Power to the people:
The molecular revolution in sustainable energy

Keywords

- Biodiesel
- Fuel cell
- Solar power
- Sustainable energy

New developments in biofuels, fuel cells and solar energy

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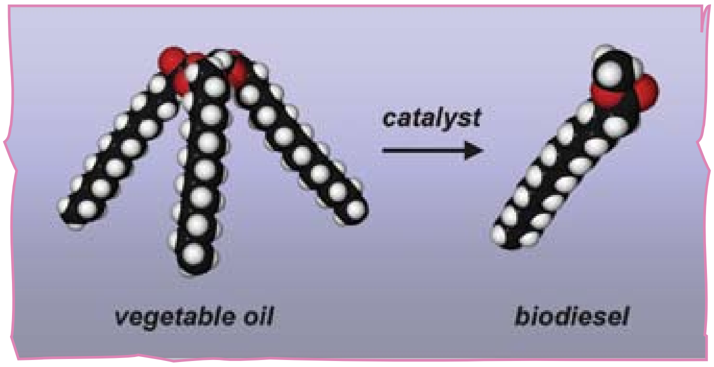

Figure 1: Chemical conversion of vegetable oil (a triglyceride) into biodiesel (a fatty acid methyl ester or FAME) using a molecular catalyst

Sustainability is the ability to meet the needs of the present generation without compromising the ability of future generations to meet their needs. The current consumption of fossil fuels as the world's major source of energy is not sustainable in two important respects. Firstly, reserves of oil, gas and coal are finite and dwindling. With energy consumption worldwide set to double by 2050, supplies will one day run out. Secondly, carbon emissions caused by the burning of fossil fuels are a major contributor to greenhouse gases, prompting concerns over global warming and climate change.

It is clear that we need to find more sustainable 'clean' sources of energy but there is no one universal fix. Over the next century the development of a variety of energy sources and technologies will be needed to alleviate the problems of both supply and pollution while also meeting the spiralling demand for energy. Research groups in the Department of Chemistry at the University of Bath are involved in the development of three of the most promising 'clean' energy solutions. These range from the short term replacement of fossil fuels with biorenewable alternatives, through the medium-term development of fuel cells, to the longer-term goal of harnessing the sun's power directly using solar cells.

BIOFUELS

When Rudolph Diesel first demonstrated his combustion engine over a century ago it was fuelled by peanut oil and Diesel himself envisaged what we now call biodiesel as the fuel of the future. However, the cheap and plentiful crude oil of the twentieth century meant that interest in biodiesel has only recently been rekindled. For example, the EU has set targets to increase the proportion of biofuels in energy consumption to 5.75% by 2010 and 20% by 2020.

To make biodiesel, vegetable oil from high-yielding oil crops such as rape is used. Vegetable oils are molecules called triglycerides, which consist of three fatty acid chains connected together by one glycerine unit. If used directly, the oil is too viscous and the glycerine clogs up diesel engines, so each triglyceride molecule has to be broken down into three molecules of fatty acid methyl ester (FAME) or biodiesel (figure 1). This process is called transesterification and requires the use of a chemical catalyst (a species that speeds up a chemical reaction but can be recovered intact afterwards). Current catalysts need very pure oil and they make separation of biodiesel from by-products difficult. At Bath we are designing new molecular catalysts to overcome these problems, thereby making biodiesel production more efficient, while also allowing impure feedstocks (such as chip fat) to be used.

Although biodiesel can make a significant contribution to reducing dependence on fossil fuels it is not the perfect solution. It is unlikely that sufficient raw materials will ever be available to meet demand without compromising the world's food supply and agriculture itself is an energy-intensive industry. This means that we have to look to more radical solutions for the generation of energy in the longer term.

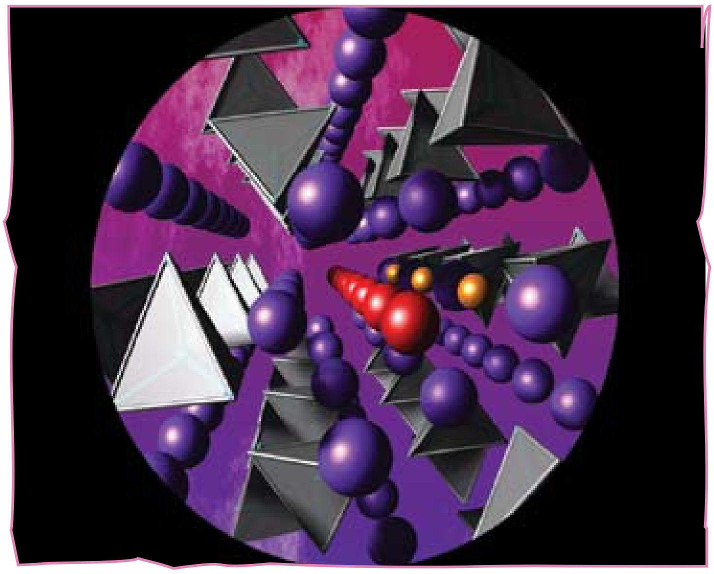

Figure 2: New apatite-type crystalline material for solid oxide fuel cells

FUEL CELLS

The concept of a fuel cell was first shown by William Grove as long ago as 1839 (with some early results published in the Proceedings of the Royal Society). Like a combustion engine, a fuel cell uses a chemical fuel (such as hydrogen). However, like a battery, the chemical energy is converted directly to electricity, without the polluting combustion step.

Polymer-based fuel cells are being developed for cars (and even London buses) while solid oxide fuel cells are suitable for heat and power generation in homes. During the 2003 New York blackout the lights only stayed on in the few buildings powered by fuel cells. In spite of their promise, there are still major challenges for fuel cell technology. In particular, new ion-conducting materials hold the key to more efficient and cheaper solid oxide fuel cells.

At Bath, we use supercomputers to build atomic-scale models helping us understand and design new crystalline and nanostructured oxides that can be tested in the laboratory. Promising alternatives to current fuel cell materials include the discovery of novel 'apatite' compounds that show fast-ion conduction through their beautiful crystalline structures (figure 2). Computer modelling allows us to gain a unique insight into ion motion in solids which in turn will lead to the design of better solid oxide fuel cells in the future.

Looking ahead, a major target in the development of fuel cells is their widespread use in the motor industry. A fuel cell car could run on hydrogen derived from renewable sources such as solar power, with the only by-product being water.

SOLAR ENERGY

The sun provides the earth with energy at a rate of more than 100 000 TW (1 Terawatt = 1 trillion Watts = 10^{12} W). This corresponds to more energy in an hour than the global fossil energy consumption in a year. This vast energy resource was first harnessed by living organisms over 2 billion years ago when molecular mechanisms of photosynthesis were developed. Photosynthetic organisms use the sun's energy to split water into oxygen (which we breathe) and hydrogen, which the organisms combine with atmospheric carbon dioxide to form the organic molecules that constitute the global biomass.

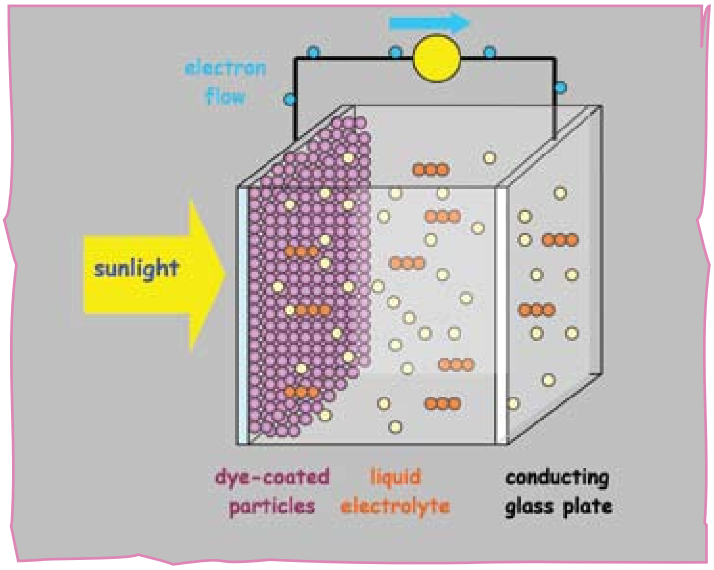

Figure 3: Principle of the dye-sensitised solar cell

Solar cells offer an artificial means of utilising solar energy. The current generation of crystalline and amorphous silicon solar cells have efficiencies between 5% and 17%, but their fabrication is expensive and consumes a lot of energy. A promising and potentially cheaper alternative is the dye-sensitised solar cell (figure 3). This type of cell mimics photosynthesis by harvesting light with intensely-coloured dyes spread as a single layer of molecules on the surface of titanium dioxide nanoparticles. When the dye absorbs visible light, it mimics the action of chlorophyll in a green leaf, except that it produces electrical power rather than biomass. The cells, which have already exceeded 10% efficiency, can be manufactured on sheets of conducting glass or on flexible plastic films suitable for mounting on windows for power generation.

In the future, we can expect to develop these technologies further into direct analogues of photosynthesis. Such devices will be able to split water directly into oxygen and hydrogen or convert carbon dioxide into methanol and oxygen.

Further information

www.bath.ac.uk/powerttp
A website dedicated to this exhibit

www.bath.ac.uk/~ch1ac
Matthew Davidson's Group, catalyst design

www.bath.ac.uk/chemistry/islam
Saiful Islam's Group, fuel cells

www.bath.ac.uk/chemistry/electrochemistry
Laurie Peter's Group, solar energy