

# Chapter 1

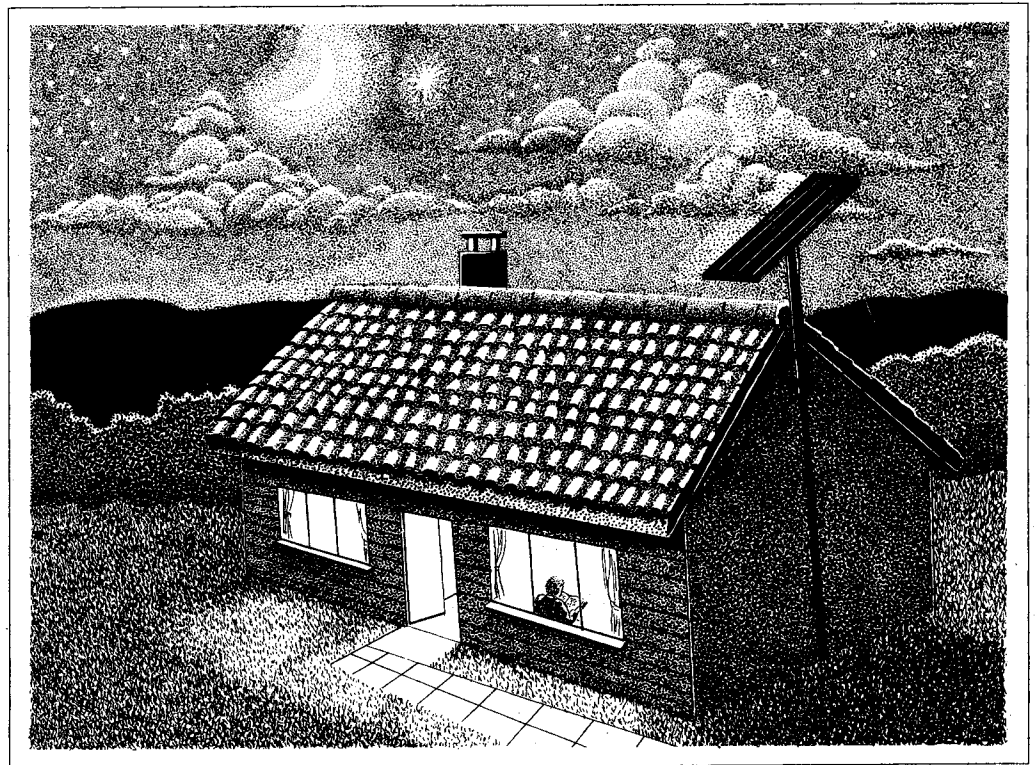
## Solar Electric System Fundamentals

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*This chapter outlines the steps required to plan and install a solar electric lighting system. It summarises the applications, parts, advantages and disadvantages of solar electric systems, and directs readers seeking specific information to appropriate chapters.*

*Specifically, the chapter reviews:*

- *concepts and terms used throughout the book to describe energy and basic low voltage electricity;*
- *principles and components of solar electric systems, including the solar resource, solar modules, batteries, charge controllers, and appliances; and,*
- *estimating energy requirements, cost cutting, planning, installing and maintaining systems.*





## Solar Electric System Fundamentals

Solar electricity is electric power generated from sunlight using devices called solar cell modules.

### The Sun and Solar Electric Technology

The sun is the source of virtually all the energy we use each day. The energy we derive from woodfuel, petroleum, paraffin, hydroelectricity and even our food originates *indirectly* from the sun. Solar energy is captured and stored by plants. We use this energy when we burn firewood or eat food. The sun also powers the rainfall cycles that fill rivers from which we extract hydroelectricity. Petroleum is made up of fossilised remains of plants and animals that collected energy from the sun thousands of years ago.

It is also possible to collect energy from the sun *directly* for heating water, cooking, raising steam and generating electricity. There are a number of types of equipment which can be used to collect solar energy. These include collector panels, which harvest solar energy for heating water, and solar concentrators which focus the rays of the sun into high energy beams for raising heat.

Solar electricity is electric power generated from sunlight using devices called *solar cell modules*. The technology is gaining popularity in Africa as prices of other electric energy sources rise. Solar electricity can replace small applications of petroleum-fueled generators, grid power and even dry cell batteries. The technology is spreading rapidly to rural areas where there is great interest in its applications.

Solar electric theory is not difficult to master, but its principles differ from 220 V ac mains (or generator) wiring. The first part of this manual gives background information and explains the work of each part of a solar electric system.

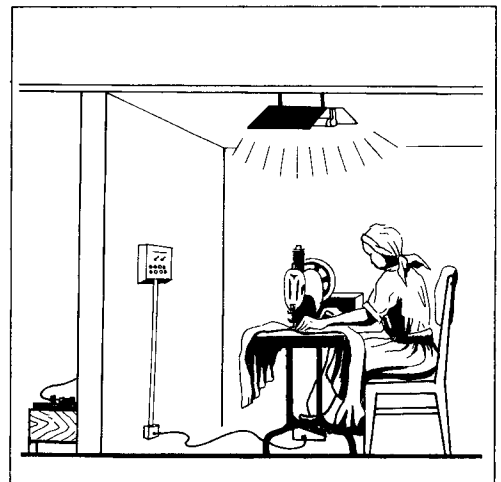
### Common Uses of Photovoltaics

In East Africa, the most common application of solar electricity is providing power for household lighting and appliances. By 1991, as many as 10,000 rural homes in Kenya were using solar electric power for household appliances. The list below describes some of the important applications for which solar electric power is being utilised.

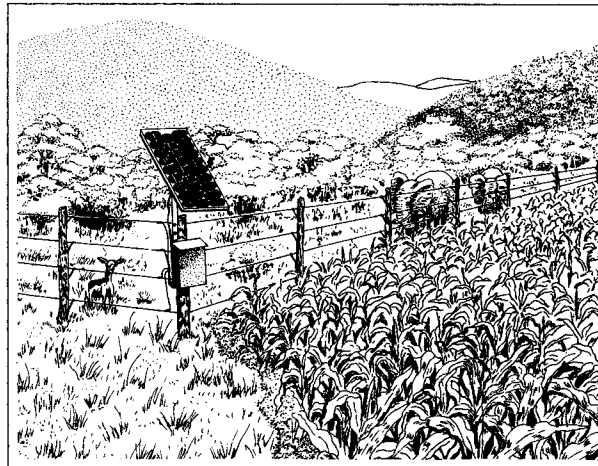
- *Household lights, televisions, cassette players, radios and small appliances.*

Night light is crucial for education, craft work and social activity, and televisions, radios and stereo systems are increasingly common in rural East Africa. Solar electric security systems are also popular among rural customers.

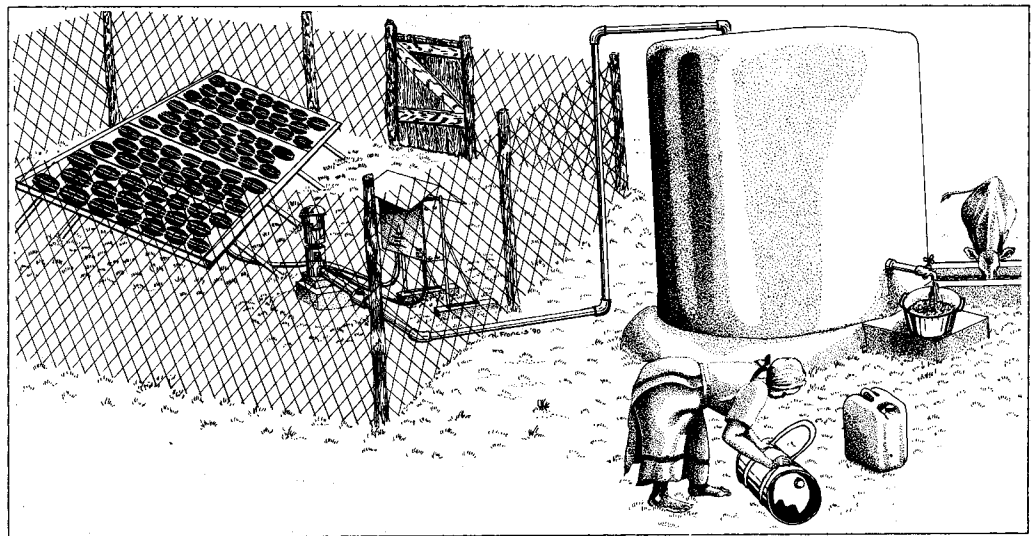
- *Small industries and institutions:* Schools and small businesses in rural areas use solar electricity to power lights, sewing machines, calculators, light tools, computers, typewriters, and security systems.



- *Telecommunications:* Because telecommunication systems are often installed in isolated places with no access to power, they often use stand-alone photovoltaic systems to power radios, remote repeaters, and even weather monitoring equipment.
- *Health centre vaccine refrigeration and lighting:* Solar electric systems are popular for vaccine refrigeration in rural health centres. Such solar refrigerators are also utilised to freeze ice packs and to keep blood plasma cool. The World Health Organisation supports programmes that install solar electric refrigerators and lighting in health centres throughout East Africa.
- *Electric fencing and other uses:* Electric fences, which keep wild animals inside game parks and out of farm land, are often powered by solar electricity. Other common uses of solar electric systems include street lighting, road sign illumination, security systems and protection of pipelines from corrosion.



- *Water pumping:* In a number of sites in East Africa, arrays of solar cell modules connected to electric pumps are used to pump water from wells or boreholes. This water is used for drinking, washing, other household purposes and for small irrigation projects. Solar electricity can also be used to purify drinking water.



Solar electric systems consume no fuel, quietly converting sunlight directly into electricity.

### Advantages and Disadvantages of Solar Electricity

#### Advantages of solar electric power:

- Solar electric systems consume no fuel. Solar modules convert freely available sunlight directly into electricity without being used up.
- They produce electricity quietly, without giving off exhaust gases or other pollutants.
- Compared to conventional generators, solar electric systems require very little maintenance. Solar modules have no moving parts and last for over 20 years.
- Solar electric systems are economical for many small applications. While the price of oil has steadily risen over the past few years, the price of solar cells has been falling. In the long term, it is often cheaper to power lights, small tools, stereo systems and TV's with solar energy than it is to power them with dry cells, lead-acid batteries or generators.
- Solar electric systems can be tailored to the power needs of individual applications: from tiny electric calculators, to small radios, televisions and lights, to electric borehole pumps. Solar electric systems can be expanded easily by adding more modules and batteries.
- Properly installed solar electric systems are safe. Risk of electric shock is small because of the low system voltage. Fire risks are lower in homes and schools lit by solar electricity than in those lit with kerosene lanterns.

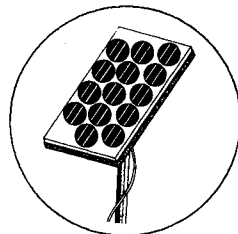


#### Disadvantages of solar electric power:

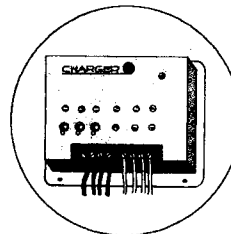
- The initial cost of solar electric systems is relatively high by rural standards. Even if a solar lighting system is more economical over its lifetime than kerosene or generators, it is still very difficult for many people to raise the cash to buy systems all at once.
- Solar electric systems require batteries for energy storage. Batteries must be carefully maintained. The performance of systems is dependent on the quality of batteries available on the local market or the availability of imported batteries.
- Appliances and lamps which run on low voltage are not as readily available as those that run on mains power. However, as more and more people install solar electric systems, the supply of 12 volt dc appliances is increasing.
- There is a lack of trained technicians to design and install solar electric systems. Because of this, poorly designed systems are sometimes installed by untrained individuals, reflecting badly on the solar electric technology.

### The Parts of a Solar Electric Lighting System

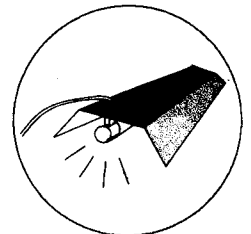
Before planning a system, make sure you are completely familiar with the various system parts as shown below:



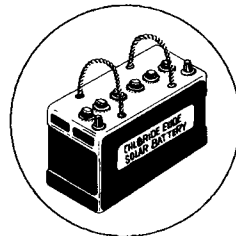
Solar Cell Module



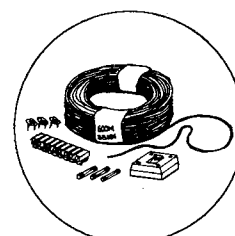
Charge Controller



The Load:  
Appliances and  
Lamps



Battery



Wiring and Fixtures

The rest of this chapter summarises the role of each part in a system, and directs the reader to the chapter in which that technology is explained in greater detail. Chapters 9, 10, 11 and 12 contain guide-lines for planning, installing, and maintaining systems.

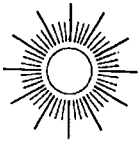
A basic understanding of energy concepts is necessary before planning a solar energy project.

#### Basic Energy Concepts

A basic understanding of energy concepts is necessary before undertaking solar energy system installation and design. Appendix 1 (page 98) contains detailed information on these terms for readers unfamiliar with them.

*Energy* is referred to as the ability to work. It is measured in units called *joules (J)*, or (throughout this book), in *watt hours (Wh)*. *Amp hours (Ah)* are also used to indicate energy transfer in solar electric systems (particularly to measure battery capacity). Strictly speaking, amp hours do not measure energy — they must be multiplied by the voltage of the system to arrive at watt hours.

*Power* is the rate at which energy is supplied (or energy per unit time), and is measured in *watts (W)*.



When installing solar electric systems, make sure that all work is supervised and checked by a qualified electrician.

*Efficiency* is the ratio of output energy to input energy. In the case of solar electric systems, the input energy is the energy received from the sun by the modules and the output energy is the electricity available for lights and appliances. An energy-efficient device uses less energy to perform a given task. Efficiency is measured as a percentage; the higher the percentage, the more efficient the transfer is.

*Energy Example*

At noon on a sunny day, equatorial solar radiation arrives at a rate of about 1000 watts per square metre (this is *power*) (see Figure 2.3, page 11). If all of the solar radiation striking one square metre in one day in a typical East African location could be collected, then a total of about 6,000 watt hours, or 6 kilowatt hours, could be harvested per square meter of solar cell module per day (this is *energy*). However, we know that it is impossible to capture all of the solar energy because some energy is always lost in transformations (as heat or in reflection).

In fact, the best solar cell modules have an *efficiency* of only about 15%, which means that they can only transform about one sixth of the arriving radiation into electricity (at noon, they transform only 150 W/m<sup>2</sup> of the incoming 1000 W/m<sup>2</sup> into electric power). Over the course of a sunny East African day, the energy converted to electricity by a square meter of solar cells is about 900 watt hours, or enough to power four 15W globe lights for 15 hours.

### Basic Low Voltage Electric Concepts

Besides understanding energy concepts, you also need a basic knowledge of electricity to install and design solar electric lighting systems. Those who are used to working with 240V ac systems will find that low voltage dc systems are safe and easy to work with. For anyone who has not had experience with electricity, Appendix 2 (page 99) explains electrical concepts in more detail, and goes through several examples. Once you have mastered the terms and principles below, then the following chapters should be readily understandable.

*Current* is the rate of flow of electrons through a circuit. The symbol *I* represents current, which is measured in *amps* (*A*). *Direct current* (abbreviated *dc*) is a flow of electric charge which does not change direction with time. With dc current, the positive terminal always remains positive, and the negative terminal is always negative. Solar cells always produce direct current electric charge, as do batteries. *Alternating current* (*ac*) is electric current which first flows through the wire in one direction and then the other, and continues to switch back and forth over time. Mains electricity, and that produced by generators, is ac current.

*Potential difference* (or *voltage*), measured in *volts* (*V*), is the difference in potential energy between the ends of a conductor that governs the rate of flow of current. It may also be referred to as the electromotive 'pressure' of electrons in an electric circuit. If there is no potential difference, there is no flow of current.

A *circuit* is a system of conductors (i.e. wires and appliances) capable of providing a closed path for electrons. Current can flow when the circuit is *closed*. No current can flow when the circuit is *open*.

*Resistance* is the property of a conductor (i.e. a wire or appliance) which opposes the flow of current through it and converts electrical energy into heat. Resistance has the symbol *R*, and is measured in *ohms*,  $\Omega$ .

*Electric power*, measured in *watts* (*W*) or *kilowatts* (*kW*), is the rate at which energy is supplied from the power source.

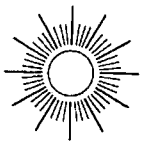
The *load* is the set of equipment or appliances that use the electrical power from the generating source, battery or module. *Series* and *parallel* refers to the arrangement of the load and batteries within the circuit (see Appendix 2).

*Power Law*: The power law states that electric power (in watts) is equal to the voltage (*V*, in volts) multiplied by the current (*I*, in amps).

$$\text{Power (Watts)} = \text{Voltage (volts)} \times \text{Current (amps)}$$

*Ohm's Law*: Ohm's Law states that the voltage of a circuit is equal to the current (in amps) times the resistance (in ohms). This law is useful in determining how much voltage is lost on long wire runs.

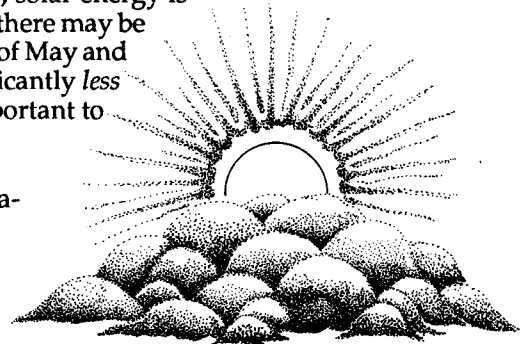
$$\text{Voltage (volts)} = \text{Current (amps)} \times \text{Resistance (ohms)}$$



## The Solar Energy Resource: How much energy is available?

When planning a solar electric system, the first question to ask is whether there is enough solar energy available. The output of a solar module depends on the amount of sun light falling on it. In most areas of East Africa, solar energy is plentiful, although at certain times of the year, there may be less energy. For example, between the months of May and August in Meru District, Kenya, there is significantly *less* solar radiation because of cloudiness. It is important to plan a system with weather patterns in mind.

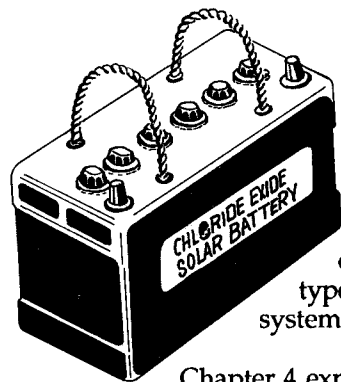
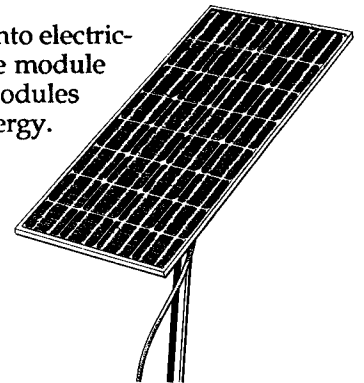
Chapter 2 explains the principles of solar radiation, and how to use meteorological records to estimate how much power will be available in a given area.



## Solar Cell Modules: Harvesting solar energy

Solar cell modules are devices used to convert sunlight into electricity. Because there are many types of solar modules, the module required for a given task should be chosen carefully. Modules should be mounted so that they can collect maximum energy.

Chapter 3 explains the principles of solar electricity, the types and behaviour of solar modules, how to size modules, and how to choose and maintain solar cell modules.



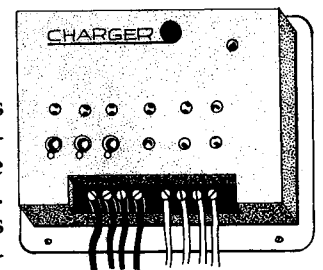
## Batteries: Storing solar energy

Lights, radios and other appliances are used at night when the sun has set; that is, when the solar modules are not producing electricity. Batteries store energy collected during sunny days for use at night and during cloudy days. Various types and sizes of batteries are available. The type of battery chosen depends on the energy requirements of a system and the budget of the user.

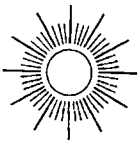
Chapter 4 explains operating principles of batteries, the different types that are available, how to size, choose and maintain them, and how to keep them charged during prolonged cloudy periods.

## Charge Controllers: Managing solar energy

Solar cell modules supply a *limited* amount of energy. For this reason, solar electric systems must be managed so that the energy collected by the solar cell modules nearly equals the amount of electricity used to power lights and appliances. Charge controllers are used to prevent damage to batteries and other parts of the system due to over-charging and deep-discharging. They may also alert the user when the battery or module is not functioning properly.

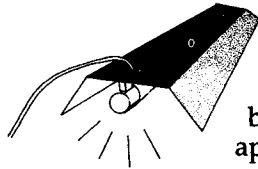


Chapter 5 explains the operation and features of charge controller, and explains how to manage energy in solar electric systems with or without a charge controller.

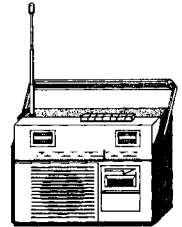


## Lamps and Appliances: The efficient application of solar energy

Unlike generators or mains (which supply electricity at 240 volts ac), solar electric systems operate on low voltage direct current. For this reason, special low voltage direct current lamps and appliances are usually installed in such systems. Furthermore, efficient fluorescent or halogen lamps are usually used in solar electric systems because they consume far less power than standard incandescent-type lamps.



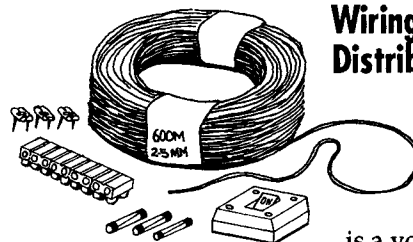
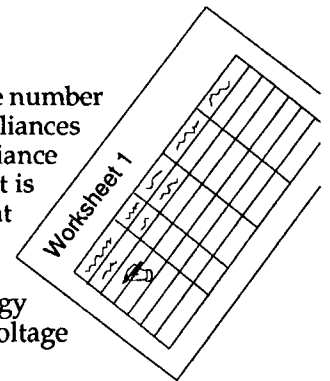
Chapter 6 explains the principles behind lamps, reflectors and ballast inverters (devices that power fluorescent lamps), and how to choose the best for a given job. It also discusses low voltage appliances, voltage converters and use of power conditioning units (i.e. inverters) to operate 240 volt ac appliances.



## The Load: Calculating your energy requirements

The electrical energy requirements of any site depend on the number of lights, radios, televisions, cassette players and other appliances used, and on the number of hours which each light or appliance operates. By adding up each appliance's energy demand, it is possible to calculate the total daily electric energy requirement of a home, school or institution.

Chapter 7 explains how to calculate the total electrical energy demand in a given system, and how to decide on the correct voltage for a system.



## Wiring and Fittings: Distributing energy

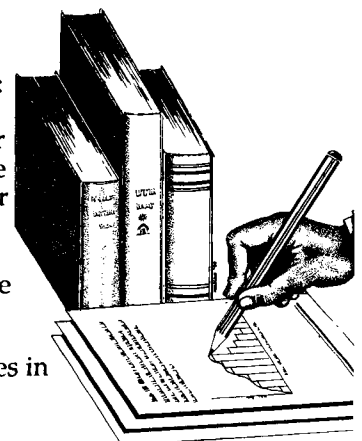
Wiring of solar electric systems is similar to the wiring of 240 V ac systems. However, low voltage solar electric systems often require thicker wires than those used in 240 V ac systems because there is a voltage drop associated with low voltage dc wires on long runs. When designing a system, consider all possible voltage drops and use the correct wire size.

Chapter 8 explains how to choose proper cables and fittings for solar electric systems, how to calculate voltage drops in long cable runs, and how to earth systems against lightning and short circuit damage.

## Planning a System

In order to properly plan a solar electric system, you must:

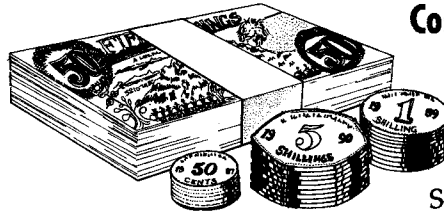
- determine how much energy is needed to power your lamps and appliances. This is done by adding up the number of lamps and appliances, tabulating their power demand, and their daily usage time;
- estimate how much solar energy is available at the site per day;
- estimate how much energy is lost due to inefficiencies in the system;





- determine the size of array, control and battery required.

Chapter 9 explains in detail the process of designing small solar electric systems, and explains how to use the planning worksheets contained at the end of this book. It also provides several examples which demonstrate their use.



### Cost Considerations: Getting the most from a solar electric system

Solar electric systems may be *expensive* investments for rural users. Before buying a system, you should compare its cost against other options.

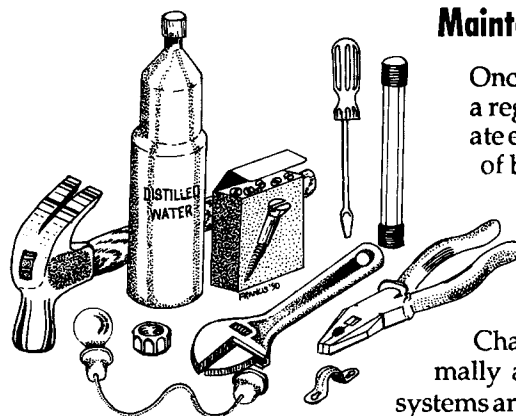
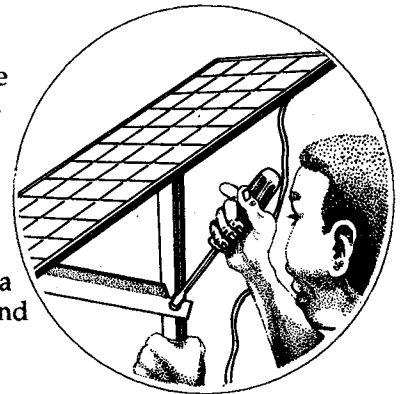
Solar electric systems are often economic over the long term, but the cost of purchasing and installing them is very high. Still, there are tactics you can use to minimize costs. An important strategy to cut costs is to collect and manage energy as efficiently as possible.

Chapter 10 explains how to compare the cost of solar electricity against alternatives. It also highlights practices and devices that reduce the cost of solar electric systems.

### Installation Steps

If a lighting system is planned properly, installing the components should proceed smoothly. Nevertheless, there is a correct order which you should follow, and there are electrical standards that need to be maintained for safety reasons and to ensure that the equipment is not damaged.

Chapter 11 explains the steps involved in installing a system, the safety precautions that should be taken and the tools necessary to do the job properly.



### Maintenance Practices

Once a system is installed, it must be serviced on a regular basis to ensure that it continues to operate efficiently. Tasks include regular maintenance of batteries and lamps, and cleaning of the solar cell modules. If you are installing a system for customers, then you must make sure that the customers are completely familiar with the maintenance practices.

Chapter 12 describes maintenance practices normally associated with small solar electric lighting systems and explains how to fix the system when it fails.