

Polymer Lifecycle Challenges for the Betterment of Society and the Environment



Introduction

Polymers play an ever-expanding role in our everyday lives. Some are easy to identify, such as food packaging, but many others are hidden in the everyday things all around us, from automotive parts to electronic circuit boards and the insulation in our homes. The road to our current polymer-infused world began, like many great endeavors, small but promising.

Modern polymer manufacturing began taking shape in the mid-1900s. In 1950, global polymer production was two million tons.¹ The next two decades showed modest growth in polymer volume and variety of end uses. Then, in the early 1970s, an increasing trend in polymer production began to emerge.² By the year 2018, global polymer production was at nearly 360 million tons, and packaging was long established as the front runner in polymer use.³

TOPICS COVERED IN THIS WHITE PAPER

Polymer Production

Challenges in Polymer Production

- Production Efficiency
- Product Testing/Failure Analysis
- Research and Development
- Regulatory Compliance

Plastics Recycling

- Recycling Methods
- Mechanical Recycling
- Use of Recyclates
- Challenges

Future Outlook

Today, the largest category of polymer use is still packaging, comprising more than one-third of all polymer use. The different uses of polymers in the European Union (EU) in 2018 are depicted on Figure 1.³

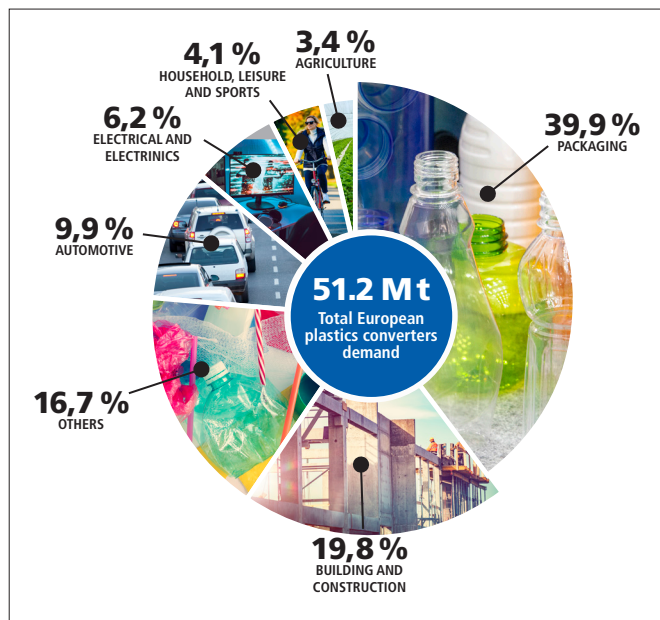


Figure 1. EU Polymer Usage (2018).

Packaging, construction and automotive are the top three categories of usage not only in Europe but also in APAC, the Americas and across the globe. The geographic distribution of global polymer manufacturing is depicted in Figure 2.³

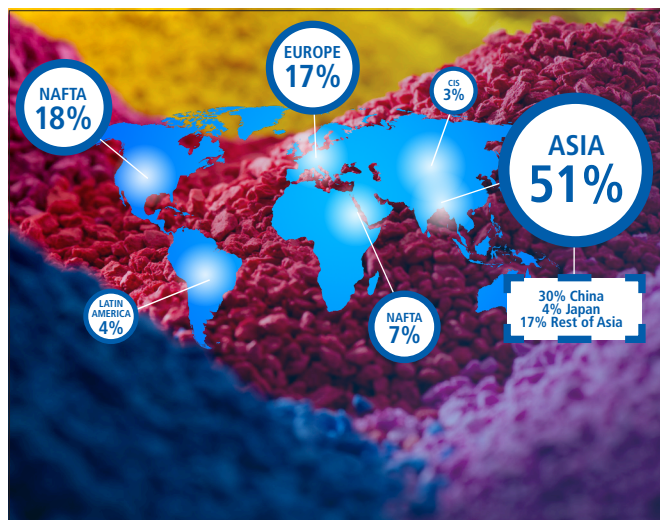


Figure 2. Global Polymer Manufacturing Distribution (2018).

The economic impact of the polymers industry is substantial. In 2018, the global plastics industry produced over USD 700 billion in revenues. APAC was the number one producer and manufacturer of plastic globally, producing more than half the world's plastics volume. EMEA and the Americas produced around 45% of the volume collectively. In terms of revenues, the United States (US) plastics industry generated USD 451 billion in revenue,⁴ the EU plastics industry generated more than USD 406 billion,³ and the China plastics industry generated USD 42 billion.⁵ These substantial revenues are mirrored by employment numbers. In 2018, more than 1.6 million people were employed by the European plastics industry,³ nearly one million were employed by the U.S. plastics industry,⁴ and nearly 600,000 were employed by China's plastic goods industry.⁵ Add to these numbers the indirect employment by material suppliers, equipment manufacturers, and support industries, and the effect is even greater.

Polymer Production

Polymer production requires input from many supporting industries in order to produce the diverse end products used today. The primary types of companies in the polymer production chain are raw material suppliers, resin producers, polymer compounders, polymer converters and polymer recyclers.

Raw Material Suppliers provide the petrochemicals, chemical feedstocks, and additives needed for polymer production.

Resin Producers use combinations of raw materials to manufacture different "master batches" of polymer resins. In many situations the resin producer is also the polymer compounder.

Polymer Compounders create plastic formulations by mixing and blending polymer resins and additives into process-ready granules and flakes.

Polymer Converters use the plastic pellets and flakes to produce end-use products; toys, keyboards, automobile dashboards, packaging for food and consumer goods, and so on.

Polymer Recyclers reclaim recyclable plastics and return them to compounders and converters for reuse.

The demand for better materials that are less environmentally impactful is an ever-present reality for these companies. The competition is fierce to develop new products with advanced performance capabilities that help advance a circular economy for plastics. In addition to industry demands, polymer production companies are continuously searching for ways to improve efficiency, control costs, and streamline their processes, all the while meeting their customers' needs and complying with regulatory standards.

Challenges In Polymer Production

There are some common challenges faced by all companies in the polymer production chain. Companies at each step of the process also have challenges that are unique to their operations.

Production Efficiency

Production delays can negatively impact a company's reputation and financial stability. A comprehensive quality management system guides and monitors the production process from input material to end product and includes the workflow equipment and in-process material specifications.

Input Materials

Quality control (QC) begins with ensuring the input material suppliers know the required specifications for each material being provided. Their pre-shipping test results should be documented and provided for each shipment.

Upon arrival and before being accepted, incoming materials are sampled and analyzed for purity and material specifications. This ensures they have not been contaminated during loading or shipment. It is also a final confirmation that the input material exhibits the required chemical and physical properties. Using a Standard Operating Procedure (SOP) for sample collection minimizes sampling errors, and having on-site analytical capabilities enables real-time decision making.

When input materials are cleared for use, they are transferred from the truck to the facility floor. A good quality management program uses SOPs to guide the transfer, whether it is bulk transfer from transport container to facility container, or transferring entire containers, such as totes or drums, from truck to facility.

INPUT MATERIALS

Raw Material Suppliers: petrochemicals and other chemical feedstocks

Resin Producers: monomers

Polymer Compounders: different polymer resins and diverse functional and processing additives, such as:

- Softeners to increase flexibility
- Stabilizers to increase lifetime use
- Stabilizers to maintain integrity when exposed to light and heat
- Flame retardants
- Dyes and pigments
- Fillers to increase mechanical strength
- Antistatic agents to prevent static charge on the polymer surface
- Lubricants to ease transport of plastic melt in processing machines
- Heat stabilizers to protect plastic during processing from damage due to overheating
- Propellants for foam production

Polymer Converters: new and recycled plastic pellets and flakes

- Polymer Recyclers: collected plastic waste



Figure 3. Company Types in the Polymer Production Chain.

Production Checkpoints

Material control and process control checkpoints along the production workflow provide invaluable data on interim material characteristics, potential contamination, and process integrity. This information can be used to:

- Make adjustments to interim materials so the final product will meet customer specifications.
- Identify contaminants and their sources so they can be removed from the production process.
- Identify workflow processes or equipment that are not functioning correctly.
- Reduce waste generation by minimizing the volume of contaminated or off-specification materials requiring disposal.

The production quality control practices, schedule, and analysis should all support the handling of high sample throughput while maintaining exceptional sensitivity. The customer's purity criteria and product specifications will determine the sensitivity required of the analytical workflow.

These raw materials and in-process quality control practices can go a long way toward maximizing production efficiency and controlling production costs.

Product Testing/Failure Analysis

Product recalls can also negatively impact a company's reputation and financial stability. Companies in each step of polymer manufacturing must carefully test their end products to ensure they meet customer specifications for purity and chemical/physical characteristics. Doing so before a shipment leaves the

facility helps ensure that delivered products are accepted by the receiving facility. Industry and/or company SOPs should be used for the sampling and analysis to aid in getting accurate test results. The "test before shipping" and "test before accepting" dual protocol provides powerful QC checks that help prevent product recalls and the monetary costs of such recalls.

Companies along the polymer manufacturing chain have some common, and some distinct, final product testing needs.

Research and Development

Corporate research and development (R&D) teams are tasked with developing new or better processes and products. The aim of such efforts is to provide the company with a competitive advantage by means of improved products or services, increased efficiency, reduced energy use and waste production, which contributes to the advancement of the circular economy.

In the polymer production industry, resin producers and polymer compounders typically have very active R&D programs, either in-house or contracted. Resin producers focus on creating polymers with specific chemical and physical properties as required by the customer and which exhibit the required characteristics.

R&D in resin production seeks to optimize reaction times, end points, and curing processes, and reduce the presence of residual monomers in the final polymer. Such optimization helps to increase production efficiency and control costs. An integrated sampling and analysis workflow provides the R&D team with fast, accurate data on the effectiveness of process designs. This reduces the amount of time and materials needed to get a new production process confirmed and operational.

Polymer compounders typically have robust R&D divisions to develop new and better compounding formulas and production processes. Compounding R&D teams are tasked with investigating many different facets of plastic production and use, such as:

- Interactions of different polymer/additive mixtures
- Improving strength, flexibility, and other plastic-specific physical attributes
- A product's usable lifetime
- Effects of chemical and environmental degradation
- Biodegradability

R&D teams also investigate innovative ways to increase the recyclability of their products. These and other R&D efforts not only bring better plastic formulations to market, they also identify ways to improve production efficiency, decrease waste generation, and control costs.

Regulatory Compliance

Companies throughout the polymer production chain need to maintain compliance with national, state, and local regulatory requirements. Let us consider a few nearly universal compliance requirements.

FINAL PRODUCT TESTING NEEDS

Raw Material Suppliers test monomers and additives for contaminants, and customer specifications.

Resin Producers test polymer resins or master batches for residual monomers, contaminants and customer specifications.

Polymer compounders test each polymer product for residual monomers, contaminants, and customer specifications including crystal orientation.

Polymer Converters test their finished products to ensure they meet customer quality requirements. The food and pharmaceutical industries, in particular, have very stringent standards for their plastic packaging. Products must be tested for potential contaminants or characteristics that could be detrimental to the end user, such as:

- Release of volatile compounds from food and pharma packaging as well as car interiors
- Toxic metals in toys
- Formaldehyde in toys and fabrics
- Styrene butadiene resin in drywall primer
- Alkylphenols in textiles
- Ethylene vinyl acetate in solar panels and footwear foam
- Polymer Recyclers testing for the quality and purity of the recycle material

Hazardous Materials Permit

A facility that uses input materials that are classified as hazardous will require a permit from the appropriate national regulatory agency to obtain, store, and use those materials. The permit stipulates the types and amounts of materials the facility can obtain, store, and otherwise use in their operations. It also defines the monitoring, record-keeping, and reporting requirements to maintain the permit.

Employee Health and Safety

The raw materials, intermediates, and products of polymer production have the potential to release volatile and semi-volatile organic compounds, and sometimes particulate matter, to the facility's indoor air. Polymer production companies need exposure prevention protocols and monitoring programs to confirm compliance with regulatory limits designed to protect employee health.

Some of the components of an effective health and safety program include:

- Personal protective equipment (PPE) requirements
- Target parameters to be monitored
- Sampling and analysis schedule and SOPs
- Analytical sensitivity requirements
- Remedial action alternatives
- Regulatory reporting requirements, schedule, and means
- Record keeping practices
- Other regulatory-specific requirements

A thorough, well-designed health and safety program promotes employee health and safety and helps the company avoid costly regulatory fines.

Waste Management

Process wastewater and other process wastes are generated by manufacturing facilities of all types. The contents of these and other waste streams produced by a polymer production company depend on the materials and processes used at the facility.

Process wastewater discharge to a treatment facility requires a permit and periodic sampling and analysis. The treatment facility will set the parameters for testing, content limitations, and reporting.

MICROPLASTICS

Microplastics are ever-increasing in the world's marine, freshwater, and terrestrial habitats. The impacts of microplastics on human health and the environment are under intense investigation and will likely be an evolving regulatory issue for the plastics industry. Forward-thinking manufacturers will begin considering ways to monitor their production processes and waste streams for microplastics and develop ways to reduce or eliminate them.

Other process wastes may come from products being off-specification or contaminated. Characterization, storage, and transport of the wastes must comply with national, state, and local requirements. A special permit may be required if any wastes are classified as hazardous. The waste disposal or treatment facility will require analytical data on the content of each unique waste stream to ensure the acceptance of the waste complies with the terms of their operating permit.

Environmental Monitoring and Compliance

The raw materials, intermediates, and products of polymer production have the potential to release organic and inorganic compounds, and sometimes particulate matter, to the outdoor air. An air emissions permit is typically required from the appropriate national regulatory agency. The permit specifies emissions limitations, sampling and analysis requirements, the monitoring and reporting schedule, and other requirements.

A stormwater pollution prevention plan may also be required, depending on the extent of outside storage or operations at the facility. The plan includes sampling and analysis procedures for stormwater discharges, remedial action alternatives, and record-keeping and reporting procedures.

Plastics Recycling

In the EU in 2018, more than 29 million tons of plastic waste collected from post-consumer waste flows. Nearly two-thirds of that plastic waste was packaging material.⁶ In the US in 2017, more than 35 million tons of plastic waste was collected from municipal solid waste flows.⁷ These data provide a glimpse at the magnitude of the global plastic wastes that need to be properly managed.

There are currently three waste management options for plastics:

- Recycling, which promotes sustainability
- Combustion with energy recovery for plastics that cannot be recycled
- Landfill disposal, which is unsustainable and poses environmental issues

Plastics recycling provides important benefits to society and the environment, such as:

- Resource conservation: By returning materials to the polymer production process, recycling reduces the need for virgin raw materials.
- Energy conservation: Using recycled resins instead of virgin resins has been shown to reduce energy consumption during plastics production by up to 88%.⁸
- Decreased environmental impacts: Using recycled plastics has been shown to reduce air emissions during plastics production by up to 71%.⁸

It is clear that plastics recycling plays a pivotal role in promoting a sustainable circular economy.

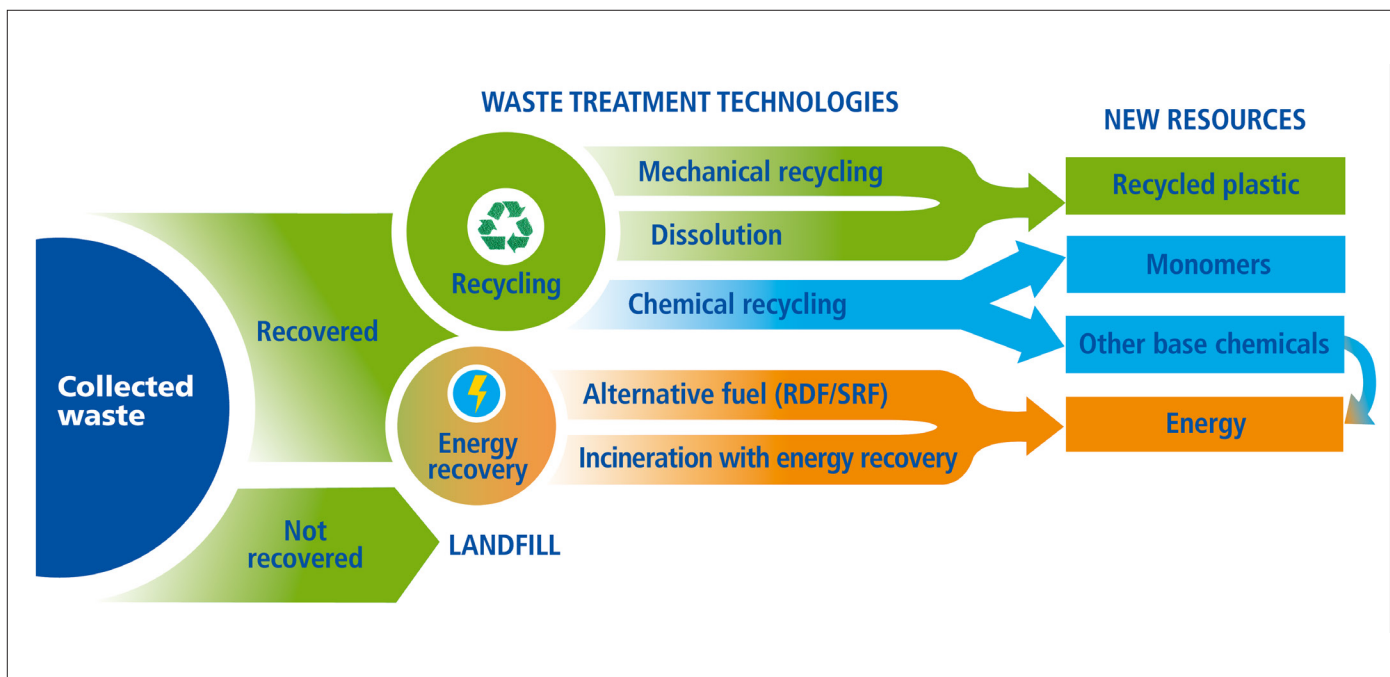


Figure 4. Recycling Methods – Mechanical, Dissolution, Chemical, RDF/SRF, Incineration.

Recycling Methods

Mechanical recycling is the primary plastics recycling method used today. Mechanical recycling involves pre-sorting, chopping, shredding, or grinding the waste plastics to provide shreds or flakes to polymer compounders and/or converters.

Two emerging recycling methods are solvent dissolution and chemical recycling. Solvent dissolution breaks down the waste plastics so they can be used to form pellets or flakes for use by polymer compounders and converters. Chemical recycling of waste plastic recovers raw materials, such as monomers and additives, that can be reused by resin producers and polymer compounders.

Mechanical Recycling

Mechanical recycling is a series of five steps that begins when the waste plastics arrive from the sorting facility.

- 1 Shredding/grinding reduces the plastic to smaller pieces known as shreds or flakes.
- 2 Pre-sorting separates the shreds/flakes according to size and other characteristics. Pre-sorting can be conducted manually or by using various automatic sorting techniques such as rotating sieve, wind sifter, magnet, ballistic separator, FT-NIR, color recognition, and shape/contour/pattern recognition.
- 3 Washing removes prior use residues and other contaminants from the sorted shreds/flakes. The washing can be conducted using a rotating drum washer or a friction washer. The washing medium can be plain water or a water/detergent mixture, and hot or cold.

- 4 Final sorting allows further removal of undesired shreds/flakes or other components. Final sorting can be accomplished using float-sink separation, wind sifter, and/or other sensor-based sorting techniques.
- 5 Extrusion pre-conditions the shreds/flakes for final recyclate formation by drying, compressing, melt filtration, venting to remove odors and degassed volatiles, and granulating the material.
- 6 Recyclates are then prepared by further granulation, compounding with other materials, deodorizing, crystallization, and polycondensation.

Accurate polymer identification leading to proper separation is critical for the recycling process. It is also important to have a final quality check of the end product.

Use of Recyclates

Recyclates can be used to produce a variety of materials. According to EU data, nearly three-quarters of recyclates are used for building and construction (46%) and packaging (24%) applications. Other uses include⁶:

- Agriculture 13%
- Automotive 3%
- Electrical/electronics 2%
- Housewares, leisure, sports 1%
- Other 11%



Figure 5. Typical Mechanical Recycling Process.

Challenges

The plastics recycling industry faces a number of challenges to growth, efficiency, and technology. Some of the key challenges are:

- Educating consumers on plastic waste recovery and recycling
- Increasing plastic waste collection
- Developing improved sorting methods
- Preventing/removing contaminants in the recycling process
- Better removal of odors and volatiles from recyclates
- Improved polymer identification and characterization methods
- Implementation of recyclate specifications and certification strategies
- Meeting government timelines for increased plastics recycling and reduced landfilling

These and other improvements and innovations are being actively pursued by polymer producers and recyclers worldwide.

Future Outlook

The polymers industry has grown rapidly over the past half-century, resulting in plastics that have many useful qualities, such as being lightweight yet strong, durable yet flexible, resistant to chemicals, good insulators, non-porous in air and water, and able to be formed into just about any shape and many others. The industry is expected to continue its strong growth throughout the 21st century but that growth will be tempered by efforts to counter the negative impacts of the plastics they make. The industry is certain to continue to develop innovations for the betterment of products, the environment, and society.

Some of the current trends and challenges to the polymer industry include the following.

Manufacturing advances:

- Moving toward Industry 4.0, or “smart manufacturing,” by implementing and linking an Internet of things with an Internet of Systems using autonomous systems that are driven by data and machine learning.
- Optimization and implementation of digital manufacturing with the ability to produce three-dimensional objects from a digital template.

Innovations that reduce environmental impacts:

- Polymers that, when landfilled, breakdown at a more rapid and controlled rate, yet still retain or even improve their functionality, durability, and cost-effectiveness.
- New biodegradable plastics using natural materials such as starch, cellulose, plant proteins, and plant oils, which will reduce fossil fuel use.
- Improved sustainability throughout the polymer production process by reducing impacts on natural resources, minimizing waste generation, and seeking out renewable energy options.

Advances in plastics recycling:

- Improved plastic waste sorting capabilities
- Improved recycling technologies
- Growth of innovative recycling approaches that can be integrated into product manufacturing and distribution facilities.

Sector-specific advances:

- Designing functional biopolymers that are sensitive to their environment and release agrochemicals on demand in a controlled fashion.
- Developing packaging that helps reduce food waste
- Making car parts that make vehicles lighter and more fuel efficient

Solving the problems of plastic while maintaining its considerable benefits will require the collaboration of parties across the plastic life cycle. The goal is to analyze and improve products and processes at every stage, from manufacturers and retailers, to recyclers, consumers, and governments. By working together, the next 50 years will be an exciting and rewarding time for the polymers industry and the world that has come to depend upon it.

References

1. OECD. 2018. Improving Plastics Management: Trends, policy responses, and the role of international co-operation and trade. OECD Environment Policy Papers, No. 12, OECD Publishing, Paris, <https://doi.org/10.1787/c5f7c448-en>.
2. Geyer, R., J. Jambeck and K. Law. 2017. Production, use, and fate of all plastics ever made. Science Advances, Vol. 3/7, p. e1700782, <http://dx.doi.org/10.1126/sciadv.1700782>.
3. PlasticsEurope. 2019. Plastics – the Facts 2019. <https://www.plasticseurope.org/en/resources/market-data>.
4. Plastics Industry Association. 2019. 2019 Size and Impact Report. <https://www.plasticsindustry.org/data/size-and-impact-plastics-industry-us-economy>.
5. Plastic Parts Manufacturing in China Industry Trends (2015-2020). <https://www.ibisworld.com/china/market-research-reports/plastic-parts-manufacturing-industry/>. Accessed on June 10, 2020.
6. PlasticsEurope. 2019. The Circular Economy for Plastics, A European Overview. <https://www.plasticseurope.org/en/resources/publications/1899-circular-economy-plastics-european-overview>.
7. United States Environmental Protection Agency. 2019. Advancing Sustainable Materials Management: 2017 Fact Sheet. November. <https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/advancing-sustainable-materials-management>.
8. Life Cycle Impacts for Postconsumer Recycled Resins: PET, HDPE, and PP. <https://plasticsrecycling.org/resources/life-cycle-study>. Accessed on May 12, 2020.

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