Design for circular economy

Research analysis based on patent literature review

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TABLE OF CONTENTS

Executive Summary

Plastics have become ubiquitous, and are valued for their convenience, performance, durability and low cost. The production and use of plastics have grown exponentially since 1950 and is projected to further increase in the next decades. However, the use of plastics result in waste, which are mostly non-degradable. When improperly disposed, plastic waste can litter the environment and ocean, thereby posing a threat for aquatic life and biodiversity. Under the context of the European green deal and the Circular Economy plan, the EU has adopted various legislations such as the single use plastic directive or the packaging directive that aim to reduce the use of plastics and by consequence plastic waste, and to promote the **reuse or recycling of plastics**.

The issue of plastic waste can be tackled through recycling. The efficiency of recycling depends on one hand on the ability to properly **collect and sort plastics waste**, and on the other hand on the **type of plastics** (family, composition, present of additives, etc). The recycling of plastic waste can be improved by applying **design for circularity** principles. Design for Circularity is an eco-design strategy which provides an approach to design more environmentally friendly products, by addressing the **whole lifecycle of a product** such as the **choice of raw materials and additives**, the **polymerisation** process, the **assembly** into the final shape for the application, product marking & labelling and the disposal.

This report includes an overall analysis of the patent landscape in the field of design for circularity of plastics. Specifically, the following topics were analysed using a combination of keywords and IPC/CPC codes: "**preparation of plastics"** and "**recovery of plastics".** The analysis shows that research activity on both the preparation and recycling of plastics has increased during the last decade, and especially in the years 2019 – 2022.

The countries with the highest patent activities in both the domain of polymer preparation and recycling are China, Japan and the United States, with China displaying a patent activity 2-6 times superior to Japan and the US. Europe is statistically behind with often no representation in the top 5 in the context of patent activity. When looking at the industrial activity, Japan is the leader, followed by the US. Belgium is lagging in this race based on patent activity, never making it into the top 20. When looking at the industrial players, they are distributed across diverse industries (electronics, consumer, packaging, chemical) suggesting the sustainability of plastics is an important topic.

The patent activity in the design of plastics for circularity confirm that there is a global interest in making plastics more sustainable with the goal of eliminating/reducing pollution caused by the latter, and hence contribute to the preservation of our environment.

With the increasing laws being adopted around plastics and the plastic taxes who will most probably keep increasing, we anticipate the number of patents will keep increasing in the future as companies work on making their plastics more sustainable.

1. General introduction

Plastics gained popularity due to their relatively light weight nature, easy synthesis and very diverse properties which can be tailored to meet various applications needs. Plastics are used in various sectors; food (bottles, packaging, appliances), automotive (car parts), agriculture (films), etc. The production of plastic has grown exponentially from 1.5 million tonnes in 1950 to 359 million tonnes in 2018 worldwide and is projected to triple by 2060 according to the OECD[1]. About 40% of plastics produced in the EU is destined for packaging, which generates plastic waste, which when not properly managed, poses a threat to our environment. The European green deal has set as one of its targets the protection of the environment and oceans, and plastics waste constitutes one of the targets due to their negative impact on ocean biodiversity.

Presently, plastic waste are tackled in three main ways: incineration, landfilling and recycling. The trade association, Plastics Europe, estimates that only about 35% of the plastics waste produced is effectively recycled.[2] Various actions have been taken at the EU level to limit plastic waste and increase the recycling, such as the publication of the single use plastic Directive 2019/904 to limit the impact of certain plastic products (food containers, drinking straws, balloons) on the environment.[3] The EU has also set ambitious targets in its packaging Directive aiming to increase the percentage of recycled plastic from 25% currently to 50% by 2025 and 55% by 2030.[4] In order to achieve the EU circular economy ambitions, plastics have to be made more sustainable. This can be achieved through the design for circularity.

Design for Circularity is an eco-design strategy which provides an approach to design more environmentally friendly products. It addresses the whole lifecycle of a product that is: from the choice of raw materials and formulation additives, the polymerisation process, the assembly into the final shape for the application, product marking & labelling and the disposal or recycling at the end of the product utilisation cycle. The recycling of the product allows to recover valuable resources, thus reducing the use of virgin raw materials and closing the loop.

This report aims to provide a trend analysis on the innovations carried out in the design of plastics for circular economy. The report will be divided into two main parts, the first part will focus on the technologies for the preparation of circular plastics (e.g. polymerization processes, shaping techniques). The second part will focus on recovery/recycling of plastics (e.g. recovery of waste material, sorting techniques).

The analysis is performed through a review of the (published) patent trends in this field using the patent database, “Orbit intelligence”[5].

[1] OECD=Organisation for Economic Co-operation and Development
[2] https://plasticseurope.org/knowledge-hub/chemical-recycling-in-brief.
[3] EU Directive 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.
[4] 2018/852/EC amending Directive 94/62/EC.
[5] https://www.orbit.com/

2. State of the art

The number of plastics produced and used has drastically increased, and with that the amount of plastic waste. Most plastics are produced from fossil feedstock, which are non-renewable, hence plastic waste that is not recycled contributes to the loss of resources. Achieving a circular economy therefore requires plastics to be sustainable. Circularity aims to ensure that the highest possible recycling of a material can be achieved. The final recyclability of plastic is determined by multiple parameters, such as the family of the polymer. Plastics from the polyesters or polycarbonates family can be depolymerized to recover the monomers in contrast to polyolefins which can only be mechanically recycled or pyrolyzed into oils. Also, the presence of permanent reticulation in the material (epoxy resins) hinders the possibility to recycle the polymer.

The design of the plastic material (monolayer, multilayer, composite (including metals, paper, clay)) is also very important. Multilayer films made from a mix of polymer families are often difficult to separate, and when recycled, result in a plastic with different properties in comparison to the virgin material, thus impacting their ability to be reused for the same application. Multilayer materials composed of a mix of plastic and metal films are limited only to chemical recycling. To improve the circularity of multilayer films, the following actions can be taken; (i) designing all the layers from the same family of polymer and/or (ii) ensure that the layers can be easily separated.

The recycling process also relies on the adequate sorting of materials, they need to be properly labelled to ensure they are placed in the right garbage bin. Therefore, to have an efficient recycling process, the product needs to have been designed following certain rules, which must be tailored to each product class due to the functional differences and formulation.

Before deep diving further, it is important to define recycling. The waste framework directive defines recycling as any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purpose. A distinction is made between two types of waste; the preconsumer waste (i.e. material separated from the waste stream during the production process) and the post-consumer waste (i.e. produced by the end-consumer of the material stream).[6] There are three main categories of recycling; mechanical recycling, chemical recycling and energy recycling.

Mechanical recycling involves the mechanical repurposing of plastics through processes including grinding, granulation and compounding. This often results in granules which can be transformed into new products. A distinction is often made between two types of mechanical recycling, the bottle-to-bottle closed loop recycling and the recycling into lower value plastics.

Chemical recycling involves the thermal treatment of plastics such as pyrolysis and gasification, to produced oil (Naptha) or syngas which can be used to prepare new monomers. Chemical recycling also includes the chemical treatment of plastics, also known as depolymerization, which is a process by which the polymers are broken down into their monomer constituents. Not all polymers are equally suited for chemical recycling, for example the chemical recycling of PET results in organic acids which are corrosive and destroy the reactors.

Energy recycling consist of producing thermal or electrical energy through incineration. This category would not be tackled in this technology watch as it does not allow to recover raw materials.

[6] World packaging organization, a global recommendation for circular packaging design, 2020.

For this technology watch, we have chosen to focus on the most common plastics wastes. According to the OECD's global plastics outlook[7] about 40% of plastic waste comes from packaging alone, with the top contributors being flexible and rigid films used in packaging (polyethylene (PE), polypropylene (PP)), bottles (polyethylene terephthalate (PET)) and trays and cups (polystyrene (PS)). The above plastics can be recycled; however the efficiency of the recycling is often limited by the following factors: combination of plastic and other materials (metals, paper), mixture of different polymers, use of pigments, contamination by secondary materials (coatings and glues) and packaging containing components of <2cm in sizes. In the following sections, we will discuss the patent activity in the technological fields of the synthesis design and handling (e.g. sorting) of the above plastic materials in the context of a circular economy.

[7] www.oecd-ilibrary.org; Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options

3. Search strategy and datasets

To explore the patent landscape related to the design of plastics for circularity, the patent search database, Orbit Intelligence, was used. Every dataset was parametrized to consider only patents still within their priority date (within the 20 years' timeframe), hence only patents with a 1st application date starting from the 1st of January 2003 were considered. Note that as patents usually are published 18 months after application, the data of calendar years 2022 and 2023 are not yet up to date.

First, a large dataset was created by searching the terms (polymer+ or film+ or plastic+) appearing in the title, abstract or claims which resulted in 5.586.049 patent families. Refining was carried out by adding the keywords (recycle+ or waste+ or recover+) to make the dataset more relevant for this technology watch, which resulted in 388.346 patents. To further refine the dataset, specific IPC and CPC codes were used to identify the relevant patent families in the field of recycling/recovery of plastic waste and create the datasets analysed in this report (**Figure 1**).

Regarding the **preparation of recyclable plastics**, a dataset was created using the IPC code B29B which focuses on the preparation or pretreatment of material to be shaped; making granules or preforms; recovery of plastics or other constituents of waste material containing plastics, and the code B32B27, which focuses on layered products essentially comprising synthetic resin. This resulted in a total of **26.691 patent families**.

Two subtopics of this field were further analysed in this field of preparation of recyclable plastics. "preparation of polyolefin layered products" and the "use of recycled feedstock in plastic materials". As the main type of plastics that contribute to plastic waste are from the family of polyolefins[8] (PP, LDPE, HDPE), the IPC code B32B27/32 was selected, which focuses on the preparation of layered products comprising polyolefins . The use of recycled feedstock for the synthesis of new materials was explored using CPC code Y02P 20/143. This is an important aspect of circularity as it ensures raw materials recovered are reused, thus closing the loop.

For the analysis of **recovery of plastics using recycling technologies**, a more focused dataset was created using the combination of IPC code C08J-011, which focuses on the recovery or working-up of waste materials; polymerization processes involving purification or recycling of waste polymers or their depolymerisation, IPC code Y02W-30/00 which focuses on plastic and rubber recycling and IPC code B09B-3/70, destroying of solid waste or transforming solid waste into something useful or harmless by chemical treatment. This resulted in a dataset of **5.943 patent families**. The topic was further explored using the IPC codes B07C-5/00 focusing on the sorting according to a characteristic or feature of the articles or material being sorted, e.g. by control effected by devices which detect or measure such characteristic or features which gave 16 patent families.

[8] www.oecd-ilibrary.org; Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options

Chapter	Search results	IPC/CPC code	Definition
4.1 Analysis of patents relating to the preparation of recyclable plastics	**26.691 Patent families**	**B29B**	Preparation or pretreatment of the material to be shaped; making granules or preforms; recovery of plastics or other constituents of waste material containing plastics.
		B32B 27	Layered products essentially comprising synthetic resin
		C08 **C08J 011**	Organic macromolecular compounds ; their preparation or chemical working up; compositions based thereon Recovery or working up of waste materials
4.2 Preparation of polyolefin layered products		**B32B 27/32**	Layered products essentially comprising synthetic resin, comprising polyolefins
4.3 Recycled plastic feedstocks and their incorporation into new plastics		**Y02P 20/143**	Technologies relating to chemical industry, the feedstock being recycled material, e.g. plastics
5.1 Analysis of patents relating to the recycling or recovery of plastics	**5.943 patent families**	**C08J 011**	Recovery or working up of waste materials
		Y02W-30/00	Technologies for solid waste management
		B09B-3/70	Destroying solid waste or transforming solid waste into something useful or harmless
5.2 Sorting of plastics		**B07C-5/00**	Sorting according to a characteristic or feature of the articles or material being sorted, e.g. by control effected by devices which detect or measure such characteristic or feature; Sorting by manually actuated devices, e.g. switches

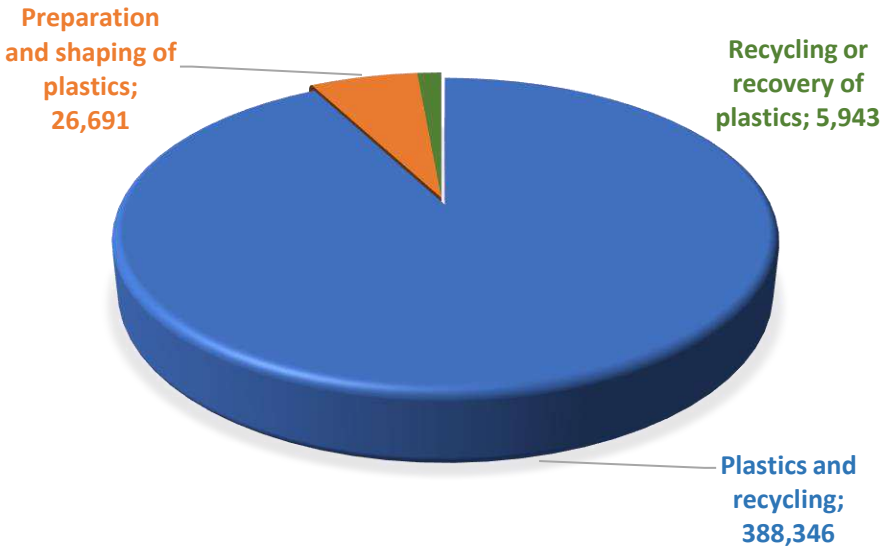

Figure 1. Patent family distribution in the field of plastics preparation and recycling. The numbers represent the patent families for the years 2003-2023.

4. Analysis of patents relating to the preparation of recyclable plastics

4.1 Overall analysis of the patent dataset

Using the dataset presented in section 3, a general overview and analysis of the field of plastics preparation was realized. Firstly, the patent activity between year 2003 to 2023 was analysed by plotting the number of patents families against the first year of publication. The results of the analysis are presented in **Figure 2**.

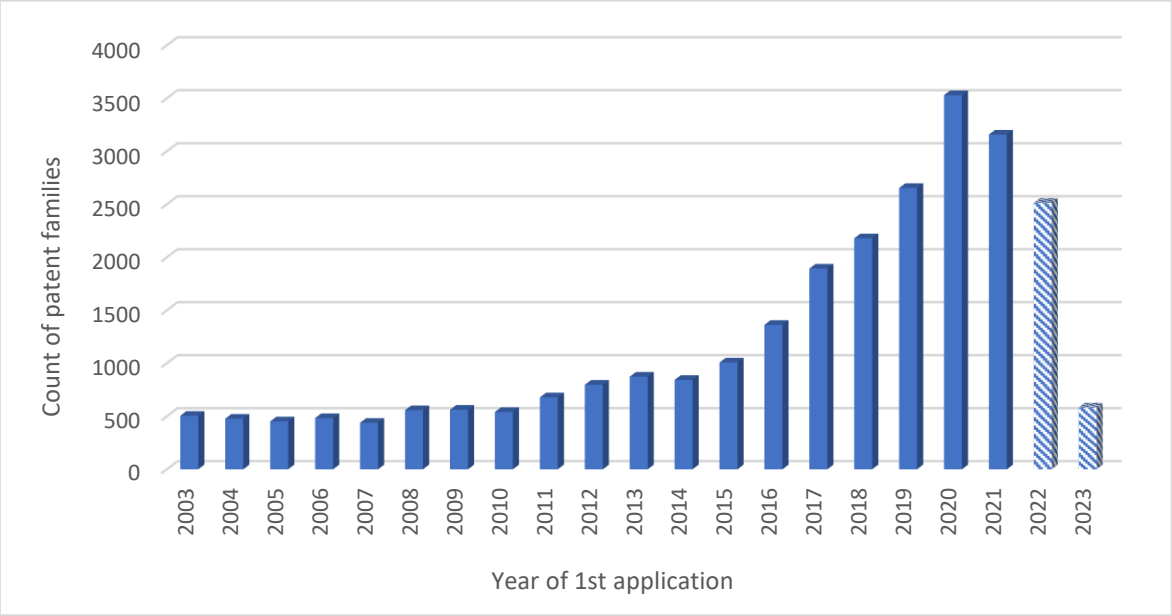

Figure 2. Evolution of patent application from 2003-2023 in the field of polymer preparation for recycling.

The number of applications in the field of polymer preparation for recycling remained relatively stable from 2003 until 2010, then we observe a gradual increase in the number of patent applications which reached a peak in the year 2020 during the Covid pandemic. When we analyze the distribution of the patent protection across the world, we see that China has the highest number of alive patents protected (**Figures 3 and 4**).

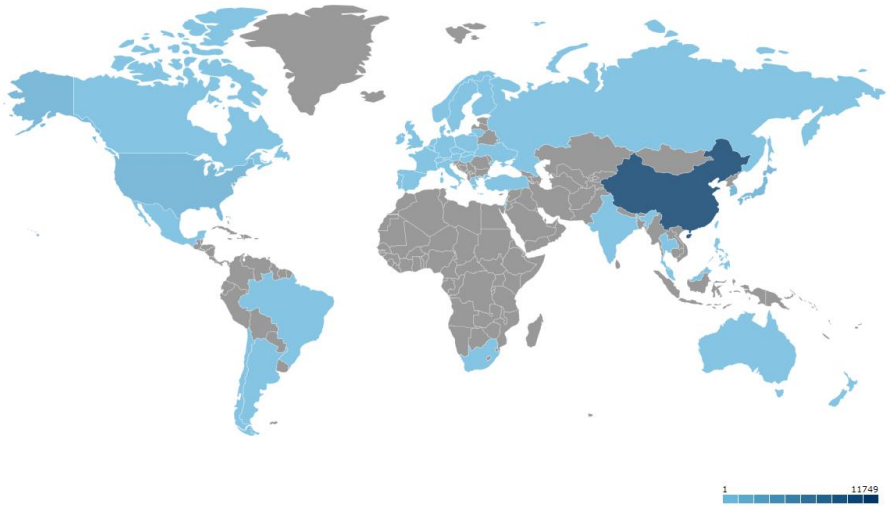

Figure 3. Distribution of patent protection in the field of polymer preparation across the globe.

China accounts for the highest amount of patent application with approximately 5 times the count of patent families in comparison to the USA, which is closely followed by Japan (**Figure 4**). The Asian continent is leading with a total of 5 countries in the top 10. Two European countries also appear in the top 10, Britain and Germany, although the number of patent applications remain relatively small in comparison to China. Belgium shows a reduced activity, appearing in 22nd place with 322 patent families published in this field.

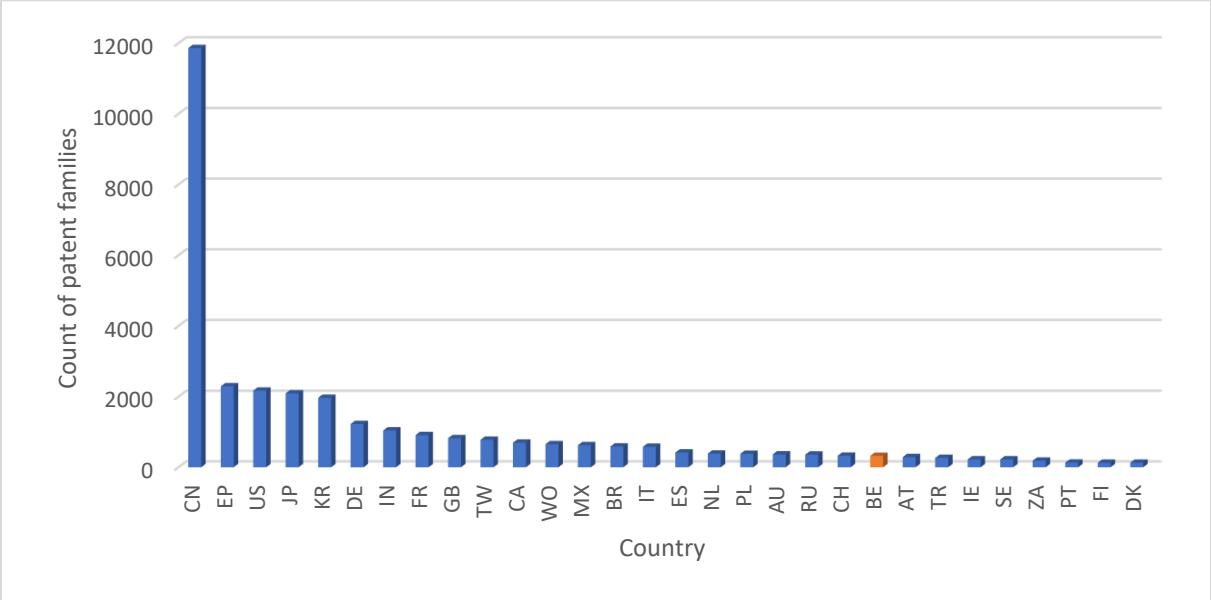

Figure 4. Patents applications per country in the field of polymer preparation

Figure 5, shows the evolution of the count of patent applications for the top 5 countries, China, US, Japan, Korea and India.

We observe a steady count of patent applications with minor fluctuations for all the countries through 2003 – 2010. From 2011, a significant growth in the count of patent families is observed for China, with a doubling of the value observe in 2011 by 2016. China's activity continued to grow, reaching a peak of approx. 3000 patent families in 2020. The patent evolution of China shown in **Figure 5** possesses the same allure as the global patent evolution shown in **Figure 2**, implying that China is the greatest contributor with regards to technology protection as further illustrated in **Figure 4**.

Figure 6, shows the analysis of the top players in the field of polymer preparation. Japan is clearly dominating, with the company Dai Nippon printing in first place, and an additional 4 players in the top 10 (Toray industries, Nitto Denko, Toyobo and Mitsubishi chemical). The US takes the second position with 3 players, Dow Global Technologies, Eastman chemical and Procter and Gamble. Only one European player makes the list, Borealis as well as a South Korean company LG chemical. Although China showed the highest count of patents families in the domain (**Figure 4**), it is currently not represented in the top 10 market players. It can therefore be assumed that the significant activity in patent published in China are distributed amongst several actors.

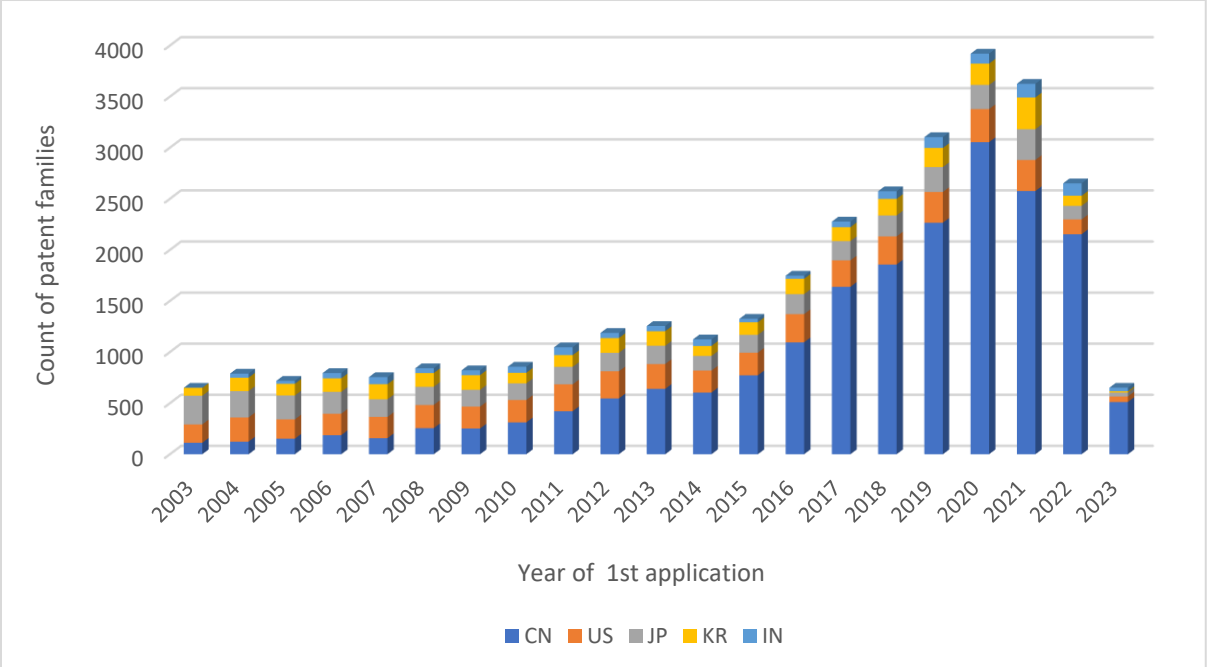

Figure 5. Evolution of patent applications through the year 2003 – 2023 for the top 5 countries (China, USA, Japan, South Korea and India).(Published data of 2022 and 2023 is not yet completely up to date)

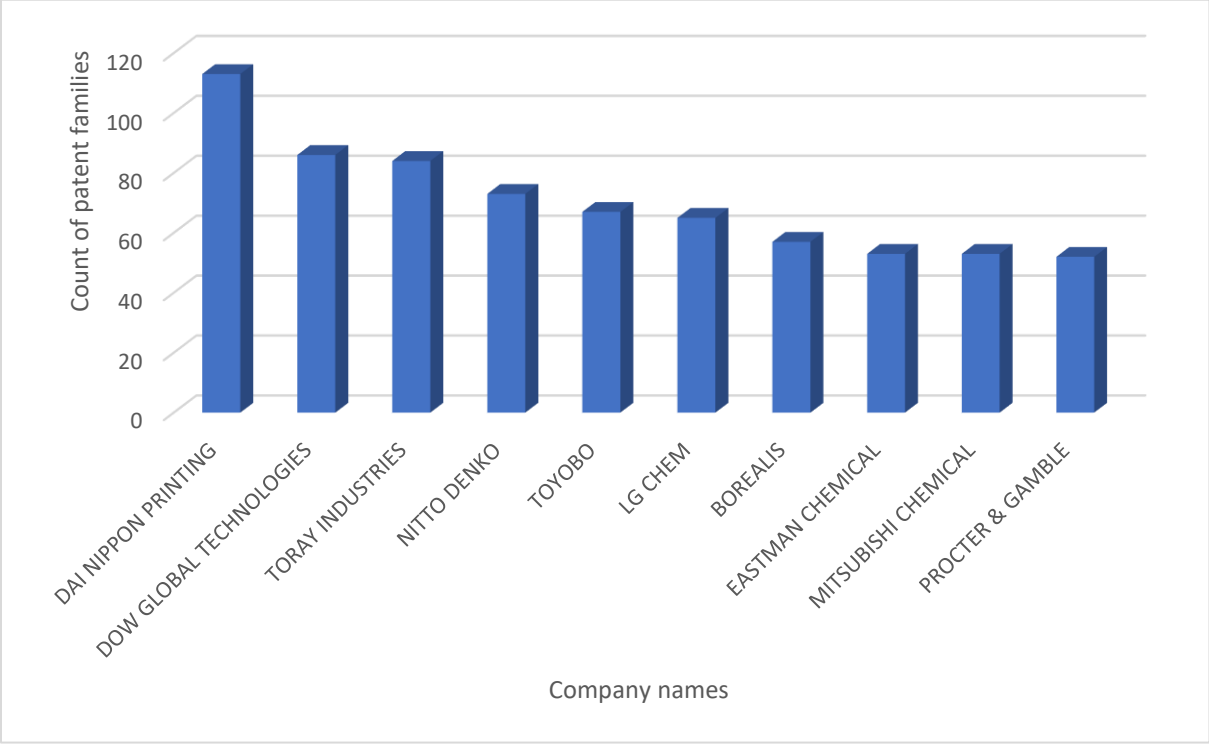

Figure 6. Top 10 players in the field of polymer preparation.

Figure 7, shows an overview of the distribution of the top 10 IPC/CPC codes used in this dataset in the field of the preparation of recyclable plastics.

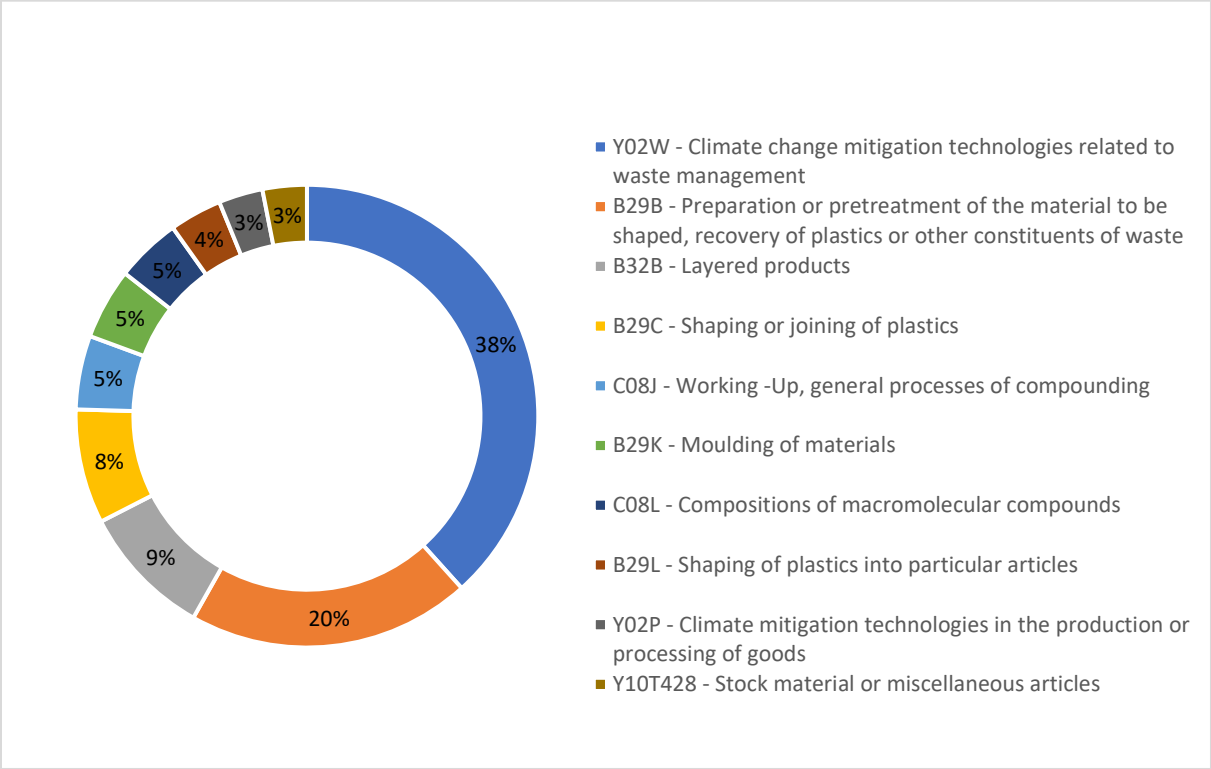

Figure 7. Top 10 IPC/CPC codes referenced in the patents in the field of plastics preparation.

4.2 Preparation of polyolefin layered products.

An analysis of the field of layered olefins was performed using the specific IPC code B32B27/32 as described in section 3. **Figure 8,** shows the leading countries in the field of olefin layered products. A similar trend is observed as in **Figure 4**, with China taking the 1st position, followed by the US, Japan, Korea. Europe is better represented with 3 countries, Germany, France and Great Britain in the top 10. Belgium appears in 24th position with 55 patent families in this field.

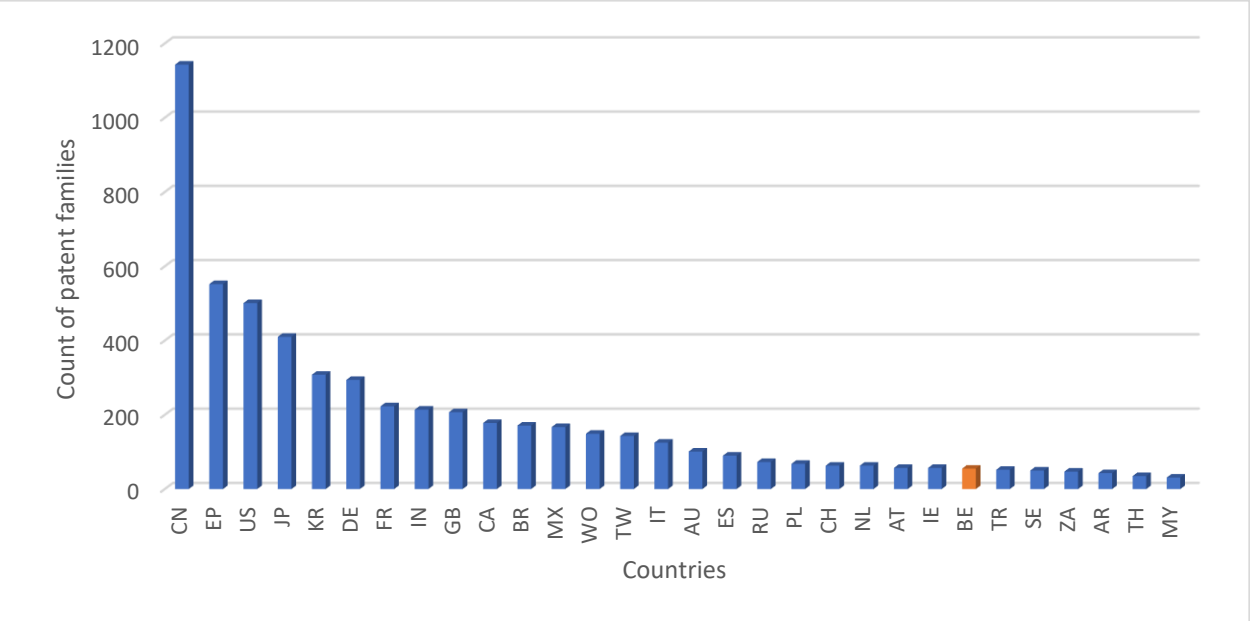

Figure 8. Count of patent families by country in the field of layered polyolefins. Top 30 countries displayed.

Figure 99, represents the top 10 players in the field of layered polyolefins.

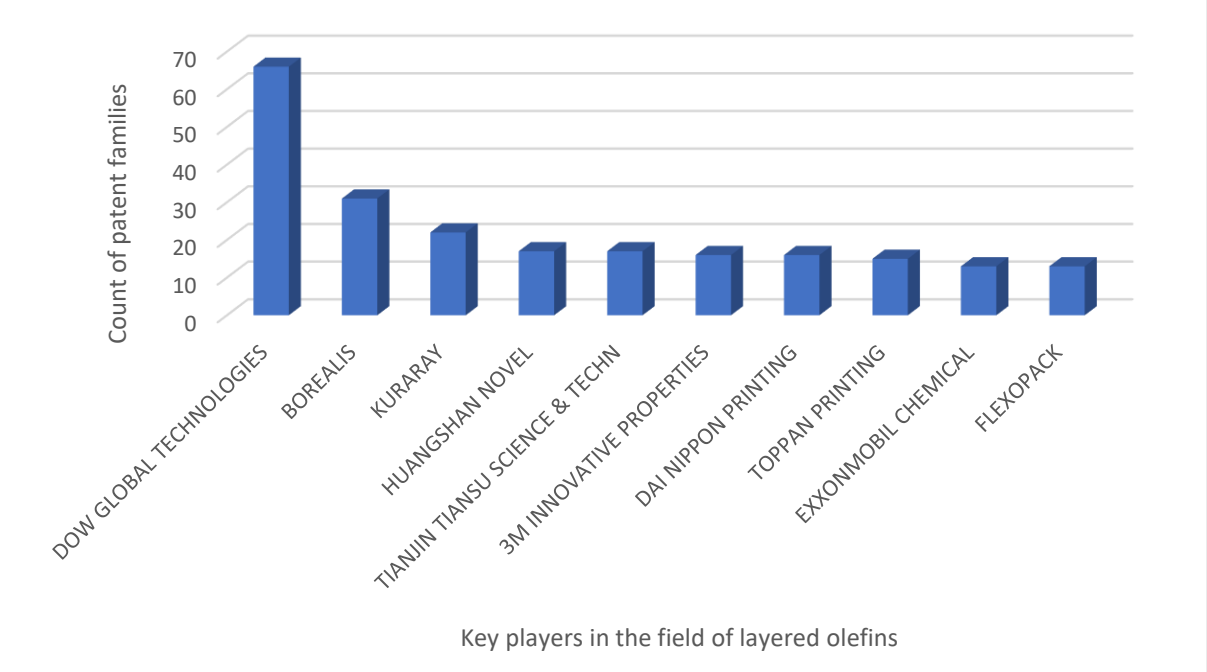

Figure 9. Key players in the field of layered polyolefins.

The US is leading with the Dow Global Technologies in 1st place and two other companies in the top 10 (3M and ExxonMobil). Japan is represented by 3 actors (Kuraray, Dai Nippon and Toppan) and the EU by 2 actors Borealis in 2nd position and the Greek company Flexopack. China is represented by only two players, Huangshan Novel and the Tianjin Tiansu science and technology university. The high patent activity of China is not reflected in this figure suggesting that several players are participating in the technology.

Relevant patents in the field of "Preparation of polyolefin layered products".

Below, we have selected some examples of patented technologies we would like to highlight.

- *Preparation of a recyclable multilayer olefin film.*

Application number: EP3040199
Assignee: Dow Global Technologies
Priority date: 2014-12-31
Title: Self-recyclable barrier packaging
Comment: The film consists of at least one polyolefin layer comprising 60-94% ethylene homopolymer/ethylene copolymer/ PP copolymer, 0-35% of a functional polymer component and 1 – 35% of a compatilizer (anhydride or carboxylic acid functionalized ethylene/alpha olefin with a melt viscosity of 200000 cP at 177°C. At least one tie layer comprising maleic -anhydride grafted polymer with a melt index of less than 50dg/min and at least a polar layer comprising a polar polymer (containing a heteroatom O, N,P or S). The film is then obtained through the classic methods (extrusion, blown film or cast-film process). The film thus prepared can be converted into flakes, and then pellets without using any compartibilizers.[9]

- *Preparation of multi-layered films consisting of only one family of polymer*.

Application number: WO2019172932
Assignee: Colgate Palmolive
Priority date: 2018-03-09
Title: Recyclable plastic package
Comment: Design of a flexible (tooth paste) package. The multi-layered material was achieved by using polyethylene film of varying densities. The outermost and innermost layer are made of high density polyethylene (HDPE) and only the bonding layer of low linear density polyethylene. The layered material prepared has a final density within the recycling range of HDPE (>0;95 g/cm^3).[10]

[9] EP3040199, Dow Global Technologies, self recyclable barrier packaging
[10] 2018WO-US21751, Colgate Palmolive, recyclable plastic package.

4.3 Recycled plastic feedstock and their incorporation into new plastics

Achieving circularity of plastics, relies on the capability to reuse recycled materials as feedstock for the synthesis of new materials. An analysis of the use of recycled feedstock for the preparation of new materials was explored using IPC code Y02P 20/143. **Figure 10** shows the patent activity of the top 30 countries in the field. The trend observed previously is reversed, the US is leading, followed by Japan, Korea, China appears in 4th position with almost half the amount of patents with respect to the US. Europe is less represented, with only Germany in the top 10. Belgium shows a low activity, appearing in 22nd position.

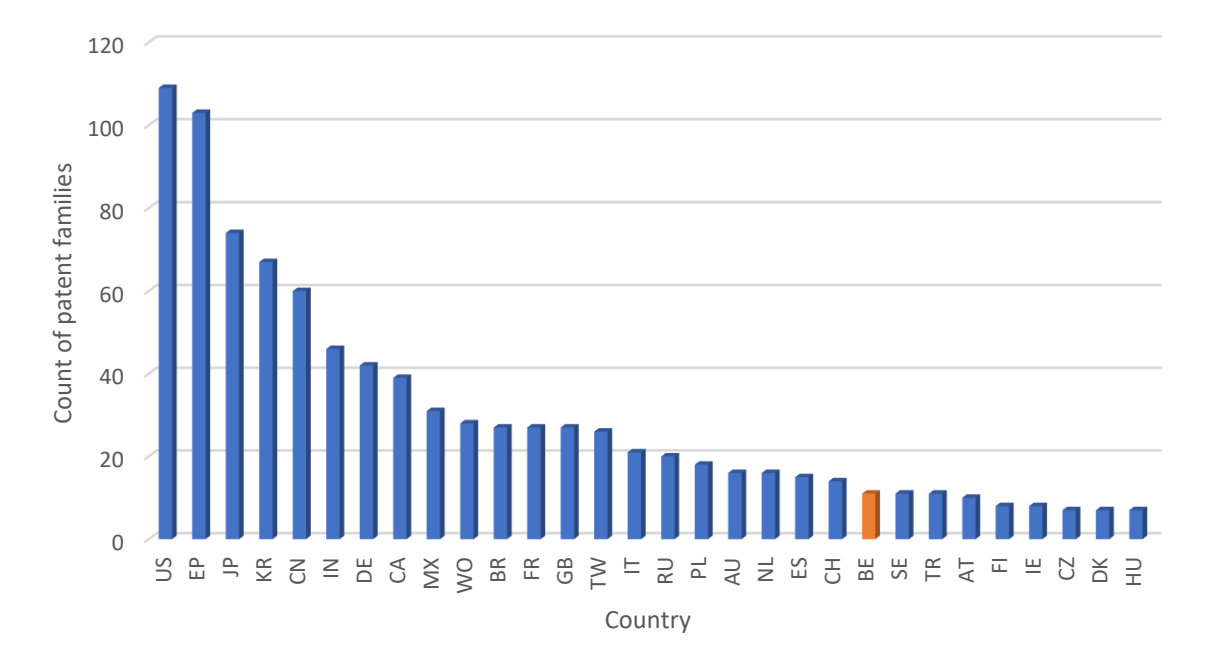

Figure 10.Count of patent families per country on the preparation of plastics with recycled feedstock.

Figure 11 shows the top 10 players in the field of polymer preparation using recycled feedstock. The US has 2 players in the top 10, the Eastman Chemical company in 1st place and UOP in 4th place. Japan is well represented with a total of 4 players (Konica Minolta, Nippon steel, Nippon steel & Sumitomo metal and Sharp). China is represented by one player (Henan Dizhilyu environmental protection technology Co., Ltd). There is one player from Mexico, Vanguardia en transf. Europe is not represented in the top 10 players. The top 10 players are distributed across different industrial sectors: petroleum, steel, chemical, electronics and plastic films. This shows that the sustainability of plastics has become important to all those who use them, irrespective of the sector of activity.

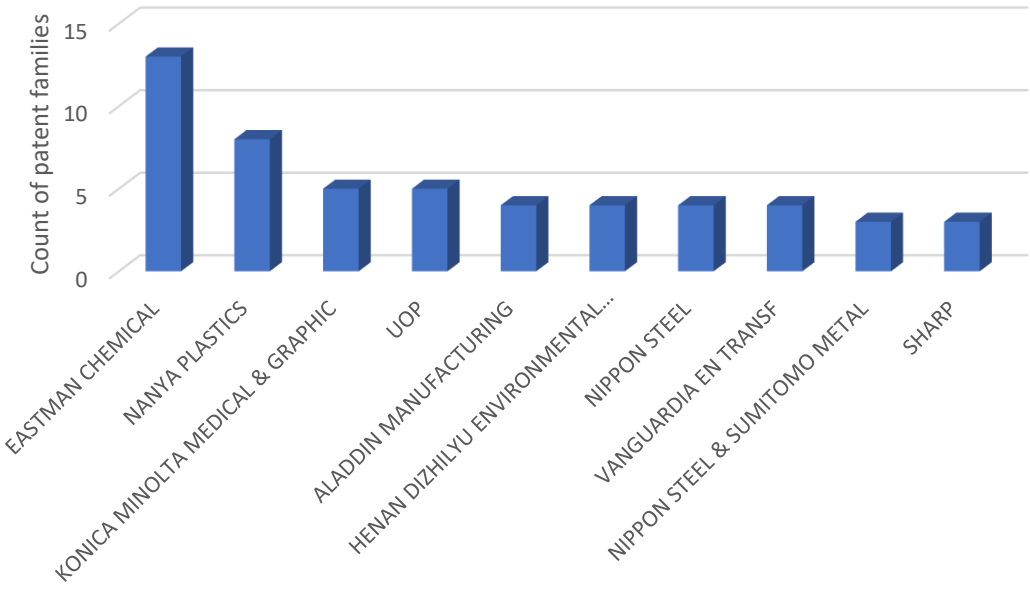

Figure 11. Top 10 players in the field of the preparation of plastics with recycled feedstocks.

The use of recycled feedstock often depends on the purity as this has an impact on the final application. Other important considerations are the properties of the recycled polymer (melt flow index, stiffness). For the recycled plastics to be used in place of a virgin plastics, it needs to possess equivalent properties. Progress has been made on the use of plastic recyclate (post-consumer recycling) for the synthesis of films such as polyethylene[11] [12] [13],polypropylene and PET[14]. Below, we have selected some examples of patented technologies we would like to highlight.

Relevant patents in the field of "Preparation of plastic with recycled feedstock".

- *Preparation of a polyolefin comprising recycled plastic (polypropylene or polyethylene) from post-consumer or post industrial waste.*

Application number: WO2020263739
Assignee: Dow Global technologies
Priority date: 2019-06-28
Title: Coupled post-consumer recycled polypropylene and process to provide same.
Comment: The process includes (i) providing a post-consumer recycled polypropylene (PCR-PP) having a melt flow rate (MFR I2) equal to, or greater than, 7.0 g/10 min; (ii) adding a 4,4'-oxydibenzenesulfonyl azide (DPO-BSA) to the PCR-PP; (iii) melt blending the PCR-PP with the DPO-BSA; and (iv) forming a DPO-BSA coupled PCR-PP having a melt flow rate (MFR I2) equal to, or less than, 5 g/10 min. The process provides PCR-PP comprising at least 70 wt% propylene-based polymer; and post-consumer recycled ethylene-based polymer (PCR-PE).

[11] KR20230057046A , PPlus, PCr post-consumer recycled polyethylene film.
[12] EP4119345A1 , Trioworld Ombree Danjou, multilayer film comprising recycled polyethylene useful as silage film.
[13] WO2023117419, Borealis, multilayer film structure comprising multimodal ethylene copolymers and recycled LDPE fo collation-shrink films.
[14] WO2020263739, Dow Global technologies, coupled post-consumer recycled polypropylene and process to provide same.

- *Process and method for compatibilization of multi-component polymer mixtures and compositions by degradation.*
  Application number: MX2017016963
  Assignee: VANGUARDIA EN TRANSF
  Priority date: 2017-12-20
  Title: Process and method for compatibilization of multi-component polymer mixtures and compositions by degradation.
  Comment: A mixture of plastic waste and an oxy-degrading additive (1-5%) is placed into an extruder and heated at a temperature of 350-400°C for about 2 minutes. The fluid obtained is then transferred to a second extruder heated at 200-300°C for about 2 minutes. The resulting product is filtered on a 0.1mm mesh to remove contaminants and produce a compatibilized molten plastic.[15]

[15] MX2017016963, VANGUARDIA EN TRANSF, process and method for compatibilization of multi-component polymer mixtures and compositions by degradation.

5. Analysis of patents relating to the recycling or recovery of plastics

5.1 Overall analysis of the patent dataset

Similar to the section 4, a general overview and analysis of the field of plastics recovery and recycling was realized using the dataset presented in section 3. Firstly, the patent activity between year 2003 to 2023 was analysed by plotting the number of patents families against the first year of application. The results of the analysis are presented in **Figure 12**.

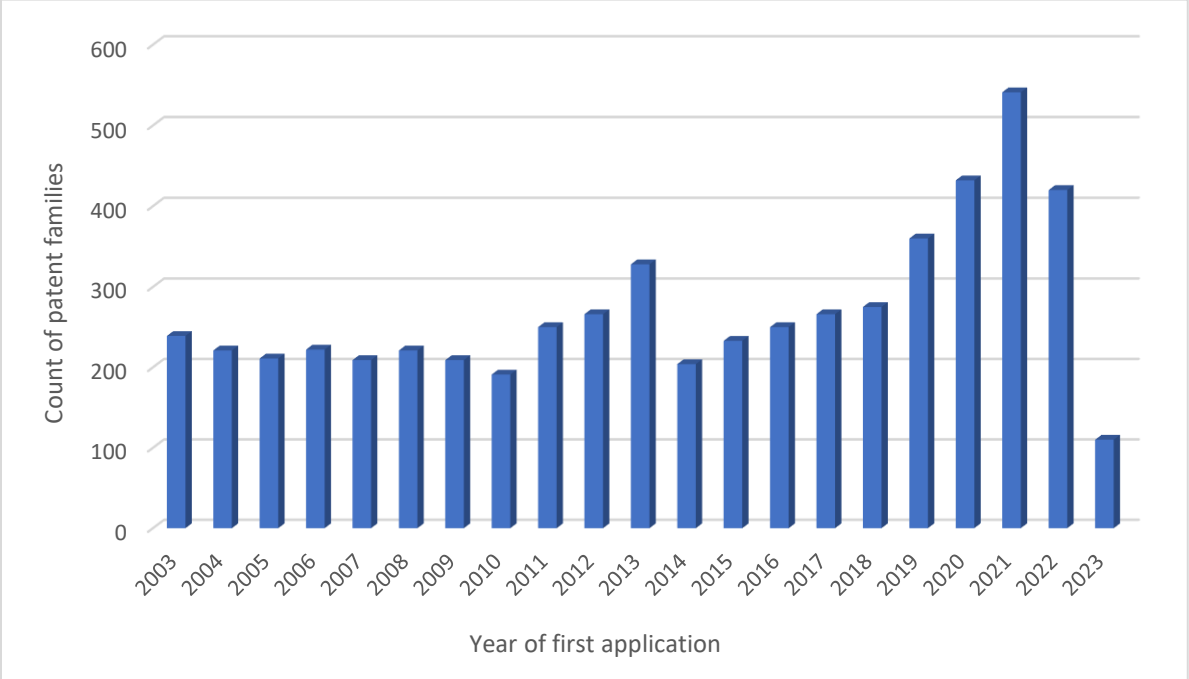

Figure 12. Evolution of patent application in the field off polymer recycling and recovery from 2003 to 2023.

The above figure, shows a certain stability in the number of patents from 2003 to 2010, followed by a gradual increase from 2010 to 2013. In 2014, a sharp decrease is observed with values similar to 2010. The number of patents continues to grow from 2015, reaching a peak in 2021 after which a slight decrease is observed. The increase in the number of patents throughout the years is less marked in comparison to what was observed for preparation of polymers (**Figure 2**).

Similar to the field of polymer preparation, China tops the podium, with the highest number of patent applications in the field, however Japan takes the 2nd position beating the US which now comes in 3rd position followed by Korea and India. The difference in the count of patents between China and Japan/US is less marked in comparison to what was observed for polymer preparation, thus implying a higher competition. Europe is lagging in the field of recycling, with none of the countries making it to the top 10. Belgium appears in 22nd position **(Figure 13).**

Figure 14, shows the evolution of the count of patent families for the top 5 countries, China, Japan, US, Korea and India. From the figure, we can observe that Japan was leading in the field of polymer recycling until the year 2010 when the US briefly took the lead before ceding to China in 2011, which has remained the top actor since then. We observe an overall increase in the count of patent families for all countries from 2011 to 2021, which is connected to the increased awareness on the need for the sustainability of plastics.

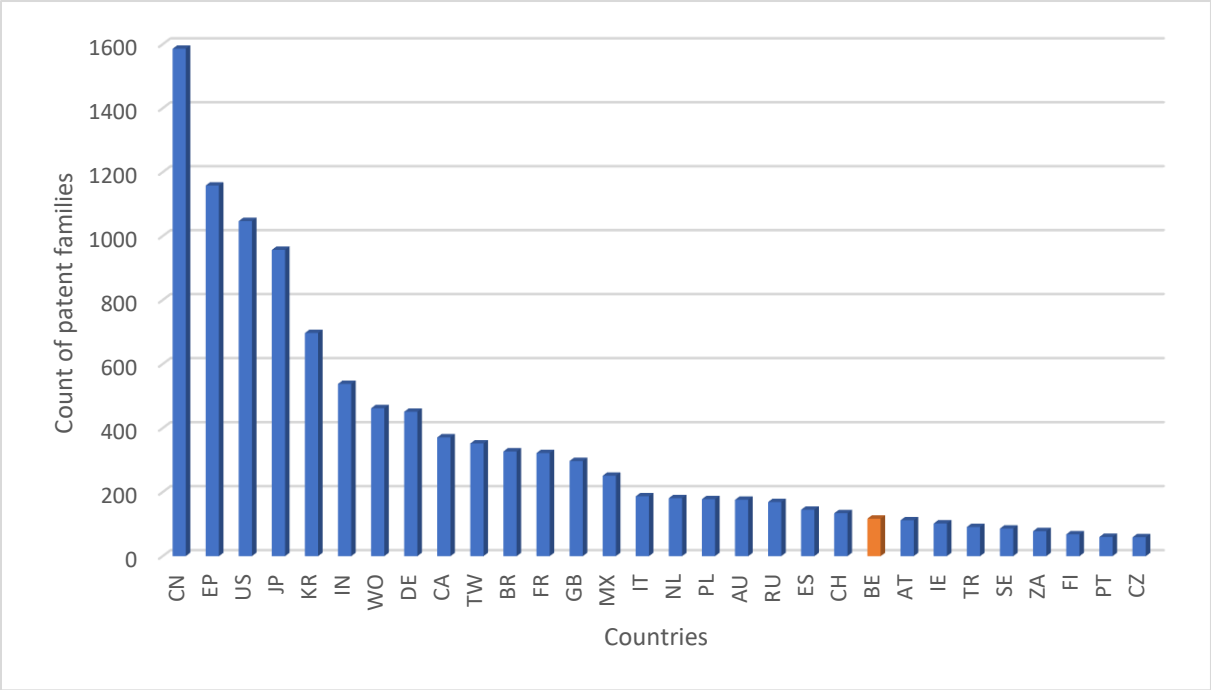

Figure 13. Number of patent applications per country in polymer recovery/recycling. Top 30 countries shown.

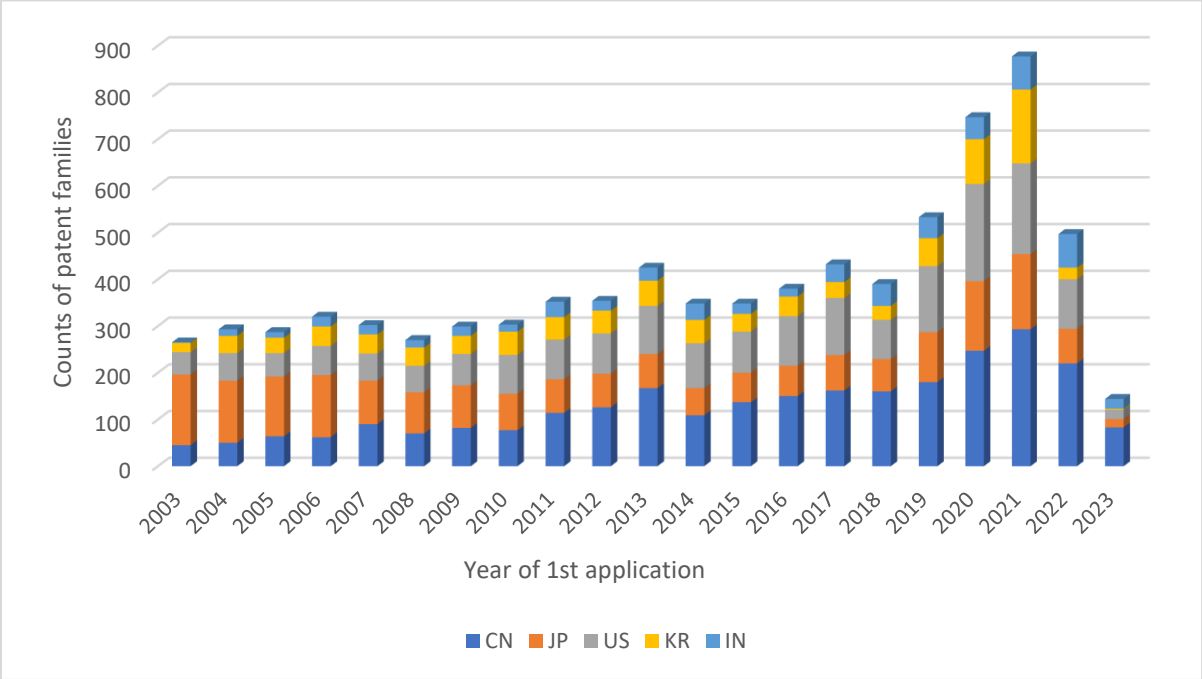

Figure 14.Evolution of patent applications for the top five countries through 2003 to 2023.

Figure 15, shows the count of patent families for the top 10 actors in polymer recycling. The following companies (Eastman Chemical, LG Chem, Borealis, Procter and Gamble) that were listed as the top actors in field of polymer preparation, are also amongst the top actors in the field of polymer recycling. The US takes the first place with Eastman chemical, followed by the Japanese (Panasonic electronic works). Although the patent activities of Japan have decreased in the last decade, it remains the leader in the field with 3 of its companies in the top 10 (Unicharm, JFE steel and Panasonic electronic works). China is less represented considering its high count of patent families with only 1 company (China Petroleum & chemical) in the top 10. Two countries that were not in the top 5 of patent counts are also represented, France (Carbios) and Taiwan (Nan Ya plastics). With 2 companies (Borealis and Carbios) in the top 10, Europe is slightly more represented.

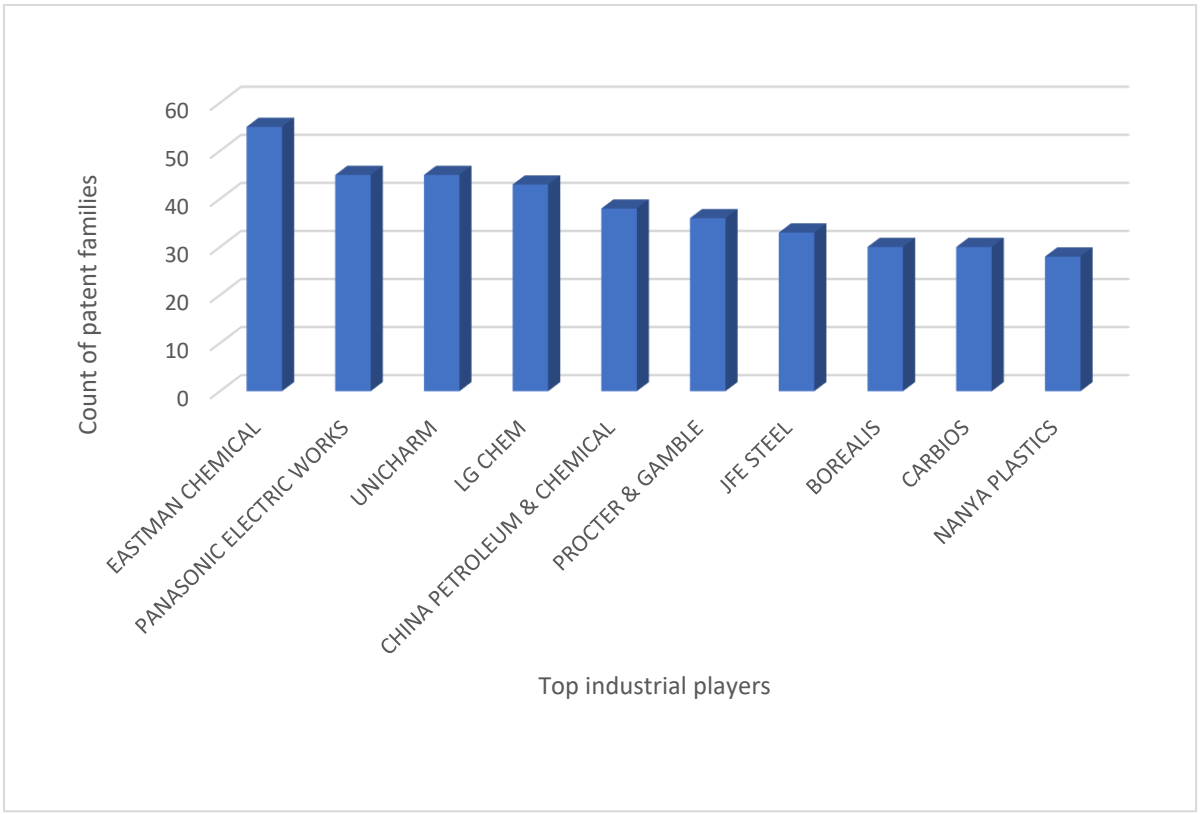

Figure 15. Top 10 players in the field of polymer recycling

5.2 Sorting of plastics

Proper sorting of waste represents the first step into any successful recycling process. The effective sorting is affected by various parameters, such as labelling, the composition of the plastics. Only a total of 16 patents have been published on sorting technologies, as shown in **Table 1** below.

Industrial players	Count of patents	Technology
Security matters	4	X-ray fluorescence
Daio Seishi	2	Infrared light
Clarios Germany	1	Density
Eriez Magnetics	1	Magnetic susceptibility
Igneo France	1	Magnetic susceptibility
MBA polymers	1	Colour
Nihon Senbetsu Kako	1	X-ray
Panasonic	1	Infrared light
PMT	1	Infrared light
Unisensor Sensorsysteme	1	X-ray fluorescence

Table 1. Industrial players developing technologies on plastic sorting for recycling.

The sorting technologies often rely on the properties of the plastic (flotation, reaction to irradiation) which are intrinsic to the polymer or can be conferred by additives during formulation. For example, the marking of polymers with fluorescent dyes which allows them to be sorted on the bases of fluorescence decay[16], the use of infrared light to irradiate chlorine atoms, thereby allowing the detection and separation of plastics with detectible chlorine contents.[17] Other technologies use x-rays to detect and remove foreign metallic substances from plastic wastes such as aluminium coated bags.[18] In addition, there are techniques which measures the magnetic susceptibility of the plastic. Such plastics must have approx. 0.05 – 5% by weight of ferromagnetic material integrated in their composition.[19] In addition, we have technologies based on cameras which detect various colours, thus allowing the sorting of plastics containing heavy metals (from vehicle waste). Lastly, we have technologies which are based on the density of the plastic, which determines if they float or sink when immersed in a fluid, or their behaviour when subjected to circular motion. Below we have selected a few examples to further elaborate on.

Relevant patents in the field of "sorting of plastics".

- *Preparation of polymers with fluorescent properties*
  Application number: US11326057
  Assignee: Unisensor Sensorsysteme
  Priority date: 2015-03-04
  Title: Automatic sorting of polymer materials on the basis of the fluorescence decay time of the intrinsic fluorescence of the polymer.
  Comment: The preparation of polymers capable of fluorescence decay requires the introduction of a fluorescent additive during polymer formulation. Various additives have been

[16] US11326057, Unisensor Sensorsysteme, automatic sorting of polymer materials on the basis of fluorescence decay time.
[17] DE10227916
[18] WO2023/080256, Nihon Senbetsu, apparatus for removing foreign substances from waste plastic.
[19] US6920982, Eriez Magnetics, plastic material having enhanced magnetic susceptibility.

identified (e.g. PTCDI, terylene dyes, perylenetetracarboxylic derivatives). These additives are preferably added to thermoplastics (e.g. PE, PET, PS, PP, PC).

- *Preparation of black polymers sortable by XRF.*
  Application number: WO2022118320
  Assignee: Security matters
  Priority date: 2021-04-21
  Title: XRF-identifiable black polymers
  Comment: Black polymers (polymers to which carbon black additives has been added) are quite difficult to recycle. This is due to the difficulty of the black pigment being identified by the IR sensors used at sorting facilities. A new carbon black formulation has been developed, including an XRF -identifiable material into the carbon black to create a new carbon black pigment which is XRF active. The markers are obtained by combining various salts such as MoS_2, silver nanoparticles and TiN; TiN, Cr_2O_3 and Mn_2O_3. About 0.5 – 4% of the pigment is then added to a prepolymer or polymer ideally a thermoplastic such as LDPE, HDPE, PP.

- *Preparation of polymers with enhanced magnetic susceptibility.*
  Application number: US6920982
  Assignee: Eriez Magnetics
  Priority date: 2005-07-26
  Title: Plastic material having enhanced magnetic susceptibility, method of making and method of separating
  Comment: Wire and cables are extensively recycled to recover the copper and aluminium wire which are of great quality. Unfortunately, this is not the case for the recovered plastic , which often consists of a mix of PVC, PET and other plastics. A re-engineered material was developed to recover high purity plastics that can be mixed with virgin materials. The magnetic susceptibility of the plastic is altered by including a ferromagnetic material (Fe_3O_4, ferro-silicon, iron fillings) in the formulation.

6. Conclusion

The inadequate disposal of plastic waste poses a significant threat to our environment and our ecosystems. The reuse and recycling of plastics is proposed as a strategy to help tackle the issue of plastic pollution. In this context, there are several factors that come into play when considering the recycling and reuse of plastics; (i) the ability to collect and properly sort the plastics from other waste, (ii) the characteristic of the material (e.g. single component or multicomponent material), and (iii) the properties of the recycled material which determines if it can be effectively reused with virgin materials for the primary applications. Hence, companies and research institutes have been investigating these different aspects to improve the sustainability of plastics.

The analysis of the patent trends relating to the preparation and recovery of polymers shows an increased interest as of 2019. The countries with the highest patent activities in both the domain of polymer preparation and recycling are China, Japan and the United States, with China displaying a patent activity 2-6 times superior to Japan and the US. Europe is statistically behind with often no representation in the top 5 in the context of patent activity. When looking at the industrial activity, Japan is the leader, followed by the US. Belgium is lagging in this race based on patent activity, never making it into the top 20. When looking at the industrial players, they are distributed across diverse industries (electronics, consumer, packaging, chemical) suggesting the sustainability of plastics is an important topic.

In this report, specific sub-topics were further analysed: the preparation of layered olefin products, the use of recycled feedstocks to prepare polymers and the sorting of polymers. Recent patent applications demonstrated the innovative technologies used in the context of circularity (e.g. technologies that improve the sorting of plastics through fluorescence technology, or the reuse of recycled feedstock in the preparation of PE films).

The patent activity in the design of plastics for recyclability confirm that there is a global interest in making plastics more sustainable with the goal of eliminating/reducing pollution caused by the latter, and hence contribute to the preservation of our environment.