SUSTAINABLE MANAGEMENT OF PLASTIC PACKAGING WASTE IN THE CHEMICAL INDUSTRY

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ABSTRACT

This master's thesis deals with the sustainable management of plastic waste in the chemical industry. Prompted by the growing global plastics crisis, it seeks to find effective solutions from a business perspective. The research focuses on understanding and solving the challenges associated with the accumulation of plastic waste in the chemical industry, with the aim of promoting responsible and sustainable practices.

The thesis examines various aspects, such as the analysis of packaging in the chemical industry, waste management technologies, challenges and innovations in plastic waste management, environmental impact or business strategies for sustainable management, regulations. Furthermore, it explores collaboration and networking as a key factor to improve the sustainable management of plastic waste in the chemical industry.

Key words: plastic crisis, waste management, business strategies.

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HOCHSCHULE ANSBACH

IV. Erklärung

Die nachfolgende **Erklärung** muss nach dem Thema auf der zweiten Seite in die Abschlussarbeit integriert und von dem/der Verfasser/in in allen Exemplaren unterschrieben werden:

Erklärung

„Ich versichere, dass ich die Arbeit selbstständig angefertigt, nicht anderweitig für Prüfungszwecke vorgelegt, alle benutzten Quellen und Hilfsmittel angegeben sowie wörtliche und sinngemäße Zitate gekennzeichnet habe."

Ort, Datum 18.03.2024 Unterschrift ____________

CHAPTER 1. OBJECTIVES

The main objective of this thesis is to conduct a comprehensive analysis of plastic packaging in the chemical industry, focusing on waste management technologies and sustainable practices. The general objective is to understand the environmental impact of plastic packaging and to propose business strategies for its sustainable management. To achieve this main objective, the following specific objectives will be pursued:

- To investigate and analyse the current state of packaging in the chemical industry, highlighting the types and quantities of plastic packaging used.
- Explore and evaluate existing waste management technologies related to plastic packaging, including the three Rs: reduce, reuse, and recycle.
- To assess the environmental impact of plastic packaging in the chemical industry, considering factors such as resource consumption, emissions, and waste generation.
- Propose business strategies for the sustainable management of plastic packaging, considering economic, environmental, and social factors.

CHAPTER 2. MOTIVATION AND JUSTIFICATION

2.1. Motivation

The main motivation of this thesis is to address the environmental problems generated by plastic waste, focusing specifically on the management of plastic packaging in the chemical industry. The urgent need to find sustainable and practical solutions to reduce, reuse and recycle these materials has led to the formulation of this project.

The approach is directed towards a sustainable management of plastic waste in the chemical supply chain, considering technical, environmental, and economic aspects. It will seek to assess the technical and environmental feasibility of various plastic waste management strategies, considering the full lifetime of the packaging, from its manufacture to its final disposal.

In addition, the relationship between the use of plastics and the Sustainable Development Goals (SDGs) proposed by the United Nations will be explored. The thesis aims to contribute to the achievement of sustainable goals, aligning with global efforts to tackle plastic pollution and promote more responsible practices in the chemical industry.

2.2. Justification

2.2.1. Academic justification

This master's Thesis is an opportunity to coherently integrate the knowledge and skills acquired throughout the master's programme. The selection of specific subjects within the master's programme has been decisive for the formulation and development of this project. Through courses such as "Research Methodologies (32257)", "Operations Management (34926)", "Innovation Management (31851)", "Product Project (31855)", "Plastic Processing Technology (35132)", "Chemical and Biotechnological Products and Production Processes (34461)", "Project Management (32244)", and "Lean Production Manufacturing Excellence (34465)", fundamental skills have been acquired that are essential to comprehensively address the sustainable management of plastic waste in the chemical industry.

2.2.2. Environmental justification

The creation of the 2030 Agenda for Sustainable Development by the UN General Assembly in 2015 marked a crucial milestone in the global commitment to sustainability. With 193 countries adopting the Sustainable Development Goals (SDGs), this initiative seeks to address challenges to achieve equality, protect the environment and ensure a sustainable future. This Final Degree Project is aligned with four of these specific goals: 9, 12, 13 and 14.

Goal nine aims to build resilient infrastructures, promote inclusive and sustainable industrialisation, and foster innovation. In this context, the sustainable management of plastic waste in the chemical industry contributes directly to building more sustainable industries and promoting innovative practices.

The twelfth objective, which focuses on ensuring sustainable consumption and production patterns, is directly linked to plastic waste management. By adopting more sustainable approaches to the production and consumption of plastic products, it contributes to the reduction of the environmental footprint and the efficient use of resources.

Goal thirteen focuses on taking action to combat climate change and its effects. As will be explained below, plastics are a major pollutant.

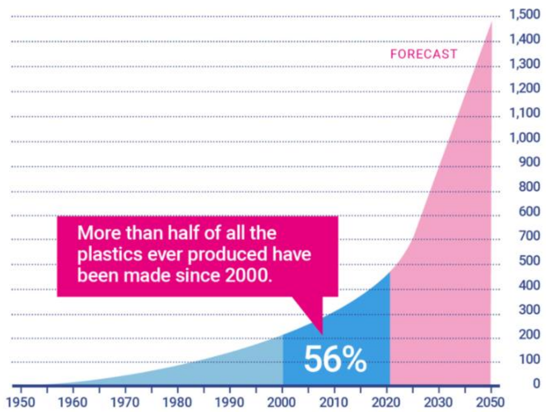
The fourteenth goal focuses on conserving and sustainably using the oceans, seas, and marine resources for sustainable development. The proper management of plastic waste contributes directly to preserving the health of marine ecosystems, reducing pollution, and protecting biodiversity.

Image 1. Objectives ODS used in this project

CHAPTER 3. INTRODUCTION

3.1. Global context: First contact with the plastics crisis

The mass production and consumption of plastics has grown in recent decades. As can be seen in Graph 1, more than half of all plastics were created after the year 2000, and this has been one of the causes of the environmental crisis it is being currently experiencing.



Graph 1. Global annual plastic production in million tonnes.
Source: (*Plastic Facts & Figures - Plastic Soup Foundation*, 2023)

The global production of plastics is enormous, in fact it reached 359 million tonnes in 2018, of which eight million tonnes per year have ended up in the oceans and it is estimated that by 2050 the oceans could contain more plastic than fish, according to UN data (Miranda, 2023). All this accumulation of plastics in the oceans causes almost 100,000 marine mammals and more than a million birds to die each year trapped in this waste (Escolares, 2021).

This raises the imminent need to address the management of plastic waste. Many governments are taking drastic measures to regulate the management of such waste, such as South Korea, which has recycling rates of over 60%, thanks to its policies, for example, mandatory recycling or smart bins that record the amount of waste generated by each user and at the end of the month pay the corresponding fees for their own recycling. Another country that can be taken as an example is Switzerland where its inhabitants are obliged to pay for the non-recyclable waste they generate (Vilet, 2022).

Although awareness of the importance of plastic recycling has been raised in recent years and measures are being taken, it is not enough to counteract the generation of new plastic materials.

The biggest contributor to global plastic generation is Coca-Cola (See Image 2) with more than 3.2 million tonnes generated annually, followed by Pepsico (See Image 2), another US multinational beverage company that pollutes with more than 2.5 million tonnes each year, and Nestle (See Image 2), the Swiss company that produces more than 920,000 tonnes, despite its efforts to reduce the weight of its packaging (Swissinfo.Ch, 2023).

Image 2. Logos of the companies that generate the most plastics.

But it is not only companies that generate plastic waste, but in houses also create an average of 48 kg of plastic per year (Lira, 2022), which directly affects pollution as only 9% of these plastics are recycled (Nebular, 2022). For this reason, it is particularly important to know and understand the process to manage this waste, which will be discussed in more detail in the next section.

3.2. Waste management: Taking responsible actions

Waste is understood as any waste generated from human activity, whether solid, liquid, or gaseous, which requires some kind of special management to avoid negative effects on the environment. On the other hand, waste management encompasses all the activities involved in the process, from the generation of the waste to its final disposal. These activities can be collection, recycling, recovery, reuse, treatment and, as a last stage, the proper disposal of the waste (Lucena, 2023).

The objective of waste management is, as already mentioned, to reduce the negative impact on the environment and human health, but also the economic impact it can have, as most of the waste can be recycled and reused for economic gain.

In the case of Spain, Acteco (See Image 3), a company that offers equipment supply, collection, transport, storage, conditioning, recycling, and valorisation of this waste. On the other hand, in some countries, there are no such companies, nor are there companies that offer ecological consultancy services. For example, India generates a large amount of plastic, 126.5 million kg of which end up in the oceans, which could be reduced or even stopped with regulation and waste management measures (Stam, 2023).

Image 3. Logo of Acteco

One of the most important principles of waste management is the pyramid shown below (See Image 4), in which one can see the order of actions taken to manage waste efficiently, prioritising the most sustainable strategies.

At the top of the pyramid is prevention, which is the least environmentally damaging action, involving avoiding and reducing waste generation as much as possible. Next is reuse, which means reusing materials whenever possible to extend their useful life. The next stage is recycling, which consists of separating materials and reintroducing them into the productive cycle by making some modifications. This is followed by recovery which focuses on recovering the valuable resources of each object and finally the disposal phase which aims to ensure that they are disposed of in a safe and environmentally friendly manner.

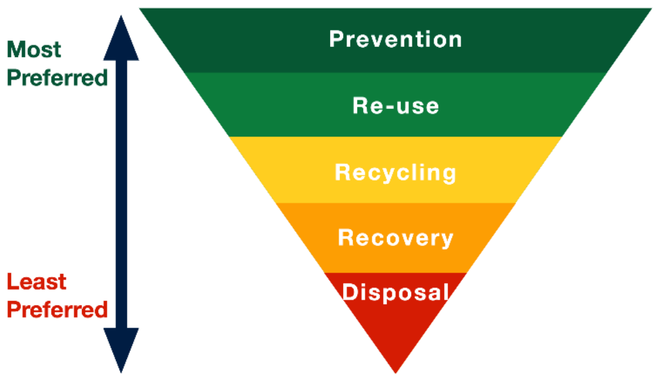


Image 4. Waste management pyramid
Source: (Waste Hierarchy, n.d.)

3.3. First steps into the world of plastics

Having understood the term 'waste management' and how to act to reduce pollution, it is essential to understand what types of plastic materials exist and how to differentiate between them to make the best use of them after their useful life.

There are three main groups of plastics: thermoplastics, thermosets, and elastomers.

Thermoplastics are those which melt at elevated temperatures and can therefore be moulded into different shapes. Once cooled, they harden and retain their shape. This property makes them easy to recycle, although they lose their physical properties in the process. Most plastics in daily use are thermoplastics, e.g. polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS), polyethylene terephthalate (PET) (Wanatop, 2022)...

On the other hand, there are thermosets. The big difference is that they can be melted and moulded only once. Once cooled, they burn when heated again. This is because when heated for the first time the molecules are strongly bonded together and therefore become rigid and very heat resistant. This makes them very difficult to recycle. This group includes some types of resins (Martinez, 2023).

Finally, elastomers. These plastics are characterised by their elasticity, which allows them to recover their initial shape after being deformed. Elastomers can rarely dissolve or melt. Some examples are rubber, neoprene, silicones, among others (Bsdi, 2021).

CHAPTER 4. HISTORY OF PLASTIC WASTE MANAGEMENT

In order to understand and study possible solutions to combat the plastic crisis, it is necessary to understand the history of plastic and where recycling comes from. In this section we will give a brief overview of the history of these materials.

4.1. The beginning

The first synthetic plastic was created in 1907 by Leo Baekeland (see Figure 5), more specifically Bakelite, a plastic that is very mouldable when hot and very hard when cold. Bakelite was the result of Baekeland's efforts to find an electrically insulating and resistant material. While researching, he experimented with the polymerisation of phenol and formaldehyde which resulted in this material.

Bakelite became the first synthetic plastic and has many applications today, including: switches and utensil handles.

This was the discovery of plastic, but it was not until the middle of the century that these materials were introduced into everyday life thanks to their great strength and ability to be moulded into thousands of shapes (BBC News World, 2017).

Image 5. Leo Baekeland portrait

Source: (The Editors of Encyclopaedia Britannica, 2023)

4.2. The boom and the negative impact

The massive use of these materials caused many scientists to begin to question the extent to which they were sustainable. In 1970 Jacques-Yves Cousteau (See Image 6) , a scientist and oceanographer, was one of the first researchers to warn of the presence of plastics in the oceans and their negative effects on marine life (Sadurní, 2023).

Image 6. Jacques-Yves Cousteau portrait

Soon, researchers took Jacques-Yves Cousteau's warnings into consideration and started to analyse and investigate the negative impact of these materials on the environment and on human health, so many of them started to study the impact of these materials on the environment, and especially to focus on what to do with these materials when they were no longer useful. From these first reflections, the first steps in plastics recycling emerged.

These first steps focused on mechanical recycling which, as will be explained in later chapters, basically the waste plastics are shredded and melted into new shapes to create new products. They also started to encourage the reuse of these materials.

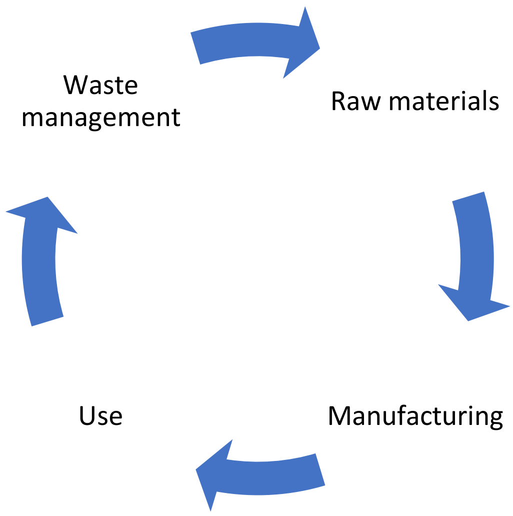
4.3. Last years

From the second half of the 20th century, plastics began to accumulate in landfills and the image of plastic-covered beaches became more and more common. It is at this time that there is a great boom in finding new techniques that allow plastics to be recycled efficiently.
In recent years, thanks to the development of new technologies and increased environmental awareness, there has been a need to find more efficient and sustainable solutions. This has led

to a lot of scientific research on the subject, resulting in many new strategies that are more environmentally friendly. Today there are many new techniques on the table such as artificial intelligence technologies, the synthesis of bioplastics or plastic-devouring enzymes, among others, which will be explained later (Qualitas, 2023b).

CHAPTER 5. LIFE CYCLE OF PLASTICS AND THEIR RELATIONSHIP WITH BUSINESS MANAGEMENT

Throughout this thesis we are going to explain the different actions that can be done with plastics to extend their useful life or once it ends, how to manage this waste, but for this it is vital to understand where these plastics come from and what their life cycle is. This life cycle can be divided into the following differentiated parts: extraction of raw materials, production and manufacture, use and consumption, and waste management. In the following graph you can see these stages.



Graph 2. Life cycle of plastics

5.1. Extraction of raw materials

The first action to be carried out in order to obtain plastics is directly related to the chemical industry, since it involves implementing chemical processes to obtain the raw materials that will be used to manufacture plastics.

The process begins with obtaining natural gas or petroleum, for which underground or submarine deposits are made, then the petroleum is subjected to processes such as refining, which take place in industrial facilities with the aim of obtaining basic compounds, such as ethylene or propylene, which are necessary to obtain the plastics. On the other hand, natural gas is usually subjected to a process known as cracking (Gasogenio, 2023).

The extraction of oil and gas is a relatively simple process although it can have many negative consequences for the environment such as soil degradation and risk to marine life, as well as causing a natural disaster in the event of a spill. As was the case in the Gulf of Mexico in 2010, where more than 780,000 cubic metres of crude oil were released into the sea due to an explosion and fire on the platform that the BP company was building to obtain oil. The disaster came when the platform collapsed, which caused the underwater well to be exposed and all the oil escaped uncontrollably. It took 87 days for the company to close the well, which caused devastating impacts on marine ecosystems (See Image 7). Unfortunately, this is just one example of many other disasters caused by the extraction of these materials (Ap, 2021).

Image 7. Conseques of the 2010 gulf of Mexico spill

Source:(EFEverde, 2015) (Vatican News, 2020) (Ap, 2021)

In addition to the problems associated with spillage, these processes are also energy-intensive and therefore emit a lot of greenhouse gases.

In an effort to reduce dependence on these materials, many scientists are developing bioplastics that use materials such as corn starch, sugar cane or vegetable oils instead of crude oil. The implementation of techniques such as these can have a very positive effect on companies, as for example the initial costs of raw materials derived from oil or natural gas are more changeable and subject to market fluctuations. Although it is true that the initial costs of sustainable raw materials such as biomaterials can be higher, the price is more stable and they can also benefit from tax incentives for their commitment to sustainability. They can also improve brand image and have a better reputation to attract more consumers.

5.2. Production and manufacturing

The production and manufacturing phase of plastics is essential in the life cycle of the materials, as it lays the foundations for the physical and chemical properties of these materials. During this stage, the synthesis of plastics takes place through a process known as polymerisation where monomers, which are the basic units obtained from petroleum or natural gas, are combined to obtain these palstic polymers. The bonding of these monomers typically involves addition or condensation processes, where chemical bonds are formed to create these polymers.

In addition, additives can be incorporated which play an important role in giving specific properties to the plastic to be obtained. These additives can be anitoxidants, colourants, stabilisers and others. The introduction of these additives allows the customisation of the properties of the plastic, adapting it to the specific needs of each producer.

Subsequently, once the polymer has been obtained, this polymer has to be moulded into the desired shape. This process usually involves the application of heat in order to melt the plastic. After reaching the desired shape, it is cooled and subjected to additional processes such as cutting or finishing which may involve needle punching or the application of coatings, for example (Hita, 2020).

It is important to note that precision at this stage is critical to ensure the quality of the resulting plastic, as any failure can lead to significant deterioration in the final properties of the material.

This is the conventional process, but by researching more efficient production processes, companies can gain great advantages. For example, conventional processes involve the use of large amounts of energy, making operating costs very high. Therefore, more efficient technologies can be explored that involve reducing energy use, for example by automating processes.

5.3. Use and consumption

The use and consumption phase extends from the manufacture of the plastic product until the end of its useful life in the hands of consumers. Plastics are materials that are mostly known for their durability and versatility, making them one of the most sought-after materials by consumers. They can be found in everything from toys to clothing.

In addition, within the chemical industry they also play a key role, being used as packaging materials for chemical products and as containers on the vast majority of occasions, the following section will explain in more detail where they can be found within this sector.

It is true that many plastics are single use, such as straws, candy wrappers or candy wrappers, but measures are increasingly being taken to change this and reduce the use of plastic. The design of more efficient materials, such as multi-purpose materials, can directly affect the final price of the product. For example, developing products that use just the right number of materials would considerably reduce raw material costs and therefore influence the final selling price.

5.4. Waste management

The management of plastic waste also represents a very important stage in the life cycle of these materials. Inappropriate waste management, such as disposal in landfills or in oceans and seas, causes irreversible and negative impacts on the environment.

Recycling is a key strategy to mitigate this environmental impact. However, it faces many challenges such as limited capacity to recycle certain types of plastics. All these challenges mean that many companies and individuals do not participate in the proper management of these materials. For example, the Citarum River, one of the largest rivers in Indonesia, is extremely polluted due to industrial waste, mostly plastics, which accumulates massively and causes great environmental problems in the area.

Image 8. Citarum River

Source: (María, 2021)

But there is not only recycling. There are various options for giving plastics a second life, from incineration for energy to reuse. Each option has different environmental consequences and needs to be studied carefully before being implemented. Later sections will explain these different options in detail. The proper management of all these techniques and therefore of the waste generated has not only environmental benefits, but also direct cost savings for the companies that implement them. Internal recycling, the reuse of by-products and the implementation of more efficient disposal processes can be some of the actions that companies can take to begin to change.

CHAPTER 5. ANALYSIS OF PACKAGING IN THE CHEMICAL INDUSTRY

Most plastics used in packaging tend to be thermoplastics, since, as mentioned above, they are easier to recycle. In this section it will be taken a closer look at the plastics used in packaging, the vast majority of which are thermoplastics.

In general, packaging plastic materials can be classified into seven diverse groups, each group is identified with a number from 1 to 7 that corresponds to the identification code of the resin from which the material is made (Garcia, 2022). This number is located on the plastic container itself, inside the recycling sign, forming a triangle made with an arrow, as shown below:

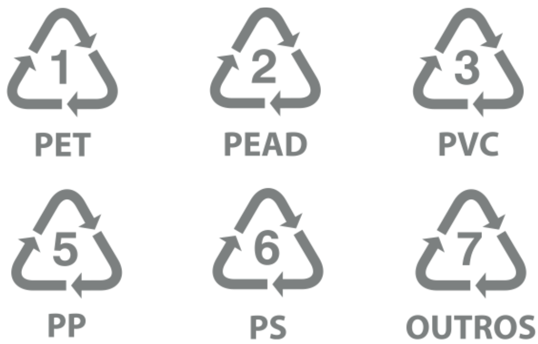


Image 9. Plastics identification

Source: (Sindiplast, n.d.)

In the image above it can be seen the name of each of these groups of plastics. Starting with the first one, PET is the abbreviation for polyethylene terephthalate. It is one of the most common plastics used in the manufacture of soft drink, water, or oil bottles, among others (De Embalaje, 2021). They also stand out in the cosmetic and sanitary industry because they can withstand very low temperatures in acidic environments. They are indispensable for the marketing of certain sensitive liquids and medicines, as well as products that require specific preservation conditions, such as medicinal oils or some pharmaceuticals (Fernández, 2022).

Some characteristics of this material are that it is rigid, amorphous, and transparent. It has very good impact resistance and melts at temperatures of around 265º (Sindiplast, n.d.). Thanks to this thermal resistance, it is an easy plastic to recycle as there is no degradation of the polymer chain during the recycling process (Polymers, 2019). The following image shows a sterile bottle that can be find easily in the laboratory containing weak acids, alcohol, and aliphatic hydrocarbons (created with carbon and hydrogen) and how the number 1 corresponding to a PET plastic is identified on a bottle.

Image 10. PET bottle and identification

Source: (Aweita & Admin, 2017)

Returning to Image 9, the second type of plastic is HDPE or high intensity polyethylene. It is an opaque material due to its higher density and high degree of crystallinity. It is resistant to low temperatures, lightweight, waterproof, rigid, with excellent chemical and mechanical resistance. Being chemically resistant, it can be used as a container for cleaning and chemical products (as can be seen in Image 11), e.g. from drums, jerry cans, bottles, or approved containers. It is also used in the manufacture of automotive parts and some pipes (Sindiplast, n.d.). In the laboratory it is also used as a table cover as corrosive materials are often managed. Like PET, it is an easy-to-recycle plastic.

Image 11. PEAD bottels

On the other hand, number three is PVC or polyvinyl chloride, a very versatile material, since by adding additives such as plasticisers or lubricants, different properties can be obtained. PVC is used in food packaging, cosmetics, hoses, cable sheathing and as packaging for chemicals , also used to create pumps and pipes (Sindiplast, n.d.) ... adding additives also has negative consequences, in this case, most of the time, they are mixed with toxic particles that prevent their recycling (Tornero, 2023).

Image 12. PVC plastic

Source: (Tarasov_Vl, n.d.)

The fourth type of plastic is LDPE or LDPE or also known as low density polyethylene. It is a material with low electrical and thermal conductivity. It is also resistant to chemical attack and is non-toxic. At low thicknesses, it is flexible and lightweight, which allows it to be used in flexible containers for food and personal hygiene, and as drums for less aggressive chemicals such as distilled water bottles found in all laboratories (Sindiplast, n.d.).

Image 13. PEBD o LDPE plastic

The plastic shown in Image 14 is known as PP or polypropylene. It is a heat-resistant material and does not allow moisture, grease, or chemicals to penetrate. This property makes it suitable for the manufacture of butter and yoghurt containers, as well as straws and bottle caps. It can be safely reused. Relatively low impact resistance, but excellent compatibility with weak and concentrated acids, bases, and alcohol.

Image 14. PP plastic

Returning to Image 9, it can be seen that the sixth group of plastics is PS or polystyrene, which is a rigid, light, transparent and shiny material. It has low chemical, thermal and mechanical resistance (rigid and brittle). It is used in disposable cups, plates and cutlery, toys, office products, among others (Sindiplast, n.d.). Like PVC, it is often mixed with additives and therefore presents toxic substances, which can complicate its recycling.

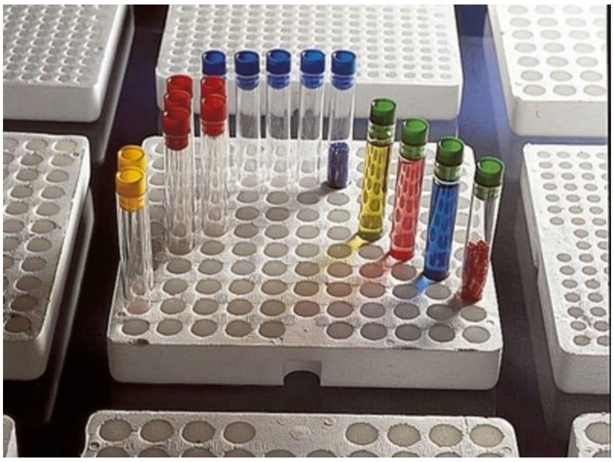


Image 15. polystyrene test tube trays

Finally, other types of plastics can be found at number 7, for example PC (polycarbonate), which is common in ketchup bottles, feeding bottles, syringes, and CDs (Tornero, 2023).

Considering all the above, the presence of plastic materials in the chemical industry is undeniable. In fact, if you look at the most common materials in a laboratory you will find them: Pipettes, essential for the accurate measurement of liquids, are often made of low-density polyethylene (LDPE). In the safe storage of chemical reagents, containers and bottles are made of polypropylene (PP). PVC (polyvinyl chloride) pipes and fittings are widely used to transport liquids and gases in industrial installations. In the manufacture of transparent and resistant equipment, polycarbonate and polymethylmethacrylate (PMMA) find application in the creation of windows and protective covers in chambers and laboratory equipment.

The following table provides an overview of the various containers mentioned above, which play a vital role in the laboratory.

Image 16. Types of plastics in laboratory summary
Source: (Lionstalkscience, 2022)

CHAPTER 6. PACKAGING WASTE MANAGEMENT TECHNOLOGIES

Each scientist in the laboratory produces fifteen times more plastic waste than the average individual at home (Lionstalkscience, 2022). In 2014 alone, the world's biological, medical, and agricultural research laboratories discarded around 5.5 million tonnes of plastic, the most used materials being gloves, test tubes, microplates, and pipettes (Admin, 2016).

An environmental rule that is known all over the world is the 3R rule, which aims to reduce the amount of waste. The 3Rs refer to the following actions: reduce, reuse, and recycle. These words are ordered according to their importance in waste management. Reducing waste is the first and most crucial step towards environmental sustainability, and recycling is the last resort for the waste that is produced. In fact, only 9% of all plastic produced has ever been recycled (Lionstalkscience, 2022). For this reason, reducing plastic consumption is the most important step, and reusing it is the next step to keep it out of landfills. Plastic recycling should only be done for non-reusable products.

This section will look at these three measures in detail.

6.1. First R: Reducing Plastic Impact

Reducing is about generating less waste and reducing consumption of both energy and material goods. Companies involved in the production and distribution of plastics have a significant role to play in reducing the amount of plastic generated. One measure that can be taken is to design more environmentally friendly packaging, for example by creating thinner packaging and eliminating non-essential layers. Another measure could be to create refill systems that allow customers to refill existing packaging. In addition, precise dosing systems can be designed that allow the user to get the exact amount of product he/she wants, thus reducing material usage and therefore not buying more (including packaging).

On the other hand, the use of alternative materials such as glass, which has a much higher recycling rate, can also be studied.

Although most of the responsibility for reducing plastic lies with manufacturers and institutions, the role of the scientist in its consumption cannot be ignored.

In general, experiments can be planned in the most efficient way, e.g. by analysing the order to be followed, the use of pipettes can be reduced. Another measure that can be taken is to buy larger containers, i.e. instead of 4 x 250 mL bottles, one can buy 1 L bottle. These practices can reduce the amount of plastic consumed, but there are also procedures where we can avoid using plastic altogether.

Plastics are generally used for sterile applications, but not everything you do needs to be sterile. If you are preparing a media solution that will be filtered, you do not need to use sterile single-use plastics to prepare all ingredients. Moreover, the use of single-use packaging can be avoided.

Finally, educating staff through recycling programmes is essential to raise awareness of the importance of reducing plastic use. In line with the above, researcher Jane Kilcoyne and her colleagues at the Oranmore Marine Institute in Ireland initiated the replacement of their plastic packaging, eliminated single-use materials and reduced material purchases. As a result, they managed to reduce plastic consumption by 23%, saving more than 15,000 euros in one year. According to their own statements, without the collaboration of all staff, they would not have reached their goal (Contreras, 2022).

6.2. Second R: reusing strategically.

The second action of the 3R rule is to reuse, which consists of extending the useful life of materials by giving them more than one use (Lnatur, 2021).

In this context, companies dedicated to the manufacture of plastic materials for the laboratory play a fundamental role, since the capacity to reuse these materials is related to the quality of the product plastic. The higher the quality and the more durable the product, the greater the chances of reuse. Furthermore, as mentioned above, the implementation of a refill system on used plastic containers can encourage reuse among customers. On the other hand, it is also possible to create reconditioning programmes where parts of the product that are incomplete or damaged are refurbished or repaired.

On the other hand, scientists can take many environmentally friendly measures related to the reuse of plastic products. For example, many laboratory products, such as test tubes and microtiter plastics (See Image 17), can be properly cleaned and sterilised. Instead of discarding them, rigorous cleaning protocols can be implemented to ensure that the materials are in perfect condition for their next use.

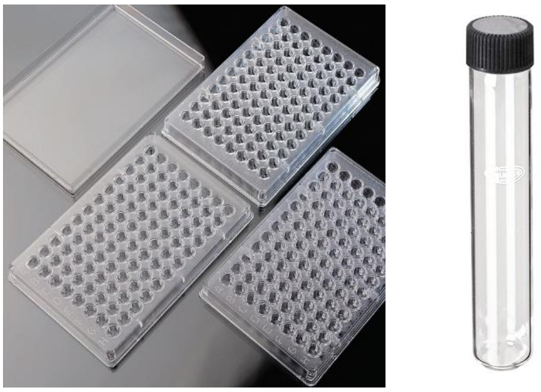


Image 17. Microtiter plates and test tubes

One measure that could be beneficial would be the implementation of internal material exchange programmes in the laboratory, which would allow scientists to share and reuse equipment and supplies they no longer need. In addition, not only plastic products can be exchanged, but also data and experimental results can be exchanged to avoid duplication of experiments. This reduces the need for additional resources.

6.3. Third R: Smart Recycling

On a technical level, it could be said that recycling is the most complicated part because unlike reducing and reusing, understanding recycling requires some basic technical knowledge.

Briefly, it can be said that recycling is the collection and processing of waste so that it can be used in new manufacturing processes, thus eliminating the waste generated, saving on industrial processes, and reducing the exploitation of natural resources (Baeticadigital, 2019). Furthermore, it is important to understand that there are broadly three diverse types of recycling: chemical recycling, energy recycling and mechanical recycling. The following sections will explain each of these in more detail.

6.3.1. Mechanical recycling

Mechanical recycling in plastics refers to the process by which temperature and shearing are applied to convert waste into recycled material that can be used again as raw material (Garcia, 2023). This method is one of the most traditional when it comes to recycling and is common for recycling plastics such as PET and HDPE, which as previously mentioned are quite easy to recycle, although each time the plastic is recycled, its elongation, toughness and impact resistance are reduced. For this reason, additives such as impact modifiers or heat stabilisers are sometimes added.

This method has several indispensable stages, among which are the following:

The first stage is the classification which consists of separating the types of plastics e.g. HDPE, LDPE, PP (explained in previous sections), they are also divided by colour and the way in which these were produced, in this case plastic bags, hard plastics... among others would be separated.

The next step would be the shredding or fragmentation where basically the plastic waste is taken to a mill where it is reduced in size (Tornero, 2022). This is followed by a washing process to remove impurities and contamination and then drying, in which they pass through a centrifuge so that the humidity is maintained at 3-5% for the next stage.

The last stage known as extrusion is the most complex, here the pieces of plastic materials are taken to an extruder machine where they are heated until they melt and are shaped like spaghetti, then they are cooled in a bathtub with water at room temperature and cut with a granulator to form granules of recycled plastic material (Castro, 2023). These granules are then shaped to create new recycled materials.

The following image shows a representation of the process.

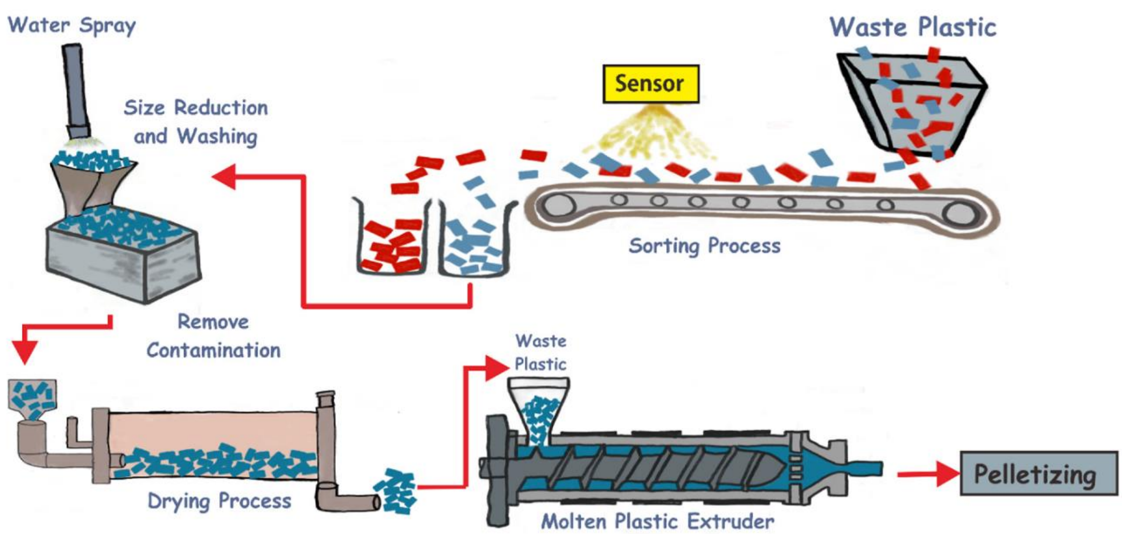


Image 18. Mechanical recycling representation
Source: (Damayanti et al., 2022)

As we have seen, this method is not extremely complicated, and has many advantages including: reducing waste to landfill, reducing the use of virgin polymers, and reducing greenhouse gas emissions (Prieto, 2023).

6.3.2. Chemical recycling

Chemical recycling, like mechanical recycling, aims to transform plastic waste into useful substances to give them a second life, the difference being that chemical reactions are used to break down the waste and convert it back into its original molecules.

Chemical recycling was born out of the need to find a recycling process that would not imply a loss of quality in the materials and that would give a second life to plastics that are difficult to recycle, such as multi-coloured plastics, multi-laminated (mixture of different resins) or contaminated with food waste (Intarex, 2023). However, this process is relatively young, complicated, and not yet universally accepted and cannot yet be used for all types of plastics, but there are high hopes for the future of this process.

Chemical recycling has several stages: First, a stage known as chemical depolymerisation or pyrolysis, where solvents and heat are used to transform the polymers into smaller molecules (monomers), for example with plastic PET, ethylene glycol or methanol is used as a solvent to obtain the corresponding double esters of terephthalic acid (BHET). In the following picture you can see the latter.

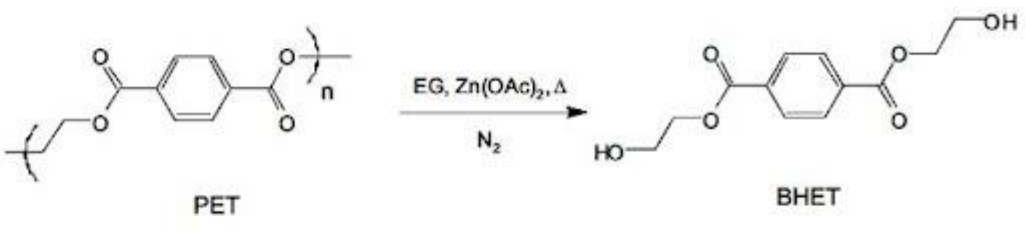


Image 19. Depolymerisation of PET with ethylene glycol
Source: (Elgegren, n.d.)

Another way to depolymerise the polymer is through hydrogenation or hydrocracking, which basically consists of heat treatment of the plastic in the presence of hydrogen at temperatures between 400-500ºC, high pressures and with catalysts. This process produces highly saturated products that can be used as fuel or raw material in the refinery.

This process is a good solution for mixed plastics as it allows their treatment and produces hydrocarbons with yields close to 85%. However, it is an expensive process and special safety measures are necessary (Elgegren, n.d.).

Once the monomer is obtained, some purification steps can be carried out and then directly to repolymerise where these new monomers are used to obtain new polymers.

6.3.3. Energy recycling

Energetic recycling is a viable alternative when plastics cannot be reused due to e.g. standards with the recycled material or the quality of the material or directly because the technology does not exist to give them another life. When the materials cannot be recycled in any other way, the remaining waste can be used for energy recycling, which consists of applying techniques and methods for the recovery of electricity, heat, or fuel. This action can reduce human-generated waste by up to 90% (Tornero, 2022a).

Although at first glance, it may seem that burning materials may generate more toxic gases, the U.S. Environmental Protection Agency has stated that waste-to-energy recovery produces electricity with less environmental impact than other sources of electricity. The same agency estimates that energy recovery by this method avoids the emission of thirty-three million metric tons of carbon dioxide per year (Tornero, 2022a).

There are several types of energy recycling, including the following:

OBTAINING LIQUID FUELS

This technology converts unrecycled plastics into oil that can be refined to be used as fuel for cars. The process to obtain it would begin by classifying the plastics and selecting the non-recyclable plastics, followed by pyrolysis where the plastics are heated to temperatures between 300 and 900º degrees, in an oxygen-free environment, with the aim of melting them to liquid. With this, simple hydrocarbons are obtained which, after a process of purification or distillation, many products can be obtained such as petroleum, synthetic crude oil, gas oil or paraffin (Ecoembes, 2023).

The following image shows what has been explained above:

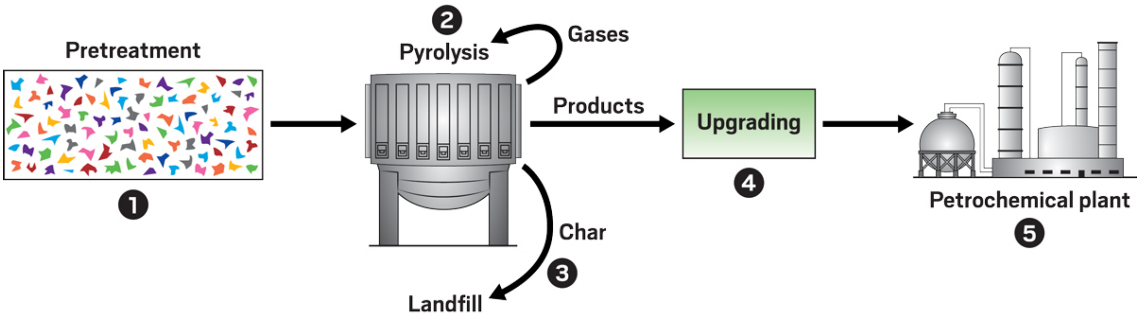


Image 20. Plastic pyrolysis process
Source: (Tullo, 2023)

<u>OBTAINING SOLID FUELS</u>

The objective of this technology is to obtain solid fuels such as coal or alternative fuels from non-recycled plastics. This technique is basically like the previous one where a combustion in the absence of oxygen (pyrolysis) was conducted to obtain the final product. In recent years, an improvement of this process has been studied, known as copyrolysis, which combines the pyrolysis of natural polymers such as cellulose or mehiculose with synthetic polymers (plastics). The combustion temperatures can reach between 300 and 700 degrees in an oxygen-free environment. With this technique, carbon can be obtained that can be used as a solid fuel (Marina, 2020).

<u>OBTAINING GASEOUS FUELS</u>

Another solution that can be given to plastics is to convert them into a gaseous fuel to produce electricity. This process is known as gasification and involves burning carbon-based materials for energy or heat, usually using wood waste and agricultural biomass to produce it. Nowadays, waste gasification is not widely used, although countries such as Japan and South Korea have been using it for years (Tornero, 2022b).

CHAPTER 7. CHALLENGES AND INNOVATIONS IN WASTE MANAGEMENT

6.1. Challenges of plastics waste management

After a detailed study of the different technologies for the management of plastic waste, it can be said that although these methodologies are quite effective, they are not without their challenges. Some of these challenges are outlined below (Qualitas, 2023):

VARIETY AND COMPLEXITY OF PLASTICS

As discussed in previous chapters, there are a wide variety of plastics, ranging from propylene to polystyrene. Each type of these plastics has different properties and chemical structures, so the exact same recycling method cannot be applied to all of them, as the same results would not be obtained for all of them. For example, as already explained, there are certain types of plastics to which additives are added, which often contain toxic particles, and therefore these plastics cannot be treated in the same way as plastics that do not contain these substances.

QUALITY

Another major challenge is the quality of the recycled plastic, as in general all plastics lose their properties after one or two recycling cycles (Gabriel, 2022). In addition, during collection, plastics come into contact with impurities, which has a negative impact on the recycling efficiency and decreases the quality of the plastic.

ASSOCIATED COSTS

On the other hand, it is very important to take into account the price of plastic recycling. According to a Greenpeace study, 85% of plastic packaging is not recycled because it is much more expensive than buying new plastic (EconoSus, 2023). Although this situation is changing thanks to innovations in technology, it is still a challenge to find economically competitive solutions.

INFRASTRUCTURE

The lack of efficient plastic recycling facilities is also a major challenge. This leads to limited recycling processes as it hinders the implementation of advanced processes. This challenge has a direct impact on the quality and quantity of recycled plastics. In addition, the scarcity of facilities means that traditional recycling methods are used, which may be less sustainable and more likely to generate secondary waste.

PUBLIC AWARENESS

The level of public awareness and understanding of plastic waste management and the importance of recycling is also limited. Only 14% of the world's waste is recycled, with Mexico, Turkey and Kuwait being the countries that recycle the least (Management, 2023). An involved population can contribute significantly to the success of recycling and waste separation.

TECHNICAL LIMITATIONS

Despite advances, there are technical limitations that prevent 100% successful recycling. The lack of advanced sorting and processing technologies severely limits the process, resulting in less accurate recycling processes and lower quality.

6.2. Innovations in waste management

All these challenges mentioned above have led researchers to look for more innovative solutions. Companies such as Angirus and Again are dedicated to combating the waste crisis. Angirus offers sustainable bricks made from plastic waste, although they may appear at first glance to be less strong than ordinary bricks, they claim to have equivalent strength (Angirus® IND, n.d.). On the other hand, Again is a company that receives, de-labels, washes, cleans and applies plastic containers for redistribution (Again Technologies, n.d.). Toynovo, which repairs and resells toys and educational materials in Colombia, also stands out (Toynovo, n.d.).

But there are not only these, many companies around the world are taking drastic measures to try to remedy the situation. In fact, more than 50 countries have joined a UN campaign for clean seas and oceans. Thanks to this agreement, many companies are being forced to control their waste, for example Nestle has committed to create 100% recyclable packaging by 2025 or Cocacola has pledged to increase the amount of recycled content in its plastic bottles to 50% (United Nations Environment Programme, n.d.-a).

In general, it can be said that today there are some measures that almost every company can take to reduce waste pollution. For example, products can be developed with eco-design. This means that from the very beginning products are designed with all phases of their life cycle in mind, including disposal and recycling. Therefore, before the product is created, it will already have a secured future.

Another measure to be considered is product traceability. In the last few years many digital labelling techniques have been developed that allow a better traceability of the products and provide the necessary information to be able to be recycled.

On the other hand, it is clear that in recent years new technologies such as artificial intelligence has been growing exponentially. In this field, these new technologies could be used for the development of tools that allow a better management of waste management at the administrative level, e.g. they could show where is the best location to place recycling containers considering the population or the frequency of waste collection in cities (Ecoembes, 2023a).

CHAPTER 8. ENVIRONMENTAL IMPACT OF PLASTIC

The use of plastic materials in the chemical industry has been increasing in recent decades. This trend is since these materials have a good resistance to chemical attack and their ability to resist contact with corrosive substances, which makes them a material of great interest in the sector (Díaz, n.d.).

This resistance translates into great durability, allowing these plastic materials to maintain their properties even in highly aggressive environments. However, despite the advantages in terms of chemical resistance, there is an important aspect to take into account that has been growing in recent years: the environmental impact associated with their use.

5.1. Impact on human life

The issue of plastic waste is of growing concern as it has a direct impact on people's daily lives and seriously affects human health.

The widespread presence of plastics in the environment, from food packaging to everyday products, has led to the contamination of air, water and food with chemicals resulting from the decomposition of these materials. Studies have shown that certain components of plastics, such as phthalates found in especially PVC (Phthalates, n.d.) and bisphenols present in polycarbonate (PC) plastics (European Food Safety Authority, 2023) can be harmful to humans. Phthalates can cause infertility, endometriosis, or insulin resistance (E. Fernandez, 2021), while bisphenols can cause brain damage, cancer, or obesity among other things (Picric, 2021).

In addition, the accumulation of microplastics in the food chain raises concerns about inadvertent ingestion of plastic particles, adding potential risks to human health.

5.2. Impact on flora y fauna

Plastics take between 100 and 1000 years to degrade completely (Ecoembes & Ecoembes, 2023), which leads to the accumulation of plastic waste in different areas, from urban environments to seascapes, and this not only affects the aesthetics of the environments, but also has detrimental consequences on fauna and flora. Every year, more than 1.5 million animals die because of plastic pollution (Monicaal.Lozanop, 2014). The death of these animals is because many mistake the waste for food and die when they try to eat it. This is evidenced when pieces of plastic are found in the stomachs of many dead animals (See Image 21).

Image 21. Plastics found inside a fish
Source: (Lapresa et al., 2018)

In the North Pacific more than 30% of fish have ingested plastic in their lifetime, as this is where what is known as the 'seventh continent' is found. This refers to a mass of plastic debris floating adrift in that specific region (Monicaal.Lozanop, 2014). Located between California and the Hawaiian archipelago, this phenomenon is more than 60 years old and occupies more than 1.8 million square kilometres, which is equivalent to twice the surface area of France (Thegravi, 2024).

But there is not only this mass of plastic waste, but there are also many others distributed all over the planet. In the following image you can see a representation of the world map with the main oceans and their pollution.

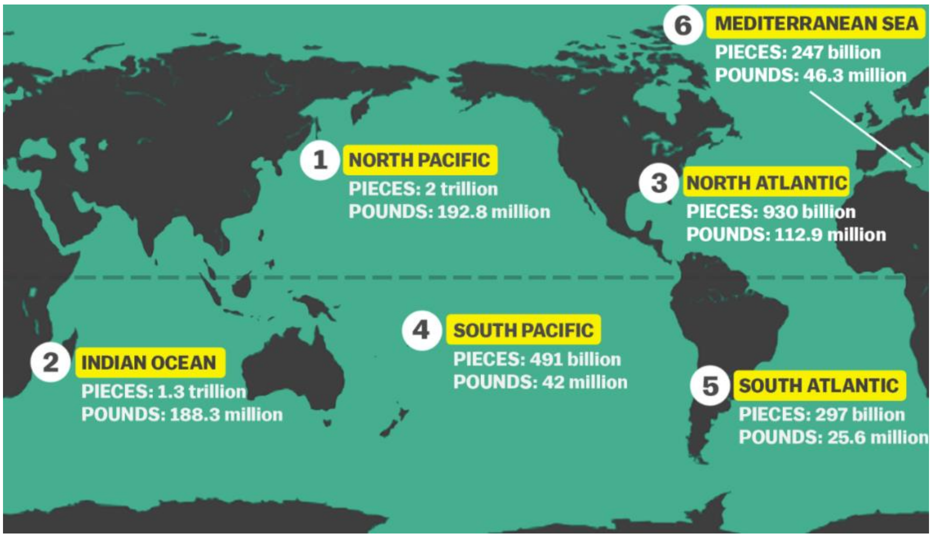


Image 22. World map with pounds of waste.
Source: (Crockett, 2016)

5.3. Impact on the air

The problem of plastic pollution does not only affect humans and animals; it also contributes significantly to the atmospheric crisis.

The journal Environmental Chemical Letters has investigated the presence of plastics in the air. In this study, researchers collected cloud water samples from the summits of two Japanese mountains, Mount Fuji, and Mount Oyama, and analysed them in detail. The result revealed the presence of nine different types of polymers and one type of rubber in airborne microplastics, including up to 14 pieces of plastic per litre of water in cloud samples (Euronews, 2023).

This phenomenon is caused by the aerosolization of plastic, where plastic waste, once released into nature, travels through water, wind, and ocean currents. Over time, these plastics are broken down into microplastics and nano plastics, which, due to their weight, can be released into the atmosphere. Logically, these particles may contain toxic additives that would also be released into the atmosphere. This can be very harmful to humans, as they may be inhaling tiny particles of plastic that can affect breathing and cause lung problems (Rodriguez, 2023).

In addition, there is the environmental impact of plastic production, a high-energy process that contributed 1.8 billion metric tons of greenhouse gas emissions in 2019, representing 3.4% of the global total (United Nations Environment Programme, n.d.).

CHAPTER 9. BUSINESS STRATEGIES FOR SUSTAINABLE PLASTIC PACKAGING MANAGEMENT

Nowadays, there are many companies that are environmentally aware, but even so, there are many that do not know how to deal with this problem. In this section, a case study will be conducted in which it will be possible to see what strategies, based on business techniques, can be applied to optimise waste management in the chemical industry.

For this purpose, a fictitious scenario will be created in which a laboratory, representative of the chemical industry, has not applied any efficient waste management strategy so far.

8.1. Previous context

The laboratory to be studied specialises in the research and development of new compounds and chemical formulations. On a day-to-day basis, this laboratory is constantly conducting experiments, analyses and tests involving a wide variety of materials, among which plastics play a crucial role. As mentioned above, chemical industry is one of the major contributors to pollution, in fact it is estimated that in 2014, medical, biological, and agricultural research laboratories created more than 5.5 million tonnes of plastic (Admin, 2016b).

These polymeric materials are widely used in the creation of packaging, containers, and laboratory utensils, which are of significant importance in the handling, storage and transport of chemical substances. Among the plastics that can be found in this laboratory are polyethylene, polypropylene, polyesterene and others, which are distributed as follows:

At the entrance, in the centre of the room, are the worktables, which are fitted with chemical-resistant protective covers, usually made of high-density polyethylene or polypropylene. On top of the table are various plastic materials (See Image 23) including plastic containers (1), test tubes in plastic holders (2), pipettes (3), flasks (4), flasks (5), jars (6), funnels (7), among many others.

Image 23. Plastic materials on a worktable in the laboratory

On the workbenches you will also find a lot of other equipment that is mostly made of plastic, such as balances (1), centrifuges (2), incubators and ovens (3), shakers and ph. meters (4), distillers (5), microscopes (6), among others. All this equipment is basic and can be found in any laboratory, although there are also many other devices on the market, such as chromatographs or spectrophotometers, depending on the specialisation of the laboratory.

Image 24. Laboratory equipment

It is also important to highlight the fundamental materials, which although obvious, have a fundamental role in the daily operations, such as safety glasses, gloves, face shields, masks, shoe covers or even some gowns, all made of plastic.

As we have seen, plastics play an especially important role in the day-to-day life of this laboratory. However, there is a lack of efficient waste management practices in this laboratory. The lack of a structured system for inventory control, the absence of effective recycling protocols and the poor organisation of plastic waste disposal have created a scenario where the unnecessary accumulation of plastic waste has a negative impact on both internal operations and environmental sustainability. In the following section, a few strategies that can be applied to avoid this situation will be explored.

8.2. Business strategies

The implementation of strategies derived from lean manufacturing could be a promising solution to enhance operational efficiency and promote sustainability in the workplace. Lean manufacturing is based on waste elimination, process optimisation and continuous improvement (Daniel, 2023). Among the strategies that could be applied are:

KANBAN SYSTEM

Kanban is a visual system that is characterised by having visual cues that indicate when and how much to replenish a given material, avoiding excess inventory, and reducing waste (Martins, 2022).

In the laboratory context, the Kanban system can be applied by labelling varied materials with visual codes or cards that represent different inventory levels. For example, marking a container of plastic gloves with a line, so that when the quantity of gloves is above the mark, it indicates that there are enough gloves and there is no need to replenish. On the contrary, when the quantity of gloves is lower than the mark, the gloves should be replenished. In the following image you can see the same case but with masks, where the red line is the resupply mark.

Image 25. Mask refilling with the kanban system

With this simple gesture, laboratory staff can quickly and visually track inventory levels of certain plastic, preventing overages. This not only optimises materials management, but also minimises unnecessary plastic use and reduces waste generation.

<u>5S STRATEGY</u>

The 5S method is one of the most widespread and popular management tools, aimed at improving productivity and operational efficiency. The 5S method is named after the Japanese initials: Seiri, Seiton, Seiso, Seiketsu and Shitsuke (Santos, 2024).

Seiri, the first of the S's, translates as classification. At this stage, one must identify all items and eliminate the unnecessary, with the aim of reducing clutter and freeing up workspace. In the context of the laboratory, this process starts with the identification and sorting of the various plastic materials used, from containers to utensils, with the aim of recognising the materials that are not unusable and can therefore no longer be ordered.

The next S is **Seiton**, which refers to order. After sorting the essential items, they should be arranged in a way that facilitates quick access to them, minimises search times and minimises material waste. In the laboratory, specific storage areas can be assigned for each material to facilitate more efficient access. This will not only optimise the organisation of materials but will also raise awareness of the amount of material available, which is often unaccounted for due to clutter.

Seiso is the third S and translates as cleanliness. Basically, this step encourages cleanliness and keeping the workspace tidy. A consistent cleaning protocol facilitates the identification of surpluses and contributes to the reduction of plastic usage by keeping only essential items.

The fourth S is **Seiketsu**, which refers to the state, and involves establishing rules and procedures, so that the previous 3S are maintained. In the laboratory, written guidelines or written protocols could be created for the proper use of plastic materials.

Finally, **Shitsuke** means discipline. This stage is key to keeping the improvements implemented. It is crucial to promote individual and collective responsibility to ensure that sustainable practices are maintained in the long term.

In the following image you can see many of the materials mentioned in the previous section and the before and after of a laboratory that has applied this strategy. In the first image there is much more clutter, with materials scattered all over the space and no clear placement of materials. The second image shows a laboratory that has applied the 5S strategy. This organised environment leads to a more efficient management of resources, minimising the unnecessary use of plastics and reducing waste generation.

Image 26. Laboratory comparison applying the 5s

VALUE STREAM MAPPING

Value stream mapping (VSM) is a Lean manufacturing strategy that consists of illustrating a process with the objective of identifying waste and eliminating it. This strategy is more oriented towards eliminating phases or sub-processes or tasks that are not necessary (Asana, 2022).

Mapping the laboratory using VSM provides a clear view of the flow of materials, equipment and plastic utensils used on a daily basis. It is very important to identify and visually represent each stage of the process, as ideas can be gained on how to improve the flow of materials, e.g. materials can be redistributed in the laboratory space in a way that optimises the process and therefore plastic waste.

As an example, after using VSM, it can be concluded that a tap can be placed on the workbenches so that when a plastic beaker is finished, for example, there is quick access to a place to wash it, so that it will be much easier to reuse it because it will be clean. Otherwise, if the tap is far away, it is likely that the scientist will not clean it until the end of the experiment and will use other beakers, generating more plastic waste.

POKA YOKE

Another strategy widely used in lean manufacturing is Poka Yoke, a term that stands for 'mistake-proofing'. Basically, the aim of this technique is to create any mechanism that avoids or minimises the possibility of making mistakes (Mecalux, n.d.).

In the laboratory context, this strategy can be used to label waste plastic disposal containers with specific colours, which reduces the risk of recycling errors.

Clear labelling provides accurate information on the type of waste to be deposited in each container. This ease of identification is essential for laboratory team members to ensure the correct recycling of plastic materials used in daily experiments and analysis.

Another example of Poka Yoke, would be to design specific holders for the storage of each type of material, therefore these holders would have predetermined and adjusted spaces for specific items, thus avoiding the possibility of incorrectly placing them in the wrong place.

The specific shape of each holder would serve as a visual guide to facilitate the correct arrangement of the materials, thus minimising clutter in the laboratory as each material would have its own space. In the following image you can see an example of how to apply this:

Image 27. Organiser or stand for the laboratory

In this part we have explained many business management techniques that can be applied in a laboratory to improve the efficiency of the laboratory, but also these and many other technologies can be applied in larger industrial plants. A very clear example of efficient business management could be the installation of monitoring sensors to optimise the supply chain and minimise waste in the production of plastic products. Or intelligent packaging could be created to extend the shelf life of foodstuffs, for example a lot of fresh food comes wrapped in plastic. Research into this process could save companies thousands of euros.

8.3. Results

As a practical example of what is explained in this section, one can take 'The Laboratory Plastics Recycling Programme' implemented by the MIT Office of Environment, Health, and Safety. Since its launch in 2019, this programme aimed to manage plastic waste efficiently in research laboratories.

The programme has been a remarkable success, collecting almost 77 kg of plastic per week from each participating lab in 2020 and increasing to over 120 kg of plastic. These results were achieved through the implementation of Lean strategies, such as those mentioned above. Waste elimination, process optimisation and efficient collaboration have been key pillars in achieving these results (Ltd, 2023).

These results support the effectiveness of the application of Lean strategies in plastic waste management, aligned with principles of continuous improvement, operational efficiency, and waste elimination.

CHAPTER 10. BUSINESS OPPORTUNITIES IN PLASTIC WASTE MANAGEMENT

It is undeniable that the plastic crisis is a global challenge, with very damaging consequences for the environment and for society. However, it also presents a unique business opportunity for companies. This chapter explores the different business possibilities generated by this problem.

There are a wide variety of opportunities related to the management of plastics, from the diversification of products and services to the development of new innovative technologies. These are explained in more detail below.

10.1. Diversification of products and services

The strategy of diversification through the incorporation of recycled materials can be a very appropriate solution, as by integrating these recycled materials, companies can develop a more diverse range of sustainable products. This diversification not only meets the changing demands of the environmentally conscious consumer, but also responds to the growing need to create sustainable solutions in various market sectors. In fact, brands such as Nike, Audi or Ikea use this type of material for decorative purposes such as display cabinets, counters or furniture (Admin_Instore2k, 2022). In the following pictures you can see recycled plastic used as furniture.

Image 28. Recycled plastic used in furniture

Incorporating recycled plastics into the production of materials such as packaging, household utensils or everyday consumer products can highlight a company as a leader in environmental responsibility. This can generate customer loyalty and capture the attention of those consumers seeking to contribute to environmental care.

Similarly in the industrial sector, the use of recycled plastics not only reduces dependence on virgin raw materials, but also positions companies as committed to sustainability. This diversification of supply can translate into significant business opportunities, as more and more companies are looking for suppliers that share their environmental values.

10.2. Innovation in business models

The transition from linear business models to new circular business models presents a strategic opportunity for companies. These circular models are designed to extend the life of products by transforming plastic waste into valuable resources, following the process shown in the Image 29 (Travel Booking LP, n.d.). A very visual example of this change could be: in an electronics company, designing removable products with components that can be easily replaced instead of products where a part fails and a new one has to be purchased. When consumers no longer use the devices, they could return them so that the company could recover and reuse components. This would not only reduce waste generation, but also optimise the supply chain by reducing reliance on new raw materials.

Image 29. Circular business model
Source: (Kmps_Admin & Kmps_Admin, 2022)

10.3. Innovative technologies and processes

Investing in innovative technologies and processes in plastic management can also be a good business investment.

The adoption of these technologies can improve the recycling process towards more efficient processes that for example have shorter production times or reduce costs. This investment in innovative processes not only makes the company stand out in the market by demonstrating its commitment to the environment but can also lead to the development of new products and services. Some of these technologies have been explained in previous chapters.

10.4. Business partnerships

Collaboration between companies can also become a great business opportunity, as it allows the sharing of resources and expertise and can lead to the development of more innovative solutions. The consequences of these actions can be very positive for all the companies involved as they can reduce operational costs and maximise efficiency in the management of plastic waste. Synergies can also result in expanding the market into unexplored segments, generating growth and diversification.

CHAPTER 11. REGULATIONS AND COMPLIANCE

9.1. Normative at national level

The growing awareness of the negative impacts of plastics on ecosystems has led to the implementation of certain regulations and policies that address the problem of plastic waste.

In Spain in 2022 a new decree known as 1055/2022 has been created where companies are obliged to include more information on packaging. This means that from the very beginning products are designed with all phases of their life cycle in mind, including disposal and recycling. Therefore, before the product is created, it will already have a secured future. On the other hand, this decree also obliges companies to register in the register of ministry producers for the ecological transition where they have to report information on the packaging they put on the market (Envases, n.d.).

But it is not only Spain that takes measures in favour of proper waste management, many other countries are equally or even more aware. The countries with the most regulations are Germany, Switzerland, and Belgium, which exist not only because of their effective regulations but also because of the high level of understanding of their population.

It is important to highlight the Agenda 2030 where the members of the United Nations are implementing certain measures to achieve the 17 goals set to achieve economic, social and environmental sustainability. Many of these goals are directly related to the management of plastics and although it is not a law as such, it implies a commitment on the part of the member countries that has many benefits.

9.2. Regulations at company level

CSR is defined as the integration of corporate social responsibility, or in other words, it involves considering not only the economic aspects of all business operations, but also the social and environmental impacts (Nestor, 2024). In other words, CSR has a focus that goes beyond short-term financial benefits. In the specific case of plastic packaging management, this perspective implies recognising and addressing not only the regulatory and compliance challenges, as set out in decree 1055/2022 in Spain, but also the ethical and moral responsibility to minimise the adverse effects of plastic packaging on society and the environment. For example, it involves consideration of the entire life cycle of products, from design to recycling or incorporating principles of eco-efficiency and sustainability.

Furthermore, this integration of CSR in the management of plastic packaging has a direct impact on the corporate image of companies. By positioning themselves as responsible and conscientious companies, they can strengthen consumer confidence and foster brand loyalty.

CHAPTER 12. CONCLUSIONS

Throughout this master's thesis was to conduct a comprehensive analysis of plastic packaging in the chemical industry, focusing on waste management technologies and sustainable practices. Therefore, it can be said that the main objective of this project has been fulfilled. When examining the more specific objectives, it can be seen that the different points have been studied in detail:

To meet the first specific objective, which was to investigate and analyse the current state of plastic packaging in the chemical industry, the history of sustainable plastic management was briefly explored. Then, the life cycle of plastic packaging was studied, examining each stage in detail up to its production. In addition, each of these stages has been related to the business world. A comprehensive analysis of the seven types of plastic packaging has also been carried out, providing concrete examples of their application in the chemical industry and highlighting the ease or difficulty associated with their recycling. This comprehensive approach has allowed for a thorough understanding of the current landscape of plastic packaging in the chemical industry, fulfilling the first special objective.

The second objective was to evaluate existing waste management technologies related to plastic packaging, taking into account the three R's: reduce, reuse and recycle. To do this, a detailed analysis of the techniques associated with each of these practices was carried out and an examination was made of what improvements companies can make at each of these stages, giving practical examples of actions that companies can take. In addition, the challenges facing these technologies today are explored. Finally, it explored future innovations that could be applied to address these challenges

The third objective was to analyse the environmental impact of plastics on the environment by analysing in detail the negative effects of plastic mismanagement on flora and fauna, on human lives and on the air.

Finally, we wanted to study in detail the business strategies that could be taken to try to minimise the negative impact of plastics on the environment, for which a case study has been carried out in which a physical laboratory has been described and the measures that could be taken have been explained. In addition, it has been studied what new business opportunities there are around this problem.

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