

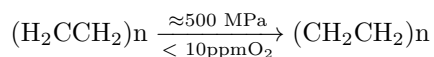
# Lifecycle of High-Density Polyethene

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High-density polyethene (HDPE) is a practical and economical thermoplastic used for pipes, bottles, containers, construction materials, and several other uses. It is UV stable and chemically quite resistant - it is almost impossible to damage with acids or bases. Further, HDPE is easily recycled, and has a resin identification code of "2". In 2015, the HDPE market was worth about \$80 billion (AUD).[1]. HDPE has enabled streamlining of manufacturing processes and cheap access to durable, safe products throughout the world.

## 1 Invention and Manufacture

High-density polyethene (polyethylene) consists of many thousands of ethene monomers  $\text{H}_2\text{CCH}_2$ , forming a long chain structure. Whilst ethene occurs naturally in plants, polyethene must be synthesised. In 1898, a German chemist Hans von Pechmann accidentally created a compound, polymethylene, which was the basis for the invention of polyethylene. In 1933, Fawcett and Gibson synthesised polyethylene using high pressure and a small proportion of oxygen, at the British Imperial Chemical Industries. This is illustrated below[4]:



However, this high-pressure method can only be used to synthesise low-density polyethene (LDPE) because the high pressure causes a lot of random chain branching (i.e. the molecules are non-linear). In the case of most low-density polyethene, branches occur every 10-20 carbon atoms. Linear molecules used in HDPE are stronger due to their larger intermolecular forces resulting from their surface area, giving them a more amorphous (shapeless) structure – see fig. 1.

During the 1940s-50s, two chemists independently discovered methods of synthesising HDPE using organometallic (carbon-metal) catalysts to break the C=C double bond in ethene. Karl Ziegler from Germany used titanium halides  $\text{TiCl}_n$ , and Phillips Petroleum in America used chromium trioxide  $\text{CrO}_3$ :

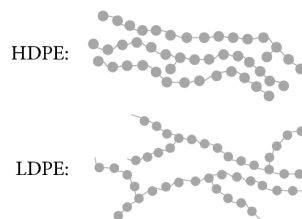
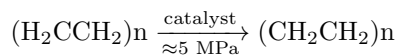
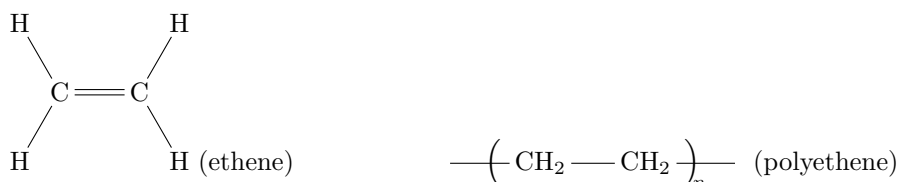


Figure 1: amorphous vs crystalline polymers[2]

Note that this method only requires 5 megapascal of pressure, whilst the first method used to synthesise LDPE required 500 megapascals. This makes the manufacture of HDPE much more energy efficient and practical, allowing mass production.

Soon after the discovery of this method, HDPE was produced industrially using both Zielger's and Phillips' methods, primarily by DuPont. Early HDPE was used for internal shielding in cables, infrared lenses, and generally replaced PVC in many applications. This low-pressure synthesis is currently the only method of HDPE mass production, but is efficient and cheap. The only major change in HDPE synthesis has been the addition of a magnesium-based catalyst.

## 2 Structure



Thanks to the low-pressure method of synthesis discovered by Ziegler and Phillips, each molecule of HDPE is many thousands of monomers long, without significant branching which would compromise its strength (see fig. 1). It has a density of about  $0.97 \text{ g / cm}^3$ , versus LDPE's density of  $0.91 \text{ g / cm}^3$ . Despite this minimal increase in density, HDPE has vastly greater strength and hardness. This is because of its low level of chain branching. Other results of the low chain branching are greater opacity and higher temperature resistance.

## 3 Uses

High-density polyethene is used for rigid plastic packaging (milk jugs, food containers, water bottles), water pipes (see fig. 2), coaxial cables, vehicle fuel tanks, wood-plastic composites (decks etc), and 3D printer filament. Most of these applications require little effort to transform the HDPE into its resulting product, due to its low melting point (about 100 C) and its ease of extrusion from beads.

## 4 Issues

### 4.1 Health

HDPE has virtually no known health risks in normal use. Its production is a safe process, and whilst toxic chemicals are used as catalysts, this process is heavily automated and restricted to licensed manufacturers. If HDPE is burnt, it releases noxious hydrocarbons, however this is true of all thermoplastics.

HDPE does not degrade as traditional steel or lead pipes do, so it offers significant advantages in safety and cost for potable water piping.



Figure 2: underground installation of agricultural HDPE pipe[6]

## 4.2 Environmental

Polyethene's monomer, ethene, is usually obtained from drilling rigs in the ocean. These rigs represent a non-renewable form of ethene, whereas less developed methods of ethene synthesis are more sustainable.

Polyethylene does not biodegrade easily, so it constitutes a significant volume of landfill. Some bacteria can accelerate the biodegradation process, but the specific species are rare.

However, HDPE can be recycled indefinitely and it is very easy to do so. Once the molecules have been synthesised, the material can be melted and formed into a product multiple times. For this reason, recycling of HDPE is commonly encouraged, and most curbside recycling collections accept HDPE, denoted by the number 2. However, it is important to note that recycled HDPE is generally unable to be used for food packaging according to regulations, but with more research this should be possible.

Common uses of recycled HDPE include timber-plastic composites (decking, outdoor chairs, signs etc), containers, wheelie bins, furniture etc.

## References

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