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Solar Energy Basics ... and More[1]

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The sun's radiation arrives at no cost and is available during any clear day. **More energy from the sun falls on the earth in one hour than is used by everyone in the world in one year.** Why might the sun's radiation be preferable to other sources of energy? How is the sun's energy harnessed to perform tasks for us? What practical value is solar energy to the average person? This publication will answer these questions...and more.

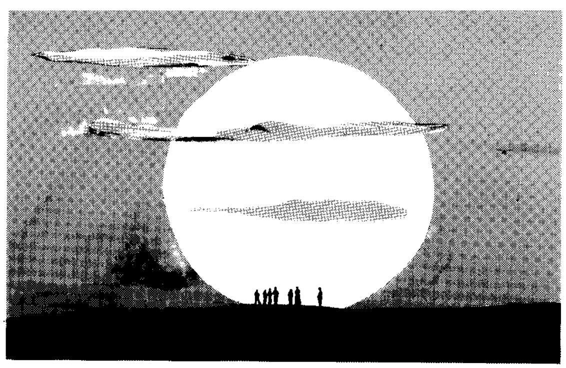

Figure 1. The sun.

"Solar Energy" implies a potential for directly heating or generating electricity by harnessing the energy radiated from the sun. In the broad sense of the term, solar energy also includes wind, wave, biomass, and fossil fuel energy as well. All these forms of energy originated as solar energy. Let's start at the beginning, the sun itself.

THE SUN

The sun (Figure 1) is an immense fusion reactor. "Fusion" simply means that hydrogen atoms are combined to make helium. This occurs on the sun because it is very hot. The sun is very hot because fusion releases a great quantity of heat. That is why fusion is called a chain reaction.

The sun's nuclear fusion process converts 508 million tons of hydrogen into 504 million tons of helium every second. The remaining 4 million tons of matter are converted to energy, making the core temperature of the sun extremely hot. As Albert Einstein found, a very small amount of matter converts to a very large amount of energy. In fact, one ounce of matter converted to energy by fusion could supply all the energy your home and car would need for a year -- plus five-thousand other people's homes and cars as well.

The energy the sun radiates is preferable to other sources of energy because solar radiation is abundant and will be for many more millions of years. Solar

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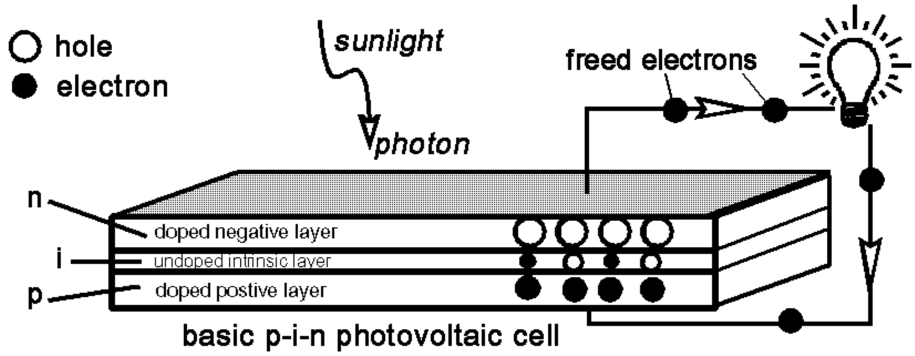

Figure 2. The photoelectric effect and PV cells diagrammed.

The Photoelectric Effect and PV Cells

The *photoelectric effect* was first discovered in 1839 by Edmond Becquerel. The effect was later explained by Albert Einstein in a Nobel Prize winning work. Photovoltaic (PV) cells make use of the photoelectric effect. A fundamental overview can be provided here.

A photon is a packet of light energy. In-coming photons strike the *outer electrons* (also called *valence electrons*; electrons are negatively charged atomic particles) in the solar cell's atoms. Only photons that exceed a certain energy threshold can free an electron. (The threshold can be seen by the eye as light which exceeds a certain brightness.) Photon energy above this threshold is converted to heat. The photon's impact "frees" valence electrons from the atomic lattice. A mobilized electron is able to conduct an electric current. A freed electron moves away from its parent atoms leaving a positively charged "hole" at its initial position.

Without *doping*, the freed electrons would eventually loose energy and fall back into holes, and no electricity would be generated. The doping process introduces a few atoms (called donor atoms) with one more (called n-type for negative) or one less (called p-type for positive) valence electron than the undoped atoms have. Layers are arranged above and below an undoped (called i-type for intrinsic) layer to make a p-i-n cell. Excess electrons in the n layer move across the i layer to fill holes in the p layer. This gives the p layer a negative charge and the n layer a positive charge. The charge imbalance is a somewhat stable and permanent characteristic of the cell. It sets up the voltage which drives a current composed of the electrons freed by photons. When an electron is freed by a photon, it moves towards the n layer because opposite charges attract. Electrical contacts draw off the freed and separated electrons to create a flow of electric current. The current flows out of the cell through a connecting wire.

There are several types of solar cells. Single crystalline cells made from thin wafers of silicon crystals are durable, reliable, 10-18% efficient, and expensive. Crystalline-microsphere cells are less expensive and almost as efficient, up to 15%. Amorphous cells are made by vapor deposition of thin layers on a substrate. Amorphous cells are inexpensive, but their efficiency is 5-9% and tends to degrade over time. Thin-film polycrystalline cells are less expensive than crystalline cells while being as efficient as single-crystal wafer cells.

radiation cannot be cut off or made more costly, unlike other energy sources. Putting solar radiation to work does not directly pollute the environment. It is a clean, safe source of energy. The only cost is the equipment used to harness the sun's energy. The energy itself is free.

Unfortunately, solar energy is not always available on demand. It is unobtainable under heavy clouds or at night. This can be overcome by storing the energy. Solar radiation arrives at low intensity and must be concentrated for high temperature (over 250°F [120°C]) applications. Collectors which can concentrate solar radiation are more costly than ones that do not.

COLLECTING AND CONVERTING THE SUN'S ENERGY

The energy from the sun can be captured and put to work indirectly or directly. Wind, wave, and biomass energy originate as solar energy, so they put solar energy to work indirectly. Photosensitive chemicals in plants convert solar energy into chemical energy in the form of carbohydrates. Conversion of solar energy directly into electricity is done using solar cells, also called photovoltaic (PV) cells. Heating solids or fluids directly is done using thermal solar collectors in a manner similar to the way the sun heats a paved road.

Photovoltaic Systems

A photovoltaic cell is a stack of thin layers of semiconductor materials which exhibit the photoelectric effect, such as silicon or cadmium telluride. The layers contain small amounts of doping agents (intentional impurities), such as the element germanium. The dopants give the semiconductor the ability to produce a current when exposed to light (Figure 2 and Table 1). Typical cells convert about five to fifteen percent of the solar energy they receive into electricity, depending on the type.

Solar cells are mounted into groups called modules since each cell produces only a small amount of electricity, typically 0.5 Volts. The module provides the combined current from all the cells. Modules power lights and appliances (Figure 3).

Photovoltaic systems sometimes have two additional components to complement the solar modules: an inverter and a storage device. Since solar cells produce direct current (DC) and most conventional equipment operates on alternating current (AC), an inverter is used to change the DC current to AC current. The energy is stored for use during overcast periods and at night. The energy can be stored as chemical energy in batteries, or as potential energy in pumped water or compressed air.

As an alternative to on-site storage, a photovoltaic system can be made *utility interactive*. Interactive systems are connected to the power company's lines so the utility can provide "make-up" power when solar radiation is low. Conversely, when the PV modules produce more power than is needed at the site, the excess is fed back to the utility grid. This causes the electric meter to run backwards, offsetting the cost of the "make-up" electricity.

Solar Thermal Systems

Active Systems

Active solar thermal systems have four main components: the solar collector panels, the working fluid, the storage tank, and the controller. The heat captured by an active system can be used to heat water or air, or to power a pump. When solar collectors are exposed to solar radiation, a working fluid flowing in passages or tubes in the panels is heated. The fluid is typically water, water and antifreeze, or a refrigerant. A clear cover over the collector slows the escape of collected heat to the outside air (Figure 4, Figure 5, and Table 2).

The working fluid is circulated by a pump or fan through the collector and to a storage tank for use as needed. If air is the working fluid, solar heated air can be blown through a solid media, such as stones, for storage. The controller turns the system on when the sun's energy is available and off during cloudy periods and at night. Without the controller, hot working fluid

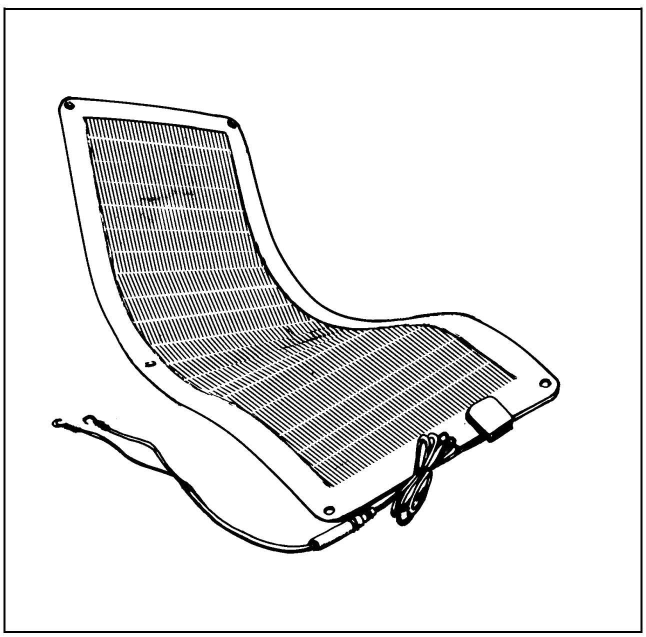

Figure 3. A portable, flexible amorphous silicon solar photovoltaic module.

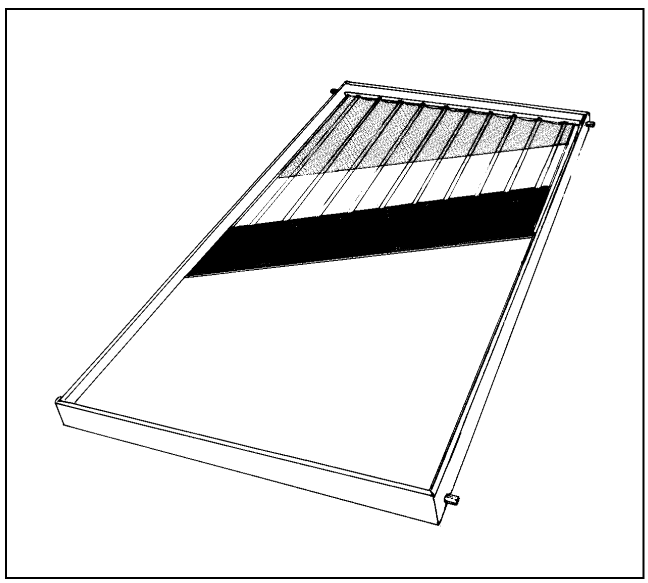

Figure 4. A cutaway view of a solar panel showing the tubes, black heat asorbing coating, and insulating glass cover.

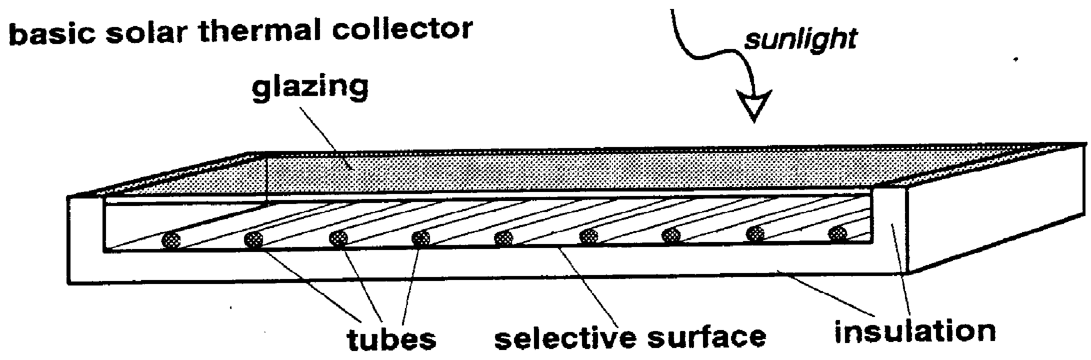

Figure 5. The flat-plate solar thermal collector.

The Flat-plate Solar Thermal Collector

The *flat-plate* collector is the most common type of solar thermal collector. In general, a solar collector is a type of heat exchanger that converts the *radiant* energy from the sun into usable *heat* energy. The function of the collector is to maximize the conversion of incoming radiation to usable heat, while at the same time limit the loss of that heat to the surroundings. The main parts of a collector are shown above. The selective surface is designed so it easily absorbs radiation, but does not reflect or re-radiate energy back out of the collector. Special black or dark-green coatings are used. The coating converts the radiation to heat by absorbing it. The working fluid flows through the tubes and collects the heat. Copper tubes transfer the collected heat to the working fluid more effectively than aluminum tubes. The cover, or glazing, reduces convection and radiation losses to the surrounding air. The cover is transparent to short-wave solar radiation, but not to infrared radiation from the selective surface. The back and side insulation, typically R-value 12, reduces conduction losses.

Flat plate collectors do not concentrate solar radiation. Unlike concentrating collectors, they make use of diffuse (also called ambient or scattered) radiation as well as the direct beam radiation from the sun. Flat-plate collectors are usually fixed to an orientation optimized according to location and time of year. Passively heated buildings can be considered a special case of the flat plate collector. The building itself functions as a large solar collector.

from the tank would be pumped to the collector at night, and instead of being heated by the sun it would be cooled by radiation to the night sky. (Sometimes this is done intentionally to cool warm swimming pool water in the middle of summer.) The controller can also automatically drain water from the collector to prevent it from freezing and cracking the collector tubes.

A heat pump can be combined with solar thermal collector panels to extract solar heat from them during winter. During summer the heat pump can discharge heat to the cold night sky very effectively, increasing air conditioner efficiency.

A solar furnace is an active system that concentrates the sun's energy at one point with mirrors or lenses (Figure 6). The heat captured by a solar furnace can be used to generate steam to work generators and other industrial equipment. Solar furnaces can be used to power industrial processes that require temperatures of less than 600°F (315 °C). This includes almost half of all industrial processes. In many cases, such as in metallurgy, solar heat produces a better product because it is clean heat.

Passive Systems

Passive systems are used to heat homes. They work the same way that the sun heats a room through a window. A passively solar heated house is oriented and designed to absorb and store heat from the sun during the winter, and to keep sunlight out during the summer. Features include large south facing (and sometimes insulated) windows to admit solar radiation into the room and a large thermal mass such as a thick stone floor to store the heat overnight. Passive systems have few or no moving parts. The collected solar heat is stored in the building materials themselves. The roof overhang is specifically designed to admit sunlight in the winter and shade the glass when the sun is higher in the sky in the summer. Strategically placed deciduous trees shade the house in summer and, after they lose their leaves, allow radiation through in the winter.

In-ground or underground passive solar buildings and houses take advantage of the steady temperature found just a few feet below ground. Underground temperature remains around 70°F (20°C) year round in Florida. This aids cooling in the summer and heating in the winter.

Practical Applications

Putting solar energy to work for you can save energy, money, and slow environmental degradation because using less electric power generated from fossil

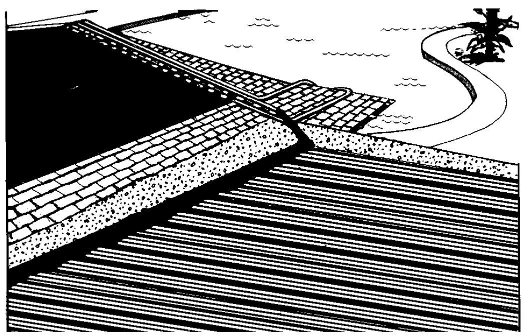

Figure 8. Roof-top [illegible] collectors heating the pool in the backg[illegible]

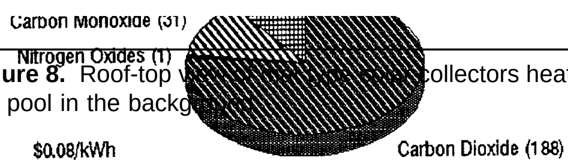

Figure 7. Using solar energy instead of electricity helps the environment.

fuels means reduced greenhouse gas and acid rain emissions (Figure 7). Three practical residential uses of solar energy in Florida today are swimming pool and hot tub heating, domestic water heating, and electricity for remote locations.

The most popular use of solar energy in Florida is swimming pool and hot tub heating (Figure 8). A solar heater can extend the swimming season by four months or longer. The installed cost of a solar system is about the same as a heat pump, or about twice the cost of a natural gas heater depending on the desired pool temperature. Operating cost is significantly reduced since only the pump draws power.

The best type of pool and tub collectors are the rubber mat type. Rubber mat-collectors are virtually indestructible and are easily repaired if damaged. Solar

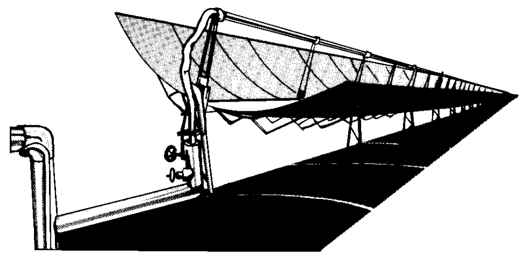

Figure 6. A parabolic concentrating collector focuses the sun's energy on a single collection tube.

energy can heat a hot tub from 75°F to over 100°F in less than two hours.

Solar domestic-water heating systems are economical where natural gas is unavailable. Modern systems supply at least 70% and up to 90% of hot water needs for laundry and bathing.

A system sized for a Florida family of four typically uses two or more 2' or 4' by 8' collectors (Figure 9). Many systems use a solar powered pump for greater efficiency. The storage tank should hold at least 20 gallons of water per family member. Extra storage capacity is a good idea and is not expensive. Solar systems should always be sized by a licensed contractor based on collector efficiency and occupant water usage.

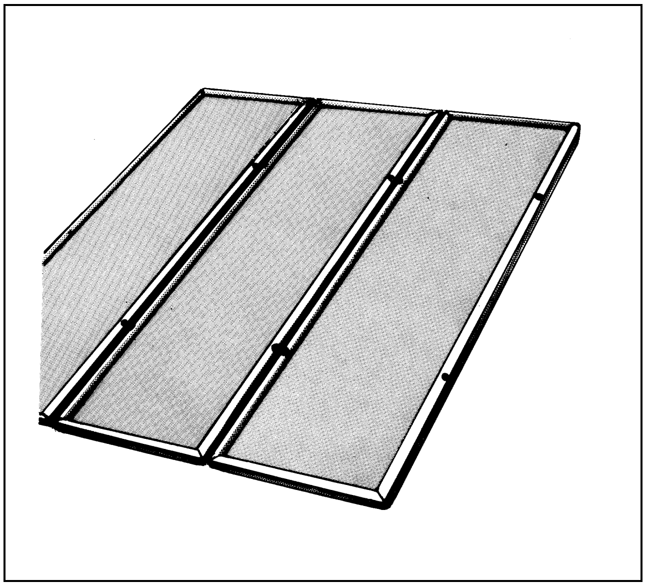

Figure 9. Water heated in a bank of solar panels is collected and pumped to a storage tank.

Most areas of Florida require a closed-loop system that uses antifreeze to protect the system from freezing. Drain-back open-loop systems are another option for freeze protection. In these systems, the water in the collector can be drained back to the tank before a freeze. Open-loop systems are suitable in South Florida.

Captured solar heat also can be used to power irrigation and livestock watering systems and to dry crops.

In outlying or isolated locations, connecting to faraway power lines can cost more than a complete PV power station. Home PV systems are a poor economic investment if power is readily available. Photovoltaic power is practical where access to utility company lines is costly, or where low power and portability are needed.

Photovoltaic systems (PV systems) can cost effectively provide electricity to rural homeowners, ranchers, and farmers for TVs, VCRs, stereos, refrigerators, computers, landscape and security lighting, pumps, electric fences, and livestock feeders. Some farmers use PV powered pumps for livestock watering on remote grazing areas. PV systems power street, billboard, bus stop, and highway sign lights, navigational buoys, and emergency telephones throughout Florida. Small PV systems provide portable power for camping equipment, computers, fans, pumps, and test equipment. PV cells are used in calculators and watches. PV cells are also used to control outdoor lights and thermal collector pumps by sensing the intensity of solar radiation.

CONCLUSION

The sun's energy is abundant, environmentally benign, and free. It can be harnessed using solar photovoltaic (PV) cells which convert solar energy directly to electricity, or using solar thermal collectors that heat a working fluid or the interior of a building. The three most practical uses of solar energy for today are swimming pool and hot tub heating, water heating, and electricity for remote locations. Putting solar energy to work can save you money, conserve precious natural resources, and slow environmental decay.

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