

Royal Society of Chemistry response S&T Committee inquiry into renewable energy-generation technologies

The Royal Society of Chemistry (RSC) welcomes the opportunity to comment on the House of Commons Science and Technology Committee inquiry on renewable energy-generation technologies.

The RSC is the largest organisation in Europe for advancing the chemical sciences. Supported by a network of 43,000 members worldwide and an internationally acclaimed publishing business, our activities span education and training, conferences and science policy, and the promotion of the chemical sciences to the public.

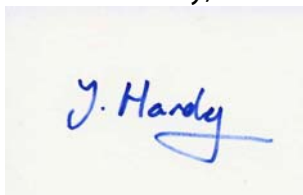
This document represents the views of the RSC. The RSC's Royal Charter obliges it to serve the public interest by acting in an independent advisory capacity, and we would therefore be very happy for this submission to be put into the public domain.

The document has been written from the perspective of the Royal Society of Chemistry and consequently our comments relate to only parts of the consultation document.

The evidence submitted was for the most part published in an RSC report entitled "Chemical Science Priorities for Sustainable Energy Solutions" [www.rsc.org/Gateway/Subject/EnvEnergy/].

If you would like further information or need anything in this document clarified, please do not hesitate to contact me.

Yours sincerely,



Dr Jeff Hardy
Environment, Sustainability and Energy Manager
Tel: 020 7440 3395, Email: hardyj@rsc.org

Attached:

Appendix A: RSC response to EFRA Committee inquiry into bioenergy

Appendix B: RSC response to Royal Society inquiry into biofuels

Appendix C: Sainsbury review of science and technology consultation

Appendix D: EPSRC knowledge transfer and economic impact consultation

The current state of UK research and development in, and the deployment of, renewable energy-generation technologies including: offshore wind; photovoltaics; hydrogen and fuel cell technologies; wave; tidal; bioenergy; ground source heat pumps; and intelligent grid management and energy storage.

Photovoltaics (solar power)

Solar power has the potential to provide a significant proportion of the UK electricity needs. The chemical sciences will be crucial in reducing the cost and increasing the efficiency of solar technology through improvements to current design and manufacture and through the development of the next generation of technology, such as technology that takes advantage of biological methods of harvesting and storing energy from light. The UK has a strong research base in areas including understanding and mimicking photosynthesis systems and also in dye-sensitised and organic solar cells. Ideally it will become routine to integrate solar power into buildings as materials of construction (for example roof tiles and windows) coupled to energy storage and low energy demand devices.

Photovoltaic (PV) devices consist of a semi-conducting material, currently most commonly silicon, which convert photons of light into electrical current by means of the photoelectric effect. They were developed in the 1950s to power space satellites, but their potential for providing remote power for telecommunications, water pumping and refrigeration rapidly increased demand for terrestrial applications. The drawbacks of early photovoltaic technology also became obvious, namely cost, low power density and intermittency of operation.

Although prices are coming down PV systems currently cost around 55 pence/kWh which is more than a factor of 10 greater than current gas, coal and nuclear power plants. A number of different technologies are at various stages of development to both reduce the cost of solar modules and to increase their efficiency. Over 80% of modules are currently based on crystalline silicon. Silicon is an excellent material for solar cell production since its technology has become highly developed as a result of the global semiconductor market. In addition, its supply is virtually inexhaustible and it is non-toxic, although its manufacture is currently highly coupled to semiconductor demand. In the late 1970s and early 1980s thin films of inorganic semiconductors made from indium tin oxide (ITO), cadmium selenide (CdTe), copper indium diselenide (CuInSe₂), amorphous silicon, thin film silicon and titanium oxide (TiO₂) were developed as potentially cheaper PV materials. Innovative research on very thin (less than 20 atomic layers), high efficiency silicon devices is now in progress.

One of the factors that keep system costs high for these technologies is the requirement of high temperature processing of the semiconductor material. This and the rapid growth of the organic light emitting diode market have resulted in considerable research on PV materials based on molecular, polymeric and nanocomposite materials. Although commercially viable efficiencies have yet to be

demonstrated, progress is rapid. In 2004 at least two manufacturers claimed efficiencies of 5% for organic PV materials that can be printed or sprayed on to a thin support, flexible backing film, potentially offering considerable production cost reductions.

Dye sensitised solar cells (DSCs) offer a near market alternative system to silicon cells. These cells were invented by Michael Grätzel and Brian O'Regan at the École Polytechnique Fédérale de Lausanne in the 1990's. DSCs currently have a sunlight conversion efficiency of 11%, which is lower than that of silicon based solar cells, however, they have a lower cost base which allows them to compete. There is significant potential to improve the efficiency and further reduce the cost of DSCs.

The growing number of uses for photovoltaic devices, and the considerable improvements in reliability and price have generated a market that is growing at about 25% per annum. Although PV began by providing power to remote locations that had no grid connection, over 50% of today's world market is for building integrated photovoltaic (BIPV) devices that are incorporated into the roofs and structures of buildings. Providing governments continue to support the installation of BIPV and introduce policies that allow net metering, by which consumers can sell surplus electricity back to the grid, it is likely that the demand for PV will continue to grow. As a result, many independent studies suggest that the costs of PV will continue to fall and that it is plausible to reduce module costs by a factor of seven or greater by 2020 – this would allow BIPV to provide electricity below today's retail price in sunny areas of the world.

Useful amounts of electricity can also be generated directly from infrared radiation using a process called thermophotovoltaics. It is unlikely that the power of the sun will be harnessed directly using this technology, but it is theoretically possible. It is more likely that thermophotovoltaics will be used to generate electricity from waste heat to boost the efficiency of conventional thermal power generation technologies.

Hydrogen and fuel cell technologies

The hydrogen economy is the name given to an economy based on hydrogen rather than carbon based fuels. The transition to the hydrogen economy represents the biggest infrastructure project of the 21st Century. A sustainable hydrogen economy would offer enormous economic, social and environmental benefits and this justifies the significant investment of resources and capital.

When hydrogen (H₂) is burned or used as fuel to generate electricity in a fuel cell, the major by-product is water. Whilst hydrogen is abundant on Earth, it is not abundant in the form H₂ and must be produced in a way that uses energy. Therefore, H₂ is potentially a significant fuel source and the key challenges are to minimise the energy used in producing H₂ and ultimately to produce H₂ from sustainable sources.

There are technical barriers throughout the supply chain of the hydrogen economy, and the key challenges for the chemical sciences are highlighted in the following sections.

Hydrogen production

Energy is required to produce hydrogen and therefore as a fuel it is only as clean as the process that produced it in the first place. Currently the most common method is steam reforming of natural gas in two-step catalytic process, producing a mixture of H₂ and CO₂. There are concerns over the economics of the process and over the release of CO₂. In the future it will be possible to employ carbon capture and storage (CCS) technology to safely store the CO₂, however, this will add to the cost of the hydrogen production and the energy required. There are a number of medium and long-term options for producing hydrogen:

- Coal and oil residues or biomass gasification. The high temperature of the process and the need to separate nitrogen from air (presumably cryogenically) are barriers to the economics of this process.
- Using electricity (preferably from renewables) to split water via electrolysis; this can be seen a method of storing (renewable) power. Further work is still needed to develop improved electrode surfaces for electrolyzers and also the materials of construction. Uses for the by-product O₂ also need to found.
- Thermochemical splitting of water in the next generation of high temperature nuclear reactors or concentrating solar power plants. There is a need for new materials and an understanding of the fundamental high temperature kinetics and thermodynamics in order to achieve this.
- Biochemical hydrogen generation. Green algae and cyanobacteria utilise light to split water, producing both H₂ and O₂. Currently O₂ concentration in the system and the rate of reaction are limiting factors. New natural microorganisms and genetically modified organisms may hold to key to increased efficiency.
- Photocatalytic water electrolysis is where the energy of sunlight is used to split water into H₂ and O₂. The system, and current R&D priorities are focussed on two basic principles. Firstly, the light harvesting system must have suitable energetics to drive the electrolysis. Secondly the system must be stable in an aqueous environment.

Hydrogen storage and distribution

Hydrogen is the lightest element and occupies a larger volume than other fuels. Currently, in prototype vehicles, compressed hydrogen is used, but this is relatively bulky. Liquid hydrogen would be a more efficient way to store H₂ (850 times denser than gaseous H₂) but with a boiling point of -253°C it is very energy intensive to maintain such a low temperature. Mechanisms to store hydrogen in a form that is safe, suitable for intended use and regenerable (if applicable) are therefore a key

research priority that the chemical sciences must rise to meet. A summary of some of the key technologies and issues are discussed below:

- High surface area nanostructured materials, such as carbon nanotubes, have been shown to be able to store and release significant quantities of H₂. Such materials are as yet unproven and much scientific endeavour is required to fully assess their potential.
- Certain metal complexes absorb H₂ reversibly to form metal hydrides. Numerous compounds have been and continue to be studied. Key requirements of a suitable metal hydride include, high H₂ content, low cost, favourable kinetics, resistance to poisoning and the materials should not ignite in air.
- There are a number of options for chemical carriers of H₂; this means that the H₂ is bound into the chemical structure of the carrier. Organic liquids, such as cyclohexane and methanol, inorganic complex hydrides such as 3Na[AlH₆] and chemical hydrides such as NaBH₄ all have potential to carry H₂. Key challenges include the mechanism of releasing H₂, recharging the materials, H₂ density and cost. R&D programmes continue to explore these issues.

There are a number of worldwide examples of pipeline networks for safely transmitting pressurised hydrogen, thus demonstrating that a larger scale network is possible. However, the compatibility of H₂ with existing natural gas infrastructures both in terms of the materials employed (potential for leakage) and the need for a faster flow rate (requiring more energy). The chemical sciences have a key role to play in material design for hydrogen carrying infrastructures.

Hydrogen may potentially be stored in large quantities in depleted oil and gas fields and aquifers. There is a significant parallel here with work being carried in the field of carbon capture and storage.

There have been concerns over release of molecular hydrogen into the lower atmosphere, for example through leakage. The presence of H₂ may lead to a reduction in the levels of hydroxy radicals (•OH), and as •OH is a sink of methane (CH₄) it may lead to an increased level of CH₄ in the atmosphere. Clearly it is important that the role of H₂ in the atmosphere is better understood.

Hydrogen use

Aside from direct combustion, fuels cells are the main method for obtaining energy from hydrogen. Fuel cells (FCs) fall broadly into three categories:

1. Low Temperature (50-150°C): alkaline (AFC), proton-exchange membrane (PEMFC) and direct methanol (DMFC) fuel cells;
2. Medium Temperature (around 200°C): phosphoric acid fuels cell (PAFC);
3. High temperature (600-1000°C): molten carbonate (MCFC) and solid oxide (SOFC) fuel cells.

The DMFC differs from the other FCs because it uses methanol as fuel, rather than H₂. Each of the six systems has preferred uses (for example stationary and mobile power generation), advantages and disadvantages and specific research priorities that need to be addressed. For chemical scientists there are numerous technical challenges to be overcome including:

- Membrane design
- Materials for construction
- Understanding the fundamental thermodynamics and kinetics
- Tolerance to impurities
- Electrocatalyst design
- Cost
- Speed of start-up

On-board storage of hydrogen is posing significant obstacles to delivering hydrogen-powered vehicles. The development of materials for hydrogen storage is a key challenge for chemical scientists.

The cost of fuel cells versus that of the internal combustion engine is also a problem, with the latter typically costing \$50 for each kilowatt of power it produces while fuel cells cost a hundred times more. Technical challenges such as making fuel cells rugged enough to withstand the stress of driving, reducing their size and weight while increasing power density, fuel flexibility and fuel cell poisoning still exist.

The RSC believes that for the hydrogen economy to become a reality, major scientific and engineering challenges need to be addressed in terms of the generation of hydrogen on a large scale, storage, cost-effective safe transportation and the next generation of materials and technology for hydrogen fuel cells. We recommend that the Government supports the science and engineering research that will ultimately deliver a sustainable hydrogen economy at a level where the UK is in competitive position in a world perspective.

Bioenergy

The RSC has recently submitted evidence to two relevant inquiries, the EFRA Committee inquiry into bioenergy (appendix A) and the Royal Society inquiry into biofuels (Appendix B). Both documents are attached to this submission as appendices.

Energy storage- Batteries

Rechargeable batteries offer the most direct means of storing electrical energy and as a result are highly efficient.

Lithium-ion batteries represent the most important development in rechargeable battery technology for a hundred years. They have three times the energy density of conventional rechargeable batteries and have had a major impact in consumer electronics. A lithium-ion battery occupying some 10 m³ could store 4.5 MWh of

energy and with a charge/discharge efficiency of over 99.9%. This technology is already the storage solution of choice in a number of energy research centres around the world.

Lithium-ion presents one of the greatest challenges for chemists. Scale up to larger batteries requires:

- fundamental advances in new cheaper, safer electrode and solid polymer electrolyte materials with better performance;
- new non-flammable liquid electrolytes or ionic liquids.

Moreover, Li-ion batteries for vehicles are comprised of hundreds of cells, if any of these fails the whole system is compromised.

Cobalt oxide is a key material for producing lithium ion batteries. The world estimated cobalt reserves are relatively small; less than a tenth of that of nickel and just over a hundredth of that of copper. Cobalt accounts for a quarter of the mass of lithium ion batteries. If 30 million battery packs capable of powering electric vehicles were made annually the world cobalt reserves would be depleted in six years (provided the global estimates are accurate). The majority of cobalt reserves are located in politically unstable regions - the top three sources of cobalt are Congo, Cuba and Zambia. This could raise a major security of supply issue. To address this electrodes based on cheaper more abundant materials must be synthesised.

A further possible driver for the development of novel battery technology at the smaller scale end of battery technology is regulation. In the EU, measures have already been taken to limit the mercury content of batteries. Further regulation will aim to reduce other heavy metals, including cadmium, nickel and lead. Also options for disposal of batteries will be limited to encourage collection and recycling.

Energy storage - Superconductors

In superconducting magnetic energy storage devices (SMES), energy is stored in the magnetic field of a coil within which a current flows. The device consists of a superconducting coil, typically made of niobium with titanium or tin, in a copper matrix, a power conditioning system (PCS), a refrigeration system for cooling the coil and a cryostat vacuum vessel. Efficiency losses are mainly due to the cryogenic system, which has to keep the coil below the critical superconducting temperature of around -268°C .

Chemists are needed to address the identification and development of new superconducting materials with higher critical temperatures, preferably room temperature, and with suitable mechanical properties for processing into coils and wires.

Wind, tidal and wave power

Advances in materials science to develop high strength, lightweight materials for turbine blades and towers are required in order to facilitate the construction and continued operation of large wind and tidal power turbines. Long lasting protective coatings will also be required to reduce maintenance costs and prolong the operating life of wave and tidal energy devices.

The feasibility, costs, timescales and progress in commercialising renewable technologies as well as their reliability and associated carbon footprints.

No comment.

The UK Government's role in funding research and development for renewable energy-generation technologies and providing incentives for technology transfer and industrial research and development.

It is important that there are sufficient trained and committed scientists and engineers to do carry out the research, development, demonstration and deployment of renewable energy-generating technologies. It is also important that the Research Councils and DTI ensure that there are collaborative funding mechanisms throughout the technology development pathway that allow scientists, engineers and technologists to work together to bring basic research through to developed products. The RSC is hopeful that the new Energy Research Institute should address this issue and be a true multi-disciplinary centre to address the technology challenges.

The RSC has recently submitted responses, relevant to this inquiry, to the Sainsbury review of science and technology consultation (Appendix C) and EPSRC knowledge transfer and economic impact consultation (Appendix D) – these are attached as appendices.

Other possible technologies for renewable energy-generation.**Artificial photosynthesis**

Artificial photosynthesis is a research field that attempts to replicate the natural process of photosynthesis, converting sunlight, water and carbon dioxide into carbohydrates and oxygen. The process essentially comprises two steps one involving a light reaction and other a dark reaction. In the first step light is captured and the energy used to split water into oxygen and hydrogen. In the second “dark” step hydrogen is combined with carbon dioxide to make carbohydrates (or possibly other products). The potential of artificial photosynthesis is huge as it offers a route to sustainable hydrogen production and also potentially to a process that removes carbon dioxide from the atmosphere and creates useful products. The scientific and technical challenges, however, are equally large – in essence this is because the natural is incredibly complex and has numerous interlinked processes. Artificial photosynthesis will require a number of years of research and development before a commercial process is envisaged.

At a recent RSC policy seminar (Harnessing Light) Professor Tony Harriman and Professor Jim Barber gave presentations on this subject. In addition to the scientific challenges it was noted that there is worrying trend in expertise loss – partly through retirement and partly through losing researchers to the competitive field of molecular photonics.

Blue energy

A significant potential to obtain clean energy exists from mixing water streams with different salt concentrations. This salinity-gradient energy, also called blue energy, is available worldwide at estuaries where fresh water streams flow into the sea. The global energy output from estuaries is estimated at 2.6TW, which represents approximately 20% of the present worldwide energy demand. Large amounts of blue energy can also be made available from natural or industrial salt brines.

Blue energy can work either on the principle of osmosis (the movement of water from a low salt concentration to a high salt concentration) or electro dialysis (the movement of salt from a highly concentrated solution to a low concentrated solution) where the saline water and fresh water be separated by a selectively permeable membrane. In the osmosis process water pressure is created that can drive a turbine. In the electro dialysis case the movement of ions creates the electricity. The by-product of blue energy is brackish water. Brackish water is simply a combination of fresh and salt water which naturally occurs in an estuary.

Though the technology of blue energy has been understood for quite sometime, manufacturing the membranes was far too expensive to become a practical energy alternative. Recently, more economical membranes have been developed which will allow blue energy technology to begin being implemented in suitable environments.

Further developments that reduced the cost or improved the efficiency of membranes would significantly improve the economics of this process. Currently blue energy is being used successfully in the Netherlands.