26.6 Green Chemistry

Green chemistry, also called sustainable chemistry, is defined as the design of chemical products and processes through chemical research and engineering that reduce or eliminate the use and generation of hazardous waste.

Green chemistry helps to maintain the balance of nature by:

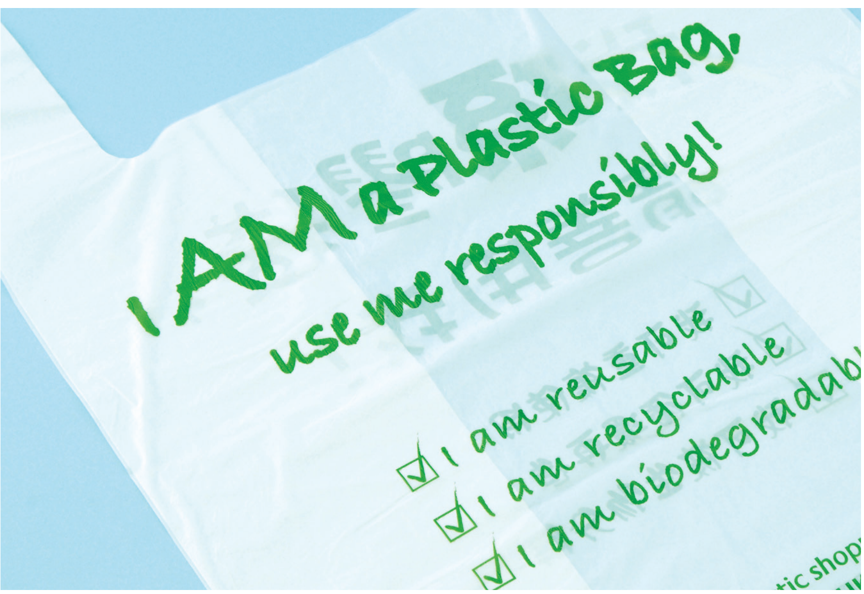
- Emulating nature through the use of renewable materials that are readily biodegradable in the environment.
- Reducing the adverse impact of chemistry on the environment through the prevention of pollution at its source and mitigating the use of fewer natural resources.
- Using materials with more efficiently less energy.
- Helping to build a sustainable future.
- Fostering innovation, creating jobs and inspiring the next generation of chemists.

Green chemistry allows for a clean and sustainable way in which new discoveries does not harm the planet. The practise of green chemistry is also economically beneficial with many positive social impacts.

Examples of Green Chemistry

Several companies throughout the world have developed materials that minimises the release of hazardous waste on the environment. These companies have developed:

- Biodegradable plastics which are made from renewable biodegradable sources. For instance the scientists, of NatureWorks in Minnesota, discovered a method where microorganisms convert corn starch into a resin that is just as strong as the rigid petroleum-based plastic currently used for containers such as water bottles and yogurt pots. Also Baden Aniline and Soda Factory (BASF) which is the largest chemical company in the world has developed a biodegradable bag that completely disintegrates into water, carbon dioxide and biomass in industrial composting system. The use of these bags instead of conventional plastic bags for kitchen and yard waste will easily degrade in municipal composting systems.



▲ **Figure 26.10** Many supermarkets across the Caribbean region are now using biodegradable plastic bags and reusable green bags.

- Sherwin-Williams has developed a water based acrylic alkyd paint with low volatile organic chemicals (VOCs) that can be made from recycled soda bottle plastics (polyethylene terephthalate – PET), acrylics and soyabean oil. In 2010, Sherwin-Williams manufactured enough of these new paints to eliminate over 800,000 pounds, or 362,874 kgs, of VOCs.

The twelve principles of green chemistry

The twelve principles of green chemistry are:

1 **Prevention** – the reduction and prevention of waste generation creates a more sustainable environment which minimizes hazards associated with waste treatment, transportation and storage.

2 **Atom economy** – this is a concept that evaluates the efficiency of a chemical transformation. Atom economy is a ratio of the total mass of atoms in the desired product to the total mass of atoms in the reactants, which is similar to percentage yield.

The reduction of haematite (Fe_2O_3), is reduced by carbon monoxide in the blast furnace, leads to an atom economy of

Fe_2O_3	+	$3CO$	→	$2Fe$	+	$3CO_2$
haematite		carbon				iron
(55.85 x 2) +		monoxide				2(55.85)
(3 x 16)		3(12+16)				=111.7
=159.7		= 84				

Waste is minimized when the chemical transformations is designed to maximize the incorporation of all materials used in the process into the final product, resulting in few if any wasted atoms. The atom economy should be as close to 100% as much as possible.

For example, Ibuprofen which is used to reduce fever and treat pain or inflammation, became obtainable without prescription in the 1980s which utilized a method with an overall atom economy of 40% which translates into 60% waste products. This means that if 30 million pounds of ibuprofen is produced each year, then more than 35 million pounds of waste is generated which is not sustainable for the environment. Through the application of green synthesis there was atom economy of 99% which translates to less than 500,000 pounds of waste for the production of ibuprofen.

3 **Design less hazardous chemical synthesis** – use less hazardous reagents whenever possible and design processes that do not produce hazardous by-products to generate only benign by-products. These practices will generate substances that possess little or no toxicity to human health and the environment.

4 **Design safer chemicals and products** – the toxicity of the chemical products should be reduced when designed so that they only affect their desired function. New products can be designed through green chemistry that are safer for the environment.

5 **Use safer solvents/reaction conditions** – harmful solvents, catalysts and substances that are used in separation techniques should be minimized or not used to maintain a sustainable environment.

6 **Increase energy efficiency** – synthetic and purification methods should be designed to be performed at room temperature and pressure, if possible, so that energy costs associated with extremes in temperature and pressure are minimized. As much as possible the heat evolved in exothermic reactions should be used for another experiment and not released to the environment to cause heat pollution.

7 **Use renewable feedstocks** – raw materials and feedstocks that are renewable should be used whenever possible to prevent the depletion of natural resources. Feedstocks are natural occurring materials that have undergone some slight processing which is used as a starting material for a chemical process. Examples of depleting feedstocks are haematite – Fe2O3 – and magnetite – Fe3O4 (iron ores). Examples of renewable feedstocks include agricultural products.

8 **Avoid chemical derivatives** – the use of protecting or blocking groups tend to require additional reagents and can generate waste. Therefore synthetic transformations are more selective and will eliminate or minimize the need for protecting groups. Alternative synthetic sequences may eliminate the need to convert functional groups in the presence of other sensitive functionality.

9 **Use catalysts** – the use of catalysts enhance the selectivity of a reaction, reduce the temperature of a reaction, and enhance the extent of conversion to products and reduce-based waste. The reduction of temperature saves energy and removes the possibility of unwanted side reactions.

10 **Design for degradation** – the products of a chemical reaction should be designed so that they disintegrate at the end of their function and do not persist in the environment. The disintegrated products should not stay long in the environment.

11 **Monitor to prevent pollution** – the progress of the reaction should be monitored to detect the presence of pollutants such as unwanted by-products. The analytical methods should be developed to control and minimize the formation of hazardous substances.

12 **Minimize the potential for accidents** – the potential for chemical accidents may be reduced by selecting reagents and solvents that minimize the possibility of explosions or fires. The physical state (solid, liquid or gas) or composition of the reagents may be altered so as to lessen the risks associated with these types of accidents.

Practice

4 Calculate the percentage atom economy for the named product in the reactions shown below:

a) sodium in the reaction $2NaCl \rightarrow 2Na + Cl_2$

b) hydrogen in the reaction $Zn + 2HCl \rightarrow ZnCl_2 + H_2$

c) calcium oxide in the reaction $CaCO_3 \rightarrow CaO + CO_2$

d) sulfur trioxide in the reaction $2SO_2 + O_2 \rightarrow 2SO_3$

e) oxygen in the reaction $2H_2O_2 \rightarrow 2H_2O + O_2$

5 Comment on the percentage waste product for the calculations in question four above.