The Sun has been, and always will be, the Earth’s largest energy reservoir—it powers every living system, from plant photosynthesis to every node of the food web. Humans, like all other organisms, depend on sunlight. Early humanity treasured the Sun’s existence, using its energy as instruments of religious rituals, fire, and war. By the rise of modern civilizations, however, Sun power has been virtually pushed off the energy spectrum. As modern civilizations improved standards of living, the demand for energy increased. This rise in demand has largely been met with fossil fuels. Technologies were developed to locate and extract these resources from the earth and mass infrastructure was built to process and distribute these energies. Figure 1 shows the estimated energy usage by source in the United States in 2009.\(^1\) 83% of the yearly energy consumption in the U.S. is derived from petroleum, coal, and natural gas, while only 8% is supplied by renewable energy. It should be noted that solar energy accounts for only 0.08%, an insignificant amount, of the total United States' energy pie.

The Sun’s the limit

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Many scientists are employed to research into novel ways to generate energy for human use since fossil fuels - currently the main source of energy - are a finite resource. One of the most promising fields is solar energy, as the Sun is a very reliable source. It is also a very ‘clean’ source, as no greenhouse gases are released during the generation of energy, and less destruction of unused land is required compared to many other renewable resources. However, photovoltaic cells are expensive and do not have very high energy conversion ratios at the moment. Ongoing research includes finding materials to make the cells cheaper, and the use of organic semiconductors, which present various advantages.

Solar History and Theory

Technology capable of harnessing the power of the Sun was first developed in 1954 at Bell Laboratories. However, the invention aroused little interest at the time because petroleum cost less than $2 a barrel and solar energy cost nearly $600 per Watt. In the
late 1950s, the National Aeronautics and Space Administration (NASA) saved the photovoltaic (PV) cell from the technological dumpster by using them as lightweight and reliable energy sources to power satellites.\[1\] As petroleum prices rapidly increased, researchers began to consider the prospect of PV cells designed for use on Earth. In the last 20 years, investment in and progress on PV cells have exploded. Many institutions of higher education, such as Harvard, MIT, and Stanford, have begun research and development (R&D) programs to produce next generation PV cells. Private labs have produced PV cells with energy conversion ratios over 20%, fueling a consumption growth of over 50% in the last 10 years.\[1\]

A solar panel is a packaged, interconnected assembly of PV cells. The typical PV cell operates in three steps to produce electricity: charge collection, charge separation, and charge extraction. A basic PV cell consists of a transparent active layer, a double-layered conductor (dubbed N and P layers), and an external circuit. The active layer absorbs light; electrons are excited in the electron-excess N-layer, and these excitons, bound electron-hole pairs, move towards the electron-hole rich P-layer. A thin gap between the two layers acts as a check valve—electrons can travel across in one direction but not the other. Because the electrons cannot return to the N-layer, a charge imbalance is created within the conductor. These excitons diffuse through the PV cell towards the external circuit, which extracts this charge by creating a bridge that allows electrons to flow between the N and P layers.\[2\] This flow of electrons constitutes an electric current.

Sunlight is Abundant

Solar energy is a viable source of energy because of its abundance. The total energy output of the Sun exceeds the output of any other energy source by several orders of magnitude. This solar energy incident on the earth's surface can be obtained by dimensional analysis:

\[\text{Energy} = \text{Flux} \times \text{Area} \times \text{Time}\]

Experimentally, the solar flux constant is 1.366kW/m² the cross sectional area of Earth is; \(\pi r^2 = 1.27 \times 10^{14} \text{ m}^2\); a year has 8760 hours. Inserting these values into the equation shows that the Earth receives \(1.5 \times 10^{17}\) kWh (kilowatt hours) of energy per year from sunshine, which is roughly 10,000 times the world annual total energy consumption of 15 terawatts. 10% efficient solar conversion system, covering 0.1% of the land on Earth would be sufficient to power the world.\[3\] With solar energy, the world does not have to worry about energy shortages and our standards of living have room to improve. In addition, the Sun is the most reliable energy source for life on Earth because it will continue to produce energy until it dies, which coincides with, when the Earth will cease to support life.

Sunlight is delivered to nearly all parts of the world year-round, which makes solar energy the ideal source for remote locations. It is economically unfeasible to integrate large electric utilities into these areas, but building a household solar energy generating unit allows energy to reach places where utilities do not go: off the grid. In addition, sunshine follows a diurnal cycle, which matches the human energy usage pattern—it shines when we use energy during the day and sets when we are asleep at night.

Solar Power is Clean

Solar energy is a viable source of energy because of its cleanliness. PV cells generate electricity by the characteristics of the material they are constructed from—that is, no physical or chemical change is involved in the production process, leading to zero waste and emission in energy production. Conventional energy sources such as coal, petroleum, and natural gas have high emission levels of carbon dioxide and other harmful greenhouse gases such as nitrogen (N), methane (CH₄), water vapor (H₂O), and ozone (O₃), which lead to global warming and smog pollution. Nuclear energy is also undesirable because it carries a high risk of radiation (alpha, beta, and gamma) and creates hundreds of thousands of tons of radioactive waste including uranium (U-238), plutonium (Pu-239, Pu-240), fission products (Sr-90, Cs-137, Tc-99), and minor actinides (Np-237, Am-241, Cm-243/244).\[1\] Moreover, nuclear radiation and waste will remain dangerous for thousands of years. The recent Japanese nuclear power plant leaks are just one example.

Solar energy is also cleaner than other renewable energy. Wind turbines must be built in order to harness wind energy, dams must be built in order to harness water power, and millions of acres of land must be cleared to support growing crops for bio-fuel. These construction (but destructive) projects often deface the surrounding environment and harm the surrounding ecosystem. In contrast, solar panels can
be built on a much smaller scale and can be easily installed on the walls and roofs of houses or other pre-existing locations.

**Solar Energy is Still Expensive**

Commercially available PV cells are composed of silicon and have an average energy conversion efficiency of 12%. So far, it has been expensive to manufacture these cells due to high energy requirements and labor cost. Therefore, the cost of manufacturing and generating energy from PV cells has always been higher than the cost of using other forms of energy. Figure 2 compares the cost per kilowatt-hour of solar energy to other major energy competitors.

The graph shows that, currently, the cost of solar energy is double the nearest competitor. However, solar energy is unique in that it has no decommissioning and production costs because PV cells require little to no maintenance. Although the current cost of producing solar power may be daunting, technological advances in the field promise a bright future for solar energy.

**Research and Development**

To make solar power competitive in the energy market, researchers and scientists have been developing new PV cells with high energy conversion efficiency and low production cost. Recently, R&D programs have been working on creating PV cells in the form of amorphous, thin films using cheaper and more flexible organic compounds. Unlike silicon units, organic PV cells are based on $\pi$-conjugated organic electronic materials. In conjugated organic molecules (systems with alternating single and double bonds) every carbon center exhibits $sp^2$ hybridization. In nature, these strings of $sp^2$ hybridized orbitals are rigid, but when these delocalized orbitals are oxidized, they degenerate into a band of electrons. When this band is partially emptied, it permits electron mobility, thus turning into an organic semiconductor.

Organic semiconductors bring a host of advantages for the development of cost-efficient and flexible thin-film PV cells. Organic semiconductors are generally made of polymers and can be deposited from solution, making a reel-to-reel coating possible for inexpensive, large scale production; organic semiconductors are also compatible with lightweight substrates such as glass and plastic, making them a prime candidate for mass production and cheap installation; organic semiconductors have high optical absorption coefficients, ideal to harvest a large fraction of the solar spectrum. Most importantly, organic PV cells can be adapted to suit a host of requirements through chemical processing. For example, one experiment at the Advanced Energy Research Center of SANYO Electric Co., Ltd. reported that by replacing the classical electron donor copper phthalocyanine (CuPc) with tetraphenyldibenzoperiflanthene (DBP) (a combination of carbon and hydrogen) the PV cell’s absorption coefficient spectra almost doubled with respect to light between wavelengths of 500 nm and 600 nm. A high absorption coefficient is crucial in PV cell efficiency, and DBP has the highest performance in wavelengths in which the Sun’s light spectrum strength is strong. With breakthroughs in composing and altering materials for organic semiconductors at the molecular level, there is now a plethora of ways to improve organic PV cells.

However, organic PV cells also have considerable drawbacks—their efficiency is roughly a third of that of inorganic PV cells and their lifetime is only a fraction of that of inorganic PV cells. To enhance lifetime, researchers are developing self-repairing organic PV cells modeled on plant chemistry. To improve the conversion efficiency, various methods and techniques are being developed to maximize exciton diffusion, forward electron transfer, and charge transport. Researchers have improved the packing of molecules in organic semiconductors to produce more excitons and facilitate separation into mobile
charges. Researchers have also found that charge carrier mobility is enhanced by blending polymers with electron-accepting materials such as fullerene (C_{60}) derivatives, cadmium selenide (CdSe), and titanium dioxide (TiO_{2}). Earlier this year, one independent research group at MIT discovered that graphene (a nanoscale carbon allotrope) exhibits flexibility, conductivity, and resistivity almost parallel to Indium-Tin-Oxide (ITO), the standard material for electrodes in organic PV cells. Whereas ITO is relatively rare and expensive, carbon is the second most abundant element in the Earth’s crust. Breakthroughs in organic PV cell technologies demonstrate promise for its future success as a world energy producer.

The Future is in Solar

In the past 30 years, various technologies have been developed and the price per kilowatt of using solar energy has dropped from $5 to less than $0.25. Solar energy is no longer in the distant future. It is becoming a reality—more and more solar panels are being installed on houses, in schools, and in open areas. In some parts of the world, where sunlight is omnipresent, the price of using PV cells has already undercut conventional energy prices. Figure 3 shows the history of the cost of PV cells and the projected future of PV cell costs.

The cost of solar energy continues to decrease as the cost of conventional energy continues to increase. Experts expect grid parity (the price at which solar energy will be competitive with conventional energy) to occur by 2015. Research and investment in organic PV cells are likely to elevate solar energy to be competitive with and cheaper than other forms of energy. Sunlight is sustainable, stainless, and singular. Sunlight is ubiquitous, boundless, and accessible. Sunlight is the tonic of nature. In the future, everything we consume or use—from the lights that we use, the vehicles we drive, to the preparation of the food we eat—will be powered directly by the Sun. Our energy usage will be forever sustainable and independent. Green energy will dominate the energy spectrum, and we will put a brake on climate change. That future is in solar energy.

References

About the Author

Dennis is currently studying physics in school. He has taken courses in chemistry, biology, and computer science and is currently studying multivariable calculus at West Valley Community College. Dennis is fascinated by nanotechnology, which led to his interest in the application of nanotechnology to solar energy, and computer science, which led him to begin developing applications for the Android platform. He hopes to attend Harvard College in the fall of 2012. In the future, Dennis plans on studying a combination of business and engineering. He plans to be a business entrepreneur.

For Teachers

- Have you seen examples of STEM work in schools which deserves to be published?
- Are there projects or coursework out there which will otherwise lie forgotten on a shelf or USB memory stick?
- Would you like to encourage a student (or group) to consider publishing it in a science journal for others to read and for posterity? (...being a published author looks great on their CV!)

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