NANOTECHNOLOGY AND RENEWABLE ENERGY (PART II)

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This is the concluding part of the write-up on nanotechnology for renewable energy development. The first part dealt with the use of nanotechnology in the solar energy and bio-energy sectors *(GE*, Nov– Dec 2007, Pg. Nos. 10–11). The concluding part deals with applications in hydrogen, fuel cells, energy storage, and new grid architecture.

HYDROGEN AND FUEL CELLS

We often hear lot of hype about the potential for a future hydrogen economy to revolutionise the way we consume and produce energy. While we've seen some promising applications of hydrogen as a fuel source in the recent past, it still seems very unlikely that we'll ever see a hydrogen-based energy market on the scale that some are envisioning. A few scientists like Prof. Craig Grimes of Penn State University, U.S., are optimistic. Here is a brief summary of the possibilities of applying nanotechnology to hydrogen production, storage and fuel cells.

Hydrogen Production: A hydrogen fuel cell takes hydrogen plus oxygen and combines them to produce electricity and pure water as a waste product. Nanotechnology is seen as holding the key to solving the two main problems with hydrogen fuel cells: producing the hydrogen and storing it. The cleanest way to producing hydrogen is via electrolysis, but the electricity used in this process needs to come from a clean source such as solar. In August 2007, Prof. Craig Grimes and his colleagues announced that they are only "a couple of problems away" to developing a cheap, viable photoelectrolytic technology to split water into hydrogen and oxygen. Grime's method would rely on thin films made up of titanium iron oxide nanotube arrays that could split water under natural light.

Hydrogen Storage: The increased use of hydrogen as an energy source, particularly through the use of fuel cells in automotive applications requires safe, efficient, and cost-effective methods of hydrogen storage. Conventional technology stores hydrogen in high-pressure tanks. Unfortunately, high-pressure storage of hydrogen presents obvious safety risks, preventing it from becoming a practical solution. Several alternative methods of hydrogen storage utilising nanotechnology, specifically, adsorption onto high-surface area solids and chemisorption into metal hydride compounds are being examined for future viability. Adsorption of hydrogen onto high-surface solid areas is a process in which hydrogen bonds to a (typically carbon) surface due to distance-dependent surface forces. Carbon nanotubes and nanostructured graphite fibres are of particular interest as adsorption mediums, due to their high surface area and surface reactivity. Current technology requires high pressure or low temperatures to achieve reasonably high adsorption mass percentages, and high temperatures to achieve desorption in some materials. Adsorption performance may be improved through the use of impurities (such as titanium) integrated with the carbon material, and by adjusting the shape and structure of the carbon surfaces themselves.

Metals-hydrogen reactions can also be used as a hydrogen storage medium in the form of hydrides, capable of storing hydrogen atoms within their metal lattices. Both the storage capacity and hydrogenation rate of metal hydrides can be increased by creating specific nanostructures in the metal or by using various metal alloys. Carbon-based nanostructured materials, especially carbon nanotubes have been examined in detail to determine their hydrogen storage capabilities.

Fuel Cells: A fuel cell is an electrochemical device in which the reactants are continually replaced. Fuel cells are advantageous in renewable energy applications since they can convert chemical energy into electricity with high efficiency (35%-70%). Despite a long history, fuel cell usage has been limited by material performance and high cost.

Fuel cells, specifically proton exchange membrane fuel cells (PEMFC) generate electricity in the following manner: hydrogen is delivered to the anode side of the fuel cell where it is catalytically split into protons and electrons; the protons pass through an electrolyte membrane and the electrons are forced through an external electric circuit to reach the cathode; oxygen is delivered separately to the cathode where it reacts catalytically with the protons and electrons to produce water and heat. To produce adequate voltage and current, multiple fuel cells will be connected to form a 'fuel cell stack'.

The catalysts attached to fuel cell electrodes are usually made of platinum. Platinum is a scarce material. When manipulated on the nanoscale, materials may be created for use in place, or in combination with platinum to produce electrocatalysts of equal or superior performance. These nanoscale materials are advantageous as they allow reduced platinum usage with increased efficiency for specific applications. Electrolytes are generally proton-conducting polymer membranes, which must allow protons to cross without conducting electricity. Development and characterisation of electrocatalysts at the nanoscale is important for progression of the fuel cell industry. These techniques allow mixed metal nanoparticles in carbon-supported structures to be adaptable for various fuels and electrolytes. This nanoscale development cycle may include optimisation of nanoparticle size, changing the mixture of supported materials, and sustaining high current densities.

Another fuel cell design currently under development is that of microbial fuel cells (MFCs), where an organism performs the electron transfer mechanism. Currently, research is focused on understanding the transfer mechanisms and microbial selection; however, some designs are already being influenced by nanotechnology. As research progresses, nanotechnology could play an important role in the development of MFCs.

ENERGY AND ELECTRICITY STORAGE

A major complaint against renewable electricity from sources like wind and solar energy is that they are intermittent i.e. they produce energy only when the source is available. On the other hand, electricity production is an on-demand service; when more electricity is required by consumers, producers must increase their output. Nanotechnology researchers are inventing battery technology that might be able to store electricity generated during low demand period and then release it to the grid for use at a later stage. The current Lithium Ion, Nickel Cadmium and Nickel Metal Hydride batteries are unsuitable for this application. But the intervention of nanotechnology could see large scale banks of these batteries saving electricity or this may come from a new form of battery currently under development such as Nanotube Super Capacitor Batteries. They utilise nanotubes to give a battery that can be charged instantly and can hold the charge with little degradation over time. This technology is expected to be commercialised in four years. These capacitors can be re-used indefinitely and hence environmental waste from discarded batteries would become a thing of the past.

NEW GRID ARCHITECTURE

Nano-engineering shows promise of developing highly efficient new conductors and superconductors (or quantum conductors) that could gradually replace current transmission infrastructure. This, along with the super capacitors for storage described in the previous section, may lead to new distributed architectures for electricity grids, enabling even ballistic electricity transport. Quantum wires spun from carbon nanotubes could carry electricity further and more efficiently. Some U.S. research institutions have already produced hundred metre long fibres consisting of well-aligned nanotubes. This is completely in tandem with the distributed generation possibilities growing with the deployment of alternative energy sources.

BEYOND THE NANO-HYPE

Having said all this, one must sound a note of caution about undue hype surrounding nanotechnology. Broadly speaking, the research so far has ignored workers' safety, consumer health and the environmental impacts of nanomaterials. Even though nanotoxicity studies of carbon-based materials and quantum dots have been conducted, a lot more work is needed. The range of nanomaterials may span the gamut from toxic to benign. For example, silver nanoparticles require separate screening and classification and the Environmental Protection Agency in the U.S. has given rulings in this regard. Research should be directed at understanding the root causes of toxicity in these materials, so that safer materials can be engineered. Industry consortiums, environmental groups and individual corporations need to take concrete action to determine the safety of materials and products before they enter the market. The environmental credentials must be proven first, especially when you are talking of 'green energy'. Nanomania should not blind us to these realities.