A Survey of Solar Power

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Introduction

As the world's population continues to explode and energy usage continues to rise as amounts of fossil fuels are diminishing, sources of renewable energy are becoming vital. The U.S. Energy Information Administration predicts that in 2030 world energy demand will be about 16.9 terawatts. U.S. demand will be 2.8 terawatts. Solar power could provide 580 terawatts if confined to non-oceanic and non-protected areas, but the world only takes advantage of 0.008 terawatts of solar power (Jacobson 2009). 4.3×10^{20} joules of energy are transmitted by the sun per hour. This is enough to provide all of the world's energy needs for a year (Biello 2008). Switching to solar power would be revolutionary and would have an enormous positive impact on the environment. It is a renewable energy source that has made significant advances in recent years with regards to efficiency and novel ideas and applications.

This paper views solar power from various angles. It provides a brief history of solar cells in order for the reader to appreciate how far solar technology has advanced. The efficiencies of a few types of solar cells are laid out so the reader knows the current state of the technology. A plan to gradually switch the United States to solar power is included to show the reader what it is going to take to become a solar powered country. Advances are reported because they are exciting in their potential to change the way the world views solar energy. These advances are a small glimpse into the future of solar energy technology.

A Brief History of Solar Cells

The relatively modern history of solar cells goes back to the nineteenth century. In 1839, Edmund Becquerel discovered that light incident on a silver-coated platinum electrode surrounded by an electrolyte produced an electric current. This was known as the photovoltaic effect. In 1879, William Adams and Richard Day built the first solid state photovoltaic devices using the photoconductive property of selenium. Five years later Charles Fritts constructed the first large area solar cell by sandwiching a layer of selenium between gold and another metal. Up until the middle of the twentieth century, the photovoltaic devices were not advanced enough to generate useful amounts of power (Nelson 2003).

During the 1950s, photovoltaic devices improved due to p-n junction structures in silicon. Thus, silicon exploded as a major solar cell component. In 1954 the first silicon solar cell reportedly had a sunlight converting efficiency of 6 percent. Silicon solar cells were applied to space devices in the 1950s and 1960s as a result of their low weight and performance reliability. While other materials such as cadmium sulfide, gallium arsenide, indium phosphide, and cadmium telluride were touted to have potential high efficiencies, silicon is still the leading solar cell material due to advances regarding silicon technology in the microelectronics sector (Nelson 2003).

The decade of the 1970s saw an energy crisis of dependency on foreign oil spur interest in alternative energy sources much like the high oil prices of the past few years have caused people to desire to use alternative energy. In the 1970s funding and development as well as the understanding of the science behind photovoltaics increased greatly (Nelson 2003).

The 1990s continued with society feeling mounting pressure to move away from usage of depleting fossil fuels towards alternatives like solar power. Economies of scale contributed to the decreasing cost of photovoltaic systems. An example of the benefits of the decreasing cost of these systems would be the market for building integrated photovoltaics increasing (Nelson 2003).

The Physics of Solar Cells

On the surface, the physics of solar cells is relatively simple. Light is converted into electrical energy. Quantum theory states that light is composed of packets of energy called photons. The energy of a photon is determined by its frequency. The energy possessed by the photons excites electrons into higher energy levels (Nelson 2003).

Albert Einstein observed the photoelectric effect in 1905. Ultraviolet light had enough energy to remove electrons from the surface of a metal. Usually the excited electrons return to the ground state rather quickly. Photovoltaic devices are constructed so that the excited electrons are removed before they can return to the ground state. The electrons are sent through a circuit. The excited electrons produce an electromotive force that moves the electrons through the circuit (Nelson 2003).

The excited state and ground state of an electron must be separated by an energy gap. A material fit for a solar cell should contain multiple energy levels. These are known as bands. The band gaps serve the purpose of preventing the electrons from dropping down to the lower energy levels as fast as they normally would. The issue with this principle is that the solar cell can only obtain energy from the photons that have enough energy to cross the gap. The excited electrons must be captured and then sent into an electric circuit. This is accomplished by using asymmetry to establish a charge separation (Nelson 2003). Usually this asymmetry includes an electric field that forces the electrons to flow into the circuit. This electric field is set up by a junction of certain materials with different properties (Sayigh 1977).

Efficiencies of Solar Cells

Modern day solar cells cannot yet achieve efficiencies of 100 percent. There are various factors that determine why a solar cell cannot reach 100 percent efficiency that go beyond the technical scope of this paper. One basic limitation is due to the fact that solar cells can only absorb certain photons with certain energies. This is due to band gaps, a concept discussed earlier in the paper. Another limitation stems from a phenomenon called radiative recombination. Since solar cells absorb light, they must also emit light. This interferes with the electrons that the solar cell wants to funnel into the circuit, and thus it is a main factor of the limiting efficiency of a solar cell (Nelson 2003). Solar cells also lose opportunities to capture energy when heat dissipation occurs. When a high energy photon is absorbed, some of the energy is lost as heat (Bourzac 2009). In a typical solar cell, this heat energy cannot be recaptured and fed back in as electricity.

The various types of solar cells yield different efficiencies. These are only a few types of the many variations of the design of a solar cell, but these seem to be at the forefront of solar technology. Silicon solar cells, typically referred to as first generation solar cells, are theoretically limited to 33 percent efficiency (Bourzac 2009). Emcore Corporation developed a high efficiency triple junction solar cell that achieves 39 percent efficiency under "concentrated illumination" ("Terrestrial Solar Cells…" 2011). However, triple junction solar cells have proven themselves to be difficult to mass produce due to their complexity. Emcore has another product called "terrestrial concentrator photovoltaic arrays" that convert sunlight to electricity with 26 percent efficiency ("Utility-Scale…" 2011). The concept of 500 sun concentration is implemented in these "photovoltaic arrays." This concept allows 1 centimeter squared of solar cell area to generate the same amount of electricity as 500 centimeters squared of solar cell area without concentration ("Terrestrial Concentrator…" 2011). This product ends up needing less solar area space to generate the same amount of power as other photovoltaic systems. This leads to cost savings. In addition, thin film solar cells are a prominent approach to decreasing the cost of solar cells. Since they are thin, fewer materials are required to produce them. Their size also allows for them to be installed in various advantageous places. For example, Dow Chemical uses thin film solar cells to produce solar shingles for houses (Woody 2009). The efficiency for thin film solar cells currently hovers around 17 percent (Martin 2011).

Switching the United States to Solar Power

Solar cells have the potential to change the way the world operates. The clean resource of energy from the sun can be harvested. Fossil fuels will become an urban legend. Pollutants will be greatly decreased due to the absence of burning the fossil fuels. The environment will not be excavated for fossil fuels such as coal. The United States will not have to depend on foreign countries for oil to power our cars. The positive benefits of solar power seem endless. This begs the question of why has solar energy not taken over as the main source of energy. One reason is the massive renovation that must be undertaken to replace fossil fuels as the main source of energy. The following paragraphs discuss a plan developed by Ken Zweibel, James Mason, and Vasilis Fthenakis for the magazine *Scientific American*. This plan aspires to power the country by solar energy.

The southwest United States contains 250,000 square miles of land that are not being utilized. This bare land happens to be satisfactory for the construction of solar power plants. This area receives 4,500 quadrillion BTUs (British thermal units) per year. Harnessing only 2.5 percent of this available energy would provide enough energy for the United States' energy consumption in 2006 (Zweibel 2008). Taking advantage of this land is crucial to the transition of the United States from environmentally degrading fossil fuels to renewable energy.

To compete with contemporary electricity costs, solar panels composed of cadmium telluride will need to convert sunlight to electricity with 14 percent efficiency. The efficiency of this type of solar cell currently hovers around 10 percent, but with expected advances it should not take long for the cell to reach 14 percent efficiency (Zweibel 2008).

By 2050, 3,000 gigawatts (GW) of power will be generated from 30,000 square miles of photovoltaic systems. This amount of land is less than the amount of land required for the operation of coal power plants when land for mining is taken into account. The National Renewable Energy Laboratory has confirmed through various studies that more than adequate amounts of land can be adopted by solar power plants that are not considered environmentally fragile, metropolitan areas, or problematic landscape. Arizona's Department of Water Conservation has stated that 80 percent of Arizona's land is not privately owned and that the state has great interest in taking advantage of the solar energy it receives (Zweibel 2008). The most viable path to solar energy seems to be through the southwest. It is reassuring that many of the requirements of this plan are feasible and not harmful to the environment.

Continuous energy just from the solar panels is not possible, however, since the sun only shines during the daytime hours. A system to store solar energy must be implemented so that the energy can be tapped into at night. This plan proposes storing the extra energy as compressed air. The energy from the solar panels could compress air, and the compressed air could be injected into subterranean caverns, deserted mines, expended natural gas wells and aquifers. The Electric Power Research Institute states that compressed air energy storage costs about half as much as lead acid battery storage (Zweibel 2008). The lower energy cost than the batteries will give the compressed air energy storage an advantage over the batteries and other new forms of storage that cost more. This is promising for the implementation of compressed air power plants.

Since it is not viable to construct photovoltaic systems throughout the United States close to where the energy is going to be distributed, a system must be constructed that transports the energy from the solar power plants in the southwest to compressed air power plants throughout the country. The alternating current transmission lines cannot handle this task. High voltage direct current transmission lines must be constructed to overhaul the ongoing system. According to the Oak Ridge National Laboratory, these direct current lines dissipate less energy than the alternating current lines do. They also cost less to construct and do not take up as much land as the alternating current lines occupy (Zweibel 2008).

The plan to convert the nation's dependency on fossil fuels to dependency on solar power consists of two main stages. Stage one includes the time period of the present to 2020. During this period it is necessary that the price of mass produced panels become competitive with the current prices of energy from fossil fuels. The government must participate by loaning money and subsidizing companies so that the prices stay competitive. Over time the prices will decrease, but subsidies will be needed at the beginning. 84 gigawatts of solar power plants will be built by 2020, and the high voltage direct current system will be in place, mostly along interstate highways (Zweibel 2008).

The second stage occurs from 2020 to 2050. Self-sufficient growth in the solar power industry must occur in this stage. Market incentives must maintain this growth. At the end of this stage, solar power will provide 69 percent of the United States' electricity and 35 percent of total United States' energy. The 35 percent of total energy includes the amount of electricity required to power 344 million plug-in hybrids. 3 million new jobs will be created mostly in solar manufacturing, which greatly outnumbers the amount of jobs that will be lost in the industry of fossil fuels. 46,000 square miles of land will be required to provide the amount of energy that is stated above. This is only 19 percent of the southwest land that is available for solar power plants (Zweibel 2008).

In order for this plan to be successful, it has to be paid for. The cost of the plan is 420 billion dollars. One suggestion is to add a carbon tax of .5 cents onto the electricity bill that normally costs around 6 to 10 cents per kilowatt hour. The governments in Japan and Germany have already begun to subsidize their solar networks (Zweibel 2008).

Technological Advances and Novel Ideas

The rate at which new information and knowledge are increasing in this digital age is astounding. Due to this phenomenon, advances related to solar cells are increasing rather rapidly. The rest of this paper will survey some new advances.

Depending on rare materials is not a long term solution for the mass production of solar cells. Some materials that are found in solar cells such as indium are rare. According to various University of Northwestern professors, a new solar cell made out of single-walled carbon nanotubes that are one nanometer in diameter may be a possible solution to the rarity issue ("Researchers Use…" 2011). Carbon is one of the most abundant elements in the world. Abundant elements also tend to cost less than rare ones. Several advantages of a solar cell made out of carbon exist. Carbon is probably going to allow the cell to be lighter and more flexible. This implies applications to clothing, fabrics, and other pliable surfaces. Solar cells could capture energy for usage on the go such as powering cell phones and powering devices that are used in the military ("Researchers Use…" 2011). In addition, Cornell University researchers attest to an efficiency improving property of the nanotubes. They have demonstrated that a carbon nanotube can turn large photons that are usually lost as heat in solar cells into more electrons that can be sent into the circuit (Bourzac 2009).

Extremely small materials in the nanoscale also have the potential to revolutionize the scope in which solar energy is captured and converted to electricity. Colloidal quantum dots are nanoscale semiconductors that convert light into electricity. Their small size allows them to be sprayed onto various surfaces. This translates into much less expensive production costs when compared with typical silicon solar cells ("Colloidal Quantum…" 2011). At the University of Toronto, researchers have obtained an efficiency of 4.2 percent with these quantum dots. 10 percent efficiency is expected to be achieved 5 years from now. The theoretical efficiency of these cells reaches to 50 percent efficiency (Morsella 2011). This advance indicates that the future of solar power includes many portable and flexible energy sources.

Advances in solar energy storage are as important, if not more important, than the advances in solar cell technology. Sunlight can be converted into electricity, but storing it effectively is an issue. Researchers from the Massachusetts Institute of Technology have proposed some innovative ideas regarding energy storage. A material composed of carbon nanotubes combined with a compound called azobenzene has a very large energy density and is composed of abundant materials. The energy density of the material is on par with lithium-ion batteries. Once this material absorbs sunlight, it morphs into a shape that has higher energy than the ground state of the material. The heat energy from the material can be extracted by some type of stimulation. For example, this stimulation could be a chemical catalyst. Although this material is great for heating applications, the heat energy must be converted from heat to electricity by generating steam to turn a turbine (Chandler 2011). Another Massachusetts Institute of Technology innovation involves storing energy with the abundant resource of water. Researchers have developed a way to use sunlight energy to dismantle water into hydrogen and oxygen gases. The gases can be recombined in a fuel cell when the energy is needed (Gaudin 2008).

Cambridge engineers have designed a system of storing energy using two silos filled with gravel. These silos are cheaper and require less space to put into place than the conventional energy storage method of pumped hydro power. The electricity from the renewable energy source such as solar energy raises the temperature and pressure of argon gas that is sent into the first silo chamber. When the gas leaves the first chamber, the gas has cooled while the gravel has been heated up to about 500 degrees Celsius. The cooled argon gas is then fed into the second chamber and then expands, causing the temperature of the second silo to get very cold, around negative 160 degrees Celsius. The electrical energy is stored as the temperature difference between the two gravel silos. The cycle is carried out in reverse in order to release the energy. The heat powers a generator that converts mechanical energy into electrical energy. This process allegedly operates with 80 percent efficiency (Jha 2010).

Although space based solar power is definitely not a new idea (it has been around since the 1960s), it has gained resurgence in the last few years (Gibbs 2009). Every day electromagnetic frequencies are beamed down from solar powered communication satellites to connect cell phone calls or to connect television signals to receivers on rooftops (Hadhazy 2009). The challenge is to develop a space based solar power system that can harness the energy from the sun and beam it down to receivers on the ground and then feed the energy into the grid as electricity. This is precisely what the Switzerland space based solar power startup Space Energy is attempting to do (Hadhazy 2009). In addition, JAXA, the Japanese space agency, is gearing up for a 250-megawatt model of a space based solar power system to be demonstrated in 2020 (Gibbs 2009). It is only a matter of time until space based solar power systems are up and running.

John Mankins, who is the co-founder of Managed Energy Technologies, LLC, stated that the technologies that are connected closely with space based solar power have made “enormous progress” in the past few years (Hadhazy 2009). This is a good omen for the future of this idea.

The advantages of this idea are that it is a clean source of energy and that it is unlimited and available 24 hours a day, unimpeded by the Earth's atmosphere and its gases and particulates. The energy received by orbiting photovoltaic systems in space is much greater than the energy received by terrestrial photovoltaic systems. EADS Astrium, Europe's biggest space company, has a goal of 80 percent efficiency of conversion from infrared radiation to electricity (Amos 2010). This would be a considerable feat to demonstrate the viability of power transmission by infrared lasers.

Problems with implementing space based solar power technologies still abound, however. First off, transporting energy by beaming microwaves is not as efficient as transporting energy by beaming lasers. Beamed microwaves could also interfere with the frequencies used by Bluetooth. Microwave beaming technology is farther along than laser beaming technology, so developments must be made in the area of beaming energy. Cost of space based solar power is probably the most important issue. In 1979, NASA conducted an estimate of the "cost to first power" of this idea. In the year 2000 dollars, it cost 305 billion dollars. The power-to-payload ratio needs to increase for the cost of space based solar power to be competitive (Gibbs 2009). Basically, the solar cells launched into space need to weigh less so that the cost to launch them is cheaper, and the cells need to be more efficient. That lowers cost too. Lighter solar cell materials are being developed, as have been mentioned in this paper. The commercialization of space is promising in that it has the potential to decrease the expense of launching solar satellites into space. Satellites could even be produced from many of the raw materials that the moon has to offer. They could then be launched into space at a much lower cost due to the moon's weaker gravitational field (Hadhazy 2009). In addition, space elevators have the potential to dramatically decrease launch costs to 1.50 dollars per kilogram (“Audacious & Outrageous…” 2000). Various technologies could decrease the cost of solar power in space, but they must be developed first.

Conclusion

It is astonishing how much energy the sun transmits to the Earth every hour. As stated earlier, this is enough energy to satisfy the world’s energy needs for a year (Biello 2008). Harnessing this energy has proved quite difficult, but the technology has considerably improved since the ability of a certain material to convert light into electricity was discovered. Efficiencies of solar cells continue to improve due to research and the incentive for solar power to overtake fossil fuels. Other advances might allow for solar energy to be applied to many other portable areas of modern day life. Seemingly futuristic beaming technologies are being developed as well so that the energy of the sun in space can be harvested. The twenty-first century is the century for solar power and energy freedom.

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