Melchett Lecture 2002: Dr Mary Archer

Realistic opportunities for renewables: innovative technology

I am honoured and delighted by the award of the Institute's Melchett Medal — honoured, delighted and a little surprised, since I am a commentator rather than an actor on the energy scene. However, I know that the recognition belongs in good part to the energy organisations of which I am President, the National Energy Foundation and the Solar Energy Society, and I am delighted to receive it on that basis.

At the moment the world consumes energy at the rate of 12.8 TW. By 2050, that energy consumption rate will more than double, to 28 TW, and it needs to do so because energy is vital to our economic and social well-being and without reliable energy supplies, economic growth will be stultified. Yet the provision of power from fossil fuels poses a major threat, for we live, the climate modellers tell us, in a globally warming world. Innovative low-carbon energy technology will be essential in powering tomorrow's world in a sustainable way. Even if global warming and sustainability were not of concern, fossil fuels are a finite resource.

This point is underlined by the logarithmic energy ladder (Figure 1), in which every rung represents an amount of energy greater by a factor of ten than the rung below. On the left is shown the energy content of the world's proven reserves of oil, gas, coal and uranium (assumed to be used in non-breeder mode). Also on the left is shown the world's primary energy supply in the years 1970 and 2000, together with an estimate for 2020. It is clear that our *annual* energy consumption is edging uncomfortably close to the *total* amount of energy in our proven resources. The oil and gas prospectors say that they will find more resources when the price is right, and so they will, but even then the years of oil plenty will pass within a few decades.

For these reasons, and others connected with energy security and diversity, renewable energy is currently attracting a lot of interest. In the pre-industrial world renewable energy was of course all there was, but people reasonably ask whether renewable resources could possibly deliver the amounts of energy we need in the modern world with its hugely increased population.

The answer is yes. On the right of Figure 1 is shown the world's energy income in joules per year from the renewables. At the top is the amount of solar energy falling on the Earth in one year, which is by far our most abundant renewable energy resource: every 44 minutes, enough solar energy strikes the Earth to power it for one year. The energy available from some of the other renewables, particularly biomass and wind, is also substantial compared with global energy demand.

Biomass and energy crops

Biomass, the organic material from dead plants and animals, was one of man's earliest energy sources and is still important today, providing about 14% of final energy consumption in the developed world, and just over one-quarter in the developing world.

Wood is the largest store and source of biomass energy, providing more than twice as much energy as does hydroelectricity worldwide. In northern Europe, short rotation coppice (SRC) is a favoured candidate as an energy crop. These are plantations of willow or poplar that grow so rapidly that the wood can be harvested as a crop every three years or so. Sweden leads the EU in the use of sustainable wood as a fuel, with about 18,000 hectares under SRC. The UK has about 2000 hectares; mostly in the ARBRE project in Yorkshire that will provide 8 MW from SRC.

Miscanthus or elephant grass is another promising energy crop that flourishes in the UK, although far from its native South East Asia. It has been experimentally grown near Ely for ten years, and the Elean straw-burning power station, opened early in 2002, will soon be burning *Miscanthus,* grown by local farmers as an energy crop on an experimental basis. *Miscanthus* is one of the plant species that has a metabolic cycle that concentrates carbon dioxide. This almost totally prevents a process called photorespiration, which causes most temperate plants to be temperate and stop growing in bright sunlight. That is why elephant grass grows so fast, which is desirable in an energy crop. The energy ratio of *Miscanthus* (the amount of energy in the dry crop as compared with the energy inputs into its cultivation) is 25:1, better than SRC at 10:1, and much better than biodiesel at 2:1.

Understanding the genetic and molecular basis of plants and plant growth offers promise for improved energy (and food) crops in the future. At present *Miscanthus* has only has one genotype, which is undesirable because it would render large plantations vulnerable to a single devastating disease, and the Royal Botanic Gardens in Kew are conducting a programme to diversify its genetic base.

Mimicking photosynthesis

We now also have a good understanding of how plants work at a molecular level. At the heart of a green plant is a reaction centre containing two elegant light-activated molecular engines, Photosystem I and Photosystem II. Each of these must capture a quantum of sunlight, absorbed by the green pigment chlorophyll, in order to drive an electron round a molecular circuit, shown in very simplified form in Figure 2. On one side of the lipid membrane in which the reaction centre is embedded, electrons are removed from water, making oxygen, which green plants discard as a waste product. On the other side, electrons are added to carbon dioxide, which is reduced to carbohydrate.

The structure of the reaction centre is the key to its successful function: the molecules in the electron transfer chain must be sufficiently close together to allow the electrons to transfer but not so close as to allow wasteful back or side reactions. This chemistry is hard to mimic *in vitro*, but attempts are afoot to synthesize a green organism that will grow in sunlight to make, for example, hydrogen by splitting water. Already molecular 'solar cells' of controlled geometry that mimic some of the processes of photosynthesis and metabolism have been synthesized.

Photovoltaic cells

Meanwhile we have another type of solar cell, the photovoltaic cell, usually made of crystalline silicon (Figure 3). These are semiconductor diodes that generate direct low-voltage electric power when sunlight falls on them.

They were developed in the 1950s for use in space but can now be found all over the place, from Pheriche Hospital, fourteen and a half feet up Mount Everest, to BP's Harmony petrol stations, which have photovoltaic roof cladding to power the pumps on the forecourt.

Crystalline silicon cells are reliable and have reasonable (~15% sunlight-to-electricity) conversion efficiencies, but they are fragile and expensive. Also such cells have to be quite thick (about 250 microns) because crystalline silicon is a poor light absorber. Other materials such as amorphous silicon and cadmium telluride absorb light much more intensely and can be made into much thinner, cheaper, more flexible solar cells. Cells made of organic rather than inorganic semiconductors are also showing promise. But cells made from these materials tend to be less efficient than crystalline silicon. Moreover, all single materials have a single threshold absorption energy and therefore degrade quite a large portion of the absorbed solar energy in a process called thermalisation, in which the energy in excess of the threshold energy is lost as heat. Attempts are now underway to make so-called 'third generation' multi-layer cell stacks of different electronically and optically matched materials, in which less energy would be wasted by thermalisation and much higher (40-60%) efficiencies could in principle be achieved.

Solar thermal conversion

The Sun's energy can of course be used simply as heat. Operational solar thermal power stations such as SEGS in the Mohave Desert have provided proof of concept of concentrating direct sunlight to generate high-temperature heat, and flat-plate solar water heaters are a common sight in sunny parts of the world. Even in the UK, there are about 50,000 of them, and there should soon be more, thanks to the efforts of the NEF Renewables self-build club, and to the Solar Energy Society, which has successfully lobbied for VAT to be reduced from 17.5% to 5% on professionally installed systems.

The possible use of solar thermal energy instead of conventionally generated heat to drive energy-intensive chemical processes is under investigation in the International Energy Agency's SolarPACES programme. Solar furnaces or power towers are used to generate high-temperature process heat to drive such reactions as the reforming of natural gas and the production of zinc, aluminium and hydrogen. In this way, solar energy could be used to substitute for fossil fuels.

Wind and water power

Back in the early nineties, when I was a member of the government's Renewable Energy Advisory Group that helped to set the UK's first national targets for use of renewable energy, wind power was in its infancy. The use of wind power has increased greatly since then, and wind-generated electricity is currently the world's fastest growing renewable resource. Recent technical innovations in wind turbines include the introduction of compact permanent magnetic generators (which avoid the 1–2% power loss suffered by synchronous wind generators) and advanced power electronics and software (to ensure grid-compliant power quality). On-shore wind has however struggled to get planning permission in the UK, largely on the grounds of visual intrusiveness, and the next phase of development is likely to take place off shore.

The power in flowing rivers has been used to drive water turbines from medieval times and wind turbine technology can be adapted to generate electricity from underwater currents. Underwater turbines would have some advantages over wind turbines: they would deliver predictable power, they would not have to withstand sudden gusts, and they would be much less visible.

Waves also carry an impressive amount of energy. A number of machines have been devised to convert wave energy into mechanical energy in a form that can drive an electric generator. These include mechanical cams, gears and levers, hydraulic pumps, pneumatic turbines and funnelling devices, but particularly important are oscillating water column (OWC) devices, in which the energy of an oscillating water/air column is converted into mechanical energy by a Wells turbine. Wave devices can either be floated in deep water or fixed to the seabed in shallow water or at the shore. Fixed devices are easier to install, maintain and connect to the grid, and less vulnerable to storms, but the power in waves is progressively dissipated as they approach the shore, so deep-water devices can provide higher power density.

Wave power research has been only fitfully supported in the UK, but wave power developers are now using some of the technology developed by the offshore oil and gas industry to make systems that should withstand the very hostile environment of the ocean better. Other countries with wave programmes include Norway, Sweden, Australia and Japan.

Energy efficiency

To the above conventional list of renewable technologies, I like to add energy efficiency (the fifth fuel, as it is sometimes called) because providing more useful output heat, light and power for less input fuel is a highly sustainable energy strategy. And there is plenty of room for improvement in energy efficiency is all sectors: there are few examples except in isolated cases, such as gas turbine performance or aluminium smelting, of the fundamental scientific limits to efficiency being approached. Report after report has noted the potential for cost-effective energy efficiency improvements; for example, the PIU's recent Energy Review has noted that the current rate of energy efficiency improvement in UK is only ~0.5% per year, and this would have to be doubled to 1% per year to achieve the 60% reduction in carbon dioxide emissions by 2050 that the Royal Commission on Environmental Pollution has called for.

Energy efficiency in homes and buildings is notoriously bad in the UK, and hard to improve because few householders or landlords care much about it and the building industry is very conservative in its practices. There is some new genuinely technology around, such as the thin insulation material for inner wall insulation being developed by BASF, but thermostatic radiator valves, condensing boilers and low emissivity glass, although hardly rocket science, are also still new technologies in the sense that we have not put much of them in our homes.

However, regulation may force the pace of improvement: the Council of European Ministers has recently agreed the Energy Consumption in Buildings Directive, which will require a home or building to have an energy certificate on construction or sale. Subsidiarity allows member states to decide what incentives and regulations they will introduce to enact this, and I hope that the National Home Energy Rating scheme, run by the company National Energy Services (which is part-owned by the National Energy Foundation) will prove useful in this regard.

Conclusion

The use of renewable energy resources is certain to increase, though it remains an open question how fast and to what level. Increased volume of sales and improvements in technology will help to bring costs down. Other technical innovations, such as micro-CHP, in-situ coal gasification, redox-flow storage batteries and smaller, safer nuclear reactors, will also help to bring a low-carbon energy economy closer.

These are some of the new technologies on the energy horizon. It is sometimes said that familiarity breeds contempt, but unfamiliarity breeds it too, and renewables are by and large unfamiliar. Don Quixote no longer roams the plains of La Mancha, but people still tilt at windmills and say that renewables cannot rise to the challenge. I think that they can. Three quarters of a century ago, when the Institute of Fuel (as it then was), whose 75th anniversary we celebrate this year, was founded, the world used less than one-tenth as much energy as it does today, coal supplied most of it, no one had heard of global warming, and Lord Rutherford (the discoverer of the proton) had recently opined that nuclear fission would always be a very poor and inefficient way of producing energy, and that anyone who looked for a source of power in the transformations of atoms was talking moonshine.

The seventy-five years between then and now have seen great changes. The changes in the next seventy-five years, taking us to clean, sustainable energy, could and should be equally great.

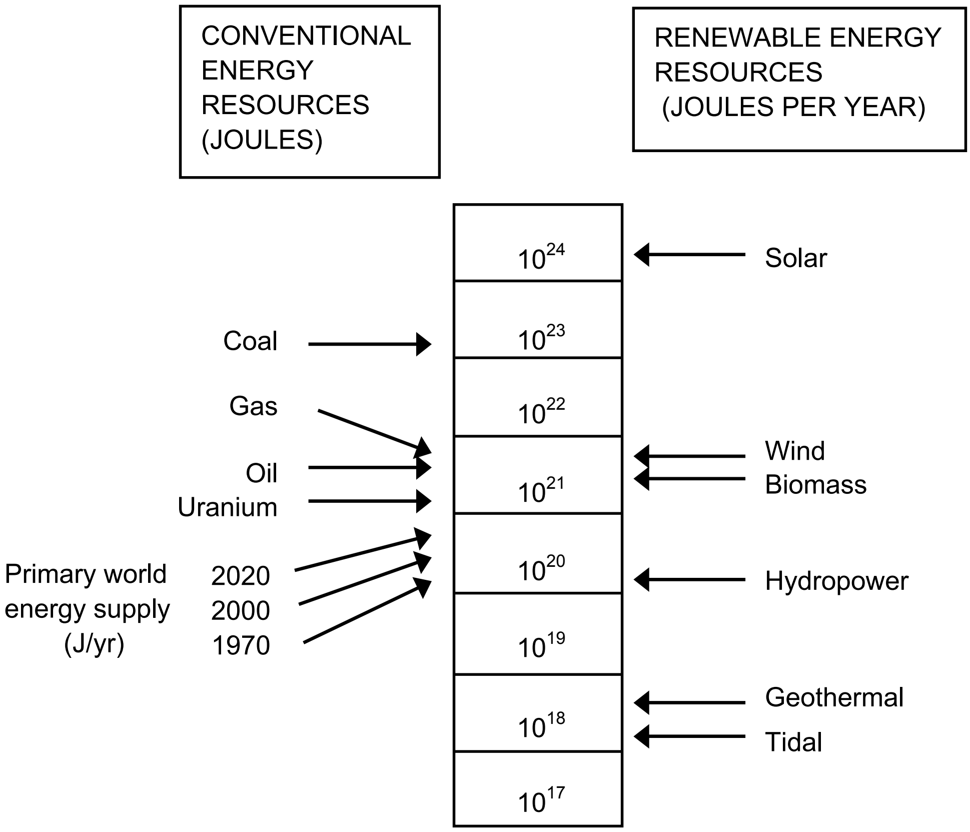

Figure 1 Global energy resources and consumption

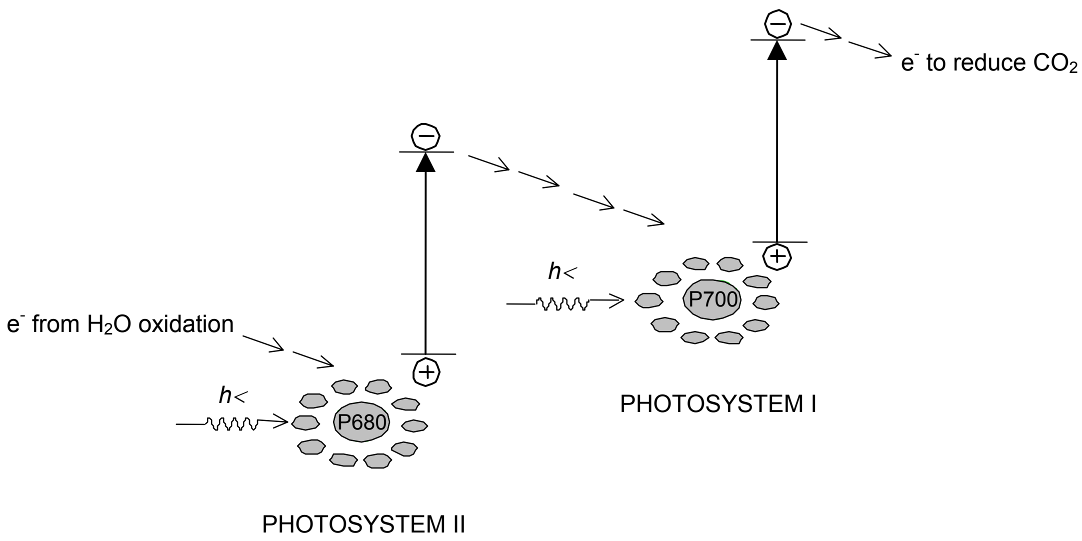

Figure 2 The electron transfer scheme (sometimes called the Z-scheme) of green-plant photosynthesis. Each photosystem absorbs one quantum of light (*h*<), an electron is ejected from the chloroplhyll pigments P680 and P700, ultimately causing water to be oxidized and carbon dioxide reduced.

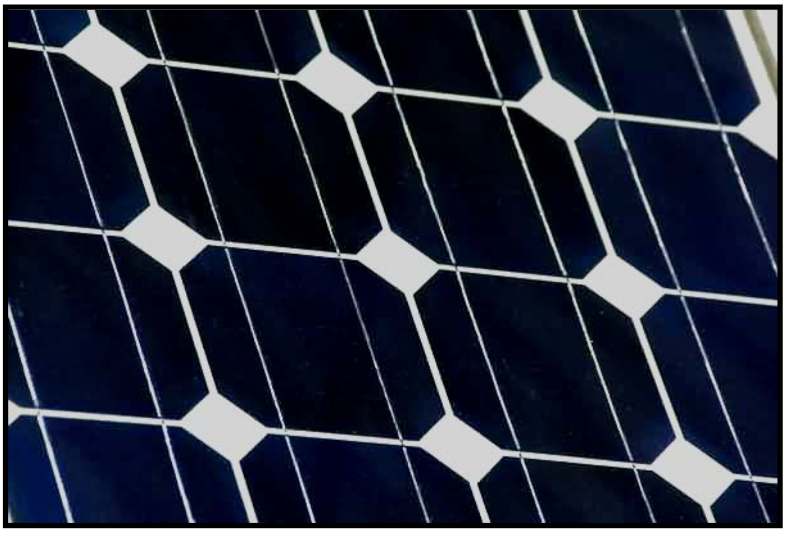

Figure 3 An array of crystalline silicon solar cells.