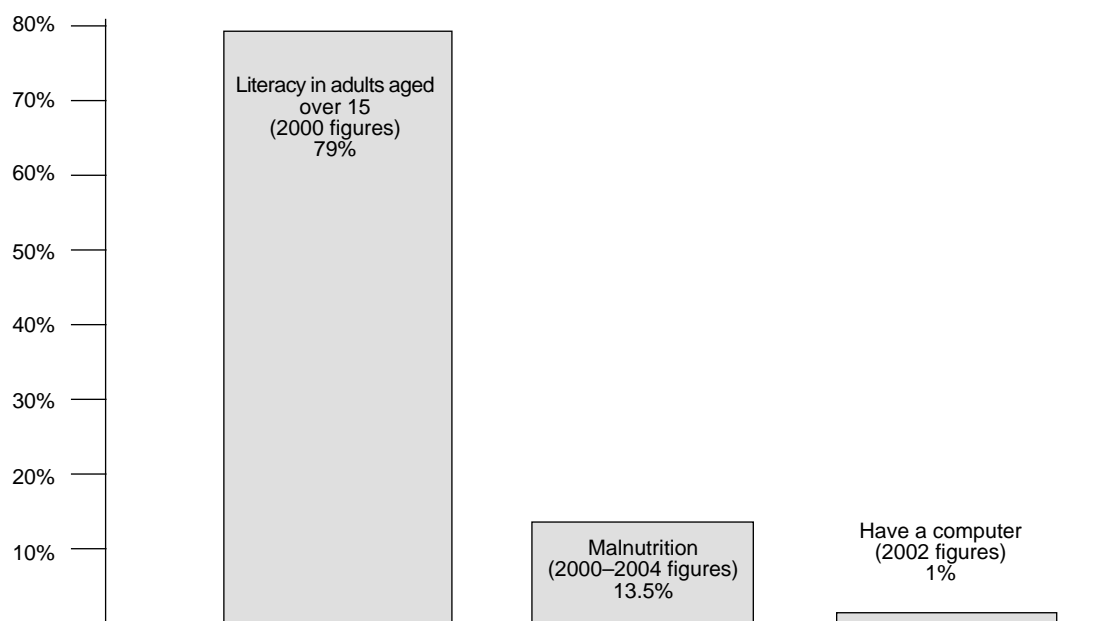

Green Chemistry, atom economy and sustainable development



For every 100 people on earth... development statistics taken from the World Bank database of indicators at <http://devdata.worldbank.org/quer/default.htm> and the UN Food and Agriculture organization website <http://www.fao.org/docrep/007/y5650e/y5650e06.htm>

A quarter of the world's people have to survive on less than 70p a day. Millions have no health care and the world's population is expected to increase by about another 3 billion over the next 50 years. Even in developed nations, poverty, education and healthcare could be improved.

To help deal with this situation, the world's economy needs to grow; in particular, the economies of developing nations need to expand. However, economic growth is often linked to environmental pollution problems. The challenge is to develop in a way that meets the needs of the present generation without compromising the ability of future generations to meet their own needs – in other words, without causing a lot of environmental damage and wasting limited resources. This type of development is called 'sustainable development' and it will be more and more critical as the population of the world increases.

One of the ways in which the chemical industry is working towards sustainable development is by using 'Green Chemistry.' One of the basic ideas of Green Chemistry is to prevent pollution and the production of hazardous materials instead of producing them and then cleaning them up. This means that Green Chemistry:

- Is safe
- Conserves raw materials and energy
- Is more cost effective than conventional methods.

There are three main ways to make chemical processes 'greener':

- Redesign production methods to use different, less hazardous starting materials
- Use milder reaction conditions, better catalysts and less hazardous solvents
- Use production methods with fewer steps and higher atom economy.

1. Why is it better to prevent pollution and the production of hazardous materials than to produce them and then clean them up?

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2. Why might using a catalyst (or a more efficient catalyst) make a chemical process 'greener'?

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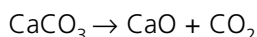
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Yield

Most of the chemical industry is concerned with turning one material (the raw material) into another one that is more useful and valuable (the product). This process may have several steps and is called a 'chemical synthesis.' All the designers of chemical processes want to make the maximum amount of product they can from a given raw material. It is possible to calculate how successful one of these processes is by using the idea of yield.

$$\% \text{ Yield} = \frac{\text{Mass of product actually made}}{\text{Maximum mass of product that could be made}} \times 100$$

3. In a chemical synthesis of calcium oxide, calcium carbonate is roasted in an oven. The equation for the reaction is:



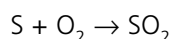
RMM or M_r :	100	56	44	which shows the maximum mass that could be made
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If 50 kg calcium carbonate is used and 21 kg calcium oxide is made, what is the percentage yield of the reaction?

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4. To make sulfur dioxide, sulfur is burnt in oxygen:



If 8 g sulfur is used, what is the maximum mass of sulfur dioxide that could be produced?

If 14 g sulfur dioxide is produced, what is the percentage yield?

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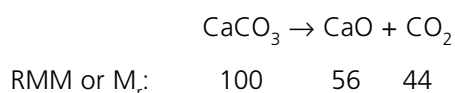
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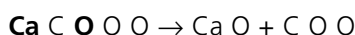
Atom economy

The idea of yield is useful, but from a Green Chemistry and sustainable development perspective, it is not the full picture. This is because yield is calculated by considering only one reactant and one product. One of the key principles of Green Chemistry is that processes should be designed so that the maximum amount of all the raw materials ends up in the product and a minimum amount of waste is produced. A reaction can have a high percentage yield but also make a lot of waste product. This kind of reaction has a low atom economy. Both the yield and the atom economy have to be taken into account when designing a green chemical process.

Look again at the reaction you considered in Q3:



If we split up the formulae, we can look at what happens to each atom in the reaction. The atoms shown below in bold end up in the product we want, the rest do not:



Waste box

1C
2O

From the original atoms, one C atom and two O atoms are wasted – they are not in the final, useful product.

Green chemists define atom economy as:

$$\% \text{ Atom economy} = \frac{\text{Mass of wanted product(s)} \times 100}{\text{Total mass of products}}$$

So for this example,

$$\% \text{ Atom economy} = \frac{56 \times 100}{100} = 56\%$$

Step-by-step: How to calculate atom economy

Step 1. Write out the balanced equation.

Step 2. Calculate the relative molecular mass of each of the products.

Step 3. Calculate the total mass of all the products (remember to account for any numbers in front of the symbols, eg $2 \text{Fe}_2\text{O}_3 + 3 \text{C} \rightarrow 4 \text{Fe} + 3 \text{CO}_2$).

Step 4. Work out which of the products are wanted and calculate their mass (again, do not forget any numbers in front of the symbols).

Apply the formula:

$$\% \text{ Atom economy} = \frac{\text{Mass of wanted product(s)} \times 100}{\text{Total mass of products}}$$

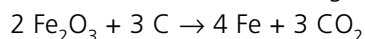
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5. Calculate the atom economy for the reaction in Q4.

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6. Iron is extracted from its ore using carbon:



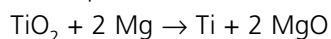
What is the atom economy of this reaction?

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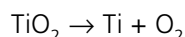
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7. Titanium can be extracted from its ore by two different methods. One uses a more reactive metal to displace the titanium:



The second method is electrolysis of the ore. The overall reaction for this method is:



- a) Calculate the atom economy for each reaction.

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- b) Which method is 'greener'? What else might you want to know before making a final decision?

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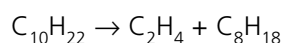
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- c) Oxygen is a useful product and can be sold. What is the atom economy of the electrolysis if the oxygen is collected and sold?

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8. Alkanes can be cracked to form alkenes. Decane can be cracked to form two products:



- a) If only the alkene can be sold, what is the atom economy of this process?

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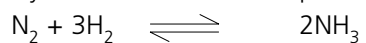
b) If both products can be sold, what is the atom economy?

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c) Explain why your answers to (a) and (b) are different.

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9. The key reaction in the Haber process for making ammonia is:



a) What is the atom economy of this reaction? (You should not need to do a calculation.)

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b) What does the symbol \rightleftharpoons suggest about the likely yield of this reaction?

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10. Explain why using reactions with high atom economy is important for sustainable development.

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