Solar Technology and the Solar Sheath

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The purpose of a solar cell is to generate electricity through the release of electrons from a material that is bombarded by electromagnetic radiation, or photons. Most crystalline solar cells are sensitive to visible radiation from 400-700 nanometers, which correspond to 3.1-1.8 electron volts, of the visible region (ACEPT, 1999) and also into the near infrared spectrum. As the wavelength of the electromagnetic radiation increases, the amount of electron volts decreases. This means that infrared radiation has less electron volts than the visible spectrum of light (because it has a larger wavelength than visible light), and ultraviolet and gamma radiation have more electron volts than both the visible spectrum of light and infrared radiation (because they have a smaller wavelength than both infrared and visible light). Abramowitz, Davidson and Neaves (2003) indicate that all forms of electromagnetic radiation originate from the atoms that contain orbiting electrons around their nuclei. When those electrons absorb more external energy than they can contain in order to be stable, the extra energy is released in the form of an electromagnetic wave. That electromagnetic wave contains a magnetic field and an electric field, one offset by ninety degrees to the other along the propagation plane.

As noted by Seale (2003), the first silicon solar cell was developed by Russel Ohl in 1941; this was similar to a photodiode with a large light-sensitive area. Aldous (2007) claims that pure silicon, the main component of silicon solar cells, is a poor conductor of electricity in itself. In fact, the silicon atom is missing four electrons in its outer shell. A phosphorous atom, on the other hand, contains five electrons in its outer shell, meaning that it can bond with silicon atoms. Since it has an extra electron that can be displaced by electromagnetic radiation, energy is created in the process. However, capturing this energy is not possible without creating an electric field. This is done by introducing impurities in the silicon material. Silicon mixed with phosphorous creates an N-type semiconductor (N-type or negative because the phosphorous contains free electrons). Silicon mixed with boron atoms (which contain only three electrons in its outer shell) represents an absence of electrons and becomes the P-type semiconductor (P-type or positive). At the plane where the N-type and P-type are joined is where the electric field is generated and the solar cell reaches electrical neutrality. The introduction of photons (electromagnetic radiation) on the N-type semiconductor (silicon and phosphorous) frees electrons that try to travel to the P-type semiconductor (silicon and boron) where the photon would remove an electron. The presence of the magnetic field between the two layers prevents this travel from occurring to a degree directly from the N-type semiconductor to the P-type semiconductor. This means that when we connect a load to the P and N semiconductors, we observe current (from electron flow) and voltage (from the magnetic field) as the free electrons move from one semiconductor to the other through the load.

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Significance of Solar Panels

A solar cell, in itself, is of little value in our energy-consumptive world. Only when solar cells are joined together into arrays or panels do we commonly see their true benefit in delivering mass volumes of energy. The number of solar panels required depends on the number of things that need power. For instance, if you were interested in powering your entire house, you would undoubtedly need several solar panels.[1]

Now that there is an understanding of how a solar cell is made, it is possible to see how a solar panel is made, since a panel is made from a collection of solar cells. All items to be used are listed in Figure 1 (URLs are given for vendors used for the parts in this project).

1	48 x 48 x 1/8 inch Acrylite UV stabilized transparent sheet; this is used in place of the glass top sheet (http://www.usplastic.com/catalog/variant.asp?catalog_name=usplastic&category_name=21314&product_id=10477&variant_id=44308)
1	48 x 48 x 3/16 inch ABS white sheet (http://www.interstateplastics.com/detail.aspx?ID=ABSsheetGP-SW1018)
4	72 x 1/4 x 1/4 inch clear extruded acrylic bar (http://www1.mscdirect.com/CGI/GSDRVSM?PACACHE=000000076797329)
1	Adhesive glue (http://www.vandykes.com/product/sb110008/gorilla-glue-4-ounce)
1	Silicone sealant/adhesive (http://www.liquidnails.com/products/product.jsp?productId=48)
2	Eight ounce Rosin core solder (http://www.radioshack.com/product/index.jsp?productId=2062713)
1	ERC81S-004 40V, 5A Schottky Barrier Diode (http://www.fujisemi.com/html/table/91500/91502.htm)
5	.060 x .002 inch by 25 feet solar cell PV tinned interconnection ribbon (http://windandsunpower.com/store/index.php?main_page=product_info&products_id=6)
36	Monocrystalline 6 inch (156mm) solar cell rated at .5VDC, 6 Amp Peak. You can get new 156mm solar cells in bulk from http://www.dmsolar.com; however, if you are interested in a set of 36 smaller solar cells, you can get a set from http://www.solarblvd.com/product_info.php?info=p1343_Polycrystaline-Solar-Cells-36-Pieces-0-55-V--4-2A.html. You could also try to locate solar cells from a seller at http://www.ebay.com or http://www.ecrater.com.
1	Four position dual row barrier strip (http://www.radioshack.com/product/index.jsp?productId=2103982)
1	Sixteen #8 insulated ring tongue terminals (http://www.radioshack.com/product/index.jsp?productId=2103306)
1	Twelve gauge hookup wire black insulator (http://www.radioshack.com/product/index.jsp?productId=2062647)
1	Twelve gauge hookup wire red insulator (http://www.radioshack.com/product/index.jsp?productId=2062646)
1	3 x 2 x 1 inch project enclosure box (http://www.radioshack.com/product/index.jsp?productId=2062279)
1	Crimping tool (http://www.radioshack.com/product/index.jsp?productId=2062789)
1	40 Watt soldering iron (http://www.radioshack.com/product/index.jsp?productId=2062738)
1	[OPTIONAL] Multimeter. About any DC voltage measuring capable multimeter will suffice. The DM9100 resembles what is actually used in this example: (http://www.byramlabs.com/product_info.php/products_id/8184)
1	[OPTIONAL] Variable temperature heat gun (http://www.toolking.com/milwaukee_8975-6.aspx)
1	[OPTIONAL] 28 square feet of .018 inch thick ethylene vinyl acetate (EVA) sheet -OR- UV resistant Surlyn sheet. This is difficult to get in small quantities, but I have seen it available at http://www.ebay.com and http://www.ecrater.com. NOTE: EVA sheet shrinks as it is heated; hence 28 square feet is recommended versus 20 square feet.

Figure 1. Solar panel components and tools. All URLs listed are the procurement resources used by the author for this project.

When purchasing individual solar cells, you may be able to find class B cells as I did. These solar cells are ones which do not meet the requirements of solar cell manufacturers for a class A rating (which are certified to perform in a specified range). I've observed that class B solar cells commonly perform at seventy percent or greater than class-A-rated solar cells, but to maximize the capacity of a solar panel you'll need to individually test and group class B solar cells with a multimeter as shown in Figure 2.

Figure 2. Measuring solar cell voltage.

Group the class B solar cells together into .05VDC stacks as shown in Figure 3. When one stack has 36 solar cells, you'll have enough to generate the theoretical 12VDC at 100 watts; of course, the actual energy level will most likely be less.

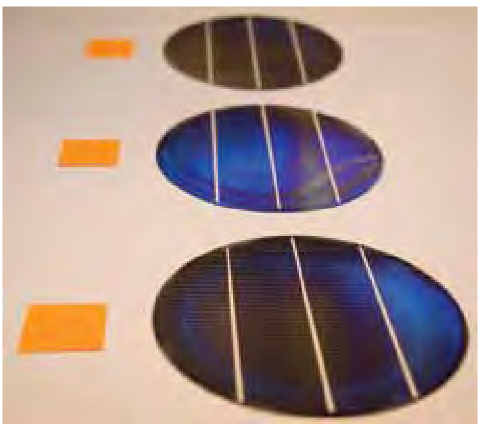

Figure 3. Grouping solar cells by voltage.

With this example, the solar cells will need to be connected together so that 12VDC at 100 watts will be generated. In order to do this, you'll need to connect the solar cells together in series (using the tinned interconnection wire; the positive side of one cell is connected to the negative side of another cell).

Step 1: Connect the solar cells together with tinned interconnection wire. In order to do this, cut the spool of interconnection wire into 10.5-inch lengths for the six-inch solar cells. See Figure 4.

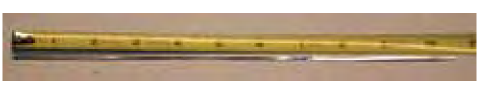

Figure 4. Length of tinned interconnection wire.

Step 2: Each length of tinned interconnection wire must have solder added to it. This is done by adding solder to 5.25 inches of the wire starting at one end. Then flip the wire length over and add solder to 5.25 inches of the wire starting at the opposite end.

Step 3: Solder a length of the interconnection wire to each connection strip on the front of each solar cell. In this case, three lengths of interconnection wire are used per solar cell. See Figure 5.

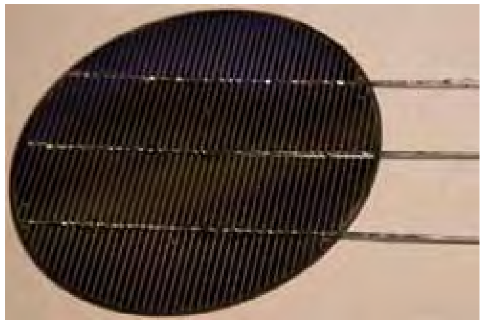

Figure 5. Soldered solar cell.

Step 4: Connecting solar cells together in series using the six-inch solar cells, as in Figure 6, uses a unique approach where all of the solar cells are soldered together in a zig-zag pattern to minimize the amount of interconnection wire used. From a schematic, soldering the solar cells together in series results in the illustration seen in Figure 6.

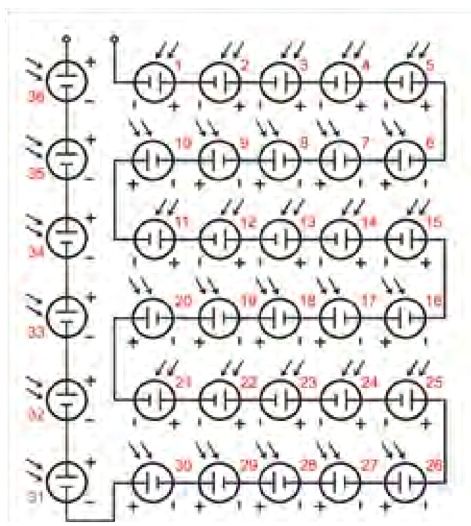

Figure 6. Solar panel schematic diagram.

Step 5: In order to solder the solar cells together, place one face down as shown in Figure 7.

Figure 7. Back of solar cell.

Step 6: Take another solar cell (face down) and place the interconnection wires on top of the previous solar cell (leave approximately 1/16 inch space between the solar cells) and solder those interconnection wires to the previous solar cell as shown in Figure 8.

Figure 8. Overlaying solar cells to solder together.

Step 7: Now that you've seen how to solder solar cells together, you'll need to know the sequence of soldering the 36 solar cells together into a compact form (starting at #1 and ending at #36). See the graphical representation in Figure 9.

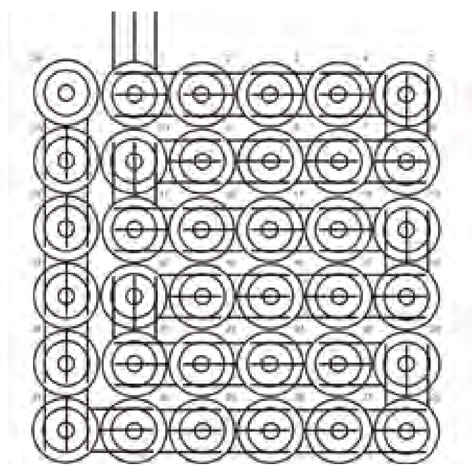

Figure 9. Soldering pattern of solar cells.

Step 8: After the 36 solar cells have been soldered together, they will resemble what is shown in Figure 10.

Figure 10. Solar cells comprising a solar panel.

Optional Step 8a: While not required, it is recommended that you sandwich the soldered solar cells inside of a protective thermoplastic material such as ethylene vinyl acetate (EVA) sheet or UV-resistant Surlyn sheet. Over time, if oxygen or other contaminants are present inside the solar panel, your solar cells will degrade prematurely. If you have one of these types of sheet, place it over the solar cells you've just soldered together (use the heat gun on the sheet so that it adheres to the solar cells).

Note that I placed the solar cells on top of white paper and then soldered them together in advance of heating an EVA sheet onto them. The reason for this is that the EVA sheet is a very adhesive material when heated (it also becomes approximately 100% transparent after heating). When flipping over the solar panel in a cardboard frame (so that the other side can have an EVA sheet applied to it), the paper can be easily removed; without the paper between the solar panel and the cardboard, it would be necessary to peel the inverted EVA sheet and solar panel from the rigid cardboard, causing damage to individual solar cells.

Figure 11. Applying EVA Sheet to Solar Panel.

Optional Step 8b: Carefully turn the panel of solar cells over, place the EVA sheet over the top of the solar cells and use the heat gun on the sheet so that it adheres to both the solar cells and the first sheet.

Step 9: Take the 48 x 48 x 3/16 inch ABS white sheet and, using a cutting tool, cut it down to a 38 5/16 x 38 5/16 x 3/16 inch sheet. Then drill a 5/16 inch hole through the sheet six inches from the top right edge and one inch down from the top right edge.

Step 10: Place the 36 solar cells, which were soldered together, face up onto the ABS white sheet and center them on the sheet. Cut off excess EVA or Surlyn sheet (if you applied it to the solar cells) so that it is approximately one inch less on each side than the size of the ABS white sheet.

Step 11: Solder approximately three inches of the color-coded wire to the appropriate positive and negative interconnection wire on the #1 and #36 solar cells. Push the other end of the wires through the 5/16 inch drilled hole.

Step 12: Cut two 72 x 1/4 x 1/4 inch clear extruded acrylic bars to a length of 38.31 inch (optimally, 38.3125 inch if using a digital caliper). Cut the remaining two 72 x 1/4 x 1/4 inch clear extruded acrylic bars to a length of 37.81 inch (optimally, 37.8125 inch).

Step 13: Glue one 38.31 inch clear extruded acrylic bar to the top of the ABS white sheet, lining the bar up with the edge of the ABS white sheet. Allow the glue to dry. Then take the second 38.31 inch clear extruded acrylic bar to the bottom of the ABS white sheet, lining the bar up with the edge of the ABS white sheet. Allow the glue to dry.

Step 14: Glue one 37.81 inch clear extruded acrylic bar to the left of the ABS white sheet, lining the bar up with the edge of the ABS white sheet. Allow the glue to dry. Then take the second 37.81 inch clear extruded acrylic bar to the right of the ABS white sheet, lining the bar up with the edge of the ABS white sheet. Allow the glue to dry.

Step 15: Cut the remaining clear extruded acrylic bar into 1 x 1/4 x 1/4 inch blocks. Glue each block, centered, in between each solar cell in an alternating pattern (this will provide strength to the solar panel).

Step 16: Take the 48 x 48 x 1/8 inch Acrylite UV-stabilized transparent sheet and, using a cutting tool, cut it down to a 38 5/16 x 38 5/16 x 3/16 inch sheet. Place glue along the top of the four acrylic bars which were glued to the ABS white sheet. Place glue on top of each of the 1 x 1/4 x 1/4 inch blocks. Line up the Acrylite sheet with the edges of the four acrylic bars and place it firmly on top. Allow the glue to dry.

Figure 12. Completed solar panel.

Following construction of the solar panel (hopefully similar to Figure 12), the last component needed to finish it off is a junction box with a reverse current blocking diode to protect the solar cells in the solar panel.

Step 17: Drill one 5/16 inch hole in the bottom of the 3 x 2 x 1 inch project enclosure box. Drill another 5/16 inch hole into the side of the box. Apply glue to the back of the box. Feed the wire, sticking out of the back of the solar panel, through the bottom hole of the box. Seat the box firmly onto the back of the panel and allow to dry.

Step 18: Assemble the junction block with wire and the diode as shown in Figure 13.

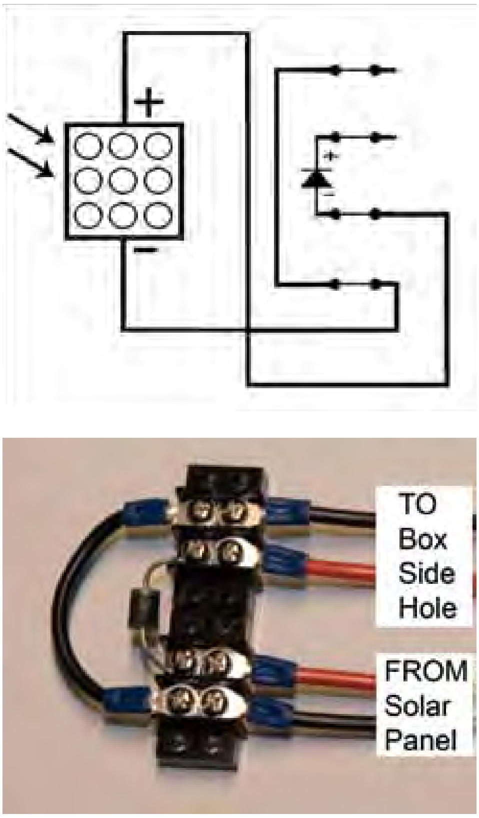

Figure 13. Solar panel diode schematic and physical representation.

Step 19: Apply glue to the back of the junction block and seat in the bottom of the enclosure box. Allow the glue to dry. Finally, apply enough of the Silicone sealant/adhesive to fill in the hole in the bottom and side of the enclosure box. Allow the sealant/adhesive to dry.

Advances in Solar Technology

The efficiency of commonly used first-generation solar cells at converting sunlight into electricity is approximately 15-25% (second-generation solar cells are constructed of thin-film material and are flexible instead of being thick and rigid like first-generation solar cells). However, constant research into improving the efficiency of solar cells has led the National Renewable Energy Laboratory (NREL) to create an inverted metamorphic triple-junction solar cell with an efficiency of 40.8% by using three junctions, where each junction layer captures a specific electromagnetic spectrum, with gallium indium phosphide and gallium indium arsenide, according to Electrical Engineer (2008).

Affordability was a key premise to the development of the iJET solar cell, patented by Nicole Kuepper at the University of New South Wales. According to Richard (2008) the iJET solar cell should reduce the cost and technical requirements of creating solar cells, making it an ideal candidate for adoption by developing countries because expensive clean rooms and high-temperature ovens are not required. Rather pizza ovens, nail polish and inkjet printers would be the primary means of producing iJET solar cells. Similarly, Poynter (2007) reports that New Jersey Institute of Technology (NJIT) researchers are working on a technology that would allow the use of a flexible light-absorbing polymer material that is placed into an inkjet printer in order to print out nanotubes onto its surface to create a flexible solar panel (or cell) of whatever size and shape are designated. This type of solar cell is known as a thin-film solar cell. Most thin-film solar cells have an efficiency of less than 15% although chalcopyrite films of copper indium selenide (CIS) have reached greater than 14% efficiency, but manufacturing costs exceed that of amorphous silicon solar cells.

The third generation of solar cells are known as thin-film dye-sensitized solar cells (DSSC), also referred to as a photochemical cell. These are being researched and developed because they are relatively inexpensive to manufacture compared with silicon solar cells, although they produce less energy. In fact, a learning kit is available which demonstrates the basic fundamentals of a DSSC such as the nanocrystalline solar cell kit available from the University of Wisconsin-Madison (at http://ice.chem.wisc.edu/Catalog/SciKits.htm#Anchor-Nanocrystalline-41703). The DSSC derives its efficiency from the dye material, such as photosensitive ruthenium-polypyridine dye and solvent, used to envelope a thin film of titanium dioxide (TiO_2) semiconductor. That film is sandwiched between a top layer of transparent flourine-doped tin oxide (the SnO_2 deposited on one side of glass) and a thin layer of iodide electrolyte which is spread over a conductive, thin platinum film. In this manner, the SnO_2 forms the negative contact and the platinum sheet forms the positive contact. A new energy conversion dye, known as black dye (such as one based on trithiocyanato-ruthenium complex) may perform better than the traditionally accepted ruthenium-based dye (N_3) because it has a response 100 nm further into the infrared spectrum (Wan, 2004).

How can electromagnetic radiation not successfully caught by a solar cell and radiation converted into kinetic energy be useful to a solar cell?

> The use of nanotechnology may allow the solar cell to capitalize on multiple methods of capturing and using energy in the same footprint as common solar cells that are seen today.

Over the past several years the electrolyte used inside of DSSC's has been researched to utilize a variety electrolyte in various forms; in fact, you can now purchase different types of electrolytes primarily used in DSSC's from Dyesol (at https://secure.dyesol.com/index.php?template=Electrolyte). The liquid form of electrolyte, according to an article published by *ScienceDaily* (2008), noted that volatile organic solvents in the electrolyte could permeate plastic and leak. Gratzel, et al have been able to use solid salts to replace the volatile organic solvents in the electrolyte solution to address that drawback. Biancardo (2008) revealed that a gel form of electrolyte has also been researched, in part to address reliability, durability and transparency (for use in architectural elements such as windows) but with mixed results in terms of energy conversion efficiency. Finally, Freemantle (2002) reports that a gel of ionic liquid polymer could be used as an electrolyte in a DSSC and that the gel could be formed into a rubber-like sheet that could be cut into pieces and used in solar cells.

Electron Flow and Thermodynamics

Electromagnetic radiation bombards solar cells. One result of this is that solar cells will produce electricity. Another result is that kinetic energy, or heat, is absorbed by solar cells. The heat that is generated plays a role in the efficiency of solar cells, silicon and thin-film more so than DSSC's. That heat causes solar cells to convert and conduct less electricity; over time, this may lead to the degradation of the solar cell. In the future it may be possible to develop solar cells which are able to successfully absorb most or all electromagnetic radiation, mitigating the effect of heat accumulation in the cell material from not being able to successfully convert the bombardment. Creating a solar cell that is able to convert more radiation into electricity will result in increases in electron flow through the solar cell material. Once again, the result is the generation of kinetic energy, or heat, that can impair the solar cell's efficiency and contribute to degradation.

The Solar Sheath

How can electromagnetic radiation not successfully caught by a solar cell and radiation converted into kinetic energy be useful to a solar cell? My concept—the Solar Sheath, still in early development—is to introduce a means of kinetic energy transfer from a metallic material using round nanotubes made from a thermally conductive, electrically isolative conduit such as polyphenylene sulfide through which the interior carries a flowing medium. The medium could be helium, sulfur hexafluoride or a liquid, such as water. See Figure 14.

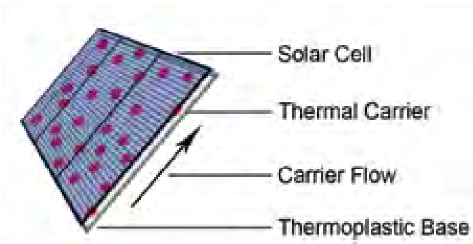

Figure 14. Simple example of kinetic energy absorption.

In order to address radiation that passes through the solar cell material unabsorbed, the second element of the Solar Sheath involves having the same nanotubes spiral-wound with a conductor, such as copper, to absorb a portion of that free-flowing radiation which would be transformed into additional electricity as that radiation interacts with it. See Figure 15.

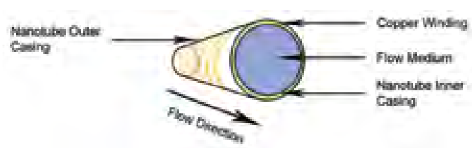

Figure 15. Wound flow-conducting nanotube.

Placement of the nanotubes within the solar cell replaces the traditional negative collector plates positioned on top of the solar cell (as demonstrated with Figure 17) after a collector strip is added to the nanotubes (Figure 16).

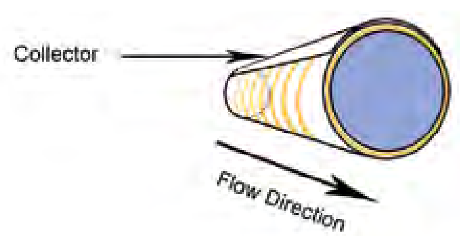

Figure 16. Collector added to nanotube.

Figure 17. Completed nanotubes embedded in solar cell.

Solar Sheath Applications

In terms of using a series of Solar Sheath solar cells, gathering kinetic energy from the wound conductor as a byproduct of the solar cell process could collectively perform the task of elevating the temperature of a water reservoir by circulating the gas or liquid contained in the nanotubes through a coil immersed in or surrounding the water reservoir. In application, this means that the same square footage consumed by the collection of solar cells to generate electricity can also be used to generate heat for water.

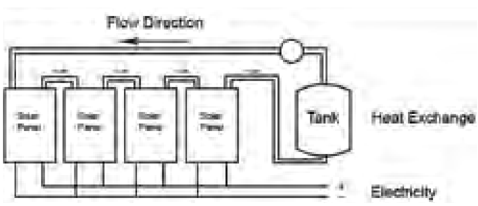

Figure 18. Application of the Solar Sheath generating power and heated water.

On a large scale, it may be possible to maximize the electrical output of Solar Sheath solar cells by focusing a maximum amount of electromagnetic radiation upon them through the use of optical lenses or reflectors wherein the cells would approach their maximum operating temperature. The resultant kinetic energy absorbed by the Solar Sheath technology may be great enough to power a turbine to generate additional electricity from the elevated temperature of the gas or liquid medium travelling through the nanotubes.

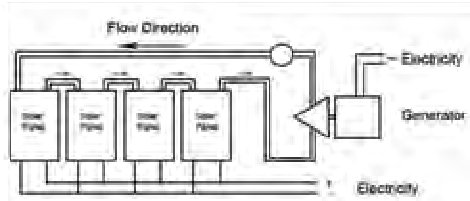

Figure 19. Application of the Solar Sheath generating power and turbine to generate additional electricity.

As previously indicated, additional electrical potential may be harnessed from the metallic winding around the nanotubes as those windings interact with radiation bombardment that the solar cell is unable to convert to electricity. The use of nanotechnology may allow the solar cell to capitalize on multiple methods of capturing and using energy in the same footprint as common solar cells that are seen today.

Prototyping the Solar Sheath

Prototyping the Solar Sheath concept involves three distinct stages. Stage 1 (currently under development) is constructing a prototype to determine how well the polyphenylene sulfide material will absorb kinetic energy from the solar cell; if successful, prototyping with the material will continue into the next phases of development. Stage 2 will involve constructing the sheathed nanotubes, while the third stage will combine the nanotubes and solar cell together (as previously described). Figure 20 illustrates the initial fabrication steps involved with constructing the prototype, less additional hardware and monitoring devices.

Figure 20. Phase 1 fabrication for material assessment.

As land becomes increasingly scarce, the capability of solar cells to perform multiple roles with greater efficiency will become more important. The possible application of the Solar Sheath does not necessarily need to be confined to the boundaries of Earth's surface. With exorbitant costs involved in maintenance of the International Space Station and space in general, the multipurpose nature of the Solar Sheath could be an alternative to traditional solar, thermal and other energy capturing systems.

To see the development of all phases of the Solar Sheath, please visit www.solarsheath.com.

Endnotes

1 There is an online calculator that may be used to get an idea of how many solar panels and other components one may need at http://store.altenergystore.com/calculators/off_grid_calculator/.

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Joe McCormack, adjunct instructor and alumnus of UAT, has been a web developer for over ten years, working on projects ranging from small websites to eCommerce platforms. Joe has published two books relating to web programming, as well as several academic articles on a range of subjects, including web-based B2B data sharing and behavioral intelligence systems. He has also developed systems certified by Authorize.Net and Paypal. Joe previously wrote about technology project management in the Summer 2008 issue.