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Energy Production: A Practical Application of Nanoscience

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Finding a clean, renewable source of energy is one of today's most significant global problems. Though this has, for many years, seemed like an issue with no solution, new developments in nanoscience may make it possible for humans to have access one day to affordable, clean, renewable energy. In 2008, 11.3 billion tonnes of oil equivalents were consumed worldwide (British Petroleum Company, 2009), a number that has been increasing every year. The pollutants resulting from the combustion of fossil fuels in this amount are having a devastating effect on the environment. They are theorized to be one of the main contributors to the process of global warming. Because fossil fuels are also an exhaustible, polluting source of energy, the world's scientists are desperate to discover a new form of energy production.

Nanoscientists such as Paul Alivisatos, the head of Berkeley's Helios project, and his team are looking at plants for inspiration. They are currently researching the development of a system that produces useable energy through an inorganic, modified form of photosynthesis using nanotechnology (U.S. Department of Energy, n.d.). This process is referred to as artificial photosynthesis, though it differs in many ways from organic photosynthesis. Nanomaterials (nanocrystals) are used to convert the sun's energy into electricity, then to take that electrical energy and convert it to chemical potential energy (Berkeley Labs Friends of Science, 2007). Because solar energy is abundant and accessible worldwide, it is the focus of most energy-related research. The driving force behind this endeavor is our managing to convert the sun's photons into fuel; at only 1% efficiency, an area of 58 million acres would replace all the gasoline used in the United States. This surface area represents the amount of idle cropland in the United States, or the sum of all roadways and roofs (Berkeley Labs Friends of Science, 2007). A conversion at 6% efficiency in that same area would be enough to satisfy the entire country's energy needs.

In essence, the process of artificial photosynthesis would convert the sun's rays in to a transportable fuel. The system transforms solar energy into a useable chemical energy, similar to the way a plant uses photosynthesis to create glucose using the sun's rays and carbon dioxide (CO_2). Artificial photosynthesis is still a theoretical concept. It must be understood that creating this kind of technology is a gradual process. What is important here is that, by analyzing the current trend in nanotechnological advances, we can predict that this form of energy production as a worldwide source is within the scope of the next three decades.

The first step in achieving the goal of artificial photosynthesis is improving solar cells and making them behave in an ideal manner. This is where nanoscience comes in. Solar cells work by using crystals that absorb "packets" of light energy known as photons and transform them into electrical energy. This is done by employing a less extreme version of the photoelectric effect, a phenomenon discovered by Einstein. His experiment involved the ejection of an excited electron from a metal surface due to incident ultraviolet rays. In a solar cell, however, electrons in the crystalline cell are excited by light rays and, instead of the extra energy being dissipated and the electron returning to its ground state, the solar cell system transfers the excited electron to a circuit using a photovoltaic device. That energy is used to produce a voltage, which, in turn, causes the electrons to travel along the circuit and form a current ("Creating 'super' solar cells", 2008).

The NREL research team is experimenting with a new design of solar cell using silicon nanocrystals instead of macrocrystals. This allows for an increase in the photon to excited electron ratio. According to researchers at the National Renewable Energy Lab (NREL) (Würfel & Nelson, 2009), today's common solar cell (monocrystalline *p-n* junction) ("Creating 'super' solar cells", 2008) produces only one excited electron per photon. The experiments revealed that nanocrystals, or quantum dots, have the unique property of enabling the excitation of up to three electrons per incident photon instead of one because they use energy from more of the spectrum than regular crystals, including specifically the blue to ultraviolet range. The other advantage of using nanocrystals is the increased active surface area. Macrocrystals need more spacing to avoid interaction and damage, whereas nanocrystals fit together very closely. This implies that there are more crystals per unit of surface area

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using nanocrystals than there would be using macrocrystals, allowing the device to absorb photons in larger amounts. The new cell design would bring today's rooftop solar cell efficiency from 20% to over 40% (Würfel & Nelson, 2009).

There are other methods of producing superior solar cells, but they are extremely expensive, and time- and energy-consuming. Multi-gap semiconductors are a type of solar cell made by combining crystals of different materials. They exceed the usual 20% efficiency range of common rooftop models, but their price of production makes them impractical and inaccessible to most of the population. The other issue with the multi-gap solar cells is that some of the materials used to make the crystals such as indium are not abundant enough to be considered for mass production ("Creating 'super' solar cells", 2008). High efficiency solar cells made with nanocrystals, however, have a relatively low price, making them the world's best option for a renewable, eco-friendly source of electrical energy. They are also the least dangerous and polluting in terms of production and disposal, as opposed to those made with different sizes and materials.

We can therefore conclude that the development of the first part of the light to fuel system is well underway. What is being developed is an improved, clean, renewable and affordable source of electrical energy using nanotechnology. The reason there is such a strong focus on perfecting the solar cell is that the artificial photosynthetic system's next step (electrical to chemical energy) is currently very inefficient. The high efficiency of the silicon nanocrystals compensates for the system's low overall efficiency.

During Paul Alivisatos's presentation, "Nanoscience at Work: Creating Energy from Sunlight", he explained the theoretical process behind the second phase of artificial photosynthesis: the photovoltaic to electrochemical energy conversion. It involves using nanophotovoltaic devices to extract electrons from the nanocrystals, then modifying these electrons using nano-engineered membranes with implanted electron manipulators that would then bind with specific molecules. The end result would be a chemical reaction that stores the energy as chemical potential energy. He referred to this as the creation of an 'artificial leaf' (Berkeley Labs Friends of Science, 2007, 52 min 25 sec) . A relatively simple example of this method would be the separation of water into hydrogen (H_2) and oxygen (O_2) using the sun's energy, a process known as electrolysis.

$$\text{Energy} + 2H_2O \rightarrow O_2 + 2H_2$$

The result would be an amount of chemical potential energy stored in the combustible hydrogen gas (Berkeley Labs Friends of Science, 2007). Ideally, after the technique is perfected, the Helios project's goal is to use the sun's energy to react carbon dioxide (CO_2) with water (H_2O) to form methanol (CH_3OH) and oxygen (O_2) according to the following equation:

$$\text{Energy} + 2\ CO_2 + 4\ H_2O \rightarrow 2\ CH_3OH + 3\ O_2$$

Ultimately, what we want is a renewable, transportable fuel (U.S. Department of Energy, n.d.).

Though this project is far from being complete, the scientific concepts behind artificial photosynthesis are sound. There is a large interest group, much funding, and scientists passionate enough about the project to ensure it is followed through to completion. This is a potential solution to one of today's most important issues, and it involves the promising, new concepts of nanoscience.

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