Eight of the most important polymers are produced from only three basic chemicals that come from naphtha.

**Ethylene C₂H₄**
- polymerization to form high-density polyethylene (HDPE), low-density polyethylene (LDPE) or linear low-density polyethylene (LLDPE)
- reaction with chlorine to form chloroethene
- reaction with benzene to form styrene
- reaction with oxygen to form ethene oxide

**Propylene C₃H₆**
- polymerization to form polypropylene (PP)
- reaction with oxygen to form propylene oxide
- further reaction and polymerization to form polyurethanes (PU)

**Butadiene C₄H₆**
- polymerization to form polybutadiene which is a synthetic rubber

### ACTIVITY 1
The table to the right shows the total Canadian virgin resin production from 1994 to 2000 (figures show thousands of metric tonnes).

1. Describe how the tonnage has changed for each plastic.
2. Summarize in one sentence how production of virgin plastics has changed over the period.
3. Suggest reasons for the changes you have reported.

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>LDPE/LLDPE</td>
<td>1200</td>
<td>1400</td>
<td>1400</td>
<td>1700</td>
</tr>
<tr>
<td>HDPE</td>
<td>650</td>
<td>700</td>
<td>800</td>
<td>825</td>
</tr>
<tr>
<td>V</td>
<td>400</td>
<td>425</td>
<td>450</td>
<td>475</td>
</tr>
<tr>
<td>ABS/PS</td>
<td>150</td>
<td>200</td>
<td>150</td>
<td>200</td>
</tr>
</tbody>
</table>
Although there are many different examples of plastics, they fall into two distinct categories:

**Those which soften on heating and then harden again on cooling**

- These are called *thermoplastic* polymers because they keep their plastic properties.
- These polymer molecules consist of long chains that have only weak bonds between the chains.
- The bonds between the chains are so weak that they can be broken when the plastic is heated.
- The chains can then move around to form a different shape.
- The weak bonds reform when it is cooled and the thermoplastic material keeps its new shape.

**Those which never soften once they have been moulded**

- These are called *thermosetting polymers* because once set into a shape, that shape cannot be altered.
- These polymer molecules consist of long chains which have many strong chemical bonds between the chains.
- The bonds between the chains are so strong that they cannot be broken when the plastic is heated.
- This means that the thermosetting material always keeps its shape.

**The bonding process.** When thermoplastic polymers are heated they become flexible. There are no cross-links and the molecules can slide over each other. Thermosetting polymers do not soften when heated because molecules are cross-linked together and remain rigid.

It is clear from this that the chemical bonding in a polymer and the shape of the polymer will affect its properties.

**ACTIVITY 2**

- Imagine that you are a small part of a thermoplastic polymer. You are part of a lump of plastic material that is waiting to be processed into a cup.
- You have strong chemical bonds along the polymer chain to parts of the molecule next to you; you also have some weak bonds across to parts of the polymer that are positioned near to you. The weak bonds keep the plastic material solid and rigid.
- As part of the manufacturing process, the plastic material is warmed to make it soft and pliable; then squeezed in a press into a new shape; then allowed to cool and solidify into the new shape.
- Describe what happens to your part of the polymer as this processing takes place.
- Use words, a diagram, or a cartoon to do this.

- Most plastics made from the basic chemicals that come from naphtha are thermoplastic.
- Examples are polyethylene (HDPE, LDPE and LLDPE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), and vinyl (V).
- Common examples of thermosetting plastics are polymers based on formaldehyde (Bakelite was the earliest example).
- Examples are melamine/formaldehyde (MF), urea/formaldehyde (UF), phenol/formaldehyde (PF) and polyurethane (PU).
- Epoxy glues are also thermosetting plastics.
There are two ways of producing polymer chains:

**Addition reactions**

The polymer is made from one monomer e.g. A-A produces

\[ \text{A} - \text{A} - \text{A} - \text{A} - \text{A} - \text{A} - \text{A} - \text{A} - \text{A} \]

In addition reaction, chains are formed from one small molecule. The monomer always contains a carbon-carbon double bond. Most thermoplastic plastics made from naphtha are addition polymers.

**Condensation reactions**

In condensation reactions, chains are formed from two small molecules. During the reaction a small molecule such as water is formed and removed (condensed out). All thermosetting polymers are condensation polymers. Some thermoplastic polymers are condensation polymers. Examples are Nylon and polyethylene terephthalate. Nylon belongs to a class of polymers called polyamides. Nytons are produced by condensation polymerisation. Two monomers which can produce Nylon are:

<table>
<thead>
<tr>
<th>Plastic</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>High density polyethylene (HDPE)</td>
<td>Garbage bins, Bottles, Pipes</td>
</tr>
<tr>
<td>Low density polyethylene (LDPE)</td>
<td>Bags and sacks, Bin liners, Squeezable detergent bottles</td>
</tr>
<tr>
<td>Polypropylene (PP)</td>
<td>Margarine tubs and food wrappings, Garden furniture, crates, suitcases, Telephones, Car bumpers</td>
</tr>
<tr>
<td>Polystyrene (PS)</td>
<td>Food containers, Computers, Video and audio cassettes</td>
</tr>
<tr>
<td>Vinyl (V)</td>
<td>Blood bags, Credit cards, Window frames and pipes</td>
</tr>
<tr>
<td>Polyethylene Terephthalate (PET)</td>
<td>Soft drinks bottles, Oven-proof trays, Winter jackets and duvet filling</td>
</tr>
<tr>
<td>Polyurethane</td>
<td>Upholstery, Sports shoe soles, Roller skate wheels</td>
</tr>
<tr>
<td>Acrylics (e.g. Perspex)</td>
<td>Sink and bathtubs &amp; tap tops, Protective glasses, Headlight covers</td>
</tr>
<tr>
<td>Polycarbonates</td>
<td>CDs, Car headlights, Firemen’s helmets</td>
</tr>
</tbody>
</table>
The family of materials that form plastics has a wide variety of different properties. Some resist high pressure and temperature extremes, some resist air and moisture. There are different forms of the same basic plastics type that can be stiff or flexible making them suitable for particular applications.

Plastics’ properties can also be tailored by the use of additives.

Polymers are converted into plastics products in seven main ways. These are listed here, along with a list of typical products.

1. **Injection moulding**
   The plastic is first heated, then the soft polymer is forced under pressure into a cool, closed mould (containers, lids, footwear, crates, gear wheels).

2. **Compression moulding**
   The polymer is placed in a mould and pressure applied to make the plastic take up the shape of the mould (electrical plugs and sockets).

3. **Blow moulding**
   The warm, soft polymer is blown into the shape of a mould by compressed air or steam (bottles, containers).

4. **Rotational moulding**
   Plastics powder or paste is heated inside a closed mould which is rotated until the walls of the mould are covered with an even layer of polymer (large, hollow items such as litter bins, fuel tanks, drums).

5. **Blow film extrusion**
   Soft polymer is forced into a tube-shape. This is blown up with air and either heat sealed or slit (bags, film).

6. **Extrusion and extrusion coating**
   The materials are heated, compressed, and extruded through a die of the desired shape. Materials can also be coated with soft polymer and then passed between rollers to give an even coating (coatings on food and drink containers).

7. **Calendering**
   Heated polymer is fed between two rollers which squeezes it into a thin sheet (flooring, tiles, panelling, sheeting).