Europäisches
Patentamt
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des brevets

Plastics in transition

Technologies for plastics waste management

April 2025

epo.org

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List of abbreviations

AI	Artificial intelligence
IPF	International patent families
FDCA	Furandicarboxylic acid
EPC	European Patent Convention
EPO	European Patent Office
PCT	Patent Cooperation Treaty
PEF	Polyethylene furanoate
PE	Polyethylen
PET	Polyethylene terephthalate
PFAS	Per- and polyfluoroalkyl substances
PHA	Polyhydroxyalkanoates
PP	Polypropylene
PVC	Polyvinyl chloride
R&D	Research and development
RTA	Revealed technology advantage
SDG	Sustainable Development Goals
WTO	World Trade Organization
UNCTAD	UN Trade and Development
UNEP	United Nations Environment Programme

List of countries and world regions

AT	Austria
AL	Albania
BE	Belgium
Benelux	Belgium, the Netherlands and Luxembourg
CA	Canada
CH	Switzerland
CN	People's Republic of China
DE	Germany
ES	Spain
EU	European Union
Europe	Europe is referred to in this report as the 39 member states of the European Patent Convention (EPC)
Eurasia	Russian Federation; and former Soviet Union
FI	Finland
FR	France
GB	United Kingdom
IN	India
IS	Iceland
JP	Japan
KR	Republic of Korea
LI	Liechtenstein
MC	Monaco
ME	Montenegro
MK	North Macedonia
NO	Norway
Other	European countries which are not EPC member states
RoW	Rest of world
RS	Serbia
SA	Saudi Arabia
SE	Sweden
SM	San Marino
TR	Türkiye
TW	Chinese Taipei
US	United States

Executive summary

Plastics are one of the most ubiquitous materials in today's world. Their pervasiveness is a serious hazard for the ecosystem and human health since they are difficult to manage after use. Reclaiming plastic waste from the environment and reinjecting these materials back into economic life are key challenges with which innovation can help.

This report examines innovation trends in the field of plastics waste management over the span of five decades. To this end, it closely monitors patenting activities across all technology fields associated with waste recovery, i.e. the separation and purification of plastics, as well as waste recycling, i.e. the conversion of plastics into new materials.

Drawing on the latest patent data and leveraging the expertise of the European Patent Office (EPO), it delivers a comprehensive analysis to inform decision-making processes in both the private and public sectors.

Innovation in plastics waste management is booming

A total of 12 924 inventions are found in the whole period 1975-2023, using international patent families (IPFs) as a standard metric. Plastics waste management innovation has demonstrated greater dynamism compared to other technology fields. Its share of overall patenting activities has risen significantly, growing eighteenfold from 1990 to 2023, and four times faster than inventions in all technology fields combined. Patenting has especially boomed since about 2015 and even accelerated into the 2020s.

While the strong growth in innovation is evenly distributed between waste waste and recycling recovery technologies, a more detailed analysis reveals some shifts in the direction of technological change, particularly in the 2020s.

Transformative developments are reshaping the field. Waste recovery is now seeing strong lead growth in selective dissolution and optical methods. Explosive growth niches are found in technologies dealing with critical challenges such as reducing persisting pollutants like microplastics, nanoplastics and PFAS (per- and polyfluoroalkyl substances, which is a class of synthetic chemicals that are highly resistant to degradation). Novel techniques such as chemical waste recovery and biological methods show low but growing activity.

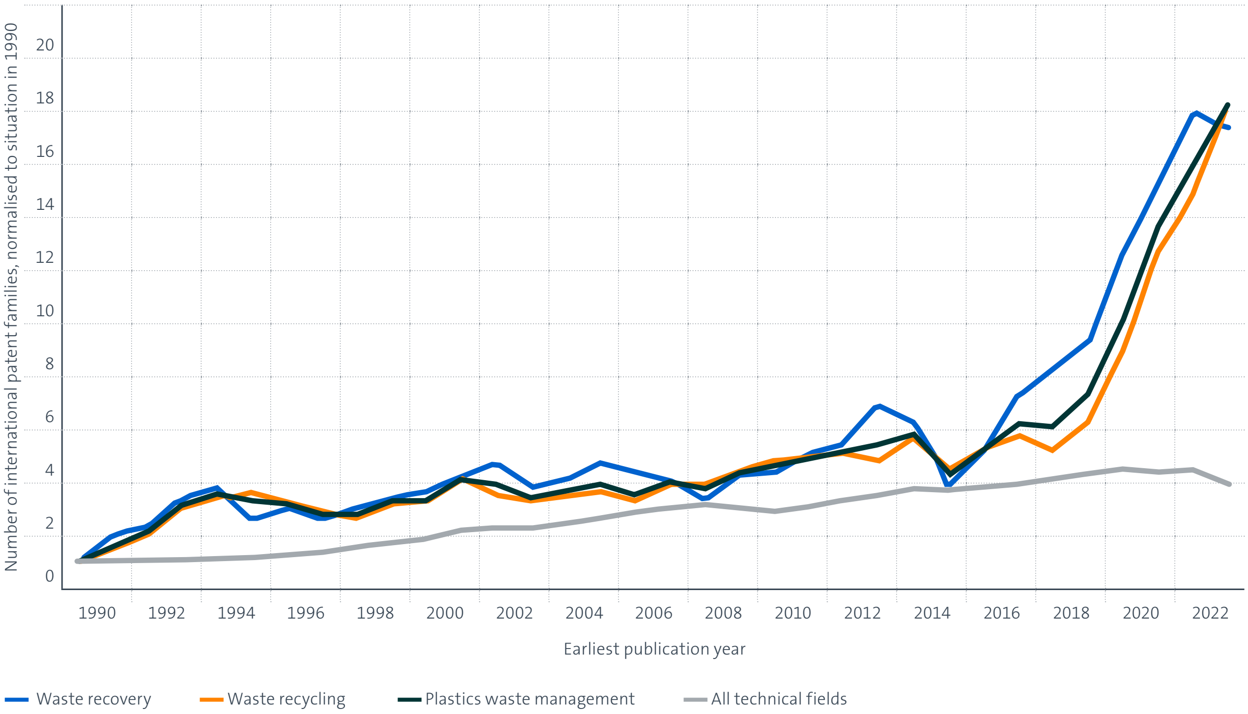
Waste recycling has long been dominated by mechanical methods, but there is now strong lead growth in advanced methods such as pyrolysis and chemolysis, which convert plastics into higher-value feedstocks for further use as raw materials. Sector-specific applications such as packaging and textiles are also showing strong growth. Patenting activity in healthcare and cosmetics, while still relatively low, are also on the rise.

The EPO Technology insight report on plastics waste management in a nutshell:

- This report provides detailed analysis of trends in the technologies of plastics waste management, in both its dimensions of waste removal and waste recycling. It includes a special focus on critical challenges such as removing plastics from water and AI-driven plastics waste management.
- The analysis draws on the EPO's unique expertise in mapping patent documentation to technology domains. It uses a cartography of the technical field that was developed by subject-matter experts at the EPO in close cooperation with specialists of patent offices in 15 EPC member states.
- International patent families (or IPFs) are used as the main indicator of patenting activities. Each IPF covers a single invention and includes patent applications filed and published at several patent offices. IPFs thus signal inventions with confirmed potential for commercialisation.
- The present work contributes to the UN's Sustainable Development Goals, namely SDG 12 (Sustainable consumption and production), but also SDG 6 (Clean water and sanitation), 14 (Life below water) and 15 (Life on land).

Figure E.1

Normalised trends for IPFs in plastic waste management and for all technology fields (reference: 1990)



Source: EPO

Long before AI entered mainstream discourse, its foundational technologies were quietly advancing plastics waste management. While over 90% of AI-related innovations emerged post-2010, its roots in the industry extend back to the 1990s. The integration of AI is most advanced in optical sorting and separation methods for waste recovery, followed by waste collection and mechanical processing of recycled plastics, underscoring its rising role in modern waste recovery and recycling systems.

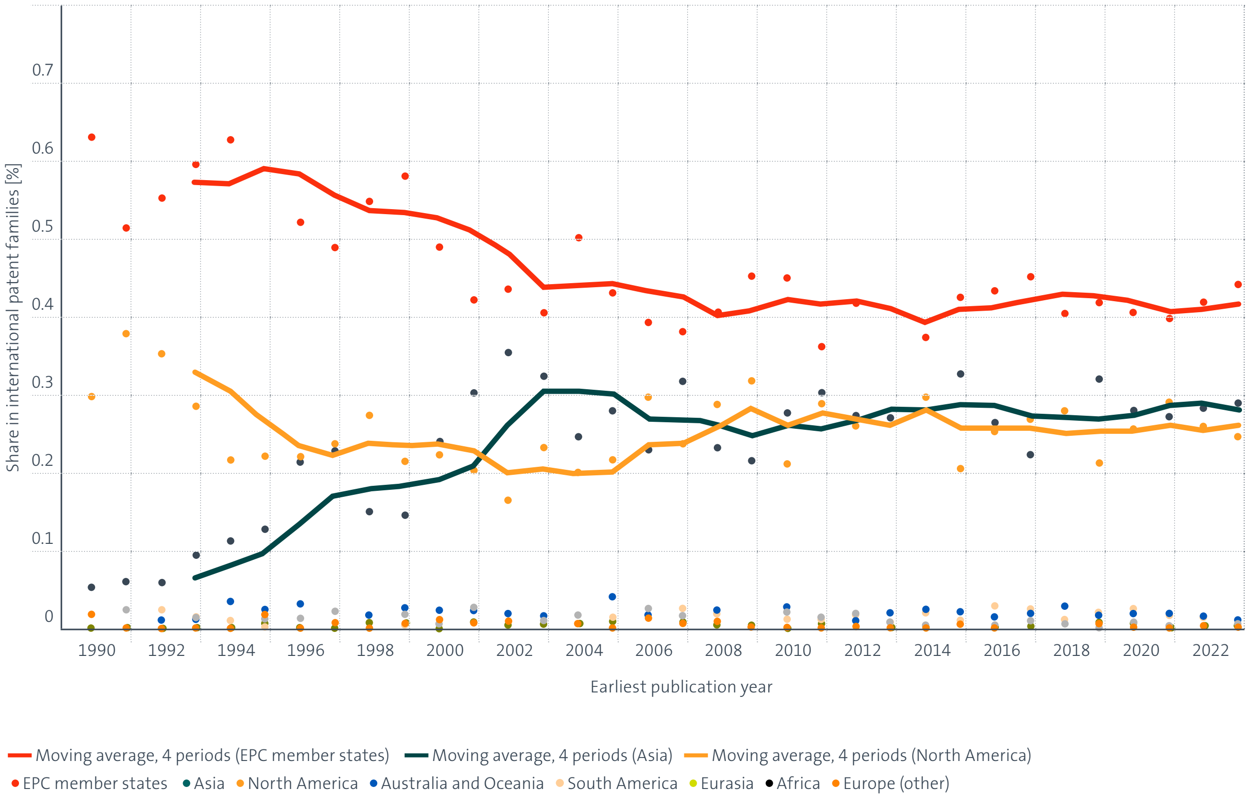
Europe at the forefront of innovation against plastic waste

Europe has consistently led innovation in plastics waste management from 1990 to 2023, accounting for 44% of related patent activity over this period. Germany, France, Italy and the United Kingdom are the leading European countries in terms of the number of IPFs in these technologies.

While Europe and North America were the main regions innovating in plastics waste management in the early 1990s, Japan, the Republic of Korea and China have since joined the field and played a significant role in the acceleration of patenting activity after 2015. As a result, Asia is now on a par with North America with just under 30% of IPFs each, while Europe's share has fallen from as much as 62% in 1995 to around 40% in the 2000s and remained stable at that level.

Figure E2

Major world regions as innovation locations in plastics waste management (IPFs, inventor country; dataset restricted to IPFs with EP and/or WO patent family members for comprehensive coverage of inventor country information; 1990-2023)



Source: EPO

Top applicants originate from a broad range of industries

Europe's lead is also evident when looking at the largest applicants, with eight and ten European applicants in the top 20 for waste recycling and waste recovery respectively. Overall, around half of the top applicants in both areas are from the chemical or tyre industries, some of which have a long track record of innovation in this area. However, a significant number of top applicants operate in other waste-generating industries such as packaging, automotive, electronics, printing or consumer goods. Interestingly, three pure plastics recycling players - all European - appear in the top 20. These are Erema (Germany) and Carbios (France) in recycling and Tomra (Norway) in waste recovery.

Table E.1

Top 20 applicants in plastic waste recycling technologies (IPFs, 1990-2023)

Applicant	Country	Mechanical processing of used plastic	Pre-consumer plastic to product	Healthcare	Packaging	Cosmetics	Electronics	Textile	Automotive	Construction	Agriculture	Pyrolysis	Chemolysis	Gasification	Liquefaction	Catalytic cracking	Enzymatic depolymerisation	Depolymerisation into original monomer	Number of international patent families
Eastman	US	39	5	0	28	3	8	7	9	1	0	101	45	41	26	6	0	14	165
Bridgestone	JP	40	1	0	19	0	4	4	91	0	0	15	15	5	0	0	2	0	153
Mitsubishi	JP	43	2	0	24	6	26	2	20	1	1	10	19	15	2	0	0	2	120
BASF	DE	23	7	2	6	0	3	3	10	5	1	18	49	0	0	1	2	26	115
Michelin	FR	29	3	0	6	0	5	5	89	2	0	3	1	0	0	0	0	0	114
Sabic	SA	6	4	0	2	0	8	0	10	0	0	47	41	0	0	10	0	7	100
Borealis	AT	13	2	0	46	0	5	2	29	0	0	3	5	0	0	0	0	0	81
GE	US	33	1	0	0	0	2	0	4	0	0	2	22	0	0	0	0	1	61
Procter & Gamble	US	6	6	6	19	1	0	2	6	0	1	0	19	0	0	0	3	0	53
Dow	US	7	3	0	25	0	4	6	10	5	0	2	4	0	0	0	0	0	52
DuPont	US	11	7	1	6	0	0	3	7	1	0	2	14	0	0	0	2	12	50
SK	KR	9	0	0	7	1	1	1	4	0	0	26	13	0	0	2	0	4	47
Erema	AT	43	13	0	4	0	2	1	0	0	0	0	2	0	0	0	0	0	45
IFP Energies nouvelles	FR	6	0	0	6	0	1	0	1	0	0	16	17	2	2	0	0	12	43
Goodyear	US	4	1	0	3	0	2	0	30	0	0	0	6	0	0	0	0	0	41
Bayer	DE	9	2	0	0	0	0	2	5	0	0	5	22	0	0	0	2	1	40
Arkema	FR	12	0	0	1	0	1	1	13	0	0	12	8	0	0	0	0	4	38
Carbios	FR	1	0	0	1	0	0	0	0	0	0	0	10	0	0	0	35	5	37
Nan Ya Plastics	TW	9	1	0	6	0	2	1	0	0	0	1	27	0	0	0	0	7	34
Panasonic	JP	18	1	0	1	0	2	1	1	2	0	2	13	0	0	0	0	0	34

0 | 1-10 | 11-20 | 21-30 | 31-40 | 41-50 | ≥ 81

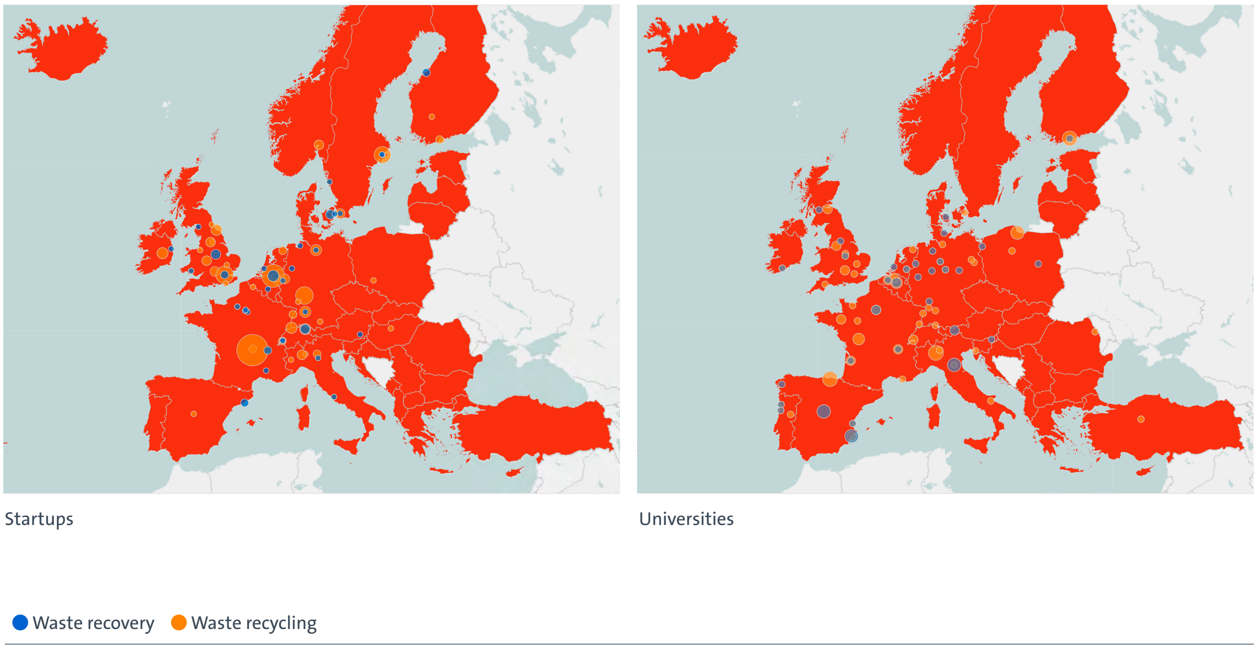
European startups and universities are ramping up innovation

A closer analysis of European startups and universities with European patent applications related to plastics waste management shows an acceleration of their patenting activities after 2015. In total, 82 European startups and 63 European universities filed applications related to plastics waste management in the period 2010-2023. About 80% of the inventions of the startups and two thirds of the inventions of the universities are focused on waste recycling, in particular on advanced waste recycling processes based on chemolysis, pyrolysis or enzymatic depolymerisation. Innovation in waste recovery technologies generated relatively less patenting activity, especially among start-ups, reflecting the technical and economic challenges of developing and deploying such technologies.

The United Kingdom has the highest number of start-ups (18), followed by France (11), Germany (9), Sweden (8), Italy and the Netherlands (6 each). However, France and Germany dominate the university ranking with 14 and 11 universities respectively. Another 6 patenting universities are located in the United Kingdom, 5 in Spain, 4 in Italy and Poland and 3 in Belgium and Portugal. It is interesting to note that the geographical distribution of start-ups and universities is different, with coastal regions in Portugal, Spain, France and Poland showing innovation by universities but no patenting activity by local startups.

Figure E.3

Geographical distribution of European startups and universities active in plastics waste management (based on European patent applications, 2010-2023)



Source: EPO

Glossary

Chemolysis	Decomposition of a substance by chemical means, often involving the use of solvents, acids or other reactive chemical agents.
DOCDB	The EPO's master documentation database with worldwide coverage. It contains bibliographic data, abstracts, citations and DOCDB simple patent family information.
DOCDB simple family	A set of patent documents relating to patent applications claiming priority over the same earlier applications. The technical content covered by the patent applications in a DOCDB simple patent family is considered to be identical.
European patent	The European patent system makes it possible to obtain European patents valid in up to 39 contracting states to the European Patent Convention (EPC) on the basis of a single application. A European patent has the same legal effects as a national patent in each country for which it is granted. As of 2023, it is also possible to request unitary effect for a granted European patent.
European Patent Convention (EPC)	International treaty signed by the member states of the European Patent Organisation. The EPC establishes a single application procedure for obtaining patent protection in Europe.
European Patent Office (EPO)	Executive arm of the European Patent Organisation. European patents are granted by the European Patent Office in a centralised, cost-effective and time-saving procedure conducted in one of the official languages of the EPO (English, French or German). Every European patent application undergoes substantive examination before a European patent is granted to make sure that inventions for which patent protection is sought meet all of the legal requirements set out in the European Patent Convention.
Espacenet	Free online patent searching service developed by the EPO. It includes information on over 150 million patent documents from more than 100 patent offices on all continents. Espacenet is available at worldwide.espacenet.com.
International patent application	Patent application filed under the Patent Cooperation Treaty (PCT). An international patent application may result in patent protection in more than 150 countries.
International Patent Classification (IPC)	The International Patent Classification system is a hierarchical patent classification system used by the EPO and more than 100 patent offices worldwide. It breaks technologies down into eight sections with several hierarchical sub-levels. The IPC system has approximately 75 000 subdivisions and is updated on an annual basis.
International patent family (IPF)	A set of applications for the same invention that includes a published international patent application, a published patent application at a regional patent office, or published patent applications at two or more national patent offices.
Invention	A practical solution to a (technical) problem. The invention may be a new product, process or apparatus or any new use thereof. To be patentable under the European patent system, an invention must be technical, novel, involve an inventive step (i.e. it must not be obvious to those having ordinary skill in the technical area of the invention), and be considered as susceptible of industrial application.
Patent	Legal title giving the patent owner(s) the right, for a limited period of time (usually 20 years as of the date of filing the patent application), to exclude others from using the protected invention in a commercial context without permission in those countries for which the patent has been granted. The protected invention is defined by the claims of the patent.
Patent application	Request for patent protection for an invention filed with the EPO or other patent office.
Patent classification system	The set of patent classification symbols assigned to categorise the technical subject-matter of a patent or utility model. There are various patent classification systems used today by national, regional and international patent offices.

Patent family	A set of patent documents covering the same or similar technical content, depending on the patent family definition.
PATSTAT	PATSTAT is a group of databases that contain bibliographical, procedural and other context information on millions of patents and utility models from numerous industrialised and developing countries. It is built from the EPO's databases of worldwide patent data.
Patent Cooperation Treaty (PCT)	An international treaty providing for a unified procedure for filing patent applications to protect inventions in its contracting states. Under the PCT, a single international application can be filed for patent protection in up to more than 150 countries. The PCT provides for a centralised procedure for filing the patent application whereby the substantive examination and the grant of the patent lies with the competent national or regional patent office(s).
Plastics	Plastics are a type of polymer engineered to have specific properties. Plastics are materials made from polymers, often enhanced with additives or other substances that serve as the main structural component in various products. Plastics include polymers manufactured from bio-based, fossil or synthetic sources, as well as chemically modified natural polymers such as cellulose acetate. They also encompass polymers produced through industrial biosynthesis and fermentation processes like polyhydroxyalkanoates (PHA). Plastics do not include natural polymers that have not been chemically altered such as regenerated cellulose or paper, which retain their natural structure regardless of the extraction method used.
Polymer	Polymers are large molecules made up of repeating units called monomers. They can be natural or synthetic. Polymers can be found in nature (e.g., cellulose, deoxyribonucleic acid (DNA)) or industrially manufactured (e.g., polyethylene, nylon).
Priority	Inventions can be protected by patents and utility models in more than one country. For a period of 12 months from the date of filing an application for a patent in a member state of the Paris Convention, the applicant or their successor can claim a right of priority from that application for any subsequently filed patent application that concerns the same invention. If the requirements are fulfilled, the date of the earlier application counts as the date of filing of the later application for the purposes of examining novelty and inventive step.
Pyrolysis	Thermal decomposition of materials in the absence of oxygen or with very limited oxygen.

1. Introduction

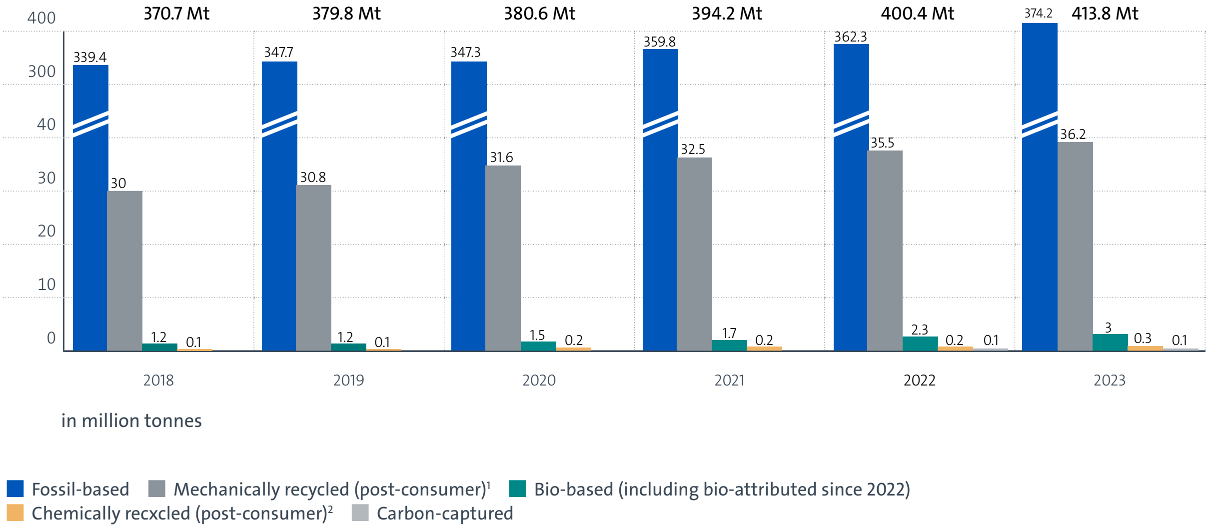
1.1 The challenge of plastic waste

Because plastics are versatile, mouldable, stable and durable, isolating and non-conductive, light-weight and non-corrosive, shock-absorbing, strong, cheap and mass-produceable, a wide range of applications have made them an integral part of an ever-increasing number of activities. The annual increase in global plastic production has been steady and has consistently exceeded economic growth. From 1950 to 2020, the increase was from 2 to around 400 million metric tonnes, equivalent to 1 to 63 kg per person (Geyer, 2020; Li et al., 2022). The packaging industry is the largest user of these materials, followed by construction and the automotive sectors.

In 2024, world plastic output totalled 413.2 million tonnes. The bulk of this output is primary plastics made out of virgin (carbon-intensive) materials, whereas recycled plastics represent 36.5 million tonnes and biobased plastics 0.3 million tonnes (Figure 1). The top three global producers of plastics are China, North America and Europe at 32%, 17% and 14%, respectively for the three main types of plastics: polyethylene (PE), polypropylene (PP) and polyvinyl chloride (PVC) (see Plastics Europe, 2015). Europe has traditionally been an important net exporter of plastics: its total trade balance boomed in the 2000s, but its surplus has trended downwards since the 2010s.

Figure 1

World plastics production and recycling, 2018-2023



Source: based on Plastics Europe (2024); in million tonnes

Over time, end products containing plastics have become ubiquitous in the economy (Brydson, 1999; Freinkel, 2011) and ultimately in the biosphere. Pollution from plastic waste is increasing, and is accompanied by toxic pollution and threats to human health. Today, only a fraction of primary plastics is ever recycled (about 8%): the majority is buried, incinerated or simply mismanaged, i.e. deliberately dumped or indiscriminately spilled into the environment (Streit-Bianchi et al., 2020). Plastics persistently escape from the economic cycle and disperse into the wider natural environment: they infiltrate the Arctic, the deep sea, deserts and mountains; they are found in living organisms and increase cancer and cardiovascular risks in humans; they disproportionately affect the poor and end up in the Global South (CEPAL, 2020; Pottinger et al., 2024; Symeonides et al., 2024).

While the dominant technologies in the plastics industry often focus on performance and durability, innovation to mitigate the hazards of plastics is also essential.
To cope with the growing volume of plastics produced, used and disposed of in today's linear economy, the

plastics industry must move to a fully circular model, where end-of-life plastic products are not discarded as waste, but become a source of value. Advances in waste recovery and transformation technologies are critical to support the systematic recycling of plastic waste and maximise the value derived from it, with regulation and international co-operation as key enablers.

1.2 Policy context

While the 1970s and 1980s saw the emergence of environmental awareness in some countries and some early legislative efforts[1], the Basel Convention, adopted in 1989, was a first major landmark at the international level. It regulates the transboundary movement of waste and was extended in 2019 to cover, categorise and ensure compliance with plastic materials. Another example of intergovernmental cooperation is the 2030 Agenda for Sustainable Development, adopted by all United Nations member states in 2015, which supports plastics governance.

The Trade-related Plastic Measures Dialogue, launched in 2020, was initiated by a group of World Trade Organization (WTO) members to foster policy learning and increase transparency in the plastic trade, while promoting safer plastic supply chains and the development of sustainable alternatives to conventional polymers such as biodegradable or compostable materials. Finally, the Global Plastic Treaty complements previous initiatives and is one of the most comprehensive efforts in the combat against the proliferation of plastics. Launched at the UN Environment Assembly in 2022, this treaty addresses the full life cycle of plastics from production to disposal; and negotiations relating to it are still ongoing.

In the UN ecosystem, many agencies have been active on matters related to polymers production, commerce and disposal. In 2024, the United Nations Environment Programme (UNEP) published a landmark roadmap to address the global plastic pollution crisis. The report emphasises the need for systemic transformation and advocates a transition to circularity, meaning a model for reducing production, reusing materials and recycling effectively (UNEP, 2024). In 2024, UNCTAD added to the plastics agenda by releasing *Beyond plastics: A Review of Trade-related Policy Measures on Non-plastic Substitutes*, a resource with recommendations on non-plastic substitutes for various functions. In particular, it stresses innovation as a critical driver for upgraded recycling infrastructures and replacing fossil fuel-based inputs in the plastics sector (UNCTAD, 2024, p. 3).

Europe has consistently been at the forefront of innovation and regulation, implementing forward-looking pilot projects and setting global benchmarks (Box 1). In particular, the European Union has been a pioneer in moving away from fossil-based plastics and towards circularity through alternative feedstocks, recovery of used inputs and recycling capacity. Europe has also traditionally been a major net exporter of plastics, but its surplus has been declining since the 2010s (Plastics Europe, 2022, 2023). In addition, its progress in actual recycling operations and infrastructure has been slow. It is no longer the largest source of alternative plastics (superseded by China) and its end-use profile is highly resistant to decline (at 107 kg/capita per year, the EU is one of the highest per capita consumers of plastics in the world) (OECD, 2022; EEA, 2024). Against this background, the recent Draghi (2024) and Letta (2024) reports both mention plastics innovation as a focus for a more circular and resilient economy, especially given the challenges associated with the high energy intensity of current recycling solutions.

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[1] The Resource Conservation and Recovery Act, enacted in 1976, became the primary law in the US governing the disposal of solid industrial, commercial and municipal waste (Archer and Huls, 1981). The testing of selective disposal systems, ecotaxes, and short-term packaging targeting was building momentum in the late-1980s/early-1990s in countries like Belgium, Denmark, Italy and Germany, leading to the 1994 EU Packaging and Packaging Waste Directive (94/62/EC) (Buclet and Godard, 2001)

Box 1. Milestones in the EU's plastics regulation

Packaging and Packaging Waste Directive (1994) – An early and influential piece of legislation. The directive highlighted the prevention of waste and set recovery and recycling targets for packaging waste, including plastics.

Waste Framework Directive (2008) – Reinforced the EU's commitment to waste reduction and recycling, and introduced the waste hierarchy (prevention, reuse, recycling, recovery, disposal).

Standardization working group (2012) – An ad-hoc group focused on the implementation of the "Lead market initiative for bio-based products".

EU Plastics Strategy (2018) – Its key goals include making all plastic packaging reusable or recyclable by 2030 and restricting the use of microplastics and harmful additives.

Single-Use Plastics Directive (2019) – Targeted the most common single-use plastic items, including straws, cotton buds, and food containers. Established design requirements and waste management obligations.

Zero Pollution Action Plan (2019) – Goal to reduce microplastics pollution by 30% and plastic litter at sea by 50% by the year 2030.

Plastic Waste Shipment rules (2021) – Ban on plastic waste exports to non-OECD countries.

Rules for biobased, biodegradable and compostable plastics (2022) – Ensures reusable packaging, eliminating unnecessary packaging, limiting overpackaging, and providing clear labels to elicit proper recycling.

Implementation decision with regard to caps and lids (2023) – Ensures that caps and lids remain attached to beverage containers.

Measures to restrict intentionally added microplastics (2023) – Covering synthetic polymer particles below five millimetres that are insoluble and resist degradation, which can be found in sports applications, cosmetics, detergents, etc.

Implementation decision regarding the calculation, verification and reporting standards (2023) – Applicable to the data concerning recycled plastic content in single-use plastic beverage bottles.

Packaging and packaging waste regulation (2024) – Replaces the 1994 directive. Addresses single-use and overpackaged items. Targets full recyclability by 2030 and establishes minimum levels of recycled content in plastic packaging. Promotes reuse/refill. Stipulates formats and harmonised labelling.

1.3 Technologies for plastics waste management

This report focuses on the technological responses to the challenge of plastic waste pollution. The management of plastic waste involves two distinct categories of technologies, relating to the recovery and recycling of plastic waste respectively, which are complementary. Technological advances in both recovery and recycling are therefore necessary to reduce plastic pollution and promote a circular economy.

The recovery of plastic waste involves techniques and infrastructure for collecting, sorting and separating discarded plastics for further processing. It focuses on recovering plastic materials from waste streams or the environment, ensuring that they are properly handled and redirected for reuse, recycling or other sustainable applications. Collection can target larger or smaller debris (i.e. macro-, micro- and nanoparticles), for example through containers and filters to recover them from water, as well as released additives (such as phthalates and bisphenol A). Removal methods include mechanical, chemical and biological techniques for extracting plastic waste from the environment, including filtration, sedimentation, biodegradation and advanced separation technologies that enable efficient recovery and pollution prevention. Sorting and separation involve classifying plastic waste by type, colour or composition using a variety of systems, including mechanical (e.g. gravity or washing) and automated (e.g. sensors and analytics) systems, to streamline recovery processes.

Plastic waste recycling involves the conversion of collected and sorted plastic waste into new materials or products by mechanical, chemical or biological processes. The main methods include mechanical recycling (melting and reshaping), chemical recycling (breaking down polymers into monomers) and advanced techniques for converting plastics into feedstock such as pyrolysis, chemolysis or enzymatic degradation. A distinction is usually made between pre-consumer plastic to product, where production waste or defective items are recycled directly into new products, and post-consumer plastic to product, where recycled polymers are used to make new items for a wide range of industrial applications, from packaging to electronics.

1.4 About this report

In this report, we focus on the transformative innovations that are driving plastics waste management, namely plastics recovery and recycling. Aimed at decision-makers in both the private and public sectors, it is a unique source of information on these technologies and the technical problems they aim to solve.

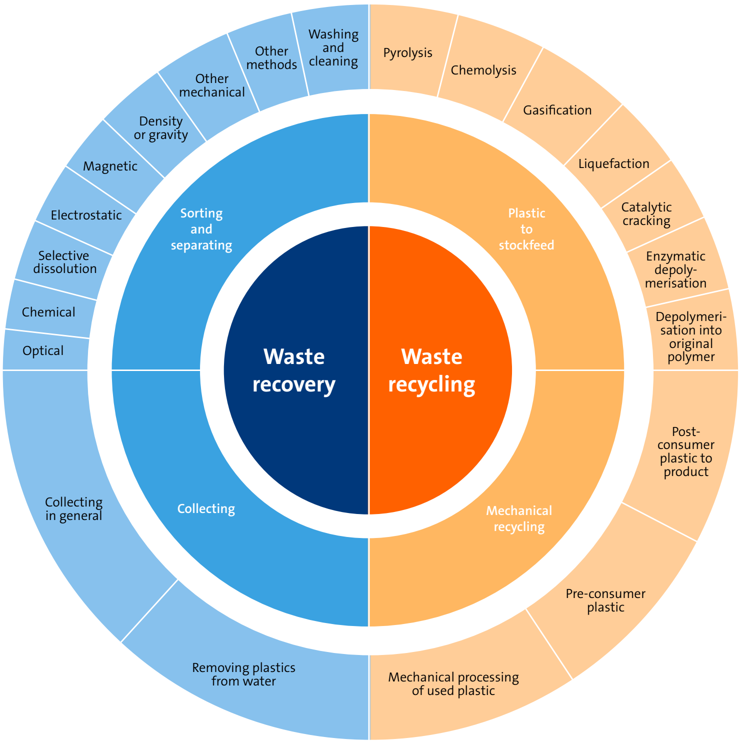
The publication draws on the latest available patent information and the expertise of EPO examiners to provide a comprehensive analysis of the innovation trends driving technical progress in plastic waste management (Figure 2). Patent information provides robust statistical evidence of technological progress. The data presented in this report show trends in high-value inventions for which patent protection has been sought in more than one country (IPFs). Further explanations on methodology and sources are provided in Annex 1.

The statistical results are complemented by in-depth qualitative perspectives from innovation highlights, case studies and individual patents. Although global in scope, the report has a stronger focus on Europe (defined here as the 39 contracting states that are currently members of the EPO).

This report contributes to the UN Sustainable Development Goals, namely SDG 12 (Sustainable consumption and production), but also SDG 6 (Clean water and sanitation), 14 (Life below water) and 15 (Life on land). It also speaks to current competitiveness debates, especially those raised within the EU concerning ways to synergise sustainability and industrial renewal (Draghi, 2024; Letta, 2024).

Figure 2

A cartography of plastics waste management technologies used for this report.



Case study: Smart recognition of recyclables

Integrating AI in circular value chains

Company:	Recycleye
Headquarters:	London, United Kingdom
Founded:	2019
Products:	AI-driven recycling technologies

Can advanced technologies, and particularly artificial intelligence (AI), catalyse the shift to a more circular economy for plastics? How can AI facilitate the transition from mechanical-based automation to a 24/7, all-material, data-driven sorting model?

As the volume of waste increases and the demand for sustainable solutions grows, the focus has turned to innovative approaches to improve the performance of material recovery facilities. One such approach has been explored by Victor Dewulf and Peter Hedley, winners of the EPO's Young Inventors Award, who have improved the prospects for better identification and classification of recyclable materials.

A new generation of innovators is looking at AI as a tool for every stage of the plastics value chain. By optimising material selection, improving the accuracy of waste sorting and enabling predictive maintenance in recycling facilities, AI can significantly reduce the inefficiencies of turning waste into input. For example, machine learning algorithms can accurately identify and categorise plastic waste, ensuring higher quality recycling outputs and reducing contamination.

Recycleye, a startup founded by Victor Dewulf and Peter Hedley, addresses key challenges in waste management through its AI-driven solutions. At the heart of their approach is the Recycleye Vision system, which uses computer vision AI to improve the identification of waste materials in complex, real-world conditions. Unlike conventional systems, which often struggle with crushed, soiled or overlapping items, Recycleye's technology uses custom algorithms trained on millions of computer-generated waste images. Installed above conveyor belts, the system captures detailed images of each item of waste, processes the data and guides robotic sorting arms to separate materials more effectively, increasing both recycling efficiency and material value. In addition, the startup developed "Recycleye Robotics" to bring a lightweight robotic sorting arm to operations.

These innovations demonstrate how advanced technologies, such as AI and robotics, can contribute to more efficient waste management practices, thus supporting the transition toward a circular economy.

Case study: Reengineering the DNA of bottles

From PET to PEF, from lab to market

Company: Avantium
Headquarters: Amsterdam, The Netherlands
Founded: 2000
Products: Technologies for the production of renewable plastics using plant-based feedstocks

Can plastic bottles transition to a post-petroleum future? Can plant sugars become the building blocks for strong lightweight bioplastics that can be easily formed into bottle shapes?

The world's most commonly used polyester, PET (polyethylene terephthalate), is derived from fossil-based chemicals. Now, however, renewable PEF (polyethylene furanoate) promises to be useful in a wide variety of applications (from bags to bottles) and may even become a substitute for non-plastic materials such as aluminium and glass.

The inventor of this alternative breakthrough was recognised as a finalist for the EPO's 2017 European Inventor Award. Gert-Jan Gruter's game-changing green process uses methanol instead of water to turn plant sugars into furandicarboxylic acid (FDCA). These FDCA monomers can be used to mass produce PEF cheaply.

With over 100 patents to his name, Gruter has spent his career bouncing between industry and university. After receiving a Doctorate degree in organometallic chemistry from the Vrije Universiteit Amsterdam, he entered the private business of polyolefins catalyst development. Gruter began lecturing part-time at Eindhoven University of Technology as an Extraordinary Professor of Polymer Catalysis, a side job he kept even as he joined a new company, which started as a spin-off Royal Dutch/Shell. It is this company, Avantium, that demonstrated the feasibility of moving PEF from the lab to the factory. Later on, it formed a joint venture with BASF for building a reference industrial facility to produce and commercialise PEF on a large scale.

PEF's prospects for widespread use are great due to its advantages for bottling and packaging. First, PEF containers keep drinks fresh longer because it is ten times better than PET at keeping oxygen from passing into the bottle. Second, PEF is five times better at keeping carbon dioxide inside the bottle, which is critical for carbonated soft drinks, beer and sparkling water. Third, because PEF is stronger, less material is required to produce equivalent-size bottles, thus reducing weight in terms of transportation and waste. Fourth, PEF needs less energy to produce and has a smaller carbon footprint.

The aim is to revolutionise plastic production by making it more environmentally friendly and reducing our reliance on fossil fuels. "To make the transition from fossil fuels to sustainable plastics, we have to rely on biomass. But for this, we need new materials," he told the EPO. This innovation has the potential to reshape the plastics industry; introducing a fully recyclable, vegetable-derived polymer could pave the way for a greener and more sustainable future.

2. Technology trends in plastics waste management

This section outlines the main time trends in plastics waste management technologies from 1975 to 2023, the latest year for which comprehensive data are available. A total of 12 924 international patent families were identified, of which 32% are related to plastics waste recovery and 68% to waste recycling.

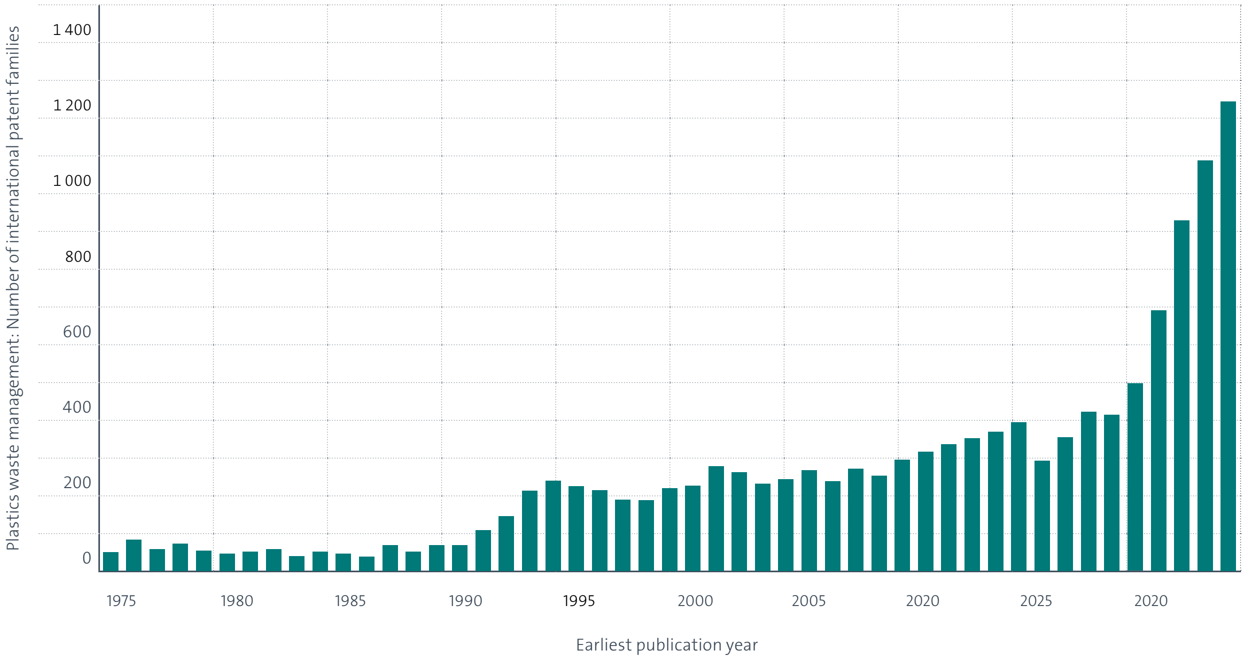
2.1 General technology trends

Figure 3 shows patenting activity in the area of waste management technologies as a whole and reveals a clear long-term upward trend. After a period of low inventive activity in the field, the number of IPFs started to increase in the early 1990s.By the middle of the decade it had exceeded the threshold of 200 inventions per year. Between 2010 and 2014, the number of patent applications rose steadily from 226 in 2000 to 395 in 2014.

The period 2015-2023 shows a dramatic acceleration, with a compound annual growth rate of 14% from 2015 to 2019, and even 22% from 2020 to 2023, compared to 6% in the period 2010-2014 (Table 1). This impressive growth also far exceeds the global increase in IPFs across all technology areas. As a result, plastics waste management as a share of total patenting activity has increased significantly, growing eighteenfold from 1990 to 2023 and four times faster than IPFs in all technology fields combined.

Figure 3

Patenting in the area of plastics waste management (IPFs, 1975-2023)



Source: EPO

Table 1

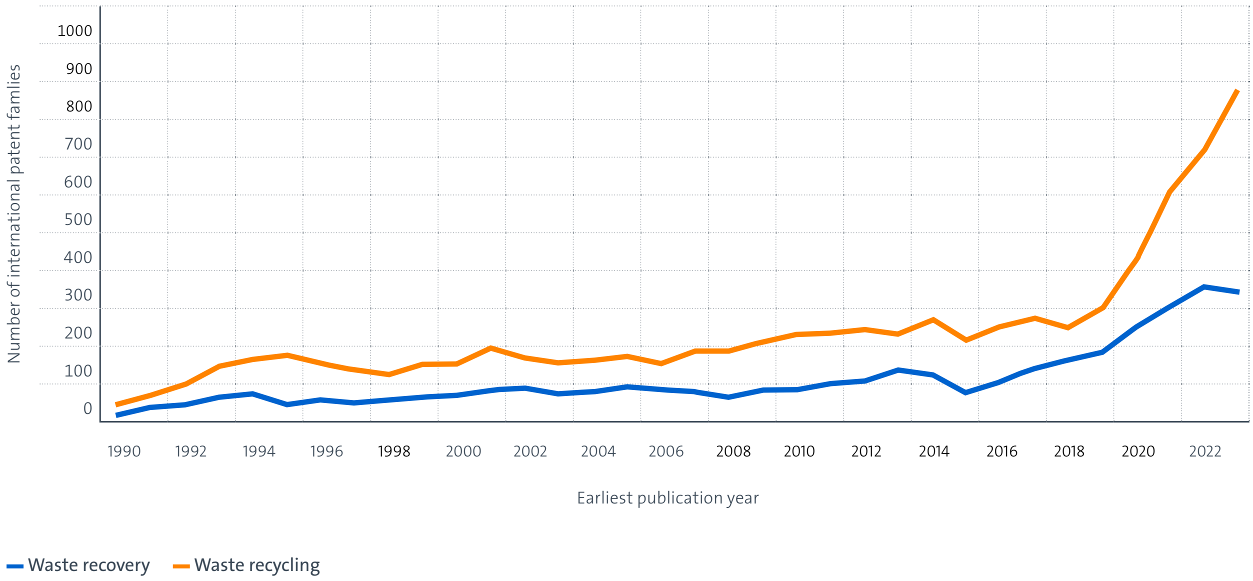
Growth in IPFs in plastics-related waste management solutions and all technologies (compound average growth rates, in percent, 1975-2023)

	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999	2000–2004	2005–2009	2010–2014	2015–2019	2020–2023
Plastics waste management	2.4	2.6	10.1	37.1	-0.6	1.8	2.6	5.7	14.3	21.7
Aggregate of all technologies	-0.6	4.3	5.5	2.6	10.1	7.1	3.5	6.6	4.1	-3.8

The two main sub-categories of plastics waste management technologies show robust growth throughout the period. Growth in waste recycling technologies is consistently higher than in waste recovery technologies (Figure 4). Growth has occurred in different phases, reflecting changes in the underlying technological capabilities and policy developments. The first phase (1990-2015) is characterised by gradual growth, with waste recycling significantly outpacing waste recovery. After 2015, both technology fields experience a strong acceleration of patenting activities. Overall, the dynamics of these two technology subfields are strongly correlated, although they involve different scientific and engineering activities. This suggests that innovation in these fields is mainly driven by external factors such as policies and regulations.

Figure 4

Innovation trends in the sub-fields of waste recovery and waste recycling (IPFs, 1990-2023)



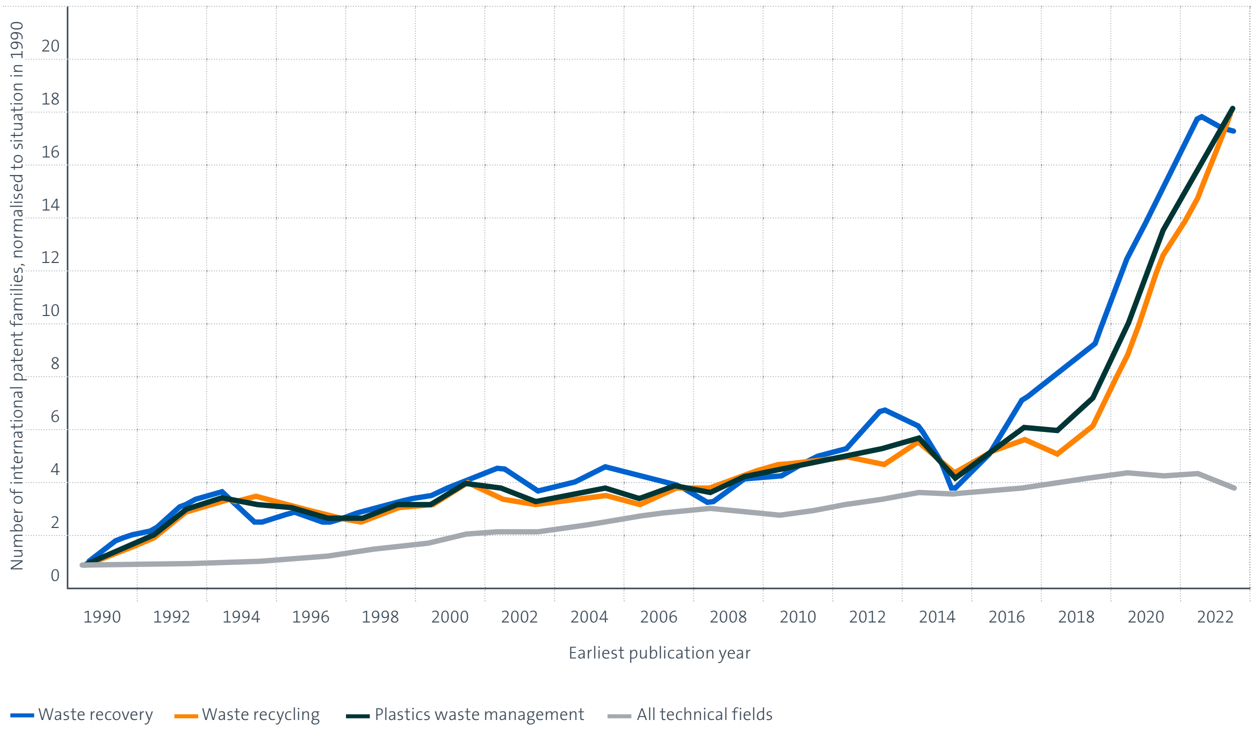
Source: EPO

Figure 5 shows index figures with 1990 as the reference year. This standardises the data and makes it possible to compare changes by expressing values relative to a reference point. The recalibrated series show that plastics waste management, although volatile, has outperformed all technology sectors over the period. In particular, the graph shows the period of rapid growth in the early 1990s and the new era of rapid technological change after 2015. In particular, the 2020-2023 sub-period stands out as a likely period of transformation, with a significant divergence between plastics waste management and all technology areas as a benchmark.

Overall, between 1990 and 2023, the share of inventions related to plastics waste management increased from 0.1% in 1990 to 0.4% in 2023 of all inventions in all technical fields. A dramatic acceleration in plastics patenting is evident: the last 9 years alone account for almost half (46%) of all plastics patents since 1990. The dynamics of inventive activity in plastics waste management during the rapid growth period 2015-2023 outperforms the global benchmark by orders of magnitude, suggesting plastics-specific drivers such as sustainability trends, regulatory changes or technological breakthroughs.

Figure 5

Normalised data for IPFs covering plastics waste management and for all technology fields (reference year: 1990)



Source: EPO

2.2 Specific technologies

A closer analysis of the different technology areas related to plastics waste management provides further insights into the drivers of the overall growth in patenting observed in this sector.

Table 2 shows the five most patented technologies at the beginning of each decade. It reveals that most of the changes take place in the 2020s. Pyrolysis overtakes mechanical processing of used plastics as the most patented technology after 2020, while chemolysis consolidates its third place. Packaging recycling enters the top 5 for the first time after 2020, indicating very high growth in patenting, while plastics waste recycling in the automotive sector remains an important but less dynamic area of recycling innovation.

Table 2

Top five technologies at the beginning of each decade (IPF-based; cumulative share of IPFs, 1990-2023)

1990-94	
Mechanical processing of used plastic	184
Chemolysis	92
Post-Consumer: Automotive	56
Pyrolysis	52
Selective dissolution	44
Total top 5	**428**
Weight in total IPFs	**55%**

2000-04	
Mechanical processing of used plastic	284
Chemolysis	124
Post-Consumer: Automotive	104
Pyrolysis	86
Washing and cleaning	71
Total top 5	**669**
Weight in total IPFs	**54%**

2010-14	
Mechanical processing of used plastic	354
Pyrolysis	201
Post-Consumer: Automotive	163
Chemolysis	157
Washing and cleaning	95
Total top 5	**970**
Weight in total IPFs	**55%**

2020-23	
Pyrolysis	540
Mechanical processing of used plastic	475
Chemolysis	473
Post-consumer: Packaging	304
Post-consumer: Automotive	199
Total top 5	**1991**
Weight in total IPFs	**50%**

Table 3 provides a more comprehensive overview of the landscape. Again, waste recycling technologies dominate the patent landscape, with mechanical processing of used plastics, pyrolysis and chemolysis emerging as the most prominent fields (see Boxes 2 and 3 for examples of recycling patents). In waste recovery, areas such as selective dissolution, washing and cleaning, and collecting in general show consistent patenting activity over time, suggesting that they are core areas of innovation.

However, the results regarding the recent directional shift in both branches of plastics waste technologies can be better understood by looking at those IPFs with robust performance from the mid-2010s onwards. The sub-fields showing emerging dynamics from 2015 and 2023 are as follows:

- **Strong lead growth technologies:** selective dissolution and optical methods stand out in recovery, while advanced methods such as pyrolysis and chemolysis to convert plastics into new feedstocks for further use as raw materials perform strongly in waste recycling
- **Explosive niche growth technologies:** technologies that address critical challenges in waste recovery, namely persistent pollutants such as microplastics, nanoplastics and PFAS, accompanied by an upturn in activity in sector-specific applications such as packaging and textiles in waste recycling
- **Areas of high future potential, displaying low but growing activity:** these areas include chemical recovery and biological processes in waste recovery, and healthcare and cosmetics in waste recycling

Table 3

Development of specific technologies (IPFs, 1990-2023)

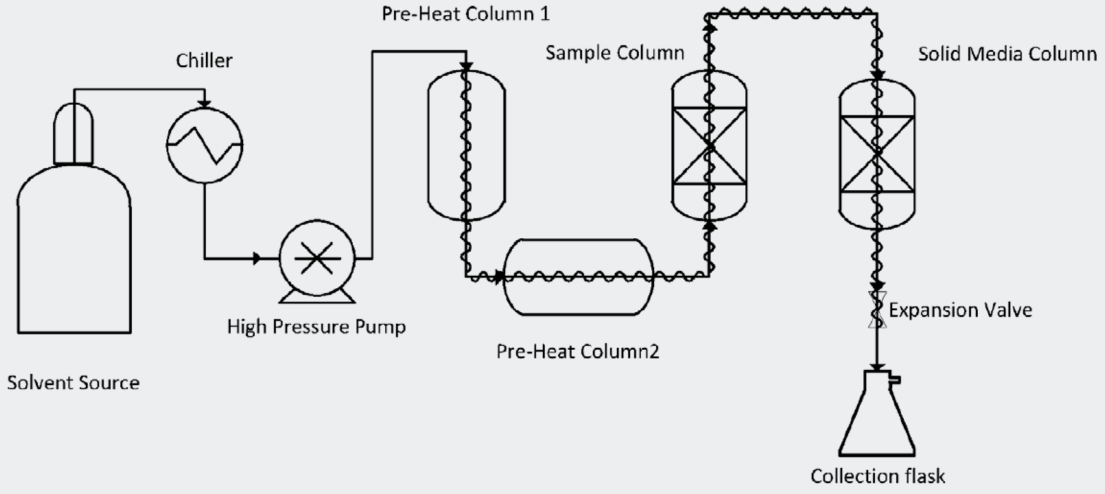
Source: EPO

Box 2. Method for purifying contaminated reclaimed polyethylene

(EP3317338A1)

This invention introduces a process for the purification of contaminated polyethylene derived from post-consumer and post-industrial waste. The process involves extracting impurities from reclaimed polyethylene using a high temperature, high pressure fluid solvent, followed by dissolution, solid media purification and separation to produce high quality, virgin-like polyethylene. The process is particularly effective at removing contaminants such as dyes, pigments and residual odours, resulting in a colourless, odourless polymer suitable for high value applications such as food packaging.

The approach uses low-boiling solvents such as C4 liquefied petroleum gas and employs solid media, such as silica, activated carbon or recycled glass, for purification. By operating at optimised temperatures (80°C to 220°C) and pressures (about 1 to 100 MPa), the process ensures efficient decontamination and minimises cross-contamination. This scalable and environmentally friendly process addresses the limitations of traditional mechanical recycling and provides a sustainable solution for producing high purity recycled polyethylene.

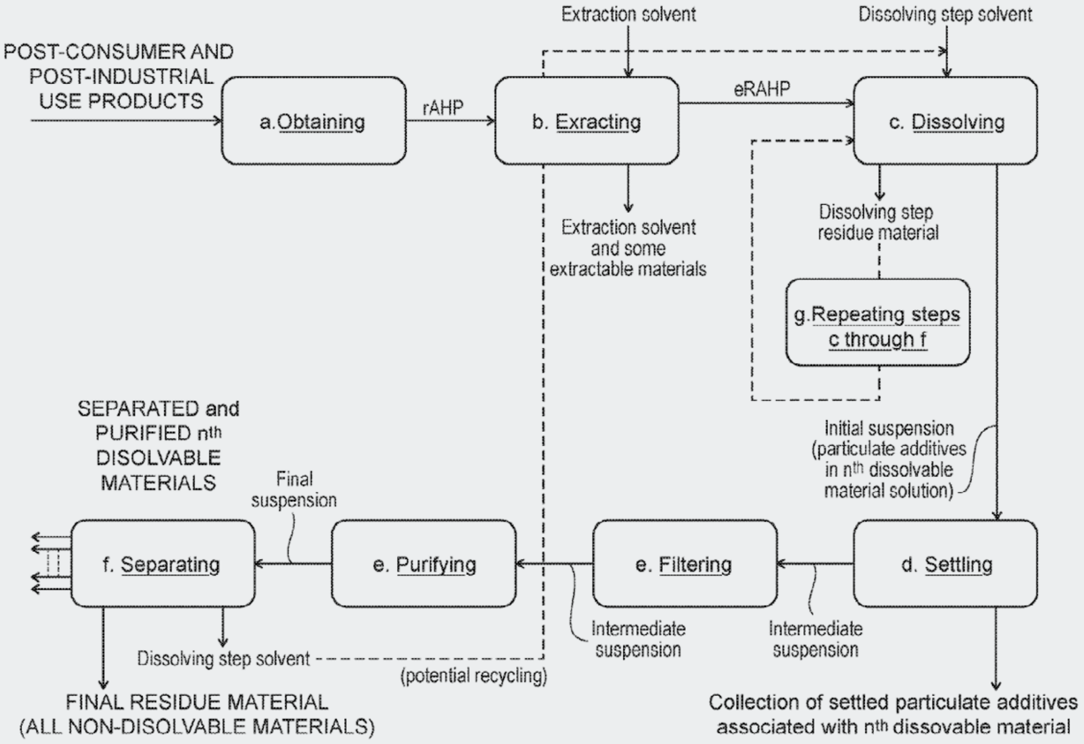


Box 3. Method for separating and purifying polymers from reclaimed product

(EP3810685A1)

This invention presents an advanced process for separating and purifying polymers from recovered products, including post-consumer and post-industrial waste such as absorbent hygiene products and packaging films. The process involves the extraction of contaminants using a high-temperature, high-pressure solvent, followed by sequential dissolution, settling, filtering and purification of individual polymers. The process produces high quality, virgin-like polymers that are colourless, odourless and free of cross-contamination. Key improvements include the use of low-boiling solvents, optimised temperature and pressure conditions, and solid media for purification.

The invention overcomes the limitations of traditional mechanical and chemical recycling and enables polymers such as polypropylene (PP), polyethylene (PE) and polyethylene terephthalate (PET) to be recovered for reuse in high-value applications, including food packaging and hygiene products. This scalable and efficient process reduces reliance on fossil-based virgin plastics, minimises waste and contributes to environmental sustainability.



3. Origins of innovation

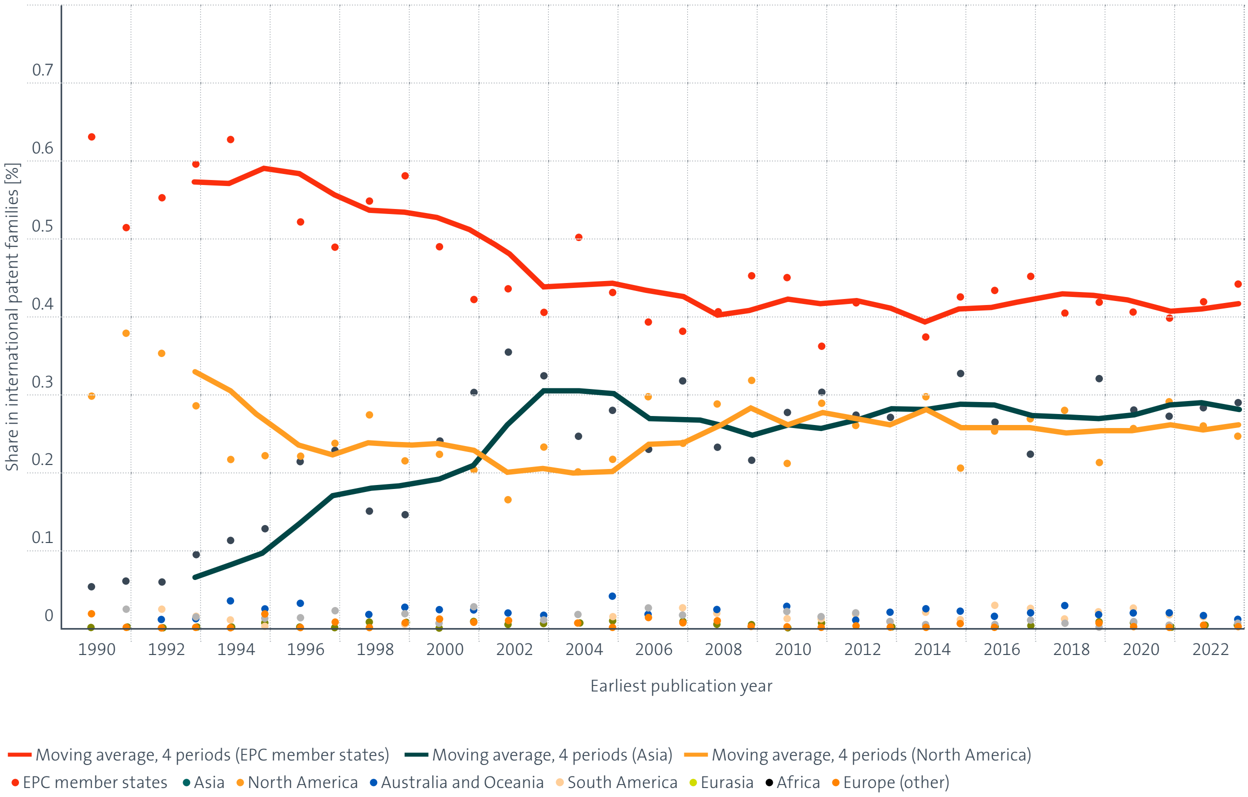
3.1. Regional trends

European applicants made the largest contribution to waste management technologies, accounting for 44% of all plastics-related patenting activity over the whole period. North America and Asia are the other two main regions from which new technologies related to plastics waste management originate.

Figure 6 traces the geographical origin of contributions to the field, illustrating the increasing globalisation of innovation capabilities and the long period of peer competition between major world regions. Concentration in terms of shares decreased significantly until around 2000 and has remained more or less stable since then. In 1990, Europe accounted for nearly 60% of all IPFs, more than twice as many as North America at 32%; with Asia accounting for only 7%. The 1990s saw the emergence of Asia as an innovator, along with major adjustments in patenting shares. By 2023, Europe remained the global leader (46%), while Asia (27%) had overtaken North America (25%).

Figure 6

Major world regions as locations of innovation in plastics waste management (IPFs; based on inventor country; dataset restricted to IPFs with EP and/or WO patent family members for comprehensive coverage of inventor country information; 1990-2023)



Source: EPO

Table 4 shows the breakdown of IPF shares for the top 20 countries in the total plastics waste management sector. It shows the countries with more than 1% of patenting share over the period 1990-2023. The US has consistently been the main player in patenting activity, but its share has gradually declined over time, peaking at 34% in 1991, bottoming out at 17% in 2015 and recovering to 23% in 2023. Japan peaked at 30% in 2022 (above the US in that year) only to decline and eventually stabilise at around 12%. The trend in Germany, ranked in third place, tends to decline for most of the period in question, but manages to reach 12% in the final year after a few years of steady recovery at the turn of the 2020s. Asian countries such as China, R. Korea and India became emerging players during these decades, while European countries such as France, Italy, the United Kingdom, the Netherlands and Austria remained constant contributors. Finally, it is worth noting that the 2010s were characterised by an increasing concentration in these top 20 countries.

Table 4

Top countries in plastics waste management technologies (IPFs, inventor countries with a share of at least 1 percent in the period 1990-2023)

Earliest publication year	Inventor country																			
	US	JP	DE	FR	IT	CN	GB	KR	AT	NL	CA	BE	AU	ES	IN	CH	FI	SE	Other	Grand Total
1990	21.05%	5.26%	19.30%	4.39%	15.79%	0.00%	3.51%	0.00%	7.02%	2.63%	8.77%	0.00%	0.00%	0.00%	0.00%	1.75%	3.51%	1.75%	5.26%	100%
1991	34.32%	5.92%	24.85%	6.51%	9.47%	0.00%	3.55%	0.00%	1.18%	1.18%	3.55%	0.00%	2.37%	0.00%	0.00%	2.37%	1.18%	0.00%	3.55%	100%
1992	31.34%	4.78%	27.76%	2.79%	4.78%	0.00%	7.70%	0.00%	3.98%	0.00%	3.98%	0.40%	1.06%	0.40%	0.00%	3.19%	2.39%	1.59%	3.85%	100%
1993	25.48%	8.27%	36.96%	3.86%	2.76%	0.00%	2.87%	0.55%	3.31%	2.87%	2.76%	1.21%	1.10%	0.00%	0.00%	3.59%	0.00%	0.55%	3.86%	100%
1994	17.57%	10.42%	36.49%	7.82%	3.47%	0.00%	2.90%	0.00%	1.16%	1.16%	4.05%	1.74%	3.47%	1.16%	0.00%	4.63%	0.58%	1.16%	2.22%	100%
1995	20.30%	9.09%	33.94%	4.24%	5.15%	1.21%	4.24%	1.82%	2.73%	3.64%	1.82%	0.00%	2.42%	0.00%	0.00%	2.73%	0.00%	2.42%	4.24%	100%
1996	20.82%	20.71%	27.20%	4.71%	2.51%	0.00%	5.02%	0.00%	3.14%	1.26%	1.26%	1.88%	3.14%	0.63%	0.00%	1.57%	0.63%	0.94%	4.60%	100%
1997	22.99%	18.44%	18.07%	8.11%	2.21%	2.21%	2.40%	2.21%	2.21%	4.36%	0.74%	1.29%	0.74%	1.48%	0.00%	2.21%	0.00%	2.95%	7.38%	100%
1998	25.08%	9.99%	26.86%	3.88%	6.66%	1.00%	2.66%	2.33%	0.67%	1.66%	2.33%	2.55%	1.66%	0.00%	0.67%	2.33%	0.67%	2.66%	6.33%	100%
1999	20.29%	10.49%	22.72%	5.24%	3.50%	0.58%	4.27%	2.04%	2.33%	0.87%	1.17%	3.20%	2.04%	0.87%	0.29%	3.20%	0.58%	4.08%	12.23%	100%
2000	21.99%	20.09%	21.90%	5.69%	2.84%	1.71%	1.71%	1.71%	3.98%	1.04%	0.28%	1.99%	2.27%	1.71%	0.00%	2.27%	0.57%	1.71%	6.54%	100%
2001	18.10%	28.04%	19.88%	3.12%	2.00%	0.45%	3.56%	1.34%	1.34%	4.60%	1.56%	2.37%	1.34%	0.89%	0.00%	0.89%	1.34%	0.00%	9.20%	100%
2002	15.31%	29.59%	19.54%	4.63%	3.24%	0.95%	6.05%	2.29%	1.82%	1.42%	1.19%	0.24%	1.90%	0.47%	1.90%	1.82%	0.47%	0.95%	6.21%	100%
2003	19.68%	29.51%	14.62%	4.06%	3.79%	1.08%	6.23%	1.62%	2.71%	0.54%	2.44%	1.90%	1.08%	0.00%	0.00%	1.62%	0.54%	0.54%	8.03%	100%
2004	19.04%	18.55%	13.83%	4.80%	6.35%	2.20%	4.48%	2.93%	4.64%	1.22%	0.98%	3.91%	0.49%	2.93%	0.49%	0.73%	0.49%	0.00%	11.96%	100%
2005	19.37%	22.38%	14.24%	3.84%	3.62%	1.96%	4.75%	1.81%	1.81%	0.00%	0.45%	2.71%	4.07%	2.26%	0.45%	1.58%	0.90%	0.23%	13.56%	100%
2006	27.51%	12.72%	13.88%	3.99%	2.99%	2.00%	3.16%	6.98%	0.50%	1.50%	1.75%	2.74%	1.25%	1.00%	0.25%	1.66%	2.00%	0.25%	13.88%	100%
2007	20.22%	25.61%	12.91%	2.46%	4.85%	1.02%	4.30%	2.05%	0.41%	0.61%	1.84%	1.64%	0.00%	2.25%	0.82%	1.43%	0.41%	0.82%	16.33%	100%
2008	27.72%	12.79%	11.30%	3.84%	1.71%	3.84%	5.76%	2.99%	2.77%	1.07%	1.07%	2.13%	2.35%	3.84%	0.21%	3.20%	0.43%	0.43%	12.58%	100%
2009	30.45%	13.35%	17.67%	2.99%	6.10%	3.24%	4.26%	2.86%	2.48%	2.29%	1.34%	0.38%	0.00%	0.76%	0.00%	1.34%	1.91%	0.95%	7.63%	100%
2010	19.17%	14.16%	15.85%	4.66%	4.90%	4.55%	4.66%	5.59%	1.75%	1.05%	1.57%	1.05%	2.45%	1.92%	0.52%	0.52%	1.40%	0.35%	13.87%	100%
2011	25.84%	13.64%	13.28%	4.33%	4.06%	5.52%	3.76%	7.14%	2.27%	1.30%	2.76%	2.87%	0.81%	0.97%	1.22%	1.43%	0.19%	0.32%	8.28%	100%
2012	22.05%	12.59%	12.67%	5.29%	3.67%	6.48%	4.17%	4.46%	1.75%	3.67%	3.35%	1.67%	0.32%	3.19%	1.91%	1.28%	0.48%	0.32%	10.68%	100%
2013	25.76%	11.29%	9.93%	4.01%	6.25%	7.32%	2.91%	3.01%	5.87%	1.66%	1.35%	1.96%	1.66%	2.06%	2.91%	0.55%	0.75%	0.45%	10.31%	100%
2014	27.98%	14.58%	11.32%	4.92%	5.11%	3.60%	4.59%	2.84%	1.14%	1.56%	1.70%	1.37%	2.18%	1.23%	3.36%	1.14%	0.85%	0.57%	9.94%	100%
2015	16.56%	17.95%	10.33%	5.98%	5.67%	5.98%	4.97%	2.83%	1.13%	2.14%	3.59%	0.13%	2.08%	2.08%	3.53%	1.45%	0.88%	1.32%	11.40%	100%
2016	24.11%	13.14%	11.54%	5.98%	5.26%	5.15%	2.63%	2.78%	1.65%	2.01%	1.18%	0.15%	0.72%	2.63%	3.55%	1.08%	1.08%	1.03%	14.32%	100%
2017	25.41%	9.75%	12.79%	5.68%	5.18%	6.55%	3.00%	2.35%	2.70%	3.26%	1.17%	2.33%	1.83%	1.46%	0.78%	0.91%	1.04%	1.31%	12.49%	100%
2018	23.75%	13.99%	7.15%	5.45%	6.01%	4.92%	3.09%	4.58%	2.35%	3.14%	3.79%	1.96%	2.57%	1.31%	2.22%	0.39%	1.83%	1.96%	9.54%	100%
2019	17.70%	14.60%	10.00%	5.33%	3.68%	10.92%	8.01%	4.48%	2.18%	1.03%	3.22%	1.26%	1.61%	0.69%	0.34%	1.65%	0.69%	1.84%	10.77%	100%
2020	21.41%	11.54%	8.21%	3.61%	4.45%	8.42%	4.48%	4.00%	2.68%	3.11%	4.06%	2.52%	1.52%	1.77%	2.11%	0.88%	1.82%	1.56%	11.85%	100%
2021	26.86%	11.90%	10.07%	5.45%	4.92%	5.55%	4.12%	3.73%	2.04%	1.98%	2.10%	2.10%	1.65%	1.52%	2.05%	1.07%	1.73%	1.03%	10.11%	100%
2022	23.12%	12.46%	11.10%	5.38%	5.64%	5.54%	3.91%	4.75%	2.31%	4.79%	2.52%	1.28%	1.50%	1.35%	2.34%	0.55%	1.84%	1.27%	8.36%	100%
2023	22.99%	13.17%	11.51%	6.08%	4.36%	3.63%	1.59%	7.43%	3.65%	2.98%	1.56%	2.67%	1.14%	2.15%	1.62%	1.20%	2.15%	1.50%	8.63%	100%
Grand Total	**23.07%**	**14.31%**	**14.25%**	**4.94%**	**4.65%**	**4.33%**	**3.93%**	**3.73%**	**2.46%**	**2.35%**	**2.19%**	**1.80%**	**1.57%**	**1.53%**	**1.42%**	**1.37%**	**1.23%**	**1.15%**	**9.72%**	**100%**

0-0.9 1.0-4.9 5.0-9.9 10.0-14.9 15.0-19.9 20.0-24.9 25.0-29.9 30.0-34.9 35.0-39.9

International competitiveness can be assessed through the technological capabilities of world regions and individual countries. Table 5 shows the specialisation profiles of world regions as measured by the revealed technological advantage (RTA) index. The RTA assesses a region's focus on a specific technological subfield compared to its overall innovation capacity. It is calculated by dividing the share of a particular technology area in the region's total IPFs by the share of that technology in the world. An RTA value above one indicates that a region or country is specialised in that particular technology. Europe shows a focus on macroplastic processing and on mechanical and physical methods (e.g. density-type separation, washing), reflecting a strong emphasis on traditional technologies. Asia is highly specialised in chemical methods (e.g. extraction, catalytic cracking) and advanced technologies (such as irradiation), indicating a focus on novel and highly efficient processes. North America relies on chemical and energy-intensive processes (e.g. hydrolysis, oxidation), but also on high-value applications and niches (such as healthcare and nanoplastics) and appears to prioritise market-oriented knowledge.

Table 5

Revealed technology advantage (RTA) in plastics waste management, top 5 subfields (IPFs, 1990-2023)

Europe	**RTA**
Recovery: Macroplastics	1.4
Pre-consumer recycling: plastic to product	1.4
Recovery: Density or gravity	1.3
Post-consumer recycling: Agriculture	1.3
Recovery: Washing and cleaning	1.3

Asia	**RTA**
Recovery: Extraction	2.2
Post-consumer recycling: Cosmetics	2.1
Irradiation	2.0
Recycling: Catalytic cracking	1.8
Recovery: Bisphenol A	1.7

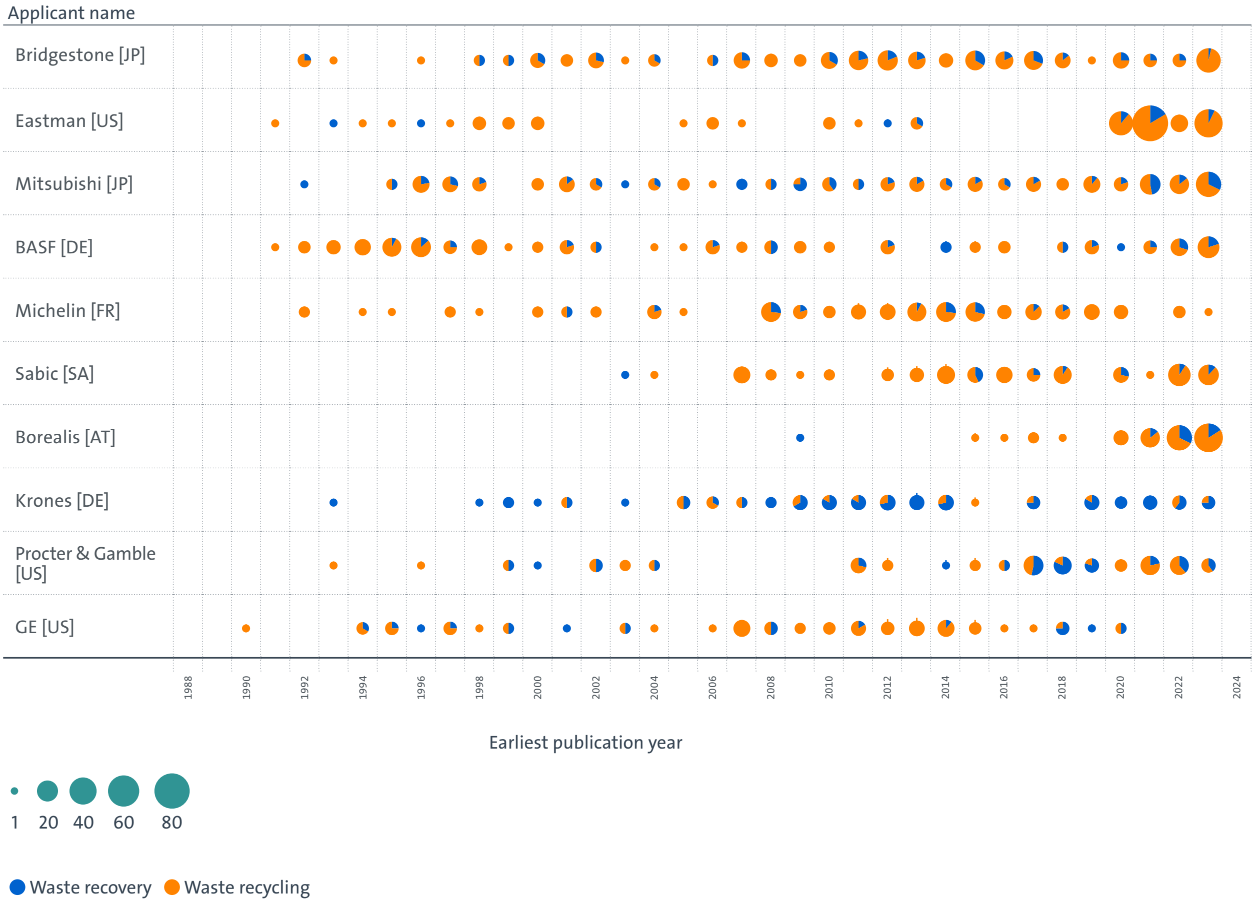
North America	**RTA**
Recovery: Hydrolysis. evaporation	2.5
Recovery: Oxidation. reduction	1.8
Post-consumer recycling: Healthcare	1.8
Recovery: Nanoplastics	1.8
Recovery: Magnetic. electrical	1.8

3.2. Top applicants

European applicants made the largest contribution to waste management technologies, accounting for 44% of all plastics-related patenting activity over the whole period. North America and Asia are the other two main regions from which new technologies related to plastics waste management originate.
Figure 6 traces the geographical origin of contributions to the field, illustrating the increasing globalisation of innovation capabilities and the long period of peer competition between major world regions. Concentration in terms of shares decreased significantly until around 2000 and has remained more or less stable since then. In 1990, Europe accounted for nearly 60% of all IPFs, more than twice as many as North America at 32%; with Asia accounting for only 7%. The 1990s saw the emergence of Asia as an innovator, along with major adjustments in patenting shares. By 2023, Europe remained the global leader (46%), while Asia (27%) had overtaken North America (25%).

Figure 7

Top 10 applicants in plastic waste management technologies (IPFs, 1990-2023)



Source: EPO

Tables 6 and 7 provide a more detailed overview of the portfolios of the top 20 applicants in waste recovery and waste recycling, respectively. Collectively, these top 20 applicants achieved 13.2% and 17.5% in the respective technologies over the period 1990-2023.

As shown in Table 6, the top applicants in waste recovery operate in a wide range of industries. The chemicals industry is the most represented (Solvay, Nitto Denko, Bayer, Eastman, BASF, Borealis, LG Chem), followed by packaging (Krones, KHS, Sidel), consumer goods (P&G, Unicharm), electronics (Panasonic, Edwards) and tires manufacturing (Bridgestone, Michelin). The list is completed by Tomra Systems (a pure player in the recycling industry), Mitsubishi (automotive), DNP (printing) and the Fraunhofer Gesellschaft (a public research organisation). Despite these differences, most top applicants focus on similar recovery technologies, such as washing and cleaning, selective dissolution, recovery through density and gravity, and mechanical methods. It is worth noting that approximately half of the top 20 applicants is headquartered in Europe.

Table 6

Top 20 applicants in plastic waste recovery technologies (IPFs, 1990-2023)

Applicant	Country of residence ofresidence	Vessels	Other devices	Macroplastic	Microplastic	Nanoplastic	Phthalates	Bisphenol A	PFAS	Filtration, osmosis	Flotation, sedimentation	Hydrolysis, evaporation	Extraction	Sorption	Irradiation	Mechanical removal	Magnetic, Electric	Flocculation, precipitation	Oxidation, reduction	Biological methods	Collecting in general	Optical	Chemical	Selective dissolution	Electrostatic	Magnetic	Density, gravity	Other mechanical sorting and separating	Other methods of sorting and separating	Washing, cleaning	**Grand Total**
Krones	DE	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	1	6	0	2	1	0	3	2	1	57	65
Mitsubishi	JP	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	1	0	1	0	3	10	0	11	8	0	4	2	1	13	48
Dai Nippon Printing	JP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	45	46
Procter & Gamble	US	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	3	0	29	0	0	5	2	0	3	40
Panasonic	JP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	12	0	12	2	1	5	1	4	4	39
Bridgestone	JP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	32	1	3	39
KHS	DE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	31	31
Unicharm	JP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	17	1	0	5	13	3	8	28
Edwards	GB	0	0	0	0	0	0	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28
Solvay	BE	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	22	1	0	2	1	0	0	27
Nitto Denko	JP	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	0	1	2	0	19	25
Fraunhofer-Gesellschaft	DE	0	0	0	0	0	0	1	4	1	0	0	0	1	0	1	3	1	0	0	0	4	0	10	0	1	3	3	1	1	24
Bayer	DE	0	0	0	0	0	0	1	0	1	1	1	2	7	0	0	3	2	1	1	0	4	0	3	0	0	1	3	1	3	24
Eastman	US	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	3	4	0	9	1	3	9	5	1	5	23
BASF	DE	0	0	1	1	0	0	0	0	2	1	0	0	3	0	0	0	0	0	0	3	4	1	8	0	1	1	2	1	1	23
LG	KR	0	0	0	0	0	2	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	10	0	0	1	0	0	7	21
Tomra	NO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	4	0	0	0	0	0	0	0	0	20
Borealis	AT	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	9	0	9	0	0	7	8	0	13	20
Sidel	IT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	19
Michelin	FR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	1	0	18

0 | 1-5 | 6-10 | 11-15 | 16-20 | 21-25 | 26-30 | 31-35 | 36-45 | 56-60

The list of the top 20 applicants in plastic waste recycling includes eight of the top applicants in waste recovery, with all top five applicants in waste recycling featuring in both rankings. The chemicals industry (Eastman, BASF, Sabic, Borealis, Dow, DuPont, Bayer, Arkema, Nan Ya Plastics) and the tyre industry (Michelin, Bridgestone, Goodyear) alone provide twelve of the top twenty applicants, with IFP Energies Nouvelles, a French research centre focused on petrochemicals, also featuring in the ranking. Notably, eight of the top 20 applicants are based in Europe, including the only two pure players of plastics recycling featured in the ranking: Germany's Erema and France's Carbios.

Table 7

Top 20 applicants in plastic waste recycling technologies (IPFs, 1990-2023)

Applicant	Country	Mechanical processing of used plastic	Pre-consumer plastic to product	Healthcare	Packaging	Cosmetics	Electronics	Textile	Automotive	Construction	Agriculture	Pyrolysis	Chemolysis	Gasification	Liquefaction	Catalytic cracking	Enzymatic depolymerisation	Depolymerisation into original monomer	Number of international patent families
Eastman	US	39	5	0	28	3	8	7	9	1	0	101	45	41	26	6	0	14	165
Bridgestone	JP	40	1	0	19	0	4	4	91	0	0	15	15	5	0	0	2	0	153
Mitsubishi	JP	43	2	0	24	6	26	2	20	1	1	10	19	15	2	0	0	2	120
BASF	DE	23	7	2	6	0	3	3	10	5	1	18	49	0	0	1	2	26	115
Michelin	FR	29	3	0	6	0	5	5	89	2	0	3	1	0	0	0	0	0	114
Sabic	SA	6	4	0	2	0	8	0	10	0	0	47	41	0	0	10	0	7	100
Borealis	AT	13	2	0	46	0	5	2	29	0	0	3	5	0	0	0	0	0	81
GE	US	33	1	0	0	0	2	0	4	0	0	2	22	0	0	0	0	1	61
Procter & Gamble	US	6	6	6	19	1	0	2	6	0	1	0	19	0	0	0	3	0	53
Dow	US	7	3	0	25	0	4	6	10	5	0	2	4	0	0	0	0	0	52
DuPont	US	11	7	1	6	0	0	3	7	1	0	2	14	0	0	0	2	12	50
SK	KR	9	0	0	7	1	1	1	4	0	0	26	13	0	0	2	0	4	47
Erema	AT	43	13	0	4	0	2	1	0	0	0	0	2	0	0	0	0	0	45
IFP Energies nouvelles	FR	6	0	0	6	0	1	0	1	0	0	16	17	2	2	0	0	12	43
Goodyear	US	4	1	0	3	0	2	0	30	0	0	0	6	0	0	0	0	0	41
Bayer	DE	9	2	0	0	0	0	2	5	0	0	5	22	0	0	0	2	1	40
Arkema	FR	12	0	0	1	0	1	1	13	0	0	12	8	0	0	0	0	4	38
Carbios	FR	1	0	0	1	0	0	0	0	0	0	0	10	0	0	0	35	5	37
Nan Ya Plastics	TW	9	1	0	6	0	2	1	0	0	0	1	27	0	0	0	0	7	34
Panasonic	JP	18	1	0	1	0	2	1	1	2	0	2	13	0	0	0	0	0	34

0	1-10	11-20	21-30	31-40	41-50	≥ 81

The most active applicants in the field of waste recycling possess a proven track record of patenting innovations related to chemolysis and mechanical processing. IPFs related to more advanced methods such as pyrolysis and depolymerisation can be observed only in subsets of the top applicants, with some patterns of specialisation. Eastman is particularly strong in pyrolysis, while BASF and Carbios are strong leaders in depolymerisation technologies respectively. The top applicants' patenting activities in postconsumer recycling are mainly focused on automotive (with strong contributions from tyre manufacturers Bridgestone and Michelin), packaging and electronics.

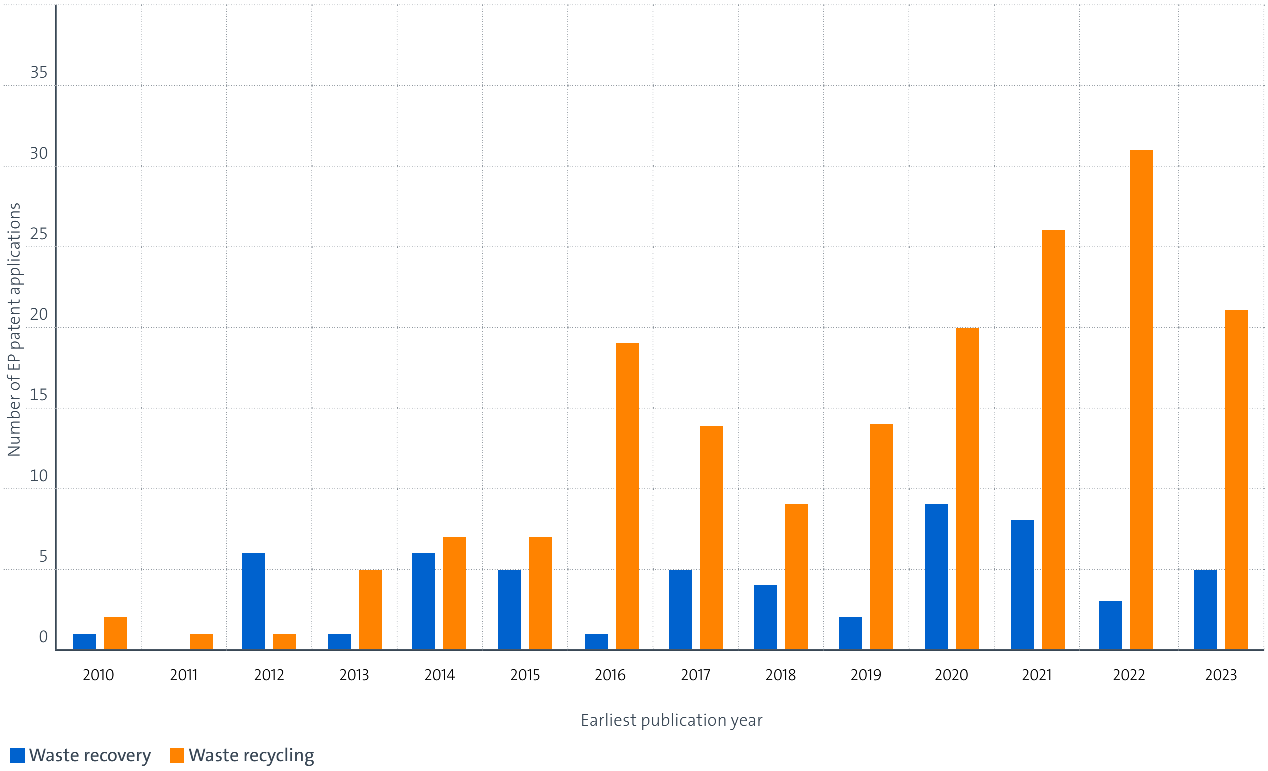
3.3 Focus on European startups and universities

Data from the EPO's Deep Tech Finder provides further insight into the contribution of startups and universities in European countries. In total, 82 individual startups from 16 of the 39 European countries (EPC member states) filed 215 European patent applications in the field of plastics waste management between 2010 and 2023. In addition, 63 European universities contributed 91 European patent applications in this field.

Both startups and universities show a stronger focus on recycling than on recovery technologies, and a rapid acceleration of innovation after 2015. The focus on recycling technologies is especially clear in the case of startups, among which the patent applications related to plastic waste recycling increased sharply over the period, whereas the number of applications related to waste recovery remained stable (Figure 8). As a result, plastics recycling technologies accounted for 80% of patenting activities by European startups between 2010 and 2023 in plastics waste management.

Figure 8

Patenting activities of European startups in plastic waste management (European patent applications, 2010-2023)

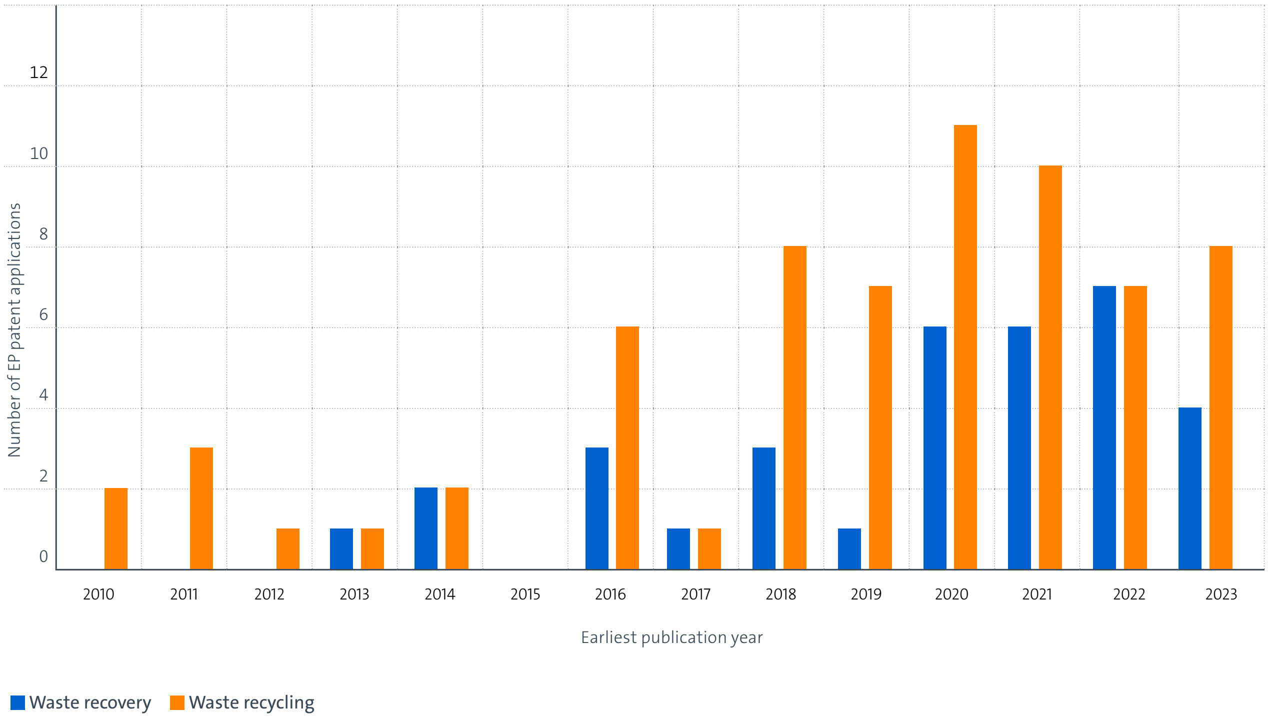


Source: EPO

By comparison, university applications are more evenly distributed between waste recovery and waste recycling technologies (Figure 9). Moreover, both technology fields show an increase in applications from universities over the period.

Figure 9

Patenting activities of European universities in plastic waste management (European patent applications, 2010-2023)



Source: EPO

Table 8 provides a detailed overview of the technology fields in which European startups and universities have been innovating since 2010. Advanced waste recycling methods based on chemolysis, pyrolysis or enzymatic depolymerisation generated the largest number of patent applications among both categories of applicants, along with mechanical processing of plastic waste and plastic recovery through selective dissolution.

While startups generally tend to produce more patent applications in each field, technologies aimed at removing plastics from water are a noticeable exception with more than twice the number of applications filed by universities. This probably reflects both the technical and economic challenges of developing and deploying such plastic removal technologies.

Table 8

Patenting activities of startups and universities by technology fields (European patent applications, 2010-2023)

			Universities	Startups	Total
Recovery	Collecting	Removing from water	15	7	22
		Collecting in general	0	3	3
	Sorting and separating	**Selective dissolution**	**11**	**24**	**35**
		Mechanical	3	15	18
		Density or gravity	2	12	14
		Washing and cleaning	5	9	14
		Optical	4	4	8
		Electrostatic	1	2	3
		Magnetic	1	0	1
		Other methods	3	2	5
Recycling	Mechanical recycling	**Mechanical processing of used plastic**	**14**	**44**	**58**
		Pre-consumer plastic to product	9	20	29
		Post-consumer plastic to product	9	8	17
	Plastic to stockfeed	**Chemolysis**	**29**	**41**	**70**
		Pyrolysis	**12**	**42**	**54**
		Enzymatic depolymerisation	**4**	**44**	**48**
		Depolymerisation into original monomer	0	12	12
		Gasification	2	4	6
		Catalytic cracking	0	3	3

Note: The top 5 fields with the largest numbers of combined contributions by startups and universities are highlighted in bold.

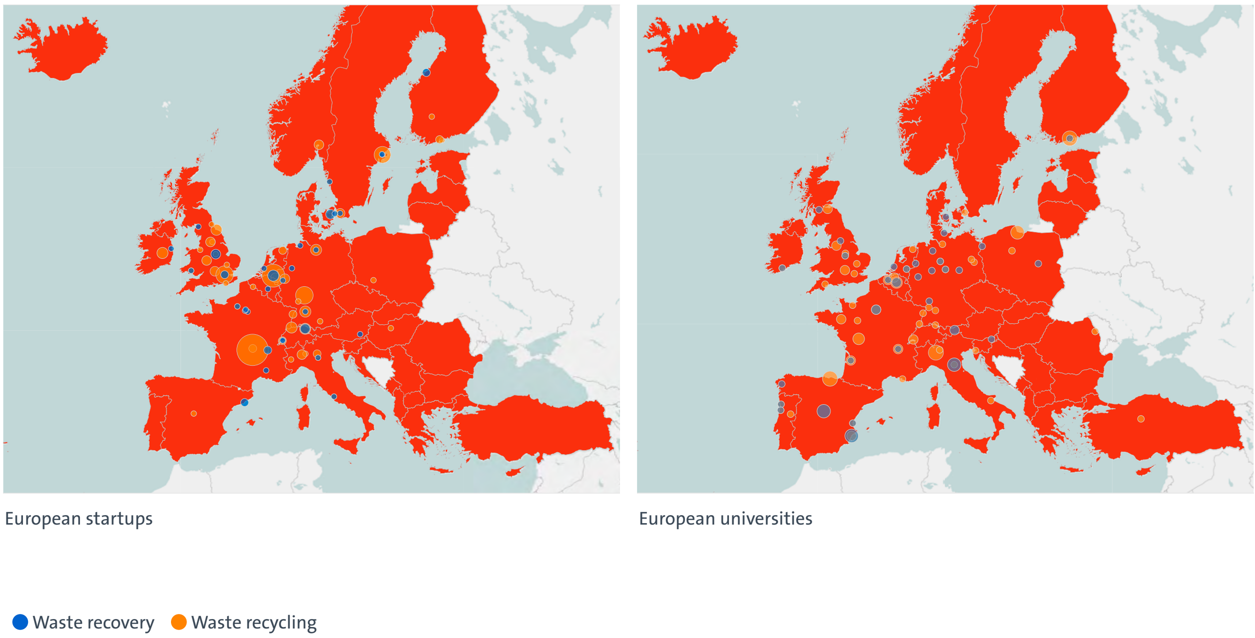
Source: EPO

The number of IPFs contributed by academic institutions is just under half that of start-ups. Growth on both fronts of plastics waste management was steady and consistent as of the mid-2010s, but levelled off in the 2020s. There are 78 universities from 18 countries active in this field, six of which have filed more than 10 patent applications: France, Spain, Germany, the United Kingdom, Italy and Belgium.

Figure 10 shows the geographical distribution of European patent applications filed by startups and universities in the field of plastics waste management technologies. The highest number of startups is seen in the United Kingdom (18), followed by France (11), Germany (9), Sweden (8), Italy and the Netherlands (each with 6 startups). By contrast, France and Germany dominate the university ranking with 14 and 11 universities respectively. Another six patenting universities are located in the United Kingdom, five in Spain, four in Italy and Poland and three in Italy and Portugal. Figure 10 shows that the geographical distribution of enterprises and universities is not identical. While the United Kingdom, the Benelux region, the Upper Rhine region, Switzerland and Northern Italy have a combination of both categories of applicants, a number of coastal regions in Portugal, Spain, France and Poland show significant inventive activity by universities but no patenting activity by local start-ups.

Figure 10

Geographical distribution of European patent applications filed by startups and universities in plastics waste management (European patent applications, 2010-2023)



European startups

European universities

● Waste recovery ● Waste recycling

Source: EPO

Innovation highlight: removing plastics from water

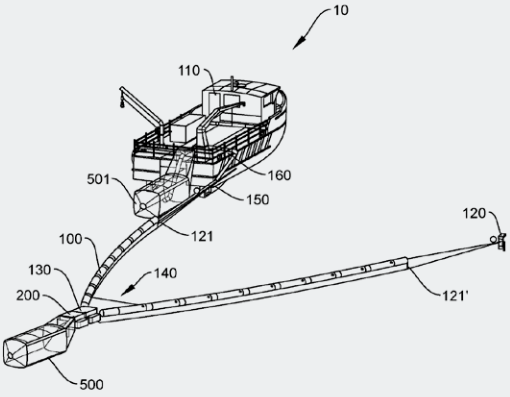
Technologies for water cleanup have become critical since polymers-based waste continues to increasingly threaten aquatic ecosystems and human health. These technologies, which can filter microplastics or capture larger plastic debris from water bodies, can be deployed in riverine, estuarine, coastal and marine environments. Examples are granular media filters and floating barriers that can be used to purify water courses and intercept plastic waste before it reaches oceans. Other developments involve magnetic separation techniques, i.e. ways to bind with nano- or microparticles (the theme of this report's cover), and bioremediation approaches, i.e. enzymes that can break down plastics into harmless byproducts. Such approaches are adaptable, may be enhanced with AI and sensors, and promise to improve cleaning efficiency and effectiveness in the future, especially for collecting plastic waste in hard-to-access areas such as deep ocean floors or densely vegetated waterways.

WO2024005646A1

Patent application example: Trawling system for collecting and sorting floating waste

This invention presents a solution for cleaning oceans, lakes and rivers of floating waste. The system features a sorting unit that separates debris based on size, with larger objects directed towards an exit area and smaller objects collected via a vacuum-assisted conduit.

The approach integrates advanced hydrodynamic engineering including a tapered conduit for optimised water flow, a vacuum-based collection mechanism, deflection components to guide waste and vortex-creating barriers to enhance sorting efficiency. The unit's structured design improves waste retrieval, thus contributing to scalable and effective marine cleanup efforts.

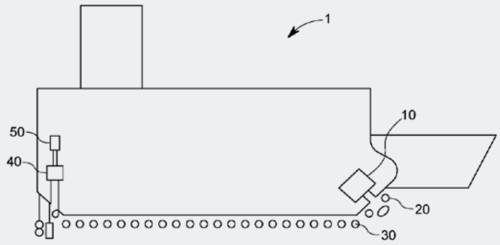


WO2024176045A1

Patent application example: Digital interconnection between vessels for collection of micro-plastics

This system for establishing a secured digital interconnection between vessels seeks to optimise the collection of micro-plastics from aquatic environments. The system includes a collection unit for filtering microplastics, sensors to measure microplastic concentrations and environmental conditions, and a communication device for secure data sharing between vessels. A processing unit analyses this data to predict the optimal route for collecting the maximum amount of microplastics without delaying the vessel's journey.

The system also features an air bubble generation unit to enhance microplastic collection and a purifying unit to separate micro-plastics from water. By enabling real-time data exchange and route optimisation, the invention allows vessels to efficiently contribute to environmental cleanup while maintaining their commercial operations.

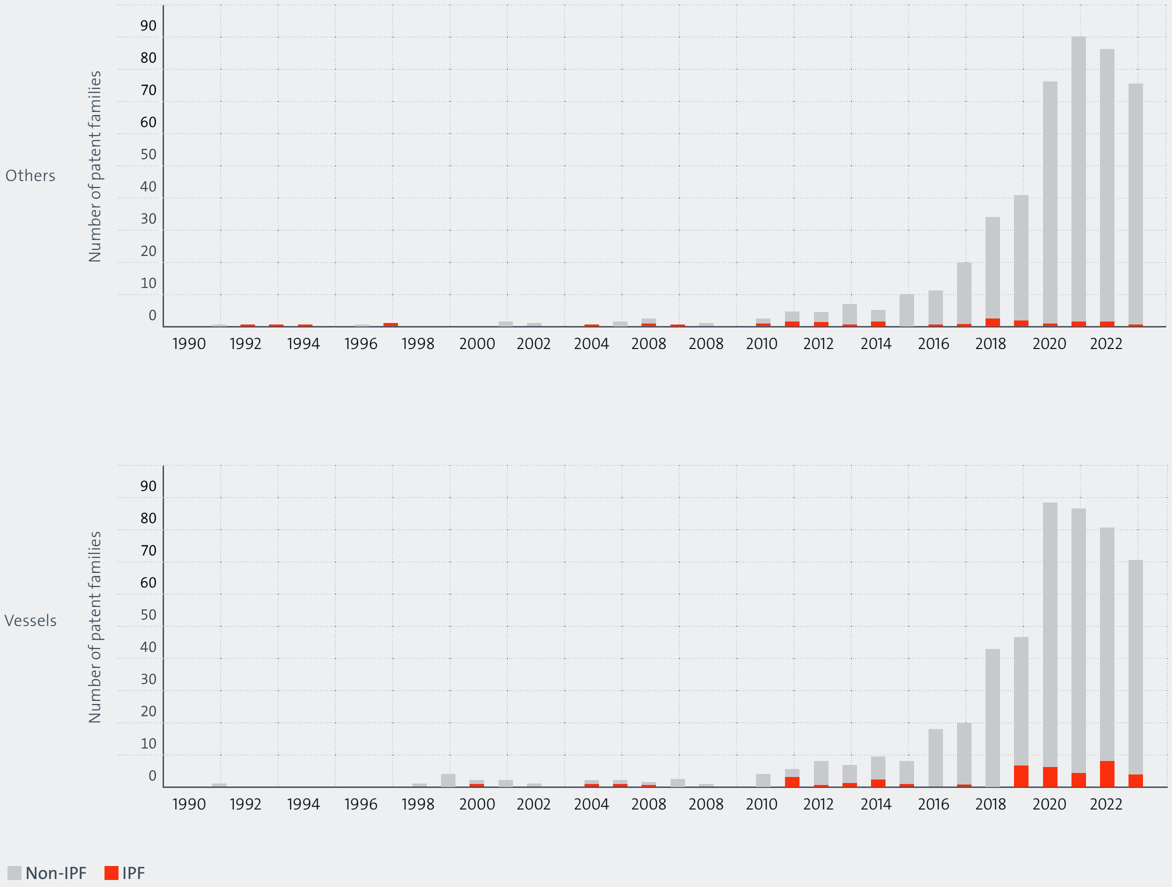


Innovation highlight: removing plastics from water (continued)

Patent statistics for specific technologies related to devices for the removal of plastics from water and technologies related to the removal of additives from water reveal specific subfields in which domestic-oriented patenting differs significantly from international fillings.

There could be several substantive reasons for that, all of which are interesting. Some inventive activity may be driven by individual inventors wishing to do something to solve the problem. IPFs may severely underestimate the extent of such voluntary efforts, but non-IPF can still convey the contextual characteristics of grassroots innovation, as shown by other devices for removing plastics. Another possible explanation may be the inherent difficulty of some industrial lines of research such as the plasticisers found in packaging or personal-care products, or binding agents like phthalates. Here science is still well ahead of technology and regulation.

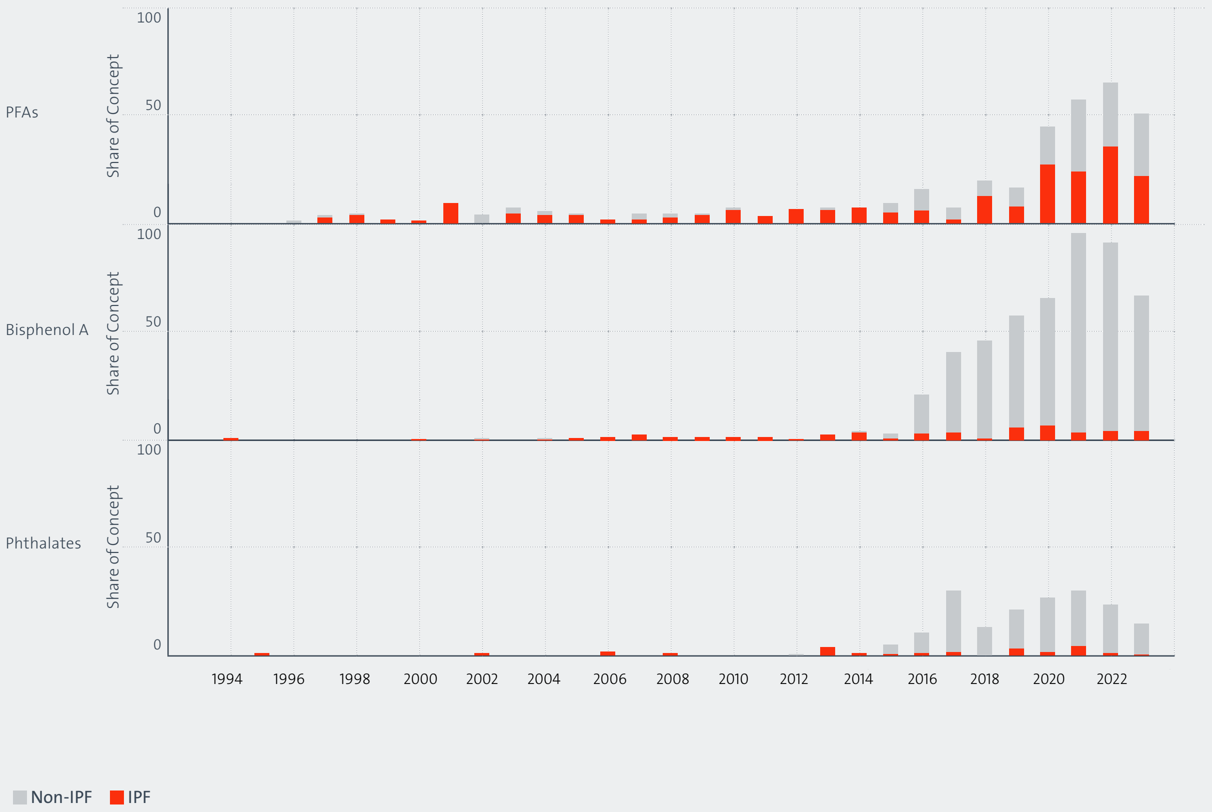
Devices for removal of plastic particles



Source: EPO

Innovation highlight: removing plastics from water (continued)

Removal of additives from water



Source: EPO

Innovation highlight: AI for plastics waste management

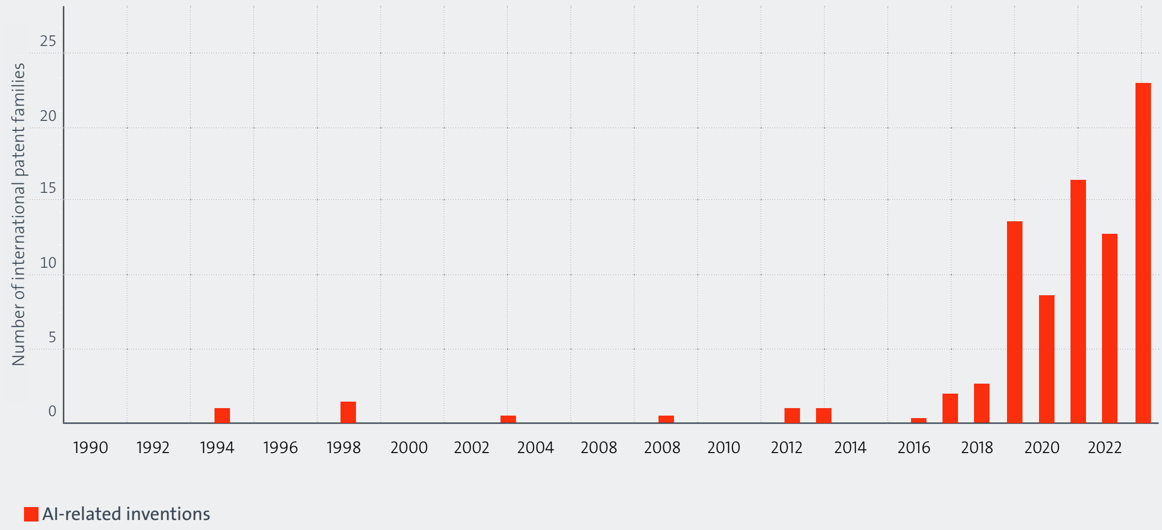
Artificial intelligence in plastics waste management is helping to close the loop in systems and processes for recovering and recycling contaminated plastic materials. With millions of tonnes of plastics of all types generated each year, traditional methods of identifying, separating and treating waste are often inefficient and unable to cope. AI-powered systems, such as machine learning algorithms, digital recognition vision and intelligent robotics, can radically improve collection routing and optimise cleaning tasks through predictive analytics.

Long before AI became a common topic in mainstream conversations, its underlying technologies were making quiet but significant inroads into plastics waste management in the 1990s. In the early years, computational methods and early forms of AI were used, particularly through optical-based sensing devices that relied on growing data inputs to identify patterns in waste streams, enabling more accurate separation of materials such as plastics, metals and paper. Arguably, waste has been a lead market for ICT-driven automation, as processing facilities pose health and safety risks and are filled with noxious fumes, while removing the human element from the attention-demanding tasks of identifying and categorising diverse and damaged used products.

A total of 85 unique inventions related to plastics waste management equipment and processes were identified using search concepts that combine relevant patent classification codes (see Box 4), and keywords related to AI technologies and plastics waste management. The first observations related to AI for plastics waste management are visible from the mid-1990s onwards, only to become uninterrupted about 20 years later i.e. after 2016 all years show AI activities. More than 90% of all AI-related inventions took place after the mid-2010s. It is a recent phenomenon, but with long roots in the industry.

With 39.7% of the total, the EPC member states are the leading applicants for AI inventions, followed by Asia with 23.9% and North America with 26.1%. This leadership is even more pronounced in the boom years of the 2020s.

It is also interesting to compare AI with the other plastics management technologies. The results show that by far the strongest integration is with optical sorting and separation methods (waste recovery), followed by collecting in general (waste recovery) and mechanical processing of used plastics (waste recycling).



Source: EPO

4. Conclusions and outlook

This report sheds light on the field of plastics waste management from the perspective of technological innovation. Patenting activity in this area grew eighteenfold from 1990 to 2023, far exceeding the fourfold increase observed in the benchmark. The acceleration since 2015, particularly in the 2020s, reflects the growing global emphasis on tackling plastic waste. Europe has consistently led in innovation, accounting for 44% of patent activity from 1990 to 2023, with Germany, France, Italy, and the United Kingdom standing out as key contributors. Asia, and particularly Japan, China and South Korea, has emerged as a major innovator, marking a shift in global innovation dynamics.

Plastics waste management technologies are broadly divided into waste recovery and waste recycling, with waste recycling dominating with 68% of inventions. Recent years have seen a shift in the dynamics of innovation, with advanced methods such as pyrolysis and chemolysis gaining prominence in recycling, and selective dissolution and optical methods leading in recovery. Explosive niche growth has been observed in sector-specific applications for waste recycling, including packaging and textiles, and in addressing critical challenges in waste recovery such as microplastics and PFAS. European countries are at the forefront of these advances, particularly in AI-based systems and technologies for removing plastics from water, which stand out as critical technologies for sustainability and competitiveness.

Looking ahead, the outlook for innovation in plastics waste management remains promising. Emerging areas such as enzymatic depolymerisation, chemical waste recovery and biological processes hold significant potential for future growth. While start-ups and universities have yet to play a transformative role, their increased involvement since the mid-2010s signals a growing interest in niche and less explored technologies. As global priorities continue to shift, the move towards circular innovation is setting the stage for further specialisation and radical technological improvements, particularly in tackling persistent pollutants and improving the efficiency of waste recovery and recycling processes. The ongoing reconfiguration of the industrial knowledge base, albeit on a changing international playing field, suggests a dynamic landscape, with Europe set to play a leading role in advancing solutions for plastics waste management.

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Annex

1. Methodology

1.1 Using patent information

In essence, patents are legal rights that give patent holders the right to exclude others from commercially exploiting the patented invention. They can be valid in the country or region for which they are granted. Patents can help attract investment, secure licensing agreements and provide market exclusivity.

Accordingly, patent systems promote innovation, technology diffusion and economic growth by allowing patent holders to secure investment in research and development, education and infrastructure, while requiring them to make their inventions available to the public. The publication of patent applications is a key feature of the patent system and creates a rich repository of technical and other content known as patent information. Patent information enables other inventors, researchers, engineers, managers, investors and policymakers to build on existing inventions, to access knowledge often unavailable elsewhere, and to analyse trends in innovation and market developments. As a result, patent information is at the heart of any patent system.

Patent information enables inventors to build on the published inventions of others and thus avoid the mistake of investing in developing a solution to a problem that has already been solved and potentially protected by others. Patent information contains a wealth of technical and other information, much of which cannot be found in any other source. As the leading provider of high-quality patent information worldwide, the EPO has collected, standardised and harmonised information on more than 150 million patent documents from over 100 countries in its databases, containing more than one billion records. These databases are growing by tens of millions of records every year.

Patent information from these databases is available through numerous free and commercial patent information services provided by patent offices and service providers around the world. The information can be used for a variety of analytical purposes, such as exploring technical trends and the filing strategies of applicants, or calculating indicators of innovation activity, commercialisation and knowledge transfer.

1.2 Methodology of this EPO technology insight report

This EPO technology insight report aims to provide useful insights into technologies related to plastics waste management.

The report is based on publicly available patent information and provides an overview of the relevant technologies.

The methodology of this report is based on a three-step process:

Step 1: create and tune a basic dataset
A basic dataset is created, usually by using different custom search concepts such as building on keywords and on patent classification symbols for specific technologies. It is usually necessary to remove unrelated patent documents, either automatically or manually, in order to improve the quality of the basic dataset.The creation of a meaningful basic dataset is critical to providing a reliable basis for sound patent analysis in step 2.

Step 2: patent data analysis
In this second step, analyses are performed on the basic dataset by aggregating the data to patent families as a representative of inventions, generating descriptive statistics, testing hypotheses, identifying patterns in the data, etc.

Step 3: further processing and visualisation
In this third step, the data is further analysed and processed. The results are visualised and summarised.

1.3 Patent retrieval

For this report, EPO experts developed specific search strategies to identify patent documents related to plastics waste management. The search strategies combine relevant keywords and patent classification symbols (see Box 4: “Plastics waste management technologies and patent classification schemes”). The search strategies were optimised for the EPO’s in-house search tools (see section Annex 1.4). The patent classification symbols and keywords used for this report efficiently capture documents with a focus on plastics waste management.

The volume of search results obtained using the search methodology will increase over time due to the dynamic nature of the technical field and the patent databases, as patent documents related to plastics waste management are continuously added to these databases. Accordingly, we intend to update this report in the future, which would also give us an opportunity to review the latest patent trends related to plastics waste management.

Box 4. technologies for plastics waste management and patent classification schemes

Patent offices assign patent classification symbols to categorise the technical subject matter of a patent or utility model. Patent classification symbols are defined as part of what are known as "patent classification systems". There are various patent classification systems used today by national, regional and international patent offices.

Two patent classification systems are of particular importance.

The **International Patent Classification (IPC)** system is a hierarchical patent classification system used by the EPO and more than 100 patent offices on every continent. It breaks technologies down into eight sections with several hierarchical sub-levels. The IPC system has approximately 75 000 subdivisions and is updated on an annual basis. Further information about the IPC system is available on a dedicated website.

The **Cooperative Patent Classification (CPC)** system builds on the IPC system and provides a more granular and detailed classification structure. The CPC system has more than 250 000 sub-divisions and is updated four times a year. It is used by more than 30 patent offices worldwide, including the EPO. Further information about the CPC system is available on the CPC website.

IPC and CPC classification symbols can be used to quickly retrieve relevant patent documents using search interfaces such as the EPO's free search interface Espacenet, available on the EPO website.

For the purposes of this study, sub-divisions in the IPC and the CPC systems were used and combined with other search terms to restrict the resulting dataset to patent documents closely related to plastics waste management.

The following table shows a selection of the IPC and CPC sub-divisions used:

Sub-division	Description
B03	Separation of solid materials using liquids or using pneumatic tables or jigs; magnetic or electrostatic separation of solid materials from solid materials or fluids; separation by high-voltage electric fields
B07	Postal sorting; sorting; sorting individual articles, or bulk material fit to be sorted piece-meal, e.g. by picking
B29	Working of plastics; working of substances in a plastic state in general
B32	Layered products
B65F	Gathering or removal of domestic or like refuse
C02F1	Treatment of water, waste water, or sewage
C02F3	Biological treatment of water, waste water, or sewage
C07C	Acyclic or carbocyclic compounds
C07D	Heterocyclic compounds
C08	Organic macromolecular compounds; their preparation or chemical working-up; compositions based thereon
C10G1	Production of liquid hydrocarbon mixtures from oil-shale, oil-sand, or non-melting solid carbonaceous or similar materials
D01F13	Textiles or flexible materials not otherwise provided for: Recovery of starting material, waste material or solvents during the manufacture of artificial filaments or the like
F23G7	Incinerators or other apparatus for consuming industrial waste, e.g. chemicals
G01N	Investigating or analysing materials by determining their chemical or physical properties
G06N	Computing arrangements based on specific computational models

1.4 Data sources and tools used

The quality of the patent data analysis largely depends on the completeness, correctness and timely availability of relevant patent information in the patent databases from which the basic dataset for the subsequent analysis is extracted.

It is not possible to guarantee the absolute completeness of the relevant patent information since not all data are available from all patent offices. However, there are several patent databases with very good or excellent coverage of patent information from the main patent offices. These patent databases are mostly based on EPO worldwide patent data as a central source of prior art patent information.

EPO worldwide patent data contains bibliographic and other information on more than 150 million patent documents from more than 100 patent authorities on every continent. This data is available via the EPO's patent information products and services, and other major free and commercial search patent search interfaces.

Patent searches were carried out for this EPO technology insight report using EPO worldwide patent data from the EPO's internal data platforms and search interfaces such as ANSERA[2] in order to create the basic dataset for subsequent patent analyses.

The resulting basic dataset was combined with value-added data contained from the EPO's PATSTAT product line[3], which provided the enriched basis for the patent data analysis step and was used for further processing and visualisation of the data.

1.5 Notes on the limits of the study

This report provides a snapshot of the field of plastics waste management taken in the light of patent data[4]. The methodology on which this report is based can be used freely, which means that everyone can adapt the chosen search and analysis approach to their needs, for example to follow trends and developments in other established or emerging technical fields.

This report makes use of publicly available EPO worldwide patent data as well as EPO in-house and publicly available search and analysis tools.

Like many patent analyses, this report is based on specific search strategies combining keywords and patent classification symbols.

For most patent analyses, it is impossible to simultaneously achieve 100% recall, i.e. to retrieve as many relevant documents as possible and 100% precision, which is to exclude as many non-relevant documents as possible. This study is no exception. The search queries chosen to create the basic dataset for the field of plastics waste management were designed to strike a balance between recall and precision in order to provide a meaningful overview of the field.

[2] See Demey and Golzio (2020) and Scheu et al. (2006):

[3] The Autumn 2024 edition of the PATSTAT product line was used for this report.

[4] Date of extraction of the basic dataset from the EPO's internal data platform: March 2025. The basic dataset was combined with data from the EPO's PATSTAT product line (Autumn 2024 edition), which used backfile data extracted from the EPO's master documentation database (DOCDB) in July 2024.

2. Information on non-international patent families

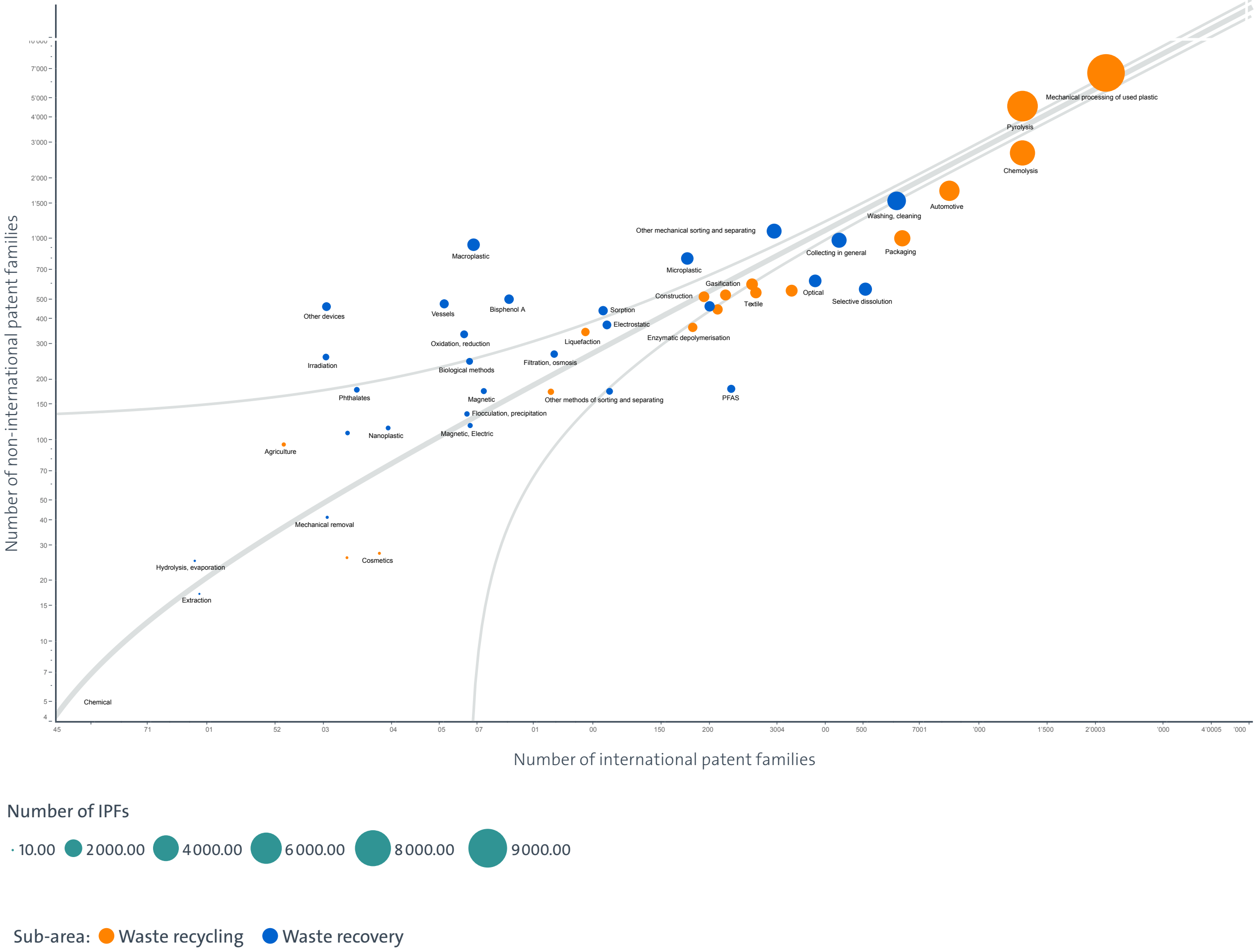
This report centres on published international patent families as a metric to assess innovation activity in plastics waste management technologies.

Putting IPFs into context can also be helpful to get a clearer view of local conditions, such as regulatory and legal constraints. Figure 11 shows the share of IPFs (horizontal axis) versus non-IPFs (vertical axis) in the plastics waste management sector, broken down by specific technologies in the sector. The distribution of technologies suggests a broadly linear relationship between IPFs and non-IPFs (the apparent non-linearity of the compensation curve (grey) is mainly due to the logarithmic scaling used in the graph).

The three technologies with the highest inventive activity in plastics waste management (i.e. mechanical processing of used plastics, pyrolysis and chemolysis) show an average distribution of IPFs versus non-IPFs, whereas other technologies may deviate significantly from the average distribution. For example, several technologies for the recovery of plastics from water, such as macroplastics, containers and other equipment, have a disproportionately high share of non-IPFs. This variation may reflect several reasons, including a response to local needs and incentives in terms of market and regulatory frameworks, and altruistic motives to solve pressing environmental problems rather than economic interests in commercialising technologies. It may also be indicative of technologies that are at an early, research-oriented stage and have the potential to develop into a technology area that creates value for both the economy and the environment.

Figure 11

Share of IPFs versus non-IPF for technologies in the field of plastics waste management (1990-2023, IPFs vs. non-IPFs)



Source: EPO

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Published and edited by
European Patent Office
Munich
Germany

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The EPO gratefully acknowledges the contribution from the following national patent offices during the preparation of this study: Austrian Patent Office, State Intellectual Property Office of the Republic of Croatia , Industrial Property Office of the Czech Republic, French Industrial Property Office, Hungarian Intellectual Property Office, Italian Patent and Trademark Office, Patent Office of the Republic of Latvia, The State Patent Bureau of the Republic of Lithuania, Luxembourg Intellectual Property Office, Monaco Industrial Property Office, Netherlands Patent Office, Industrial Property Office of the Slovak Republic, Slovenian Intellectual Property Office, Turkish Patent and Trademark Office, UK Intellectual Property Office.

The EPO gratefully acknowledges the input received from the United Nations Environment Programme (UNEP) during the preparation of this study.

The cover shows Fionn Ferreira, winner of the third place in the Young Inventors Prize at the European Inventor Award 2023 with his magnet-based method, which extracts microplastics from water.

Design
European Patent Office

ISBN 978-3-89605-397-8