Tiny materials could produce big energy solutions

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1. World energy facts

With the advent of the automobile, airplanes and the spreading use of electricity, oil became the dominant fuel during the twentieth century (Figure 1). World primary energy consumption grew by 1.4% in 2008, the slowest growth since 2001 [1], mainly due to the global financial crisis. Despite the recent economic downturn, growing demand for energy particularly in China, India, and other developing countries are expected to lead to rising real oil prices over the long term [2]. Yet, the consumption is annually increasing and reserves would be exhausted much earlier.

On the other hand, due to the evident threat of global warming, industries, individuals, governments and academics are searching to find ways to reduce greenhouse gases. It has been reported that the global CO_2 emissions from fossil fuel between 2000 and 2008 increased 29% [3]. Recently, despite the global warming statistics, the challenge at Copenhagen summit to keep global warming as far below the danger threshold of 2 °C has failed to deliver an effective agreement. Nevertheless, there is a tremendous interest in researching and developing cheap and clean (low/zero emission) alternative energy sources like hydro-power, wind-power, solar energy, bio-fuel and geothermal. Among these energy sources and technologies, converting the sunlight directly into electricity by the photovoltaic effect – solar cell – and generating electricity by a chemical reaction – fuel cell - have been attracting more and more attention in recent years due to their relatively high energy conversion rates and wide application areas.

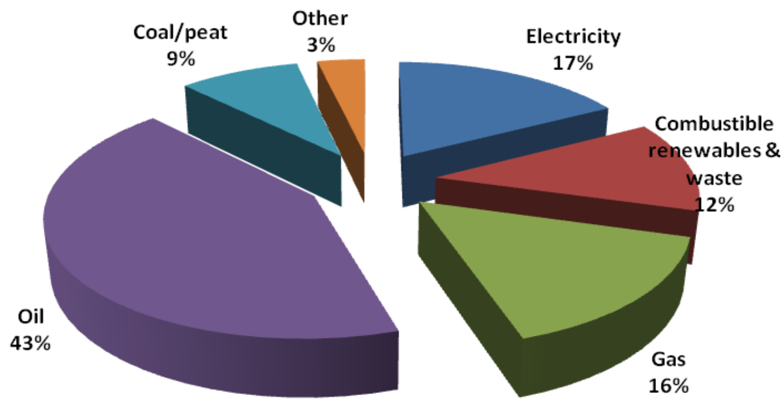

Figure 1. World total consumption by fuel – 2007 [4].

2. Fuel Cell

Japanese leading manufactures such as Panasonic, Sony, and Toshiba have already fuel cell based house-hold/mobile products in the market. Recently, Toshiba launches direct methanol fuel cell as external power source for mobile electronic devices, and Panasonic developed a direct methanol fuel cell system which can produce an average power output of 20 W for portable generator. In addition to mobile products, Toyota, Nissan and Honda developed fuel cell cars, along with GM, Ford, and Volkswagen from the oversea side. Toyota began the hydrogen-powered TOYOTA FCHV (fuel cell hybrid vehicle) at 2002, which is the world's first mass-produced hybrid vehicle. Recently, Suzuki Motor Corporation announced a fuel-cell scooter which can run at 350 km/h of speed.

While there are dozens of types of fuel cells, there are six principle kinds in various stages of commercial availability, or undergoing research, development and demonstration. These six fuel cell types are significantly different from each other in many respects; however, the key distinguishing feature is the electrolyte material. These fuel cell types are; Alkaline Fuel Cell (AFC), Molten Carbonate Fuel Cell (MCFC), Phosphoric Acid Fuel Cell (PAFC), Proton Exchange Membrane Fuel Cell (PEMFC), Solid Oxide Fuel Cell (SOFC) and Direct Methanol Fuel Cell (DMFC). Every fuel cell has an electrolyte, which carries electrically charged particles from one electrode to the other, and a catalyst, which speeds the reactions at the electrodes (Figure 2). Among the different types of carbon structures (nanobeads, microspheres and nanotubes) to prepare carbon-supported catalysts, carbon nanofibers is an interesting candidate by owing a high specific surface area and high electrical conductivity. However, traditional methods to prepare carbon nanofiber including traditional vapor growth and plasma enhanced chemical vapor deposition involve a complicated process and are high cost methods. On the other hand, it has been demonstrated that polyacrylonitrile (PAN)-based carbon nanofiber (CNF) can be produced by using the electrospinning technique [7-9]. Detailed information about this technology is given in the previous issue of this journal [10]. The electrospinning technology directly produces a web-structured fabric which can be carbonized and it does not require a second processing step to add a binder and an electric conductor such as carbon black. This is advantageous over the carbon nanotube method which needs the second step. Also, it has been demonstrated that carbon nanofiber supported non-platinum ternary alloy catalysts can be electrospun in one step (without catalyst deposition step) by incorporating the catalyst precursor(s) directly into the PAN/solvent solution [10]. In addition to electrospinning of PAN-carbon nanofiber supported catalysts, scientists used this technology to produce binary metallic nanowires of PtRh and PtRu for DMFC, preparing membranes of sulfonated poly(aryl ether ketone)s for PEM, and composite membranes consisting of polyvinylidene fluoride and Nafion for DMFC. Obviously, the electrospinning technique has many advantages and attracts much attention to use in fuel cell technology. Besides, today, the availability to produce these nanofibers at industrial scale by using electrospinning based technologies like Elmarco's Nanospider™ opens a new era in this field. Figure 3 shows the surface morphology of PAN-based carbon nanofiber produced by using the Nanospider™ technology. For more information about the technology please refer [12].

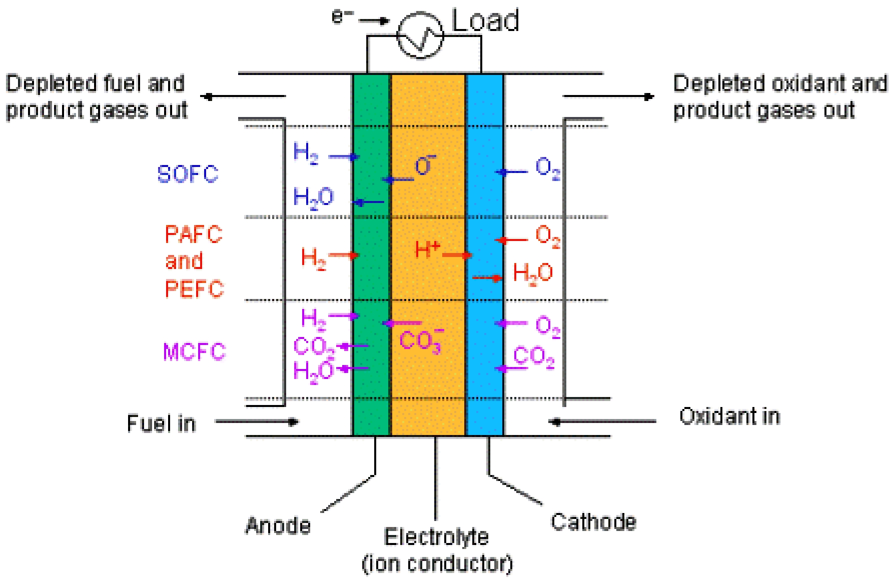

Figure 2. The five principal types of fuel cells and their electrochemical reactions [5]

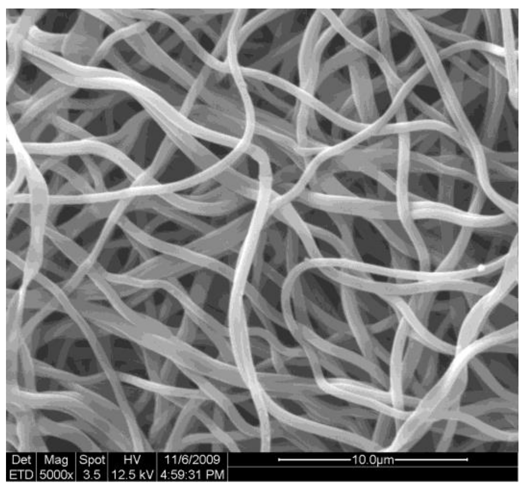

Figure 3. PAN-based carbon nanofiber produced by Nanospider™ technology (Copyright © 2009 Elmarco)

3. Solar Cell

To date, many of the solar energy systems are significantly more expensive than the traditional options available to customers (e.g., engines, gas heaters, grid electricity). The cost, performance, and convenience of these systems must be improved if solar energy is going to compete in energy markets against more traditional alternatives. In 1991, Gratzel and co-worker reported the dye-sensitized solar cell (DSSC) using TiO_2 nanoparticles and the energy conversion efficiency reaches over 10%, which is comparable to that of the silicon based solar cell [13]. A dye-sensitized solar cell is considered to be a relatively new class of low-cost solar cell. It is based on a semiconductor formed between a photo-sensitized anode and an electrolyte, a photoelectrochemical system. Despite the fact that DSSC has lower energy output than traditional silicon solar cells, it has been widely investigated due to their special features such as better performance at cloudy weather conditions and low cost (50% less). Also, DSSC can be produced transparent, flexible, and colored. Energy conversion in a DSSC is based on the injection of an electron from a photoexcited state of the sensitizer dye into the conduction band of the nanocrystalline semiconductor (TiO_2 is by far the most employed oxide semiconductor), as depicted in Figure 4.

Recently, the electrospinning technique has been used for producing TiO_2 nanofibers as photoelectrode and it has been shown that it yields better performance [14]. Moreover, hybrid nanostructures have recently emerged as a promising architecture for electron transport as well as dye adsorption, where the maximum dye adsorption is possible on spherical particle surface and the presence of nanofibers directs for faster electron transport rate [15]. It has been reported that the photocurrent of the DSSC with the electrospun TiO2 electrode increased more than 30% after $TiCl_4$ treatment. [16].

Together with these R&D achievements, the availability of an inorganic nanofiber mass production process brings a step closer to commercializing the DSSC technology. Recently, Elmarco has launched the world's first inorganic nanofiber production line which is capable to produce a variety of inorganic nanofiber materials [17], and started a co-operative project with power-producing group ČEZ with the aim to establish economically favorable solar panels, which are the first in the world using nanofibers to produce energy [18]. This technology makes possible to produce pure anatase TiO_2 nanofibers with diameters in the range of 50-500 nm and specific surface area up to 150 m^2/g as shown in Figure 5.

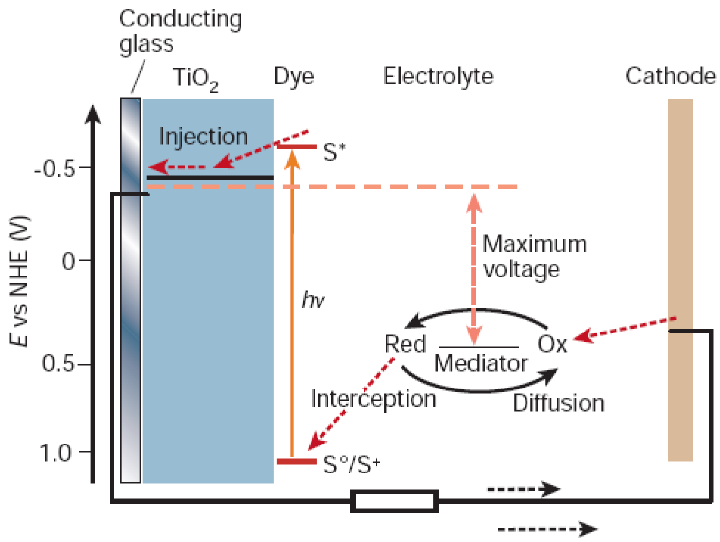

Figure 4. Schematic illustration of dye-sensitized solar cell.

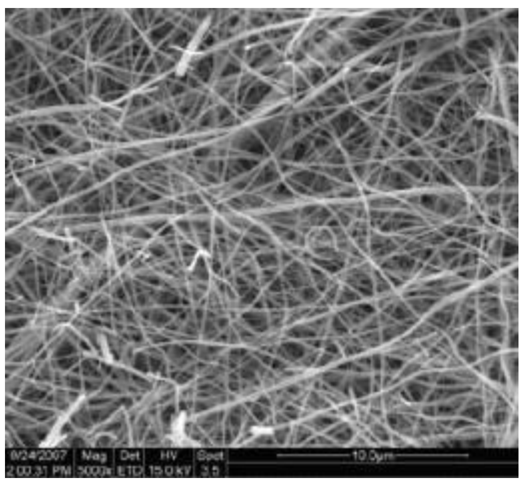

Figure 5. TiO_2 nanofiber produced by Nanospider™ technology (Copyright © 2009 Elmarco)

Acknowledgements

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