Photovoltaics as a Source of Renewable Energy

The US is a world leader in many areas, on the forefront of world trade, politics and scientific research. It is however, also a world leader in oil consumption and Carbon emissions. Our country contains a mere 5 % of the world's population, yet we consume nearly one fifth of its oil. Though it is impossible to achieve immediately, our future prosperity will depend on the use of cleaner, renewable energy sources, as opposed to fossil fuels. Many technologies are at our disposal; hydrogen fuel cells, wind energy, geothermal, and hydroelectric power, to name a few. One of the most promising of these clean, renewable, abundant sources of energy is solar energy. Sunlight is the most abundant source of energy on the planet, yet it is the supplier of only 0.1% of its electricity ("Photovoltaics"). Photovoltaic (PV) technology has the potential to be a major supplier of our electricity in the future, and could help to ensure our prosperity as we wean ourselves from fossil fuels.

How Photovoltaic Cells Work

The solar cell was first created in 1954, with an efficiency of 4.5% ("Photovoltaics"). Efficiency of a PV cell is measured as percentage of sunlight hitting the panel that is converted to electricity. Further researched in the 1970's, it gained use, but never become mainstream. Today, solar cells have widespread use, but have yet to provide for a substantial portion of the world's energy supply.

Photovoltaic cells are made of semiconductors, which absorb light energy. Silicon is the most frequently used semiconductor in solar panels. Though pure silicon in its natural state has no charge, it is combined with other elements to give it the charge required to be used in photovoltaic cells. When silicon atoms bond, they seek to fill their outermost energy level with eight electrons. In the structure of pure crystalline silicon, each atom of silicon is bonded with four of its neighboring atoms, and as silicon has four electrons in its outer energy level, this fills the outermost energy level. As sunlight hits pure silicon, an occasional electron can be knocked loose to create a charge. In pure silicon, however, a sufficient amount of electricity is not created. To create a sufficient amount of energy, Silicon is doped with phosphorus, called N-type silicon, which results in a structure in which more electrons are not included in a chemical bond. These electrons are more easily knocked loose from their atoms by photons from the sun, and when knocked loose, they are referred to as carrier electrons, because they carry a charge. The other half of the solar panel is made up of P-Type silicon; silicon doped with boron. Boron has three electrons in its outer shell, and its bond with silicon results in seven electrons in the outer shell, leaving a space for an extra electron. The carrier electrons freed from the N-Type silicon are attracted to this space. When photons from the sun hit the panel, the ninth electron in the negative plate is knocked off, and is attracted to the positive one, which creates a charge. Sunlight bombards the cells, and photons knock electrons loose. The cell has one or several electric fields, which force the freely flowing electrons into a current, which can be drawn off and used.

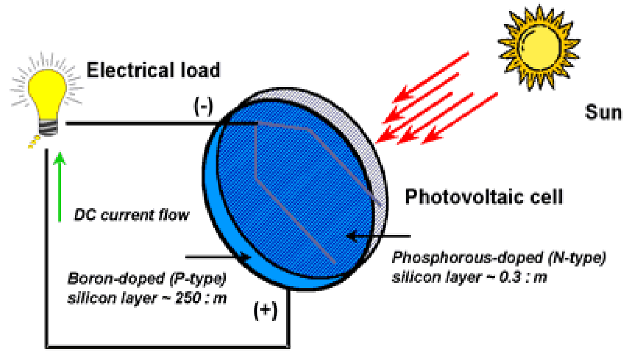

Figure 1: *Difference in charge between the n-type and p-type layers creates a current through an external circuit, powering the electrical load.*

Solar panels are created in steps: making cells, assembling them into modules, connecting them into arrays, and installing the systems. The two most essential materials in the solar cells are the conductors, most common of which is thick film paste, and silicon wafers. The conductor paste is fired to create permanent conductor traces, which are soldered together to create modules and panels.

Types of Photovoltaic Cells

Crystalline Silicon

A large variety of solar panels is available on the market, varying in price, efficiency, and size. Most Photovoltaic (PV) cells today are made of crystalline silicon (c-Si), which are 11 % to 16 % efficient (Burdic). There are two types of c-Si used in PV technology; mono-and multicrystalline. In the case of Monocrystalline silicon, thin slices are cut from single pure crystal silicon whereas multi-crystalline cells are made from silicon crystals are cast together and cut from this. Mono- is purer than multi- and results in higher quality, though more expensive PV cells. The highest efficiencies for multicrystalline silicon based cells have reached an efficiency of 20.3% ("Thin Film Solar").

Thin Film

Because high demand for c-Si has caused an increase in its price, many cheaper, but less efficient semiconductors have begun to be used in a new type of panel called thin film. These include amorphous silicon (a-Si), cadmium telluride (CdTe), copper indium diselenide (CIS), and copper indium gallium selenide (CIGS). Thin film cells are made of ultra-thin semiconductor, which is applied to a thin, inexpensive backing. This backing can be glass, flexible metallic foil, high-temperature polymers, or sheets of stainless steel. Thin-film Photovoltaic cells require much less energy to create than traditional solar cells and can be produced by multiple methods, allowing them to be produced much cheaper, and makes it significantly more affordable than traditional multicrystalline silicon cells. This technology, because of its light weight, and lower cost, could be useful in space applications, and in portable electronics. Thin film PV cells are significantly cheaper than those made from c-Si, but are generally only eight percent efficient. They could also be used for architectural applications, such as possible photovoltaic roof shingles, windows, siding, and many other features. Thin-film can also be spread over wide areas, maximizing electricity generation on cloudy days.

Figure 2: *(above) A thin film solar panel.*
Figure 3: *(below) A crystalline silicon solar panel.*

Advances in Photovoltaic Technology

Crystalline Silicon and Thin Film Photovoltaics

As solar technology advances, the efficiency of PV cells is constantly increasing. The highest efficiencies for multicrystalline silicon based cells have reached 20.3% (“Thin Film Solar”). Research is also taking place in the creation of more efficient thin-film solar technology. The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) has created cells rivaling the efficiency of multicrystalline silicon cells. This could lead to new technology useful for commercial builders and building owners interested in renewable energy sources. These cells, made from copper indium gallium diselenide (CIGS) have recently achieved an efficiency of 19.9 %, which is a record for thin-film solar technology ("Thin Film Solar").

New Photovoltaic Technology

In addition to advances made to old types of PV cells, research has been made in the creation of new types of cells. One of the most promising of these new photovoltaic technologies is Photoelectrochemical (PEC) photovoltaics. The PEC cell uses liquid, rather than solid semiconductor layers to absorb electricity. Light is absorbed in dye, and converted to a current through a layer of nanocrystalline titanium dioxide semiconductor. The cells are surrounded by a carbon layer, bounded by glass on either side. These cells are anticipated to be much less expensive than solid-crystalline cells.

Figure 4: *A Concentrating Photovoltaic panel. Lenses mounted above solar panel concentrate light onto PV cells.*

Another PV system being developed is the concentrating PV cell, which use lenses or mirrors to concentrate light onto PV cells. They allow for a great decrease in the amount of space needed to collect sunlight, making them up to 40% efficient (Burdic). To be this efficient, however, constant sunlight is required to hit the surface of the panel. To ensure this, the panels and or lenses can be linked to motorized tracking systems. These motors would require maintenance, making concentrating photovoltaic cells higher maintenance than traditional solar technology.

Implementation of Photovoltaic Technology

Solar technology has the potential to supply a large amount of our energy in the future. The article, "A Grand Solar Plan" from Scientific American discusses a possible scenario for the future in which solar is a major supplier of the U S's energy. According to this plan, 69% of U.S. electricity and 35% of U.S. total energy could come from Solar Plants by 2050. Tons of Photovoltaic cells would be built in the southwest US, and the excess power generated during the day could be stored as compressed air in underground caverns. This plan would require funding of over $400 billion over the next forty years, but would result in savings of billions of dollars annually, because solar plants require little or no fuel to provide electricity. The plan could also end dependency on imported fuel from unstable countries in the Middle East, and would reduce greenhouse gas emission by 1.7 billion tons a year (Mason).

Figure 5: *World's Largest PV farm opens in Jumilla, Southern Spain.*

While the United States still has a ways to go before photovoltaic technology provides for a substantial portion of its electrical power, there are several countries around the world that have begun to use solar plants to provide for their electrical needs. Germany, Japan, Spain, and Australia are among the leading countries in implementing use of solar panels.

In Spain, for example, about seven percent of the energy is supplied by renewable resources, according to the Spanish Minister of Industry. The world's largest PV farm has recently been opened in Jumilla, a wine making region of southern Spain. It has a peak power capacity of 20 megawatts. The local mayor says that in its location, it is guaranteed 300 days of sun annually. It has 12,000 solar panels, covers 247, and creates enough electricity to power 20,000 homes. A group of investors owns this farm, which is expected to create 28 million dollars and reduce CO_2 emissions by 42,000 tons annually ("Powering 20,000 homes").

Implications for our Energy Future

Though it won't happen overnight, our future prosperity will depend on our ability to make the switch from fossil fuels and natural gases to clean, renewable sources of energy. In the future, our sources of energy will be determined by their availability, affordability, stability of technology, sustainability, and security. It will only be possible to meet energy demands if we both conserve energy and diversify energy sources. Solar energy satisfies many of these demands. It is the most abundant source of energy on the planet, making it an obvious choice as a reliable efficient source for our electricity needs. Photovoltaic technology is advancing rapidly, and with new

Figure 6: *The Largest PV farm in the US, at Nellis Air Force Base in Nevada. At an output of 14.2 megawatts, it is exceeded in size and output only by the Photovoltaic Farm in Jumilla, Southern Spain ("Air Force base").*

technologies such as thin film, Photoelectrochemical, and concentrating photovoltaics, solar power could easily be one of the most affordable sources of clean, renewable energy in the near future. The technology is here and available to us, and as it advances will become even more feasible for widespread use. Though it will take a large commitment, a switch to renewable energy could be in the near future.

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