Chemical Recycling in Spain:

Fostering a Circular Future

Report conducted by:

AIMPLAS

PLASTICS EUROPE
Enabling a sustainable future

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Spanish Chemical Industry Federation

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With the support of: EsPlásticos, SUSCHEM ES, forética, Foro Química y Sociedad, Responsible Care RSE, Smart Chemistry Smart Future, EXPOQUIMIA Encuentro Internacional de la Química, EQUIPLAST Encuentro Internacional del Plástico y el Caucho

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EXECUTIVE SUMMARY

Plastics are materials of great value and extremely useful for the industry, the economy and for society as a whole. They are currently present in all application sectors, thus contributing to sustainability thanks to their intrinsec characteristics.

At the end of their service life, products made of plastic materials become waste and must be properly managed and recycled in order to recover them and reintroduce them back into manufacturing processes, thus fostering the transition towards a circular economy.

There are different recycling technologies: mechanical, dissolution and chemical. ***The combination and complementarity of these technologies are levers to achieve the EU's and industry's own objectives of sustainability, circularity and climate neutrality.***

Chemical recycling is the set of technologies that allows breaking down waste plastics and other polymers from different waste streams into their basic components to transform them into valuable secondary raw materials, including monomers and oligomers which are used as starting point for the production of new chemicals and circular polymers.

These new products have the same characteristics as the ones coming from virgin materials and are a good opportunity for the manufacturing of products requiring high performance and high quality standards.

Currently, mixed or potentially contaminated plastic waste is landfilled or incinerated, as it cannot be mechanically recycled. Chemical recycling becomes a solution for this type of waste.

Chemical recycling does not replace but complements mechanical recycling by introducing new possibilities for plastic waste management

The investments announced in Spain will allow a 40-fold increase in waste treatment capacity via chemical recycling, reaching almost half a million tonnes by 2025

This emerging technology opens up new possibilities for the management of plastic waste*, as a complementary technology to mechanical recycling.* ***However, there are still significant challenges*** *ahead that need to be overcome, in some cases, through improvements in the processes themselves.*

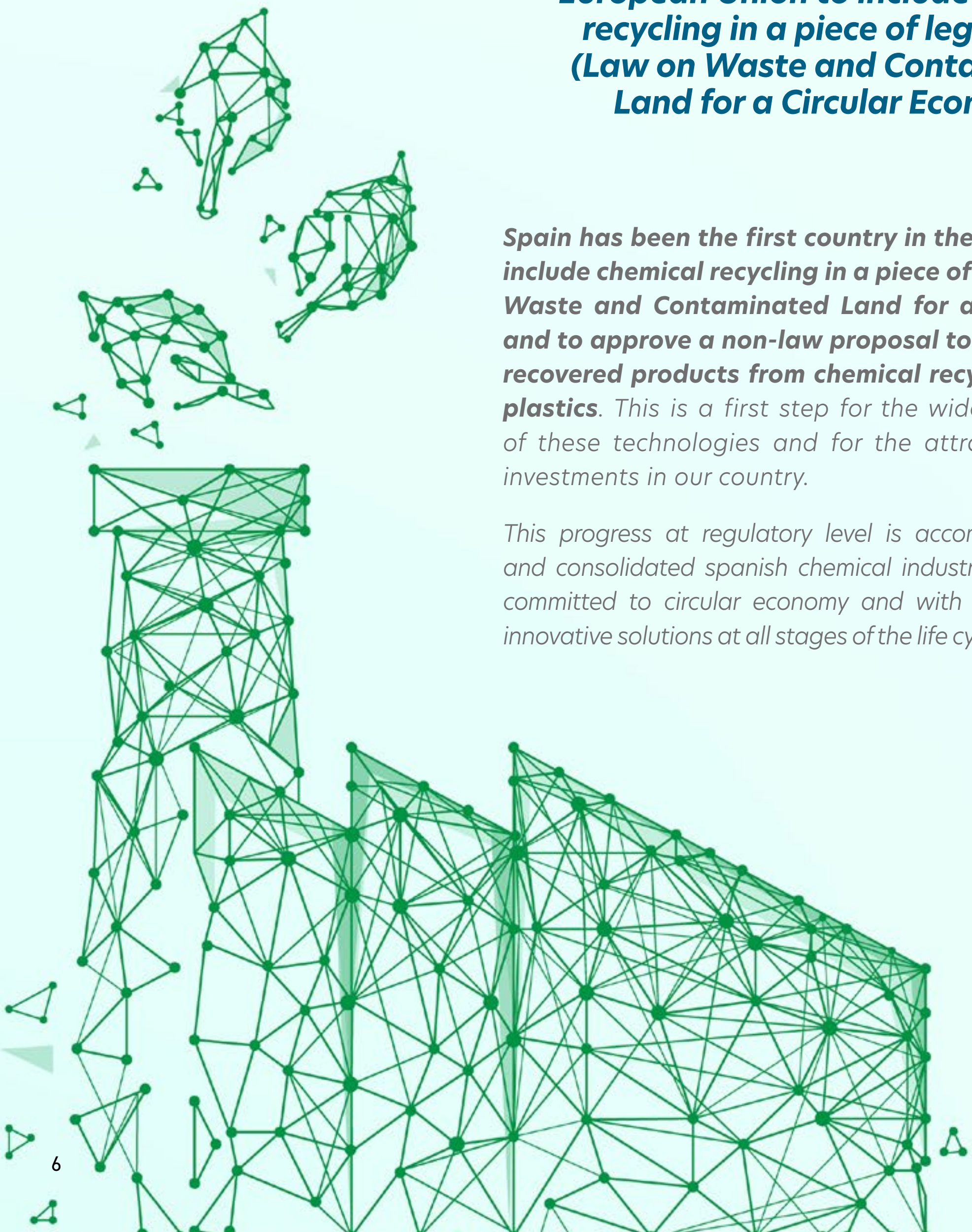
The technologies used to treat plastic waste via chemical recycling are very diverse, depending on the chain-breaking agent. There are three main cracking processes: thermal, chemical and biological. All of them result in products and materials of wide application. In those cases where energy is obtained or used directly as fuel, they are considered as energy recovery processes, not recycling processes, standing at a different level, according to the waste hierarchy.

There are processes that can combine the production of both energy and substances. For this reason, together with the need for clear traceability for processes that are similar to those of the chemical industry itself, ***a certifiable and recognised methodology such as mass balance is required.***

All these chemical recycling technologies are not yet widely implemented at industrial level *in Spain, as in the rest of Europe. However, the large number of companies interested in developing this type of projects, the increasing number of related patents, the great diversity of Research &Innovation (R&I) projects in this area, the large number of research organisations working on this topic together with the need to have more recycled plastic materials, among other reasons, allow us to predict a very significant growth of chemical recycling in the coming years in our country. In fact, it is estimated that the investments announced in Spain will allow the waste treatment capacity via chemical recycling to be multiplied by 40, reaching almost half a million tonnes by 2025.*

Once their technical feasibility has been proved, the necessary investments for the implementation of these technologies at industrial scale require measures that favour innovation to improve the efficiency of these processes and a stable and harmonised regulatory framework that generates legal certainty and clarity in waste streams, in terms of quantity and quality, with homogeneity in the criteria for end-of-waste status at both European and national level. This will make it easier for plastic and/or polymer waste that is currently incinerated, landfilled or wasted - generating no added value - to be recycled into new circular feedstocks for the production of plastics or other chemicals.

Spain is the first country in the European Union to include chemical recycling in a piece of legislation (Law on Waste and Contaminated Land for a Circular Economy)



Spain has been the first country in the European Union to include chemical recycling in a piece of legislation (Law on Waste and Contaminated Land for a Circular Economy) and to approve a non-law proposal to promote the use of recovered products from chemical recycling processes for plastics*. This is a first step for the widespread deployment of these technologies and for the attraction of productive investments in our country.*

This progress at regulatory level is accompanied by a strong and consolidated spanish chemical industry and plastics sector, committed to circular economy and with the capacity to offer innovative solutions at all stages of the life cycle of plastic products.

This, together with the existence of a consolidated and well-coordinated value chain, which includes raw material producers, plastic material converters and mechanical recyclers, among others, places our country in an outstanding position for chemical recycling to have the potential to become a reality at industrial level allowing us ***to accelerate the circularity of plastics and reach the recycling rates set by the European Union.***

For chemical recycling to be reliably implemented in our country, public-private collaboration, together with other actors in the value chain, is a fundamental condition, ***together with the need for a stable and predictable regulatory framework that defines recycling from the standpoint of technological neutrality.***

This document is completed with a description of the 10 myths that currently exist around chemical recycling, which must be refuted with scientific arguments as they lead to unfounded prejudices about these technologies.

In summary, this report provides an overview of the present and future of the chemical recycling industry in Spain and its potential contribution to the circular economy and climate neutrality.

KEY FINDINGS

1 To meet the European Green Deal's ambitions on circularity (recycling and recycled content) and climate neutrality, mechanical recycling needs to be complemented by chemical recycling.

2 Spain has an R&D&I ecosystem that is particularly conducive to the development of different chemical recycling technologies. The promotion of public-private collaboration throughout the value chain, together with a favourable framework that attracts investment, can help Spain to position itself as a world leader in this type of recycling technology.

3 The investments planned by the industry in Spain will allow a 40-fold increase in waste treatment capacity through chemical recycling, reaching almost half a million tonnes by 2025.

4 The different chemical recycling technologies are promising but they are still in their infancy and need time to scale up projects and demonstrate their techno-economic feasibility before reaching their full potential at industrial level.

5 For chemical recycling to become a reality on an industrial scale, a stable and predictable regulatory framework is needed to define recycling in a technology-neutral manner.

6 Although Spain is the first European country to incorporate chemical recycling into its legal system, it is still necessary to develop a clear and harmonised definition of chemical recycling and clear end-of-waste criteria. It is equally important to recognise Mass Balance as a methodology for tracing the recycled content produced by these new technologies.

1 Plastic materials

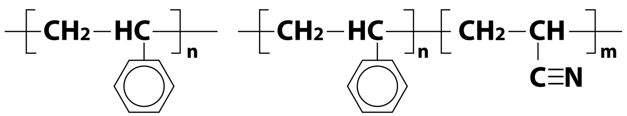
1.1 Plastics: polymers and additives

Plastics are a family of materials with a great versatility and diverse properties. They can be: lightweight; insulating or conducting; transparent or opaque; resistant to corrosion and chemical agents; durable or biodegradable to list but a few, making them unique materials.

The versatility and diverse properties of this material are achieved using the appropriate combination of the different components that are present in a plastic: polymers and additives.

Polymers are large molecules (macromolecules) that are multiples of simpler chemical units called monomers.

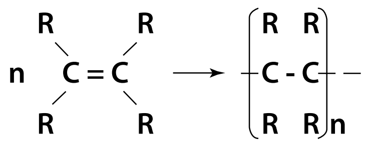
Example of a polymer structure | FIG 1



The chemical reaction by which monomers are joined together to form a polymer is called a polymerisation reaction. This type of reaction can be of two types: Polymerisation by addition (polyaddition) and polymerisation by condensation (polycondensation).

In a polyaddition reaction, monomers are joined together so that the resulting polymer contains all the atoms of the initial monomer. Polymers synthesised by this process are called addition polymers.

Example of a polyaddition reaction | FIG 2

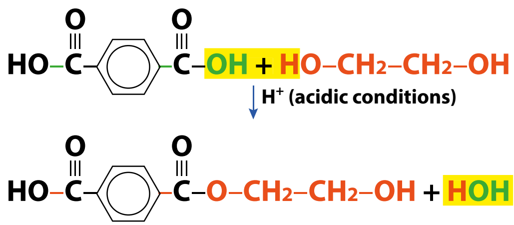


Examples of addition polymers are polyethylene (PE), polypropylene (PP), polystyrene (PS) and polyvinyl chloride (PVC).

In a polycondensation reaction, monomers with reactive functional groups are joined together and a small molecule, usually water, is released. The resulting polymer, called a condensation polymer, does not contain all the atoms of the initial monomer.

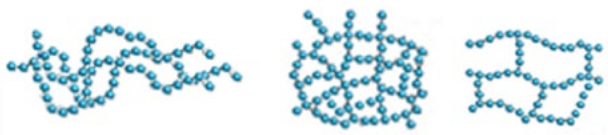
Examples of condensation polymers are: Polyamide (PA), polyethylenterephthalate (PET) and polycarbonate (PC).

Example of a polycondensation reaction | FIG 3



Taking into account the nature of these polymers, they can be additionally classified into three main groups: thermoplastics, thermosets and elastomers.

Structure by polymer type, from left to right: thermoplastic, thermoset and elastomer | FIG 4



Some thermoset polymers are: Unsaturated polyester resins (such as orthophthalic polyester resin or isophthalic polyester resin) and some polyurethanes (PU)

Thermoplastic polymers are linear or branched chains that are held together by intermolecular forces. They soften and melt when the temperature is increased, and solidify when cooled; this cycle of softening-melting-solidification can be repeated several times, making these polymers suitable for mechanical recycling.

Some thermoplastic polymers include: polyethylene (PE), polystyrene (PS), polyamide (PA), polycarbonate (PC), and others.

Thermoset polymers consist of polymer chains arranged in a highly cross-linked three-dimensional structure and held together by covalent bonds. Once the structure is formed, thermoset polymers do not melt or dissolve, nor are they transformed by conventional processes, so they cannot be mechanically recycled into new recycled polymers.

Some thermoset polymers are: Unsaturated polyester resins (such as orthophthalic polyester resin or isophthalic polyester resin) and some polyurethanes (PU).

Finally, elastomeric polymers are chainlike molecules that are linked together, normally by covalent bond, which gives them elastic properties. This family of polymers has a low degree of cross-linking, unlike thermoset polymers. They do not melt or dissolve and tend to swell in the presence of solvents. They can be mechanically recycled, though the process is more complex than it is for thermoplastic materials.

Some elastomeric polymers include silicone or rubber.

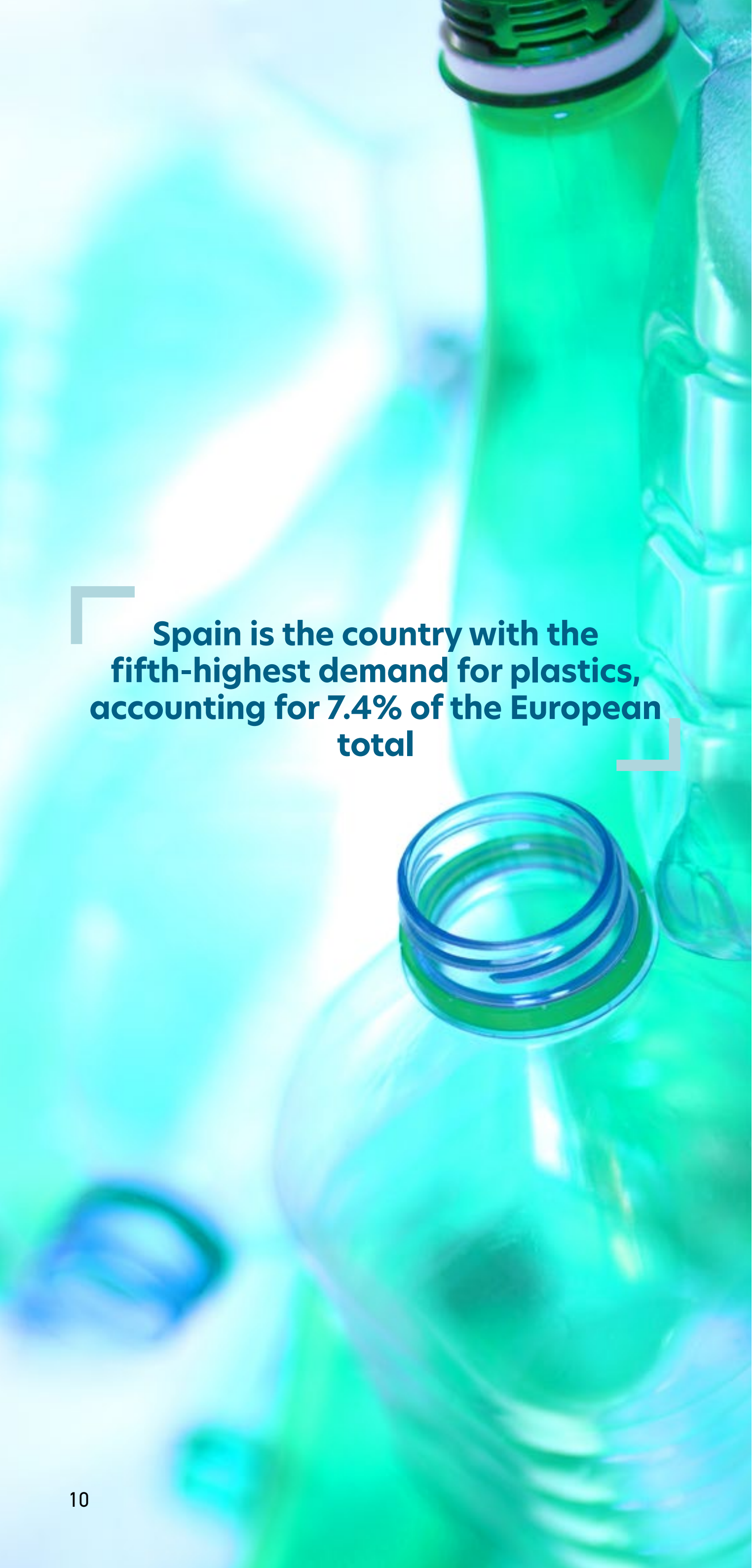
Chemical recycling is applicable to thermoplastic, thermoset and elastomeric polymers.

In order to meet the different performance requirements for these materials in their various applications and to obtain or improve certain properties, different types of additives are added to the polymers. Usually, the percentage of additives in polymer formulations is low, between 0.5% and 5%, although there are additives such as flame retardants or plasticisers, which may require higher percentages for certain applications, around 30-40%.

The characteristics provided by additives to the final plastic products are very diverse and provide different functions, as shown in the following table:

Use of additives in plastic materials and their contributing function | TABLE 1

Additive	Function
Stabilisers and lubricants	Facilitate processing
Plasticisers and reinforcing fillers	Modify mechanical properties
Anti-static agents and non-stick agents	Modify surface properties
Pigments and dyes	Modify optical characteristics
UV stabilisers	Protect against UV rays and ageing
Fungicides and biocides	Protect against biological agents



Spain is the country with the fifth-highest demand for plastics, accounting for 7.4% of the European total

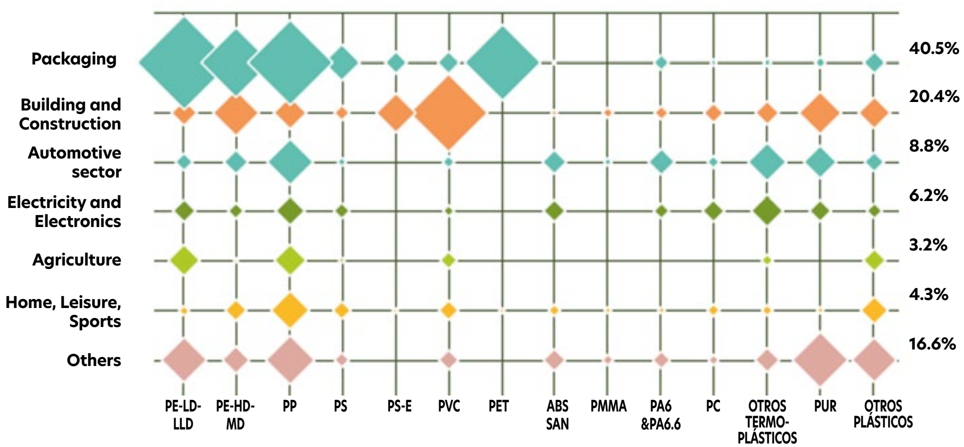
1.2 Plastics application sectors

Plastics are present in all sectors, with the packaging sector being the largest, followed by the building and construction sector and then the automotive sector.

367 million tonnes of plastics were produced globally in 20201; almost 15% of which originated from Europe. The demand for plastic materials for processing in Europe was 49.1 million tonnes that same year. Spain is the country with the fifth-highest demand for plastics, accounting for 7.4% of the European total.

Plastic materials, through their applications, contribute to sustainable development in different sectors. For example, lightweight parts in the automotive sector reduce the total weight of the vehicle, minimising fuel consumption and thereby reducing greenhouse gas emissions. Another example is the building and construction industry, where plastic insulating materials are used to improve the energy efficiency of buildings. Meanwhile, greenhouses and irrigation systems, both made of plastics, significantly reduce water consumption.

Demand for plastics by converters from the Member States of the European Union, the United Kingdom, Norway and Switzerland | FIG. 5



Source: Plastics Europe[1].

1 Plastics Europe. Plastics - the Facts 2021 An analysis of European plastics production, demand and waste data

2 Plastic waste and its conversion to resources

2.1 Plastic waste and recovery

Once the life of a product is over, it becomes waste. When it comes to plastic products, it is important to understand the different applications of these materials and their average product life in order to address their waste management. In this regard, around 60% of plastic applications have a product life of between one and fifty years. For plastics used in the packaging industry, their product life is significantly shorter and they tend to become waste in shorter periods of time.

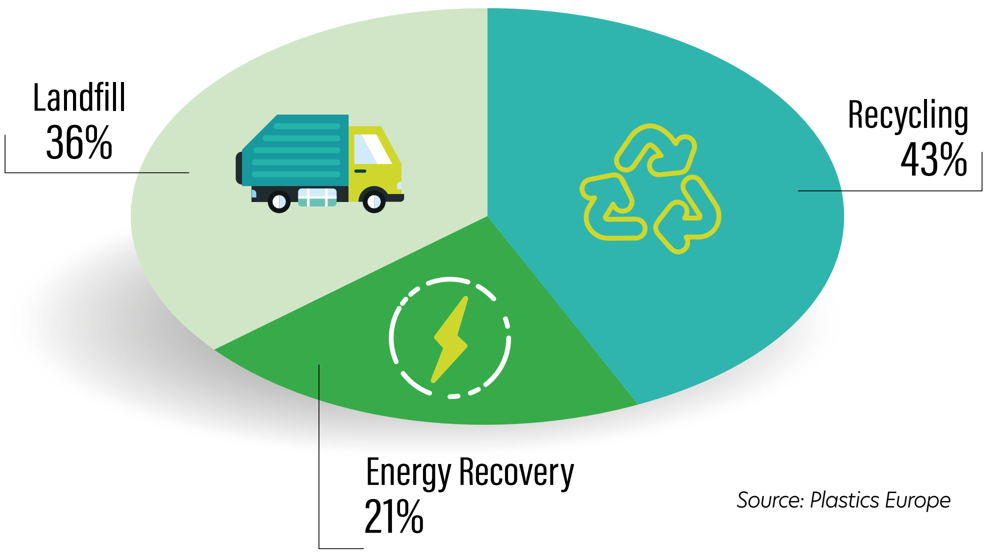
Plastic waste reflects the use of plastics in many applications and sectors, and accounts for 1% of all post-consumer waste[2] of all EU Member States, including the United Kingdom, Norway and Switzerland.

Proper management of plastic waste is key to achieving greater sustainability. The first step is to consume them responsibly and sustainably. Once they've been used, they must be managed appropriately in order to be used as resources, favouring the transition to a circular economy.

In 2020, more than 29 million tonnes of post-consumer plastic waste were collected in Europe[3]: 34.6% was recycled, 42% was used to generate energy, and 23.4% was landfilled.

The evolution of this data in Europe over the last 15 years has been positive, both from an environmental and economic point of view, with an increase of more than 115% in the recycling of post-consumer plastic waste and a decrease of more than 45% in the disposal of plastic waste.

Post-consumer plastic waste collected in Spain (2020) | FIG. 6



Source: Plastics Europe

2 The circular economy of plastics. A European vision. Plastics Europe
3 Plastics Europe. Plastics - the Facts 2021 An analysis of European plastics production, demand and waste data

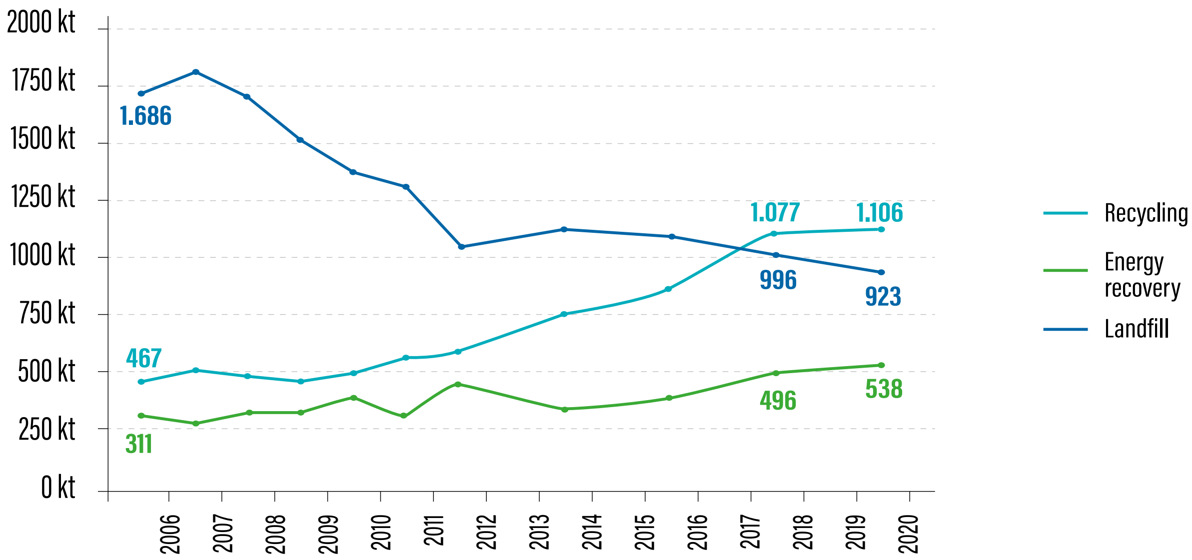
In Spain, 2,567 kt of post-consumer plastic waste was collected in 2020, of which 43% (1,106 kt) was recycled. Despite good recycling rates, it is important to remember that the remaining 57% ends up in landfill (36%) or is recovered as energy (21%). This is not optimal as the intrinsic value of the plastic is not being utilised. In terms of evolution, over the last 13 years, recycling has increased by more than 120%. The increase has been lower, although still significant, in the case of energy recovery, with an increase of around 75%.

Waste management varies greatly between countries, mainly due to three factors:

1. Waste collection systems
2. Infrastructure
3. Citizen/consumer involvement

Current European legislation[4] restricts the volume of waste that can be landfilled, which is causing, and will continue to cause, a shifting trend in waste treatment in favour of other recovery processes. This situation favours the emergence of new recycling processes that were not considered viable until now and which will enable ambitious and necessary targets to be reached.

Evolution of plastic waste management in Spain | FIG. 7



Source: Plastics Europe

To achieve these targets, it is necessary to establish a holistic approach for plastic waste, actively working in five main areas:

1. Prevention and responsible consumption.
2. Eco-design.
3. Innovation and technological development.
4. Partnerships and cooperation along the value chain.
5. Changing consumer behaviour.

In order to fully realise the potential of plastics in a circular economy, a combination of legislative measures, investments in innovative technologies and sectoral initiatives are required to enable this systemic model change.

4 Directive (EU) 2018/850 of the European Parliament and of the Council of 30 May 2018 amending Directive 1999/31/EC on the landfill of waste.

2.2 Legislative framework

The existing legal framework at both national and European level has clearly influenced the evolution of waste and waste treatment.

One of the key aspects is the need for a waste policy that applies the waste hierarchy principle, thus contributing to the implementation of circular economic models.

The waste hierarchy principle was established in the Waste Framework Directive[5]. This principle makes possible to decouple the relationship between economic growth and waste production, and establishes the priorities for waste action. The aim of implementing this hierarchy is to transform the European Union into a society that is more efficient in the use of its resources and contributes to the fight against climate change.

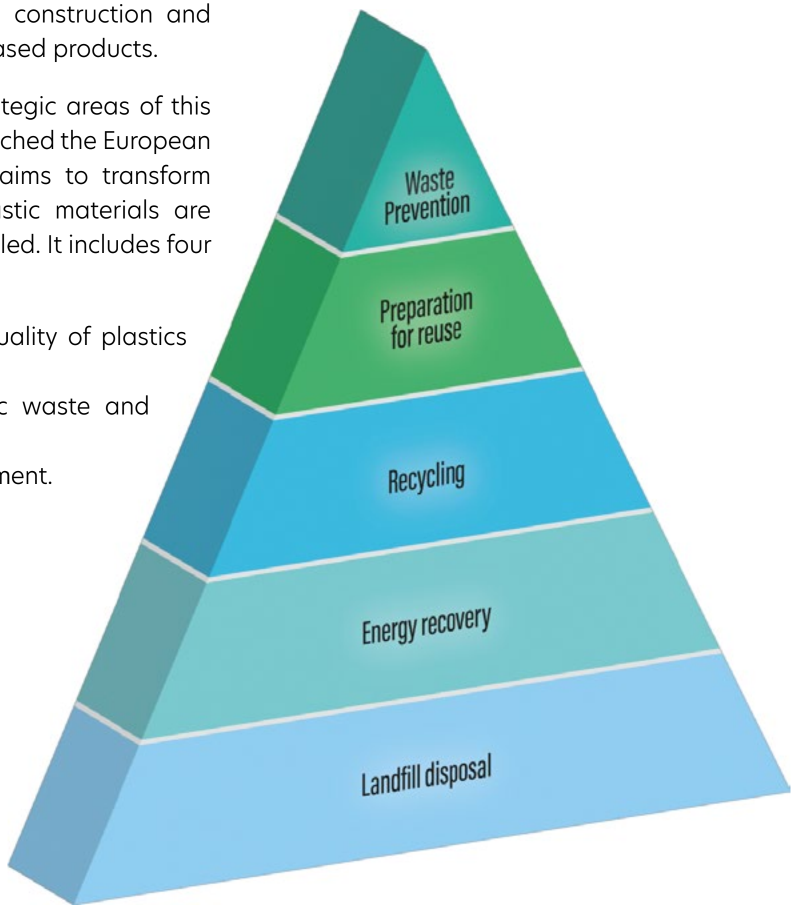
On a more global standpoint, in 2015 the European Commission published the EU Circular Economy Action Plan[6], which set out 54 measures that were considered necessary to advance the transition to a circular economy. These measures affect the different stages of the product life-cycle: design and production, consumption, waste management and the use of waste resources and their reintroduction into the production cycle.

In addition, five priority areas were identified: plastics, food waste, critical raw materials, construction and demolition, and biomass and bio-based products.

With plastics being one of the strategic areas of this Plan, the European Commission launched the European Plastics Strategy[7] in 2018, which aims to transform the way products made from plastic materials are designed, produced, used and recycled. It includes four main measures:

- Improving the economics and quality of plastics recycling.
- Reducing the amount of plastic waste and littering.
- Increasing innovation and investment.
- Efforts to create global action

Waste Hierarchy | FIG. 8



5 Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.

6 COM(2015) 614 final Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "Closing the loop - An EU action plan for the Circular Economy"

7 COM(2018) 28 final Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "A European Strategy for Plastics in a Circular Economy"

One of the objectives set by this strategy is to introduce 10 million tonnes of recycled plastic into the European market by 2025.

To promote this market for recycled plastics and achieve this goal, the Circular Plastics Alliance (CPA), an initiative covering the entire plastics value chain, was formed. With over 300 organisations that represent industry, academia and the authorities, this alliance is linked to voluntary industry commitments. A CPA study[8] indicates that in order to reach the target of 10 million tonnes of recycled plastic by 2025, 16.7 and 11.8 million tonnes of waste should reach European sorting centres and recycling plants respectively. Products recycled from this waste must be of adequate quality to meet the needs of the end market.

Subsequently, in 2020, the European Commission adopted a New Circular Economy Action Plan for a cleaner and more competitive Europe[9]. The plan is linked to sustainable growth and aims to:

- Make sustainable products the norm in the EU.
- Empower consumers and public purchasers.
- Focus on the most resource-intensive sectors where the potential for circularity is highest, such as: Electronics and ICT, chemicals, batteries and vehicles, packaging, plastics, textiles, construction and buildings, food, water and nutrients.
- Ensure that less waste is generated.
- Make circularity work for people, regions and cities.
- Lead global efforts in the field of circular economics.

Boosting the transition through research, innovation in new circular business models, and new production and recycling technologies including the exploration

8 *Circular Plastics Alliance. Design for recycling work plan. Updated final draft - Version Sept. 2021.*
9 *COM(2020) 98 final, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "A new Circular Economy Action Plan for a Cleaner and more Competitive Europe"*

One of the objectives set out by this strategy is to introduce 10 million tonnes of recycled plastic into the European market by 2025

the potential of chemical recycling is one of the key aspects of this plan which aims to keep resources in the production cycle for longer.

This issue also seems to be aligned to some extent with the implementation of chemical recycling, as it allows for high quality products and stimulates the development of technologies to deal with contamination in recycled materials and/or the presence of legacy substances.

According to the report "Roadmap to 10 Mt recycled content by 2025"[10] recently published by the CPA, there are three main obstacles we need to overcome in order to obtain a higher quantity of recycled plastics in Europe:

- Recycled plastics must be of appropriate quality and adapted to their use.
- Recycled plastics must be readily available with good supply security.
- The competitiveness (in terms of attractiveness and social acceptability) of recycled plastics compared to virgin plastics.

To overcome these challenges, this roadmap also sets out four areas for action:

- Improve the design of plastic products.
- Increase the collection of plastic waste and improve the quality of sorting.
- Invest in the development and deployment of better recycling technologies.
- Structurally support the demand for recycled content.

Law 7/2022 on waste and contaminated soil for a circular economy[11] was recently approved in Spain on the 8th of April 2022, that aims to regulate waste management, amongst other things.

This law not only transposes some of the measures of the Directive on the reduction of the impact of certain plastic products on the environment[12] and of the Waste Framework Directive[13], but also puts forward new proposals which aim to: promote the transition to a circular economy, prevent and reduce the impact of certain plastic products on the environment, streamline the end-of-waste declaration, create new recycling targets by material type (for plastics packaging: 55% by 2030) and the creation of fiscal measures including the introduction of two new taxes: a tax on landfill disposal, incineration and co-incineration of waste and a tax on non-reusable packaging containing plastics of €0.45/kg.

It should be clarified that this is a tax on virgin plastic, since the amount of recycled plastic incorporated into the packaging will not be taken into account when calculating the tax base. Both recycled plastics from mechanical recycling and chemical recycling are tax deductible[14]. Similar taxes are being considered in other European countries such as the United Kingdom and Italy, though each has their own particularities.

This means that the introduction of chemical recycling plants is likely to be favoured in the short and mid-term to cover the industry's need for recycled materials.

10 Circular Plastics Alliance - Roadmap to 10 Mt recycled content by 2025 23 September 2021.
11;14 Law 7/2022, of 8 April, on waste and contaminated soils for a circular economy.
12 Directive (EU) 2019/904 of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment.
13 Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste.

The current and future legislative framework lays the foundations for the development of new complementary recycling technologies to meet market requirements.

In addition, the new Royal Decree on packaging and Packaging waste on a national level (which was submitted to public consultation last October 2021 and is currently in the processing phase[15]) sets specific targets for reducing both the weight of packaging produced and the number of single-use plastic bottles placed on the market. The aim is to ensure that all packaging put on the market is 100% recyclable and, where possible, reusable, by 2030.

It will also include ecomodulation criteria, which consider the recyclability and recycled content of the products, among other things. It will also make it a requirement for plastic packaging to contain at least a percentage of recycled plastic which will be set according to the packaging type and time frame. This Royal Decree will require the necessary aspects (such as recycled material content) to be verified by means of certification.

Mandatory recycled plastic content in packaging will also be one of the key aspects in the future European Directive on packaging and packaging waste[16] which is currently under review. In addition, in December 2021, the European Commission published a new communication[17] stating that at least 20% of the carbon used in chemicals and plastics must come from sustainable non-fossil sources by 2030.

Legislative changes in the field of circularity and recycling go beyond packaging, affecting a wide range of sectors, such as the automotive sector[18] or the building and construction sector[19]. In short, the current and future legislative framework sets a clear trend towards a greater use of recycled materials in a growing range of applications. This creates space for the development of new complementary recycling technologies to respond to the needs of the market in the not-so-distant future.

15 *https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/participacion-publica/210927proyectorddeenvases_tcm30-531124.pdf*
16 *Directive 94/62/EC on packaging and packaging waste*
17 *COM(2021)/800 Communication from the Commission to the European Parliament and the Council Sustainable Carbon Cycles.*
18 *Proposal for a European Parliament and Council Directive amending Directive 2000/53/CE on end-of life vehicles, as regards the implementing powers conferred to the Commission*
19 *Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC Text with EEA relevance*

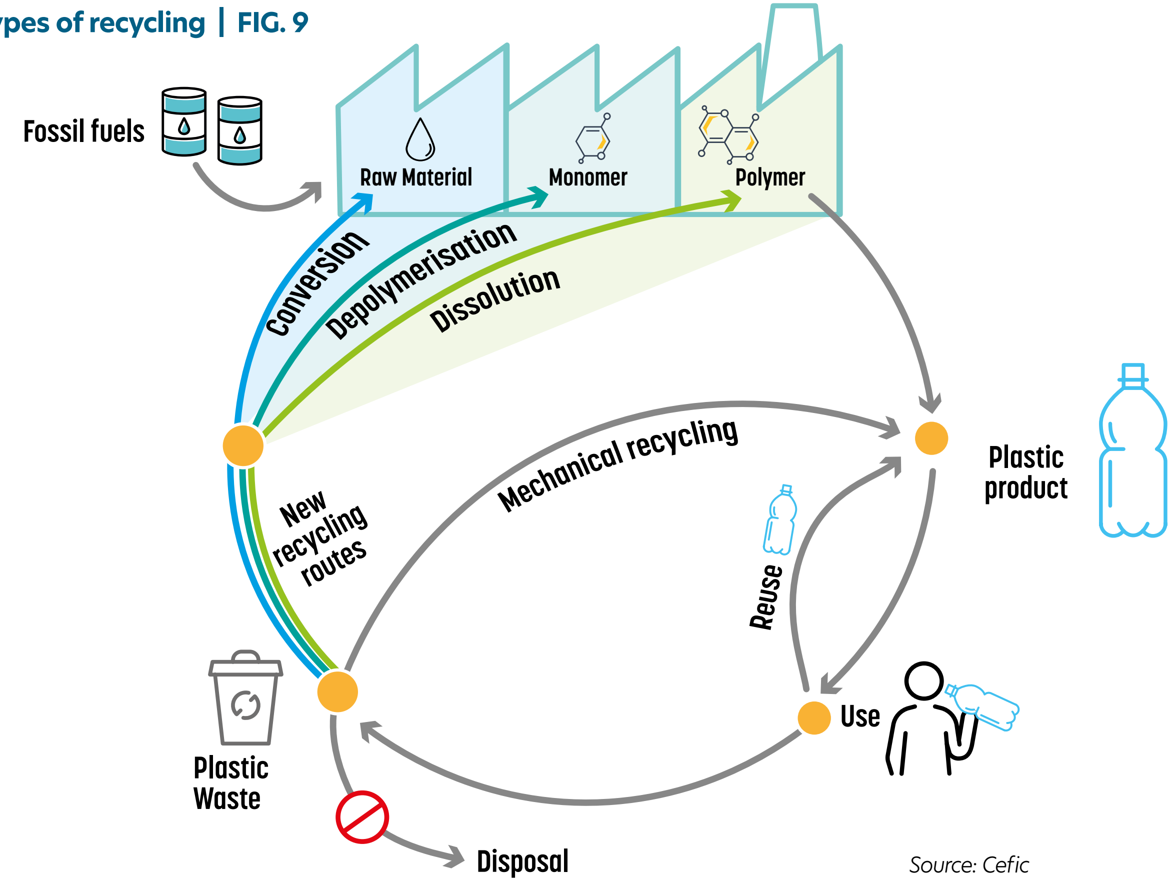
3 An overview of chemical recycling and associated technologies

3.1 Waste hierarchy and chemical recycling

The Waste Framework Directive[20 21] and its subsequent amendment[22] defines recycling as *"any recovery operation by which waste materials are reprocessed into products, materials or substances, whether for the original purpose or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations".*

In the treatment of plastic waste, there are different recycling technologies and processes that convert this waste into resources. Of these, mechanical recycling is the most widespread and long-established, and currently provides the vast majority of recycled plastics on the market.

Types of recycling | FIG. 9



Source: Cefic

20. [Cefic: Chemical Recycling: Making Plastics Circular]
21 Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.
22 Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste.

MECHANICAL Recycling

Mechanical recycling is the process of recovering plastic waste by means of heat and shear in order to convert it into a recycled material that can be used for the same, or an alternative, use. This process does not disrupt the polymer chains, that is, there is no chain breakage, except that due to possible degradation of the polymer itself.

Mechanical recycling is applicable to plastic materials, although in the case of thermoset materials this is mostly limited to recycling where the result is incorporated as a filler and not as a polymer (as the polymer cannot be re-melted).

DISSOLUTION Recycling

Dissolution recycling (also known as physical recycling) is a recovery operation in which plastic waste is treated with solvents and other chemical agents, causing the polymers to dissolve and separate from the rest of the waste. The purpose of this operation is to separate polymers, or even additives, without causing the polymer chain to break. This allows us to obtain separate materials that can then be incorporated as recycled raw materials. As the chain does not break, it is not considered chemical recycling, although it is sometimes included in this category.

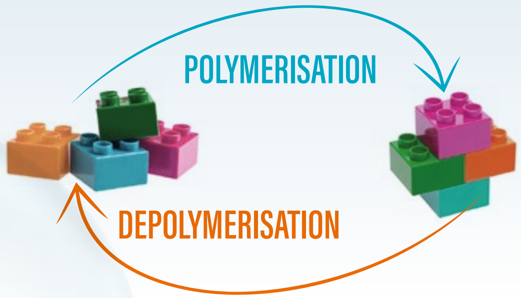
CHEMICAL Recycling

According to ISO 15270:2008[23], **chemical recycling** or **molecular recycling** is the "conversion to monomer or production of new raw materials by changing the chemical structure of plastics waste through cracking, gasification or depolymerisation, excluding energy recovery and incineration".

According to this definition, Chemical Recycling should be included in the waste hierarchy, within the recycling section, above energy recovery and landfill disposal

Recycling by dissolution and chemical recycling are emerging techniques, and major development is expected in the coming years.

Diagram of Polymerisation and Depolymerisation (a type of chemical recycling) | FIG 10



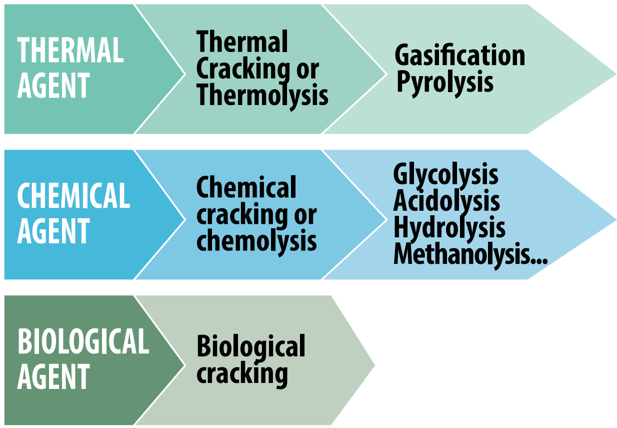
23 ISO 15270:2008 *"Plastics – Guidelines for the Recovery and Recycling of Plastics Waste."*

3.2 Types of chemical recycling

Chemical recycling is a type of recovery operation where the polymer chain is broken by different agents (thermal, chemical or biological) to produce smaller substances that are required by the chemical and/or polymer industry.

Different types of chemical recycling can be distinguished, depending on the agent used to break the polymer chain:

Types of chemical recycling | FIG 11

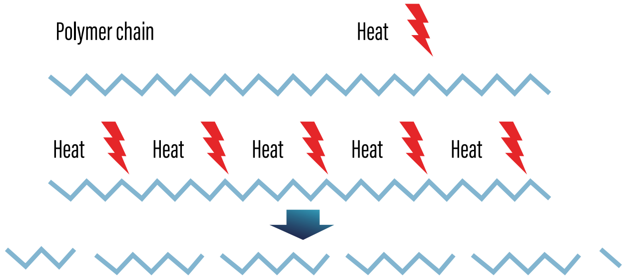


Thermal cracking (Thermolysis). The polymer chain is broken using temperature and, in some cases, catalysts. The main processes or techniques are **pyrolysis** (carried out in the absence of oxygen) and **gasification** (with oxygen). Generally, thermolysis takes place under more stringent conditions than total combustion. It is applicable to waste composed of both addition and condensation polymers.

The new raw materials obtained by pyrolysis and gasification (pyrolysis oil and synthesis gas respectively) are reintroduced into the production cycle, replacing the traditional raw material to obtain new products, such as new polyolefins or methanol.

Both processes aim to recycle mixed plastic waste. Higher flows of PE, PP and PS are sought when it comes to pyrolysis, since the higher proportion of carbon-carbon bonds in these polymers improves the process yield.

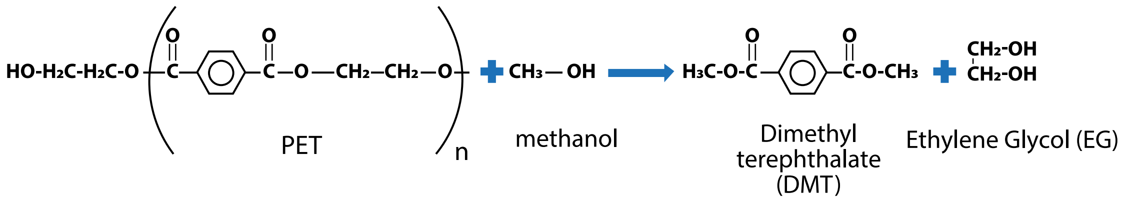
Diagram of the thermal cracking process (thermolysis) | FIG 12

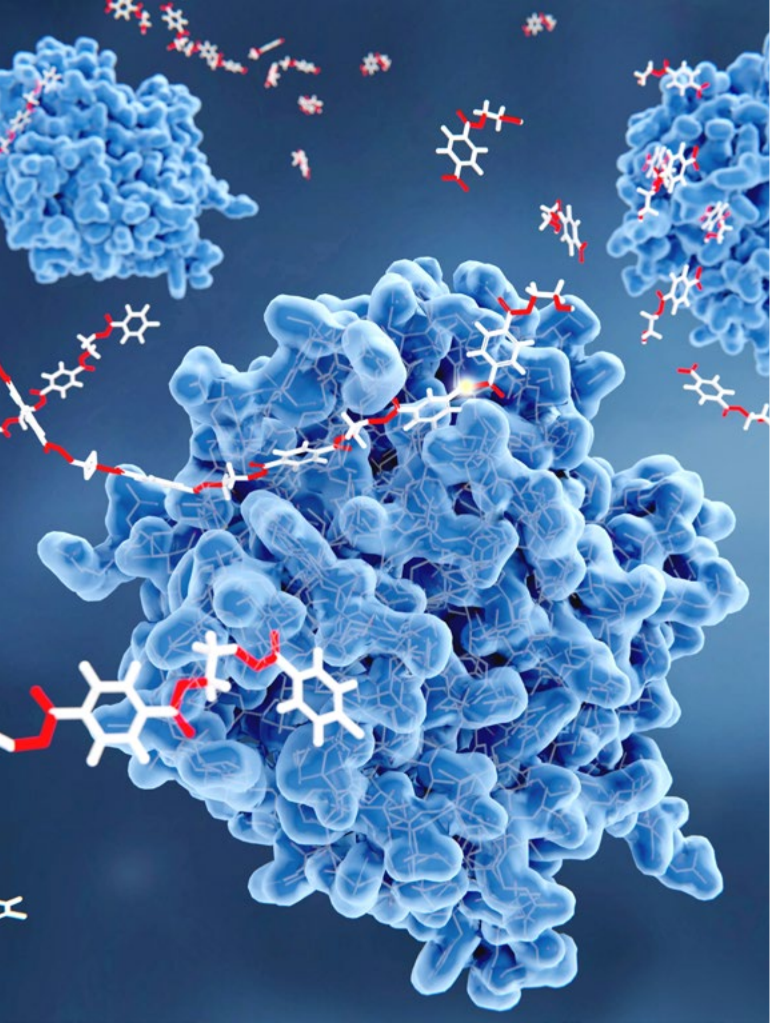


Chemical cracking (chemolysis): This is often referred to as solvolysis or depolymerisation. The polymer chain is broken by the action of a reagent (which can be a solvent) together with the use of temperature and in some cases pressure and catalysts. This produces monomers or oligomers. It can be used for waste composed of condensation polymers.

Generally, the solvolysis process is more selective, so it is usually applied to mono-material waste such as PET, PA, PU, polymethylmethacrylate (PMMA) or polylactic acid (PLA).

Example of chemical cracking reaction | FIG 13

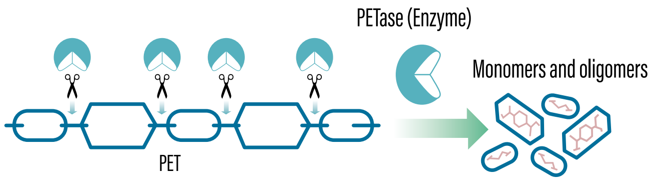




Picture of PETase

Biological cracking has a very promising future. It could potentially be applied to any type of plastic waste

Example of a biological cracking reaction | FIG 14



Biological cracking: Chain-breaking occurs through the use of enzymes as biocatalysts, degrading both addition and condensation polymers into monomers or oligomers. Enzymes are highly selective and should be selected appropriately.

Currently, biological cracking is only used to recycle PET and polyester fibres24, although it is a method that could potentially be applied to any plastic waste.

All of the above are processes that cause the polymer chain to break.

Table 2 shows chemical recycling processes according to the kind of polymer. Note that in the case of chemical cracking, the polymers must be condensation polymers. Although it is possible to use thermal cracking on all types of polymers, the yields are much lower if there are heteroatoms other than C or H present. When it comes to reinforced materials such as glass-reinforced polyester (GRP) or carbon fibre reinforced polyester (CFRP), both chemical and thermal cracking allow for the recovery of fibre, a material of great interest to the industry.

Most plastic waste could be chemically recycled. Chemical recycling focuses on waste flows that are currently not suitable for mechanical recycling, therefore their current end of life is landfill disposal or incineration.

Chemical recycling processes by polymer type | TABLE 2

	PE	PP	PET	PS	PA	PC	PVC	PU	GRP	CFRP	Mixed
Thermal cracking	■	■		■					■	■	■
Chemical cracking			■		■	■		■	■	■	
Biological cracking (*)			■								

**PET is shown here, although it could be applied to any plastic waste in the future*

24 https://www.carbios.com/fr/

The ideal waste flows for chemical recycling are:

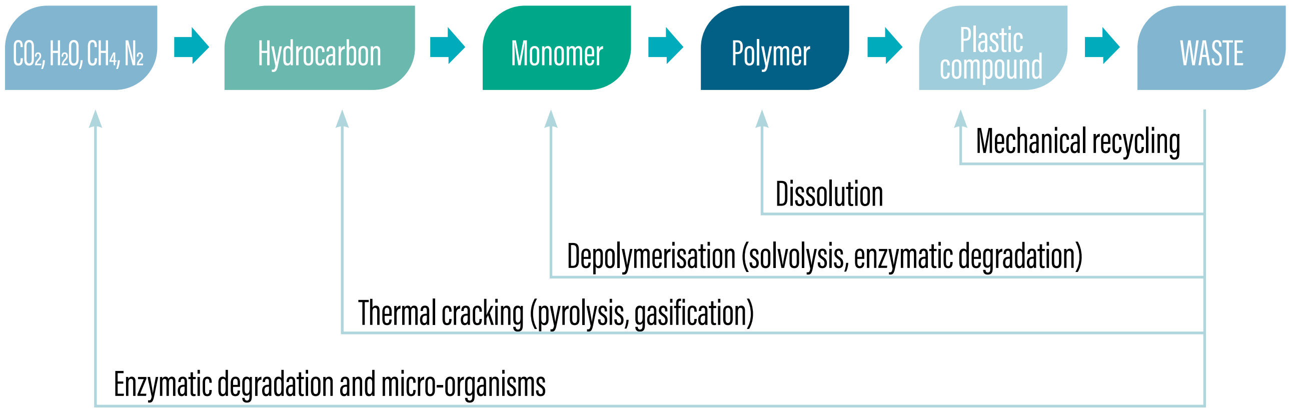
- Waste with closely mixed components containing different thermoplastic polymers that are difficult to sort (e.g., some types of multilayer packaging, automotive pieces waste, or waste from electrical and electronic devices shredders)
- Waste with a high level of impurities, such as plastic waste that has been extracted from the sea, including fishing gear, waste containing adhesives or grease, contaminated industrial packaging, etc.
- Waste that is small in size and escapes from waste sorting plants
- Waste from mechanical recycling processes
- Thermosetting plastics such as polyurethane mattresses, plastics used for refrigerator insulation, etc.
- End-of-life products containing plastics that have been mechanically recycled several times with progressive depletion of their properties
- Waste containing restricted substances that need to be extracted from the recycled plastics

Each recycling process produces substances or products that can be reintroduced into the plastics value chain. The point in the value chain where the waste is reincorporated determines how many processes will be required to achieve the final product. The products will have a different environmental impact (including a different carbon footprint).

It is therefore important to consider a full life-cycle analysis of the process when assessing the greenhouse gas (GHG) impact of this technology. Chemical recycling can avoid the incineration of plastics and can facilitate their reuse as feedstock, which would help to avoid refining operation, therefore reducing GHG emissions associated with these processes, favouring a positive emissions balance.

There are numerous scientific studies showing the benefits of combining mechanical and chemical recycling in terms of reducing emissions[25-27]

Value chain and types of recycling | FIG 15



25 *Rebekka Volk, Christoph Stallkamp, Justus J. Steins, Savina Padumane Yogish, Richard C. Müller, Dieter Stapf, Frank Schultmann. Techno-economic assessment and comparison of different plastic recycling pathways. A German case study. Journal of Industrial Ecology 2021;1-20.*

26 *Chemical Recycling: Greenhouse gas emission reduction potential of an emerging waste management route. QUANTIS & CEFIC. October 2020.*

27 *Chemical Recycling of Polymeric Materials from Waste in the Circular Economy, Final Report. European Chemicals Agency & RPA Europe. August 2021.*

All recycling processes are considered necessary and complementary, as each one can be used for different solutions and applications

3.3 Other recovery processes and their complementarity

As previously stated, there are different recycling processes: mechanical, dissolution and chemical. All of these are listed above energy recovery in the waste hierarchy.

Energy recovery is the use of waste as a source of energy by converting it into electricity and/or heat. This recovery can occur in some industrial facilities such as cement or pulp and paper mills which require large amounts of energy and traditional fuels such as gas or coal are replaced by a waste product.

It should be noted that thermal processes, such as pyrolysis or gasification, can produce new raw materials as well as fuels. The former would be a result of chemical recycling and the latter would be energy recovery.

Global waste-to-energy capacity grew significantly in 2021, reaching an all-time high[28] with a technical treatment capacity of about 41 million tonnes of solid waste per year.

All recycling processes are considered necessary and complementary, as each can be used for different solutions and applications. If waste cannot be recycled, energy recovery is a solution that prevents it from being sent to landfill whilst simultaneously providing an energy source.

Chemical recycling offers solutions that complement mechanical recycling:

- Allows better mechanical and organoleptic properties to be obtained both in the final product and during the production phase
- Avoids functional defects and visual flaws in end products
- Facilitates easy batch-to-batch reproducibility
- Helps to continuously strengthen the increasing quality requirements demanded by the market and pushed by legislative changes.

Thus, chemical recycling offers advantages related to taking materials back to their original form, the concept of an infinite cycle and the non-restriction of material. The process breaks down polymer chains, which results in the production of hydrocarbons that can be incorporated into petrochemical processes to obtain monomers (ethylene, propylene, etc.). These are subsequently used in synthesis or polymerisation reactions. In other words, materials identical to virgin materials can be obtained from plastic waste rather than conventional fossil resources.

Chemical recycling, like mechanical recycling, requires a series of pre-treatments. These can include, but are not limited to, waste size reduction, separation of flows or contaminants, or densification of material. These processes will be more or less intensive depending on the starting waste and the chemical recycling process used.

28 In 2021, the global waste-to-energy capacity is growing more than ever before. RETEMA n° 235, November - December 2021.

Chemical recycling contributes to:

- Increasing resource efficiency.
- Closing the loop in the transition to a circular economy for plastics, making use of these resources that would otherwise end up being incinerated or landfilled.
- Reducing the carbon footprint of current end-of-life solutions for some plastic waste going to landfill or incineration when considering the life-cycle of the entire plastic item.
- Reducing the use of fossil resources by replacing virgin material with chemically recycled material.
- Contributing to the independence of third country resources.
- Reducing CO_2 emissions.

All recycling technologies are necessary and complementary in order to meet the EU's recycling targets. A holistic approach to plastic waste management is therefore required. Cascading processes will provide a global and efficient solution to waste by producing plastics and chemical raw materials for industry, with each product having the appropriate quality and characteristics for its application, in line with the European Green Deal.[29].

All recycling technologies are necessary and complementary to meet the EU's recycling targets

29 COM/2019/640 final. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. The European Green Deal.

> **Chemical and mechanical recycling will coexist to provide solutions for different fractions of plastic waste, the market will find a balance between the two**

3.4 Challenges of chemical recycling

It's necessary to promote chemical recycling both in Spain and in Europe. For chemical recycling to become a reality, it is necessary to work on technical aspects that can limit its implementation, and which are often defined in comparison with mechanical recycling itself.

If chemical recycling is compared to mechanical recycling, it should be noted that:

- In general, technologies associated with chemical recycling are still in their early stages. In the coming years, it is expected that greater scalability of this technology will allow us to obtain more data on its actual technical-economic feasibility.
- Chemical recycling processes have different economic models to mechanical recycling for two reasons:
  - The yields of a chemical recycling process are typically lower than those of mechanical recycling, with less recycled product obtained via chemical versus mechanical recycling.
  - The recycled products obtained via chemical recycling are equivalent to those obtained from virgin raw materials and can be used for any application, including those requiring the highest quality standards and consumer protection, such as food use.
- The environmental impact of chemical recycling is greater than that of mechanical recycling, predominantly due to two reasons. One of these reasons stems from the difference in yield between the two processes. Chemical recycling typically has a lower plastic waste to pyrolysis oil or plastic waste to monomer conversion rate than the plastic waste to recycled plastic conversion rate achieved by mechanical recycling. This means that the entire environmental impact of the process is attributed to a lower amount of the desired end product. On the other hand, in petrochemicals, products from chemical recycling replace a hydrocarbon or a monomer which then needs to be polymerised, increasing the number of processes compared to mechanical recycling.
- The emission savings are lower compared to mechanical recycling, but in return, it produces a fully circular product which is equivalent to a virgin polymer, with no limitations on market use.
- Chemical recycling involves chemical processes. Intrinsic complexity should be taken into account, as well as aspects related to chemical risks. Integration with the chemical industry is key.

The recycling of plastic waste, whether chemical or mechanical, contributes to a circular economy. The characteristics of the plastic waste and its intended application will determine the most appropriate treatment. This is why these technologies are complementary and not substitutes.

Chemical recycling is a good option for producing high-quality materials from very specific flows:

- Waste containing a mixture of different plastics
- Contaminated waste
- Thermoset waste
- When very specific characteristics or applications are required

4 Accounting and Traceability of Chemically Recycled Plastic: Mass balance

4.1 Definition and applications

The plastics and recycling industry needs to be able to trace its materials, products and processes, as this allows us to understand and guarantee factors such as its origin or the amount of recycled plastic within a product.

According to the RAE (Royal Spanish Academy), traceability is defined as the "ability to identify the origin and different stages of a production and distribution process of consumer goods."

The UNE-EN 15343: 2008 standard[30] specifies the procedures necessary for the traceability of mechanically recycled plastics, with traceability being used as the basis for the calculation of the recycled content:

$$\text{\% of recycled content in the product} = \frac{\text{mass of recycled materials in the product}}{\text{total mass of the product}} \times 100$$

This percentage takes into account the pre-consumer and post-consumer materials used. Material recovered in the manufacturing process itself (scraps, trimmings…) is not considered when counting the recycled content.

The UNE-EN ISO 14021: 2017 standard[31] defines the following concepts:

Pre-consumer material. Material diverted from the waste stream during a manufacturing process. The reuse of scrap or rework materials generated in a process, which have the capacity to be recovered [returned] in the same process that generated them, is excluded.

Post-consumer material. Material generated by households—or by commercial, industrial and institutional facilities in their role as end users of a product—that can no longer be used for its intended purpose. This includes returns of supply chain material or returns from the installation of plastic products (e.g., offcuts of insulation, flooring, or wall coverings).

Recycled material. Material that has been reprocessed from recovered [returned] material through a manufacturing process and converted into a final product or a component to be incorporated into a product.

Recovered [returned] material. Material that would otherwise have been disposed of as waste or used for energy recovery, but instead has been collected and recovered (returned) as input material for a recycling or manufacturing process rather than using new raw material.

30 UNE-EN 15343:2008 *"Plastics. Recycled plastics. Plastics recycling traceability and assessment of conformity and recycled content"*
31 UNE-EN ISO 14021:2017 *"Environmental labels and declarations. Self-declared environmental claims (Type II environmental labelling)"*

Mass balance establishes a set of rules that ensure the allocation of recycled raw material into new products

Calculating the recycled content in a product is straightforward when it comes to mechanical recycling; however, this calculation is not applicable to chemical recycling, where a chain is broken and then rebuilt to produce a recycled polymer. It is therefore necessary to apply a methodology that, whilst covering the same veracity and control of the traceability of the standard, ensures the following concepts:

- The percentage of recycled content in a product.
- The origin of the waste (pre-consumer or post-consumer).
- The proportion represented by energy recovery (waste used as energy) and the proportion represented by chemical recycling (waste used as material), in the case of heat treating.

This methodology, known as the **mass balance**, establishes a set of rules that ensure the allocation of recycled raw material into new products, making the waste/raw material route traceable and establishing a realistic and transparent traceability along the entire value chain, from raw material input (waste) to product output (circular material). The ISO 22095 standard[32] establishes the bases and concepts related to mass balance and chain of custody.

Mass balance is applicable to any chemical recycling process, regardless of the resulting product. The mass balance model allows for the physical mixing of materials and intermediates from waste and virgin raw materials as well as the chemical reactions of materials and substances.

32 *ISO 22095:2020 Chain of custody — General terminology and models.*

This methodology is certifiable by an independent third party at each stage of the value chain, thus ensuring the status of recycled material and the differentiation between chemical recycling processes and energy recovery processes. In addition, it can be used to obtain fiscal advantages such as a reduction on Spain's non-reusable plastic packaging tax, relating to Law 7/2022 on waste and contaminated soils for a circular economy[33].

Companies or entities applying this methodology must calculate the average input and output (as a percentage) of a process or set of processes (e.g., a gasification line). In each case, they must specify the time frame over which the average percentage is taken. The shorter the time frame, the more realistic the data is, especially if the process fluctuates a considerable amount. For this reason, the ideal time frame would be batch by batch, although in many cases this may not be feasible.

In each case, information shall be provided on: the type (waste, virgin and recycled raw material), quantities and origin of each input. It must be specified when the inputs are of a different origin.

All this information must be documented throughout the supply chain. In addition, it has to be verified that the amount of circular output product does not exceed the amount of input waste. The yields of each of the individual process steps must be taken into account in each case.

The yields or conversion factors of each of the processes may vary over time due to technical reasons as well as market-related issues. For this reason, each batch or each time frame considered must have a different yield or conversion factor than the previous or subsequent batch or time frame.

The company must measure the performance of each process used to obtain the recycled products (chemical recycling) or their direct use as fuel/energy (energy recovery), as appropriate. These yields must be documented by batch or time frame and must be verifiable.

Mass balance model allows for the physical mixing of materials and intermediates from waste and virgin raw materials as well as the chemical reactions of materials and substances

There are currently voluntary certifications related to mass balance applicable to chemical recycling. A brief summary of these certifications is provided in Annex I of this report.

Two examples of the application of mass balance in two typical chemical recycling processes are shown next: pyrolysis of mixed waste and PET solvolysis.

33 Law 7/2022, of 8 April, on waste and contaminated soils for a circular economy. Official State Bulletin n° 85 of the 9th April 2022.

4.2 Mass balance applied to pyrolysis

Mass balance should be applied to the whole value chain and not just to one process in the system, since some products of certain processes, such as pyrolysis, generate other products such as fuels for direct use, that should not be considered as recycling but as energy recovery, as shown in the figure below, which illustrates how mixed plastic waste feeds a pyrolysis plant that produces two main products: a gas, which is burned and used as energy for the pyrolysis process itself, and pyrolysis oil (liquid) that can be cleaned and refined for different uses.

This pyrolysis oil must be further processed in a hydrotreating and/or cracking facilities in order to obtain monomers for new circular materials. Due to the nature of the process, a small fraction will also end up in fuels.

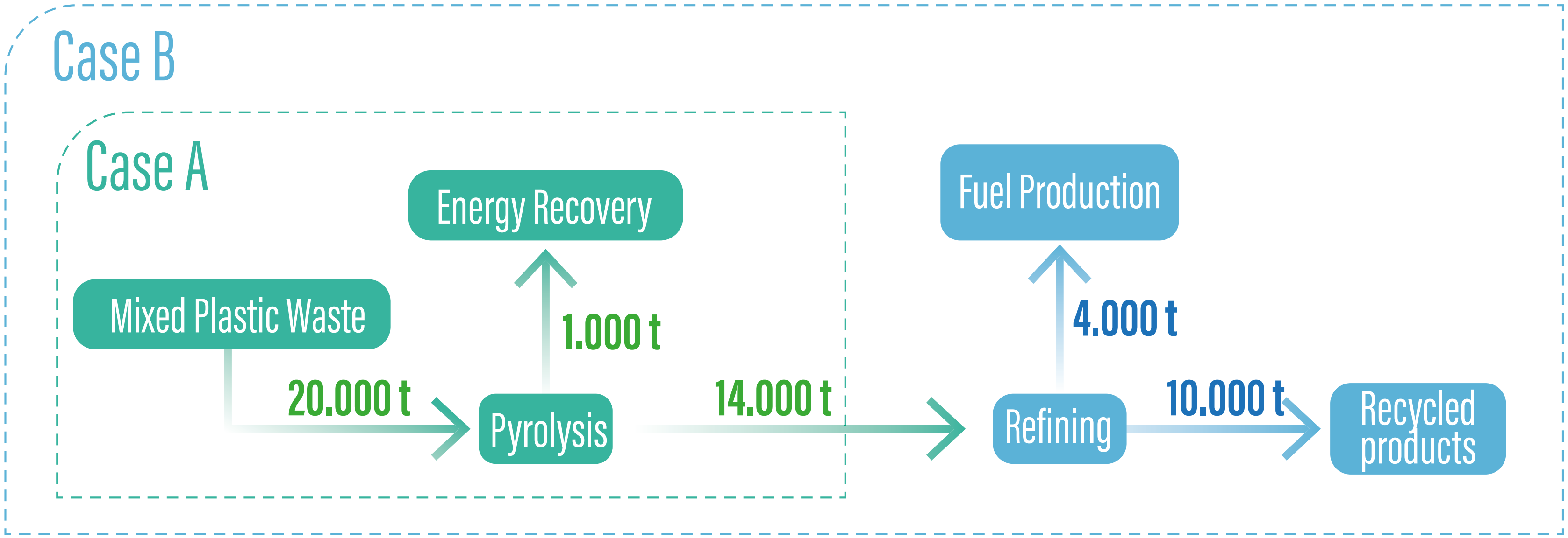
If the mass balance was to be applied only to the pyrolysis process (case A in Figure 16), in many cases the data relating to fuel production would not be known and therefore a larger amount would be allocated to recycling. However, by including the subsequent refining process (case B in Figure 16) this division is identified, giving a more accurate amount.

The mass balance applied to the overall process, from the plastic waste to the recycled product, allows the corresponding recycling allocation to be transparently traced

Applying mass balance to the overall process from plastic waste to recycled product allows the corresponding recycling allocation to be transparently traced.

It is therefore recommended to apply the procedure to the entire value chain.

Mass balance applied to pyrolysis | FIG. 16



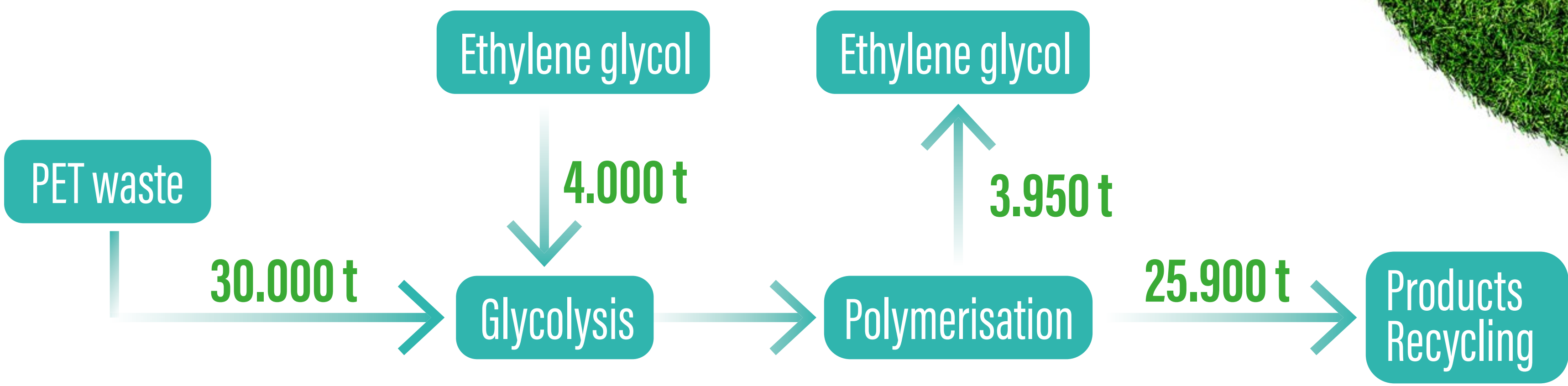
4.3 Mass balance applied to solvolysis

Mass balance can also be applied to a chemical cracking or solvolysis process. The figure below shows an example of PET waste from various sources feeding a glycolysis reactor (one of the different types of solvolysis processes; in this case the chemical agent is a glycol). This reactor is fed with other reagents such as ethylene glycol. Following a polymerisation reactor, the recycled product is produced along with ethylene glycol and other products.

There is no energy recovery here as only recycled PET products are obtained. It is important to note that ethylene glycol is a process input, but it is not considered in the mass balance since it does not become a recycled product. The same applies to other products that contribute to the process such as catalysts, water and/or natural gas. They should not be considered in the mass balance as they are not transformed into final products.

This solvolysis process is simpler than the pyrolysis one, as the substances obtained are directly used in the production of recycled materials and no differentiation between other processes, such as energy recovery, is required. However, it is equally recommended to apply the procedure to the whole value chain to show traceability.

Mass balance applied to solvolysis | FIG. 17



5 The state of the art in Spain

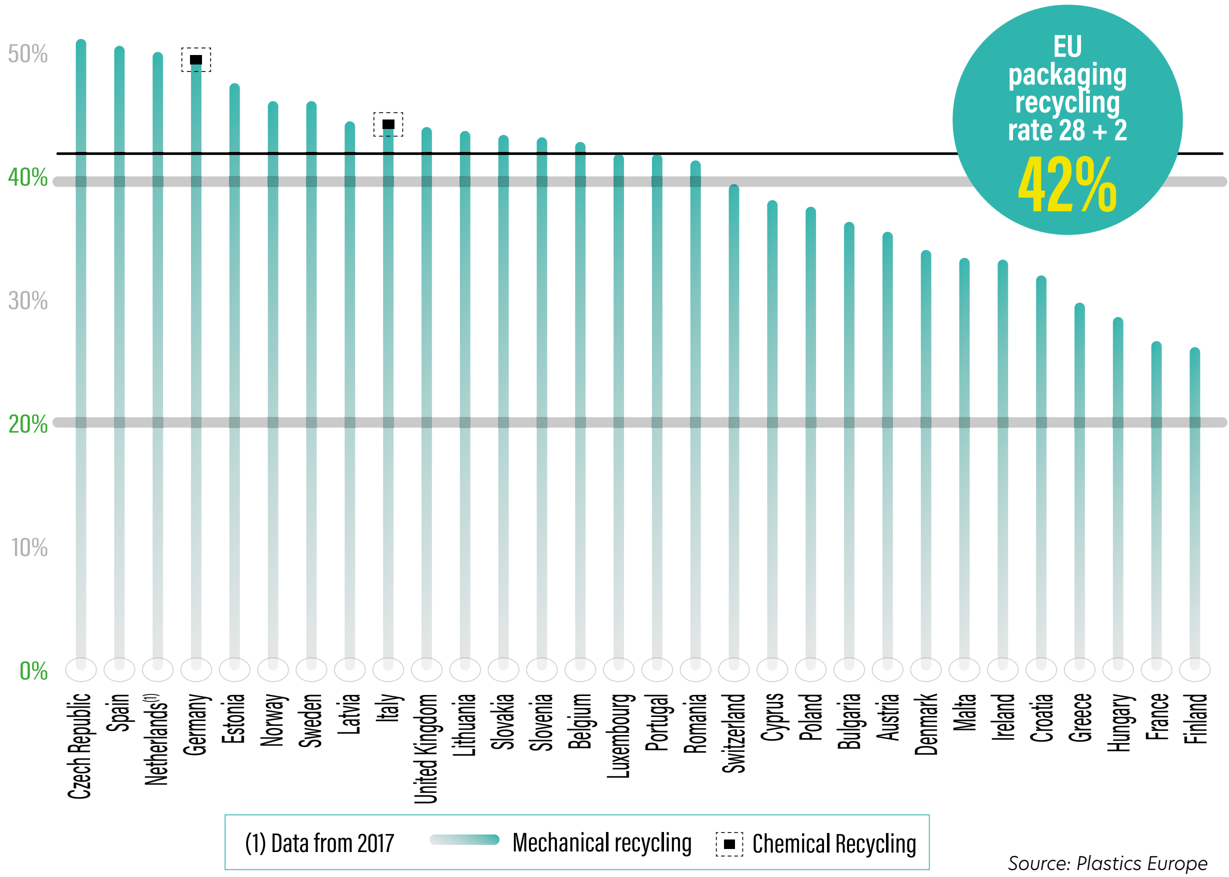
5.1 Chemical recycling companies

Although chemical recycling is a good opportunity to convert plastic waste into a resource, the fact is that it is not widely used at present. The number of chemical recycling plants in Spain and Europe is very limited, both in terms of number and production capacity.

This figure shows a lower percentage of chemical recycling compared to mechanical recycling. The former is present only in two of the analysed countries: Germany and Italy. It is estimated that currently only 0.2% of post-consumer plastic waste collected in Europe is recovered through chemical recycling processes.

The situation in Europe is similar to the current situation in Spain, since there are still few industrial plants that chemically recycle plastic waste.

Plastic Packaging Recycling Index by Country in 2018 | FIG. 18



Source: Plastics Europe

Table 3 shows some of the existing chemical recycling plants in Spain.

Examples of chemical recycling plants operating in Spain | TABLE 3

Company	Process	Capacity (tonnes waste/year)
PLASTIC ENERGY[34] (Seville)	Pyrolysis	5,500 (*)
PLASTIC ENERGY (Almeria)	Pyrolysis	5,500 (*)
RECICLALIA[35]	Pyrolysis	500
TOTAL		**> 11,500****

Note (*): Tonnes of pyrolysis oil produced/year
Note (**): A higher capacity is indicated as some data refer to the production of pyrolytic oil and not the actual tonnes of waste treated.

With the current capacity of chemical recycling in Spain, more than 11,500 tonnes of plastic waste are treated.

It is worth noting that there are other plants such as SULAYR36 that have a treatment capacity of 38,000 tonnes/year for value-added processes such as dissolution recycling.

Considering the current number of plants, expected growth is significant. This is due to the volume of laboratory and pilot plants and projects that already exist in the country, and due to the implementation, that is expected in the field in the short term.

Some of the companies have only just started their activity and are a spin-off from a Spanish university or the Spanish National Research Council. This shows Spain's capacity for the innovation and development of technology within this field.

Emerging companies with chemical recycling technology in Spain | TABLE 4

Company	Process
B-CIRCULAR[37]	Pyrolysis
POLYKEY POLYMERS SL[38]	Solvolysis
GSF UPCYCLING[39]	Thermal cracking
YASED LAB[40]	Dissolution recycling
FYCH TECHNOLOGIES[41]	Dissolution recycling
EVOENZYME[42]	Biological cracking

34 https://plasticenergy.com/
35 https://reciclaliacomposite.com/
36 https://sulayrgs.com/
37 https://www.bcircular.com/
38 https://polykey.eu/
39 https://gsfupcycling.com/
40 https://yasedlab.com
41 https://www.fychtech.com/
42 https://evoenzyme.com/

In terms of the new industrial chemical recycling plants, it is worth noting:

- **REPSOL**[43] is building a polyurethane solvolysis plant in Puertollano that will be operational by the end of 2022 with a treatment capacity of 2,000 tonnes of waste/year.
- **SACYR** y Honeywell plans to install a pyrolysis plant in Andalusia in cooperation with Honeywell. It will be operational by early 2023 with a treatment capacity of 30,000 tonnes of waste/year.
- **Plastic Energy**[44] has announced it is constructing a second pyrolysis plastic recycling plant in Seville in cooperation with TotalEnergies. It will be operational by 2025 with a treatment capacity of 33,000 tonnes of waste/year. The recycled material obtained will be used for food packaging.
- **Plastic Energy**[45] has announced the construction of a plastic film waste treatment plant in Santa Cruz de Tenerife.
- **REPSOL**[46] has joined forces with Enerkem and Agbar to build a waste gasification plant in Tarragona that will be operational by the end of 2025. It will have a treatment capacity of 400,000 tonnes of non-recyclable MSW/year and will obtain 220,000 tonnes of methanol/year, which will be transformed into circular materials or advanced biofuels.

New chemical recycling plants planned in Spain | TABLE 5

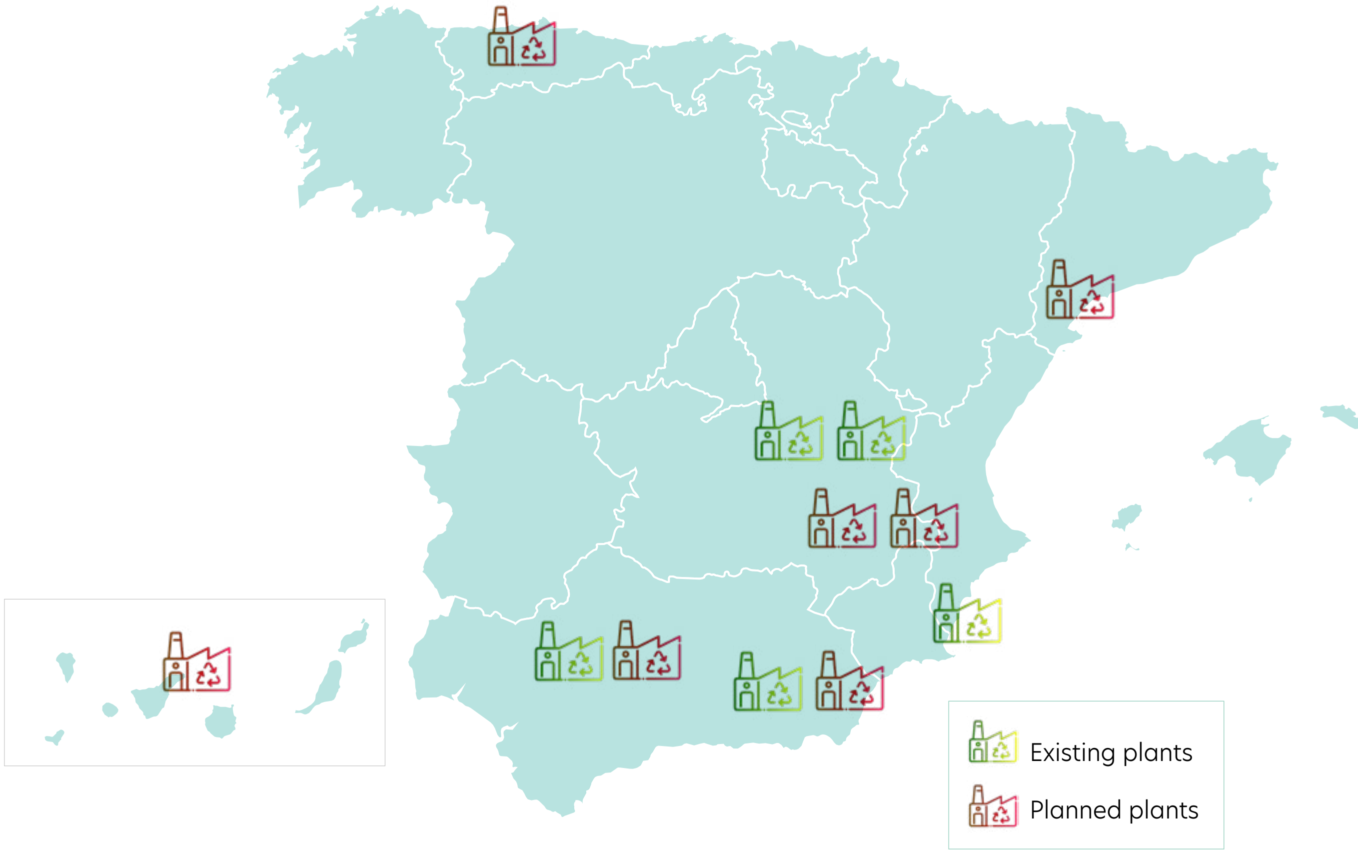
Company	Process	Operation start	Treatment capacity (tonnes waste/year)
REPSOL	Solvolysis	2022	2000
SACYR/HONEYWELL	Pyrolysis	2023	30,000
PLASTIC ENERGY/TOTALENERIES	Pyrolysis	2025	33000
REPSOL/ENERKEM/AGBAR	Gasification	2025	400000
PLASTIC ENERGY	Pyrolysis	2024	N/A
TOTAL			**>465,000**

In addition to these plants, there are other plants already in in operation or in the pipeline, which are not currently associated with chemical companies, but which sell or could sell pyrolytic oil to them, expanding the country's chemical recycling capacity. One example is the company PRECO[47] which currently has 4 plants on the Iberian Peninsula (1 in operation and 3 under development). The plant in operation has a waste treatment capacity of 20,000 tonnes of plastic waste per year and those under development have a total waste treatment capacity of 430,000 tonnes of plastic waste per year. In the same vein, there is the new plant that has been built by WPR Global S.L.[48] that treats 8 tonnes of plastic waste a day to produce biodiesel and petrol.

Companies are currently testing and developing the solvolysis of waste (both thermosets and thermoplastics) to obtain primarily different substances such as bis(2-Hydroxyethyl) terephthalate (BHET) or derivatives and polyols. These types of companies are sometimes small manufacturers of plastic raw materials (in many cases thermosets) that in the short term are looking to diversify their production towards chemical recycling within their own facilities. The main advantage is that they work with reactors very similar to polymerisation/formulation reactors. This situation may favour an increase in chemical recycling capacity in the coming years and a diversification in terms of starting waste and the recycled products obtained.

43 https://www.repsol.com/es/productos-y-servicios/quimica/quimica-news/repsol-construira-puertollano-primera-planta-reciclado-poliuretano-espana/index.cshtml
44 Packaging Insights Newsletter 11 de enero de 2022 "Plastic Energy and TotalEnergies plan second advanced recycling plant in Spain"
45 Plásticos y Caucho. Año XXVI, nº 1.181 - Lunes, 31 de enero de 2022.
46 https://www.repsol.com/es/sala-prensa/notas-prensa/2021/repsol-se-une-a-enerkem-y-agbar-para-construir-una-planta-de-val/index.cshtml
47 https://precocircular.com/proyectos/
48 https://wprglobal.es/

Chemical Recycling Plants (existing and planned) | FIG.19



The installed capacity for waste treatment by chemical recycling in our country is expected to increase 40-fold over the next 3 years

Large multinational companies in the sector, such as BASF[49], COVESTRO[50], VERSALIS[51], DOW[52-55] or SABIC[56], have expressed their intention to build, or are already building, plants with similar characteristics to those above throughout Europe. The existence of a favourable regulatory framework, together with the incorporation of chemical recycling in the recently approved Law on Waste and Contaminated Soils for a Circular Economy, is an additional incentive to promote the implementation of similar facilities within Spain, which also allows them to benefit from proximity to generated waste.

This implementation and growth of chemical recycling plants is taking place worldwide. According to Rabobank data, the number of chemical recycling plants is expected to double by 2025 and their capacity is expected to triple or even quadruple. Europe and the United States are the biggest investors in these technologies, the former accounting for 45-50% of the total number of plants worldwide.

49 https://www.basf.com/global/en/who-we-are/sustainability/we-drive-sustainable-solutions/circular-economy/mass-balance-approach/chemcycling.html
50 https://www.covestro.com/press/closing-the-loop-for-polyurethane-mattresses-trade/
51 https://www.eni.com/en-IT/media/press-release/2020/02/versalis-to-launch-hoop-tm-chemical-recycling-towards-infinitely-recyclable-plastic.html
52 https://corporate.dow.com/en-us/news/press-releases/dow-and-mura-technology-announce-partnership-to-scale-game-chang.html
53 https://corporate.dow.com/en-us/news/press-releases/dow-expands-global-capabilities-for-circular-plastics--with-init
54 https://corporate.dow.com/en-us/news/press-releases/dow-to-build-market-development-unit-to-enable-manufacturing
55 https://corporate.dow.com/en-us/news/press-releases/dow-invests-in-plastogaz.html?msclkid=2fc576c6c08a11eca6865ce164c710ec
56 https://cartagena.sabic.com/es/news/26266-sabic-y-plastic-energy-preparados-para-comenzar-la-construccion-de-una-pionera-instalacion-de-reciclaje-avanzado-con-el-fin-de-aumentar-la-produccion-de-polimeros-circulares-certificados

The Circular Economy Strategic Project for Economic Recovery and Transformation might serve as another lever with which the industry can further advance the circularity of plastics and recycling development

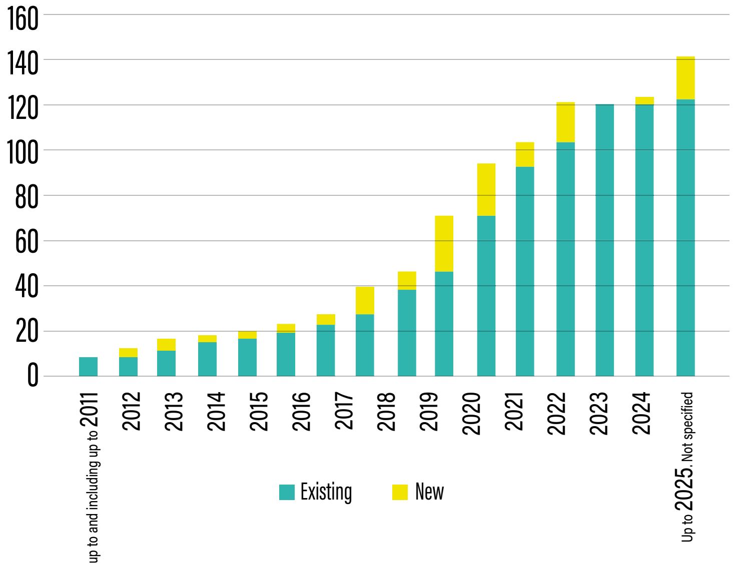
This growth is in line with the significant increase in planned investments in chemical recycling at European level[58], from 2,600 million euros in 2025 to 7,200 million euros in 2030, with 44 projects planned in 13 EU countries. Production of chemically recycled plastics is estimated to increase to 1.2 Mt by 2025 and 3.4 Mt by 2030. Based on these figures and extrapolating them to Spain, it is possible to forecast that investments will be in the region of 500-650 million euros by 2030.

The Circular Economy Strategic Project for Economic Recovery and Transformation[59] (PERTE EC) may provide additional leverage for the sector to further advance the circularity of plastics and the development of recycling. This strategic project will channel funding calls amounting to 492 million euros, which will be implemented, between 2022 and 2026, through two lines of action. The first, totalling 192 million euros, covers horizontal actions to promote a circular economy in companies with the aim of improving competitiveness and innovation in the industrial sector across four categories: consumption of virgin raw materials reduction, eco-design, waste management and digitalisation.

The second line of action, with a budget of 300 million euros, focuses on actions in three key sectors: Textiles, plastics and renewable energies. Actions taken across all three sectors aim to promote reuse and recycling, with chemical recycling. Among the eligible activities for the plastic sector, chemical recycling is explicitly mentioned.

These grants should promote the circularity of the sector. It should be noted that a circular economy is estimated to have the potential to create around 700,000 jobs in Europe, of which at least 10% could be created within Spain.

Growth outlook for the number of advanced recycling plants until 2025 | FIG. 20



Source: RABOBANK[57]

57 Packaging Insights Newsletter 4 de mayo de 2021 "Rabobank strategist: Advanced recycling is proliferating but not the circular economy silver bullet".
58 Plastics Europe. Chemical Recycling in Brief 26 May 2021.
59 https://planderecuperacion.gob.es/https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/temas/economia-circular/perteenec_baja_tcm30-537854.pdf

5.2 Chemical recycling R+D+I projects

Despite being an emerging technology on an industrial level, many R&D&I initiatives are being developed by the different organisations within the innovation ecosystem. Annex II shows some examples of funded European projects on chemical recycling[60] with participation from Spanish entities. This Annex also includes projects with national funding.

The large number of projects not only shows the interest of industry and other technology and research entities on this topic, but also that of Public Administration itself, which is committed to finding solutions for plastic waste and its integration into the production chain through calls for proposals such as the CDTI's Science and Innovation Missions[61] or the State Bureau of Investigation's Strategic Priorites[62]. Through these calls for proposals, the Ministry of Science and Innovation supported projects related to circular economy and sustainability of plastics worth over 4 million euros in 2021. These projects encourage public-private collaboration and facilitate the development and implementation of chemical recycling technologies as well as the development of pilot plants, forming a solid foundation for industrial development at the national level, enabling Spain to lead chemical recycling advancements.

All these projects, with different technology readiness levels, are expected to become a reality in the market in the short and medium term.

Interest in these technologies as a way of tackling the challenge of plastic waste is also developing in neighbouring countries. It should be noted that, although there are also European projects in these areas in which Spanish organisations do not participate, the number is relatively small. This shows the specialisation and involvement of Spanish entities in this area.

60 La relación de proyectos incluye craqueo térmico, solvólisis, craqueo biológico y reciclado por disolución
61 https://www.cdti.es/index.asp?MP=100&MS=902&MN=2&TR=C&IDR=3016
62 https://www.aei.gob.es/convocatorias/buscador-convocatorias/proyectos-idi-lineas-estrategicas-colaboracion-publico-privada

Many of the current projects are being developed through public-private partnerships

Some examples of European Projects are shown below. The interest of these projects lies in their specific subject matter or because they constitute a starting point for current and future pilot and/or industrial plants.

- RESYNTEX[63]: A new circular economy concept: from textile waste towards chemical and textile industries feedstock.
- CHEMPET[64]: Industrial-scale PET chemical recycling via an innovative glycolysis process.
- Industrial[65] scale PET chemical recycling plant based on innovative glycolysis process
- CRNPE[66]: Chemical Recycling for the New Plastic Economy.
- CATALEPTIC[67]: A developed thermochemical approach for catalytic depolymerization of plastics. 101033386.
- OPTIMA[68]: Process intensification and innovation in olefin Production by Multiscale Analysis and design.
- MMATWO[69]: Second generation Methyl MethAcrylate.

Many of the running projects are being developed through public-private collaboration. Annex III contains a list of Universities, Technology Centres and Public Research Bodies throughout Spain that are dedicated to research into the chemical recycling of plastics that are international leaders in the field.

In addition, there are other private investment initiatives aimed at improving processes, such as the PYROPLAST project in which Repsol, Axens and IFPEN have developed the Rewind Mix process, which allows pyrolysis oils to be purified through the elimination of impurities such as chlorine, silicon, diolefins and other metals. This novel process allows it to be used directly as a feedstock without the need for dilution in existing petrochemical units.

63 https://cordis.europa.eu/project/id/641942
64 https://cordis.europa.eu/project/id/871386
65 https://cordis.europa.eu/project/id/773863
66 https://cordis.europa.eu/project/id/739775
67 https://cordis.europa.eu/project/id/101033386
68 https://cordis.europa.eu/project/id/818607
69 https://cordis.europa.eu/project/id/820687
70 https://www.repsol.com/content/dam/repsol-corporate/es/productos-y-servicios/productos/qu%C3%ADmica/qn23062021-desarrollamos-axens-ifpen-nuevo-proceso-producion-materiales-circulares.pdf

5.3 Chemical recycling patents

A recent study on patents in the circular economy of the plastic sector[71] reveals that the United States and Europe stand out as global innovators in plastic recycling.

Table 6 shows the revealed technological advantage index. This index establishes the level of specialisation in the relevant technology. A value less than 1 indicates low specialisation, whilst a value greater than 1 indicates high specialisation.

In this regard, Germany has a higher number of patents on plastics recycling than other European countries; however, its revealed technological advantage index is less than 1, indicating that it lacks real specialisation in the field. It should be noted that in other European countries, such as Italy or France, the index of revealed technological advantage is considerably high despite having a lower number of patents. In the particular case of Spain, despite having a lower number of patents per million inhabitants, 3.2, it has a revealed technological advantage index of 1.3, which demonstrates our high level of specialisation. This is also the case in.

Origins of international patent families related to plastics recycling (2010-2019) | TABLE 6

Country	NO.	Percentage	Number per million inhabitants	Revealed technological advantage index
United States	4,640	30.8	13.9	1.52
EU27	3,829	25.4	8.6	1.13
Japan	2,665	17.7	21.6	0.77
Germany	1,242	8.2	14.8	0.83
People's Republic of China	801	5.3	0.5	0.48
Republic of Korea	749	5.0	14.5	0.59
France	644	4.3	9.8	1.19
The Netherlands	440	2.9	25.6	2.27
United Kingdom	436	2.9	25.6	2.27
Italy	349	2.3	5.7	1.26
Belgium	219	1.5	18.9	2.4
Spain	**151**	**1.0**	**3.2**	**1.3**
Switzerland	141	0.9	16.2	0.77
Denmark	105	0.7	18.1	1.21
Sweden	89	0.6	8.8	0.48

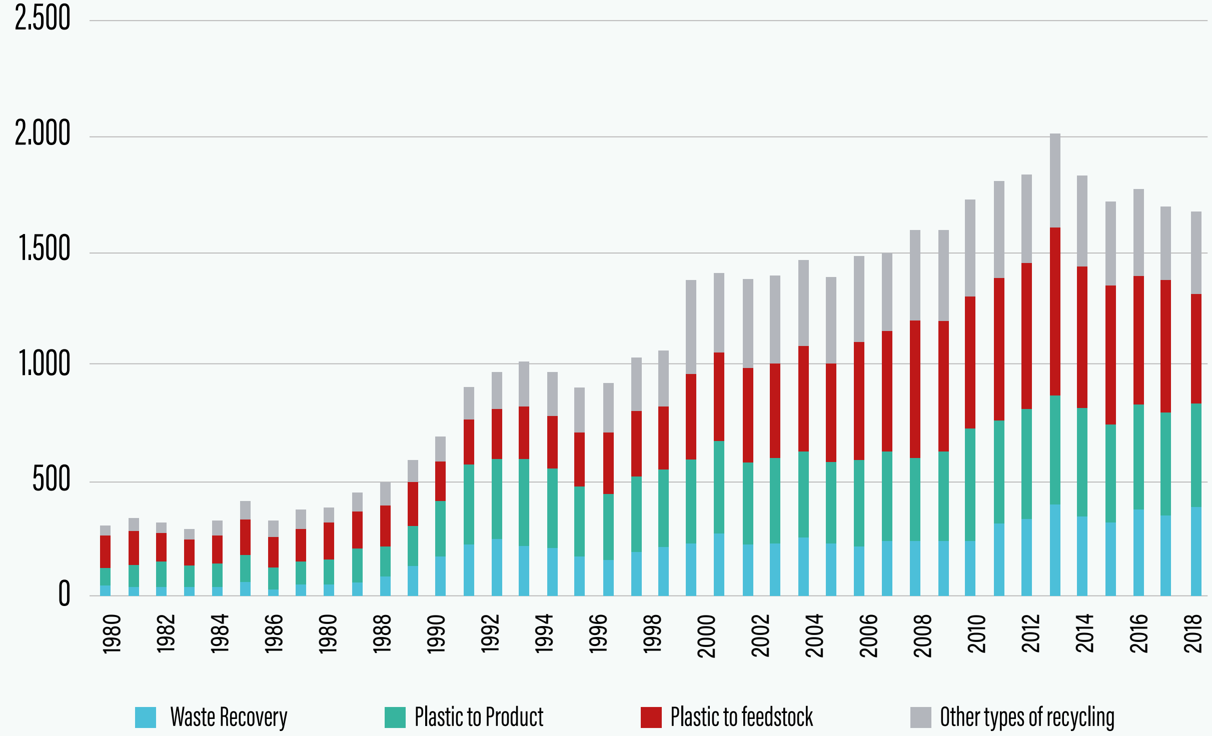
Source: European Patent Office

71 Patents for tomorrow's plastics. Global innovation trends in recycling, circular design and alternative sources European Patent Office. October 2021. ISBN 978-3-89605-277-3

> **The large number of patents within chemical recycling demonstrates that both, the industry and the scientific community, are interested in these technologies and supports their expected growth following their entry into the market**

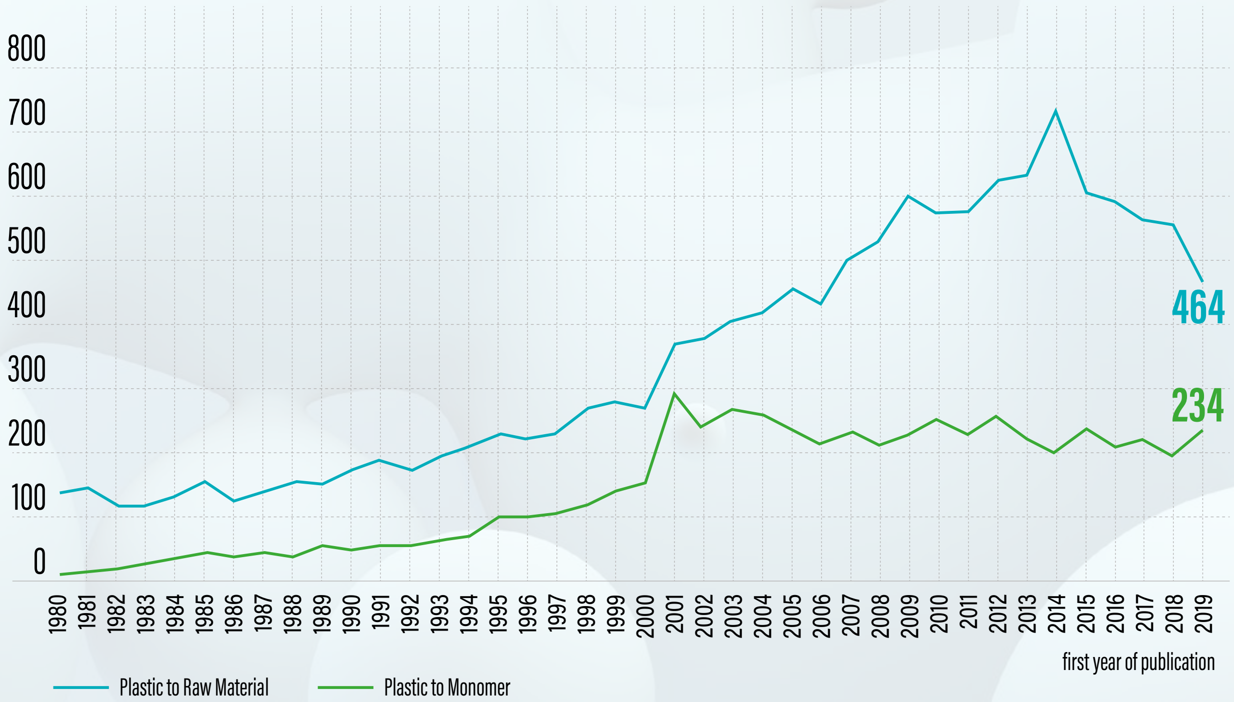
As for the evolution of patents, patents on mechanical recycling (plastic-to-product recycling) were dominant until the 1990s. Since then, patents related to chemical recycling have exceeded them, as shown in the following figure.

Number of patent families related to waste recovery and different types of recycling between 1980 and 2019 | FIG. 21



Source: European Patent Office

Number of patent families related to chemical recycling between 1980 and 2019 | FIG. 22



Source: European Patent Office

The large number of patents within chemical recycling demonstrates that both the industry and the scientific community are interested in these technologies and supports their expected growth following their entry into the market.

The figures above show the number of patent families related to chemical recycling, divided into two types of technologies: "plastic to feedstock" and "plastic to monomer". "Plastic to feedstock" refers to obtaining naphtha-like raw materials through, for example, pyrolysis, which then need to go through other cracking and refining processes in order to obtain the final monomer. "Plastic to monomer" refers to processes that directly obtain the monomer, such as solvolysis (though there are also some pyrolysis processes which are able to directly extract monomers, such as the pyrolysis of PS).

6 Trends in chemical recycling

Chemical recycling is an emerging technology with clear potential for growth. In the coming years, industrial plants will be built on all continents. This will result in a clear decrease in the amount of plastic waste going to landfills or incinerators, leading to resource recovery.

While large amounts of chemical recycling treatment capacity seem to focus on thermal cracking processes, solvolysis processes will also be developed mainly for polyester and polyurethane waste. This growth requires close collaboration between chemical companies, technology developers, waste managers and recyclers. In most cases, these recycled materials will be included in the portfolio of large raw material manufacturers that will provide plastics with different percentages of recycled materials from different origins, following the quality and sustainability criteria of the companies in question.

These materials, and in many cases their processes, will be endorsed by internationally recognised certifications and standards that will enable their traceability and ensure their quality and specific applicability (compliance with properties and legislative requirements for different applications).

The processes themselves will gradually evolve towards technologies with lower energy consumption, coming from the modification of processes themselves, such as the use of processes coupled with microwaves, or through the use of selective catalysts. This energy minimisation will lead to a decrease in the carbon footprint of the process and materials, resulting in more sustainable materials with a lower environmental impact. It will also have a significant impact on process and product costs.

Meanwhile, processes related to other technologies are expected to be developed for the same purpose: to increase efficiency. These processes include partial polymerisation which will not require a 'cracking to monomer' stage, obtaining polymers with lower molecular weight directly. These intermediates will, in turn, require less repolymerisation, which will lead to an economic and environmental reduction in both processes. Similarly, this partial depolymerisation will be used to obtain tailor-made recycled products, for example, those with a different fluidity or viscosity index than the starting waste.

In most cases, these recycled materials will be included in the portfolio of large raw material manufacturers that provide plastics with different percentages of recycled materials

In the same vein, chemical recycling helps obtain substances that might become a starting point for a polymer with an identical or different nature from the polymer they originated from.

This possibility of recycling and subsequent tailor-made formulation can facilitate the entry of recycled polymers other than those of the starting waste or in another sector, thus decoupling collection and dependence on the sectors themselves. For example, polyester waste from the textile sector can be chemically recycled into a polyol which can then be used in the manufacture of polyurethane for the construction sector.

Another trend in chemical recycling is the development of mechanochemistry which allows for a drastic reduction in solvents and process times; reductions that will be essential when it comes to increasing the viability and industrial deployment of solvolysis processes. Additionally, the development and use of ionic liquids should increase the feasibility of processes currently using solvents for chemical cracking.

The combination of some of these technologies bodes well for the future of chemical recycling, with more efficient and sustainable processes and lower operating costs.

In the coming years, industrial plants will be set up on all continents, which will lead to a clear decrease in the amount of plastic waste going to landfills or incinerators

7 Necessary framework for the development of chemical recycling into a reality

Chemical recycling is a complementary recycling solution that will allow us to increase the circularity of end-of-life plastics and reduce their carbon footprint.

However, in order for this technology to reach its full potential, both the market and current waste legislation need to adapt. There are still many open questions regarding this emerging technology, its economic viability and the regulatory framework that affects it.

A stable and predictable regulatory framework that defines recycling in a technology-neutral way is required for the development of new alternatives as well as existing ones; particularly if we are to ensure that they meet EU recycling and recycled content targets. To this end, this regulatory framework must:

- Provide a clear and harmonised definition of chemical recycling.
- Develop an appropriate, accepted and harmonised methodology to comply with customer requirements for recycled content and its control. This methodology must be certified, clear and recognised for the measurement and reporting of the use of circular polymers from chemical recycling, like the mass balance. This is essential as the recognition of chemical recycling alone is not enough, it must be accompanied by the recognition of mass balance as a monitoring tool.
- Recognise chemical recycling as a complement to mechanical recycling in the waste hierarchy. It is therefore necessary to clarify the difference between chemical recycling and energy recovery, even if they are the same process, when the purpose of the products obtained is different. This is the case, for example, with pyrolysis, which produces pyrolysis oil or synthesis gas (syngas) which can produce monomers (chemical recycling) or to products which can be used as fuels (energy recovery). Energy recovery would be below mechanical or chemical recycling in the waste hierarchy and above incineration and landfilling.

A stable and predictable regulatory framework that defines recycling in a technology-neutral way is required for the development of new alternatives as well as existing ones; particularly if we are to ensure that they meet EU recycling and recycled content targets

- Development of clear "end-of-waste" criteria and consequent legislative development so that, in a direct and harmonised manner throughout the country, chemically recycled plastic waste is no longer considered waste when transformed into a new product.
- Clear inclusion of chemical recycling in basic legislation, such as REACH[72] and food grade plastics among others, with wording that makes chemical recycling possible in practice and affords the technology the same express mention of the development of standards, methodology and traceability where they do not yet exist.
- Harmonised and technologically neutral legislation, which allows for the development of new recycling alternatives, as well as existing ones, in time for investments to be made available to implement them in order to meet European climate and circular economy targets.
- The environmental impact of the different end-of-life solutions for virgin materials and recycled materials are compared using a life-cycle analysis approach, especially when the alternative for some waste is incineration or landfill.
- Real commitment along the whole value chain, including public and private actors related to regulation and legislation. This includes collaboration on innovation and technology transfer with the aim of sharing information and creating a link for the development of major and secondary technology and processes.
- Inclusion of products made from recycled plastic within innovative and green public procurement tenders, accepting all existing recycling technologies, including chemical recycling.
- Promoting investment to enable the construction and start-up of new industrial plants.
- Promotion of aid that allows, through public-private co-financing, the development of R&D&I projects that help develop more efficient and effective processes.
- Encouraging society as a whole to become more aware of the importance of not releasing waste into the environment and the importance of participating in selective collection, which allows for the subsequent recycling of plastic waste and its incorporation into the production process as a resource.
- Improving selective collection and waste selection processes.
- Simplifying the administrative processes for granting end-of-waste status in order to market the products obtained and count them as recycled.
- Reducing deadlines for obtaining the environmental authorisations and licenses necessary for the start-up of new industrial plants.

72 *Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC. Official Journal of the European Union L 396 of 30 December 2006*

All these measures will help implement chemical recycling as well as encourage the country's economic and industrial development.

Spain is currently the leading country in the European Union for chemical recycling as its Public Administration recognised this technology in an NLP (Non-Law Proposal) in 2021[73]. Additionally, in the Law on Contaminated Waste and Soil for a Circular Economy, material obtained from chemical recycling is recognised at the same level as material obtained from mechanical recycling, in terms of exemption from non-reusable plastic packaging tax. It is necessary to continue taking steps in this direction in order to advance and assist the implementation of this technology in Spain.

Spain has two major strengths that should favour the introduction of chemical recycling:

- A strong chemical sector that contains technologies necessary for, or adaptable to, chemical recycling, which should be used to their full potential. The Spanish chemical sector (NACEs 20 + 21) is one of the most consolidated industrial sectors within the Spanish economy. Composed of more than 3,000 companies, the Spanish chemical industry experienced a productive growth of 5.9% in 2021, ending the year with an annual turnover of 77,241 million euros. Taking into account its indirect and induced effects, this currently represents 5.4% of the Gross Domestic Product. Alongside production growth, the number of direct jobs within the sector increased to 210,000, a number that rises to 711,000 if you also consider indirect and induced jobs. This is equivalent to 3.7% of the wage-earning labour force. This was largely made possible thanks to the sector's export capacity of 44,000 million euros (which represents 57% of the turnover) and its clear commitment to R&D+I investment, accumulating 26.8% of the industrial total.
- A strong and united value chain, including raw material manufacturers, plastic material processors and mechanical recyclers. This value chain consists of more than 4,000 companies, with a turnover of 25,844 million euros (which, taking into consideration indirect and induced effects, represents 2.7% of the Gross Domestic Product as well as 90,000 direct jobs). Including indirect and induced employment, the plastics industry generates more than 255,000 jobs in Spain with an export capacity of 11,056 million euros.

These points set Spain apart from other countries and offer a competitive advantage.

73 Diario de Sesiones del Congreso de los Diputados, nº 411 (Document 161/002363)

8 10 myths about chemical recycling

MYTH 1

Chemical recycling is not recycling, it is energy recovery

False. Chemical recycling and energy recovery are two different concepts, although both involve breaking the polymer chain. In chemical recycling, this produces different substances, excluding those used as fuels or as a means to generate energy. If fuel or energy is produced, it is energy recovery. In the waste hierarchy, chemical recycling is above energy recovery and helps create circular raw materials.

MYTH 2

Chemical recycling will replace mechanical recycling in the short term

False. Chemical recycling is complementary to mechanical recycling, not a substitute for it. Whenever possible, mechanical recycling should be chosen. However, when starting with waste that is highly mixed, potentially contaminated, non-recyclable, thermoset or needs to meet specific requirements e.g., food safety, chemical recycling should be chosen.

MYTH 3

Chemical recycling is a contaminating process that releases toxic substances into the environment

False. Chemical recycling involves a wide variety of chemical processes that are regulated to control their impact on the environment.

European and national legislation regulates these processes, which ensures their control and minimises their impact with the aim of providing an overall reduction of their environmental footprint.

MYTH 4

Chemical recycling has a high carbon footprint

False. To calculate the carbon footprint, a full life-cycle analysis must be carried out. If the manufacturing process from chemical recycled feedstock is compared to the manufacturing process from virgin feedstock, it has a lower carbon footprint.

In a pyrolysis process, the carbon footprint of the pyrolysis oil has to be compared with the production of naphtha. In the case of glycolysis, the carbon footprint of producing the monomer must be compared with the carbon footprint of producing the same monomer via the traditional process.

MYTH 5

Chemical recycling is not on an industrial scale

False. Products incorporating plastics obtained from chemical recycling are already on the market. There are plants using different chemical recycling processes that treat tonnes of waste per year and market the recycled materials.

MYTH 6

Chemical recycling is a technology with high GHG emissions

False. Chemical recycling can prevent plastics from being incinerated and can be used as feedstock, thus avoiding the refining process and reducing the GHG emissions associated with these processes, resulting in a favourable emissions balance.
There are numerous scientific studies that show the benefits of combining mechanical recycling and chemical recycling in terms of emissions.

MYTH 7

Chemically recycled plastic materials cannot compete with virgin plastic

False. Chemically recycled plastic is a new material on the market. Therefore, its price will vary against virgin plastic according to supply and demand. For this reason it will be self-regulated. Its competitiveness against virgin plastic will be the product of environmental and economic factors, including global factors, such as the cost of waste management in other processes (such as incineration or landfill) or taxes on virgin material.

MYTH 8

Chemical recycling is the magic solution for recycling all plastics

False. Chemical recycling could theoretically be applied to all waste. However, tailor-made solutions must be sought to ensure the optimal solution is used: in some cases, this will be mechanical recycling, in others chemical recycling. Therefore, the optimal solution for plastic waste should be analysed on a case-by-case basis and science should be applied by measuring the environmental impact using recognised tools such as life-cycle analysis.

MYTH 9

Chemical recycling is not conducive to circular economy

False. Chemical recycling is a major step towards a circular economy. It allows resources to be reintroduced into the productive system and gives waste a new life, providing circular raw materials and decoupling the plastics sector from non-renewable resources.

MYTH 10

Spain does not have the capacity to lead chemical recycling technology

False. Spain has everything it takes to become a leader in chemical recycling technology:

1. A strong and consolidated plastic and chemical industry,
2. A value chain that works coherently to create a sustainable system, that has made investments in the sector and that is committed to this technology,
3. Public Administration that has shown its support for this technology by providing financial support through specific funding instruments such as the Strategic Projects for Economic Recovery and Transformation,
4. A scientific-technological sector consisting of universities, public research organisations and technology centres that are experts and world leaders in chemical recycling and its secondary technologies.

Abbreviations

BHET Bis(2-Hydroxyethyl) terephthalate

CPA Circular Plastics Alliance

GHG Greenhouse gases

PA Polyamide

PC Polycarbonate

PE Polyethylene

PERTE Strategic Project for Economic Recovery and Transformation *(in Spanish)*

PET Polyethylene terephthalate

PLA Ácido poliláctico

PMMA Polylactic acid

PP Polypropylene

GRP Glass-reinforced plastic

CFRP Carbon fibre reinforced polyester

PS Polystyrene

PU Polyurethane

EPR Extended Producer Responsibility

MSW Municipal Solid Waste

TRL Technology Readiness Level

UV Ultraviolet radiation

GLOSSARY

Ecomodulation: Tool to adjust the rates of EPR systems to a set of sustainability criteria in product design.

Enzyme: Organic molecule that acts as a catalyst for chemical reactions, accelerating the reaction rate. It is usually proteinaceous in nature and is extremely selective with the substrates or molecules on which it acts in order to obtain the relevant products.

Monomer: Chemical substance that is the smaller unit from which larger molecules (polymers) are made.

Oligomer: A molecule composed of a small number of repeated units (monomers).

Strategic Project for Economic Recovery and Transformation: Public-private collaboration figure created by Royal Decree-Law 36/2020, of 30 December.

Polymerisation: A reaction in which two or more molecules combine to form another in which structural units of the original molecules are repeated.

Polymer: A molecule (macromolecule) composed of a chain of a large number of repeated units (monomers).

Addition polymer: A polymer made by polyaddition, where the entire monomer molecule becomes part of the polymer, without loss of atoms. The chemical composition of the resulting chain is therefore equal to the sum of the chemical compositions of the monomers it is made from. Examples of this kind of polymer are PE or PP.

Condensation polymer: A polymer made by polycondensation, where part of the monomer molecule is lost when it becomes part of the polymer. Simple molecules, such as water, are normally lost. Examples of this type of polymer are PA or PET.

Plastic: Combination of one or more polymers and additives.

Dissolution recycling: Recovery process in which waste is subjected to chemical agents such as solvents, producing a solution of polymers and/or additives.

Mechanical recycling: A recovery process in which waste is subjected to a series of mechanical treatment stages (such as grinding, washing, drying, separating or melting) without significantly changing the polymer chain structure of the material, resulting in a recycled plastic raw material.

Chemical recycling: A set of technologies that break down waste plastic and other polymers from other waste flows into their basic components and transform them into valuable secondary raw materials for the production of new chemicals and plastics.

Municipal Solid Waste: Waste generated in private homes, businesses, offices and services. It also includes waste not classified as hazardous that, by nature or composition, is similar to waste produced in the aforementioned scenarios.

Legacy substance: Additives that are not currently authorised, but that have been in the past (or may no longer be authorised in the future) and which may limit the potential applications and marketing of recycled plastics.

Energy recovery: Thermal process which breaks the bonds in the polymer chains within plastic waste to produce energy. The energy obtained must be greater than the energy used to break the bonds.

Landfill: Waste disposal site for the deposit of waste on to or into the land.

Product life: The estimated lifespan of an object or product in which it successfully fulfils the function it was intended for.

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9 Annexes

Annex I: Mass Balance Certifications

There are international mass balance certifications applicable to the value chain. Initially they were developed for the biomass sector and their scope has been gradually expanded. They can now be applied to plastic waste and chemical recycling, covering the entire value chain. These certify the recycling content along the recycling chain, also differentiating between chemical recycling and energy recovery flows.

These certifications have 4 distinct phases.

Phase **1**	**Scope and start of the project.** The scope of the project is defined.
Phase **2**	**Audit.** This audit is both desk-based and face-to-face to check the system's operability.
Phase **3**	**Corrective measures.** A report is issued after the audit. This contains any non-conformities or deviations and the company has to take corrective actions.
Phase **4**	**Final certification.** The adoption of corrective actions against the non-conformities or deviations is checked and the decision on the final certification is made.

It should be noted that this certification is related to the whole value chain, so the supplier-company-customer relationship is key.

The most recognised international certifications are currently: ISCC Plus[74] , REDcert2[75] y 2BSvs[76]

74 https://www.iscc-system.org/
75 https://www.redcert.org/
76 https://www.2bsvs.org/

Annex II: Examples of funded projects on chemically recycled plastics with the participation of Spanish entities | TABLE 7

The following table gives examples of both Spanish chemical recycling funded projects and European chemical recycling funded projects involving Spanish entities.

Project	Scope	Subsidising Entity (Document No.)
BIOICEP: Bio Innovations of a Circular Economy for Plastics https://www.bioicep.eu/	European	Commission of the European Communities (870292)
BIOMAT: An Open Innovation Test Bed for Nano-Enabled Bio-Based PUR Foams and Composites https://cordis.europa.eu/project/id/953270 https://biomat-testbed.eu/	European	Commission of the European Communities (953270)
CIRCPACK: A new circular economy for the plastic packaging sector https://circpack.eu/	European	Commission of the European Communities (730423)
DECOAT: Recycling of coated and painted textile and plastic materials https://decoat.eu/	European	Commission of the European Communities (768573)
ECOXY: Bio-based recyclable, reshapable and repairable (3R) fibre-reinforced EpOXY composites for automotive and construction sectors https://cordis.europa.eu/project/id/744311 https://ecoxy.eu/	European	Commission of the European Communities (744311)
ELIOT: End of Life (EoL) for biomaterials https://project-eliot.eu/	European	Commission of the European Communities (886416)
ICAREPLAST: iCAREPLAST: Integrated Catalytic Recycling of Plastic Residues Into Added-Value Chemicals https://www.icareplast.eu/	European	Commission of the European Communities (820770)
INN-PRESME: Open INnovation ecosystem for sustainable Plant-based nano-enabled biomateRials deploymEnt for maSS MarkEt industry https://www.inn-pressme.eu/	European	Commission of the European Communities (SEP-210637309)
LIFE ECOTEX: Demonstration of polyester of footwear waste recycling into new textile products using glycolysis technology http://www.life-ecotex.eu/index.php/es/	European	Commission of the European Communities (LIFE15 ENV/ES/000658)
MIXUP: MIXed plastics biodegradation and UPcycling using microbial communities https://cordis.europa.eu/project/id/870294	European	Commission of the European Communities (870294)
MULTICYCLE: Advanced & sustainable recycling processes and value chains for plastic-based multi-materials http://multicycle-project.eu/	European	Commission of the European Communities (820695)
PLAST2bCLEANED: PLASTtics to be CLEANED by sorting and separation of plastics and subsequent recycling of polymers, bromine flame retardants and antimony trioxide https://plast2bcleaned.eu/	European	Commission of the European Communities (821087)

Project	Scope	Subsidising Entity (Document No.)
POLYNSPIRE: Demonstration of innovative technologies towards a more efficient and sustainable plastic recycling https://www.polynspire.eu/	European	Commission of the European Communities (820665)
PUReSmart: Recycling long-lasting thermoset polyurethane foam https://www.puresmart.eu/	European	Commission of the European Communities (814543)
REPLAXTIC EF-SE: Plastic upcycling for sustainable new generation batteries https://cordis.europa.eu/project/id/101028975	European	Commission of the European Communities (101028975)
SOL-REC2: Innovative digital watermarks and green solvents for the recovery and recycling of multi-layer materials https://cordis.europa.eu/project/id/101003532	European	Commission of the European Communities (101003532)
UPLIFT: sUstainable PLastIcs for the Food and drink packaging indusTry https://upliftproject.eu/	European	Commission of the European Communities (SEP-210659299)
DICKENS: Investigación y Desarrollo Integral de Composites a partir de fuEntes NaturaleS	National	CDTi (CDTIE2019-015363)
EROS: Economía ciRcular en compOSites: del sector eólico y aeronáutico a la industria cerámica y el transporte	National	AEI (RTC2019-007206-5)
FOAM2FOAM: Economía circular de espumas poliuretano vía reciclado químico	National	MINECO (RTC-2017-6755-5)
Investigación de nuevas tecnologías de reciclado y valorización de residuos plásticos complejos	National	CDTi (MIG-20211051)
RED OSIRIS: Cooperación estratégica en tecnologías para la economía circular de composites y de materiales plásticos complejos de alto valor añadido		CDTi (CER-20211009)
Enhancing circularity by using renewable monomers and sustainable Chemical strategies of polymer upcycling	National	AEI (PLEC2021- 007793)
Valorización pirolítica de residuos termoplásticos complejos no reciclables mecánicamente	National	AEI (PLEC2021-008062)
Síntesis y reciclado enzimático de polímeros furánicos biobasados	National	AEI (PLEC2021- 007690)
BIOREACT: Reciclado biológico de residuos plásticos de almidón mediante su fermentación a ácido láctico	Regional	AVI (INNEST/2021/9)
ENTOMOPLAST: Microbiomas de insectos como herramienta para la valorización de residuos plásticos de envases multicapa	Regional	AVI (INNEST/2021/334)
LISOL: Soluciones basadas en líquidos iónicos para diversificar las oportunidades de la industria vasca	Regional	Gobierno Vasco
NEOREC: Nuevos enfoques de reciclado para residuos complejos	Regional	IVACE (IMDEEA/2021/96)
Obtención de polioles verdes a partir del reciclado químico de residuos poliuretano	Regional	AVI (INNCAD/2021/84)
RECITURF: Reciclado de césped artificial mediante procesos biológicos	Regional	AVI (INNEST/2020/29)
REQUIPLAST: Reciclaje químico de residuos plásticos. Un enfoque real de la economía circular de los plásticos	Regional	IHOBE
RECIPAM: Reciclado de poliamida de alta calidad a partir de residuos de envases multicapa https://www.aimplas.es/proyectos-desarrollados/reciclado-de-poliamida-de-alta-calidad-a-partir-de-residuos-de-envases-multicapa/	Regional	AVI (INNEST00/19/097)

Annex III: Examples of leading Spanish research centres in the chemical recycling of plastics | TABLE 8

The following table shows a list of universities, technology centres and public research bodies that are leading the chemical recycling sector in Spain.

Entity
AIMPLAS[1], Technological Institute of Plastics
AINIA[2]
AITEX[3] Textile Industry Research Association
CARTIF[4]
CENER[5], National Renewable Energy Centre
CIDAUT[6], Foundation for Transport and Energy Research and Development
CIDETEC[7]
EURECAT[8]
GAIKER[9]
Institute of Catalysis and Petrochemistry9[10] (ICP-CSIC)
Institute of Chemical Process Engineering[11], University of Alicante
Institute of Chemical Technology (ITQ)[12], joint research centre of the Polytechnic University of Valencia (UPV) and the Spanish National Research Council (CSIC)
ITAINNOVA[13], Technological Institute of Aragon
TECNALIA[14]
Department of Inorganic Chemistry[15] University of Alicante
Department[16] of Earth Sciences and Condensed Matter Physics, University of Cantabria
The SUPREN group[17] of the Department of Chemical Engineering and Environment of the Bilbao School of Engineering, University of the Basque Country
Chemical and Environmental Engineering Group[18] Rey Juan Carlos University
The Materials Technology and Sustainability Research Group (MATS)[19] of the Department of Chemical Engineering of the University of Valencia

1 https://www.aimplas.es/
2 https://www.ainia.es
3 https://www.aitex.es/
4 www.cartif.es
5 www.cener.com
6 https://www.cidaut.es/
7 https://www.cidetec.es/
8 https://eurecat.org/es/
9 http://www.gaiker.es/default.aspx
10 https://icp.csic.es/es/
11 https://iipq.ua.es/
12 https://itq.upv-csic.es/
13 www.itainnova.es
14 https://www.tecnalia.com/
15 https://dqino.ua.es/es/
16 https://web.unican.es/departamentos/citimac
17 https://www.ehu.eus/es/web/supren/hasiera
18 http://www.giqa.es/
19 https://www.uv.es/uvweb/departamento-ingenieria-quimica/es/investigacion/grupos-investigacion/grupo-investigacion-tecnologia-materiales-sostenibilidad-mats-/presentacion- 1286186264647.html

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PLASTICS EUROPE
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Spanish Chemical Industry Federation

Report conducted by: AIMPLAS

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