recycled, with the resultant recyclate being manufactured into the same product again. That is to say, milk bottles become milk bottles again, although this is only sometimes possible for clear products or food-contact applications. Recyclable waste products are often recycled into lower quality yet still useful products, such as PET bottles recycled to make polyester textiles for clothing or duvet inners.

To facilitate plastic mechanical recycling into high-quality products, the incoming materials must be separated into different plastic material streams, free from any other material (e.g., metal fasteners or wood inserts), and be as clean as possible. Incoming recyclable materials sourced from the mixed solid waste stream are often contaminated with wet waste, sand, and organic matter. The cleaning process then becomes energy- and, consequently, cost-inefficient. In such cases, the recyclate can be used for other products, often with a longer and more durable application: milk bottles become plastic bags, and plastic bags become irrigation pipes, etc. Mechanical recycling is the most common form of recycling in Africa.

Chemical recycling is the breaking down of plastic polymers back into their monomer building blocks, typically by applying heat and chemicals. There are different versions of chemical recycling, including pyrolysis, gasification, and hydrolysis. In pyrolysis, plastics are heated in a vacuum - thus distinguishing it from incineration – which breaks the polymers down into petrochemical products like diesel, paraffin, and waxes. Pyrolysis produces quality raw materials from plastic waste that can serve as fuels for other processes, to produce energy, or to be used as feedstock to manufacture chemicals like solvents or waxes. Hydrolysis is a similar process but is used for polyesters and polyamides, where water is removed from the molecules to form the original building blocks or monomers. Hydrolysis is typically used to recycle polyurethanes and polyesters. Pyrolysis is the most successful of the processes mentioned above, i.e., it gives the highest yield for polyolefins.

There are challenges though. To produce energy, liquid fuels, chemicals, or monomers, the waste needs to be available at competitive prices with the current low-grade coal (typically used to produce energy and raw materials), but this may not be the case in Africa. The collection and transport of South African waste, for example, is too expensive to make chemical recycling viable.

Despite its benefits and the large proportion of recyclable waste generated, especially in urban areas (Mebratu 2022), recycling rates of MSW in Africa are generally still low at only 4% (Figure 2.12), although there are some exceptions. South Africa has a recycling rate of 43% (Plastics SA 2023), and Cairo (Egypt) and Moshi (Tanzania) also recycle relatively large volumes of waste (UNEP 2018). A few recyclers have established their own collection networks and agents in surrounding towns, collecting recyclables for them specifically. Generally, though, collectors and waste management companies sort and bale recyclable materials to sell to plastics recyclers. Alternatively, citizens may dispose of recyclables at designated drop-off sites. In Africa, the informal waste sector – waste reclaimers or waste "pickers" - plays a crucial role in collecting and sorting recyclable waste from landfills or dumpsites, driving the high recycling rates of South Africa (Godfrey and Oelofse 2017).

Fortunately, African entrepreneurs are starting to seize the opportunities in recycling. Companies such as Green Industry Plast (GIP) in Togo[19] set up collection units and sorting facilities in major urban areas across Togo to optimise the recovery of waste for recycling, and Chanja Datti[20] in Nigeria recycles a variety of plastic waste material, while also providing an income for informal waste collectors.

19 See https://www.afrik21.africa/en/africa-afri-plastics-awards-toto-safi-from-kigali-and-seven-other-green-start-ups/.
20 See http://www.chanjadatti.com/.

2.5.3. INCINERATION AND WASTE-TO-ENERGY

One solution to eliminating waste is to burn it in a controlled manner without sorting, including all components from the solid waste stream. Scrubbers are used to capture potentially hazardous fumes. Incineration can manage high volumes of mixed waste. However, as a potential move to a circular economy, incineration is not an option as the captured petrochemical energy is lost.

If the heat generated is captured, it can be used to warm water to generate steam for powering steam generators to provide energy. The waste will then replace alternative petrochemical sources to generate energy. Consistent high-volume waste blends at a constant feeding rate are required for efficient waste-to-energy solutions. The additional costs to collect, homogenise and feed sufficient volumes of consistent waste is a significant barrier to waste-to-energy solutions for waste.

2.5.4. ALTERNATIVE SOLUTIONS

The current collection networks and mechanical recycling business models do not address the materials that are not commercially viable to recycle; solutions need to be found for these. These materials could be collected and converted on a small scale to energy, heat or even building blocks. The end product must be for the benefit of the local community. Some external funding may be required to capitalise the processing centre. Also, not all plastic waste can be effectively recycled. This could be due to chemical damage, UV exposure, thermal degradation, or contamination levels that render the product uneconomical or unsafe to clean sufficiently for recycling. Multilayer packaging used for barrier films to ensure food safety in protein and dairy packaging cannot be mechanically recycled because of the different materials in one product. Recyclables could also be too far from the recycling centres or available in too little volume to justify the cost of sorting, compacting and transport. Innovative thinking is required to find workable solutions to collect small and difficult-to-recycle litter items.

MacRebur[21] caught media attention in 2019 for its trial road in Jeffreys Bay, on the south coast of South Africa. About 1.5 tonnes of plastic, comparable to 1.8 million plastic bags, was used to build a 1km stretch of road with plastic-infused tar. The plastic was turned into pellets using a special formula and then added to the asphalt (or bitumen) mix used for the top layer of the road. The plastic pellets replace a portion of the bitumen. In September 2019, a second road, made from 200 tonnes of plastic, was laid on a stretch of the N3 highway in the province of KwaZulu-Natal. The recycled plastic was generated from local waste plastic and supplied by a local recycling plant, and the binder – the bitumen holding the plastic aggregate together - was manufactured in South Africa. The South African National Roads Agency (SANRAL) has approved the trial and will monitor it for long-term performance. Strict national standards and specifications govern the South African road construction industry to ensure the performance of road pavements. The use of waste plastic in road construction is not new. This technology has been used elsewhere in Africa, notably Ghana, Nigeria, and Kenya, and internationally, including Australia, Canada, India, the Netherlands, New Zealand, the United Kingdom, and the United States of America.

Non-recyclable plastic waste can also be used in constructions other than roads. A South African design centre in Cape Town[22] is perfecting a process that turns plastic waste into building blocks for construction. Plastic waste is ground into small plastic particles that are mixed with a sand and cement mixture to create a durable and water-resistant brick. Two major cement manufacturers are testing these blocks in the Western Cape province. The building blocks for a standard $40m^2$ house have the potential to accommodate 500kg of mixed plastic waste.

One significant advantage of this technology is its ability to use all plastics, including the lower value waste. Envirolite Concrete and Greenlite Blocks are examples of lightweight cement developed for cement building blocks with post-consumer foam-extruded polystyrene trays and punnets. Communities will eventually benefit from these projects[23].

Various technologies exist that mix plastic waste with sand to manufacture paving bricks, roof tiles and building blocks. In most cases, the initial capital investment required is a stumbling block for new entrants. The production costs will be balanced with the sales of the products but with lower-than-designed-for yield, the capital investment would not be covered. External funding could make these projects viable – based on the need to clean the environment rather than to generate profit.

Finally, Clariter[24], an innovation company specialising in environmentally friendly solutions, commissioned a trial plant in the first quarter of 2019 to manufacture solvents, waxes, and other value-added products from polyolefin waste. Clariter ZA produces Solventra® 200 solvents used in fluids, coatings, paints, cleaners, inks, lamp oils and grease.

Innovative solutions like these can significantly support efforts to reduce plastic waste and pollution. However, it is also important to monitor such new technologies for potential unforeseen negative impacts.

21 See https://www.macrebur.com/.

22 https://crdc.global/south-africa-announces-plans-to-scale-operations/.

23 See here for more about community projects using these technologies: https://sapt.co.za/khaya-khanya-lightweight-concrete-factories-bring-hope-to-communities-in-sa/.

2.6. Conclusions

In this chapter, we briefly introduced the main components of the plastics value chain, with particular emphasis on the various manufacturing processes used to produce the vast array of plastic consumer goods available today.

Each manufacturing method imparts specific properties and characteristics to the product made. Link this to the choice of raw material, and a handful of processes combined with a couple of different materials can produce a myriad of products. By comparing a high-voltage cable that powers an entire town to a small synthetic crayon a preschooler uses to draw their dreams, we can see the vast possibilities of plastics and their manufacturing processes.

As the industry developed in the last few decades, humanity was excited about the possibilities and created many beautiful and useful products, giving our lives value and meaning. However, humans did not anticipate the durability of these products and the unintended consequences on natural resources, ecosystem services and our environment. This issue extends beyond plastic to include our use of energy, water, and other natural resources.

As a result, Africa is drowning in poorly managed waste. Only a fraction of waste is dealt with responsibly, and even less waste is reprocessed circularly and economically. Every stakeholder and political leader needs to get involved in the best possible sustainable waste management solutions. Plastics are a valuable and incredibly useful material and, therefore, need to be handled with responsibility and care throughout the value chain, from capturing the energy by-products all the way to finally discarding it once it has served its purpose.

2.7.

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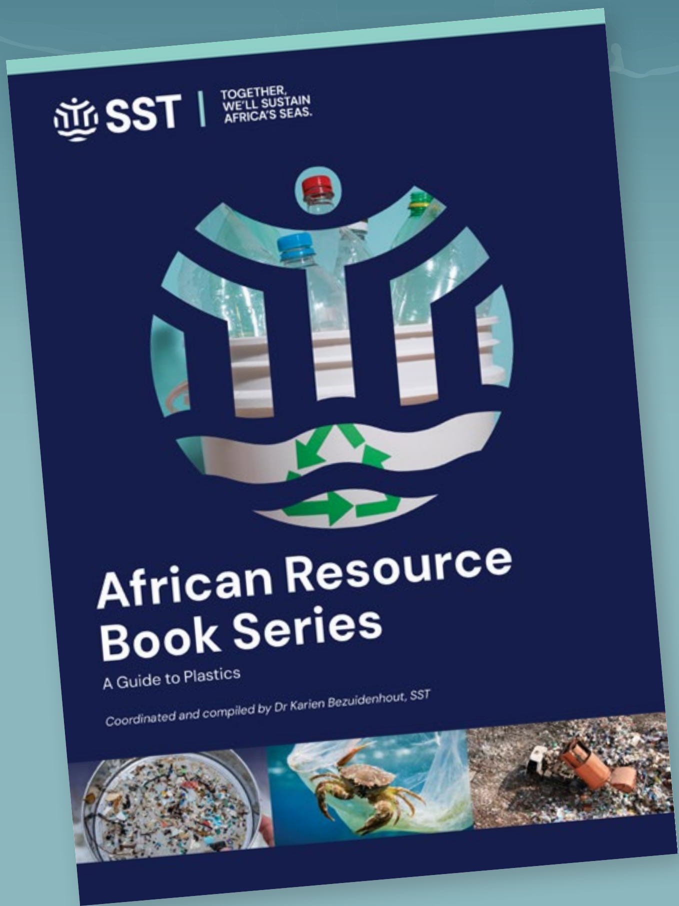

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