Green Chemistry

Green Chemistry refers to the processes in the chemical industry that are being reinvented to make them more sustainable. The term sustain means to keep going. If we use resources faster than they can be replaced, clearly this is a situation that cannot keep going. Sustainability is about living in a way that preserves resources and the environment for future generations.

The idea of "green chemistry" is to obtain all the valuable products, but in ways that do not damage the environment. Green chemistry is about making the chemical industry more sustainable.

The Chemical industry needs to become greener to;

- Reduce waste.
- Develop more economically viable processes.
- Reduce their environment impact.
- Save limited resources.

Five ways in which the Chemical industry can become Greener

- Change to renewable resources.
- Find alternatives to very hazardous chemicals.
- Discover catalysts for reactions with high atom economies,
  e.g. the development of methods used to produce ethanoic acid based on catalysts of cobalt, rhodium and iridium
- Make more efficient use of energy,
  e.g. the use of microwave energy to heat reactions in the pharmaceutical industry
- Reduce waste and prevent pollution of the environment.

Changing to renewable sources

If renewable resources replace non-renewable materials raw materials will be conserved and the process becomes more sustainable. Plants can be used as a source of certain organic compounds instead of oil. These can be extracted directly from plants or derived from processing plant material, such as using fermentation to produce ethanol from plant starch and sugars.

Use of alternatives to hazardous chemicals

This involves replacing dangerous chemicals used in a process with less harmful chemicals which can do the same job. It includes changing processes so that less risky reagents are used or less destructive intermediates are formed. It also includes using less damaging solvents for a process.

Use of more efficient catalysts

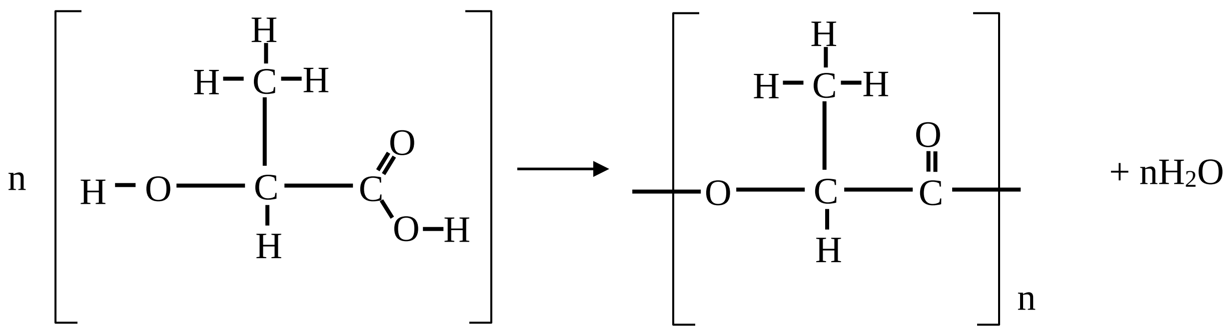
Introduction of more efficient catalyst enables lower temperatures and pressures to be used and so saves energy. More efficient catalysts create fewer bye-products and so reduce waste.

Reduction of energy use
Changing to processes that use lower pressures and temperatures reduce the energy required to make a given product. Use of exothermic reactions to provide heat reduces the amount of non-renewable energy used, for example introducing a heat transfer system (using hot products to heat incoming reactants). Use of microwaves instead of hotplates allows more efficient heating, as it heats the relevant molecules directly.

Reduction in the amount of waste
Recycling materials means that less waste is produced. Making biodegradable products means that they can be broken down by natural processes and so reduce the materials that need to be treated after use.

Examples

Polylactic acid
An example of this is the production of the biodegradable plastic, polylactic acid, PLA. The lactic acid, 2-hydroxypropanoic acid, for this process can be produced by using bacteria to carry out the conversion from plant starch and sugars.



Since lactic acid is a substance produced by living organisms it means that the PLA is biodegradable.

Roundup
A new process for the production of a herbicide called “Roundup” was developed. The original process required the use of methanol (toxic) and hydrogen cyanide (extremely toxic), but the new process, using a copper catalyst, does not use these materials. The new process utilizes endothermic reactions, so it is safer and easier to control. The original process produced 14% waste, whereas the new process re-uses the catalyst and recycles any other unconverted chemicals, and so has no waste. The new process uses fewer steps and so produces a higher yield.

Ethanoic acid
Ethanoic acid can be manufactured from methanol and carbon monoxide:

$$CH_3OH + CO \rightarrow CH_3CO_2H$$

A new process uses a combination catalyst consisting of iridium with ruthenium compounds. This catalyst produces purer ethanoic acid and so reduces the energy required for the purification.

Summary
The table below summarises which of the new processes fulfills the five main ways of making the chemical industry more sustainable.

	PLA	Roundup	Ethanoic acid
Renewable resources	Yes		
Alternative to hazardous chemicals		Yes	
Development of new catalyst		Yes	Yes
More efficient energy use			Yes
Reduction in waste	Yes	Yes	

Main Industrial Effects on the Environment

Global Climate Change
Products or waste products may enter the atmosphere and absorb Infra red radiation, thus leading to increased global climate change - **anthropogenic climate change**
e.g. Carbon dioxide, methane.

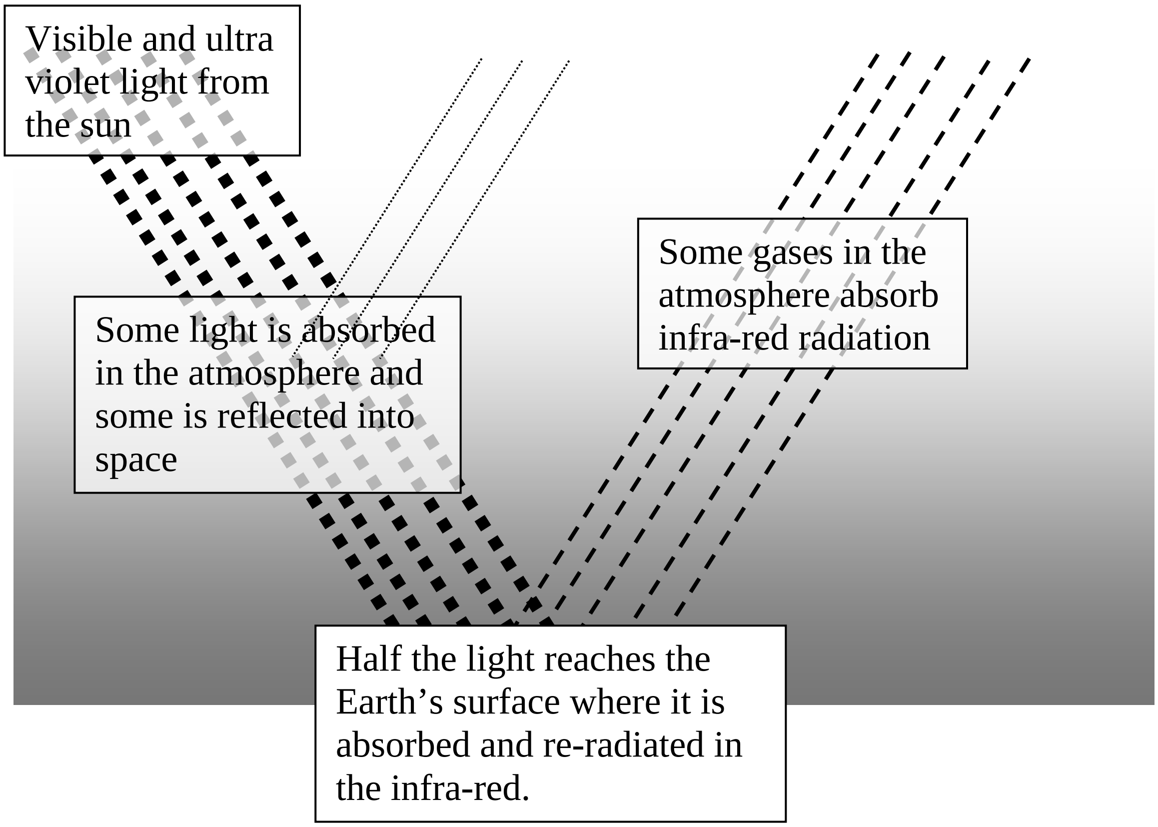
Acid Rain
Products or waste products may enter the atmosphere and dissolve in clouds to form acid rain, thus leading to change of soil pH and river water pH etc.
e.g. Sulphur dioxide, nitrogen oxides, carbon dioxide.

Ozone Depletion
Products or waste products may enter the atmosphere and lead to ozone depletion, thus leading to increased levels of UV radiation reaching the Earths surface.
e.g. CFC’s, products from combustion of plastics and Nitrogen oxides.

Climate change

One of the key concerns of sustainability is preventing damage to the environment. The atmosphere is a vital part of the Earth's environment, and so the effect of people's activities on the atmosphere needs to be understood and monitored.

The Earth receives radiation from the sun. This arrives mainly as visible light and ultra-violet radiation. Certain proportions of this radiation are absorbed by the atmosphere or reflected into space. About half of it reaches the surface of the Earth, where it is absorbed and re-radiated, but at a lower energy; in the infra-red frequency.



Some gases in the atmosphere absorb infra-red radiation. Nitrogen and oxygen, the main gases in the atmosphere do not absorb infra-red radiation as they are completely non-polar. Gases composed of polar molecules do absorb infra-red radiation. When the molecules absorb infra-red they increase their vibration and their kinetic energy, which of course increases to temperature. Such gases are therefore called "greenhouse gases" and can be responsible for climate change or global warming. Carbon dioxide, water vapour and methane are the main greenhouse gases.

The atmosphere naturally contains a certain level of carbon dioxide, but human activity increases these levels. The effects of human activity are called **anthropogenic effects**. Scientists are able to use computer projections to plot the expected climate based on there being no anthropogenic carbon dioxide. When these projections are compared with plots of global temperatures, they show clearly that it is the anthropogenic carbon dioxide that is responsible for climate change.

The extent to which human activity placed carbon dioxide into the atmosphere can be measured by use of the “carbon footprint”. The carbon footprint is the quantity of carbon dioxide a certain item or activity places into the air in a complete cycle. The carbon footprint is measured in tones of carbon dioxide. If any item or process, when input and output of carbon dioxide is considered, does not add any carbon dioxide to the atmosphere, it is designated carbon neutral.

Alternative fuels

Use of fossil fuels as energy sources for vehicles, power generation plants or domestic heating is one of the key activities which places carbon dioxide into the atmosphere. If these can be made carbon neutral or have their carbon footprint reduced, it is advantageous to the environment.

One way of reducing the carbon footprint is to use biofuels. The principle of a biofuel is that they are formed by plants that take up carbon dioxide from the air to make the plant material which is then converted into fuel, and when the fuel is burnt, it simply puts back into the air the carbon dioxide it originally removed, so overall it does not add to the carbon dioxide level, and can therefore be described as carbon-neutral.

This simple view of biofuels does not however provide the full picture. Bioethanol for example is produced from sugar cane in Brazil and from maize in the USA. The production of ethanol in the USA uses fertilizers and pesticides which have taken energy (form oil) to make. The ethanol then needs to be separated by distillation, a process again which uses energy from oil. Biodiesel is more effective in reducing the carbon footprint because it does not require distillation.

Hydrogen is a much better alternative fuel as it only produces water when it is burnt. The key point about hydrogen is how it is produced. If it is made by electrolysis using mains electrical supply, it can still have a large carbon footprint if the electrical generation involves the combustion of fossil fuels. In the same way hydrogen generated by the reaction of methane with steam, the final products being hydrogen and carbon dioxide, has a significant carbon footprint. Hydrogen produced by electrolysis, where the electrical energy was derived from sunlight would of course be very environmentally friendly.

The ozone layer and CFCs

The atmosphere is composed of several layers. Most pollutant molecules are broken down before they reach the upper atmosphere. However it is possible for some particularly stable molecules to enter the upper atmosphere. One such type of molecule are the chlorofluorocarbons, CFCs, which are stable because of the strength of the C-F bond. These were used in aerosols and refrigerants. When they enter the upper atmosphere, the CFCs can damage the “ozone layer”.

The ozone layer is formed by the energy from the sun’s ultra violet radiation being able to split an oxygen molecule into two oxygen atoms.

$$O_2 \longrightarrow 2O\cdot$$

The oxygen atom formed can then combine with an oxygen molecule to form ozone, O_3.

$$O_2 + O\cdot \longrightarrow O_3$$

The ozone formed is able to absorb harmful ultra violet radiation from the Sun, so protecting the Earth’s surface from these rays. When this happens the reaction above is reversed.

$$O_3 \longrightarrow O_2 + O\cdot$$

In the 1980s it was discovered that this protective ozone layer was diminishing during the summer over the Antarctic and that the “hole” was increasing in size. Chemists tracked the cause down to the CFCs. The stability of CFCs means that they are not broken down in the lower atmosphere, but when they reach the upper atmosphere the uv radiation causes the C-Cl bond to be broken forming Cl· radicals. These radicals then react with ozone as follows:

$$O_3 + Cl\cdot \longrightarrow O_2 + ClO\cdot$$

The radical then proceeds to react with the oxygen atoms present in the stratosphere:

$$O\cdot + ClO\cdot \longrightarrow O_2 + Cl\cdot$$

This reaction removes oxygen atoms that could otherwise generate more ozone, but it also regenerates the Cl· radical, allowing a series of reaction to take place similar to the propagation stages of the chlorination of methane. It is estimated that one Cl· radical can breakdown a million ozone molecules.

As a result scientists recommended the phasing out of CFCs. In 1987 a United Nations conference was held in Montreal to tackle the problem and an agreement was established in which there would be a phased reduction in the use of CFCs leading to an eventual ban. This agreement was called the Montreal Protocol.