

# SOLAR PHOTOVOLTAIC ENERGY

## Introduction

Photovoltaics (PV) is a technology that converts sunlight directly into electricity. It was first observed in 1839 by the French scientist Becquerel who detected that when light was directed onto one side of a simple battery cell, the current generated could be increased. In the late 1950s, the space programme provided the impetus for the development of crystalline silicon solar cells; the first commercial production of PV modules for terrestrial applications began in 1953 with the introduction of automated PV production plants.

Today, PV systems have an important use in areas remote from an electricity grid where they provide power for water pumping, lighting, vaccine refrigeration, electrified livestock fencing, telecommunications and many other applications. With the global demand to reduce carbon dioxide emissions, PV technology is also gaining popularity as a mainstream form of electricity generation. Some tens of thousands of systems are currently in use yet this number is insignificant compared to the vast potential that exists for PV as an energy source.

Photovoltaic modules provide an independent, reliable electrical power source at the point of use, making it particularly suited to remote locations. PV systems are technically viable and, with the recent reduction in production costs and increase in conversion efficiencies, can be economically feasible for many applications.



Figure 1: Array of PV Panels ©Smail Khennas/ITDG

### The use of PV electricity in developing countries

The majority of the world's developing countries is found within the tropics and hence have ample sources of solar insolation (the total energy per unit area received from the sun). The tropical regions also benefit from having a small seasonal variation of solar insolation, even during the rainy season, which means that, unlike northern industrial countries, solar energy can be harnessed economically throughout the year.

Currently, there is a fairly high uptake of solar technology in developing countries. The chart

technical brief

below (Figure 2) shows the status of the PV technology worldwide.

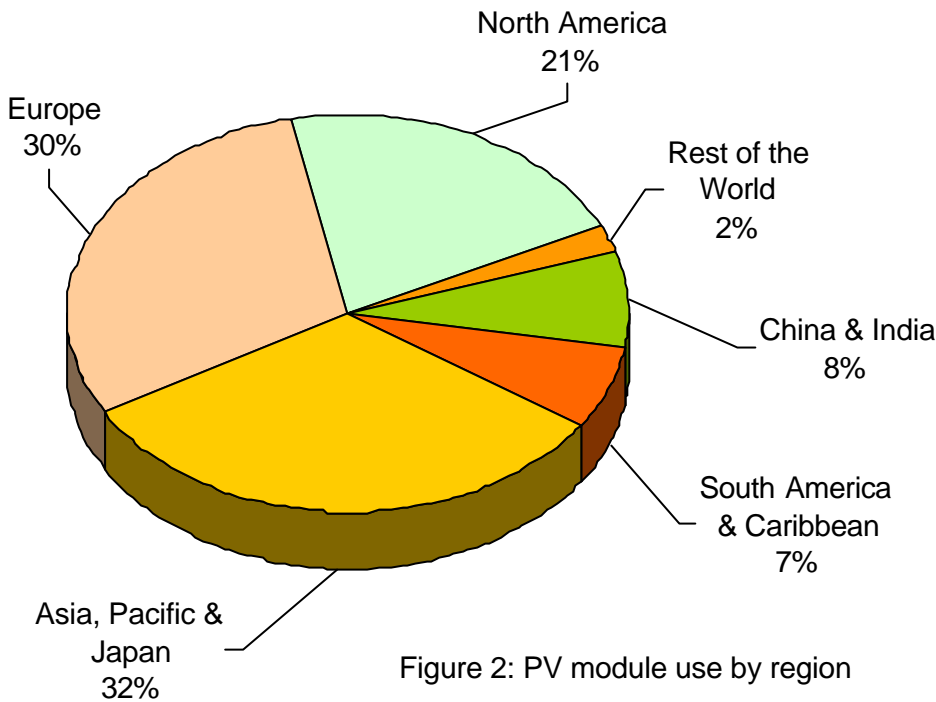


Figure 2: PV module use by region

### Technical

The nature and availability of solar radiation

Solar radiation arrives on the surface of the earth at a maximum power density of approximately 1 kilowatt per metre squared ( $\text{kWm}^{-2}$ ). The actual usable radiation component varies depending on geographical location, cloud cover, hours of sunlight each day, etc. In reality, the solar flux density (same as power density) varies between 250 and 2500 kilowatt hours per metre squared per year ( $\text{kWhm}^{-2}$  per year). As might be expected the total solar radiation is highest at the equator, especially in sunny, desert areas.

Solar radiation arrives at the earth's outer atmosphere in the form of a direct beam. This light is then partially scattered by cloud, smog, dust or other atmospheric phenomenon (see Figure 3 below). We therefore receive solar radiation either as *direct* radiation or scattered or *diffuse* radiation, the ratio depending on the atmospheric conditions. Both direct and diffuse components of radiation are useful, the only distinction between the two being that diffuse radiation cannot be concentrated for use.

technical brief

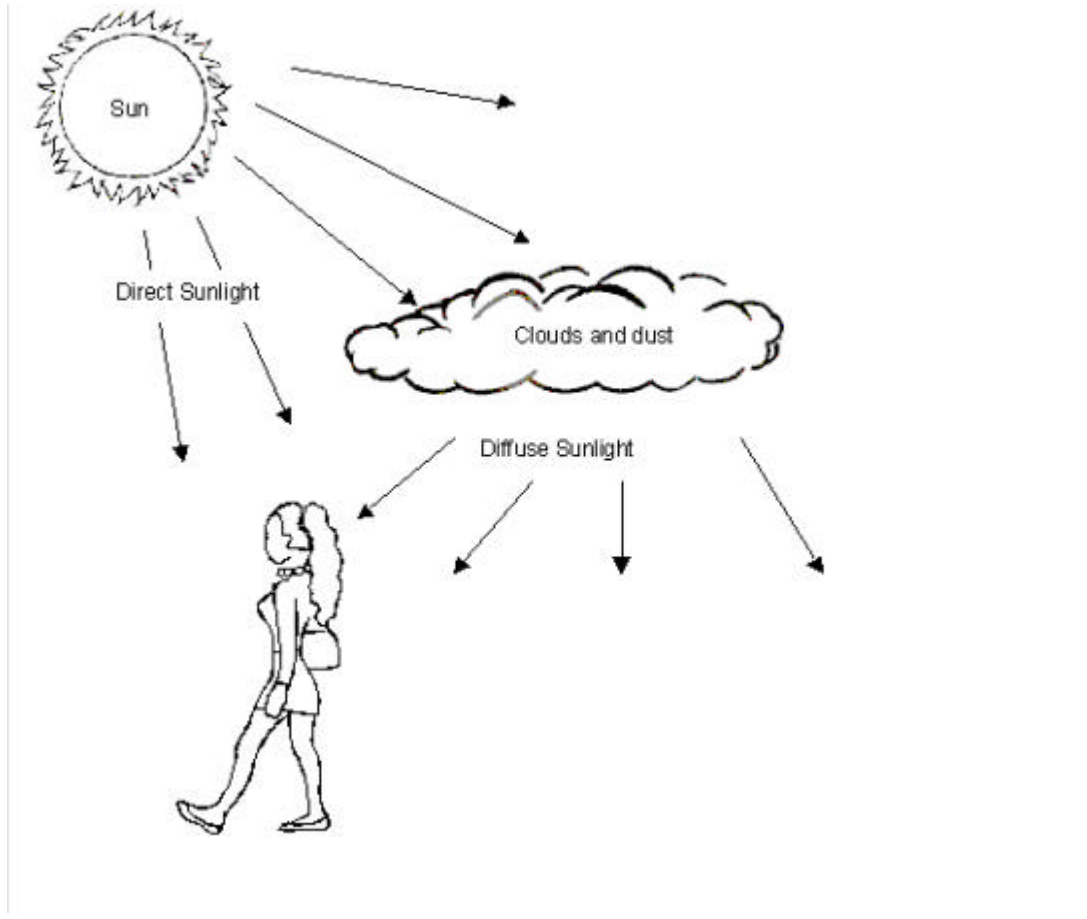


Figure 3: Direct and Diffuse Solar Radiation

#### The geometry of earth, sun and collector panel

The earth revolves around the sun with its axis tilted at an angle of 23.5 degrees. It is this tilt that gives rise to the seasons. The strength of solar flux density is dependent upon the angle at which it strikes the earth's surface, and so, as this angle changes during the yearly cycle, so the solar insolation changes. Thus, in northern countries, in the depths of winter, the sun will be low in the sky to the south, or may not even be seen at all in arctic regions. The radiation strikes the earth's surface obliquely and solar gain (solar yield) is low. If we are using a solar photovoltaic panel to capture the sun's energy then the orientation of this panel is also critical to the amount of energy we will capture. The relationship is complex and only with sophisticated tracking systems can the maximum energy be extracted for any given location.

#### The PV cell, modules and arrays

When light falls on the active surface, the electrons in a solar cell become energised, in proportion to the intensity and spectral distribution (wavelength distribution) of the light. When their energy level exceeds a certain point a potential difference is established across the cell. This is then capable of driving a current through an external load.

All modern, commercial PV devices use silicon as the base material, mainly as mono-crystalline or multi-crystalline cells, but more recently also in amorphous form. Other

materials such as copper indium diselenide and cadmium telluride are being developed with the aim of reducing costs and improving efficiencies. A mono-crystalline silicon cell is made from a thin wafer of a high purity silicon crystal, doped with a minute quantity of boron. Phosphorus is diffused into the active surface of the wafer. At the front electrical contact is made by a metallic grid; at the back contact usually covers the whole surface. An anti-reflective coating is applied to the front surface. Typical cell size is about 15cms diameter. The process of producing efficient solar cells is costly due to the use of expensive pure silicon and the energy consumed, but as materials technology improves costs are slowly dropping making PV technology more attractive.

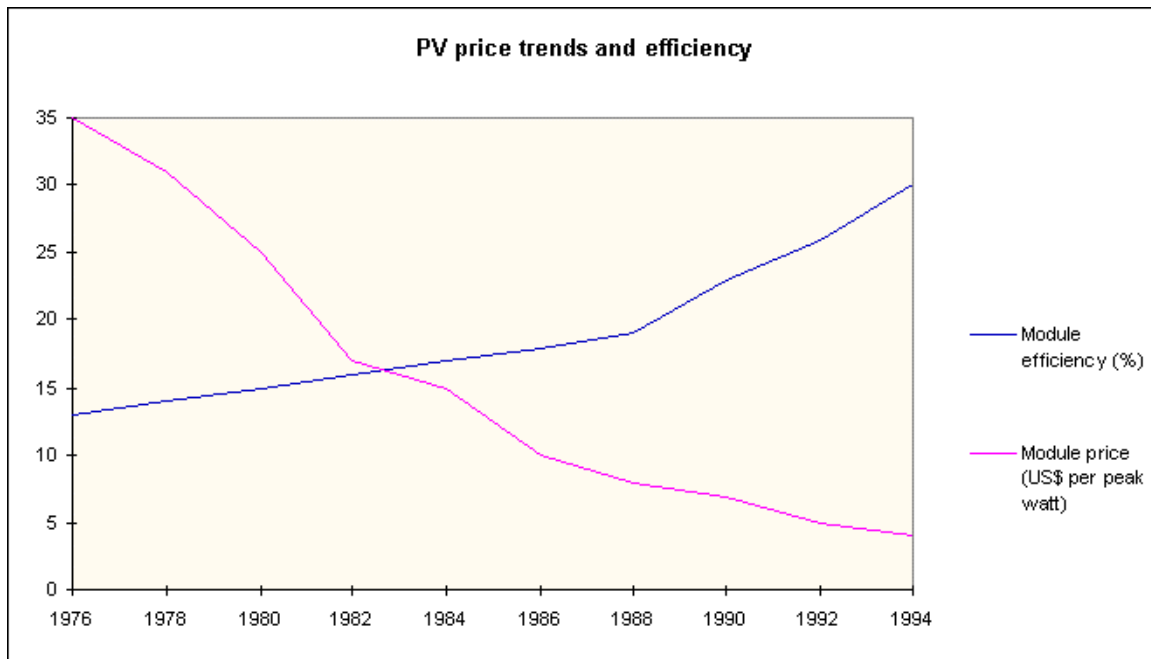


Figure 4: PV price trends

Cost has been the major barrier to the widespread uptake of PV technology. Cost of PV modules is usually given in terms of Peak Watt (Wp), which is the power rating of the panel at peak conditions - that is at  $1\text{kWm}^{-2}$  irradiance at  $25^{\circ}\text{C}$ .

Solar cells are interconnected in series and in parallel to achieve the desired operating voltage and current. They are then protected by encapsulation between glass and a tough resin back. This is held together by a stainless steel or aluminium frame to form a *module*. These modules, usually comprised of about 30 PV cells, form the basic building block of a *solar array*. Modules may be connected in series or parallel to increase the voltage and current, and thus achieve the required solar array characteristics that will match the load. Typical module size is 50Wp and produces direct current electricity at 12V (for battery charging for example).

Commercially available modules fall into three types based on the solar cells used.

- *Mono-crystalline cell modules.* The highest cell efficiencies of around 15% are obtained with these modules. The cells are cut from a mono-crystalline silicon crystal.
- *Multi-crystalline cell modules.* The cell manufacturing process is lower in cost but cell efficiencies of only around 12% are achieved. A multi-crystalline cell is cut from a cast ingot of multi-crystalline silicon and is generally square in shape.
- *Amorphous silicon modules.* These are made from thin films of amorphous silicon where efficiency is much lower (6-9%) but the process uses less material. The potential for cost reduction is greatest for this type and much work has been carried

technical brief

out in recent years to develop amorphous silicon technology. Unlike mono-crystalline and multi-crystalline cells, with amorphous silicon there is some degradation of power over time.

An array can vary from one or two modules with an output of 10W or less, to a vast bank of several kilowatts or even megawatts.

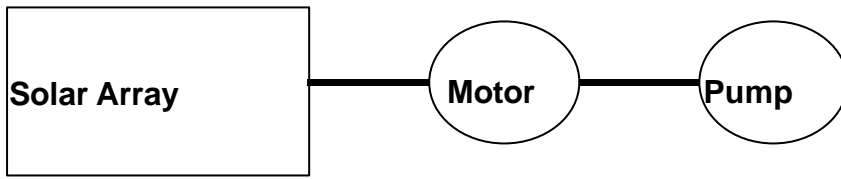
- *Flat plate arrays*, which are held fixed at a tilted angle and face towards the equator, are most common. The angle of tilt should be approximately equal to the angle of latitude for the site. A steeper angle increases the output in winter; a shallower angle - more output in summer. It should be at least 10 degrees to allow for rain runoff.
- *Tracking arrays* follow the path of the sun during the day and thus theoretically capture more sun. However, the increased complexity and cost of the equipment rarely makes it worthwhile.
- *Mobile (portable) arrays* can be of use if the equipment being operated is required in different locations such as with some lighting systems or small irrigation pumping systems.

## Solar PV systems

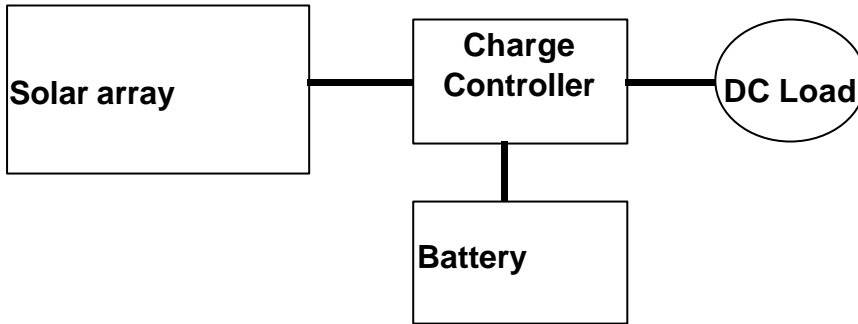
PV systems are most commonly used for stand-alone applications. They can be used to drive a load directly; water pumping is a good example - water is pumped during the hours of sunlight and stored for use; or a battery can be used to store power for use for lighting during the evening. If a battery charging system is used then electronic control apparatus will be needed to monitor the system. All the components other than the PV module are referred to as the balance-of-system (BOS) components. Below, in Figure 5, three possible configurations of stand-alone PV system are shown. Such systems can often be bought as kits and installed by semi-skilled labour. (Source: The Power Guide, ITDG Publishing 1994)

For correct sizing of PV systems, the user needs to estimate the demand on the system, as well as acquiring information about the solar insolation in the area (approximations can be made if no data is readily available). It is normally assumed that for each Wp of rated power the module should provide 0.85watt hours of energy for each kWhm<sup>-2</sup> per day of insolation (Hulscher 1994). Therefore if we consider a module rated at 200 Wp and the insolation for our site is 5 kWhm<sup>-2</sup> per day (typical value for tropical regions), then our system will produce 850Wh per day (that is 200 x 0.85 x 5 = 850).

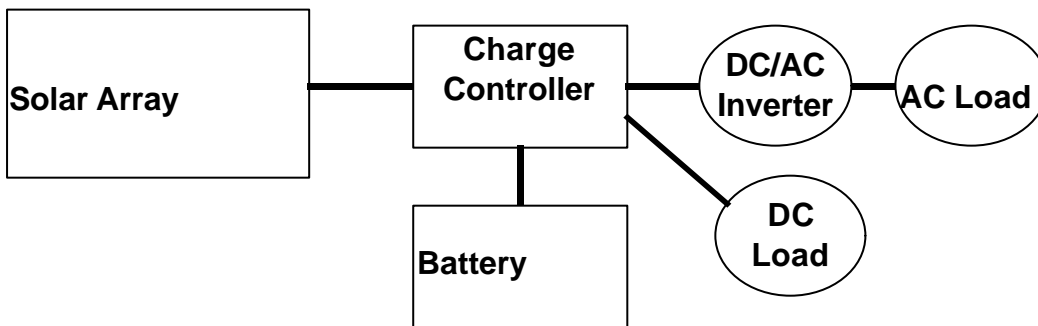
Some systems use lenses or mirrors to concentrate direct solar radiation onto smaller areas of solar cells. As the power output is directly proportional to the solar power directed onto the PV cell, this method is useful for reducing the area required for collection. The cost of the concentrators, however, often offset the cost of savings made on reducing the size of the module.



(a) System without batteries



(b) System with battery



(c) System with battery and inverter

Figure 5: Common configurations of PV systems

Some benefits of Photovoltaics

- No fuel requirements - In remote areas diesel or kerosene fuel supplies are erratic and often very expensive. The recurrent costs of operating and maintaining PV systems are small.
- Modular design - A solar array comprises individual PV modules, which can be connected to meet a particular demand.
- Reliability of PV modules - This has been shown to be significantly higher than that of diesel generators.
- Easy to maintain - Operation and routine maintenance requirements are simple.
- Long life - With no moving parts and all delicate surfaces protected, modules can be expected to provide power for 15 years or more.
- National economic benefits - Reliance on imported fuels such as coal and oil is reduced.
- Environmentally benign - There is no pollution through the use of a PV system - nor is there any heat or noise generated which could cause local discomfort. PV systems

technical brief

bring great improvements in the domestic environment when they replace other forms of lighting - kerosene lamps, for example.

PV applications in lesser developed countries

#### 1. Rural electrification

- lighting and power supplies for remote building (mosques, churches, temples etc farms, schools, mountain refuge huts) - low wattage fluorescent lighting is recommended
- power supplies for remote villages
- street lighting
- individual house systems
- battery charging
- mini grids



Figure 6: PV can be used to power water pumping systems ©ITDG

#### 2. Water pumping and treatment systems

- pumping for drinking water
- pumping for irrigation
- dewatering and drainage
- ice production
- saltwater desalination systems
- water purification

#### 3. Health care systems

- lighting in rural clinics
- UHF transceivers between health centres
- vaccine refrigeration
- ice pack freezing for vaccine carriers
- sterilises
- blood storage refrigerators

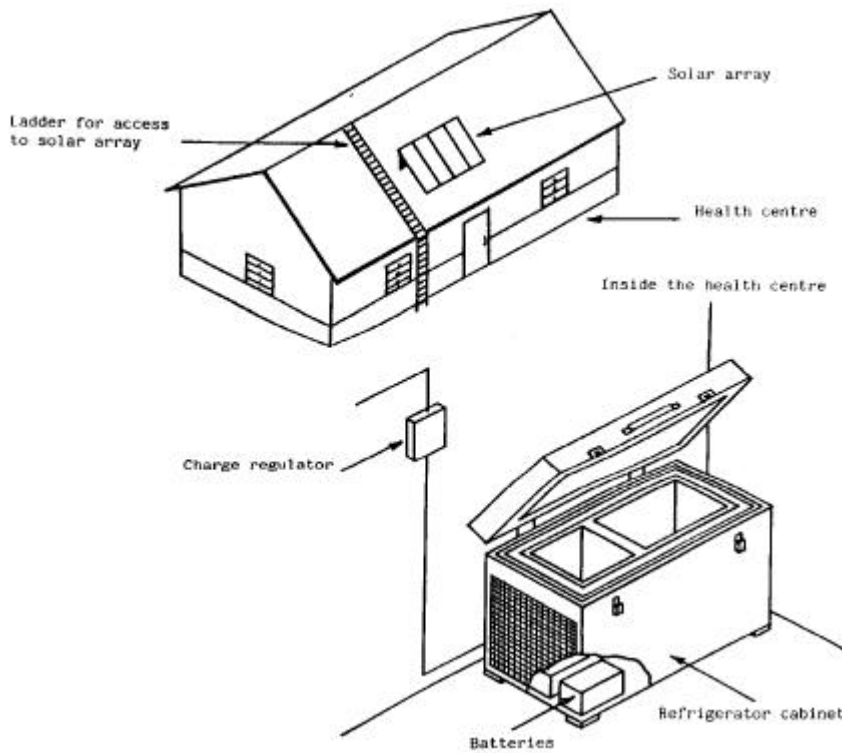


Figure 7: PV is frequently used to power vaccine refrigeration in remote health centres

4. *Communications*

- radio repeaters
- remote TV and radio receivers
- remote weather measuring
- mobile radios
- rural telephone kiosks
- data acquisition and transmission (for example, river levels and seismographs)

5. *Transport aids*

- road sign lighting
- railway crossings and signals
- hazard and warning lights
- navigation buoys
- road markers

6. *Security systems*

- security lighting
- remote alarm system
- electric fences

7. *Miscellaneous*

- ventilation systems
- calculators
- pumping and automated feeding systems on fish farms
- solar water heater circulation pumps
- boat / ship power
- vehicle battery trickle chargers
- earthquake monitoring systems
- emergency power for disaster relief

technical brief



## Other Issues

### Manufacture in developing countries

PV technology is sophisticated and the manufacturing plant is expensive. There is little scope for local manufacture in rural areas of developing countries, although some BOS components such as frameworks for mounting PV modules can be made in small workshops and will save on expensive transportation costs. There are however, large-scale manufacturers of PV modules working in developing countries. In India, for example, Central Electronics of Ghaziabad is not only the nation's largest PV producer, but are the fifth largest producer of monocrystalline silicon solar cells in the world (D.V.Gupta cited in Garg et al, 1997). There are over 60 companies in India alone producing solar cells, modules and systems.

### Dissemination

There is a vast scope for and potential for the use of PV technology in India. There are still over 90,000 villages in the country to be electrified. Recognising the importance of PV technology in the Indian context, the Government has been implementing a comprehensive programme covering R & D, demonstration, commercialisation and utilisation for more than 15 years.

Among the elements of the action plan are the following aims:

- deployment of 400,000 solar lanterns as a substitute for kerosene lanterns
- rural electrification through PV systems covering 400 villages / hamlets
- a special programme on water pumping systems
- intensified R & D on technologies which can lead to a reduction in cost
- commercialisation of PV systems for various applications by giving a market orientation to the programme and promoting manufacturing and related activities

As a result of these measures India is among the leading countries in the world in the development and use of PV technology.

Source: E.V.R. Sastry, cited in Garg et al, 1997.

### Hybrid systems

Solar PV systems can be used in conjunction with other energy technologies to provide an integrated, flexible system for remote power generation. These systems are referred to as hybrid systems. Common configurations of hybrid systems could include a solar PV array, wind generator and diesel generator set which would allow generation in all weather conditions. Such systems need careful planning.

### Solar lanterns

A recent innovation in solar technology is the solar lantern. Originally designed for the outdoor leisure market in western countries, this simple lantern with a small PV module (5 - 10 watts) is extremely appropriate to use in rural areas of developing countries for replacing kerosene lamps. Cost is still a barrier, as is the potential for local manufacture, but there is enormous scope for widespread dissemination of a simple, robust solar lantern.

### Micro grids or stand-alone

Solar PV technology is presently best suited to stand-alone applications but can also be used for providing power for small grid systems, with centralised power generation. As the cost of PV cell production drops, their use for medium scale electricity production is being adopted more widely. There is also scope for large-scale electricity production for such applications as peak power provision.

## Resources and references

H.P. Garg, D. Gouri, and R. Gupta: Renewable Energy Technologies. Indian Institute of technology and the British High Commission, 1997.

S. Karekezi and T. Ranja: Renewable Energy Technologies in Africa. AFREPREN / SEI / Zed Books, 1997.

T.B. Johansson, H. Kelly, A.K.N. Reddy and R.H. Williams: Renewable Energy - Sources for fuels and electricity. Island Press, 1993.

J. Twidell and T. Weir: Renewable Energy Resources. E & F.N. Spon, 1990.

W. Hulscher and P. Fraenkel: The Power Guide – An international catalogue of small-scale energy equipment. ITDG Publishing, 1994.

A. Derrick, C. Francis and V. Bokalders: Solar Photovoltaic Products - A guide for development workers. IT Publications and IT Power, 1991.

J.P. Louineau, M. Dicko, P. Fraenkel, R. Barlow and V. Bokalders: Rural Lighting – A guide for development workers. IT Publications and The Stockholm Environment Institute, 1994.

S. Roberts: Solar Electricity – A practical guide to designing and installing photovoltaic systems. Prentice Hall, 1991.

G. Foley: Photovoltaic Applications in Rural Areas of the Developing World. World Bank, 1995.

A. Cabraal, M. Cosgrave-Davies and L. Schaeffer: Best Practices for Photovoltaic Household Electrification Programs. World Bank, 1996.

## Internet addresses

Solarbuzz Inc.

[www.solarbuzz.com](http://www.solarbuzz.com)

Home Power Magazine

[www.homepower.com/](http://www.homepower.com/)

British Photovoltaic Association

[www.pv-uk.org.uk](http://www.pv-uk.org.uk)

U.S. National Centre for Photovoltaics

[www.nrel.gov/ncpv](http://www.nrel.gov/ncpv)

International Centre for Application of Solar Energy

[www.case.gov.au](http://www.case.gov.au)

Centre for Renewable Energy and Sustainable Technology

[www.solstice.crest.org](http://www.solstice.crest.org)

International Energy Agency Photovoltaic Power Systems Programme

[www.iea-pvps.org/](http://www.iea-pvps.org/)

Independent site operated by ECOFYS BV, Utrecht, Netherlands

[www.mysolar.com](http://www.mysolar.com)

Ekomation Solar Energy Consultants, Netherlands

[www.pvportal.com](http://www.pvportal.com)

ISES's World-wide Information System for Renewable Energy

[www.wire.ises.org](http://www.wire.ises.org)

## Manufacturers/Suppliers of photovoltaic products

Note: This is a selective list of suppliers and does not imply ITDG endorsement.

### Solar systems

Siemens Bangladesh,  
Jiban Bian Tower, 12<sup>th</sup> Floor, 10 Dikusha  
Commercial Area, Dhaka 1000, Bangladesh  
Tel: +880 2 956 3734  
Fax: +880 2 956 3740  
Email: [sblpower@bangla.net](mailto:sblpower@bangla.net)

Animatics Ltd.,  
Haile Selassie Avenue, P.O. Box 72011,  
Nairobi, Kenya  
Tel: +254 2 210 300  
Fax: +254 2 210 315

Lotus Energy Pvt. Ltd.,  
Bhatbhateni Dhunge Dhara, P.O. Box 9219,  
Kathmandu, Nepal  
Tel: +977 1 418 203  
Fax: +977 1 412 924  
Email: [info@lotusenergy.com](mailto:info@lotusenergy.com)  
Web: [www.lotusenergy.com](http://www.lotusenergy.com)

CIME Commercial S.A.,  
Av. Libertadores # 757, San Isidro, Lima 27,  
Peru  
Tel: +511 222 6083  
Fax: +511 222 6330

Link Intertrade (Private) Ltd.,  
385C Old Kotte Road, Rajagiriya, Sri Lanka  
Tel: +94 1 873 211-2  
Fax: +94 1 867 952  
Email: [intertrade@link.lk](mailto:intertrade@link.lk)

Solarman Co.,  
P.O. Box 11545, Khartoum, Sudan  
Tel: +249 11 472 337  
Fax: +249 11 473 138  
Email: [solarman29@hotmail.com](mailto:solarman29@hotmail.com)

Alternative Technologies Pvt. Ltd.,  
3 Canald Road, Graniteside, Harare, Mash

Kenital Solar Energy,  
Ngong Road, P.O. Box 19764, Nairobi, Kenya  
Tel: +254 2 715 960  
Fax: +254 2 718 959  
Email: [info@kenital.com](mailto:info@kenital.com)  
Web: [www.kenital.com](http://www.kenital.com)

Wisdom Light Group (P) Ltd.,  
Gha/2, 178 Siphak-Kalopul, GPO Box 6921,  
Kathmandu, Nepal  
Tel: +977 1 483 154/5  
Fax: +977 1 482 154  
Email: [info@wisdomlight.com.np](mailto:info@wisdomlight.com.np)  
Web: [www.wisdomlight.com.np](http://www.wisdomlight.com.np)

Ferreyros,  
Av. Industrial 675-Lima, Peru  
Tel: +511 336 7070  
Fax: +511 336 8331  
Web: [www.ferreyros.com.pe](http://www.ferreyros.com.pe)

Solar Power & Light Co. Ltd.,  
10 Havelock Place, Colombo 5, Sri Lanka  
Tel: +94 1 688 730  
Fax: +94 1 686 307

U.T.E. Group of Companies,  
P.O. Box 2074, Khartoum, Sudan  
Tel: +249 11 70147  
Fax: +249 11 70147

Solamatics,  
31 Edison Crescent, Graniteside, P.O. Box

technical brief

Cent, Zimbabwe  
Tel: +263 4 781 972-7  
Fax: +263 4 775 264  
Email: [snakes@zambezi.net](mailto:snakes@zambezi.net)

2851, Harare, Zimbabwe  
Tel: +263 4 749 930  
Fax: +263 4 771 212  
Email: [mikem@mcdiarmid.co.zw](mailto:mikem@mcdiarmid.co.zw)

#### Solar modules

Shell Solar  
Postbus 3049, 5700 JC, Helmond, Netherlands  
Tel: +31 492 50 86 08  
Fax: +31 492 50 86 00  
Email: [info@shellsolar.nl](mailto:info@shellsolar.nl)  
Web: [www.shellsolar.com](http://www.shellsolar.com)

Angewandte Solar Energie (ASE) GmbH (now RWE Solutions)  
Industriestrasse 13, Alzenau, Germany D63755  
Tel: +49 (0)6023 91 1712  
Fax: +49 (0)6023 91 1700  
Email: [ase\\_sales@ase.tessag.com](mailto:ase_sales@ase.tessag.com)  
Web: [www.ase-international.com](http://www.ase-international.com)

Sharp Photovoltaics Div  
282-1 Hajikami, Shinjo-cho, Kita-Katsuragi-gun,  
Nara Prefecture 639-2198, Japan  
Tel: +81 745 63 3579  
Fax: +81 745 62 8253  
Email: [webmaster@sharp.co.jp](mailto:webmaster@sharp.co.jp)  
Web: [www.sharp.co.jp](http://www.sharp.co.jp)

Photowatt International SA (Part of Matrix Solar Technologies Inc.)  
33 rue St. Honore, Z.I. Champfleuri, 38300  
Bourgoin Jallieu, France  
Tel: +33 (0)474 93 80 20  
Fax: +33 (0)474 93 80 40  
Email: [marketing@photowatt.com](mailto:marketing@photowatt.com)  
Web: [www.matrixsolar.com](http://www.matrixsolar.com)

BP Solar Headquarters  
989 Corporate Drive, Linthicum, Maryland, MD  
21090, USA  
Tel: +1 410 981 0240  
Email:  
Web: [www.bpsolar.com](http://www.bpsolar.com)

Central Electronics Ltd. (CEL)  
4 Industrial Area, Sahibabad, Uttar Pradesh  
201010, India.  
Tel: +91 120 4771941, 4771910  
Fax: +91 120 4771843  
Email: [cel@celsolar.com](mailto:cel@celsolar.com)  
Web: [www.celsolar.com](http://www.celsolar.com)

Bharat Heavy Electricals Ltd. (BHEL)  
Jeevan Tara Building, 5 Sansad Marg, New  
Delhi, 110001, India  
Tel: +91 11 334 7331  
Fax: +91 11 334 2769  
Email: [bhelsanchar@vsnl.com](mailto:bhelsanchar@vsnl.com)  
Web: [www.bhel.com](http://www.bhel.com)

technical brief