Photovoltaic: Basic Design Principles and Components

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History of Photovoltaic

- **The photovoltaic systems are solid-state system that convert sunlight (the most abundant energy source on the planet) directly into electricity without using heat engine or rotating equipment.**
- **PV system equipment has no moving parts and, as a result, requires minimal maintenance and has a long life.**
- **It generates electricity without producing gases emissions and its operation is practically silent.**
- **Photovoltaic systems can be built in practically any size, ranging from milliwatt to megawatt, and the PV systems are modular, i.e., more panels can be easily added to increase output.**
- **They can be set up as grid-connected or stand-alone system.**

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History of Photovoltaic …

- The history of photovoltaic systems goes back to the nineteenth century.
- 1883: the first PV device was invented by Fritts (American inventor), he coated the semiconductor material Selenium (Se) with an extremely thin layer of gold (30 cm^2 in area). He obtain a current that can be stored in batteries or transmitted a distance to be used.
- 1954: the modern age of photovoltaic started when researchers at Bell Labs: checking *silicon* wafers on which a layer of *boron* less than 1/10,000 of an inch thick has been deposited. The *boron* forms a "*pn* junction" in the *silicon*. Action of light on the junction excites current flow.
- 1960: several key papers by researchers developed the fundamentals of *pn* junction solar cell operation.

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History of Photovoltaic …

- **1973**: a significant improvement in performance of solar cells occurring. The "violet cell" were created having a 30% relative increase in efficiency over traditional *Si* cells.
- **1980**: the PV modules have been produced from *Si* wafer *pn* junction solar cells were built in the USA, Japan, and Europe.
- **1994**: Mobil Solar Energy Corporation (USA), which had developed a process for rising solar cells on *Si* strip (called the Edge film growth or EFG process) instead of more costly wafers.
- **1999**: British solar company (BP solar) had crystalline and amorphous *Si* solar cell technology. Thus, BP Solar established three technology options (standard *Si* wafers, thin films and concentrators).
- Here is a table of history of Photovoltaic.

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History of Photovoltaic …

- 1839 Becquerel (FR) discovered photogalvanic effect in liquid electrolytes
- 1873 Smith (UK) discovered photoconductivity of solid Se
- 1877 Adams and Day (UK) discover photogeneration of current in Se tubes; the first observation of PV effect in solids
- 1883 Fritts (US) makes first large area solar cell using Se film
- 1954 First 6% efficient solar cells reported: Si (Bell Lab, USA) and Cu_2S/CdS (Air Force, USA)
- 1955 Hoffman Electronics (USA) offers 2% efficient Si PV cells at $1500/W
- 1958 NASA Vanguard satellite with Si backup solar array
- 1959 Hoffman Electronics (USA) offers 10% efficient Si PV cells
- 1963 Sharp Corp (JP) produces first commercial Si modules
- 1966 NASA Orbiting Astronomical Observatory launched with 1 kW array
- 1970 First GaAs heterostructure solar cells by Alferov, Andreev *et al*. in the USSR
- 1972 First PV conference to include a session on terrestrial applications (IEEE)
- 1973 A big year in photovoltaics: Worldwide oil crisis spurs many nations to consider renewable energy including photovoltaics; Cherry Hill Conference in USA (established photovoltaics' potential and legitimacy for government research funding); World's first solar powered residence (University of Delaware, USA) built with Cu_2S (not c-Si!) solar modules
- 1974 Project Sunshine initiated in Japan to foster growth of PV industry and applications; Tyco (USA) grows 2.5 cm wide Si ribbon for photovoltaics, first alternative to Si wafers
- 1975 First book dedicated to PV science and technology by Hovel (USA)
- 1980 First thin-film solar cell >10% using Cu_2S/CdS (USA)
- 1981 350 kW Concentrator array installed in Saudi Arabia
- 1982 First 1 MW utility scale PV power plant (CA, USA) with Arco Si modules on 2-axis trackers

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History of Photovoltaic …

- 1984 6 MW array installed in Carrisa Plains CA, USA [35]
- 1985 A big year for high-efficiency Si solar cells: Si solar cell >20% under standard sunlight (UNSW, Australia) [36] and >25% under 200X concentration (Stanford Univ. USA) [37]
- 1986 First commercial thin-film power module, the a-Si G4000 from Arco Solar (USA)
- 1987 Fourteen solar powered cars complete the 3200 km World Solar Challenge race (Australia) with the winner averaging 70 kph
- 1994 GaInP/GaAs 2-terminal concentrator multijunction >30% (NREL, USA) [38]
- 1995 "1000 roofs" German demonstration project to install photovoltaics on houses, which triggered the present favorable PV legislation in Germany, Japan and other countries
- 1996 Photoelectrochemical "dye-sensitized" solid/liquid cell achieves 11% (EPFL, Switzerland) [39]
- 1997 Worldwide PV production reaches 100 MW per year
- 1998 $Cu(InGa)Se_2$ thin-film solar cell reaches 19% efficiency (NREL, US) [40] comparable with multicrystalline Si. First concentrating array for space launched on Deep Space 1 by US (5 kW using high efficiency GaInP/GaAs/Ge triple junction cells)
- 1999 Cumulative worldwide installed photovoltaics reaches 1000 MW
- 2000 Olympics in Australia highlight wide range of PV applications, and the awarding of the first Bachelor of Engineering degrees in Photovoltaics and Solar Engineering (UNSW, Australia)
- 2002 Cumulative worldwide installed photovoltaics reaches 2000 MW. It took 25 years to reach the first 1000 MW and only 3 years to double it; production of crystalline Si cells exceeds 100 MW per year at Sharp Corp. (Japan). BP Solar ceases R&D and production of a-Si and CdTe thin-film modules in USA ending >20 years of effort

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History of Photovoltaic …

- In the early days of Photovoltaic, some 50 years ago, the energy required to produce a PV panel (the basic component of producing electricity in PV system) was more than the energy the panel could produce during its life time.
- Today (2009), the cost of the photovoltaic is around $2.5 US/Watt peak and the target is to reduce this to about $1 US/Watt peak by 2020.

Note:

Modules are rated in Watts of peak power (W_P) is the electric power that a PV plant is able to deliver under standard testing conditions:

- 1 kW/m^2 insolation perpendicular to the panels;
- 25°C temperature in the cells;

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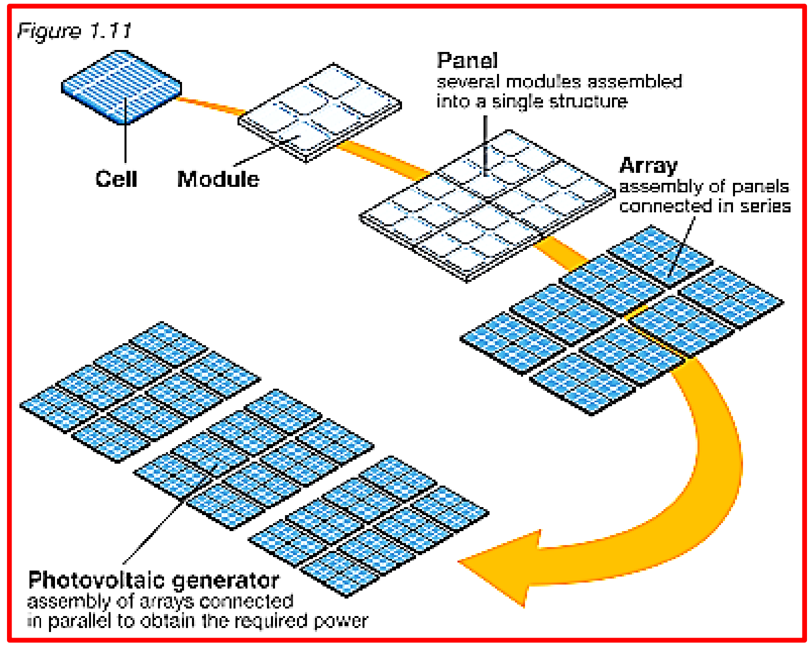
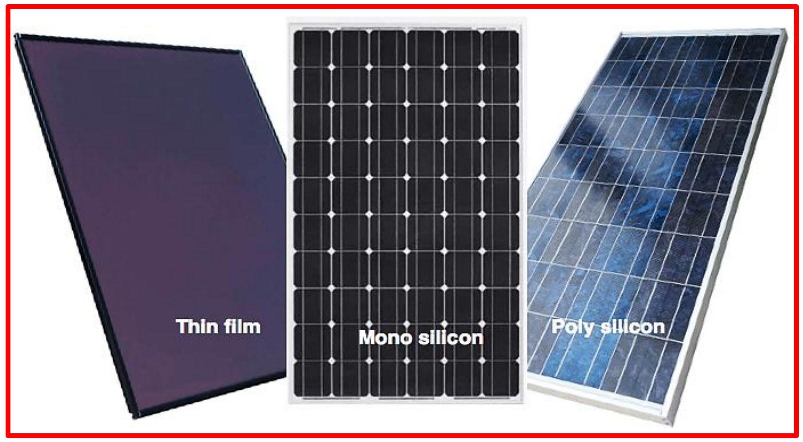
Introduction to PV Technology

- Single PV cells (also known as "solar cells") are connected electrically to form PV modules, which are the building blocks of PV systems. The module is the smallest PV unit that can be used to generate power.
- PV modules are manufactured with varying electrical outputs ranging from a few watts to more than 100 watts of direct current (DC) electricity.
- Two primary types of PV technologies available commercially are ***crystalline silicon*** and **thin film**.





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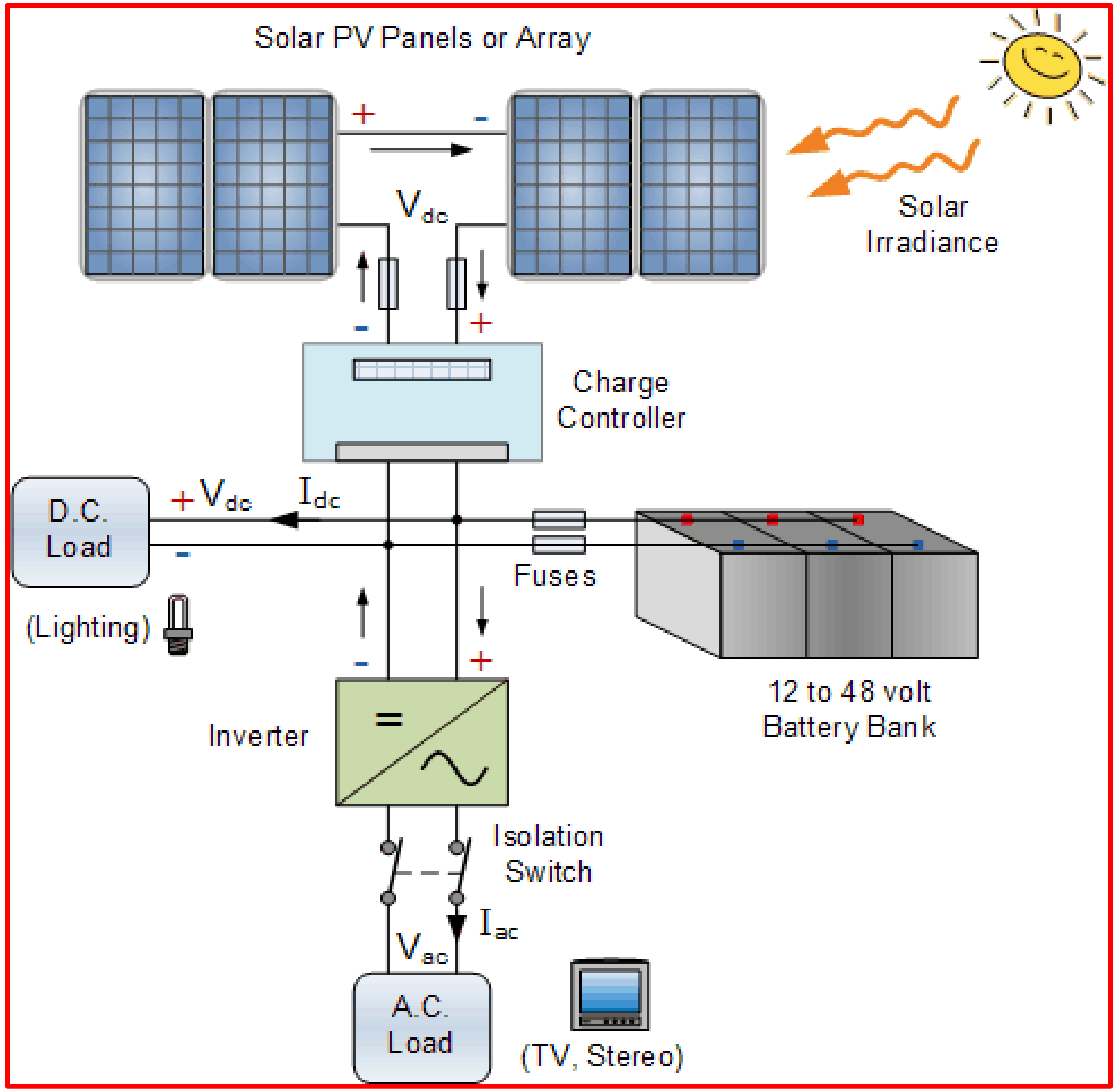
Introduction to PV Technology …

- In addition to PV modules, the components needed to complete a PV system may include a charge controller, batteries, an inverter or power control unit (for alternating current load), safety disconnects and fuses, a grounding circuit, and wiring.



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PV System Applications

Many people are familiar with PV-powered calculators and watches, the most common small-scale applications of PV. However, there are various large-scale, cost-effective PV applications, including:

- ***Water pumping*** for small-scale remote irrigation, stock watering, residential uses, remote villages, and marine sump pumps;
  - ***Lighting*** for residential needs, security, highway, streets and parking sign, pathways, recreational vehicles, remote villages and schools, and marine navigational buoys العوامات الملاحية البحرية;
- ***Communications*** for remote stations, emergency radios, orbiting satellites, and cellular telephones;

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PV System Applications …

- *Refrigeration* for medical and recreational ترفيهية uses;
- *Utility grids* that produce utility- or commercial-scale electricity; and
- *Household* appliances such as ventilation fans, televisions, blenders, stereos, and other appliances.

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How Do I Select a PV Dealer?

- ***1st consideration*** **choosing a PV professional dealer will be one of your most important decisions. If you choose a professional dealer, you won't need to know all the details of designing, purchasing, and installing your PV system. Instead, you can rely on the dealer's expertise to design and install a system that meets your needs. However, just like buying a car or a television, you must have confidence in the dealer's products and services.**
- ***2nd consideration*** **is the dealer's experience in the field. How long has the company been in business?. You should also ask the dealer how many systems like yours he has designed and installed. Ask to see installations, and talk with owners of systems similar to the one you want to purchase.**

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How Do I Select a PV Dealer?…

- ***3rd consideration*** in selecting a system installer is the variety and quality of products offered for each component of the system. Because PV systems are often designed for a specific site, one company's products may not be appropriate for all applications. When a dealer recommends a product, ask what the recommendation is based on, whether there are consumer or independent testing facility reports you can read, and whether the products are listed with Underwriters Laboratories (UL).
- ***4th consideration*** consider the service agreements and performance guarantees the dealer provides and the warranties given by the product manufacturers. No system is maintenance-free. When problems occur with your system, what services? What warranties do the manufacturers provide? What costs should you expect to pay, and which costs will be assumed by the dealer and/or the manufacturer?

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When Are PV Systems Appropriate?

People select PV systems for a variety of reasons. Some common reasons for selecting a PV system include:

- Cost: when the cost is high for extending the utility power line or using another electricity-generating system in a remote location, a PV system is often the most cost-effective source of electricity.
- Reliability: PV modules have no moving parts and require little maintenance compared to other electricity-generating systems.
- Modularity: PV systems can be expanded to meet increased power requirements by adding more modules to an existing system to increase the output power of the system.

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When Are PV Systems Appropriate? …

- **Environment: PV systems generate electricity without polluting the environment and without creating noise.**
- **Ability to combine systems: PV systems can be combined with other types of electric generating systems (wind, hydro, and diesel…etc) to charge batteries and provide power on demand.**

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When Are PV Systems Appropriate? …

PV systems are not cost-effective for all applications. The following discussion gives some general guidelines to consider when deciding whether a PV system is appropriate for your situation.

- **First, if your site is already connected to a utility grid, or within ¼ mile of the grid, a PV system will probably not be cost-effective. Each utility company spreads the cost of its power plants and fuel costs among all its customers. When you install a PV system, you are essentially installing your own mini-utility system. You pay all the costs of generating the electricity you consume. Although the sun's energy is free, the PV equipment is not free.**

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When Are PV Systems Appropriate? …

- **Second**, small PV systems are not practical for powering heating systems, water heaters, air conditioners, electric stoves, or electric clothes dryers. These loads require a large amount of energy to operate, which will increase the size and cost of your PV system. Therefore, select the most energy efficient loads available. For example, if your PV system will power lights, look for the most energy-efficient light bulbs. If your system will pump water for toilets and showers, look for the most energy-saving water pumps.

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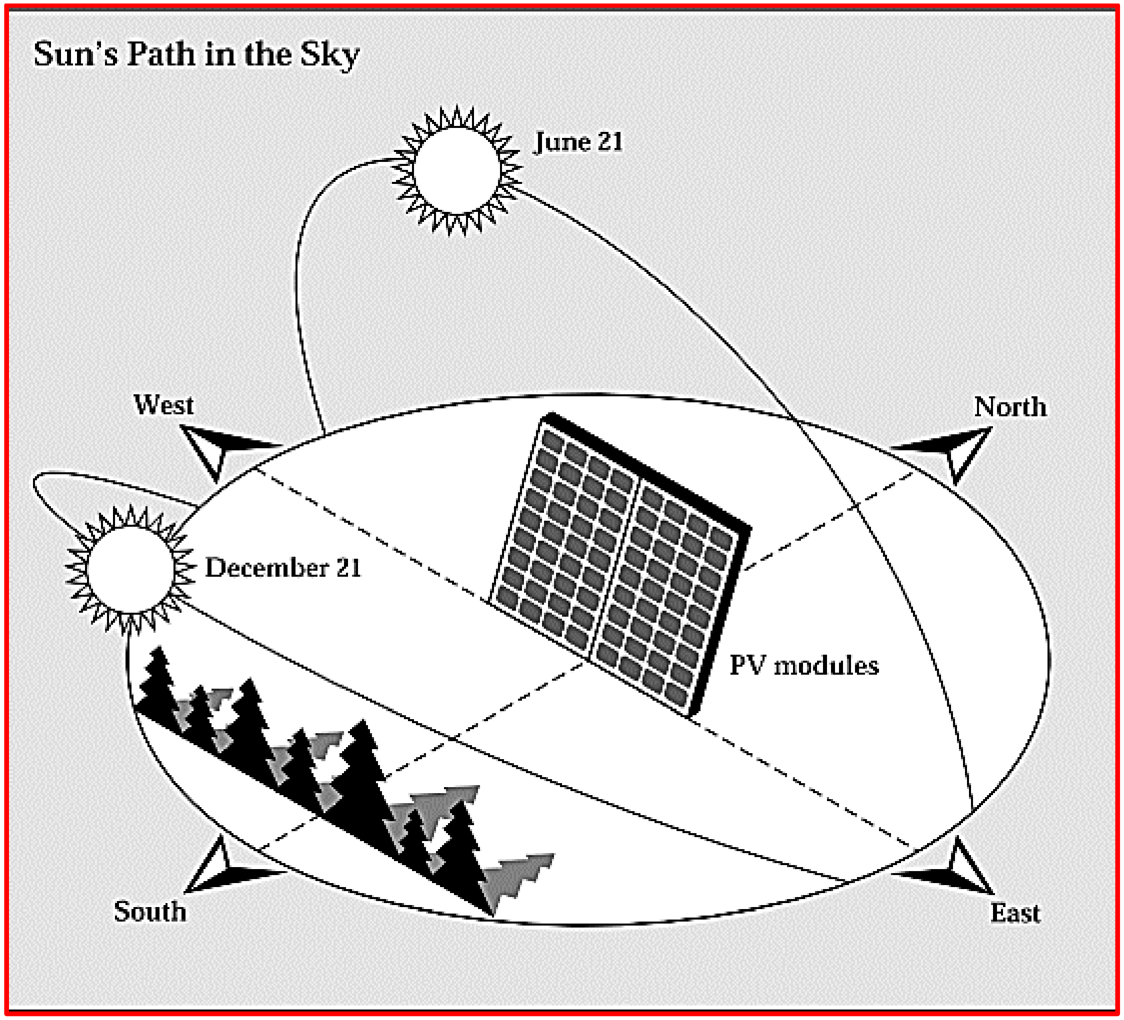
The best way to fix a PV Module



The sun's noontime height above the horizon changes seasonally. This is important to consider when siting and positioning a PV module.

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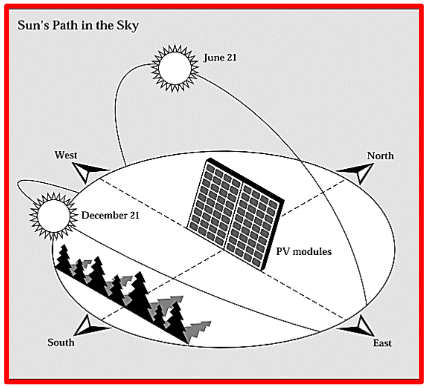
Is My Site Adequate for PV?

There are three factors to consider when determining whether your site is appropriate.



- **First**, for maximum daily power output, PV modules should be exposed to the sun (southern exposure) for as much of the day as possible, *especially during the peak sun hours 10 a.m. to 3 p.m.*
- **Second,** the southern exposure must be free of obstructions such as trees, mountains, and buildings that might shade the modules. Consider both summer and winter paths of the sun, as well as the growth of trees and future construction that may cause shading problems. Also the flat site is appropriate whereas a rocky hillside is not.

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How Does Weather Affect PV Module Output?

- **Unlike utility power plants, which produce electricity constantly despite the time of day and year or the weather, the output of PV modules is directly related to these two factors.**
- **Where you live will affect the number of PV modules you will need for power, because different geographic regions have different weather patterns. Seasonal variations affect the amount of sunlight available to power a PV system.**
- **Module temperature also affects its output. The conversion efficiency of crystalline-silicon modules falls significantly at elevated module temperatures.**
- **When designing a PV system, be sure your PV installer obtains data specific to your area, rather than relying on general data.**

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Advantages of PV System

- Fuel source (i.e., the sunlight) is huge and essentially infinite.
- No emissions, no combustion, no pollution.
- Low operating costs (no fuel).
- No moving parts (no wear).
- High reliability in modules (>20 years).
- Modular (small or large increments).
- Quick installation.
- Can be integrated into new or existing building structures.
- Can be installed at nearly any point-of-use.
- Daily output peak may match local demand.
- High public acceptance.
- Excellent safety record.
- No on-site operator required.

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Disadvantages of PV System

- Fuel source is diffuse (sunlight is a relatively low-density energy).
- High installation costs (i.e., High initial capital investment).
- Poorer reliability of elements (e.g., batteries system).
- Lack of manufacturers for enable you a good choice of best PV system.
- Lack of economical efficient energy storage.
- Lack of infrastructure and limited access to technical services in remote areas.
- Photovoltaic system will require too much land area to ever meet significant fraction of world needs.

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Goals of Today's PV Research and Manufacturing

- **Since the overall goal is to produce a low cost PV system, we need more than low-cost-efficient solar cells, we need a low cost efficient system including mounting hardware, power conditioning electronics, fuses, cables, storage, tracking, and so on. Less research and development has gone into these areas than into PV solar cells and modules.**
- **Goals of current solar cell research and manufacturing:**
  1- **Manufacturing thinner cell with less expensive, less perfect semiconductors, more pure and more perfect.**
  2- **Increase material utilization by reducing waste in semiconductor and cell fabrication.**
  3- **Increase solar radiation utilization by absorbing more of the spectrum efficiently.**
  4- **Increase speed and progress of manufacturing processes.**