credit: http://commons.wikimedia.org/wiki/File:EFluor_Nanocrystal_Vials.jpg

I'll tell you how the Sun rose

One dot at a time

By Abhishek Chintapalli

Currently, annual world energy consumption is approximately 18 terawatts, 85% of which is due to burning crude oil, natural gas, and coal. Moreover, global demand for crude oil is growing at a rate of 1.6 million barrels per day, and developing countries are largely responsible—China, India, and Brazil show no signs of curbing consumption in the near future (1). Rising global temperatures, increased levels of atmospheric carbon dioxide, and widespread pollution all demonstrate the complexity and scope of a worldwide problem, especially since only 12% of global energy supply is met by sources such as hydroelectric plants and nuclear facilities, while only 1% derives from cle¬an and renewable sources such as solar energy, wind power, and biomaterials like of wood and refuse (1).

"The sunlight intercepted by Earth's atmosphere amounts to a massive 1.75 x 10^{17} watts per annum, almost 10,000 times the total amount of energy used by humans on Earth..."

Most solutions confronting this crucial problem use a combination of various legislation and technology. Many advocate for a clean, flat carbon tax to encourage the economy to seek more sustainable business plans as well as a broad injection of funding to encourage research across a variety of scientific fields. Research ranging from extracting algae lipids for producing renewable diesel to improving current nuclear technology is absolutely crucial so as to not to forsake any potential alternatives (2).

Without a doubt,solar energy is likely

to play the most significant role in advancing energy sustainability. The sunlight intercepted by Earth's atmosphere amounts to a massive 1.75^{17} watts per annum, almost 10,000 times the total amount of energy used by humans on Earth (3). Such an enormous amount of untapped energy has convinced scientists that "a massive switch to solar power is the logical answer" (4).

Basics

Producing electricity from Photovoltaics requires incoming photons to knock electrons into high energy states in semi-conducting materials such as silicon. Specifically, when a photon hits a piece of silicon, one of three things can happen: (1) The photon may strike the panel but remain unabsorbed because it struck with less than the necessary energy (the *band gap*). (2) The photon may be scattered from the surface. (3) The photon may be absorbed and any excess energy it carried will be dissipated as heat. These high-energy state electrons are said to be "excited" electrons.

Excited electrons "jump" from their latent state, called the valence band, into a higher, more mobile state called a mobile conduction band. The conduction band is at a higher energy state than the valence band, and in semi-conductors, is usually comprised of fully occupied molecular orbitals. Once knocked free, excited electrons flow through the material, forced to move in a single direction by the structure of the cells, to produce electricity.

The fundamental limitation on the efficiency of a solar cell is the band gap of the semi-conducting material. The band gap is the energy required to boost an electron into an excited state. Most semi-conducting materials have a band gap of less than 3.2 electronvolts (eV), corresponding to the range from the visible spectrum to near the infrared region of light. Luckily, about 50% of incoming sunlight lies in the visible portion of the spectrum, with the remaining amount in the near-infrared region

▲ **Figure 1:** A typical photovoltaic cell in Zaragoza, Spain.

credit: http://commons.wikimedia.org/wiki/File:Solar_Panels.jpg

and ultraviolet region (1,5).

Solar Cell Generations

Solar cells can be classified into three "generations," with subsequent generations corresponding to newer, more complex technologies.

First generation cells (see figure 1) will almost certainly not be able to provide a competitive alternative energy source. Because 1st generation cells are large-area, high quality solar cells made of silicon wafers, for large-scale production, manufacturing such cells would be incredibly expensive and impractical. Although material for production of 1st generation cells is in ample supply, producing the global electricity supply solely from 1st generation solar cells would require a 100 fold increase in the current number of factories. (6). While 1st generation cells play a crucial role in producing electricity at high efficiency, alternative faster and cheaper solutions must be found to achieve a sustainable future.

Fortunately, 2nd generation (thin-film) approaches minimize production and labor costs, with the most successful cells composed of cadmium telluride, copper indium gallium selenide, and amorphous or micromorphous silicon. These second generation cells have great potential to achieve higher light-electricity conversion efficiencies, but the raw materials needed to make them are dwindling in supply (6).

Second generation solar cells are cheaper and less efficient than 1st generation cells. While first generation solar cells have a theoretical maximum efficiency of about 31%, second generation solar cells often have a light-electricity conversion efficiency of around 15% (7). In many cases, however, the reduced cost of producing the thin-film solar cells (second generation solar cells) often outweighs the costs of their reduced efficiency (15).

Third Generation Cells

It is in 3rd generation solar cell technology that many of the most recent breakthroughs in solar technology have been made. 3rd generation cells may achieve over 60% light-electricity conversion efficiency—a feat impossible for first and second generation analogs (8). Moreover, research in 3rd

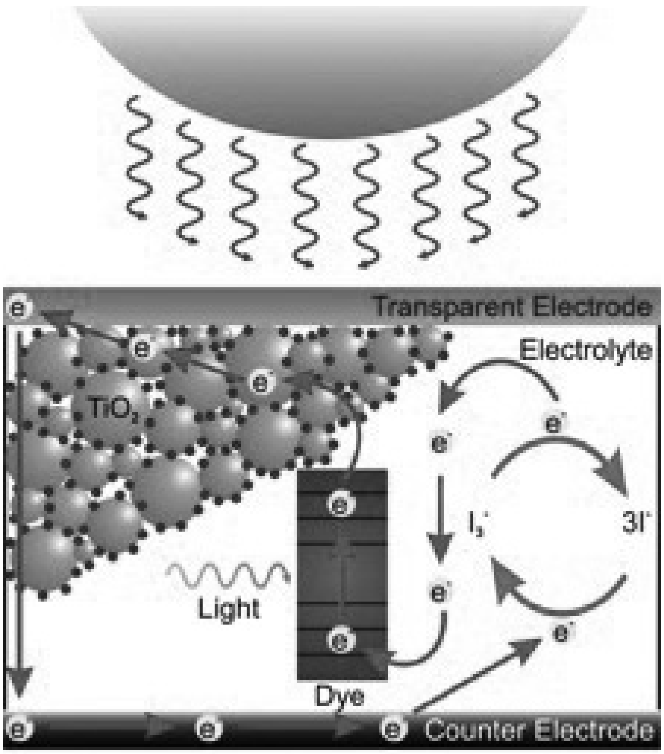

Figure 2. Dye Sensitized Solar Cell Schematic.

credit: http://commons.wikimedia.org/wiki/File:Dye_Sensitized_Solar_Cell_Scheme.png

generation technology is striving to lower costs, thereby increasing practicality, of solar cell use.

One promising field of 3rd generation solar cell technology involves Quantum dots. Quantum dots (or nano-particles) are semi-conducting crystals of nanometer dimensions. The size of these dots corresponds to the wavelength of light they can absorb (larger quantum dots absorb red light); thus, a solar panel "sprayed" with these dots can be designed to absorb different wavelengths of light (9). Conventional solar cells are limited to a particular wavelength of light, sinceexcess energy is dissipated as heat and low-energy photons are not absorbed at all. In contrast, solar panels comprised of quantum dots can be fine-tuned to absorb photons over a wide range of wavelengths. A mixture of quantum dots absorbing different wavelengths can be sprayed over solar panels to harness the optimal amounts of energy (10).

Dye-sensitized cells (DSCs) are currently the most efficient third-generation solar technology available, with efficiency levels reaching 11% (11). Such cells hold great potential in non-industrial applications such as rooftop solar collectors, where their rugged and light-weight build are advantageous; however, a serious obstacle to DSCs is maintaining their efficiency levels under low temperatures. High temperatures promote electrons to the conduction band, while lower temperatures risk the liquid electrolyte freezing, terminating power production. Replacing the liquid electrolyte is a major research challenge; Michael Grätzel and colleagues have measured cells' efficiencies at 8.2% using novel solid electrolyte and hope for improvements in the future (12).

A severe limitation of solar cell technology has historically been their dependence on weather conditions. Fortunately, a recent development in 3rd generation solar technology involving infrared devices, known as nanoantennas, may provide solar energy even in the absence of sunny conditions. Idaho National laboratories has designed nanoantennas to absorb wavelengths in the range of 3-15 micrometers, demonstrating their potential to produce energy by collecting background infrared energy, which the Earth continuously radiates at night after absorbing energy from the sun during the day (13). It is envisaged that these "nantennas" can be formed into flexible sheets which could power a computer, car, or iPod.

Conclusion

Producing the world's energy supply from solar power within this half-century remains to be a great obstacle for the nanotechnolog industry. Although first-generation and second-generation cells have found their way into industrial and commercial uses, their costs relative to crude oil make them unattractive. Third generation cells show great potential in terms of efficiency and practicality, but they are a bleeding edge technology and will not enter the market anytime soon. Hopefully, with shifts in public policy, growing public awareness, and accelerated research and development, solar energy may spearhead the next generation of energy technology, transforming our fossil fuel-based energy system to one founded upon the premise of sustainability. H

—Abhishek Chintapalli '14 is a prospective Mathematics concentrator in Canaday Hall

References

1.United States. Short Term Energy Outlook. , 2010. Web. 31 Oct 2010. <http://www.eia.doe.gov/steo/contents.html>.
2.Pimentel, D., 1925-. (2008). Biofuels, solar and wind as renewable energy systems : Benefits and risks. New York: Springer.
3.Kennewell, John, and Andrew McDonald. "Educational." Australian Government IPS Radio and Space Services. IPS Radio and Space services, n.d. Web. 31 Oct 2010
4.Zweibel, Ken, James Mason, and Vasilis Fthenakis. "A Solar Grand Plan." Scientific American 16 December 2007: n. pag. Web. 31 Oct 2010.
5.Lugue, A. (A, and Steven Hegedus. Handbook of Photovoltaic Science and Engineering. Hoboken, NJ: Wiley, 2003. Print.
6.Rhodes, C.J. (2008) Metals shortages. Chem. Indust., 25th August, 21-22.
7.Martin A. Green, Third generation photovoltaics: solar cells for 2020 and beyond, Physica E: Low-dimensional Systems and Nanostructures, Volume 14, Issues 1-2, April 2002, Pages 65-70, ISSN 1386-9477, DOI: 10.1016/S1386-9477(02)00361-2. (http://www.sciencedirect.com/science/article/B6VMT-454TDH4-4/2/e774c0e70b407c3e0b0ce5679ba6af2c)
8.United States. Innovation. , 2010. Web. 8 Nov 2010. <http://www.nrel.gov/overview/pdfs/47571.pdf>.
9.Ho, M.-W (2006) Ho MW. Quantum dots and ultra-efficient solar cells? Sci. Soc., 29, 48-49
10.Salafsky, J.S. (2001) A channel' design using single, semi-conductor nanocrystals for efficient (opto)electronic devices films. Solid-State Electron., 45(1), 53-58
11.United States. Basic research needs for Solar Energy utilization. , 2005. Web. 31 Oct 2010. <www.science.doe.gov/bes/reports/files/SEU_rpt.pdf>.
12.Yu Bai, Yu., Cao, Y., Zhang, J., Wang, M., Li, R., Wang, P., Zakeeruddin, S.M. and Grätzel, M. (2008) High-performance dye-sensitized solar cells based on solvent-free electrolytes produced from eutectic melts. Nature Mater., 7, 626-630.
13.Lin, G.H. Rejimjan, A. and Bockris, J.O'M. (1996) Investigation of resonance light absorption and rectification by subnanostructures. J. Appl. Phys., 80(1), 565-568.