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Energy From The Skies: Empowering Future Generations

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Energy from the Skies: Empowering Future Generations

By Petros J. Katsioloudis, Stella Bondi, and Walter F. Deal

From the beginning of civilization, humans have been experimenting with the power of the sun.

Photo 1. Sandia's photovoltaic programs are part of the National Center for Photovoltaics, which unites much of the photovoltaic work in the United States into a working partnership (Courtesy Sandia National Laboratories).

A majority of companies around the world are riding the renewable energy wave. In Memphis, TN, the electronics company Sharp retooled an old plant to become the largest U.S. producer of solar panels. In 2010, Infinia will begin repurposing idled auto assembly plants to make solar dishes that can be "stamped out like a Chevy and installed like a Maytag," according to CEO J. D. Sitton (Solutions, 2009). Solar thermal applications have been acknowledged among the leading alternative solutions endeavoring to face the uncontrollable oil price variations, the gradual depletion of fossil fuel reserves, and the chain of environmental consequences caused by excessive usage (Kavadias *et al*., 2004).

From the beginning of civilization, humans have been experimenting with the power of the sun. Evidence has been found that people may have been burning ants with magnifying glasses as early as the seventh century BC (Kavadias *et al*., 2004). The first account of the use of solar power during war in western civilization was in the second century BC during the battle of Syracuse with Archimedes' famed Death Ray. Solar energy was used for various purposes, from igniting fire for religious reasons to heating Roman bathhouses to warming Native American Adobes. People have always pondered solar power's technical evolution, but some major progress was achieved during the eighteenth and nineteenth centuries. Although Swiss scientist Horace de Saussure is credited with making the first solar collector in 1767, the first person to patent solar thermal electric technology to produce power from the sun's thermal energy was Robert Sterling in 1816 in Edinburgh, Scotland. In 1839, Edmond Becquerel discovered that exposure to sunlight increased the energy generation of metal electrodes placed in electricity-conducting solution, also known as photovoltaic effect (U.S. Department of Energy, 2008). Photovoltaics (PV) are the conversion of solar radiation into electrical energy.

In the late 1800s and early 1900s many advances occurred with regard to the Industrial Age. Innovations included the invention of solar-powered engines, the discovery of the photoconductivity of selenium and its ability to produce electricity when exposed to light, and the construction of the first solar cells from selenium wafers. Other important milestones of that time included the discovery that the lowest voltage capable of causing a spark to jump between two electrodes was affected by ultraviolet light, the advent of the first commercial solar water heater, and the discovery of additional photosensitive materials (U.S. Department of Energy, 2008). According to Swanson (2008), the first phase of solar power began with the creation of single crystal, single-layer junction diode silicon wafer on solar cells. These solar cells proved to be the start of an emerging sustainable power generation. The unlimited supply of energy from the sun, along with minimal emissions and negligible environmental impacts, makes photovoltaics an ideal choice. A direct relationship between energy consumption and solar energy production is in place. In countries like Cyprus and Israel, where annual temperatures are relatively high, electricity use is dominated by air conditioning. The abundance of solar radiation, together with a good technological base, has created favorable conditions for the exploitation of solar energy on the island of Cyprus. This has led to the development of a pioneering solar-collector industry, which in the mid-1980s was flourishing and resulted in outstanding installed solar collector area per inhabitant ratios (Kalogirou et al., 2006). Nowadays, Cyprus is cited as the country with the highest solar collector area installed per inhabitant worldwide (Kalogirou et al., 2006). A positive correlation, therefore, between sun intensity and electricity production, is needed to satisfy energy needs. Solar panels produce more electricity and are more efficient when sun intensity is high and can therefore provide a solution to the energy problem. Along with Cyprus, several other countries are using solar power to cut the cost of electricity. In Germany, government funding of the purchase and installation of PV Solar Panels can bring the cost down from $8/watt to $4/watt. Government- and utility-sponsored solar power rate tariffs can bring the power cost down from 20¢ per kWh to 10¢-12¢ per kWh (Solarbuzz, 2008). A solar panel with these incentives can have a rate of return of 5 to 7 years.

Historical Background

In 1905 Albert Einstein, during the process of explaining the nature of existence and the universe, developed his theory of relativity. This was published in a paper on the photoelectric effect. The scientific explanation for the fact that light can be converted directly into electricity was also provided by Albert Einstein in 1905. His essay on the law of the "photoelectric effect" supplied the foundation for modern photovoltaics. This advancement in solar power technology enabled William J. Bailey of the Carnegie Steel Company to invent a solar collector with copper coils and an insulated box, which is roughly the same design used for solar panels today. Einstein's many philosophical and scientific advancements, including the photoelectric effect, earned him the Nobel Prize in 1921. Like other innovations developed as a result of Albert Einstein's publications, solar technologies such as passive solar buildings were much in demand during World War II due to an emerging energy crisis (U.S. Department of Energy, 2008).

Photovoltaic technology was born in the United States in 1954 when Daryl Chapin, Calvin Fuller, and Gerald Pearson developed the silicon photovoltaic cell at Bell Labs—the first solar cell capable of converting enough of the sun's energy into power to run everyday electrical equipment (DOE, 1993).

Starting with 4% efficiency and later with 11%, Bell Telephone Laboratories produced a silicon solar cell. Even though the discovery was beneficial, its prohibitive cost kept it out of the electrical power market. Anxious to find commercial outlets for solar cells, novelty items such as toys and radios run by solar cells were manufactured and sold (DOE & EERE, 2006). Even though the technical progress of silicon solar cells continued at rapid speed—doubling their efficiency in eighteen months—commercial success eluded the Bell solar cell. Even though the invention was exciting, the cost was still too high and inefficient for most consumers, as a one-watt cell cost almost $300, while a commercial power plant cost 50 cents a watt to build at that time (DOE & EPA, 2009).

Regardless of the solar cell's success in powering both American and Soviet satellites during the 1950s and early 1960s, many at NASA doubted the technology's ability to power its more ambitious space ventures (NASA, 2009).

NASA viewed solar cells as merely a stopgap measure until nuclear power systems became available. Later, solar engineers proved the skeptics wrong by meeting the increasing power demands and by designing ever larger and more powerful solar cell arrays (NASA, 2009).

Photovoltaic (PV)

At first, photovoltaics remained an expensive form of technology used only for special applications. But then the oil crisis in 1973 and the Chernobyl reactor catastrophe in 1986 spurred the search for new, regenerative sources of energy. This need has resurfaced again today, with the current shortage of fossil fuels and the worldwide demand for green technologies. Solar cells offer an attractive source of power for many reasons, most importantly to reduce dependence on fossil fuels, to preserve the earth, and to increase financial efficiency (Evans, et al., 2008). The process of purifying silicon has decreased over the years mainly because fossil fuel is the predominant source of energy; however, researchers continue to look for means of alternative energy with solar technology that combines low cost and high working performance to satisfy the required demand. Nanotechnologies and organic materials integrated into solar cells are believed by many to be the answer in solar technological advancement. For the last twenty years researchers have been experimenting with laboratory prototypes made out of organic cells that would improve the source of energy and lead into light-producing prototypes (Cunningham, 2007).

Nuclear energy, in contrast, never powered more than a handful of satellites. The increasing demand for solar cells in space opened an increasing and relatively large business for those manufacturing solar cells. Even more significantly, our past, present, and future application of space research would have been impossible if not for solar cells, and the telecommunication revolution would never have gotten off the ground if not for solar-powered satellites.

Even though the concept of collecting the sun's rays and using them as a source of energy was in the minds of many scientists for thousands of years, the solar collector became the fundamental basis of the modern flat-panel collector. Currently the design for photocells is much the same as William Bailey's solar collector design. Silicon is infused with two materials that create an electric field in the cell. When light strikes the cell, its energy frees electrons within the silicon. Driven by the electric field, the electrons travel to an electrode and thence into an electric circuit. As early as 1958, the first satellite fitted with a photovoltaic energy device was launched into space. When NASA sent Mariner 4 to take a closer look at Mars and capture some images, it was proven without any doubt that Mars wasn't covered with water-filled canals. Mariner managed to produce just 21 images showing a barren surface, pockmarked with numerous craters. This was an amazing discovery; it was not, however, the empowerment of the sophisticated camera to capture the breathtaking images made all things possible: The 1.3 meter probe was powered by 28,224 solar cells in four solar panels, providing 310 Watts when it passed Mars. Without the use of solar energy it would have been impossible to complete this mission (NASA, 2004). Today, energy supplied by photovoltaic modules is standard for spacecraft and the International Space Station (Photo 2).

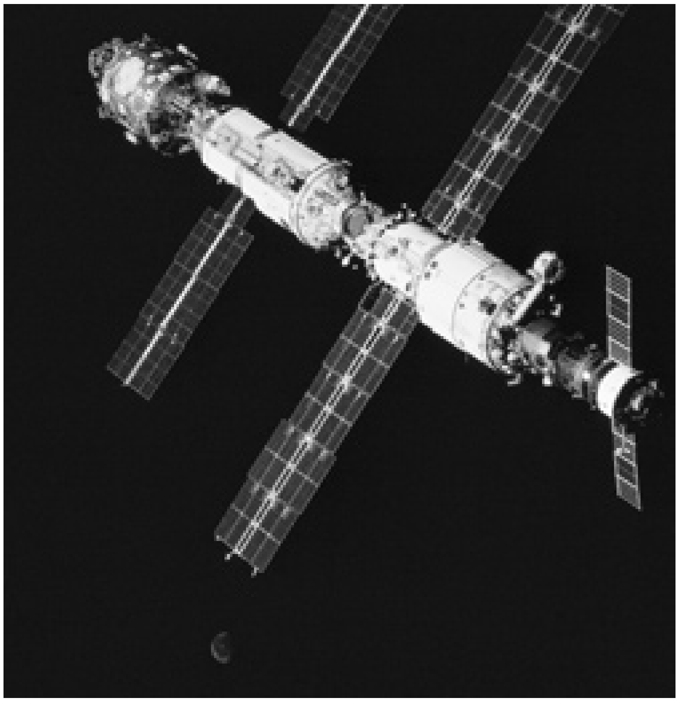

Photo 2. The STS-106 crew members captured this view of the International Space Station (ISS) showing the darkness of space in the background and the multiple PV arrays. The International Space Station makes extensive use of solar arrays to generate electrical energy to maintain the operational status of the ISS, the ongoing experiments, and the crew. (Courtesy of NASA)

Different Types of Photovoltaic Manufacturing Processes

There are three main types of photovoltaic manufacturing processes used in the market: monocrystalline, poly-crystalline, and amorphous. Monocrystalline is the process of refining silicon into cylindrical metal molds using a specific process (Polar Power, 2008), which is a crystalline growth method. The cylindrical mold is then sliced into burn cell disks, called wafers, and applied to the array. The benefit is a 25% efficiency rating, which is the highest possible for silicon due to its form (Seale, 2003). The largest drawbacks are the expense and difficulty in obtaining the wafer. Additionally, there are issues with circular cells on a square array, causing a reduced square footage per panel. This led to the development of polycrystalline disks. They're made through a similar process, but one that uses less refined methods. Instead of creating a single large ingot using an expensive crystalline growth method, Poly-Si uses molten silicon and cools it carefully to create square ingots (Seale, 2003).

The final method, called amorphous silicon, or "ribbon technology," is the process of using molten silicon and drawing it, or applying it, in a thin coat straight onto a cheaper surface. This process reduces waste, sometimes upwards of 20%, during the cutting of the silicon ingots (DOE & EERE, 2005). Again, the less refined process does result in lower efficiencies, but the reduction in production costs makes this an excellent competitor (Seale, 2003). As a note, according to National Renewable Energy Laboratory (NREL), the typical commercial solar cell in today's market has an efficiency of 15% (NREL, 2007).

The two greatest advantages being explored now are amorphous silicon's ability to be applied onto flexible surfaces and in specific shapes. Many of the flexible thin film products that are emerging are also made to be very resilient. These products can be handled very carelessly—they can be dropped, thrown, or stepped on with little or no damage. This fact reduces the shipping costs of the product dramatically. Beyond that, installation costs will drop since labor can be less skilled and the chance for damage is low. Many companies are using these resilient materials and producing roof shingles that match the style and look of traditional masonry shingles.

Summary

With the future development of solar technology, a practical renewable energy source could become largely available for commercial and private use that is both earth-friendly and economical. Researchers are developing ways of improving the collection of the sun's rays as solar energy becomes an unlimited resource for the sustainability of energy for Earth. "Compared to using land for bioenergy cultivation and consecutive conversion to electricity, or worse, biofuel for internal combustion engines and transport, solar cells are incredibly area efficient" (Sanden, 2008). Solar-empowered energy is one of the most abundant resources. The possibilities are endless because the sun reaches every geographical part of Earth indiscriminately. Although solar technology has advanced, there is still plenty of room for expansion. If the sun shines, solar systems will work.

Design and Technology

Humans have used the energy of the sun for thousands of years. The sun's energy has been used for warmth, for agricultural purposes, and also for processing materials used for building structures and pottery. Today, in many parts of the world, solar energy is being used the same as it has been for thousands of years!

Today it is common to think of solar energy as an alternative energy. However it has the potential to be a significant source of energy that can complement other alternative energy sources such as wind and geothermal as well as fossil fuels, nuclear, and hydroelectric energy resources.

Growing concern over climate change and global warming, along with governmental incentives and regulations, has fostered a renewed interest in solar energy resources. Additionally, photovoltaic energy technologies are experiencing rapid growth because of rapidly escalating fossil fuel demand and prices. While the price of fossil fuel and petroleum may rise and fall, they are still considered nonrenewable energy resources.

As we travel the highways and coastal waters, we can see many applications of photovoltaic technologies used in road signs, crossing markers, and traffic survey instruments. Additionally, we see photovoltaic technologies integrated with flashing marker buoys on inland and coastal waterways. PV power technologies are used for lighting, pumping water, operating ventilation fans, and many other activities that require electrical power. Typically these types of PV technologies employ photovoltaic cells that incorporate charging circuits to recharge batteries that power the devices.

Increasingly we are seeing photovoltaic technologies being incorporated in green or environmentally friendly business and residential installations. Currently, many localities and power stations allow consumers to generate electricity that contributes to the local power grid. These are called "grid-connected" systems. Generally we do not see many of these installations in city areas because of the cost and accessibility of electricity. However, in remote locations where there is no convenient access to electrical power distribution, stand-alone PV systems become very attractive (Arizona Solar Center).

As we look more closely at photovoltaic technologies, we can see that photovoltaic energy has many advantages. PV electricity is reliable, costs little to install and operate, has very little environmental impact, and it is produced domestically—thus creating jobs, research initiatives, and reducing energy imports (*Why PV is Important*, U.S. Department of Energy). Photovoltaic cells, unlike other sources of energy, generate electricity directly and do not need an intermediate step for conversion to a useful form. It should be noted that PV cells generate direct current (DC) and require an inverter (AC) to be useful with home appliances and must be grid-connected with a utility company.

The basic building block is the photovoltaic cell. Photovoltaic cells are connected together to increase the voltage and current-generating capabilities. PV cells that are connected together are called modules, and groups of modules may be connected together to form arrays. PV modules are generally small in size, ranging from several square inches to a number of square feet or meters and producing a few watts to several hundred watts. PV arrays are much larger and are capable of producing larger quantities of power in the kilowatt range. Arrays frequently are fixed installations but some may incorporate tracking technologies (*Technologies*, U.S. Department of Energy).

Research and Design Project

Photovoltaic modules may be installed with a fixed orientation to the sun based on geographic location and season. They also may be installed with a system that will track the sun and its path across the horizon. Generally, very large PV solar arrays will be designed, constructed, and installed for fixed-position operation. However, this is not always the case, as large arrays may also incorporate tracking systems.

Fixed arrays require little maintenance and adjustment after installation. As we consider tracking systems, it is necessary to consider a number of factors in their design and construction. The tracking mechanism must be capable of supporting the solar PV array and moving the array as necessary. Additionally, the tracking mechanism must be capable of tracking the sun and making the necessary adjustments to maintain its orientation for the maximum sunlight. However, there are times when the sun is obstructed by clouds or there is no sun at all, such as at night, and the tracking system must also accommodate these variables.

As we consider fixed-PV modules in comparison with those modules with tracking technology, we may ask which system will produce the most power. We also could consider any efficiency differences between the two systems and what the benefits may be.

The first task would be to address two research questions. The first question would be to determine which type of photovoltaic installation may produce the highest average power over a given period of time. Second, which of the two installations would be the most efficient in generating electricity?

Optionally, a second task can be included to design and construct an automated tracking system for one of the solar arrays.

Technology, Materials, and Concepts

As you can see from Photo 3, the photovoltaic station is a fixed mount and support design, whereas Photo 4 shows a tracking photovoltaic station. The orientation of the modules in our experiment was a Southerly direction. Solar panels should be oriented true South in the Northern Hemisphere. Typically panels or modules are tilted horizontally at a degree setting equal to the latitude plus 15 degrees in winter. During the summer subtract 15 degrees. A solar array orientation map is helpful in adjusting your

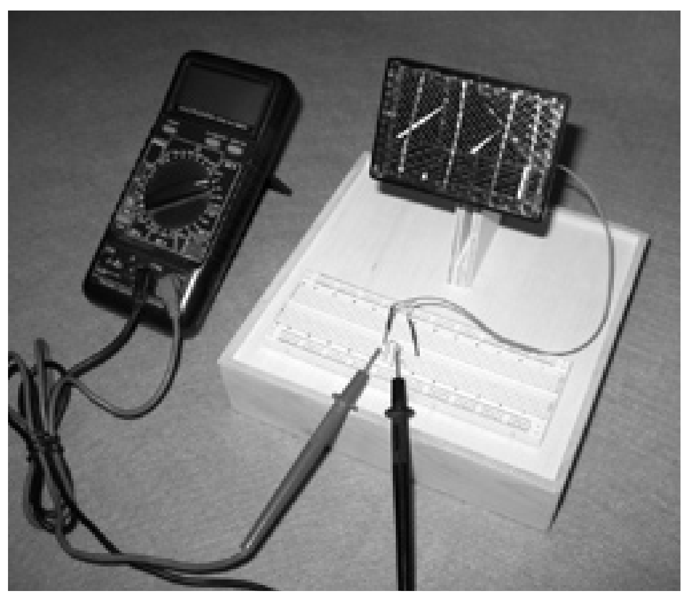

Photo 3. A fixed orientation photovoltaic module as shown is simply mounted on an adjustable base that can be positioned toward the sun. The position is determined by the geographic location and the season of the year.

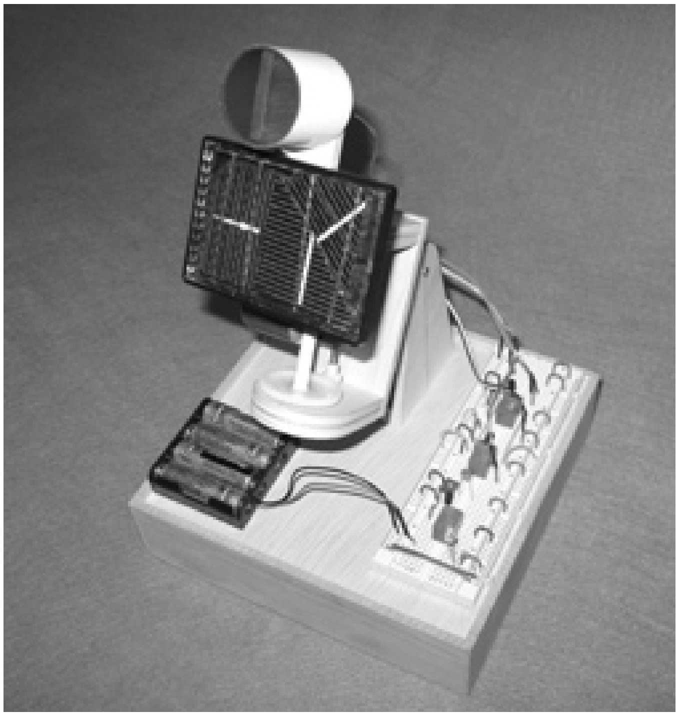

Photo 4. The photovoltaic module shown here illustrates the tracking concept using a pair of SPDP relays and a gear motor drive. Photoresistive cells are mounted in a plastic tube with a divider in the middle. As the sun moves across the horizon, it will cast a shadow on one of the photoresistive cells. This turns on the motor briefly until both cells are in full sun.

PV modules for the most efficient placement according to your location. There are a number of solar array orientation maps accessible on the Internet. The tracking PV module also faces South and is oriented the same as the fixed unit, but has the capability to track the sun across the horizon. The tracking movement for the tracking PV module can be accomplished several ways. The simplest method is to periodically move the PV module manually. A time chart can be prepared as part of the data being collected, where the voltage and current of each system is measured and recorded. Accordingly, the "tracking" module can be moved every 60 minutes during the testing and data-collection period.

The tracking control circuit consists of two 5-volt SPDT relays with transistor drivers, a pair of cadmium sulfide photoresistive cells. The photoresistive cells are placed in a "shadow housing" so that the tracking motor will move the solar module toward the brightest direction of the sun. A third photoresistive cell and relay are used to turn the system off at night or on cloudy days. The parts for this activity are readily available at electronic parts suppliers or school supply firms. This same activity can be constructed using LEGO Mindstorm™ or LEGO NXT™ materials using the RCX controller, revolution counter, and light sensor, or other construction materials.

Defining the data collection process and parameters is an important part of the experiment. The data collected would typically be in open-circuit voltage measurements. Voltage and current under a load (in this experiment a 100 Ohm resistor was used as the load) and the power generated (voltage X current) under load. The efficiency is normally expressed as a percentage and can be calculated using the formula that is based on the amount of energy produced divided by the energy that could have been produced times 100. Observations and generalization can be made about the power and efficiency of each of the PV systems by consulting a solar radiation chart like the one shown on page 17. The data can be analyzed and a technical report prepared and presented to the class that describes the results using a spreadsheet and graphs.

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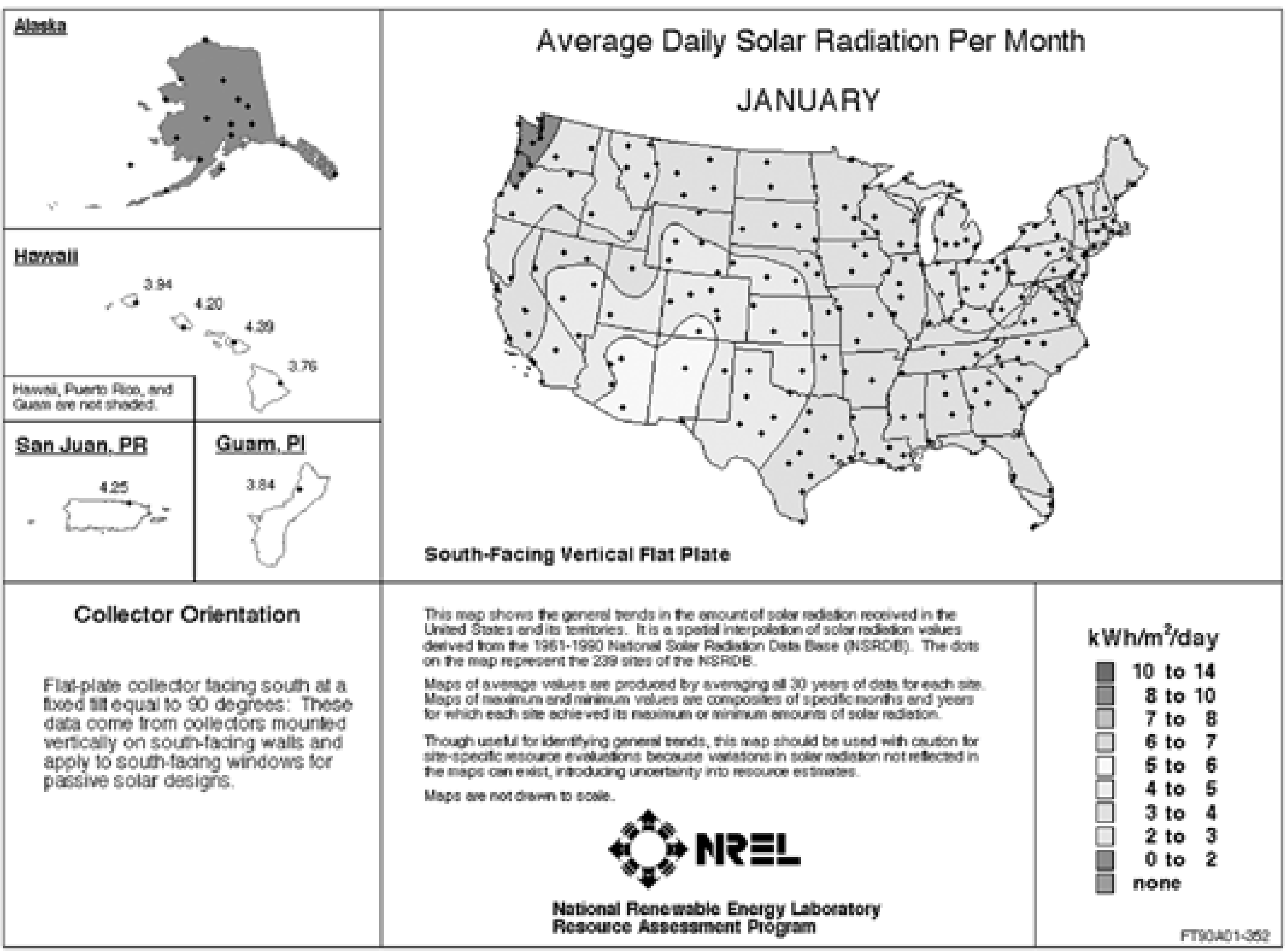

The National Renewable Energy Laboratory Research Assessment Program (NREL) chart shows the average daily solar radiation in kilowatts per square meter per month. This chart shows that the average solar radiation can vary from 0-2 kilowatts per square meter to as much as 10 kilowatts per square meter with a flat-panel collector. This kind of information can be helpful in our data collection and analysis.

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