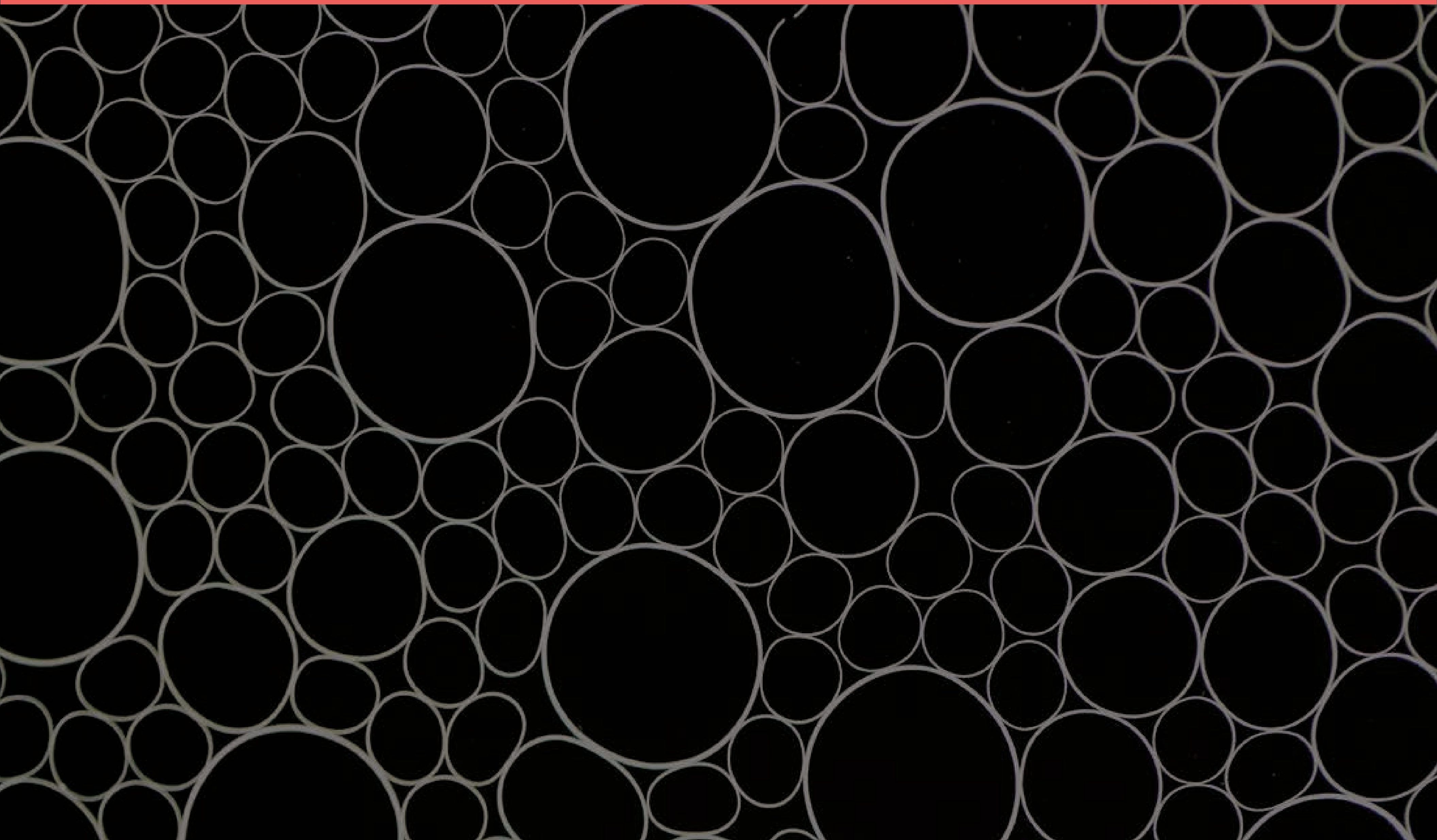
Polymers

101 Material Report

Material ConneXion®
A SANDOW Company



What you need to know

Nylon, polyester, and Styrofoam™ are a few examples of the many polymers we may encounter in our daily lives. From bags and bottles to drug delivery systems and 3D printed prototypes, polymers have revolutionized the way we live. In this report, Material ConneXion will break down everything you need to know about polymers: what they are, how they can be used, and what should be kept in mind when designing with them.

01 What is a polymer?

Polymers are macromolecules comprised of hundreds, thousands, or even hundreds of thousands of repeated units called monomers. The monomers are joined together to form long chains through a process called polymerization.

02 Natural vs. Synthetic

Polymers can be natural or synthetic. Natural polymers are naturally-occurring macromolecules such as cellulose, silk, and even DNA. However, most polymers we encounter are synthetically produced using fossil fuels (natural gas, or oil). Bio-based polymers, which are derived partially or fully from renewable resources, are a growing class of polymers that help to bridge the gap between natural and synthetic.

03 Polymer or Plastic

While the term plastics is often used interchangeably with polymers, there is a distinction between the two terms. Polymers are the macromolecules comprised of the monomers, whereas plastics are materials comprised of groups of polymers.

Polymer Lifecycle

The chemical composition and structure of the polymers are responsible for their physical and performance properties. Polymer chains are predominately comprised of carbon and hydrogen, but oxygen, silicon, nitrogen, and halogens, such as chlorine, are commonly present.

Synthetic

Created through chemical synthesis

Oil Gas Bio-based

Natural

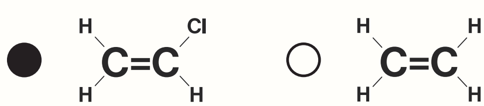
Naturally-occuring macromolecules

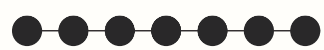
Silk or Wool Cellulose Chitin

Monomers

Polymerization

Polymers





Copolymers

Copolymers are a specific type of polymer that are formed when two or more types of monomers are used in the polymerization process. The combination of multiple monomer types allows for adjusted mechanical and physical properties to meet specific needs.

Recycling

Processing

Blow-molding, Extrusion, 3D Printing

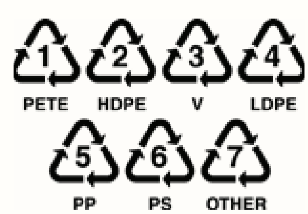
Final Product

End of Life

Landfill, Biodegradable, Compostable

End of Life

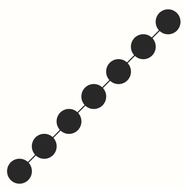
Thermoplastics and thermoplastic elastomers are commonly recycled. Because of their cross-linking, thermosets and elastomers are much more difficult to recycle. Recycling codes, such as the ones shown here, are commonly found on thermoplastic products to help identify what the product is made of.



Polymer Structure

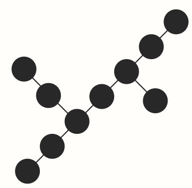
Polymers can take many structures, such as linear, branched, and cross-linked. These structures directly affect the properties of the material.

Linear



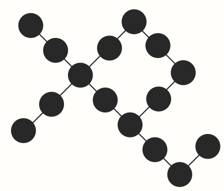
Linear polymers are long chains of monomers with no branching. Linear polymer chains can become entangled with each other, but they remain different macromolecules.

Branched



Branched polymers consist of a linear backbone with additional monomers branching off to form side chains. Like linear polymers, branched polymers can become entangled, but remain distinct macromolecules.

Cross-Linked



Under certain conditions, polymers can become cross-linked. When cross-linked, polymer chains become irreversibly joined together to form a single molecule.

Thermoplastics
Comprised of linear or branched polymer chains.

Elastomers
Comprised of tangled, cross-linked chains.

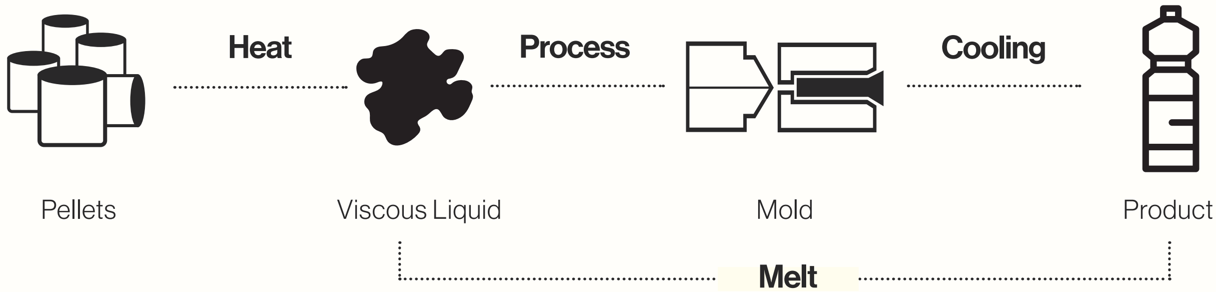
Thermosets
Comprised of highly cross-linked polymers.

Thermoplastic Elastomers
Comprised of thermally reversible cross-linked chains when at moderate temperatures.

A Note on Recyclability

In general, thermoplastic polymers are recyclable, but thermosets are not. This is because thermoplastics can be remelted and reformed, whereas thermosets do not melt in any appreciable way (the cross-linking means that heat alone cannot separate the chains from each other). Exceptions are possible if the thermoset can be chemically 'depolymerized,' and thus broken down into monomers once more for reprocessing. This is a recent and not widely used process. Natural polymers are not typically recyclable except in a semi-finished format such as a yarn or fiber for cotton.

Linear/Branched Polymers



Thermoplastic

Thermoplastics are comprised of linear or branched polymer chains. Thermoplastics solidify when cooled, but become fluid at high temperatures, allowing them to be reshaped to serve a new purpose.

Example Polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polytetrafluoroethylene (PTFE).

Applications Polyethylene is available in a wide variety of densities and molecular weights, allowing for a more rigid material (such as in bottles and piping) or a more flexible material (such as in grocery bags and plastic wrap) depending on the need.

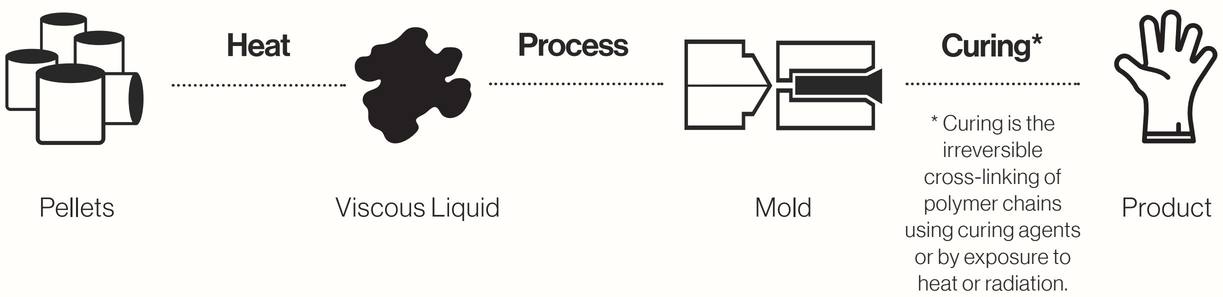
Thermoplastic Elastomer

At moderate temperatures, thermoplastic elastomers are comprised of cross-linked chains, allowing them to behave as rubbers. However, unlike in rubbers or thermosets, these cross-links are reversible. Because of this, when heated, the cross-links can break and the material acts as a thermoplastic.

Example Thermoplastic polyurethanes (TPU), thermoplastic olefinic (TPE-o), styrenic block copolymers (TPE-s), thermoplastic copolyester (TPE-E), thermoplastic polyamide (PAE, TPA, TPE-A).

Applications Phone cases, adhesives, and inks.

Cross-Linked Polymers



Elastomers

Comprised of tangled, cross-linked chains, elastomers can be stretched to significant lengths and return to their original shape. Due to their chemical crosslinking, they decompose, rather than melt, at high temperatures and cannot be reshaped.

Example Nitrile butadiene rubber (NBR), styrene-butadiene rubber (SBR), butyl rubber (IIR; isobutylene isoprene rubber), polyacrylic rubber (ACM; alkyl acrylate copolymer), polyisoprene (IR).

Applications Applications include single-use gloves, industrial tubing, and footwear.

Thermosets

Comprised of highly cross-linked polymers, thermosets are tough and rigid at room temperature. At high temperatures, thermosets decompose rather than melt, so they cannot be reshaped.

Example Epoxy resins, unsaturated polyester, vinyl ester, phenolic, polyurethane (PU).

Applications Applications include adhesives, epoxy resins, protective coatings, and electrical insulation.

Common Polymers

Imides

PI polyimide
PAI polyamide-imide
PBI polybenzimidazole
PEI polyether-imide
PSU polysulphone
PEEK polyether ether ketone
PPS polyphenylene sulfide

Fluoropolymers

PTFE polytetrafluoroethylene
PVDF polyvinylidene fluoride
PCTFE (or PTFCE) polychlorotrifluoroethylene
ECTFE ethylene chlorotrifluoroethylene
PFA fluorinated ethylene propylene

Urethanes

PU polyurethane (typically thermoset, as the thermoplastic verison has TPU as an acronym)
TPU thermoplastic polyurethane

Polyamides

PA polyamide (nylon)
Meta-aramid (Nomex)
Para-aramid (Kevlar)
POM polyoxymethylene (acetal)
PMMA polymethyl methacrylate (acrylic)
PC polycarbonate

Styrenes

ABS acrylonitrile butadiene styrene
PS polystyrene

Polyesters

PET polyethylene terephthalate
PBT polybutylene terephthalate
PETG polyethylene terephthalate—glycol modified

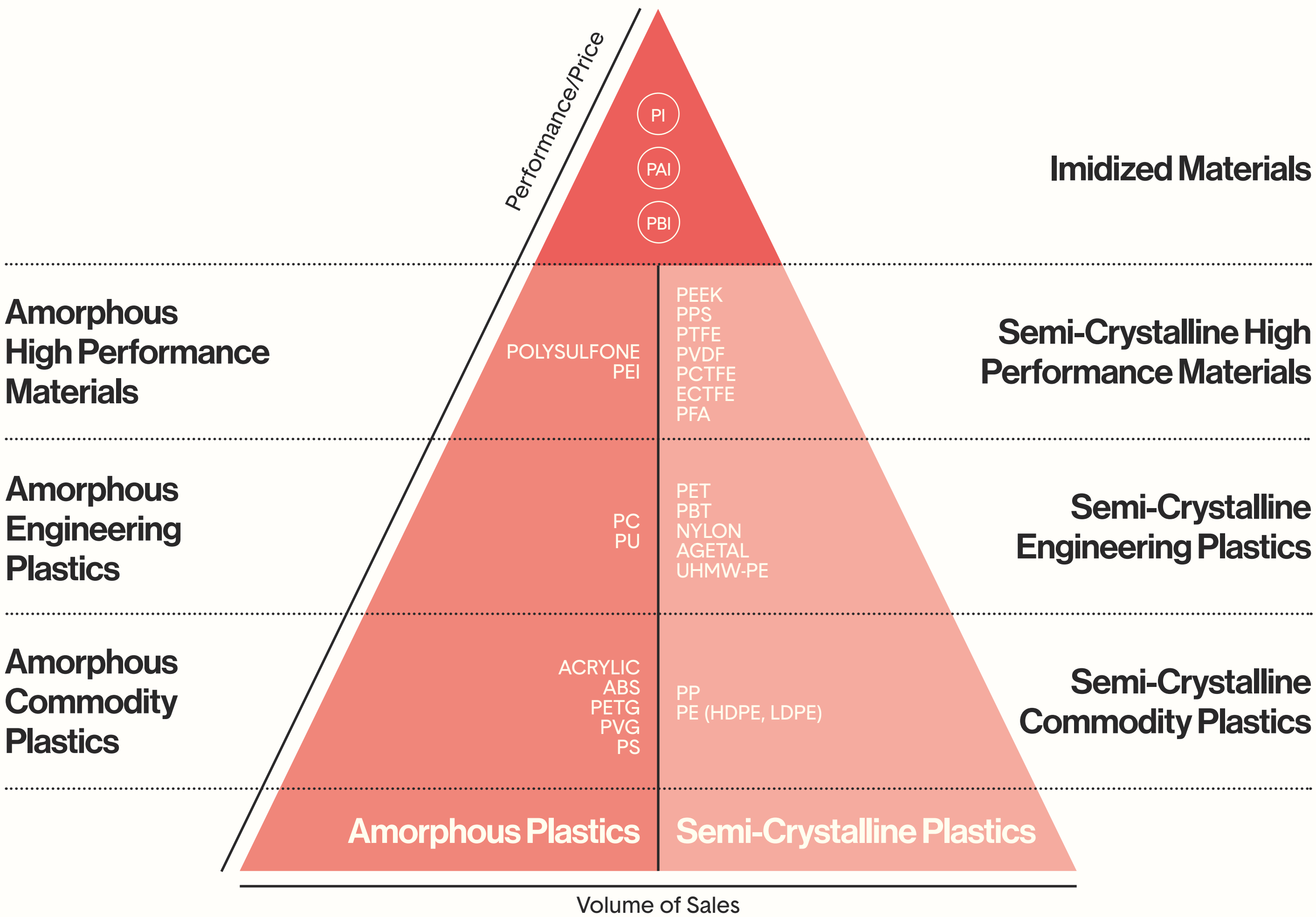
Vinyls

PVC polyvinyl chloride (vinyl)
PVB polyvinyl butryal

Thermoplastic Olefins or Polyolefins

PP polypropylene
PE polyethylene
LDPE low density polyethylene
LLDPE linear low density polyethylene
HDPE high density polyethylene
UHMW-PE ultra high molecular weight polyethylene

Amorphous vs. Semi-Crystalline



Amorphous Exhibit no ordered structure of polymer molecules, have good formability, good transparency, soften over a broad range of temperatures, but in general have poor chemical resistance.

Semi-Crystalline Exhibit regions of highly organized structure amongst areas of amorphous structure, have less formability than amorphous plastics, poor transparency, and sharp melting points

Imidized Plastics Perform best at very high temperatures, have strong chemical and wear resistance, but are very expensive compared to other polymers.

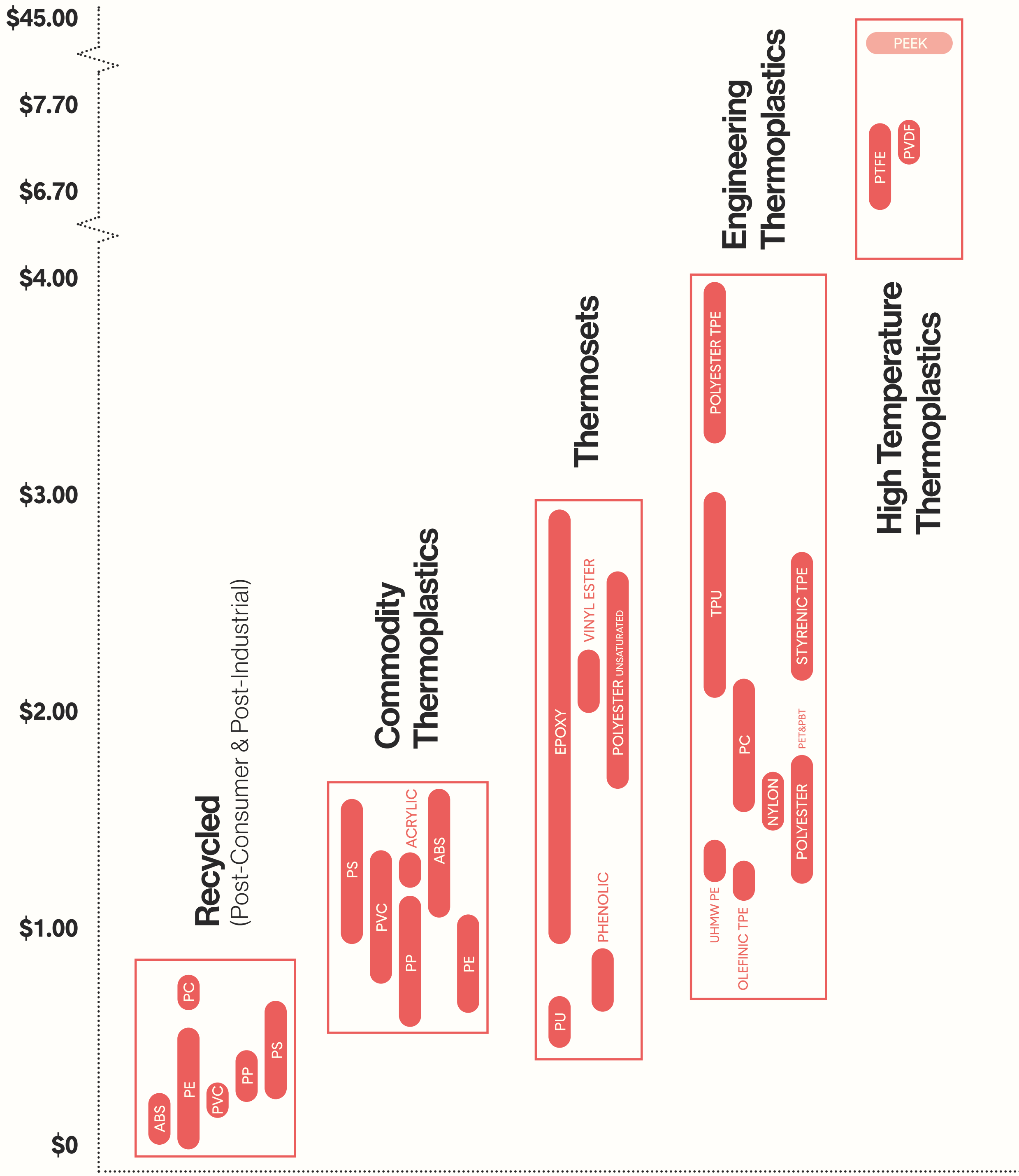
High-Performance Plastics Exhibit high temperature resistance and good wear and chemical resistance for both amorphous and semi-crystalline structures.

Engineering Plastics Moderate cost, temperature resistance, and strength, but are more durable than commodity polymers.

Commodity Plastics Low cost, comparatively low temperature resistance and strength, and are generally used for consumer products.

Price Data

These prices are in $ per pound in the US Market. Plastics prices vary by manufacturer, by grade, by market (US, Europe, etc.), and over time. These values are based on averages in the US Market in 2017.



Polymers

Polymers are macromolecules made of long chains of repeated units called monomers. These macromolecules can be naturally occurring or synthetically produced using fossil fuels, renewable resources, or a combination of the two. The structure, chemical composition, and arrangement of polymer molecules directly affects the chemical, physical, thermal, structural, and electrical properties of a plastic. Polymers are a rapidly growing industry with huge potential; check out our database and library for the latest innovations in the field.

Polymer Composites

Polymers are extremely useful additions to composites, which are substances made from two or more different materials. Combining polymers with naturals, metals, ceramics, or even other polymers creates a composite material that can take beneficial physical and/or performance properties from each material to produce a more advanced material. Polymers are commonly used as both the bulk material of a composite (such is the case for fiberglass) and as reinforcements for ceramic- or metal-based composites.

Bioplastics

According to the American Society for Testing and Materials (ASTM), bioplastics are plastics that are bio-based, biodegradable, or both. Bio-based plastics are comprised of polymers where a portion of the carbon used is derived from renewable sources such as corn or soy rather than fossil fuels. To learn more about bioplastics, biodegradability, and compostability, see our Compostability vs. Biodegradability 101 report, and be on the lookout for our Bioplastics 101 report, coming soon!

Additives

Plastics are rarely comprised solely of one type of polymer molecule. A wide range of additives are often used to manipulate properties like flexural strength, color, and durability. Some examples of additives are plasticizers, which increase the flexibility of a plastic, pigments to add color, and stabilizers to hinder thermal or UV-caused degradation.

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2nd Edition
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What Is A...Polymer?
By Material ConneXion
Video Link

What is a polymer?
By Physics Worlds
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What is a Polymer?
By Fantastic Plastics!
Video Link

Thermosets and Thermoplastics
By Fantastic Plastics!
Video Link

Polymers - Crash Course Chemistry #45
by Crash Course
Video Link

Science 101: What are Polymers?
By Public Domain TV
Video Link

Learning Guide

Discussion Questions

What aspect of the report surprised you the most?

What are some characteristics of polymers and the materials made from them?

What are some polymers you interact with in your daily life?

Aside from chemical composition, what are some properties and characteristics of a polymer you would want to know when designing a product?

How can polymer structure affect recyclability?

What are some current or potential applications for commodity plastics? How do these differ from applications of imidized plastics?

Why do you think polymers are commonly used in composite materials? What benefits might a composite material have over a traditional plastic?

Short Answer Questions

What is the difference between a natural and synthetic polymer? What are some examples of each?

How does a bio-based polymer differ from other synthetic polymers? How does it differ from a natural polymer?

Are any polymers compostable? Which ones?

How does a thermoplastic elastomer differ from an elastomer? What benefits for thermoplastic elastomers does this difference create?

How do amorphous and semi-crystalline plastics differ? What are some examples of each?

According to ASTM, what is a bioplastic? Using the database, find at least three materials that are bioplastics according to this definition.

While plastics are generally thought to be cheap, there is actually a wide variety in pricing. What are some of the most expensive polymers? Why do you think these are more expensive?

Learning Guide

Long Form Essay

There are fewer uses of polymers in architecture compared to other industries. Explain why this might be the case, and the reasons why the existing materials are better suited to the application. Where are the areas of architecture that polymers are becoming more prevalent? Why is this? Is there a way in which polymers can find greater use in architecture in general? Would this change the way in which buildings are created and designed? How?

Choose a polymer. Is this polymer a thermoplastic, elastomer, thermoplastic elastomer, thermoset, or can it be more than one? Find two to three examples of this polymer in the database. What are some applications of this polymer? While they possess many useful properties, polymers often get a bad reputation for health and environmental issues. Research and provide a brief overview of the safety and sustainability of your polymer. For example: What, if any, are the health concerns associated with it? Is it safe for food contact? Is it recyclable? Are there bio-based versions available?

Team Activity

You are designing an office chair. Present the design including 5 different polymer selections for different parts of the chair. Give reasons for the choice of polymer that consider:

- Price
- Performance
- Aesthetics
- Sustainability

Materials relevant to this report

Silky Luster
MC 8177-01

An additive to plastics that combines two different particles to create the effect of an iridescent luster, much like a pearl. Unlike most of these types of effect pigments, it is not metallic, so it can be used in more applications.

iglidur® J260-PF
MC 7296-02

Adding dry lubricants in the same way that polymers are colored gives the plastic a super slippery surface with no need for oils or Teflon™. Great for applications in clean rooms and for hard to reach places on moving parts.

Elastomeric Bead Foam
MC 7461-02

Complex moldability like a plastic, but with the lightweight properties of a foam. It is also possible to mold in hardware and electrical componentry.

FusionFX
MC 5808-10

Colorability in plastics that adds a level of randomness much like "paint splatter." This is done by adding color particles with different melting temperatures than the plastic, so they melt and flow differently when the part is molded.

NAS 30
MC 7209-01

Water-clear and "glass like" plastic from the same material type used to create Solo® cups. It molds easily, and can be used for lenses, cosmetics bottles, and medical devices.