Photovoltaics

From Appropedia

(Redirected from Photovoltaic)

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Introduction

Every day across the globe, the sun shines down on the earth. The energy in the photons from the sun can be converted to electrical energy. The term for this process is the ´Photovoltaic Effect´.

Since the first commercially available solar panel in the 1960´s, photovoltaic (PV) technology has continued to be explored and developed throughout the world (Pratt & Schaeffer 51). The constant development of this technology has resulted in an increasing level of efficiency and PV panels that are more affordable than ever before, though still initially expensive. Today, humans continue to search for new ways to make photovoltaic technology a viable option for everyone throughout the world. Since most of us are not studying the atomic level of this technology, we can help in other ways - by gaining an understanding and spreading that understanding of photovoltaics, as well as by helping others to gain access to solar, or photovoltaic, systems.

This article explores the components of a photovoltaic system, describes their role and importance, and works as a beginning guide to those wishing to invest in a photovoltaic system.

Photovoltaic System Components

Cell
: Thin squares, discs, or films of semiconducting material which generate voltage and current when exposed to sunlight.

Panel or Module
: Configuration of PV cells laminated between a clear superstrate (glazing) and an encapsulating substrate.

Array
: One or more panels wired together at a specific voltage.

Charge Controller
: Regulates battery voltage and controls the charging rate, or the state of charge, for batteries.

Deep-Cycle Battery
: Type of battery (Direct Current electrical energy storage device) that can be discharged to a large fraction of capacity many times without damaging the battery.

Inverter
: Changes direct current (DC) to alternating current (AC).

Load
: Any electrical component within a circuit that draws power from that circuit.
Most loads can be turned on and off, such as a lightbulb or a refigerator.
Loads are either AC or DC.

Circuit Breakers and Fuses
: The two types of overcurrent protection.
When a current exceeds a circuit breaker or fuse´s rated amperage, the circuit opens and stops all current flow. When a fuse has "blown", it must be replaced while a circuit breaker must be reset.

Disconnects
: A switch gear used to connect or disconnect components of a PV system for safety or when maintanace is needed.

A circuit breaker can be used as a type of disconnect.

Meter
: A gauge that allows you to see from where you are pulling your power, and how much power is being drawn from the loads.

Solar Site Analysis

Solar Radiation

When the sun hits the earth at a particular time and place, it is called INSOLATION. Insolation can be described as power density, and is expressed as watts per meter squared (W/m^2) and, in PV, is often presented as average daily values per month. We receive 1,000 W/m^2 when we have 100% full sun insolation. (Pratt & Schaeffer 56).

When analyzing a site to install a PV system, it is important to know which month has the lowest and highest rates of insolation, or the lowest and highest average amount of sun that particular site will receive in that month. This information will be important when you are trying to determine the tilt angle of your PV array. Considering all of the months that you will be utilizing your pv operation, it is best to know the daily insolation, or average hours per day of full sun, for the worst weather month of the year. The insolation data will allow you to find an angle that is most appropriate, allowing your panel to sit at an angle that will provide the highest potential for power to your system.

Peak Sun Hours

Peak sun hours is the number of hours during one day when full sun is available.

Solar Noon

Solar noon refers to the time during the day when the sun is the highest in the sky; it is the moment when the sun is the strongest. To find Solar Noon, calculate the length of the day from sunrise to sunset and divide by two.

Gathering Site Data

Solar Insolation Data

Determine which month has the least amount of sun on average. This is the month that you want to use if you are building a system that will be used year-round. (if you are only going to be using it for summer or winter, find month with least sun during months that you will use the system.)

PV Array Location

Sun/Clouds: It is important to estimate the sun availability and cloud cover. Sometimes you can obtain this information on the web if it is a large enough town.

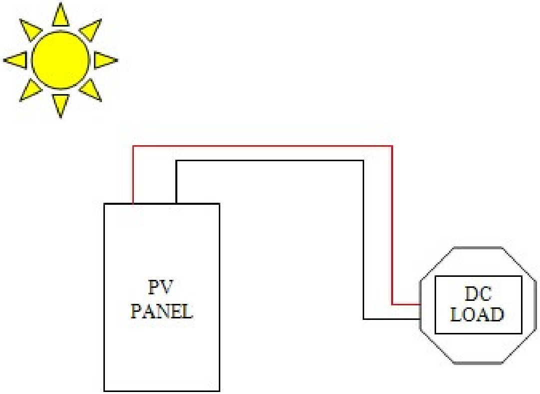
Shade: You want to choose a location that is on or near the place where you loads will be. The MOST IMPORTANT thing to consider when choosing a location for your Array is shading obstacles. Shade covering just one PV cell can reduce the current dramatically. A small amount of shade covering the panel can reduce the panel performance by 80%. As a general rule, the array should be free of shade (during each month in use) from 9am to 3pm. This is the optimum timeframe a panel has to receive light and is called the Solar Window.

PV Module

A Photovoltaic panel can be directly wired to a DC Load if the load is needed only when there is sun, and the load is not sensitive to large voltage fluctuations.

Examples include:

- A greenhouse fan - this is a load that will serve to cool down the greenhouse during the day. The more direct sunlight there is, the more the load will be working and compensating for the heat within the greenhouse.
- A waterpump - this is a load that does not need to be operational at specific times, and hence, is only operating when there is enough sunlight to power the pump.



Batteries

Batteries are required for any system that needs some sort of storage capacity. If you will be using your system at times when there may not be sunlight available, a battery will store the energy from the pv array in order to power the loads at a later time.

Pv 2 battery.JPG

Purpose/Importance

- Batteries allow you to store energy directly from the energy generated by the PV Array.
- Batteries store DC energy and allow you to utilize the energy during the night, when there is not a sufficient amount of sunlight, or when there is a blackout (if you are connected to the grid).
- Batteries are an extremely important power supply for critical electrical loads that consistantly require usage. If you are wishing to power a load only during the day, a battery may not be required, i.e. to power a fan on sunny days inside of a greenhouse. Utility grid-connected pv systems do not require the use of batteries,

though they can be used as an emergency backup power supply.

Days of Autonomy

- Autonomy refers to the number of days a battery system will provide a given load without being recharged by the pv array or another source.
- General weather conditions determine the number of "no sun" days, which is a large variable when determining autonomy.
- The general range of autonomy is as follows:
  - 2 to 3 days for non-essential uses or systems with a back-up power supply.
  - 5 to 7 for critical loads with no other power source.

Battery Capacity (AH)

- Batteries are rated by amp-hour (AH) capacity. The capacity is referring to how much energy that particular battery is capable of storing. The capacity of the battery needs to be capable of supplying energy to the load. It is necessary to factor in the days of autonomy in order to determine how much storage capacity is required of your battery. The AH will tell you how many amps you can pull from the battery in one hour.
- If more storage capacity is required for the pv system than one battery is capable of supplying, batteries can be wired in parallel to add additional storage capacity. Higher voltages are obtained through series wiring.
- Initially, the battery capacity should be slightly larger than is required by the load because the batteries will lose capacity as they age. But if you greatly oversize the

battery bank, it may remain at a state of partial charge during periods of reduced insolation - ultimately shortening the battery life. Determine the battery based on the size of your load.
- The AH capacity will be listed on the battery.

Rate and Depth of Discharge

- A battery is charging when energy is being put in and discharging when energy is being taken out. One cycle is considered one charge-discharge sequence, which often occurs over a period of one day.
- The rate at which the battery is discharged directly affects it capacity. The faster the discharge, the lower the capacity. The slower the discharge, the larger the capacity.
- The discharge rate refers to period of time at which the battery discharge was tested. For a battery rated at C/20, the discharge C (in Ah) was reached after 20 hours of discharge. For instance a 220 Ah battery, rated at 220Ah/20 would be discharged for 20 hours at 11 Amps continuously.
- Depth of Discharge (DOD) refers to how much capacity can be withdrawn from a battery. Most PV system batteries are designed for regular discharges of 40 to 80 percent. Battery life is directly related to how deep the battery is cycled; the shallower the cycle, the longer the life span.

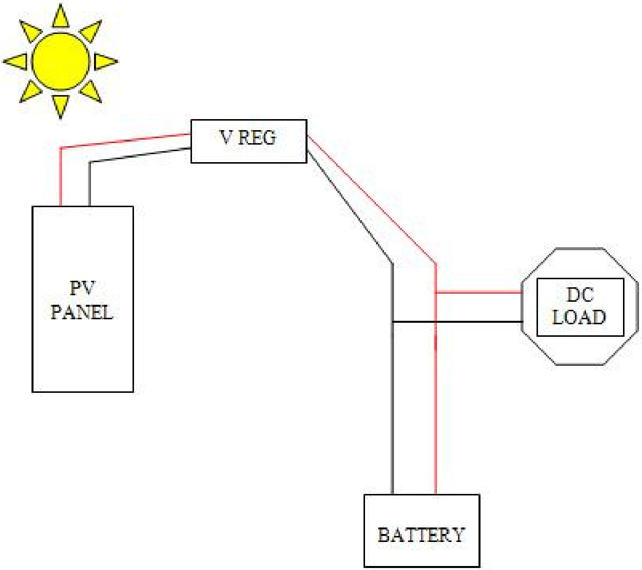
Environmental Conditions and Battery Sizing

- It may be unreasonable to size a battery system that would be capable of providing power during extreme weather conditions, such as three to four weeks without sun.

Hence, it may be a better option to size the system according to the average number of cloudy days or to create a design with a hybrid approach adding in a generator or a wind turbine.

- Battery capacity decreases at lower temperatures while battery life increases.
- When sizing a battery, you can compensate for the effects of temperature by using a battery temperature multiplier. Multiply the battery capacity needed by the battery temperature multiplier.

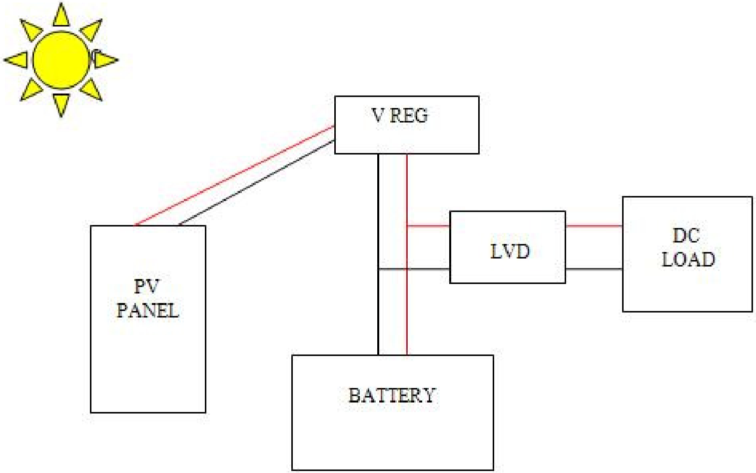
Voltage Regulator



Purpose/Importance

The Voltage Regulator prevents the pv panel from overcharging the battery by regulating the voltage to always be below a certain limit. The battery will specify that it cannot continue to accept current past a certain charge. The voltage regulator lowers the current as it reaches closer to this limit in order to lessen the amount of current charging the battery.

Low Voltage Disconnect



Purpose/Importance

- A Low Voltage Disconnect prevents the battery from discharging too deeply.
- (LVD) is a feature that can disconnect DC loads from the battery so that is does not discharge to the point of damage.
- If batteries are being discharged to a low level, a controller can shut off the current flowing from the battery to the DC load.
- The LVD must be capable of handling the maximum amperage, or load current.

Lights or Buzzers on a controller can be used for critical DC loads instead of the LVD. This is important for appliances such as refrigerators that must not be cut off from a power supply without proper warning.

Meters

METER.JPG

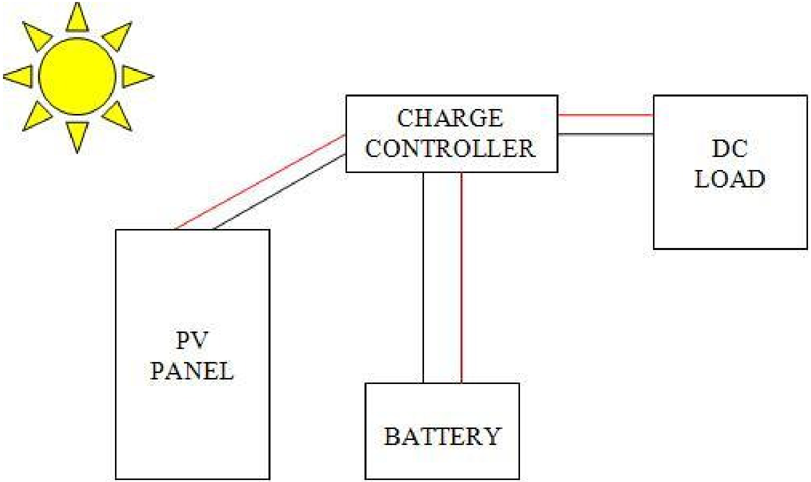
Purpose/Importance

A meter acts as a gauge that informs you of where you are pulling your power from, and how much power is being drawn at any given moment.

Volt Meter

- Battery Voltage (state of charge)
- Panel Voltage, Current, Power and Total Energy produced over a certain period
- Load Power and Total Energy used over a certain period

Charge Controller

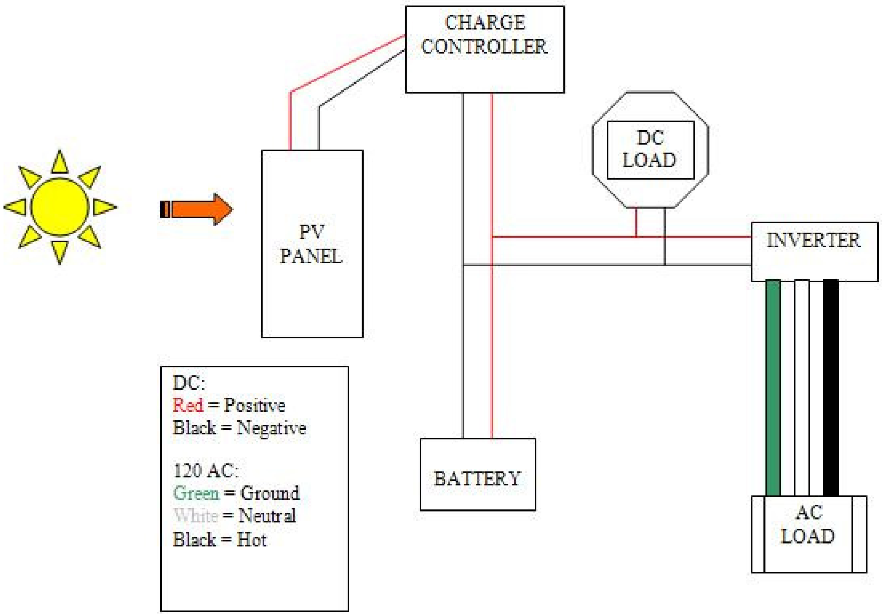


Purpose/Importance

- The charge controller functions as a voltage regulator. The main function of a controller is to prevent the battery from being overcharged by the pv array.
- The charge controller is capable of sensing a battery´s current state of voltage. When a battery is fully charged, the controller will either stop or slow down the amount of current flowing into the battery from the pv array.
- Charge controllers come in different sizes and must match the pv system voltage.
- The controller must also be able to handle the maximum pv array current flowing through the controller at any given moment.

Inverter

Inverters convert DC to AC. To power any AC Loads, the current must be converted via an inverter.



Purpose/Importance

- Photovoltaic modules generate only DC power. Batteries can store only DC power. An inverter is used as a "bridge" which converts DC electricity into AC electricity.
- AC is easier to transport over long distances, this is an important component for many pv systems.
- AC appliances have become the conventional modern electrical standard, inverters

are necessary to power any type of AC load.

Watts Output

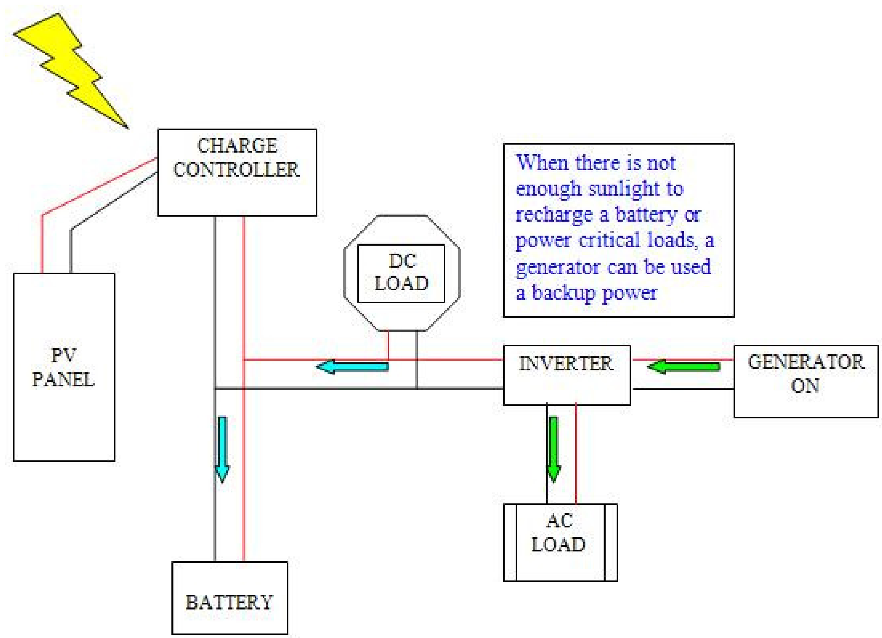
- This indicates how many watts the inverter can supply during standard operation.
- Choose an inverter that can handle the system´s peak AC load requirements.

Voltage Input or Battery Voltage

- This indicates the DC input voltage that the inverter requires to run - usually 12, 24, or 48 volts.
- The inverter input voltage must match the nominal pv system voltage.

Generator

A Generator is an optional alternative source to a power supply for those needing extra assurance that there will be power available to their system in times of need.



- Generators may be AC or DC.
- The diagram above shows how an AC generator can be wired through the inverter to supply DC power to the battery and DC loads. There are only specific inverters that are capable of operating in this way.
- DC generators can be directly wired to through the charge controller to supply the entire system.

Wiring

Color Coding

Color Coding of Wire	
DC Wiring	**120 AC Wiring**
Red = Positive	Black = Hot
Black = Negative	White = Neutral
	Green or Copper = Ground

Wire Size

- Ampacity: The current carrying ability of a wire. Hence, the larger the wire, the more capacity it has to carry current.
- Voltage Drop: The loss of voltage due to a wire´s resistance and length.
- Wire sizing must be based on the maximum current through and length of the wiring.

Overcurrent Protection

Operating too many loads at once or faulty wiring will cause a fuse failure, which protects the wires and systems from damaging by integrating overcurrent protection into the system.

Fuses

- Fuses consist of a wire or metal strip that will burn through when a predetermined maximum current passes throughthe fuse, which opens up the circuit to protect wires from damaging.

Circuit Breakers

- Circuit Breakers, unlike fuses, do not need to be replaced. When the current exceeds a circuit breaker´s rated amperage, the circuit opens and stops the current flow.

Disconnects

- Every component in the system must be capable of disconnecting from all sources of power. Disconnects can be switched fuses or circuit breakers.

Grounding

- To ground a wire means to connect to the earth or to some conducting body that serves as the earth.
- Grounding limits voltages due to lightning, line surges or unintentional contact with higher voltage lines.
- Grounding stabilizes voltages.

- Grounding equipment provides some protection from shock.

Sizing a PV System

To size your system requires seven main steps:

1. Estimating your electrical load
2. Estimating solar energy available
3. Sizing an array
4. Sizing batteries
5. Specifying a controller
6. Sizing an inverter
7. Sizing system wiring and switches

These worksheets (http://www.sandia.gov/pv/docs/Wkshts1-5.html) from Sandia Labs (http://www.sandia.gov/) will lead you through the first four steps, and these (http://www.sandia.gov/pv/docs/Wkshts6-9.html) will lead you through the last three steps. Here is an example AC/DC residence design (http://www.sandia.gov/pv/docs/ResidenceSize.html#AnchorAC/DC) .

You can also refer to Photovoltaics: Design and Installation Manuel, by SCI.

For more detailed PV systems desing it may be useful to use a Solar photovoltaic software simulation program such as RETScreen.

Advantages of Photovoltaic Technology

Photovoltaic technology holds a number of unique advantages over conventional power-generating technologies. PV systems can be designed for a variety of applications and operational requirements, and can be used for either centralized or distributed power generation. PV systems have no moving parts, are modular, easily expandable and even transportable in some cases. Sunlight is free, and no noise or pollution is created from operating PV systems. PV panels do not require the use of fossil fuels such as coal, oil or natural gas in the energy production process. Alternatively, conventional fuel sources have created an array of environmental problems, namely global warming, acid rain, smog, water pollution, rapidly filling waste disposal sites, destruction of habitat from oil spills, and the loss of natural resources (Solar Energy International 2004). PV modules use silicon as their main component. The silicon cells manufactured from one ton of sand produce as much electricity as burning 500,000 tons of coal (Solar Energy International 2004). PV systems that are well designed and properly installed require minimal maintenance and have long service lifetimes. If properly maintained [1](cleaned and protected), pv panels can last up to thirty years or longer. Other aspects of the system, such as the battery, have much shorter life spans and may need to be replaced after several years of use. Solar Energy International (2004) indicates that there are many other benefits to consider when choosing photovoltaic technology:

- **Reliability**: Even under the harshest of conditions, PV systems maintain electrical power supply. In comparison, conventional technologies often fail to supply power in the most critical of times.
- **Durability**: In general modules are carry a warranty of 80% of their rated power for

20 or more years. Thus the worst case is an expected 1% decrease in performance per year. There have been several studies showing even less degradation than this at around 0.2%/year. PV modules produce more energy in their lifetime than it takes to produce them.[2]

- **Low Maintenance Cost**: PV systems do not require frequent inspection or maintenance. Transporting supplies may get costly, but these costs are usually less than with conventional systems.
- **No Fuel Cost**: Since there is no fuel source, there is no required expenditure on the purchasing, storing, or transporting fuel.
- **Reduced Sound Pollution**: PV systems operate silently and with minimal movement.
- **Photovoltaic Modularity**: Unlike conventional systems, modules may be added to photovoltaic systems to increase available power.
- **Safety**: PV systems do not require the use of combustible fuels, and are very safe when properly designed and installed.
- **Independence**: PV systems may operate independent of grid systems. This is a large advantage for rural communities in nations lacking basic infrastructure.
- **Electrical Grid Decentralization**: Small-scale decentralized power stations reduce the possibility of power outages, which are often frequent on the electric grid. See:Distributed generation
- **High Altitude Performance**: When using solar energy, power output is optimized at higher elevations. This is very advantageous for high altitude, isolated communities where diesel generators must be de-rated due to the loss in efficiency and power output.

Disadvantages of Photovoltaic Technology

Solar energy is a fairly inexhaustible source of energy, but that does not necessarily translate to PV being the same. PV systems are:

- **Expensive**- Very high initial cost. System components are expensive to replace. The cost of a typical PV system in the U.S. is running between $5 and $10 per WP[3] To power a typical US home with a 5kW system thus costs between $25,000 and $50,000. For more efficient homes and those that have more modest electric loads (e.g a few high efficiency CFLs) the costs are considerably less. For current prices on PV see http://www.solarbuzz.com/. A recent shortage in solar grade silicon halted the decades long reduction in cost as manufacturing capacity increased. The trend in costs decreasing is being restored as more solar grade silicon[W] plants come online. In addition, as truly large scale manufacturing utilizing industrial symbiosis is initiated solar PV is slated to be cost competitive with grid provided electricity.[4].
- **High Tech**- Require a skilled labor force to create, although operation and maintenance of PV cells themselves is relatively easy. There are currently no good methods for people to make their own PV systems from local materials. The high tech nature gives a large advantage to scale of production with current technologies.
- **Some PV materials are toxic**. E.g. the Cadmium in Cadmium Telluride solar cells. Many authors have argued that in the panel itself the Cd is secure from the environment -- but then it demands careful end of life treatment.
- **Intermittent**- Solar cells only produce electricity when the sun is shining. At night or in bad weather, you need either storage batteries or a secondary power source. (On

the other hand, solar panels are excellent for load balancing because maximum electricity usage and peak solar generation both occur on hot sunny days.)

There are two disadvantages often used in the environmentalist camps concerning high tech PV:

- **Production Pollution**- Fossil fuels are extensively utilized to extract, produce and transport PV panels. These processes also entail corresponding sources of pollution. This is true of just about any product made today. Fortunately, the life cycle analysis of a PV system is a net positive for the environment because it can offset fossil fuel energy production over its approximately 25+ year lifetime.
- **High energy cost**- Require much energy to produce. In the past it was even argued that it took more energy to produce than they consume. This is just wrong. [5] In this paper the authors clearly show that the three types of photovoltaic (PV) materials, which make up the majority of the active solar market: **single crystal, polycrystalline, and amorphous silicon solar cells pay for themselves in terms of energy in a few years (1-5 years)**. They thus generate enough energy over their lifetimes to reproduce themselves many times (6-31 reproductions)depending on what type of material, balance of system, and the geographic location of the system.

Education about Solar Photovoltaic Cells

- Solar Photovoltaic Open Lectures

- Solar Power Naturally in the classroom (http://www.powernaturally.org/Programs/SchoolPowerNaturally/InTheClassroom/de - The curricular materials created for the School Power...Naturally program include 64 lessons that meet learning standards for New York State students in grades 5 through 12.
- A paper about harnessing the green purchasing power of universities to catalyze solar photovoltaic economies of scale: Joshua M. Pearce, “Catalyzing Mass Production of Solar Photovoltaic Cells Using University Driven Green Purchasing (http://www.emeraldinsight.com/10.1108/14676370610702226) ”, International Journal of Sustainability in Higher Education, 7(4), pp. 425 – 436, 2006.
- Solar Power Beginner (http://www.solarpowerbeginner.com/) - An online resource that provides a basic understanding of photovoltaics and how they work. Features information on crystalline and thin-film solar panels as well as interviews with experts in the field.

See also

- Solar-charged vehicle

Interwiki links

- Wikipedia:Photovoltaics

External links

Web sites for current information on PV

- Solar Buzz (http://www.solarbuzz.com/)
- PV Portal (http://www.pvportal.com/)
- Solar Access (http://www.solaraccess.com/)
- Home Power Magazine (http://www.homepower.com/)
- Photovoltaics World (http://www.pvworld.com/index.html)
- PV Tech (http://www.pv-tech.org/)
- Thin Film Today (http://social.thinfilmtoday.com/index.php)
- pvXchange (http://www.pvxchange.com/en/index.php/index.html)

Current production: 10.7GW in 2009 [4] (http://www.electroiq.com/index/display/photovoltaics-article-display/8084204276/articles/Photovoltaics-World/industry-news/2010/september/solar-cell_production.html?cmpid=$EnlEIQDailySeptember272010)

Useful government web sites on PV

- U.S. Department of Energy Photovoltaics Program (http://www.eere.energy.gov/solar/)
- National Center for Photovoltaics (http://www.nrel.gov/ncpv)

- Sandia National Laboratories (http://www.sandia.gov/pv)
- Million Solar Roofs (http://www.millionsolarroofs.com/)
- Surviving Disaster with Renewable Energy (http://www.nrel.gov/surviving_disaster)
- National Renewable Energy Laboratory Photo Library (http://www.nrel.gov/data/pix/pix.html)
- Open PV Mapping Project from NREL (http://openpv.nrel.gov/)

How to Afford PV Now

- DSIRE USA Economic Incentive Programs (http://www.dsireusa.org/)
- Grameen Shakti: microfinanced photovoltaic programme in Bangladesh (http://www.gshakti.org/)

Designing Your Own PV system

- PV System Design Considerations (http://www.sandia.gov/pv/docs/Design_and_Installation_of_PV_Systems.htm)
- Solar resources available for your area (http://rredc.nrel.gov/solar/old_data/nsrdb/)
- http://rredc.nrel.gov/solar/pubs/redbook/ - Solar radiation data manual (mostly just U.S. data)
- http://www.roofray.com/ - A free site for estimating your home's solar electric potential using Google maps (works best in areas with good satellite map resolution)
- http://www.iea-shc.org/outputs/task16/task_16_photovoltaics_in_buildings_p3.pdf - Large pdf with total sizing information for many regions.

- http://www.retscreen.net - Software, user manuals and case studies from Canada. This is an excellent resource.
- http://www.energy.ca.gov/reports/2003-03-11_500-03-014F.PDF - buyers guide to PV systems
- http://www.pequals.com/at/pvbarn/ - Example design of a photovoltaic barn
- http://www.appropedia.org/Photovoltaic_system_at_St._Jude%27s_church - Project summary of 8.4kW PV system on a church
- DIY Solar Power (http://gomakesolarpanels.com/) A practical guide to energy self sufficiency.

General Resources

- Photovoltaics FAQ (http://www.engineering.sdstate.edu/~roppm/PVFAQ.html)
- Photovoltaic CD-ROM for free (http://www.udel.edu/igert/pvcdrom/index.html)
- EnergyPlanet-Photovoltaic Site Directory (http://www.energyplanet.info/Photovoltaics/)
- Kyocera Presentation on PV (http://www.kyocerasolar.com/pdf/KSI-PV101_online.pdf)
- Solar Power Beginner (http://www.solarpowerbeginner.com/)
- -Desert Knowledge Solar Centre (http://www.dkasolarcentre.com.au/flash/processmap.html) - Australian Government test site on PV info

Misc

- Tools for predicting sun angles, position, path, and overhang designs (http://www.susdesign.com/tools.php)
- Amazing battery FAQ (http://www.uuhome.de/william.darden/)
- CCAT's Mobile Energy On Wheels (http://www.pequals.com/at/ccatsmeow/index.htm)
- China's Solar Push More than Just Low-Cost? (http://www.renewableenergyaccess.com/rea/news/story?id=44457) - developments and investment suggestions in photovoltaic manufacturing.
- Applied Materials Fab 2 Farm concept (http://fab2farm.appliedmaterials.com/)

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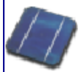

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- First browse the articles and subcategories below for examples and possible collaborations.
- Type a proposed name for the project, organization, thesis, how to or other Photovoltaics related resource in the following **create** box.
- Add information. Do not worry about formatting or completeness, others will help and changes are easily made. Be BOLD.

Create page

References

- Pratt, Doug & John Schaeffer. Solar Living Source Book. Tenth. NV: Chelsea Green Publishing Company, 1999.

1. ↑ For a very good summary article of O&M of large systems see part 1: [1] (http://www.renewableenergyworld.com/rea/news/article/2009/10/solar-electric-facility-o-m-now-comes-the-hard-part) and part 2: [2] (http://www.renewableenergyworld.com/rea/news/article/2010/01/solar-electric-facility-o-m-now-comes-the-hard-part-part-2?cmpid=SolarNL-Tuesday-January19-2010) .
2. ↑ Joshua Pearce and Andrew Lau, “Net Energy Analysis For Sustainable Energy Production From Silicon Based Solar Cells”

(http://www.cede.psu.edu/users/alau/ASES02_Net_Energy_PV.pdf) , Proceedings of American Society of Mechanical Engineers Solar 2002: Sunrise on the Reliable Energy Economy, editor R. Cambell-Howe, 2002.
3. ↑ A good role of thumb is to double the price of the module to account for system components and installation - for uptodate averages on panel costs see the retail price survey here (http://solarbuzz.com/) .
4. ↑ Pearce, J.M. 2008. “Industrial Symbiosis for Very Large Scale Photovoltaic Manufacturing”, Renewable Energy 33, pp. 1101–1108. [3] (http://dx.doi.org/10.1016/j.renene.2007.07.002)
5. ↑ For a detailed analysis of the life cycle energy costs of solar cells see: Joshua Pearce and Andrew Lau, “Net Energy Analysis For Sustainable Energy Production From Silicon Based Solar Cells” (http://www.cede.psu.edu/users/alau/ASES02_Net_Energy_PV.pdf) , Proceedings of American Society of Mechanical Engineers Solar 2002: Sunrise on the Reliable Energy Economy, editor R. Cambell-Howe, 2002.

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