



# FACULTY OF CHEMISTRY

## LITERATURE REPORT

**Master: CHEMISTRY OF ADVANCED MATERIALS**

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**UNIVERSITATEA  
DIN BUCUREȘTI**  
VIRTUTE ET SAPIENTIA

## **FACULTY OF CHEMISTRY**

**DEPARTMENT OF ORGANIC CHEMISTRY, BIOCHEMISTRY  
AND CATALYSYS**

# **Valorization of plastic polymers using biocatalytic approach**

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## Introduction

The production of plastic dates back to 1950' and since then they have become one of vital materials used in everyday life applications. The variety of plastics available and the cheap production of those are the main reasons of the grow of plastic industry [1]. Although the plastic industry consumed 6% of world oil production in 2014, from the 26% used in packaging applications, only 5% was recycled causing a huge economic loss. By 2050 the plastic industry is estimated to consume 20% of the world oil production [1].

The plastic wastes accumulation has been growing in the recent years and it became one of the most severe environmental and social issue [2]. It is estimated that between 2010 and 2025 100 MT of plastic waste will enter in the ocean [1]. It is predicted that by 2025 for each three tons of fish, there will be one tone of plastic in the ocean [3]. This will cause widespread contamination of marine ecosystems since the microplastics (smaller fragments of plastics which was degraded) can be ingested by zooplankton and phytoplankton which will have a negative impact on their health. Since approximatevely 70% of the world's oxygen is produced from the photosynthesizing of marine plants, the plastic will have a huge impact in climate change and global warming [1].

Since the plastics with polymer structures are especially designed to mentain optimal material properties, most of the plastics can not be attacked by microorganisms. The evolution could not develop enzymes to degrade these man made materials and therefore usually the plastics do not rot in the biological environment [4].

With the discovery of Tokiwa and Suzuki in 1977 of some lipases that are able to attack the ester bonds in some aliphatic polyesters and can depolymerize such materials, more attempts were made to design similar enzymes [4]. Also with the increasing problem of plastic waste, the pursuing of making biodegradable plastics started [4].

## Theoretical part

### 1. Synthetic plastics – general consideration

The term "plastics" generally refers to synthetic polymers that are omnipresent in modern society. Plastics are that common in our everyday life, that it is estimated each person consumes 50 kg per year in the European Union and 68 kg per year in the United States [5].

Plastics find applications in a different domains such as packaging, biomedical devices, clothing and sport equipment, electronic components [5].

Unfortunately, the main problems of them are that they are obtained from the nonrenewable sources of petroleum/natural gas and the deposition rate accelerated past the rate of production [5][6].

The global production and consumption of plastics increased at an alarming rate over the last few decades accumulating persistent in the landfills and the environment, only 9% of plastic waste being successfully recycled in 2015 in the United States [5].

### 2. Types of synthetic plastics

Synthetic plastics like polystyrenes (PS), polyethylene (PE), polyurethane (PUR), polypropylene (PP), polyvinyl chloride (PVC) and polyethylene terephthalate (PET) have a very important role to almost every aspect of our lives [2].

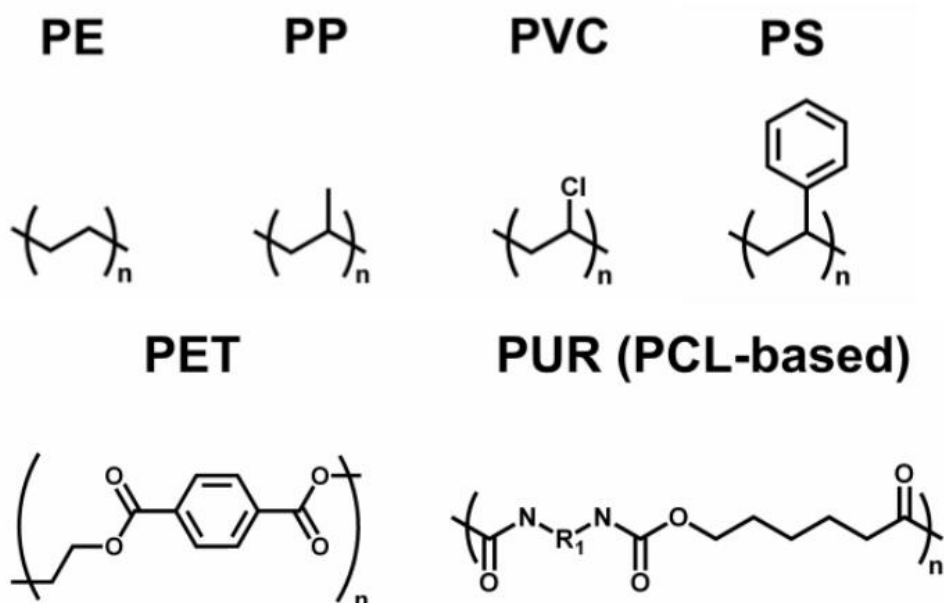


Figure 1. The main types of synthetic plastics [2]

## 2.1 Polystyrene (PS)

Polystyrene is the simplest aromatic hydrocarbon polymer based on the monomer styrene having a hard texture, high tensile strength and excellent transparency [7][8]. Since it can be monoextruded, coextruded with other types of plastics, injection molded or foamed, it can generate a large range of products [7]. Polystyrene is generally used in the food industry having applications like protective packaging (for eggs, meat, fish etc.) and disposable plastic silverware (lids, plates, bottles, cups etc.) [7][8]. It is one of the most widely used plastics, mostly because it is an inexpensive resin per unit weight [9].

PS is a clear, odorless, hard, tasteless, colorless material with outstanding properties including thermal stability, mechanical strength, relatively low density and low production cost. The particular reason for its highly stable structure and resistance to decomposition is its structure of phenyl groups and single C-C bonds [10].

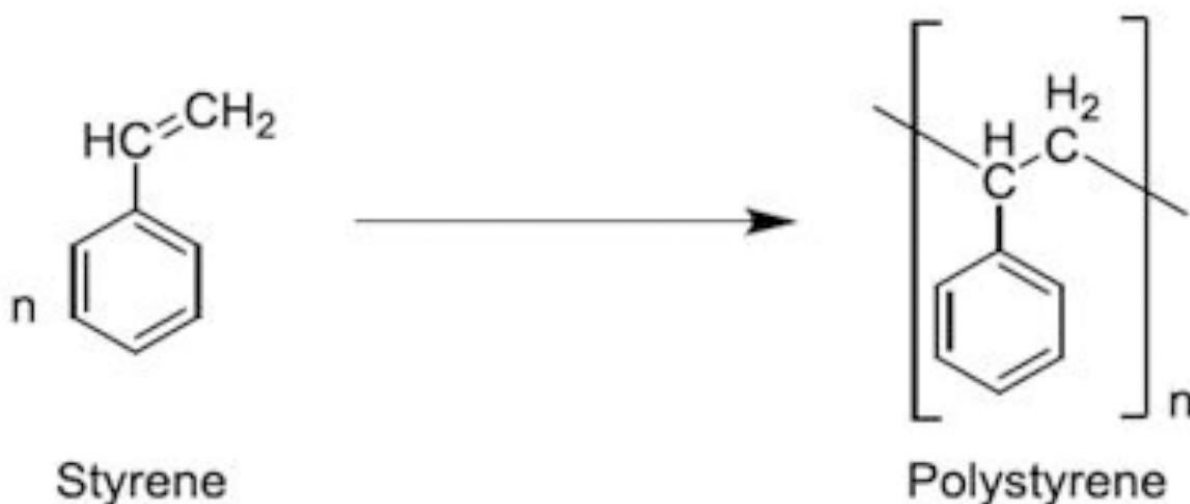


Figure 2. Polymerization of styrene to polystyrene [10]

Naturally polystyrene is transparent, but it can be coloured with different colourants. Being a thermoplastic polymer, polystyrene is in solid state at room temperature, but above  $100^\circ\text{C}$  it starts to flow [11].

Polystyrene is rather chemically inert being waterproof and resistant to many acids and bases, this being one of the reasons of its popularity in fabricating many objects of commerce. But it can be easily attacked by organic solvents like acetone, aromatic hydrocarbon solvents and chlorinated solvents [11].

Polystyrene can be used in either solid and expanded forms, both of which can be recycled. Solid PS such as coffee cups, trays etc. can be recycled and transformed into office equipments, videocassette cases etc [12].

PS is manufactured in three main commercial forms: expanded polystyrene (EPS), general purpose polystyrene (GPPS) and high-impact polystyrene (HIPS). There is a fourth type of fabricated PS with the name of syndiotactic polystyrene (SPS), but it has a relatively minor grade [10].

## 2.2 Polypropylene (PP)

Polypropylene is one of the most popular plastics because of its low density and excellent chemical resistance. It can be processed through many converting methods including injection molding and extrusion [13].

Polypropylene is an olefin polymer, thermoplastic with a low melting point. PP fiber is the fourth largest volume artificial fiber, the 2014 worldwide production value being US\$56.73 million. PP's major use is in industrial applications like geotextiles, ropes, carpets, surgical sutures and sanitary products [14].

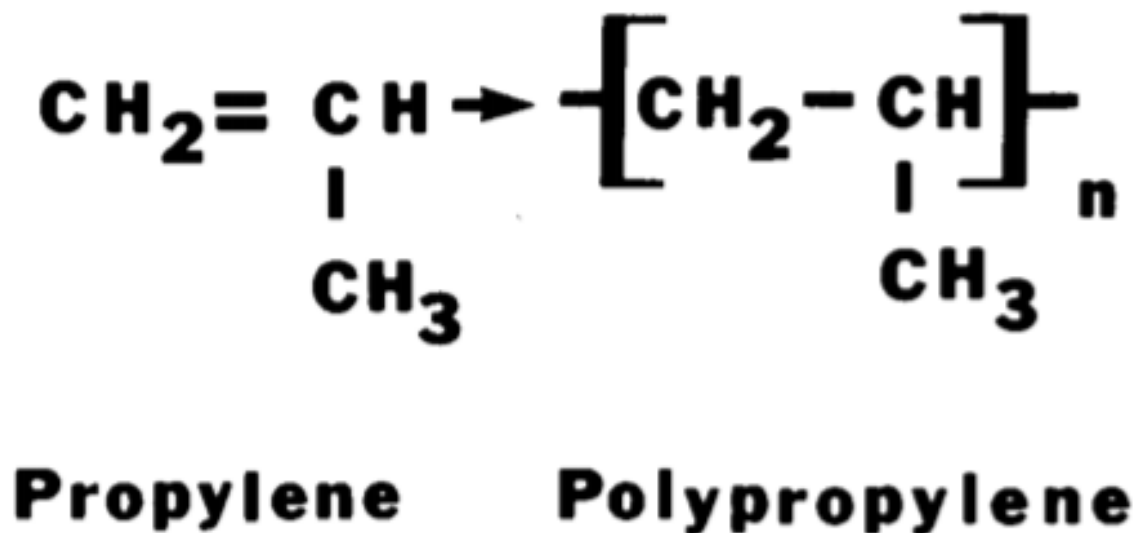


Figure 3. Polymerization of propylene to polypropylene [15]

Polypropylene is a transparent, free-color material and it is produced through a process of monomer connection called addition polymerization [13]. PS is formed from propylene, a liquefiable hydrocarbon gas [15].

Three stereoisomeric forms of PP exist: isotactic, syndiotactic and atactic. Isotactic PP has methyl groups on one side of the polymer chain, syndiotactic PP has methyl groups that alternate along the chain and atactic PP has methyl groups arranged randomly. Between all three types of PP, only the isotactic one has commercial importance [15].

Its high temperature resistance makes polypropylene suitable for items such as funnels, bottles, trays, pails and jars that have to be sterilized frequently [13]. The melting



poing of PP is around 165°C, but this can vary with the degree of chemical and steric purity [15].

### 2.3 Polyethylene (PE)

Polyethylene is the most common plastic in use today having the simplest molecular structure of any polymer [16][17]. It is primarily used for packaging and it is the largest tonnage plastic material [16][17]. Polyethylene represents 34% of the total plastic produced annually with over 100 million tonnes [16].

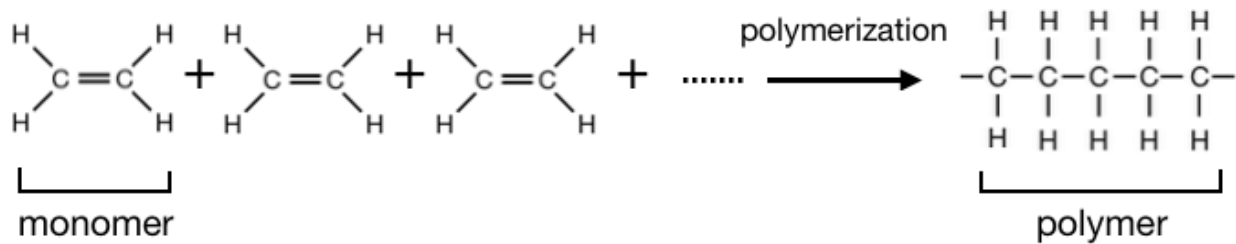


Figure 4. Polymerization of ethylene to polyethylene [17]

PE is an inert material and it is very difficult to degrade in the environment. In a study made with a polyethylene sheet, only after 12-32 years it showed partial degradation and negligible weight loss being kept in a moist soil. The particular reason for this circumstance is the water insolubility, the hydrophobicity due to high molecular weight, presence of linear backbone of carbon atoms and its degree of crystallinity [17].

PE is a mixture of similar polymers of ethylene. It can be low density or high density, depending on the pressure and temperature applied when manufactured: the low density PE (LDPE) is prepared at high pressure and high temperature and high density PE (HDPE) is prepared at low pressure and low temperature [16].

LDPE is inert at room temperature, but it can be attacked by strong oxidizing agents and some solvents. LDPE is characterized by tear strength, tensile strength, opacity, rigidity and chemical resistance due to its degree of crystallinity within the range of 50-60%. It is generally used coating on paper, textiles, mulching agricultural fields and constructing polyhouse [17].

HDPE is produced during a catalytic process and has little branching. It provides stronger intermolecular forces and greater tensile strength than LDPE. It is widely used industrial and day-to-day applications like milk jugs, carry bags, margarine tubs, detergent bottles, water pipes etc. due to its opacity, hardness and durability at higher temperatures [17].

### 2.4 Polyurethane (PUR)

Polyurethane is a very versatile polymer having the structure property relationship of diisocyanates and polyols providing ample customization to the manufacture [18].

Polyurethane is formed by the reaction between di/poly isocyanate and a diol or polyol, creating repeated urethane linkage in the presence of chain extender and other additives [18].

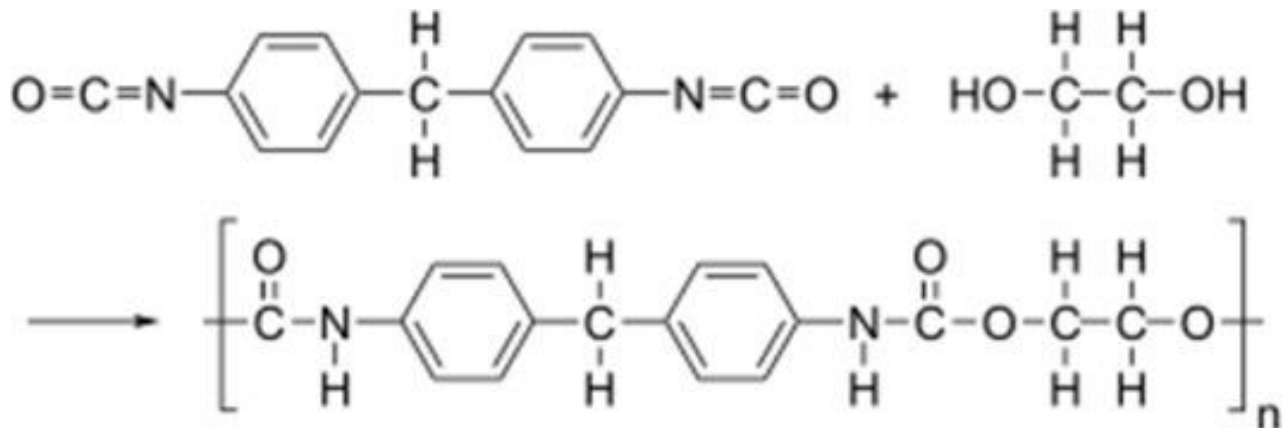


Figure 5. Polyurethane formation [18]

The properties of polyurethane are diverse, these can range from soft touch coatings to very hard rigid material used in construction. PUR has attracted not only the scientific community, but also the industries due to its properties and ease of tailoring [18].

PUR has many different applications in different domains. Due to the advances in different techniques of modern times, manufactures are able to produce this polymer in a wide range of polyurethane apparel. Some applications of PUR in this department are: manmade skin and leathers, sports clothes, and a variety of accessories [19].

PUR find other application in major appliances like rigid foams for refrigerator and freezer thermal insulation systems, in household materials such as flexible foam padding cushions, floors, in modern material science like composite woods [19].

### 2.5 Polyvinyl chloride (PVC)

Polyvinyl chloride is a widely used polymer and it is one of the most valuable products of the chemical industry. PVC is produced from its polymer, vinyl chloride, and is a hard plastic that it can be made softer with the help of plasticizers. Over 50% of PVC manufactured is used in construction being inexpensive, hard and easy to assemble [20].

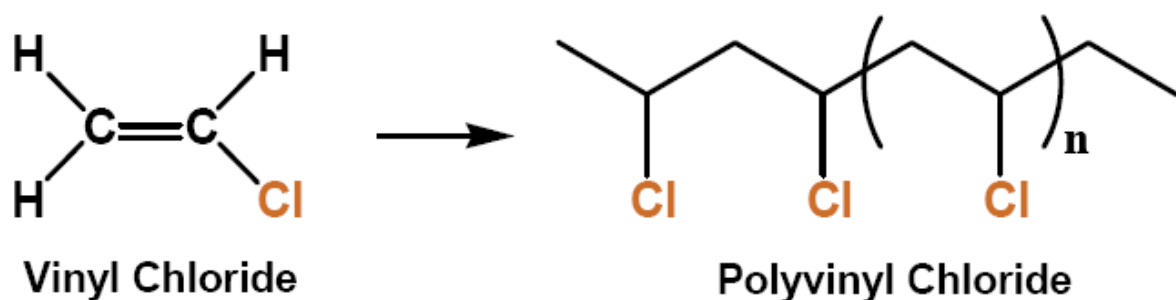


Figure 6. Polymerization of vinyl chloride to polyvinyl chloride [21]

PVC with 57% of mass by chlorine is an ‘infrastructure thermoplastic’ material. Being thermoplastic, PVC softens when heated and hardens when it cools. Because of this property, PVC can be subjected to different techniques: extrusion, calendering, injection and blow molding [22].

Due to its low density, PVC provides low material cost on a volume basis [22]. Although appearing to be an ideal building material, replacing in recent years the traditional building materials as wood and concrete, concerns have been raised about the environmental and human health costs of PVC [20].

### 2.6 Polyethylene terephthalate (PET)

Polyethylene terephthalate, commonly referred as polyester or PET, is a semiaromatic polymer synthesized from ethylene glycol and terephthalic acid [23].

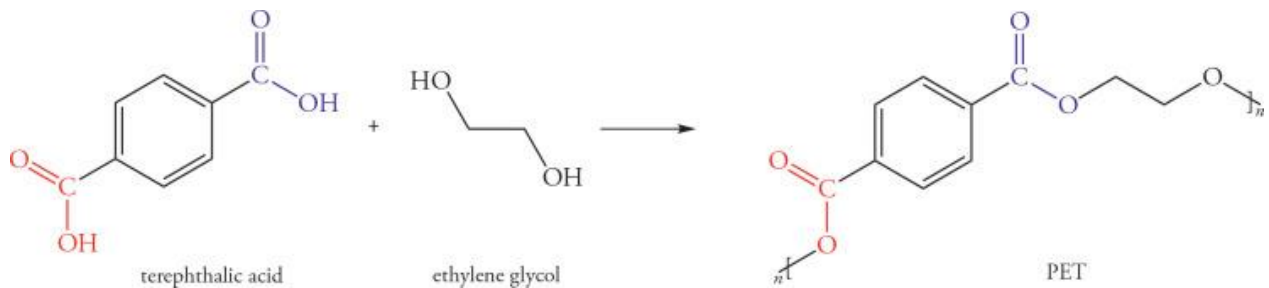


Figure 7. Polymerization of terephthalic acid and ethylene glycol to PET [24]

PET is used in industrial applications due to its excellent moisture and fair oxygen barrier characteristics having a glass transition temperature of around 67-81°C and a melting point of 260°C [23].

The half life of the polymer at 37°C in a normal saline environment is of 700 years [25]. Due to its very important property to be colourless and transparent (if amorphous) or translucent (if semi-crystalline), the consumers can see the content from the bottles [26].

PET is lightweight (compared to a 750 ml wine bottle, a 1L PET bottle weighs 335 less grams), thermoplastics, semi-rigid to rigid, robust and mechanically resistant to impact. It is extremely inert compared with other plastics and it does not contain plasticizers (in the case of PVC the use of plasticizers is essential), but it can be blended with other polymers to improve certain properties [26].

Because all of these properties, PET is the third most commonly used plastic in the packaging industry with a continuous growing demand [26].

### 3. Plastic waste

#### 3.1 Methods of disposing plastic waste

The current methods for disposing of plastic wastes mainly include landfilling, producing the same or similar product (primary recycling), mechanical recycling (secondary recycling), chemical recycling (tertiary recycling) and incineration (quaternary recycling) [1][2]. Landfilling is the major method due to its low cost and operability, especially in the developing countries [2].

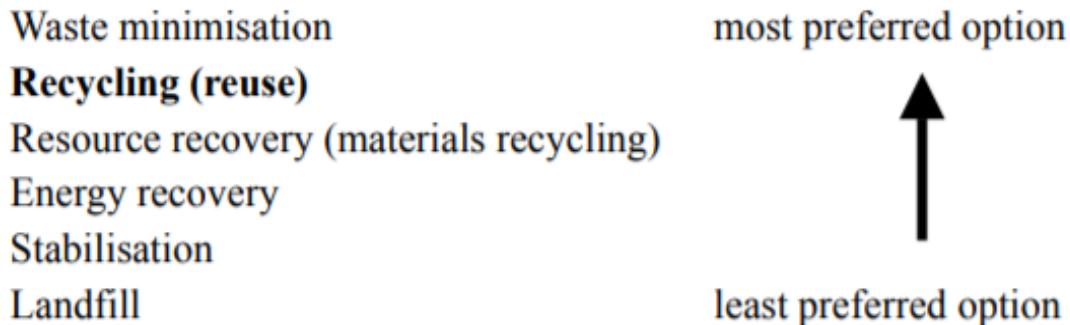


Figure 8. Generally accepted European Community Strategy for dealing with waste [27]

Primary recycling refers to either reusing the material or recycling the plastic to produce products with the original structure. It is a closed loop recycling method and can be only used on high quality plastic [1].

Secondary recycling indicates the conversion of waste plastic into a less demanding product via mechanical transformations. Mechanical recycling has various advantages over chemical recycling (tertiary recycling): lower global warming potential, less acidification and eutrophication, more renewable energy use and last, but not least, a lower processing cost [1].

Tertiary recycling describes the chemical reaction used to depolymerise and degrade plastic waste into monomers or into other useful materials. There are many chemical recycling methods and these depends on the polymer type and on techniques used, each of them having advantages and disadvantages. Although mechanical recycling presents some advantages over chemical recycling, the tertiary recycling has also some advantages over the secondary one: the potential of producing circular polymer since recovered monomers can be repolymerised and the opportunity to achieve new materials with added value [1].

Quaternary recycling indicates the energy that is recovered via incineration of low grade plastic waste. When plastics are burned, they result heat energy that is used to generate steam and electricity. The quaternary recycling should only be used as a last solution since the imbedded energy of the polymers molecular structure is lost and harmful chemicals and dioxins are released into the atmosphere [1].

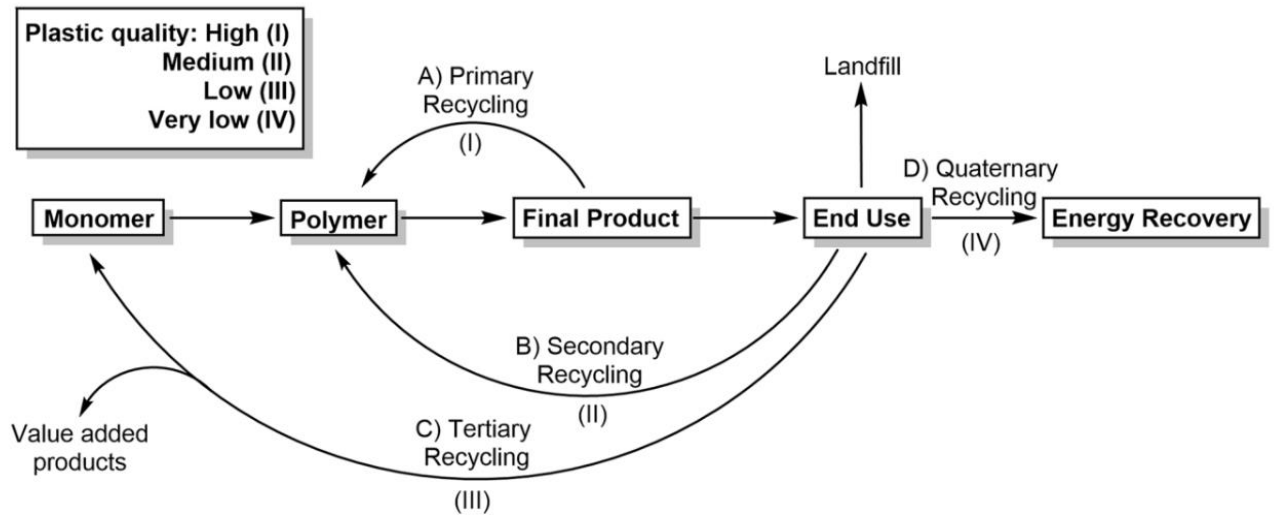


Figure 9. Different plastic waste treatment options and associated plastic quality [1]

### 3.2. Methods of disposing PET wastes

#### 3.2.1 Mechanical recycling

Because of the large amount of PET circulating, its mechanical recycling is well established and the recycled PET has applications in a variety of domains. In the process of mechanical recycling, PET usually suffers the process of yellowing discoloration, a nontoxic procedure. Around 72% of recycled PET found its use in fibre applications. If the PET becomes so low grade that it can not be mechanically recycled anymore, then chemical recycling should be used to recover its monomers [1].

PET can be subjected to mechanical recycled via melt extrusion up to 40 cycles without a significant change to be observed in its mechanical properties. After this, the melting temperature is dropping due to recuded crystallinity of the polymer. PET is highly stable to any type of solvolysis [1].

#### 3.2.2 Hydrolysis

PET can be hydrolysed into its monomers terephthalic acid (TA) and ethylene glycol (EG) and the conditions are either acidic, alkaline or neutral. Hydrolysis has some disadvantages like high temperature and pressure requirements in addition to long reaction times [1].

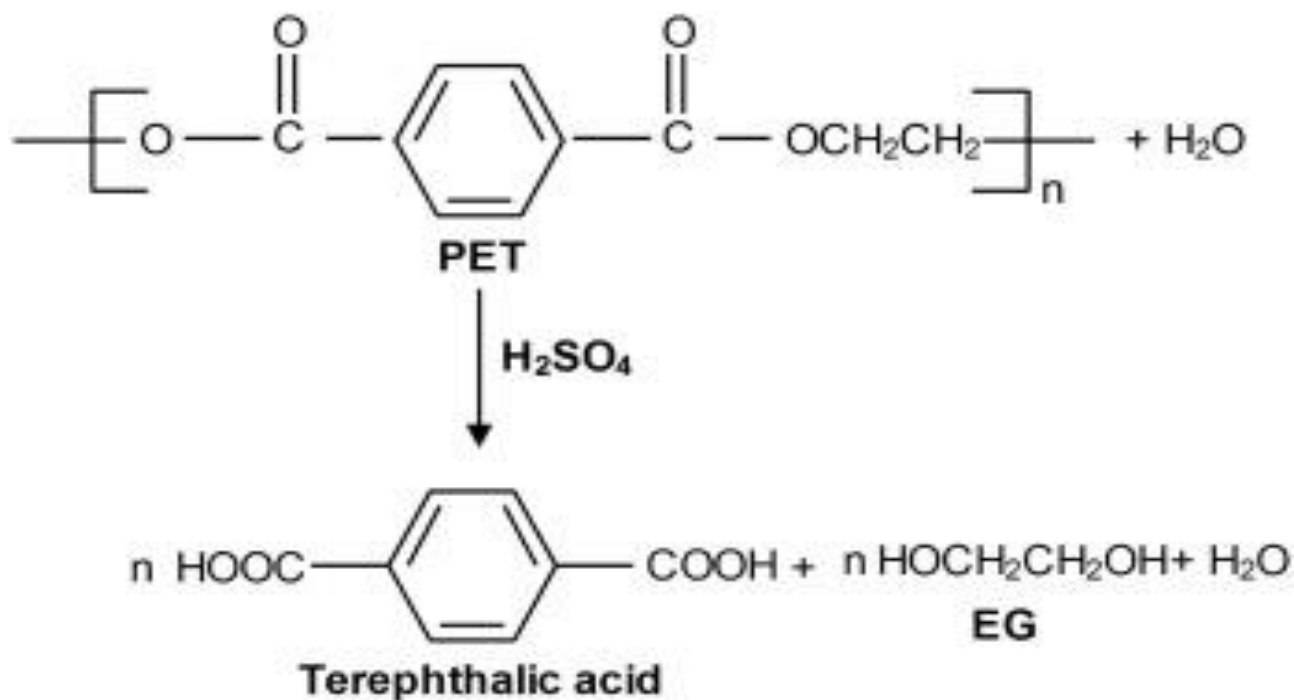


Figure 10. Hydrolysis of PET [28]

Acidic hydrolysis takes place using concentrated acids like phosphoric, nitric or sulfuric acid. The yields obtained from this methods are high, but the main disadvantage is that the separation of EG from the highly acid solution is difficult. Additionally, the high amount of acid needed to industrialize this method poses economic and environmental problems [29].

Alkaline hydrolysis is typically carried out in aqueous solutions of 4–20 wt% NaOH. This process has relatively good yields, but the longer reaction times and high temperatures are some drawbacks of the method [29].

Neutral hydrolysis uses also high temperature and elevated pressures. Without the need for stoichiometric acid or base, this type of hydrolysis would be the ideal one, but this process usually processes low purity monomers and have a slow rate of reaction [29].

### 3.2.3 Glycolysis

Glycolysis is the most used chemical recycling method for PET and it consists in an insertion of a glycol into the PET chains. The glycol breaks the ester linkages and it replaces with hydroxyl terminals for producing Bis 2-Hydroxyethyl Terephthalate (BHET), oligomers and dimers. For obtaining mostly BHET with a very little amount of oligomers the optimum parameters for glycolysis are: a pressures of 0.1–0.6 Mpa, a temperature range of 180–240 °C, a transesterification catalyst, between 0.5 and 8 h for completion and a high EG/PET ratio [1].

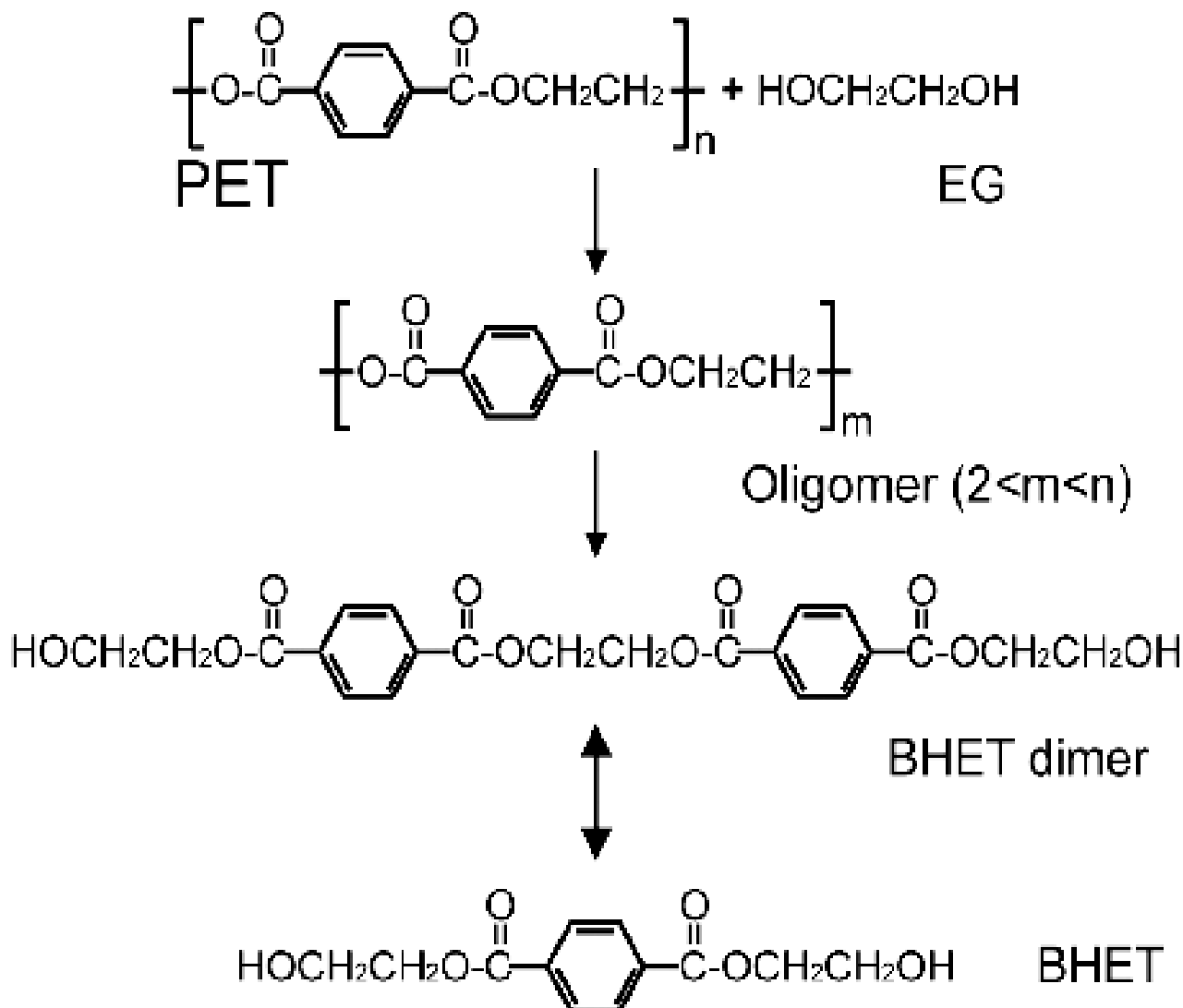


Figure 11. Glycolysis of PET [30]

Glycolysis takes place using a very large variety of glycols such as EG, diethylene glycol (DEG), propylene glycol (PG) and dipropylene glycol. Usually, the catalysts used are metal acetates. The zinc acetate is considered the best among them. Although, these catalysts are often used in industry, they have some disadvantages like: difficulty separating the catalyst from the products, side reactions and product impurities. For more recyclable and simpler purification, ionic liquid catalyst can replace the usual ones [1].

### 3.2.4 Pyrolysis

There are two major types of pyrolysis of PET: thermal pyrolysis and catalytic pyrolysis [29]. The thermal pyrolysis of PET takes place at high pressure and temperature leading to the formation of a solid char and a volatile fraction. Then, the fraction can also be separated into a condensable hydrocarbon oil and a noncondensable gas. The hydrocarbon oil is composed of a mixture of organic compounds like toluene, styrene, ethylbenzene etc [1].

Catalytic pyrolysis utilizes a catalyst for reducing the temperature and reaction time and thus improving the selectivity and economic viability [29]. Although catalytic pyrolysis has a narrower distribution of hydrocarbon products, it presents a higher market value. Catalysts like silica alumina, ZSM-5 and zeolites are usually used and it was proven that some of them achieved a higher conversion rate of valuable aromatic compounds in the oil compared with the thermal pyrolysis [1].

### 3.2.5 Alcoholysis

PET can be depolymerised via methanolysis resulting a stoichiometric mixture of its monomers N,N-Dimethyltryptamine (DMT) and ethylene glycol (EG). Methanolysis is carried out at high temperatures and pressures using divalent metal catalysts. The methanolysis also generates several byproducts like Bis(2-Hydroxyethyl) terephthalate (BHET), 2-hydroxyethyl methyl terephthalate (MHET), oligomers, and dimers of DMT and BHET [1].

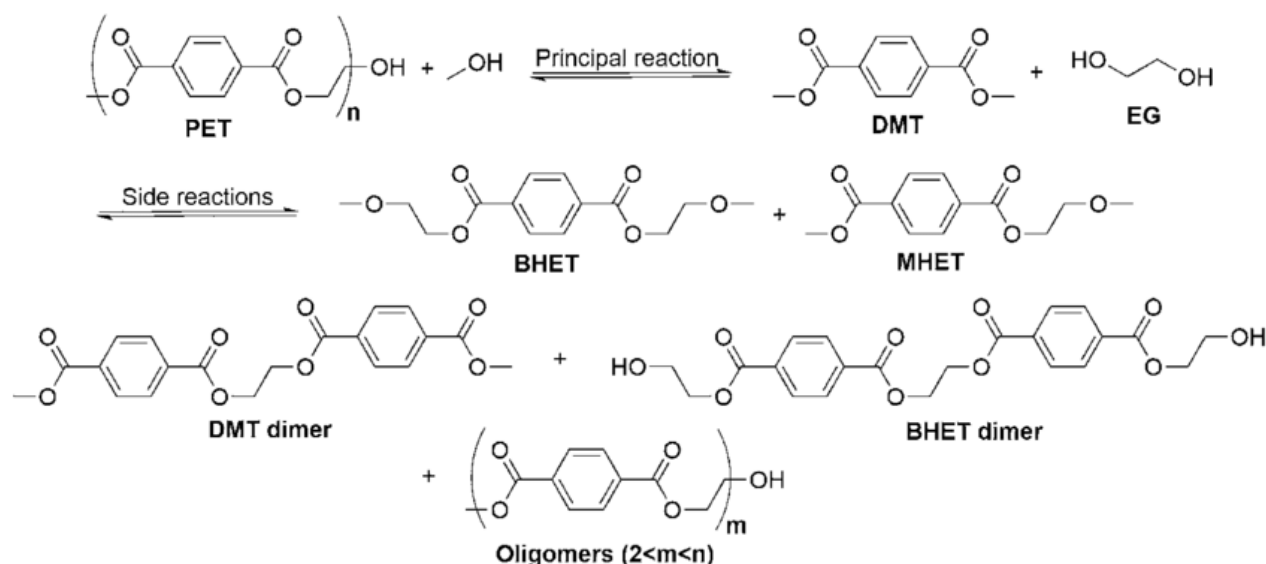


Figure 12. Overall reactions for PET alcoholysis using supercritical methanol [1]

Although in this process the products obtained have high value, it has some major problems. Firstly, it is a costly process because of the separation and refinement of the byproducts produced. Secondly, the major product of this process is DMT and nowadays the majority of PET is synthesis from terephthalic acid (TA). Therefore, an additional conversation of DMT to TA is needed in order to complete the cycle [1].

## 4. Additional steps for the PET degradation/decomposition

### 4.1 Pre-treatment and post-treatment of plastic waste



In order to improve the process performance for PET recycling (degradation/ fragmentation/ decomposition), PET samples are often pre-treated in different ways. PET fabrics were cut into pieces of 0.5 - 1 g and only after that were incubated in glass vessels. [31, 32]. Another method involved to cut into pieces smaller than 20 x 20 mm. Then, the samples were subjected of a solution of Tween-80 at 2% v/v at 50°C for 1 hr. The last step of the pre-treatment consisted in washing of the samples with distilled water for 1 h and drying in an oven at 40°C for 24 h [33].

The PET can be designed as a film of size 1.0 / 0.5 cm which was washed with an aqueous Na<sub>2</sub>CO<sub>3</sub> solution (2g l<sup>-1</sup>) at 37°C for 0.5 h followed by washing twice with distilled water [34]. Also, the PET films were prepared by melting in a heated hydraulic press. Then, each film was washed with ethanol and placed in a 10 ml glass vial. The glass vials contained 5 ml of phosphate buffer (Na<sub>2</sub>HPO<sub>4</sub>/KH<sub>2</sub>PO<sub>4</sub>, 100 x 10<sup>-3</sup> M, pH 7) [4]. There was another alternative for which a circular film (Ø 64 mm) was punched out of the polyester films. It was cleaned with ethanol and placed in a 300 ml glass beaker. Then 10 ml of 25 mM NaH<sub>2</sub>PO<sub>4</sub>·H<sub>2</sub>O buffer was added [35].

After degradation process, the plastic samples were often treated before analysis. So that, they were simple washed with water and dried in air [32], or washed with 2g L<sup>-1</sup> Na<sub>2</sub>CO<sub>3</sub> at 60°C for 1 h. Finally, these were double-washed with deionized water for 1 h [31]. Sometimes, the samples were washed in a solution of 2g/L of Na<sub>2</sub>CO<sub>3</sub> for 2 h in order to stop the enzymatic reaction. At the end, the polymers were washed firstly in 10g/L Tween-80 at 25°C for 1 h and then in distilled water [33].

Other alternatives could be washing with water and ethanol and dried overnight at 50°C [4] or only the ajustment of the solution pH to 5-6 with a small amount of 1 M HCl.

After the enzymatic treatment, until the HPLC analysys, the solution was stored at 4°C [35].

Another type of treatment is the UV pre-treatment before enzymatic degradation. In this case, amorphous PET films had a thickness of 250 µm. Then, UV irradiation of PET samples was carried out over 14 days using a 1-kW xenon arc lamp. A water filter was applied to filter the IR radiation and a water bath was used for further cooling during irradiation [36].

#### 4.2 Analytical methods for monitorization of PET degradation (decomposition)

The samples after degradation process could be considered the pieces of PET and also the solution resulted after degradation process. The solid samples samples were analysis in order to identify any modifications of the surface morfology. In this case, the characterization

techniques for solid surface were useful (FTIR, AFM, XRD, SEM/TEM, TSC-TGA, XPS) [31]. The second direction of analysis was focused on the solution. In this case, HPLC and GC coupled with MS for identification and DAD/RID for quantification were performed [34, 35].

## 5. Derivatization of PET using biocatalytic methods

### 5.1 Surface modification of poly(ethylene terephthalate) (PET) fibers by a cutinase from *Fusarium oxysporum*

Cutinases are serine esterases that have the role of hydrolysis of ester bonds in cutin and belong to the hydrolase fold family. They have the capacity to hydrolyze the ester bonds of synthetic polyesters and this makes them proper for the surface modification of PET [31].

The polyester fabrics were cut in pieces and incubated in glass vessels. It was applied the enzymatic treatment and then the fabrics were washed with Na<sub>2</sub>CO<sub>3</sub> for an hour. At the end, it was double-washed with deionized water [31].

The whole enzymatic process was proved to be environmentally friendly and without affecting the thermal and mechanical properties of the PET fabric. The changes were confirmed by DSC-TGA analyses, tensile tests, FT-IR ATR analysis, XPS and SEM. The free hydroxyl and carboxyl groups were detected with the help of FT-IR ATR and XPS analyses [31].

It was concluded that the enzyme *F. oxysporum* cutinase is capable of derivatization of PET without compromising the polymer structure and properties [31].

### 5.2 Production of heterologous cutinases by *E. coli* and improved enzyme formulation for application on plastic degradation

The aim of this work was to optimize the process of degradation of polyethylene terephthalate using an enzyme from *E. Coli*. The hydrolytic action of the enzyme was applied to the degradation of the plastic [33].

The enzyme used was cutinase. Two types of cutinase were prepared for this experiment: one wild type form from *Fusarium solani pisi* and its C-terminal fusion to cellulose binding domain N1 from *Cellulomonas fimi*. The cultures used were *E. Coli* CUT for the first type and *E. Coli* CUT-N1 for the second type [33].

Both cutinases were treated first with ampicillin and isopropyl β-D-1-thiogalactopyranoside. The optimum pH of both cutinases was around 7.0 and they were stable between 30 and 50°C. By addition of glycerol, PEG-200 and (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> to the metabolic liquid, followed by ultra filtration, the mixture became stable during 60 days at 28°C. Treating the PET with the help of cutinase led to a weight loss of 0.90% [33].

In conclusion, recombinant microbial cutinases have advantages in the treatment of PET using enzymatic treatments [33].

### 5.3 Rapid Hydrolyse of Poly(ethylene terephthalate) using a hydrolase from *T. Fusca*

Due to the increasing problem of plastic waste at the end of 1980, there were attempts to design biodegradable plastics. But most of the biodegradable plastics are based on aliphatic polyesters which exhibit limited useful properties. Aromatic polyesters such as PET or poly(butylene terephthalate) (PBT) which provide excellent properties can not be attacked by hydrolytic enzymes and can not serve as biodegradable source of plastic [4].

But the reason of missing biodegradability of aromatic polyesters was found by Marten et al.; the mobility of the polymer chains in the crystalline part controls the biodegradability. This can be correlated with the temperature difference between the melting point and the temperature at which degradation takes place [4].

This work presents the ability of a hydrolase isolated from the actinomycete *Thermobifida fusca* to depolymerize the aromatic polyester PET at a higher rate than other hydrolases such as lipases [4].

The experiment started with the characterization of the samples of PET. For the degradation process, the materials were melted using a heated hydraulic press. The samples were washed with ethanol and placed in a glass vial containing phosphate buffer. Degradation was started by adding the enzyme solution. At the end, the vials were placed in a rotational shaker and thermostated [4].

The results of the experiment demonstrated that commercial PET can be hydrolyzed by an enzyme. Within 8 weeks, microbial action resulted in an approx. 15% weight loss of the PET fibers [4].

### 5.4 Degradation of Poly(ethylene terephthalate) Catalyzed by Metal-free 2 Choline-Based Ionic Liquids

The glycolysis of PET is an expected way for degradation of PET to its monomer bis(hydroxyethyl) terephthalate (BHET) since BHET can be polymerized again to form new PET materials and provides possibilities for a permanent loop recycling. However, most of the used glycolysis catalysts are metal-based which have a high cost and present a negative environmental impact [37].

This study aims to develop a series of choline-based ionic liquids with a role in the glycolysis of PET without using any metals [37].

The catalyst used was Choline acetate [Ch][OAc], a cheaper, more biologically compatible and environmentally friendly substitute of the conventional imidazolium metal-

based ionic liquids. It was found that under the optimum conditions (PET (5.0 g), ethylene glycol (EG) (20 g), [Ch][OAc] (5 wt %), 180 °C, 4 h, atmospheric pressure), the choline acetate can achieve even better performance than the initial metal based catalyst, the yield of BHET reaching up to 85.2 % [37].

## **6. The aim of this thesis**

We proposed a detailed study for developing a technology for PET recycling. So that, our study will be directed to set up and optimise an enzyme biocatalysis for PET degradation/fragmentation/ decomposition. Screening of enzymes will allow to decide and choose the best biocatalyst for process performance. Detailed optimization of the biocatalytic method will be considered. The system performance will be monitored directed the analysis to the characterization of the plastic surface and also looking for the composition of the process environment after incubation time. For the determination of any modifications of the surface morphology, the techniques such as FTIR, XPS, DSC-TGA, AFM, SEM/Tem will be used. HPLC-DAD/RID and/or GC-MS/FID will be performed for the evaluation of the reaction phase containt after incubation time.

## **7. Conclusions**

The literature study underlines that there is still a great difference between the amount of plastic waste and how much of this is recycled for the moment. Generally, new processes are required coupled or not with the existed processes in order to solve the problem of massive amounts of plastic waste being produced.

The research community has already started to search for new alternative of the plastics valorization and the general strategies seem to be the chemical/biochemical transformations. Usually, chemical modification of the plastic by degradation/decomposition leads to value-added chemicals which can be a convenient avenue to supplement current recycling processes.

We consider that biocatalysis could be an alternative for plastics (PET) recycling. Continued efforts need to be focused on enzyme biocatalysts (cutinase/lipase/carbonic alhydrase) to improve the overall efficiency with minimum energy consumption for the set up process.

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