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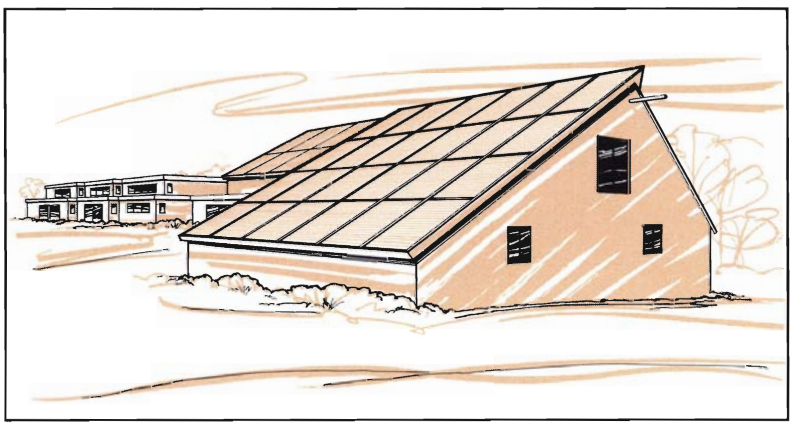
Photovoltaic Product Directory and Buyers Guide



April 1984

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

Battelle

PNL-5052

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

NTIS Price Codes
Microfiche A01

Printed Copy

Pages	Price Codes
001-025	A02
026-050	A03
051-075	A04
076-100	A05
101-125	A06
126-150	A07
151-175	A08
176-200	A09
201-225	A010
226-250	A011
251-275	A012
276-300	A013

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Photovoltaic Product Directory and Buyers Guide

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PREFACE

Photovoltaic (PV) generation of electricity marks the dawn of a new energy era. In total silence, PV systems remarkably and simply convert sunlight directly into electricity. This electricity powers the tools of civilization from the mountain tops to the seas and into the far reaches of outer space. It is now possible to build a home anywhere you desire or even to travel to the moon and have the conveniences of a secure and reliable PV power supply. In recognition of the energy savings potential of PV systems for terrestrial applications, the Department of Energy in conjunction with the U.S. PV industry has conducted research and development to continue improving the PV technology. This effort has succeeded brilliantly, bringing this space age dream down to earth so that in many applications, PV is now the cost-effective and most reliable choice.

A major obstacle to the widespread use of PV was a lack of information on how PV operates and the types of PV products available. In response to this need, the Pacific Northwest Laboratory under contract to the Department of Energy prepared the *Photovoltaic Product Directory and Buyers Guide* in 1981. Thousands of copies have been purchased and its distribution is worldwide.

Since publication of the first edition in 1981, the PV industry has grown tremendously. This growth has not only occurred in kilowatts of PV sold annually, but also in terms of the variety and range of products and services offered. Therefore, a revised edition is required to reflect these changes.

Photovoltaics are providing energy for an ever-growing number of applications worldwide. More than ten thousand residences, including vacation chalets and remote residences, enjoy the advantages of simple and easily maintained PV power supplies to provide daily electrical needs. More than ten thousand navigational beacons and warning lights, using stored PV power, provide safe passage for ships and aircraft. Photovoltaics are also used in utility applications in southern California. The list of viable applications continues to grow as inventive thinkers ponder the possibilities of PV technology.

The information presented in this directory should be of interest to a wide audience because it describes products and appliances that have use for the home, farm, or factory as well as on the road or seas and in remote areas of the great outdoors. Reliable and cost-effective PV-powered products are available for those who are willing to apply them. This directory is intended to help you decide if currently marketed PV products are appropriate for your needs.

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1.0 INTRODUCTION

A major reason why photovoltaics (PV) have not been widely accepted or used has been the lack of practical information on the way these systems work and on the types of systems and products available. The purpose of this directory/buyer's guide is to provide up-to-date information on the PV industry in a form that you can easily use to better understand PV. The directory also lists as completely as possible the PV product sources as of December 1983. The directory includes material that explains the language (used in the industry), operation, design guidelines, and approximate list prices of currently available PV systems and their components.

The directory is intended to be a representative list of PV products, applications, and manufacturers. However, space limitations prevent us from listing the entire PV product line offered by each manufacturer. Also, this directory focuses on PV products and system components that can be purchased off-the-shelf or ordered from catalogs rather than special-order or custom-built products. The discussions are written from a potential customer's point of view and are intended to reveal products that can meet your needs. The information should also be of value to manufacturers because it identifies new market opportunities.

The material in the directory has been formatted to help anyone interested in PV as well as to make it easy to use by professionals in the field. The directory guide is organized to do the following:

- help you understand PV systems (Chapter 2)
- show products available off-the-shelf (Chapter 3)
- assist in designing a PV system (Chapter 4)
- provide information on financial incentives (Chapter 5)
- help the buyer determine if PV products can meet his/her needs (Chapter 6)
- provide information on actual PV user experiences (Chapter 7).

We have also included four appendices to provide detailed information in the following areas:

- information on various financial incentives available from state and federal governments (Appendix I)
- sources of additional information on photovoltaics (Appendix II)
- a source of various types of PV products (Appendix III)
- a listing of addresses of PV product suppliers (Appendix IV).

The material presented in this directory is based on information obtained from three sources. A literature search of material dealing with PV manufacturers, products, and projects provided information on publications and programs sponsored by the Department of Energy (DOE). The same literature search also produced information on publications from private companies. Finally, responses were received from announcements in the trade press publicizing the compilation of the directory and from letters mailed to all identified companies producing PV products or products that can be used with PV power supplies.

In the directory's listings, some firms have undoubtedly been overlooked because of the industry's rapid growth. However, we have painstakingly attempted to contact all firms listed in directories prepared by the Solar Energy Industries Association, the DOE, Solar Energy Research Institute, *Solar Engineering Magazine*, and the *Solar Age Resource Guide*, among others. Any firm that has been overlooked is requested to contact the authors to insure that it will be included in the next update.

All product information in this directory has been assembled on the basis of catalogs and data sheets submitted to us by PV suppliers. Because we could not test and verify claims by manufacturers, we recommend that potential buyers obtain additional information from PV users, suppliers and other reliable sources. Reputable product suppliers frequently offer warranties and maintain lists of satisfied customers to back up their claims. Neither Pacific Northwest Laboratory nor the government recommends the purchase or use of any specific product or supplier.

The prices listed for PV components and appliances are retail for small quantity purchases. Many of the companies listed frequently change their prices and provide discounts for large quantity purchases. Therefore, it is strongly recommended that the consumer contact the appropriate manufacturer or dealer for current price information.

2.0 BACKGROUND INFORMATION ON ELECTRICITY AND PHOTOVOLTAICS

This chapter discusses PV technology and provides basic information for readers who are unfamiliar with PV energy systems. After briefly summarizing the history of photovoltaics, we describe the different components of a PV system. Finally, important electrical terms are defined to help you understand the operation of PV products and how they are rated.

The term "photovoltaic" is derived from two Latin words—"photo" meaning of or produced by light and "voltaic" meaning of or producing an electric current and voltage. Photovoltaic, also known as solar cell, technology is an exciting alternative source of energy that converts sunlight directly into electricity without any moving parts. PV systems operate efficiently in a wide range of applications including small, low-power devices for remote communication instruments; mid-size systems for residences and schools; and large power systems for high-demand operations.

Vigorous efforts are under way within the DOE's National Photovoltaic Program to increase the number of PV systems installed across the country. These installations promote greater public awareness of PV's practicality, strengthen confidence in their use, and help to stimulate growth of the industry. Industry growth and better manufacturing techniques have dramatically improved the economic attractiveness of photovoltaics. Continued encouragement of PV power generation will help move the economy from one based on fossil fuel to one based on alternative sources of energy.

In 1954, scientists at Bell Laboratories reported an improved solar cell that allowed PV technology to be used as a practical energy source. With this improvement, solar cells were primarily used to power spacecraft equipment. In 1975, the Energy Research and Development Administration (ERDA) began a research and development program to encourage production of solar cells and to promote their use. The program has grown to include hundreds of scientists who work in industry, universities, and laboratories across the country, and it has brought about significant advancements in PV's efficiency, durability, and cost effectiveness.

Today, most of the reliable and inexpensive solar cells are made of crystalline silicon. Silicon is the second most abundant element on earth and is found in various types of sand. However, the steps required to process this inexpensive and plentiful raw material into efficient, reliable PV cells are costly. The high cost results from purifying the material and making crystalline slices in the proper form so that they can be processed into PV cells. In the last several years, large-scale pilot plants demonstrated the crystalline cell's reliability and allowed it to be mass produced, which rapidly reduced its cost.

Crystalline silicon cells are being used confidently in power modules and are expected to have a long, efficient life. However, the production cost is expected to be reduced more slowly right now than in the past. Private industry and the federal programs are shifting emphasis to longer-term approaches that may reduce costs more in the future.

One of these research approaches is the use of thin films of PV materials that are made from less expensive pure material and that also can potentially be processed at less cost per square foot. One thin film with considerable commercial success is amorphous silicon. This material is being widely used in hand calculators and other consumer goods, although it is not being used in devices that require large areas of materials. Only two problems prevent widescale use of amorphous silicon PV modules: 1) large-scale devices have been much less efficient than would be expected from the laboratory results on small test samples, and 2) larger modules have not yet demonstrated the stability, reliability and life needed in power generation applications.

It has taken more than 10 years for manufacturers of the crystalline silicon PV cells to develop and demonstrate ways of manufacturing and packaging that allow for long, stable, reliable life. It may not take ten years to do the same for the thin film cells. Some homeowners will be interested in purchasing the very first thin film modules available even though these modules haven't demonstrated the reliability and life needed. Others will prefer to stick with crystalline silicon for some time to come.

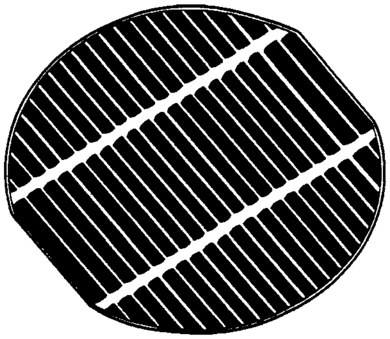
Crystalline silicon cells that are commercially available are made in three ways:

- Single crystals of silicon are drawn slowly from a pool of very pure molten silicon and allowed to cool. These single crystals are then sawed with a diamond saw into very thin slices that are processed into PV cells.
- Silicon ingots are cast from very pure silicon and cooled by various methods so that large crystals are grown in the ingot. The ingot is later sawed as above.
- A thin ribbon is drawn from the pool of pure silicon by being guided through special shaping dies in the desired thickness, which eliminates sawing required in the other two approaches.

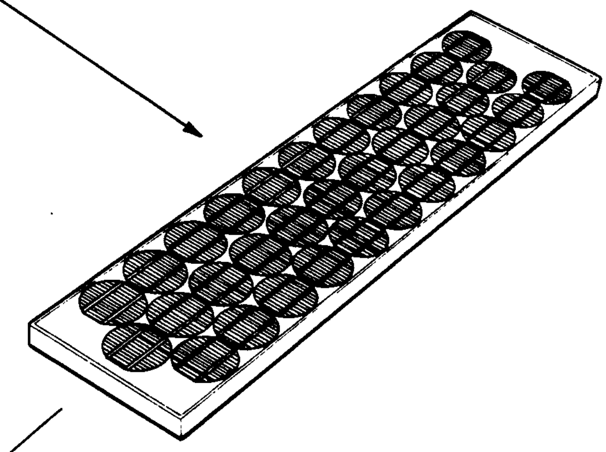
Good modules can be made by any of the three methods, and the potential buyer can use the normal criteria for making such a purchase—price, performance, warranty, and credibility of the manufacturer.

2.1 Photovoltaic System Components

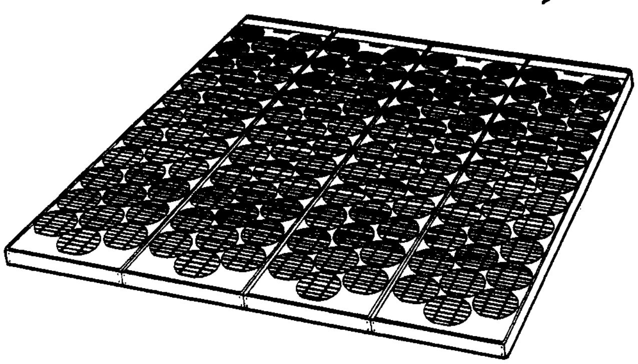
The components in a typical PV system are briefly defined below. Not all PV systems have or need all of these components, but they are defined here for your information.



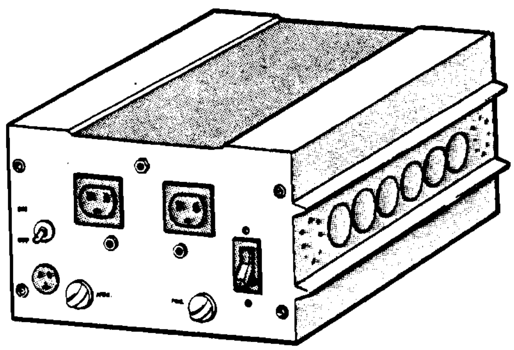
Photovoltaic Cells are discs or squares of specially treated silicon (or other material) that generate a DC voltage when exposed to light.



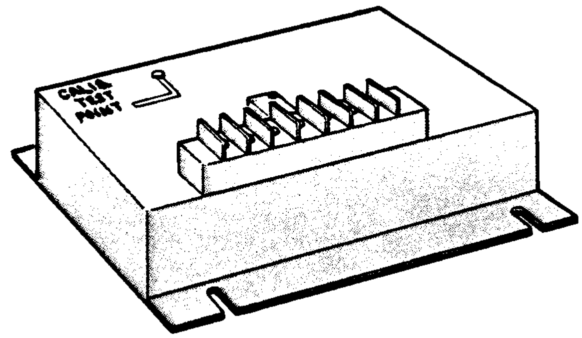
Photovoltaic Modules contain several PV cells that are sealed between metal and transparent plates. Modules are either flatplates or use special designs to concentrate the sunlight on the cells. The electrical output of the modules depends on the efficiency and number of cells.



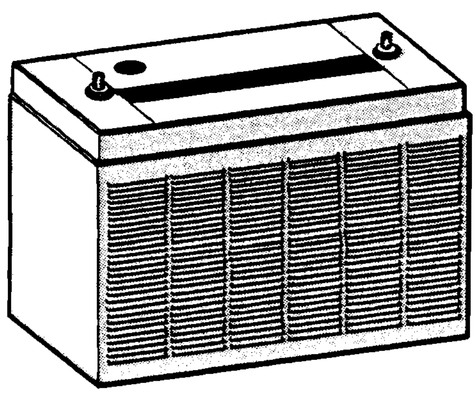
Photovoltaic Arrays are groups of PV modules connected together to produce a predetermined voltage either to be stored for future use or to be used directly (without energy storage) by a direct current (DC) appliance.



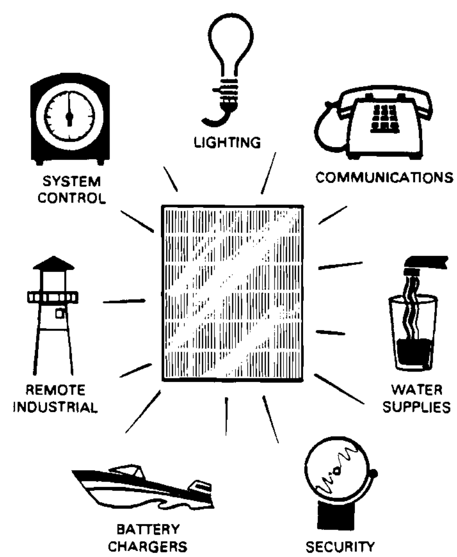
Inverters change the direct current (DC) produced by the cells or stored in the batteries to alternating current (AC) for use with AC products and appliances.



Charge Controllers protect the battery system from both excessive charge and discharge.



Energy Storage is usually done with lead acid batteries. The type and size depend on the requirements of the specific application.



End-Use equipment (that is, application) includes a wide variety of AC and DC products including fluorescent lights, refrigerators, pumps, fans, etc.

2.2 Electrical Definitions

This section defines some of the basic elements of electricity. This information will help you in reading catalogs supplied by PV manufacturers/distributors, and it will help you when expressing your energy needs to these people.

Ampere (A) is a standard unit of current. It is the rate of flow of a charge past a given point in an electrical circuit. This can be compared to the quantity of water passing by a given point in a garden hose. The two types of electrical current are direct (DC) and alternating (AC). It is not really that important to know the specific details of these currents, only that some products/appliances operate strictly on DC or AC and some, such as portable TV sets and certain universal (brush type) motors, can run on either.

Lumen (lm) is a measurement of the amount of light produced by an incandescent or fluorescent light bulb. A 100-W incandescent light bulb produces about 2000 lumens of light.

Voltage (V) is the force that causes the current to flow through a wire. Most automobile batteries are either 6 or 12 volts.

Watt (W) is a unit of power. One watt is the amount of power that is supplied when a current of one ampere is driven by a potential force of one volt. If you look at a typical light bulb, it will state that it requires 25, 50 or 100 W of power to operate. A watt is **not** a measurement of the amount of light given off by a light bulb.

Watt-Hour (Wh) is a unit of energy measured as the product of power (that is, one watt) and time (one hour). If a 25 W light bulb is operated for one hour, it will use 25 Wh of electricity.

Ampere-Hour (Ah) is sometimes used as a unit of energy where voltage is fairly constant. For instance, storage batteries have a fairly constant voltage and are frequently rated in terms of ampere hours of capacity. Similarly, an electric clock requires a fairly constant current and its energy requirements can also be specified in Ah. Ampere-hours can be changed to watt hours by multiplying by the voltage of the system. In a 6-V system with 2 Ah of capacity, the total would be 6 x 2 = 12 WATT HOURS of energy. In a 12-V system with 2 Ah of capacity, there would be 24 WATT HOURS of energy.

3.0 READY-TO-USE PHOTOVOLTAIC PRODUCTS AND SYSTEMS

This chapter is written for people who want the conveniences of modern electric living and a) own recreational vehicles or water craft, b) own a remote retreat home or live in a locality where there is no dependable utility, or c) would like to achieve some energy independence by using a renewable energy resource. The chapter is also written for farmers, industrialists, and construction workers who want to use electrical or electronic equipment away from power lines. One can watch television, read at night, wash clothes, drink pure water, keep food and medicines fresh, and stay cool in hot weather by using products that are powered by photovoltaics without depending on an electric utility system. Remote communications, corrosion protection, crop irrigation, and stock watering are other examples of modern PV use.

The following sections give an idea of the various types of PV products and systems currently available off-the-shelf. These PV systems are pre-engineered to meet specific end uses and include all the components necessary to be placed into immediate service. The PV systems have been sorted into four categories: products without batteries, battery chargers, power packages, and home electric systems. For each, we discuss typical applications and list the types of products available. Approximate prices are often given but in an age of continuing inflation, they can quickly be out-of-date. Before buying one of these PV products or systems, you should contact the manufacturer for additional product information.

3.1 Products Without Batteries

Some electrical needs occur, or can be shifted to occur, only when the sun shines. Such applications are termed "sun synchronous" and do not require the use of storage batteries. The energy is used as it is generated. Energy for cooling work and living areas, and irrigation pumping are ideal candidates for PV power supplies. Such items as attic fans, casa blanca fans, evaporative coolers for residences, circulating pumps for solar hot water heaters, and domestic or agricultural water pumps also are available with PV power supplies.

These PV applications are efficient because the electricity generated from the arrays is immediately used. For example, PV-powered exhaust fans installed in buildings, vehicles, and boats can be used to prevent overheating; the more intensely the sun shines, the more rapidly the fan removes excess heat. Furthermore, these systems are the most maintenance free and long lived because they are basically simple and free from electrical storage requirements. Table 3.1 lists some of the commercial fans available.

One attractive feature of these fans is that they can be retrofitted (or added) to existing buildings by the handyman without shock or fire hazard. Also, the cost is often lower than connecting the fans to the building's power supply. In addition, controllers are unnecessary because no batteries are used. Thus, the fans are frequently installed in grid-connected (utility-connected) houses.

TABLE 3.1
PV-Powered Vent Fans

Company	Catalog Number	Rating (CFM)[a]	Description	Price
ARCO	9310	800-1300	Attic fan	$525
Parker McCory	Parmak solar vent fan	300	8" attic fan	299
Solarex Corp.	Solarvent	350 6W 4-60 unipanel	vent fan, 5 blade, 8" dia., aluminum	300
Wm. Lamb Co.	Casa Blanca fan	2000	3-blade Casa Blanca fan	465

(a) Cubic feet per minute.

Another battery-free product contributing to living comfort is the PV-powered evaporative cooler for cooling recreational vehicles and residences. The two sizes presently available with matched PV components are listed in Table 3.2.

A PV-powered circulating pump for a conventional solar thermal collector may improve the collector's performance and reliability. It does this by circulating the fluid rapidly through the collector when the sun is at full brightness and by pumping slowly when the sun is partly obscured. This "proportional control" is said to enhance the efficiency of a solar water heating system by as much as 15% above that possible from conventional systems using household current and temperature-sensitive instruments to provide system control. Some pumps available for this purpose with matched PV modules are listed in Table 3.3.

3.2 Battery Chargers

PV-powered battery chargers can be added to an existing battery-powered appliance or system to provide additional power and to maintain batteries at a high charge level. PV-powered battery chargers are available in various sizes and voltages to match the battery. For as little as $20, one can purchase a charger for 3, 6 or 9 volt nickel cadmium (flashlight size) batteries. Much larger systems are available for industrial or recreational use. Currently marketed battery charger systems are listed in Table 3.4.

If a back-up generator is available, you do not have to precisely size the PV battery

TABLE 3.2
Evaporative Coolers with Matched PV Power Supplies

Company	Rating	Description	Price
Wm. Lamb Co.	1800-2000 CFM	Residential evaporative cooler with 3, M61 PV panels	$1,150
Wm. Lamb Co.	5000 CFM 1/2 hp fan motor with circulating pump	Residential evaporative cooler using DC motors	7,200

TABLE 3.3
PV Pumping Systems

Company	Catalog Number	Rating[a]	Description	Price
A.Y. McDonald	150103DJK, DDK	60 ft wells	1 PV panel, 1 centrifugal pump, 1 jet injector, 2 deep-cycle storage batteries	1,895
A.Y. McDonald	820305DS	1500 GPH @ 25 ft	8 PV panels, but no batteries	4,500
Milton Roy	CP-10B-12DC	2 GPM @ 7ft and 12V	PV-powered DC circulating pump	93
Pulstar Corp.	Pulstar System 1	3.5 GPM	Solarex PV modules (7 or 9 W) to circulate water in solar thermal DHW systems	499
Solarwest Electric	Sunmill 1	700 GPD @ 100 ft	1 Sunmill pump, 4 ASI 16-2000 modules, 1 Sunmill controller, module pole mount, connecting wires	$4,599
Solarwest Electric	Sunmill 2	1000 GPD @ 100 ft	1 Sunmill pump, 6 ASI 16-2000 modules, 1 Sunmill controller, module pole mount, connecting wires	5,514
TriSolar Corp.	Jack pump series	up to 10,000 GPD @ 150 ft	PV-powered Jack pump	Starts at 4,500
TriSolar Corp.	Centrifugal pump systems	up to 6,000 GPD @ 13 ft	Centrifugal pump for livestock or irrigation	Starts at 5,000

(a) GPD = gallons per day
GPH = gallons per hour
GPM = gallons per minute.

TABLE 3.4
PV-Powered Battery Chargers

Applications	Company	Catalog Number	Description	Price
Railroad crossings	Solarex	1800/12	1, 18-W panel with pole-mounting set, 2 blocking diodes, 2 Exide batteries	$ 510
Marine environment	Tideland Signal	MG 650	0.6 A @ 6 V	
Marine environment	Free Energy Systems	129 SL	0.6 A @ 14 V	369
Battery charging	ARCO	GS-8-48	240 W, 6 M61-modules, 8 Trojan batteries, Best inverter	9,082
RV charger	Solarwest Electric	RV charger	1 M81 panel, 2 to 3 Ah per day	185
Harsh environments	Solec	Solar charger 2	30 W	595

charger. You can start with a small PV unit and add more modules if desired. One caution is in order—you may save money by buying one charge controller large enough to handle the final number of modules desired. Adding PV modules would then be fairly simple as long as you don't exceed the rated capacity of the charge controller and wiring or the batteries' charging rate.

3.3 PV-Powered Packages

PV-powered packages consist of panels, storage batteries, and power conditioning equipment such as an inverter. These systems are available from various sources in many sizes. Their performance depends on the type of electrical needs and the amount of sunshine available.

Two basic types of power packages are available—those that provide only direct current (DC) and those that also provide alternating current (AC). The major difference between the systems is an "inverter", which converts DC to AC power. Because of the power requirement of the inverter, AC systems are significantly less efficient than their DC counterparts. For more detailed information on inverter efficiencies, see Section 4.5.

When selecting a PV power package, several key issues must be considered besides determining if AC or DC power is needed:

- the expected peak load
- the average energy requirements
- the expected climate conditions
- the required system reliability.

The storage and power conditioning systems must be large enough to handle the maximum or peak load. In the case of AC power, peak load usually occurs when electric motors are started—check the "surge" power requirements to determine peak load. In the case of DC power, peak load is the sum of the appliance ratings that will be used at the same time. Not only must this peak be met by storage, but the daily and seasonal average power requirements must be considered to insure that the batteries are kept at a satisfactory level of charge.

Two climatic factors are of primary importance: the expected sunshine intensity (solar insolation), and the expected temperature extremes. Obviously, the amount of sunshine available will determine what size PV array is needed. Temperature also is important because it affects the performance of the array and the storage systems. If freezing conditions are expected, the batteries must be suitably protected.

Finally, the required system reliability must be considered. If power is needed for essential uses such as navigational or safety lighting, the system must be oversized to insure that enough power is available under any circumstances, such as extended cloudy periods. PV systems for such applications should be discussed with a supplier who understands potential liability risks. On the other hand, if the system is used for recreational purposes or intermittent applications, oversizing might not be economically attractive. The sizing of PV power packages is therefore very important and must be done properly. A report by NASA Lewis, DOE/NASA/ 019581/1, *PV Stand Alone Systems Preliminary Engineering Design Handbook*, will be helpful in determining proper sizing. A preliminary or "first-cut" sizing procedure is outlined in Chapter 4. In the following two subsections, DC and AC power packages are discussed separately.

3.3.1 DC Power Packages

Most suppliers of PV modules have sold many custom-designed DC power packages. Currently, however, several companies offer standard DC systems shown in Figure 3.1. Most module manufacturers will help potential buyers to design a PV system to meet

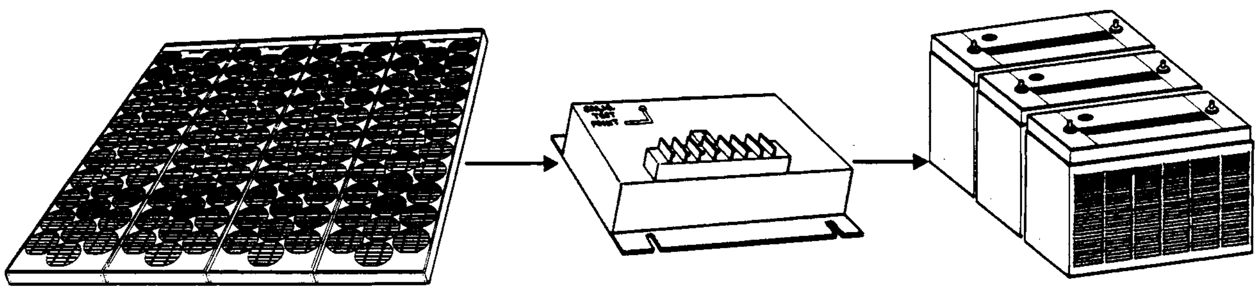


FIGURE 3.1 DC Power Package

their personal needs. However, this section considers only those systems available off-the-shelf.

Many common AC home appliances cannot be used with a DC power system unless a DC to AC inverter is purchased. However, a growing number of DC appliances are available and are discussed in Section 4.2.

Purchasing a PV power package and using it for various purposes is quite straightforward. The power packages work in any climate, although the energy output is directly related to the amount of sunshine striking the panels. Obviously, in northern climates the systems can supply more power in the summer than in the winter. As long as the electrical needs are adjustable and the user can tolerate reduced availabilities during periods of low insolation, the performance information supplied by the system manufacturer may be sufficient to size a satisfactory system.

These DC systems are intended to supply power where it is inconvenient or excessively expensive to make a connection to a utility grid. To connect an individual user to utility lines usually costs more than $20,000 per mile, and often the lines are maintained at the buyer's expense. With the current tax credit situation, you can install a modest-sized solar electric generator system and have no subsequent utility bills for a comparable investment. It is particularly attractive to install a modest system and add capacity each year while the tax credit lasts. The economic benefits of such a strategy are discussed in detail in Chapter 5, and additional information on state tax credits is provided in Appendix I.

These PV power packages are rated in their ability to satisfy a given load measured in ampere hours (or watt hours) per day or week. For help with estimating your expected power needs, see Section 4.1. Most of the currently available PV power packages are rated far below the average electrical requirements of conventional residences. This is a consequence of the currently relatively high price of PV power compared to that available from utility grids. It makes more economic sense to first make small PV purchases to reduce your electrical needs than to purchase huge PV arrays initially to eliminate your electrical needs. Table 3.5 lists some DC power packages currently available.

3.3.2 AC Power Packages

With an adequately sized AC power package (Figure 3.2), a consumer can operate conventional household appliances. Special AC power packages can be designed to connect to the electric utility supply lines so that excess power can be sold to the utility (with utility approval). These will become more

TABLE 3.5
DC Power Packages

Company	Catalog Number	Peak Power	Description	Price
ARCO	DC-1-12	30 W	1 M61 Module, 1 Delco battery	$ 829
ARCO	DC-2-12	60 W	2 M61 modules, 2 Delco 2000 batteries	1,364
ARCO	DC-4-12	120 W	4 M61 modules, 4 Delco 2000 batteries	2,434
ARCO	DC-6-12	180 W	6 M61 modules, 6 Delco 2000 batteries	3,504
ARCO	DC-8-12	240 W	8 M61 modules, 8 Delco 2000 batteries	4,574
Acurex Solar Corporation	10 kW DC starter	10 kW DC	A 10-kW DC starter system that can be scaled down to a 4 kW DC	Contact manuf.
Solarex	SHP-12-4	144 W	4 36-W modules, 4 Delco 2000 batteries, charge controller	2,495
Tideland Signal	SV-3U	2 Ah/day • 6 or 12V	Used on navigational aids	533
Tideland Signal	SSV-72US	33 Ah/day • 12 V (other voltages available)	Also available in 6-, 18- or 24-V models	8,082
Tri Solar Corporation	HES 12-5	200 W	5 40-W modules, 4 batteries	Contact manuf.

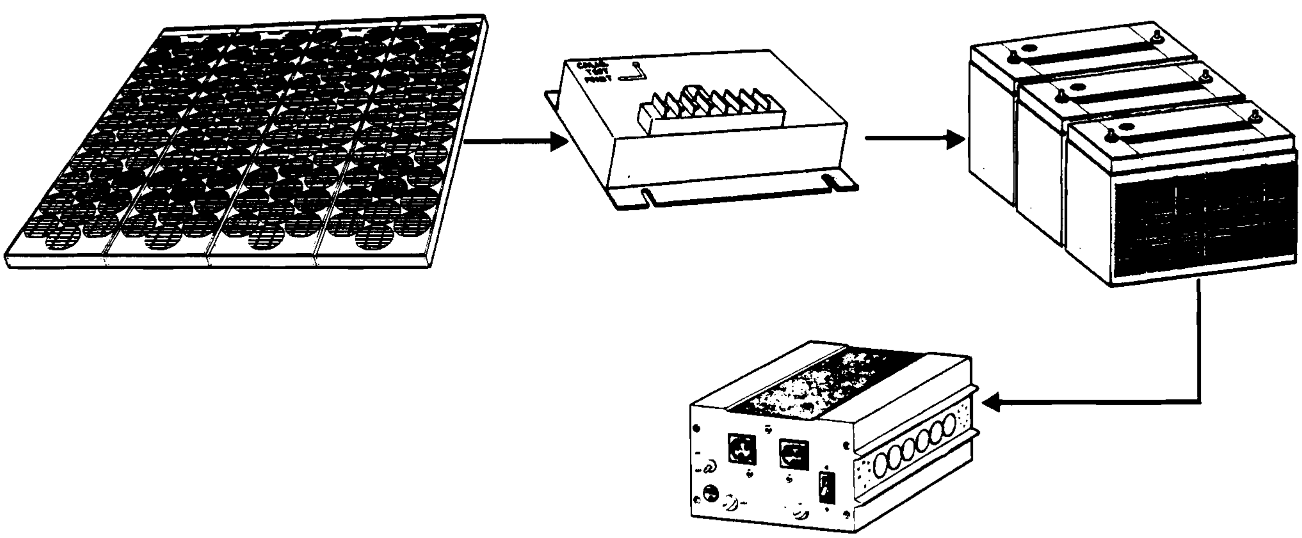


FIGURE 3.2 AC Power Package

common in the future, but presently only a few are available through ARCO Solar distributors. Most of the PV systems listed in this section are **not** intended to connect to conventional AC power grids (Table 3.6).

An AC power package typically costs more than DC counterparts for three reasons: a) there is the added cost of an inverter, b) PV array sizes and battery storage must be increased 15% or more to make up for inverter losses, and c) typical AC appliances have been designed with little regard for energy efficiency. For example, a typical incandescent AC-powered light bulb requires 100 W of power, whereas a highly efficient special DC-powered fluorescent bulb requires about 25 W to supply the same amount of light.

Although a 12-V DC system is the least costly and most energy-efficient approach to energy independence, many people want to use AC appliances that they already own, such as TV consoles, sophisticated stereo equipment, vacuum cleaners, hair dryers, etc. Because all of the AC power packages use the DC power supplied by the PV panels, it is possible and indeed may be advantageous to investigate the possibility of installing a hybrid (mixed) AC/DC system.

Ideally, a hybrid would supply DC power to everything except those appliances that require an AC power supply. This would minimize inverter cost and power losses. Because inverters consume power even if no power is being drawn from them, it is important either to place the inverters so they can be easily turned off or to use remote or automatic switching mechanisms. If you are considering a hybrid system, make sure that the DC power is available at 12 V.

3.4 Home-Electric Systems

Home-electric systems are comprised of the components in the power packages listed above as well as one or more matched appliances (Figure 3.3). A home-electric system is an especially easy way to get started with PV. Table 3.7 lists some of the home-electric power packages that are available.

If a particular appliance package is not listed in this table, contact one or several of the companies listed because a wide range of home-electric packages is available.

TABLE 3.6
AC Power Packages

Company	Catalog Number	Peak Power (watts)	Description	Price
ARCO	AC-8-24	240	8 M61 modules, 8 Delco batteries, 1 Best M24-2500 inverter	$ 7,006
ARCO	AC-16-24	480	16 M61 modules, 16 Delco batteries, 1 Best M24-2500 inverter	11,251
ARCO	AC-20-24	600	20 M61 modules, 20 Delco batteries, 1 Best M24-2500 inverter	13,379
ARCO	AC-24-24	720	24 M61 modules, 24 Delco batteries, 1 Best M24-2500 inverter	15,501
ARCO	LT-15-240	600	15 M53 modules, Sunshine inverter, grounding unit, support structure, no batteries because it is a utility-connected system	14,112

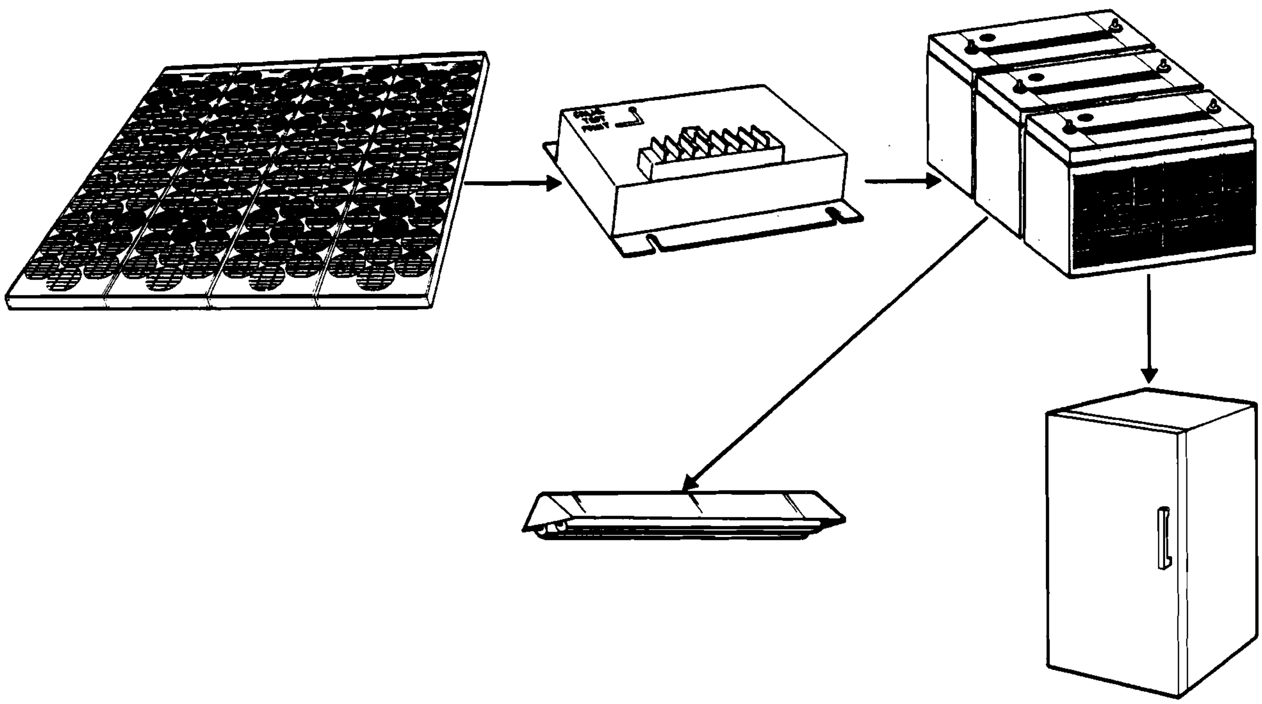


FIGURE 3.3 Home-Electric System

TABLE 3.7
Home-Electric Power Packages

Manufacturer	Catalog Number	Appliance	Description	Price
Free Energy Systems	Light	Fluorescent light	1 PV module, 1 28-Ah gel cell battery, 1 8-V, 12-W fluorescent light	$ 350
Polar Products	RR-22	Refrigerator	127 liter capacity includes refrig., PV modules, battery bank and wiring	3,400
Solarex	RHC-100	Refrigerator/freezer	3 65-W powerline PV modules, 1 100-liter refrig/freezer, mounting hardware & interconnects, 2 PV batteries	5,000
Solavolt	MSPL40R26	Fluorescent lights	1 40-W module, 1 Delco 2000 battery, 1 26-W light	756
Solavolt	MSP5R160	Refrigerator	4 40-W PV panels, 3 Delco 2000 batteries, 1 voltage regulator, wiring & structures, 1 4-cu ft refrig.	4,000
Solarwest Electric	Light	Fluorescent light	1 15-W light, 1 35-W PV module, 1 Delco 2000 battery, 1 controller	675

3.5 Specialized PV Products

Table 3.8 lists some specialized off-the-shelf products that use PV power sources. The list includes several novelty items, educational items, and other particularly useful PV applications.

3.6 Custom-Built Components and Systems

Since the mid-1970s, the federal government and the U.S. PV industry have worked together to produce low-cost, high-efficiency PV systems. The federal government has spent more than $670 million for PV research and development.

With about 60% of the world market, the U.S. PV industry is established as the world leader in photovoltaics. The industry has this leadership mainly because it developed cost-competitive systems for remote applications. The industry has been extremely responsive to consumers needs and has developed a variety of off-the-shelf components and systems. However, in some applications, off-the-shelf items won't work. In these cases, several options exist: a) purchase a special-order system, b) design and build your own custom system, or c) have someone else design and build a custom system.

This section describes a few of the many custom PV systems already in operation to give the reader an idea of the flexibility and ingenuity of the PV industry. We also list PV firms who have expressed the capability to provide custom systems.

3.6.1 Custom Systems Currently in Operation

Currently, there are literally thousands of custom PV systems operating in the U.S. Many of the smaller-scale systems have been funded through the Federal Photovoltaic Utilization Program (FPUP). The purpose of this program has been to develop the PV technology by establishing demonstration sites that will provide performance information to help direct future R&D efforts. Table 3.9 lists some of the systems funded through FPUP.

Other experiments have installed medium- and large-scale custom systems. Some of the applications of these systems are listed in Table 3.10.

The following are brief descriptions of a few custom systems:

TABLE 3.8
Specialty PV Appliances

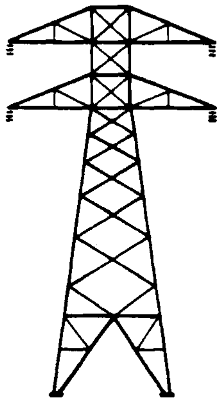
Manufacturer	Appliance	Description	Price
Braden Wire & Metal Products	Solar game feeder	—	$215
Parmak	Fence charger	Controls up to 25 miles of fence. Will operate for 21 days in total darkness	180
Solarex	AM/FM radio	4.5 V operation from 2 rechargeable AA batteries	30
Solarex	Flashlight	170 mA, uses 2 D-size batteries	39
Solarex	SolAir Cool Safari Hat	PV-powered fan with batteries for indoor operation	80

TABLE 3.9
Small-Sized Custom Systems Funded Through FPUP

	Peak Power (kWp)	Total Systems
Residential Sector		
Grid-connected homes	2-20	2
Individual homes	1-25	232
Other residences	0.1-8.5	22
Water pumps	0.2-10	43
Commercial Sector		
Radiation samplers	0.04-3	30
Visibility monitors	1.5	6
Noise monitors	0.01	2
Navigational beacons	1	18
Weather monitors	1	4
Particulate sensors	0.4-10.5	30
Meteorological sensors	1	325
Military ammunition security		122
Electric fence	1	1
Intrusion detectors		6
Cathodic protection		
Power line towers	1	12
Submarine cables	1	12
Transportation Sector		
Beacons	0.02-3	1,427
Buoys	0.05	3
Anemometer	0.004	1
Moving-target indicators	1	41
Radar beacons	1	9
Aircraft arresting systems	1	2
Astronomical monitor	0.5	1
Flash beacons	0.1-1.5	12
Remote-instrument platforms	0.5-9	33
Starpex beacon	1	1
Agricultural Sector		
Forest lookout towers	1	67
Repeaters, special purpose	0.01-1.2	35
Venting systems, sanitation	1	248
Miscellaneous	0.2-25	29
TOTAL		2,772 Systems

TABLE 3.10
Intermediate-Sized Custom Systems

Location	Peak Power (kW)
Wilcox Hospital/Acurex Kauai, Hawaii	35
Sky Harbor Airport/ Arizona Public Service Phoenix, Arizona	225
BDM Corporation Albuquerque, New Mexico	50
E Systems Dallas, Texas	27
Lovington Shopping Center/ Lea Country Electric Lovington, New Mexico	100
El Paso Electric/ New Mexico State University El Paso, Texas	17
Oklahoma Center for Science and Arts/Science Applications, Inc. Oklahoma City, Oklahoma	135
Beverly High School/Solar Power Beverly, Massachusetts	100
San Bernardino Concrete Plant San Bernardino, California	35
WBNO Radio Station Bryan, Ohio	15
Irrigation & Crop Drying Mead, Nebraska	25
Air Force Station Ft. Belvoir, Virginia	60
College Power System Mississippi Country Community College Blythesville, Arkansas	250
N.W. Mississippi Junior College Senatobia, Mississippi	100
Remote Stand Alone Power System Natural Bridges National Monument Blanding, Utah	100

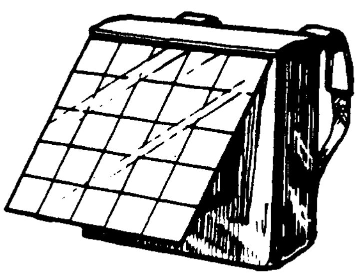


- **Solar-powered warning lights for transmission towers, Bonneville Power Administration (BPA) in Washington, Oregon and Idaho**

  Using Solarex PV arrays, the DOE and BPA have installed PV warning lights on several transmission towers in Washington, Oregon, and Idaho. A battery storage system with a capacity of 500 Ah is also used. This is a more cost-effective system than other energy approaches. BPA has installed an Ah monitoring device to see if the size of the present system could be reduced.

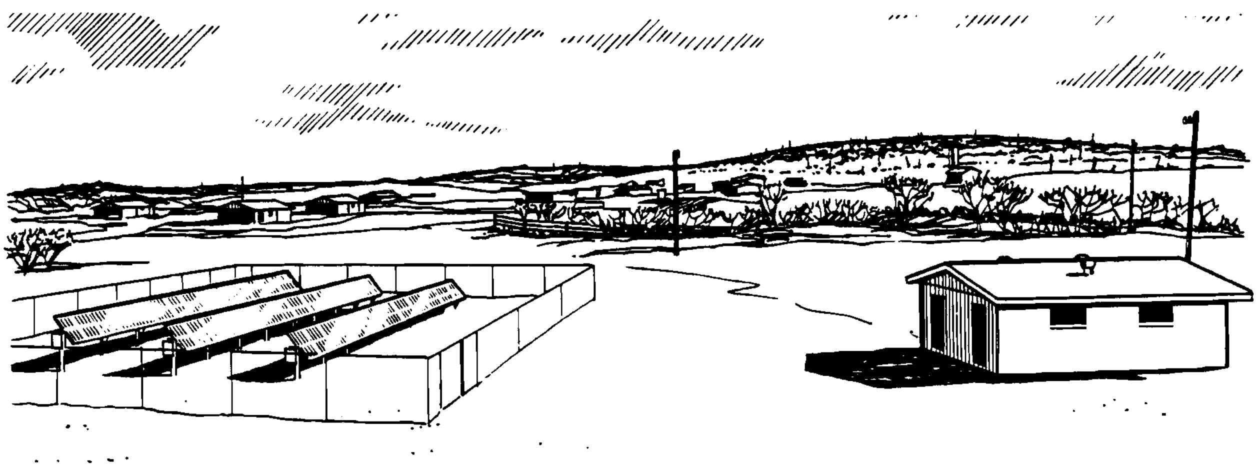
- **Solar-powered forest lookout towers, Lassen National Forest, California**

  The U.S. Forest Service has installed a 294-W, 12-V (DC) PV array on two lookout towers. These systems are used to power a 3-cubic foot refrigerator, fluorescent lights, a USFS radio, a bilge pump, and a 12-V (DC) television set. These systems have been in operation since 1976.



- **Solar-powered backpack, Environmental Protection Agency**

  The Environmental Protection Agency developed a PV-powered backpack unit as a power supply for various types of remote instrumentation. The unit is a Solarex PV panel that can provide up to 120 W and more if interconnecting units are added. Such a unit could easily be used for other remote applications.



• **Solar-powered indian village, Papago Indian Village of Schuchuli in Southwestern Arizona**

Since 1978, the 15 families of the Papago Indian Village of Schuchuli have had their power needs met by a PV system. The 3.5 kW system provides electricity for a water pump, refrigerators, clothes washer, sewing machine and fluorescent lights. In all cases, energy-efficient appliances were chosen.

Most individuals' energy needs will be met with components or systems already designed and built for similar applications. It may take a little time and a few telephone calls, but the chances are that your unique energy need is not unique. You may find that a PV firm designed and built a custom system a few years ago for someone else's unique need, and that this firm now offers this system on special order. However, if your energy need cannot be met with off-the-shelf or special-order systems, many companies within the PV industry will be willing to design and build a custom system. Remember, the design services provided by PV firms are usually not free, and you will be paying more (at least initially) for the custom-built system than you would for an off-the-shelf system. Ask for a cost estimate before any work is done. Then, seriously consider the tradeoffs involved in having a custom system designed and built. Remember, it does pay to shop around!

Table 3.11 lists PV companies that indicated that they will either design and build custom systems or have systems that can be special ordered.

TABLE 3.11.
Firms Offering Custom-Built or Specialty Components or Systems

Company	Custom Component/System
AAI Corporation	Modules
Abacus	DC to DC converters
Acurex Solar	Concentrating collectors
Applied Solar Energy Corporation	Concentrating collectors
ARTU	AC power systems & special DC to AC inverters
A.Y. McDonald	Water pumping systems
Free Energy Systems	PV modules & refrigeration, lighting, & communications systems
General Electric	Modules and systems
Globe	Batteries and hardware
Helionetics	Inverters
IOTA Engineering	DC ballasts
Jim Cullen	System design
March Manufacturing	Pumps
Milton Roy Company	Pumps
Mobil Solar	Systems
Solavolt	Power systems
Parker McCrory	Panels
Photon Power	Arrays
Photovoltaic Energy Systems, Inc.	Consulting and energy information products
Roger R. Ethier Assoc.	System design
Silicon Sensors, Inc.	Arrays
Solar Contractor's Inc.	PV systems
Solar Energy Corp.	Modules
Solar Power Corporation	PV systems
Solar Usage Now	Remote water pumping systems
Solarex	General applications assistance
Solarwest Electric	AC & DC power packages
Solenergy Corp.	Modules, arrays, PV systems, cells
Spire	PV process equipment, assembling PV modules
Teledyne Inet	Inverters
Tideland Signal	DC power packages
Tri Solar Corporation	Irrigation systems, home-electric systems
United Energy Corp.	Modules and systems
Windworks	Power conditioning equipment
Zomeworks	Passive solar trackers

4.0 BUILDING YOUR OWN SYSTEM

The purpose of this chapter is to help you estimate your energy needs and to begin the design of a PV energy system to meet these needs. After going through this procedure, you may discover that a PV system is not the most suitable power source for your needs. Before making this decision, you should also read Chapters 6.0 and 7.0. Chapter 6.0 discusses the usefulness of a PV system, depending on your estimated needs and Chapter 7.0 reports users' actual experiences with PV.

Many users who did not follow the procedure in this chapter are happy with PV electric systems (see Chapter 7). Instead of estimating their needs, they started with what they could afford. However, if your energy requirements are demanding and inflexible, this procedure can be helpful but must be used only as a preliminary guide. Before selecting a PV system, you should contact several PV manufacturers to see or discuss their systems. Upon request, most PV manufacturers will supply design guides that are tailored to their products or will assist serious inquirers in designing their systems with the use of sophisticated computer techniques. This service is extremely valuable and should be used after you have estimated your needs using the process outlined here. The information in this chapter will help you to understand the design process, will help you to assess the appropriateness of a PV system, and will help you talk to suppliers.

To design your own PV system you should follow the steps below:

1. evaluate your energy needs
2. select appropriate appliances
3. choose the type and size of array
4. choose the type and size of battery
5. select power conditioning equipment
6. review your energy needs and design the PV system.

Although the process has several steps, the arithmetic is simple and the procedure should be easy to follow for most readers. The best approach is to do a rough estimate first and then refine the calculations the second time.

In this discussion we do not emphasize applications such as warning beacons, navigational aids, etc. because they are outside the scope of this effort. There are companies who understand these kinds of applications and sell complete systems. Two companies with experience in this field are Automatic Power (a Division of Pennwalt Corporation) and Tideland Signal Corporation. Properly designed PV systems are reported to be the most reliable power source in these applications, but designing these applications is not for the amateur.

4.1 Evaluation of Energy Needs

The key task in designing your own system is deciding how large a system you need or want. In practical terms, you will have to decide on the size of both your initial system and your ultimate system. Although most Americans use large amounts of electricity (particularly by world standards), very few know how much energy is used for particular applications. This is understandable since electricity, in this country, is about the cheapest in the world and is widely available. However, because electricity rates have increased rapidly, analyzing your energy needs is useful, even if you are not planning a PV installation.

Another result of cheap electricity has been an apparent lack of concern about the energy efficiency of products. Increasing the energy efficiency of most appliances adds to their price; however, the value of the energy saved over the product's lifetime usually is more than the added initial cost. Therefore, when selecting new appliances for PV systems, energy-efficient appliances are highly recommended. Refer to Section 4.2 for more information on appliance energy use.

To evaluate your energy needs, the following information is necessary:

- the power requirements of the appliances
- the expected daily length of use for the appliances
- the comparative need or priority of appliance use
- the scheduling of appliance use (daytime or nighttime).

As you may recall from Chapter 2.0, a watt-hour is a unit of energy equal to applying one watt of power for one hour. Because our goal is to determine the average number of watt hours required per day, we need to know the input power requirements (watts) of the appliances to be used, and we need to estimate the average number of hours they are used each day. Multiplying these two factors gives you the estimate of watt-hours needed per day.

We suggest that you use the format shown in Table 4.1 to figure your energy requirements and to categorize the relative level of need. Before filling out this form in earnest, we recommend that you pencil in the information and finish reading this chapter so that you have an idea how appliance selection and scheduling will affect the PV system's size and cost.

The power requirements (in terms of watts) of most appliances can usually be found in writing on the back of the appliance, in an owner's handbook, or from a specification's sheet (see Table 4.2 for some typical power requirements) . Some appliances are rated in terms of amps at a specified voltage. In this case, the watts can be estimated by multiplying the figures (i.e., amps x voltage = watts). An important distinction to be made is whether the appliance requires AC or DC power. **If you list AC equipment, you must add 15% to the power requirement of the appliance to power the inverter that will be required in a PV power system.** Enter the name and power requirements of the appliances you intend to use with a PV system in a form like Table 4.1.

You must also list the AC inverter as an appliance because it will draw standby power even when it is connected to a battery, although no appliance is being used. Standby power can be considerable but can be avoided in two ways. First you can use a "demand start" model, which automatically turns the inverter on or off when the appliance is turned on or off. Or, you can turn the inverter on and off manually. (See Section 4.5.2 for a more detailed discussion).

The next step requires you to classify the power requirements and estimate the average daily hours of need. You can define the classes of power requirements however you wish, so long as you recognize that all uses are not equally important. The classifications we suggest are as follows:

Class I: Essential Uses not easily scheduled, such as refrigeration

Class II: Priority Uses, such as exhaust fans and appliances

Class III: Optional Uses, such as power tools and entertainment equipment

TABLE 4.1
Estimate of PV System Size

Appliance	Power Req.	Daily Energy Requirement (W/hrs) Class I (Essential)	Class II (Priority)	Class III (Optional)	Percent w/o Sun	Storage Req.
DC Powered						
DC TOTALS						
AC Powered						
AC TOTALS						

Power Conditioning
Peak Demands (watts): ________ Inverter Capacity: ________

Battery Sizing
Storage Req.: ________ watt-hours Depth of Charge Limit: ________
Number of Days Storage: ________ Battery Capacity Req.: ________

Array Sizing
Average Daily Load: ________ watt-hours Sun hours per day: ________
Storage Req X .2: ________ watt-hours Array Size (watts): ________
Adjusted Total: ________ watt-hours Module Req: ________

TABLE 4.2
Power Requirements for Common Appliances

Appliance	Power Requirement
High-Efficiency 12-V DC Fluorescent	
• 3000 lumens (approx. equal to 150 W bulb)	36 W
• 2000 lumens (approx. equal to 100 W bulb)	24 W
• 1500 lumens (approx. equal to 75 W bulb)	18 W
Medium-efficiency 12-V DC fluorescent	
• 1700 lumens (slightly more than 75 W bulb)	26 W
Standard Light Bulb (at 20 lumens/W)	
• 2000 lumens (example)	100 W
Ovens	
• Microwave oven (120 V AC)	1.35 kW
• Typical electric range (120 V AC)	10 kW
Refrigerators	
• 7.1 cu ft, 12 V DC	60 W
• Standard 120 V AC	500 W
Stereo	
• DC Car Type	15 W
• Home Stereo (AC)	50 W
Evaporative Coolers	
• 5500 CFM	455 W
• 1200 CFM	70 W
Small Household Appliances	
• Coffee perculator, 115 V AC	1300 W
• Mr. Coffee, 120 V AC	1625 W
• Color TV	60-300 W[(a)]
• Toaster	750-1200 W
• Washing Machine	300-600 W
• Fan (small)	25 W
• C.B. Radio, 12 V	12 W (transmit)
• Vacuum cleaner, AC	700 W
• Hair dryer, AC	1400 W

(a) Varies considerably depending on size and model.

The procedure is then to estimate the hours of appliance use in each of the classes, multiply by the power requirement and enter the figure under the appropriate use column.

In some cases entries will be more involved than it first seems. Although refrigerators are used 24 hours/day, they typically draw current for only 6 to 12 hours/day depending upon the refrigerator and the usage. The energy-efficiency labels required on new appliances by the Federal Trade Commission may be of help to complete this table. Section 4.2 on appliance selection will help you estimate the energy needs of appliances or to see how yours compares with energy-efficient ones. You should contact several appliance manufacturers to compare appliance efficiency.

Some appliances draw so little current that you don't need to worry about them, or their period of use is so short that their average power consumption is negligible. For example, electric clocks draw very little current, and garbage disposals are used for very short periods. However, it doesn't hurt to list them because you may need to account for them when sizing power conditioning equipment (for example, inverters).

The timing of appliance use is important because it affects the size of battery storage and the capacity requirements of the power system. For each item in your appliance list, estimate what percentage of the time they will be used when the sun **isn't** shining. You must decide what classes of use you will include when you calculate storage requirements, but we suggest the sum of Classes I and II. Multiplying this percentage times the daily use for each appliance and then totaling them provides a basis for estimating battery storage capacity. The smaller the number, the smaller the battery requirements and cost. Therefore, some lifestyle changes that permit daytime use of the system may reduce overall system cost. This effect is discussed in more detail in Section 4.3.

Table 4.3 shows one example of appliance scheduling. In this example, a 50-W AC B&W television set is used. If you consider it **essential** to watch 2 hours during the daytime and place a **priority** on watching 2 more hours in the evening, then your entry would appear as shown in the table.

Appliance scheduling will also affect the peak demands on the system and, therefore, its capacity rating. The peak demand on the system will occur when the maximum number of watts is drawn at one time. To determine this figure, you must anticipate which appliances will be used at the same time. Typically, the lower the capacity rating,

TABLE 4.3
Example PV System Entry

Appliance	Power Req. (W)	Daily Energy Requirement (W/hrs) Class I	Class II	Class III	Percent w/o Sun	Storage Req.
AC Powered						
B&W Television	50(a)	115	115		50	115

(a) 15% is added for inverter power for AC appliances.

the lower the system costs. Another factor that cannot be overlooked is that many AC appliances have higher power requirements when being started than during normal operation. Where AC is used, be sure to consider the "surge" power requirements when determining system capacity. More information on this issue is given in Section 4.5.

If you've followed our suggested method, you have no doubt discovered that the arithmetic is much easier than deciding what to include. The technical aspects may be a bit confusing at first but really aren't difficult. Making this table is something you must do yourself since each item is likely to be different or unique (some people like TV, others don't, etc.). To be happy with the results, it is advisable to be realistic, **not** idealistic.

In Sections 4.3 and 4.4 we will do further calculations to finish Table 4.1. When you have completed this table, you will be more able to make several important decisions: a) Can you get along with DC alone? b) If AC is required, can small relatively inexpensive systems be used, for instance, to power a shaver or a radio? c) Do the AC needs outweigh the DC needs so much that a hybrid system will simply be a nuisance? and d) Can you start with a small system and work up in size over several years, therefore taking the fullest advantage of the tax breaks?

4.2 Appliance Selection

Selecting appliances to be powered by PV energy systems may encourage you to examine your choices more carefully than usual. The task is not complex or confusing, but does require some additional investigation into the energy efficiency and power demands of the equipment. The information in this section should help you to become an informed "comparison shopper." If you do not have the appliances you expect to use or if you realize that your present appliances require too much power, be sure to consider the following guidelines in selecting new appliances:

- whether the appliance requires AC or DC current
- the relative energy efficiency of the unit
- the power demands of the unit when it is running
- the percent of time it is actually running.

Clearly, not all appliances are alike, even though they may appear identical and offer the same features. What you don't see is the amount of energy required to operate the equipment, unless an appliance energy-efficiency label is attached. Often times you can compare the efficiency of equipment if you look in the owner's manual or on the back of the appliance for the power ratings.

DC appliances are sometimes preferred for use with power supplies. To run an AC appliance from a PV power supply, an "inverter" must be used. This inverter adds to the expense of the system and reduces the system's efficiency. One shortcoming of some DC appliances is that they may not be as efficient or durable as AC appliances, although the quality of DC appliances is rapidly improving.

Some appliances are only available with AC power requirements as yet. Therefore, either they must not be used or must be used in conjuction with an inverter. However, products for use with a DC power supply are becoming available in growing numbers, primarily because of the demand for them by boat or recreational vehicle owners. Most cities now have distributors for such equipment. We recommend that you look in the Yellow Pages under Recreational Vehicles to locate distributors in your area.

The tables that are discussed in the rest of the chapter list several appliances specifically designed for 12-V DC application. They are generally quite energy efficient. We've deliberately left out 12-V light bulbs, which are available from auto and hardware stores, because they mainly are practical for intermittent short-duty use. We've also not listed 115-V AC energy-efficient appliances beginning to appear in most product lines in ordinary stores. These appliances are typically much better than the older designs they replace, but are not generally as well suited to **small** PV power supply systems as are the DC appliances.

It is usually to your advantage to purchase the most efficient appliances available because they minimize the power supply system costs. Clearly, a balance exists between added cost for the efficient appliance and the resulting savings in power system cost. In almost all cases after you calculate your sizing needs, you will find the most efficient appliance results in the lowest total cost. An example at the end of this section will show this.

Although light fixtures are commonly sold based upon the power (watts) they consume, buyers are really interested in the amount of light (lumens) produced. A common home light bulb (incandescent type) will consume 100 W to provide 2000 lm. This means you get 20 lm/W. A common 12-V AC fluorescent fixture rated at 20 W provides about 750 lm of light or about 40 lm/W. This fixture is about twice as efficient as the incandescent bulb and furthermore, should outlast it. Very efficient DC fluorescent light fixtures, available from many RV equipment centers, can be twice as efficient as AC fluorescent lights and deliver about 80 lm/W. Those who are annoyed by the "flicker" of fluorescent lights will be glad to know that the **high-efficiency** DC fixtures operate at a "flicker rate" many times as high as conventional bulbs, which should be beyond human detection. Producers or distributors claiming to produce some DC lighting fixtures in excess of 60 lm/W are listed in Table 4.4.

One of the lamps shown in Table 4.4 converts an incandescent lamp to a fluorescent table lamp. It is especially aesthetic in that it produces a warm tone to the room while giving light for working or reading.

Refrigerators are also available with widely differing efficiencies and power

TABLE 4.4
Efficient DC Light Fixtures

Company	Catalog Number	Peak Power	Description	Price
Iota Eng. Co.	ID12-1-4/6/8	10-14 V	Iota has been acquired by Robertson Transformer Company. High wattage ballast	$15
Iota Eng. Co.	ID12-1-1-30/40	10-14 V	High wattage ballast	23
Iota Eng. Co.	Revi fixture	20 W	Dimensions 24.5" x 4.2" x 4.5", 24-V lights are also available	44
REC	110	15 W	Round 9.5" dia x 1.5" deep, approx. 70 lm/W	60
REC	147	24 W	42" long x 2.3" wide x 1.3" deep, 90 lm/W	44
REC	153	36 W	48" long x 2.75" wide x 2.4" deep, 87 lm/W	78

requirements. Although DC refrigerators typically are more expensive than the AC models currently available, they do not need inverters and therefore may be more cost effective. Also, the models that operate off of liquid propane gas (LPG) also ensure that refrigerator temperatures will be maintained regardless of the availability of sunshine or the status of the batteries. Because they don't depend on sunshine or batteries, these refrigerators can be shifted from Class I to Class II or III status (in filling out Table 4.1). Some of the DC refrigerators available are listed in Table 4.5. Additional refrigerators were included in Table 3.7. Be sure to examine the peak power demands while the compressor is running as well as the normal amount of time the compressor must run to keep the refrigerator cold.

The impact of using a conservation approach can be shown by comparing two systems. This comparison, shown in Table 4.6, involves both energy-efficient products **and** lifestyle changes to minimize energy needs. Space and water heating, cooking, and air conditioning are assumed to be provided by non-electric methods. The remaining electrical loads are estimated in Table 4.6 for standard and energy-conserving appliance use.

The tables shows that lifestyle changes and use of efficient appliances can reduce the energy requirements dramatically. Such a reduction will allow one to begin using PV systems in a modest way. The difference between standard and energy-conserving appliance use is even more impressive when the resulting costs of the needed PV energy system for each are compared.

For the example in Table 4.6, the AC PV power package AC 8-24, listed in Table 3.6, would handle the 609 Whr with more than a 50% reserve margin at a system cost of about $7,000. With standard AC appliances, three ARCO AC-24-24 would be required at a cost of about $45,000. Tax credits, which can significantly reduce PV system costs, are discussed in Chapter 5.0.

In addition to considering the amount of energy an appliance requires, you should also consider the amount of capacity needed. Some appliances require large bursts of power to get them started (AC induction motors, for example), whereas others demand relatively small amounts. The lower the capacity needed, usually the less expensive

TABLE 4.5
DC-Powered Refrigerators

Company	Catalog Number	Power Req. (watts)	Description	Price
Arctic Kold	AKSNT-5	36	5.3 cu. ft. refrigerator, 8 cu. ft. model also available	$ 628
Marvel	4RFD	72	4.5 cu. ft. refrig./freezer	815
Norcold	DE-728	84	Front-loading refrigerator, can be operated by 120-V AC or 12 V-DC, 16.5 cu. ft.	995
Norcold	DC-254	54	Front-loading refrigerator, 4.2 cu. ft.	415
Sun Frost	SF-17	120	17 cu. ft. refrig./freezer, available in 24 volt.	3,150

TABLE 4.6
Comparison of Standard and Energy-Conserving Appliance Use

Lighting	Daily Use (hrs)	AC Standard System (WHrs/day)	Energy-Conserving System 12-V DC (WHrs/day)
5-15 W Fluorescent	3	—	225
5-75 W Bulbs	3	1125	—
Refrigerator 66-W Cooling Unit	4[a]	—	264
Refrigerator Standard 500-W Unit	10[a]	5000	—
TV 12" B&W 15 W	4	—	60
TV 17" Color 50 W[b]	4	200	—
Car Stereo 15 W	4	—	60
Home Stereo 50 W	4	200	—
Dishwasher 1200 W	1	1200	—
Handwash Dishes	1	—	0
TOTAL		7725 Whrs/day	609 Whrs/day

(a) Based on approximate duty-cycle of the compressor.
(b) More energy efficient than most color TVs.

the system is to supply it. When comparing two appliances with otherwise similar features, choose the one with the lowest amperage requirement.

4.3 Array Sizing and Selection

Determining the size of the needed PV array will depend upon the average daily load on the system, the amount of inefficiency losses from the system, the average amount of sunlight available, and the back-up power supply available . Very sophisticated computer modeling techniques have been developed to calculate array and storage system size and form the basis for the hand-calculated technique described here. Some manufacturers and installers will use these computer tools to assist you in refining your design.

Return to Table 4.1 to continue calculations for estimating energy needs. To determine energy sizing, the first step is to determine a grand total for your energy needs from Table 4.1 by adding the AC and DC power requirements. Next, add 20% of the storage requirement total to account for energy losses in the battery charge/discharge cycle. Since you've already accounted for the inverter losses if any, this figure represents the adjusted average daily energy your PV array must supply if no back-up is to be used.

The next step is to consult Figures 4.1 and 4.2 to determine the effective (or equivalent) sun hours available in your climatic area. If the system is designed for year-round use and your wintertime loads must be met with the PV array alone, the array should probably be sized according to Figure 4.2,

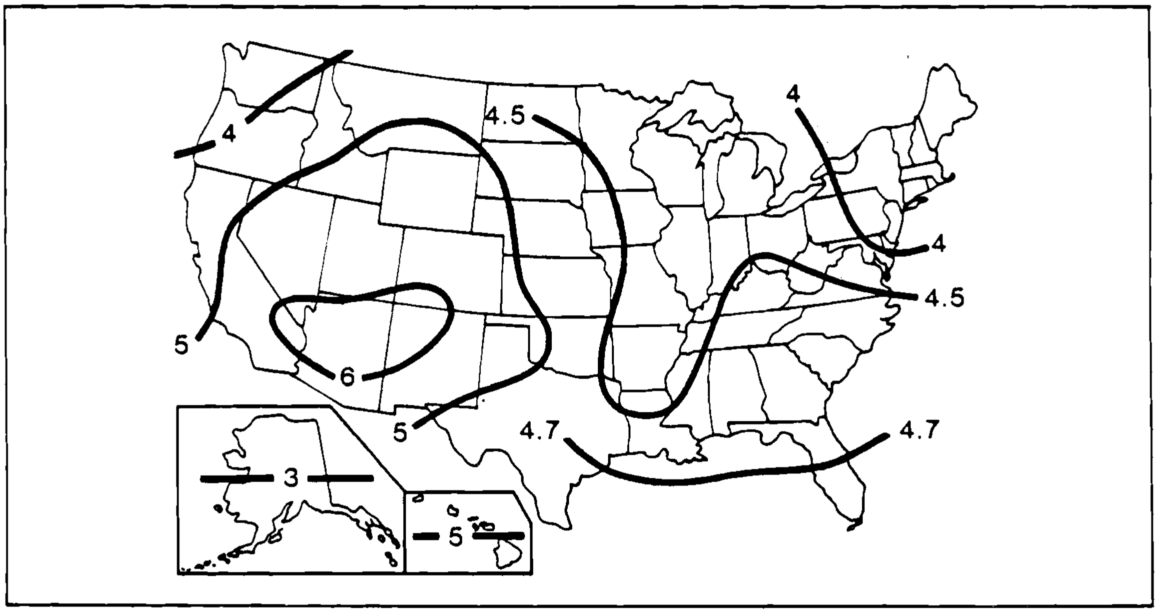


FIGURE 4.1. Peak Sun Hours Per Day - Yearly Average

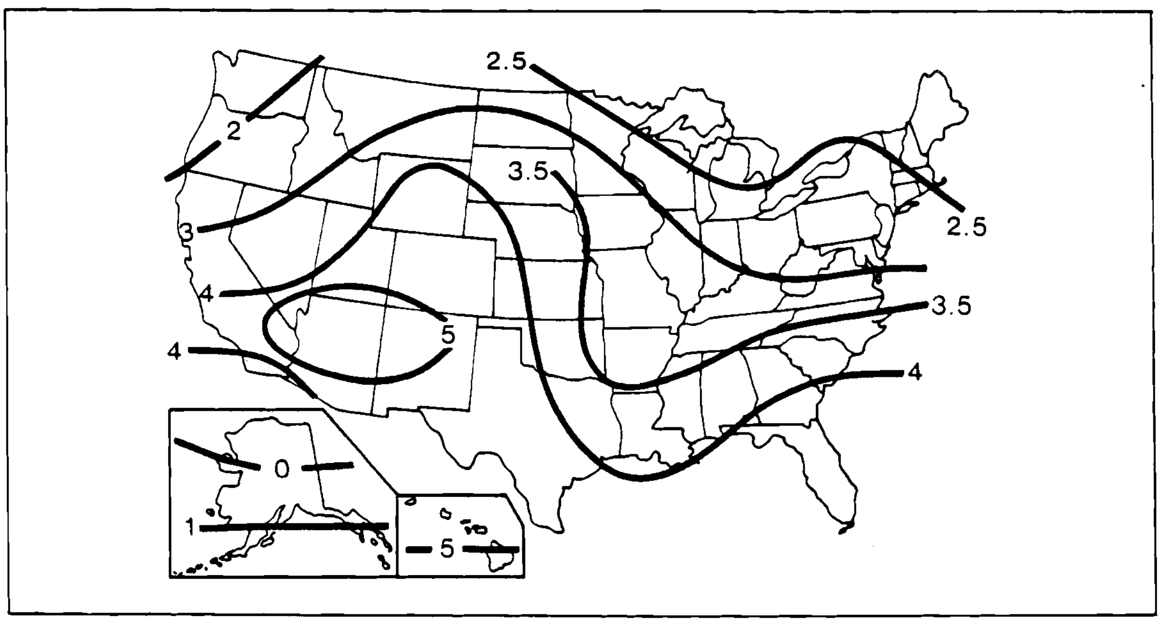


FIGURE 4.2. Peak Sun Hours Per Day - 4 Week Average 12/7-1/4
(Courtesy of Solarex Corporation)

which provides an estimate of the lowest average seasonal levels of sunlight. To calculate array capacity needed, divide the adjusted average daily energy requirement calculated above by the sun hours. This is your array wattage requirement.

$$\frac{\text{Total Average Daily Energy Requirements}}{\text{Number of Sun Hours}} = \text{Array Wattage Requirement}$$

To determine the number of modules required, divide the array wattage by the wattage of the module. The resulting figure should then be rounded up to the next whole number. This is your estimated module requirement.

$$\frac{\text{Array Wattage Requirement}}{\text{Module Wattage}} = \text{Number of Modules Required}$$

Check module requirements with the manufacturer or distributor, or use the NASA Report listed in Appendix II.

Table 4.7 is a list of many firms who manufacture PV modules in the U.S., with an example of the type of PV module available. Most companies manufacture a variety of module sizes, and you should contact several manufacturers before purchasing a module.

The PV cells represent a significant part of the costs of a PV system, and therefore it is worthwhile to derive as much power from the cells as possible. Two methods currently being used to increase the output of PV cells are concentrators and tracking devices.

Concentrators are either mirrors or lenses that concentrate the sun's light on the PV cell (Table 4.8). The amount of power produced by the PV cell increases linearly with the increased light intensity. One shortcoming of concentrators is that you have to make provisions to reduce the increased heat caused by the higher light intensity.

If you use concentrators, you must also use tracking devices. These devices ensure that the cells remain facing the sun all day. Studies have shown that tracking devices can double the output of a PV cell. Zomeworks manufactures a passive solar tracker that can be used in many home-electric systems.

Several factors should be considered when purchasing a concentrator array:

- the reliability of the tracking device
- the maintenance and service requirements of concentrators and tracking devices
- their performance in the specific climate conditions
- appearance factors (a pedestal tracking array looks unusual in some neighborhoods)
- any unusual environmental conditions.

4.4 Battery Sizing and Selection

This section presents a method for estimating battery storage requirements and provides some guidance in selecting batteries. The reader is cautioned that battery technology is quite complex. Therefore, spending time to study and select batteries is very worthwhile.

We cannot possibly present and explain in this directory all battery issues and products available. However, we will try to point out very important issues and offer some guidance in the design and selection of electrical storage batteries. If you've completed Table 4.1 up to this point, you are well on your way to determining the battery storage requirements.

4.4.1 Sizing Battery Storage

By estimating the percent of time that appliances will be used during nonsunlight hours and by multiplying this figure times

TABLE 4.7
Manufacturers of PV Modules/Arrays

Company	Catalog Number	Peak Power (watts)	Description	Price
ARCO	ASI 16-2000	35	Dim. 47.9" x 11.9" x 1.5"	$ 450
ARCO	M-53	43	Dim. 48" x 12" x 1.5"	515
ARCO	M-61	30	Dim. 48" x 12" x 1.5"	385
ARCO	M-81	7	Dim. 14" x 12" x 1.5"	185
Chronar	CPV-4030	1	Module is made from amorphous silicon 1' x 3'	8
Mobil Solar Energy Corp.	RA 30	30	Dim. 35 11/16" x 11 3/16" x 2", price discounts for large purchases	$ 330
Mobil Solar Energy Corp.	RA 15	15	Dim. 24" x 12 3/8" x 2", price discounts for large purchases	292
Mobil Solar Energy Corp.	RA 180	180	Dim. 47.38" x 70.5" x 2", price discounts for large purchases	2,592
Mobil Solar Energy Corp.	Cath. protect.	400	For use on well heads, bridges, & storage tanks	contact manuf.
Mobil Solar Energy Corp.	Desalination	8 kW array	—	contact manuf.
Silicon Sensors, Inc.	SPP-4000-12	45	Dim. 34.5" x 24" x 2"	530
Silicon Sensors, Inc.	SPM-150-10	1.2	1.2-W minimum PV module	80
Solar Power Corp.	LG250-12	40	Dim. 52.4" x 11.9" x 1.4", offers PV modules from 20 to 40 W	515
Solarex Corp.	SX-120	40	Dim. 17.5" x 42" x 2.1"	449
Solarex Corp.	PL-120	70	Dim. 50.5" x 25.7" x 0.47"	875
Solavolt International	MSP43E40	40	Dim. 47.9" x 14.1" x 1.5", also supply 10- and 20-W modules	440
Solec International	S-4134	35	Dim. 37.4" x 15.6" x 1.5", made from single crystal silicon cells	299
Solec International	S-1136	9.9	Dim. 16.0" x 12.5" x 1.5"	149
Solec International	Military pack	11.28	Pack has 5 PV modules, weighs 3 lbs., can be used for remote communications	850
Solenergy Corp.	SG 1264-P or -G	34	Dim. 28.5" x 23.75" x 1.75"	contact manuf.
Tideland Signal	MMG-1800/6 V	12	Dim. 14" x 14" x 0.75"	448

TABLE 4.8
PV Concentrators

Company	Number	Rating	Description
Intersol	PV concentrator array	5.4 kW	Uses point focusing Fresnel lens to concentrate sunlight about 70 times, array dim. 49' x 9'
United Energy Corp.	Module 5000	2.5 kW	Uses silicon cells and laser-tuned mirrored concentrators, also produces 40,000 Btu of hot water/hour

the average watt-hours used per day, you have determined the amount of energy that typically needs to be removed from battery storage each night for that appliance. By adding up this figure for all the appliances, you derive the total amount of energy needed to be removed from the battery storage system on a typical daily cycle.

A battery's life, and therefore its cost effectiveness, is based on a) the number of times the battery is discharged or "cycled", b) the percentage of the total battery charge (depth of discharge) that is removed during the cycle, and c) the quality of maintenance. Because each type of battery responds differently, you need to determine what depth of discharge is best to maximize battery life and to minimize storage size. However, various batteries are available with differing characteristics and with widely differing loads placed upon then, so a simple, universal answer is not possible. The question is best resolved by discussions with battery manufacturers or suppliers.

In "typical" PV applications, good-quality batteries are considered ideal if they have a 10% average depth of discharge that will last about 5 years. Using fewer batteries and increasing the depth of discharge to provide the same amount of energy daily may shorten battery life and reliability but may still be cost effective. On the other hand, using more batteries and further reducing the average discharge depth increases the cost of the storage system to a point that may not be recovered by the batteries' expected longer life. In actual practice, deep-cycle batteries are being discharged more than 10% on a daily basis. They have a fairly good life, which saves considerably on system first costs.

The actual depth of discharge in a PV system can vary from 0 to as much as 90% of capacity if the battery is designed for this. An occasional deep discharge isn't too harmful. However, one is faced with the inescapable trade-off between battery life and depth of discharge. Leaving batteries in the discharged state for extended periods causes premature failure. Some batteries can stand more of this type of use than others.

One way to ensure that batteries are not discharged excessively so that life can be maximized is to install an alarm system or automatic shut-off mechanism (as described in Section 4.5.3). The system or mechanism would operate when the battery is at a specified depth of discharge. A backup system, such as a gasoline generator set, can then be used to return the batteries to full charge and at the same time provide the appliance electrical needs. If no back up is used, the user has three options: 1) discharge the batteries more deeply (and pay for it in reduced life expectancy), 2) install additional battery capacity, or 3) wait for more sunshine.

The second option may be perfectly acceptable because of the modular nature of battery systems. If more power is frequently needed than can be provided by a reasonable depth of discharge, additional batteries can be added. Of course, if the charging system (say the PV array) is inadequate to return the batteries to full charge in a typical daily cycle, then the charging system must also be enlarged.

To determine the size of your initial system, go back to Table 4.1 and take your estimate of daily storage requirement from the table and multiply by 10 to estimate the total capacity of the battery system if you have a backup generator. If no backup is available, multiply expected necessary energy needs by a factor of 15 to 25 to ensure adequate battery life. If the sun is frequently obscured and no backup battery charger is available to provide for these cloudy periods, the array and battery system size must be increased.

One final check to make after sizing a battery system is to see if the maximum power output (amperes) of the PV array is less than 1/20th of the total amp-hour capacity of the battery system. This check is needed because the maximum constant charge rate for conventional lead acid batteries should not exceed about 5% of the battery capacity. For example, if the output of PV array is 100 amps, then the storage capacity of the battery system must be at least 2000 amp-hour.

The following section describes the key factors to keep in mind in selecting and using a battery system.

4.4.2 Factors to Consider in Selecting and Using a Battery System

Automotive-type batteries are frequently not suitable for PV use. PV battery systems need the following:

- **Deep-Discharge Capability.** Automotive-type batteries are not designed for PV use. They can be seriously damaged if fully discharged and left for any period of time. In a PV system the battery may sometimes be fully discharged.
- **Adequate Life.** The length of life will be affected by the number of charge/discharge cycles and the depth of the discharge/charge cycle.
- **High Charge/Discharge Cycle Efficiency.** The efficiency of the battery and charge controller together should be about 80% or better for normal operation. If this isn't true, a larger PV array would be needed to make up the difference. A good PV battery will only consume internally 2 to 4% of its full charge per month. Automotive type batteries may self-discharge as much as 30% of their full charge in a month without any outside power load.
- **Maintenance.** Maintenance-free batteries are available for PV use and may be important for those who don't intend to become "knowledgeable" about storage batteries. Other types of batteries absolutely require some maintenance (water level adjustment etc.) to prevent premature failure.
- **Safety.** Batteries are safely used by the millions in automobiles. They are inherently safe when used properly, but they typically contain strong acids and can generate hydrogen gas, which is highly explosive. Large quantities of batteries should be isolated from living quarters in well-vented enclosures. Suppliers should be consulted about housing and protecting batteries. Ordinary batteries can be fitted with "hydrocaps", which help them behave like maintenance-free batteries. They are available from Hydrocap Corporation.
- **Freeze Protection and Shading.** In northern climates, batteries need freeze protection. Batteries fully charged are quite resistant to freezing, although they may have drastically reduced capacity. Your car may not start well on cold mornings

because of this problem. Specially designed batteries can be obtained so that they won't freeze even if discharged; however, they still won't put out full power when cold. It may well pay to build a separate underground protective enclosure in northern climates where freezing and cold weather are encountered. In warmer climates an underground enclosure also can prevent excessive overheating and can help prolong satisfactory battery operation with reduced maintenance.

- **Convenience.** In some uses, gel electrolyte batteries are convenient because they can be overturned without spilling corrosive acid.

Summarizing, you should consider several factors when buying a battery system:

- **Cost and Life.** What are the tradeoffs between initial costs and life expectancy?
- **Storage Capacity.** How many days can you operate "without sunshine"?
- **Efficiency.** Does the battery selection affect the size of PV array needed?
- **Ruggedness.** Can the battery withstand the conditions of use, that is, the amount of discharge it may encounter, etc.? Is it physically designed to cope?
- **Safety and Reliability.** What costs, if any, will be required to make the system safe and reliable? Do you need a special building, etc.?
- **Maintenance.** How much maintenance is required?

The battery field is very dynamic and we cannot possible list all suitable batteries. Table 4.9 presents examples of the PV batteries available.

4.5 Selecting Power Conditioning Equipment

This section discusses the various power conditioning equipment that is necessary and available to ensure stable, safe, and efficient operation. The equipment falls into three categories: power controllers, inverters (DC to AC and DC to DC conversion), and battery monitors.

4.5.1 Power Controllers

The use of PV panels to charge batteries wouldn't require any controls or electronic devices if you could disconnect the panels in the afternoon and at night. This would prevent the batteries from overcharging in the afternoon and would keep the modules from using power out of the battery at night. It is assumed that you would remember to reconnect the array to the battery when the battery gets "low". In some applications, such as warning beacons, batteries and PV arrays can be matched so well that the batteries will never overcharge.

The ARCO Company has designed a little black box to prevent overcharging and undercharging of the batteries. It has a switch (actually a relay) that is controlled by an electronic circuit called a universal charge controller (UCC). Most UCCs are available to operate on voltages of 12 to 48 volts nominal system voltage. It can even be ordered with a special probe to sense the temperature of the batteries and to adjust its operation to the exact voltage the battery should have when fully charged **at that temperature.** It can handle up to 25 A of current from panels at 12 V DC and can handle up to 1 kW of panels at 48-V DC nominal voltage. The UCC unit sells for about $325 from Solarwest Electric.

TABLE 4.9
Suppliers of PV Batteries and Accessories

Company	Catalog Number	Peak Power	Description	Price
C & D Battery	DCPSA-15	219 Ah/8hr @ 12 V	Lead calcium batteries can be discharged 20% of rated capacity daily	$ 654
C & D Battery	QP75-25	900 Ah/6 hr @ 12 V	Lead calcium batteries can be discharged 80% of rated capacity daily	2,154
Delco Remy	DELCO 2000	105 Ah, @ 12 V	Price information is available from GMC	90
Exide	89454	875 Ah, @ 12 V	Deep-cycle battery allows up to 1800, 80% discharges, up to 5-year service	1,888
Gates Energy Products	0800-0004	5.2 Ah @ 2 V	Rechargeable batteries for use with PV systems	7
Gates Energy Products	0840-0004	13.0 Ah @ 2 V	Rechargeable batteries for use with PV systems	17
Hydrocap Corp.	—	—	Hydrocaps recombine hydrogen & oxygen gases into pure water, thus reducing battery maintenance	8
Power Sonic Corp.	PS-1265	6.5 Ah @ 12 V	Provide a complete range of rechargeable batteries	27
Surrette Storage Batteries	6NF 29	490 Ah, @ 6 V	Deep-cycle, heavy-duty batteries for use with PV and wind systems	746
Surrette Storage Batteries	HR8D	221 Ah, @ 12 V	Deep-cycle, heavy-duty batteries for use with PV and wind systems	356

However, this device does have disadvantages. It has mechanical contacts that may wear out and break more easily than solid-state approaches (described later). (The solid-state approach eliminates this problem but has other disadvantages.) The UCC unit uses about 70 mA at 12-V DC during charging and uses 15 mA at 12-V DC the rest of the time.

The most widely used approach to deal with overcharging and undercharging in small systems is to omit the charge controller but to place a "diode" (or one-way valve) in series with the array to keep the current from flowing back out of the battery and through the array at night. This diode is usually called a blocking diode and can be ordered to be built as part of the module. Batteries in small systems are less likely to overcharge. Even if they do, it is not serious if battery water levels are maintained. Diodes are not needed and shouldn't be used with the UCC described above because they would consume power during the charging process.

If a system is to be used under changing load conditions, some sort of charge control is needed in addition to the "blocking diode." A commonly used approach is the "shunt regulator". This device turns on some extra load when the battery is fully charged and its voltage gets too high. It "shunts" or bypasses the current away from the battery until the battery gets low and needs to be charged again. You may remember when battery voltage was not regulated in automobiles and on long trips it was advisable to turn on the headlights to keep the battery water from boiling away. The shunt regulator does a similar job using a solid-state switch to connect a resistor that uses up the excess power.

The disadvantage of the shunt regulator is that it generates a lot of heat that has to be dissipated. To cool faster, therefore, they are fairly large. Table 4.10 lists some of the various voltage regulators available.

For satisfactory results, you should discuss the system to be regulated with the regulator supplier. The module/array supplier can usually design and supply a regulator to meet your specific needs. He will want to know the battery type (lead acid, lead calcium, etc.) and will, of course, know the array size you are ordering and be able to supply adequate voltage regulator capacity for excellent system performance.

If batteries are not used and if the devices to be connected can tolerate the high voltage generated by an unloaded panel, power controllers are necessary. The so-called "sun-synchronous" application, with a motor or other load matched up to the panel, will have no difficulty under normal conditions. An unloaded 1/2 hp DC motor may not load a 450-W array enough to keep the voltage in the normal operating range, but shunt-type battery charge controllers can be used for this purpose **even though batteries aren't used.** We recommend that you discuss these applications with the module supplier.

4.5.2 DC to AC Conversion

In small systems, the most efficient way to use the power generated by PV panels is in the DC form in which it is generated. For this reason, many PV systems have started out as pure 12-V DC systems. Most of the major

TABLE 4.10
Voltage Regulators

Company	Catalog Number	Maximum Watts	Voltage
ARCO	UCC	1500	12
Boss	SSR 10/20	700	12 or 24
Silicon Sensors, Inc.	REG series	500	6, 12, or 24
Solarex	SRO 12100 LVD 3L	100	12
Solec	VM 100	100	12
Specialty Concepts	Sci1-12-AB	360	12
TriSolar Corp.	BCR series	1000	12, 24, or 48
TriSolar Corp.	MPCB series	100 kW	12-120

needs such as pumping, refrigerating, and lighting can be provided by 12-V DC appliances and products. However, sooner or later the user of a pure DC system will want to operate AC appliances. To use these appliances, a DC to AC inverter is required.

Because a wide variety of inverters is available, we will describe some representative inverters. Most PV module suppliers can supply inverters or suggest sources for the right inverter for your needs.

Inverters fall into several classes:

- Superlight duty for intermittent use with specific small appliances such as electric razors—operated from battery systems.
- Light-duty inverters suitable for extended use with entertainment equipment, computers, etc.
- Medium-duty inverters for light hand drills, etc. and small appliances, such as hand mixers, which have modest starting surges—operated from 12-V battery systems.
- Heavy-duty inverters for starting and operating heavy-duty appliances such as large AC refrigerators, air conditioners, table saws, etc. that have a requirement for starting surges as much as six times the normal full load current—operated from a DC battery bank.
- Grid-tie inverters that connect to the electric power company lines don't use any batteries and can't operate when the utility power is shut down.
- "High-Quality"[a] inverters that can connect to the power line or can operate in a "stand-alone" mode connected to a battery.

(a) The high-quality sine wave inverter may be better for operating critical data-processing computers or special equipment. However, according to published accounts, heavy-duty inverters may be a better choice for starting motors.

The **superlight** inverter is made to be used right with the appliance, such as an electric razor. Since inverters do draw current, they should be shut off when the appliance is not in use. No special house wiring is required and they do the job very well within the limits of their design. Superlight inverters are available from radio supply houses or recreational vehicle equipment suppliers. However, PV owners use very few inverters of this type.

Light-duty inverters are suitable for extended use powering home computers and home entertainment equipment. They are available in two types. The least expensive has no frequency-locking circuits, so the frequency will vary with changes in supply voltage or with changes in load. This type of inverter is suitable for operating some equipment but not for use with television sets, stereo turntables and tape drives. The second type of light-duty inverter has frequency control (FC). Some examples are listed in Table 4.11. The FC has been reported to work satisfactorily with a wider variety of electronic equipment. One problem with all lower-cost inverters is that some electronic

TABLE 4.11
Light-Duty Inverters

Company	Description	Output Wattage[a]	Price
Tripp-Lite	PV 100	100	$ 63
Tripp-Lite	PV 200	200	79
Tripp-Lite	PV 500	500	169
Tripp-Lite	PV 250 FC[b]	250	189
Tripp-Lite	PV 500 FC	500	299
Tripp-Lite	PV 1000 FC	1000	429

(a) Continuous wattage.
(b) Frequency-control model.

equipment picks up "interference". Because it is outside the scope of this directory to adequately address this question, you should try out the electrical equipment on an inverter before it is purchased or obtain an agreement from the dealer allowing return.

Light-duty inverters are usually turned off when they are not supplying a load, because inverters consume power if left connected. They may be fairly inefficient, but this effect is small if use is limited to short duration on an occasional basis. Also, inverters can generate considerable noise, both audible and electrical. Their electrical noise may be translated into audible noise ("static") in a radio or stereo.

The **medium-duty** inverters (Table 4.12) are available for operating small appliances, electric razors, light power tools, etc. They should be operated well below their maximum rating and most should be turned off when not in use. Some inverters are available with a "load-demand-start" feature that automatically starts the inverter when the appliance is turned on and turns off the inverter when the appliance is shut off. This feature should be ordered even though it costs a little extra because it can save your battery supply by eliminating the consumption of standby power. A word of caution is in order here! This demand control works well for "normal" loads, but users report that for very light loads (i.e., small radios), some automatic start controls do not start. Manual override switches would appear to be a solution to this problem.

The medium-duty inverters listed here for operation from 12-V DC can operate loads continuously and reliably up to their rated limits. Limitations may result from the use of DC supplies. For example, heavy-duty cables are required to connect the batteries to the higher rated 12-V inverters. The cables and the connectors used to hook them up tend to limit the surge power available from the inverters even when the internal elec-

TABLE 4.12
Medium-Duty Inverters (12-V DC to 120-V AC)

Company and Model Number	Maximum Watts Continuous Output	Maximum Watts Peak Output	Input Watts No Load	Price[a]
Best M-12-1000[a]	600	4000	45 W	$1,659
Dynamote B-5	500	1000	—	730
Dynamote M B-10	1000	2000	Including auto start	1,035
Dynamote M B-18	1800	3500	—	1,300
HEART H 12-1000	1000	1600	1-3[b]	800
Helionetics[a] AC-12-6	600	1500	—	1,418
Helionetics[a] AC-12-12	800	2000	—	1,734

(a) Without load demand start and stop (add about $150 for this feature).
(b) The HEART inverter uses unique circuitry to eliminate most of the usual "no load" input watts.

tronics and other elements are heavy enough to stand the extra surge. This surge power limitation also limits the size of the electric motors that can be started successfully by using the inverters operated from the 12-V sources. The larger of these inverters can start portable power tools as large as a 2 HP skillsaw because they use universal (AC/DC) motors. Universal motors require less surge capacity than standard AC induction motors. The units listed in Table 4.12 don't have enough surge capacity for starting large AC induction motors. The heavy-duty inverters discussed below operate from higher supply voltages and are less subject to this problem.

Heavy-duty inverters are required to start large AC induction motors. Table 4.13, supplied by T.D. Paul of Best Energy Systems, compares the starting and running watts for typical AC induction motors. He has several practical suggestions for those designing their own systems in his book *How to Design an Independent Power System.*

The inverters we have discussed up to this point are all solid-state units and efficiencies are about 85% efficient if the loads are 25% or more of the inverter rating. The wave shape produced by these inverters is not a smooth "sine wave" that is preferred for AC loads, but is a variation of it. The amount of variation partially explains the differences in price.

TABLE 4.13
Comparison of Starting and Running Power for AC Induction Motors

Horse-power	Start/Run Watts	Horse-power	Start/Run Watts
1/6	1500/325	1/2	6000/1000
1/4	3000/525	3/4	8000/14.000
1/3	4500/725	1	10,000/1800

Best's B-48-5000 and Dynamote's MB-60-48 (Table 4.14) have specifically been recommended by the manufacturer as having the capability to **start** and **operate** typical household appliances. If a typical 5,000-W range inverter is used to operate freezers, etc., so that it has to be left on continuously, it will consume up to 1.7 kWh/day just in standby power. If left turned on 24 hrs/day, it would quickly discharge a small PV system's batteries even if no load is connected. Therefore, an alternative for small systems might be hybrid systems that use both AC and DC appliances.

Heart Interface has designed a unique line of inverters that supposedly has extremely low standby power and high efficiencies at relatively low power levels. It is not unusual for good-quality inverters with capabilities in the 5 kW range to have efficiencies in the 80% range for loads only greater than 1 kW or so. At lower loads, the efficiency drops rapidly. The Heart Interface 5-kW design claims to have an efficiency of 80% at a load of 50 W and an efficiency better than 90% at a load of 150 W. The standby power for this unit is 3 W. This inverter supposedly does not need to be turned off to conserve power, and therefore there is less incentive to install the hybrid DC-AC system.

In large systems with many loads, it may be simpler to operate the inverter full time and add enough panels to handle the loads and the standby power of the inverter. All of the units listed so far are designed to operate from storage batteries, and none have been intended for connection to a power line to sell excess power back to the utility.

Grid-tie inverters are used where the PV owner wants to use PV for his power needs and wants to sell excess power to the utility. Several inverters are available for grid-tie application from reputable manufacturers at reasonable prices (Table 4.15).

TABLE 4.14
Representative Units Having High Surge Capacity

Company and Model Number	Maximum Continuous Load (W)	Surge Load (W)	Battery Voltage Nominal	Universal Tool Rating (HP)	No Load Input (W)	AC Induction Motor Rating (HP)	Approx. Price
Dynamote MB18-24	1,800	3,000	24	NA[b]	Auto start standard	0.5	$1,300
Best/Solar Electric[a] M-24-2500	1,800	10,000	24	3	40	0.75	2,261
Helionetics[a] AC-24-24	2,400	6,000	24	NA	NA	NA	2,354
HEART H24-2500	2,500	4,500	24	NA	1.5	NA	1,200
Dynamote B30-24	3,000	6,000	24	NA	Auto start standard	1	1,725
Helionetics[a] AC-48-48	4,800	12,000	48	NA	NA	NA	3,365
Best/Solar Electric[a] M-48-5000	5,000	20,000	48	6	70	2	3,360
HEART H 48-5000	5,000	9,000	48	NA	3.0	NA	2,300
Dynamote MB60-48	6,000	18,000	48	NA	Auto start standard	2	2,400

(a) Automatic load demand start and stop control available for about $150.
(b) Not Available.

TABLE 4.15
Grid-Tie Inverters

Company	Model Number	Maximum Continuous (W)	Input (V)	Output (V)	Approx. Price[a]
American Power Conversion	APC Sunsine, UI-2000	2,000	230 DC 209-300	240 AC	$5,350
American Power Conversion	APC Sunsine UI-4000	4,000	230 DC	240 AC	7,950
Helionetics	61300-11	2,500	240 DC 209-300	230 AC	4,774
Windworks	Gemini, S1-20-12V-31	2,000	DC 50-100	120 AC	4,570
Windworks	Gemini S1-20-24V-31	4,000	DC 100-200	240 AC	4,840

Grid-tie inverters have the following **advantages**:

- reduced electric bills
- batteries not required to provide electricity at night
- all peak load requirements supplied by the power line
- no diesel or gas generator required for cloudy periods
- lower overall system cost for houses with usual grid connections.

The **disadvantages** of grid-tie inverters include the following:

- no power available when utility power is off
- economics heavily influenced by "sale price of power to utility"
- complete system must conform to utility standards.

Do not consider grid-tie systems without consulting the utility to which you intend to connect your system. Find out the utility's buyback price for electricity and how your grid-tie system will affect the price you pay for the electricity you buy from the utility. The utility is naturally concerned that you do not send power back into the line when they have it shut down for repairs. The 230 V you send back to the power pole gets stepped up to 2,300 or perhaps 4,600 V or higher at the transformer. Also, your system must conform to all normal electrical codes besides those codes unique to PV systems selling power to the utility. Hundreds of grid-tie systems have successfully operated for several years; therefore, most of the earlier problems with these systems are reported to have been eliminated by improved designs.

Grid-tie systems will not operate away from the utility, and the "wave shape" of the current produced isn't the same as that produced by the utilities. This could produce special problems. If enough inverters were to be operated from the same utility distribution transformer, serious problems might be encountered. On the other hand, your utility may have no problem at all (at least 600 are operating in the U.S. at the present time).

It is advisable to purchase the grid-tie system from a dealer who is knowledgeable about the complete system needs. He will be able to offer advice about the need for special filters, isolation transformers, power trackers to increase the output of the system, circuit combiners for larger array fields, etc. It is beyond the scope of this directory to cover all such requirements in detail. These options are mentioned because inverters may or may not include all of these options, and these options may or may not all be required.

Progress has been made in providing reasonably priced, reliable grid-tie inverter systems to the potential PV system owner. The decision to go with a grid-tie system is now an economical rather than a technical decision (based on lack of adequately demonstrated reliable equipment).

Several "high-quality"[a] inverters are available for either grid or non-grid application. The Nova Electric Manufacturing Company and the Topaz, Powermark Division make several "high-quality" sine wave inverters, which are listed in Table 4.16. Abacus Controls make a line of DC to AC inverters (Table 4.16) to operate with a DC input voltage of 120 V and another sunverter line operating with 200 V DC (nominal) input (160-240 V DC with or without battery). Part of the Sunverter line is also described in Table 4.16. Prices are about $5/volt ampere (VA) for a 250-VA inverter, but the price per VA decreases as the size of

(a) The "high-quality" refers to the purity of the wave shape, which is needed in only a few applications.

TABLE 4.16
High-Quality Sine Wave Inverters
(12 V AC, 60 Hz Output)

Model and Supplier	Output Power (VA)	DC Input Voltage	Approx. Price
1260-12 Nova	125	12-120	$ 590
250 GZ 12/24 60-115 Topaz	250	12/24	1,365
2560-12 Nova	250	12-120	840
500 GZ 12/24-60-115 Topaz	500	12/24	1,885
5060-12 Nova	500	12-240	1,235
1000 GZ-12/24-60-115 Topaz	1,000	12/24	2,560
1K60-12 Nova	1,000	12-240	2,135
443-4-120 Abacus	4,000	120	7,340
5K60-48 Nova	5,000	48-240	5,905
463-4-120 Abacus	6,000	120	10,690
10K 60-120 Nova	10,000	120-240	11,020
483-4-120 Abacus	10,000	120	14,230
743-4-200 Abacus	4,000	160-240[a]	9,360
763-4-200 Abacus	6,000	160-240[a]	12,240
714-4-200 Abacus	10,000	160-240[a]	16,330

(a) These are "sunverters" and operate directly from PV arrays with or without battery banks and can feed power back into a utility grid and operate over the voltage range indicated.

the inverter increases. The "sunverters" can operate in a stand-alone mode or connected to a utility power line. The wave form is much closer to the ideal with this type of inverter than with lower cost inverters. In spite of this, do not plan to connect to the power company without checking with the power company first.

A special word of caution is needed here. We recommend that you get assistance from experienced designers and installers of these inverters that connect to the power line. There are many potential problems that are beyond our scope to discuss here, including safety issues, laws, rules, and regulations that must be followed in these installations. The inverter manufacturers may be willing to assist with these problems or may be able to refer you to someone who can give professional assistance in your locality.

The problems associated with smaller stand-alone inverters are more manageable by the **knowledgeable** do-it-yourselfer. The stand alones are being used by do-it-yourselfers already. This isn't the case for the utility-connected (grid-tie) inverters right now. As time passes the problems will be better understood and less skill will be required to install these utility-connected systems. In addition to Windwarks and Abacus, there are other companies able to design grid-tie inverters for various applications, including Helionetics and Applied Research and Technology Corporation of Utah (ARTU).

In summary, inverters can supply AC from DC sources for most reasonable home and light industry needs. At present PV costs, it may be better to use high-efficiency DC appliances where possible, especially where the use is fairly continuous. Appliances used occasionally can be supplied with AC from very efficient inverters and add much to the enjoyment of the PV power system. For example, a very small inverter (200 W) can supply power to a sewing machine or portable mixer.

4.5.3 DC to DC Conversion

Selecting system DC voltages presents some challenge. There are advantages and disadvantages to any voltage that may be selected. A choice is available wherever several 12-V DC solar panels and 12-V batteries are used to store the energy. The panels can be connected in parallel to charge the batteries at 12 V or connected in series for a higher voltage: 24, 36, 48, etc.

If the system is a small one (less than 250 W of PV modules) it is likely that a 12-V system may be chosen. However, if the system is large, it is likely that a higher voltage will be selected for the DC systems. Often, one may want to start small and add panels to the system and then increase the DC system voltage to supply the heavier-duty inverters to handle large AC motors and other 120-V appliances (as discussed in the previous section on inverters).

One of the disadvantages of this approach is that the homeowner may have a considerable investment in the 12-V DC appliances that he doesn't wish to abandon. The DC to DC down converter is one solution to this problem. In this section, DC to DC down converters are listed for use with the 12-V appliances.

The 12-V system has several advantages for use as a starter system. There is a reduced shock hazard, and frankly, these simple systems are reported to be very reliable (possibly because of their simplicity). Several appliances are designed just for use on these systems, including very efficient fluorescent lights.

A **seemingly** simple solution to the problem is to hook a resistor in series with the appliances to be powered from the higher voltage source. However, that approach is **not** recommended because it can destroy the appliance under certain conditions. There are situations where this approach can be used safely, but it is especially hazardous for sensitive electronic equipment with a wide variation in current consumption during normal operation. For example, a C.B. radio may use twice as much current during transmission compared to standby and listen mode. In this case, if you select the dropping resistor for the correct voltage during the listening mode, the radio would get only about half voltage during attempts to transmit. Selecting the resistor for transmission mode would greatly overvoltage the appliance during the receiving mode.

DC to DC converters can match the supply voltage to the needed load voltage. They are available in a wide variety of voltages and power ratings. They do an excellent job of providing DC power for various appliances, but they consume some power during standby mode and should be switched off when the appliance is not needed. While being operated, they are typically about 80% efficient. Some examples of DC to DC converters that have been around for some time are listed in Table 4.17.

Table 4.18 lists several DC to DC inverters from a new line put out by Newmar. They may not have as "smooth" an output as the converters previously listed and the output voltage may be more affected by the amount of load, but they will probably satisfy the need of typical appliances.

DC to DC converters are a satisfactory solution to the problems of operating DC appliances, but they do have three disadvantages. First, they lose about 20% of the power they convert while being used. Second, they use power even during standby mode with no load attached. Finally, these converters add more complexity to the system and consequently add to system expense. Despite these disadvantages, they are likely to be used extensively as typical PV systems grow in size and power ratings and as high-powered AC inverters demand higher DC supply voltages.

4.5.4 Battery Monitors

Alarm systems can be obtained to warn of low voltage or high voltage or of a 24-hour period with no power coming from PV modules. The module suppliers are usually

TABLE 4.17
DC to DC Converters

Company and Model Number	Nominal Supply Voltage	Nominal Output (V DC)	Output Current (A)	Standby Power (No Load)	Approx. Price[a]
Solarwest Electric 16-40	24 DC	13.8	11 A max	1 watt	$320
Wilmore Electronics 1385	24 DC	13.8	15	NA	625
Wilmore Electronics 1265	24- or 48-V DC (specify)	12[a]	30	NA	696

(a) Voltage is adjustable from 12-V DC to 14-V DC by a screwdriver adjustment on the front panel, and output is highly regulated from no load to full load from 20- to 29-V DC input or 40- to 58-V DC for the higher voltage model.

TABLE 4.18
Downconverters by Newmar[a]

Model	Input Voltage Range (V DC)	Output Voltage (V DC)	Output Current (A)	Efficiency (%)	Idle Current[b] (mA)	Approx. List Price
32-12-3A	20-40	Factory set at 13.6	3 int. 2 cont.	50 at 24-V DC input	150	$ 65
32-12-6C	18-50	Factory set at 13.6 adjustable 12.6-14.5	6	75%	30	150
32-12-10	20-50	Factory set at 13.6 adjustable 12.6-14.5	10	85%	45	195
32-24-10	32-50	Factory set at 24.5 adjustable 21-27	continuous	—	—	220
32-12-15C	20-50	Factory set at 13.6 adjustable 12.6-14.5	15	85%	45	239
32-12-25A	20-50	Factory set at 13.6 adjustable 12.6-14.5	25	85%	45	355
32-24-25A	32-50	Factory set at 24.5 adjustable 21-27	continuous	—	—	380
32-12-35A	20-50	Factory set at 13.6 adjustable 12.6-14.5	35	85%	140	425
32-12-50	20-50	Factory set at 13.6 adjustable 12.6-14.5	50 intermittent, 20 min. maximum	85%	50	575

(a) Input and output have common ground. Isolated converters available, contact factory. Operating temperature range 0-40°C. Derate to 50% load @ 60°C. Remote control option available, contact factory.
(b) Indicator lamp draws 25 mA.

able to provide alarm capability. We are aware of two models available from Real Goods for 12-, 24-, 36-, 48- and 120-V systems. Dynamote also lists voltage guards for 12-, 24- and 36-V systems. They can warn that some power loads must be dropped or that other action should be taken.

4.6 Design Review

The purpose of this section is to help you review your electrical needs and design a PV power system to meet them. First, we will highlight the most important factors from the previous sections and then present an example calculation to demonstrate the design process. It will be helpful for you to refer to a copy of Table 4.1 as you study this material.

4.6.1 Estimating and Reviewing System Sizing

The first task is to estimate your expected energy needs. This is done by listing the appliances you intend to use in Table 4.1 according to whether AC or DC power is required for them. Enter the power requirements (watts) of the appliances under the second column. Remember to add 15% (multiply requirements by 1.15) of the power requirements of AC appliances listed to account for the power consumption of the required inverter.

Next, you must estimate the hours that each appliance will be used according to classes of need: Class I (essential), Class II (priority), or Class III (optional). Under each of these classes, enter the product of the number of hours times the power requirement for each appliance. This should be expressed in terms of watt-hours because you've multiplied the power requirement in watts times the number of hours of average daily use.

The next step is to estimate the storage requirements to size the battery storage system. For each appliance, estimate the percentage of time the appliance will be used when the sun is not shining. By multiplying this percentage by the daily energy requirement (i.e. watt hours) calculated above, you have a preliminary estimate of the amount of energy that needs to be extracted from batteries on an average daily cycle for each individual appliance.

Now, total up the columns for the DC appliances and the AC appliances and enter them on the table. The next task requires you to anticipate the maximum power requirement (peak) that will occur with your system. You can estimate peak load by adding up the requirements of these appliances that might operate at the same time. The resulting total for the **AC appliances only** is your inverter capacity requirement. Enter this total in the power conditioning section. The peak **simultaneous** power requirement for both the AC and DC appliances should be inserted in the peak demand blank.

The method we use to estimate the battery storage requirement is based on conventional practice. Enter the total of the storage requirement column (AC plus DC) in the Storage Req blank in the Battery Sizing section. Enter 10% for the depth of charge limit and multiply your storage requirement by 10 to determine your battery capacity requirement. If you live in a frequently cloudy area, estimate the number of days that you expect cloudy conditions and enter that number in the Number of Days of Storage blank. Add 10 to this number and multiply by the storage requirement to estimate the Battery Storage Requirement.

Finally, we need to size the PV array required to keep the batteries sufficiently charged. Sum the DC and AC energy requirements in Class I and II and enter that number in the Average Daily Load blank under Array Sizing. Multiply the storage requirement calculated above by 0.20 and enter the result below. Sum the average daily load and the 0.2 times storage requirement figure and enter as the Adjusted Total.

The next step is to consult Figures 4.1 and 4.2 to determine the average sun hours in your location. If the PV system must provide all of the Class I and Class II needs at all times, you must use the lowest of the sun hour figures. By dividing this figure into the Adjusted Total, you determine the Array Size necessary in watts. By dividing this figure by the output watts of the modules selected and rounding, you have an estimate of the Number of Module Panels Needed for your installation.

By looking back through the tables on products available it is possible to estimate the cost of your system. Having gone through this exercise, you may wish to reconsider the appliances used or the hours of use to reduce the cost of the PV supply. An important factor to keep in mind in this effort is that a Federal Tax Credit is available, which provides a 40% tax credit for expenditures up to $10,000. The economic and other advantages of PV electric systems is discussed quite extensively in Chapter 5.0.

4.6.2 Example System Design

The best way to illustrate the design process is to do an example problem. We have arbitrarily selected an energy-efficient retirement home to be located more than two miles from an existing utility line near Phoenix, Arizona. The house is earth sheltered and oriented to the south to minimize cooling requirements and to remove the need for all but occasional heating. A solar hot water heater using a PV-powered pump is installed to supply nearly all of the hot water requirements.

Since the house is earth sheltered and the climate is typically dry, evaporative cooling is sufficient to provide comfort on all but the hottest of days. Because both the water heater pump and cooling energy requirements are sun synchronous, we can dedicate arrays to those particular uses with no need for battery storage. The arrays for the cooling system, however, can be wired to provide power for other uses when the cooling system is not needed. Since water heating is needed year round, it is probably better for the water heater array to be isolated from the rest of the system.

Cooking, back-up water heating, and space heating energy are assumed to be supplied by a liquid propane gas system. The rest of the electrical needs are assessed using the suggested table (4.18). The 180 watts (two 1800-2000 CFM systems from Table 3.2) of PV modules dedicated to the cooling system selected can be used as additional back up for periods of occasional cloudiness in the winter months, or to supply Class III (optional) needs when cooling is not required.

Our completed Table 4.1 is shown as Table 4.19. Each of the entries is explained below:

- A portable 50-W color TV is used for 3 hours in Priority class and for 3 hours Optional. An estimated 50% of the use occurs when the sun is not shining. The storage requirement is then 50% of 150 (both Priority and Optional), or 50% of 150 (Priority). For the table we determined the needed storage for both the Priority and Optional use.
- A small Hi-Fi radio rated at 15 W is used for 2 hours in Priority class and 2 hours Optional. Because 50% of use was determined to be without sun, the storage requirement is 30 watt-hours.

TABLE 4.19
Estimate of PV System Size

Appliance	Power Req.	Daily Energy Requirement (W/hrs) Class I (Essential)	Class II (Priority)	Class III (Optional)	Percent w/o Sun	Storage Req.
DC Powered						
Color TV	50		150	150	50	150
Hi-Fi	15		30	30	50	30
Fan	25		100		0	0
CB Radio	12		12	24	50	18
Refrigerator	36	480			50	240
Lighting	20	160			100	160
DC TOTALS		640	292	204		598
AC Powered						
Toaster	1150		288	288	25	144
Wash Mach.	575		144	144	0	0
Vac. Cleaner	690		173	173	0	0
Hair Dryer	1380		345	345	50	345
AC TOTALS			950	950		489

Power Conditioning
Peak Demand (watts): 1466 — Inverter Capacity: 1380

Battery Sizing
Storage Req.: 1087 watt-hours — Depth of Charge Limit: 10%
Number of Days Storage: ____ — Battery Capacity Req.: 10.870

Array Sizing
Average Daily Load: 1882 watt-hours — Sun hours per day: 6
Storage Req X .2: 217 watt-hours — Array Size (watts): 350
Adjusted Total: 2099 watt-hours — Module Req: 9

- A fan rated at 25 W is used 4 hours in Priority daily, exclusively during the day so no storage is necessary.
- A CB Radio rated at 12 W is used for 1 hour in priority class and 2 hours optional 50% of use is without sun, so the storage required is 18 watt-hours.
- A small 36-W refrigerator uses its compressor for 13 hours per day resulting in a Class I (Essential) energy need of about 480 watt-hours. 50% of the compressor running time is assumed to occur when the sun is not shining, resulting in a storage requirement of 240 watt-hours.

- Several 20-W high-efficiency DC lights are used for a total of 8 hours per night (i.e., two lights for 4 hours each). Because all this use occurs when the sun is not shining, it must all be stored in batteries and is considered essential.
- An AC toaster rated at 1000 W is used for 15 minutes in Priority use and 15 minutes Optional. First, the power requirement is increased by 15% to account for the inverter power requirement. Then this figure is multiplied for 0.25 (1/4 hour) to yield an energy requirement of 287.4 or say 288 watt-hours. 25% of the use is assumed to occur when the sun is not shining, resulting in a storage req. of 144 watt-hours.
- A 500-W AC washing machine is assumed to be used exclusively during the daytime for an average of 15 minutes per day in the Priority class and 15 minutes Optional. Although the typical washing cycle may be longer, this is the estimated time the motor is actually running. There are advantages of running one load daily instead of 7 loads once a week because the batteries are more evenly discharged.
- A 600-W AC vacuum cleaner is used for 15 minutes daily in Priority mode and 15 minutes Optional, exclusively during the daytime.
- A 1200-W AC hair dryer is used for 15 minutes of Priority use and 15 Optional. Half of the use is expected to occur when the sun is not shining, requiring 345 watt-hours to be stored.

Next, the columns have been totaled for the DC and AC appliances individually. To estimate power conditioning requirements, we assume that the maximum load on the AC systems will occur when the hair dryer is operating alone. Therefore, if a 1380 inverter is purchased, the user must assure that no other AC appliances are being used at the same time or else a fuse will blow. Another caution is to ensure that the surge power requirements of the washing machine and vacuum cleaner do not exceed this figure.

The peak demand is assumed to occur when the hair dryer is used while the color TV is turned on and the refrigerator is running. The figure is the sum of 1380 plus 50 plus 36 or 1466 watts. In your case, the size of this number (peak demand) will depend upon your needed or desired level of control over appliance use.

We then sum the storage requirement of 598 for the DC appliances with the 489 watt-hours for the AC appliances and get 1087 watt-hours, which is entered in the appropriate space under battery sizing. Because the common rule of 10% depth of discharge is acceptable, we determine that a battery system with 10 times the storage requirement is necessary to limit **average** daily discharge to 10%. This means that 10,870 watt-hours of storage is necessary. Since the weather in Phoenix is generally clear, no additional storage is deemed necessary.

Finally, we size the array to supply the system. We add all the power requirements for both AC and DC needs in Classes I and II to come up with a average daily load of 1882 watt-hours. This is the sum of 640, 292, and 950. The optional uses are assumed to be exercised only if greater than average sun is collected or if other loads have been reduced. To this, we must add 20% of the storage requirements (1087 watt-hours) due to losses in the storage system. The adjusted total energy requirement is 2099 watt-hours per day.

To calculate the capacity of PV array necessary to supply our needs, we must consult Figures 4.1 and 4.2 to determine the effective number of sun hours for our location. We use an average figure of 6 because the aircooler panels can be diverted for other uses during the least sunny winter months.

Dividing our adjusted total (2099) by 6 yields an array size of 350 watts. In addition, 180 W of power are required for cooling and 1 PV panel will be dedicated to the solar water heater pump.

Consequently, our retirement home would require a total of fourteen 43-W panels and about 11,000 watt hours of battery storage. Delco 2000 batteries rated at 105 amp hours each will hold 1260 watt-hours apiece (105Ah X 12 V). Thus, 9 batteries would be required.

Connectors and wiring should not be overlooked in the design process. They should be selected after the rest of the design system is complete. A connection diagram should be made before selecting the switches, fuses, circuit breakers, and wiring and connectors. Many of the "off-the-shelf" systems include switches, fuses, connector cables and/or a harness for connecting the system.

One benefit of the PV power system is the inherent reliability of the solid-state components of the system. Every electrical system has potential maintenance problems. The experienced troubleshooter expects that if all of the components are sound, the most common cause of difficulty would be faulty wire connections. The following will help to assure quality system performance:

- Use large enough wires so that overheating does not occur (see the National Electrical Code as well as local codes). These wires become quite large in 12-V systems where large amounts of power are to be handled. Thus, higher voltages are used as systems become larger.
- Solder the connections or use well-designed terminals (Amp Inc. makes a wide variety of wire terminals and one line specifically suitable for PV terminals).
- For wires and terminals select insulation that is suited to the environment they encounter.
- Protect the wires from future mechanical stress or abuse.

Properly installed wiring and connections add greatly to trouble-free enjoyment of the system.

Using prices listed in Tables 4.7, 4.9 and 4.12, we determine the following system costs:

14	ARCO Solar Modules @ $515 each	$7,210
9	Delco Batteries @ $90 each	$ 810
1	Dynamote B-18 Inverter	$1,300
1	UCC Charge Controller	$ 280
	TOTAL	$9,600

The only recurrent cost is replacement batteries about every 5 years. Therefore, once the system (without batteries) is paid for at a price of $8,790, the only expected operating cost is about $162 per year for batteries ($810 divided by 5). After taking advantage of the 40% Federal Tax Credit, the net system cost without batteries is less than $5000. Comparison of such a PV system with available alternatives is discussed in Chapter 6.0.

5.0 FINANCIAL INCENTIVES

To encourage the use of renewable energy sources and conservation, the federal government and many states are offering reductions in taxes of one form or another. The type of tax breaks varies from state to state and even within a particular state.

This chapter is intended to introduce you to the various types of tax incentives available to purchasers of PV and energy conservation devices. It is not meant to be a comprehensive tax guide or an outline of how to apply for the tax breaks. Although every effort has been made to assure that the material is accurate, new legislation concerning these incentives is introduced almost daily. Therefore, the information presented here should be used for illustrative purposes only. Contact your state or local energy office for the most recent information on available tax breaks. See Appendix I for the addresses and telephone numbers of your state energy office.

5.1 Photovoltaic Tax Incentives

This section discusses the different types of tax incentives available to purchasers of PV systems. Currently, tax credits are available at both the federal and state level.

5.1.1 Federal Tax Incentives for Photovoltaic Systems

The Federal Residential Energy Credit allows a tax credit to directly reduce the amount of federal income tax that an individual pays. It differs from a deduction, which reduces the gross income of the taxpayer before the amount of taxes is calculated. For example, if you are in the 25% tax bracket, a **deduction** of $4,000 would reduce your tax liability by about $1,000 (25% of $4,000). However, a tax **credit** of $4,000 (the maximum) would reduce your tax liability by a full $4,000. If your tax liability for the year is less than the amount of the tax credit you are eligible for under the Federal Residential Energy Credit, the unused portion of the credit may be carried over and used in future tax years. Thus, if you are eligible for a $4,000 Federal Residential Energy Credit in 1984 but your tax liability is only $3,000, your 1984 tax bill would be reduced to zero and you would be able to reduce your 1985 tax liability by $1,000 ($4,000 - $3,000).

Table 5.1 lists the qualifications, limits, and eligibility requirements for the Renewable Energy Source portion of the Federal Residential Energy Credit.

5.1.2 State Tax Incentives for Photovoltaic Systems

The type and amount of solar tax incentives available at the state level vary significantly from state to state. Generally, three types of state solar tax incentives are possible, depending on the tax structure in the particular state: state property tax exemptions, state income tax incentives, and state sales tax exemptions or refunds. Some states offer all three types of tax solar incentives, others offer none.

The most widely available type of state solar tax incentive is an exemption from state property taxes for PV systems. If you

TABLE 5.1
Federal Residential Energy Credit (Renewable Energy Source)

1. The cost of purchasing and installing renewable energy source property (PV systems) is eligible for the Federal Residential Energy Credit if the following three conditions are met:
   A. It is installed for use at an individual's principal residence.
   B. The equipment is new when installed.
   C. The equipment is reasonably expected to remain in operation for 5 years.
2. The following limits apply to the renewable energy source portion of the Federal Residential Energy Credit:
   A. The credits are available for expenditures made through 1985 (currently there is legislation pending to extend these credits for several years).
   B. The credit is 40% of expenditures up to $10,000, for a maximum credit of $4,000.
   C. The maximum amount of $4,000 is applied on a one-time basis, not a yearly basis.
   D. If the amount of the credit exceeds the tax liability of the individual in a particular year, the unused portion of the credit may be carried over until it is used up. Credits may only be carried over until the end of 1987.
3. The Federal Residential Energy Credit may be taken for qualified expenditures made by an individual for that individual's principal residence, whether they are the homeowner or tenant.
   A. A proportion of the qualified expenditures for multiple unit (separate owners) housing may be taken by the owner/resident (e.g., condominiums or town houses). Each owner/resident is eligible for the full credit.
   B. Multiple owners of a single dwelling are treated as a single taxpayer and must divide the available credit amounts among themselves.
4. For more information, contact the Conservation and Renewable Energy Information and Referral Service (telephone: 800-523-2929), or contact the IRS and request income tax form 5695.

live in a state that has a property tax exemption, installing a PV system on your dwelling will not increase your property taxes. Currently, 33 states have an exemption from property taxes statewide or offer a local option. These states are listed in Table 5.2.

State income tax credits or deductions are the next most prevalent type of solar tax incentive offered by states. The difference between a credit and deduction is examined in Section 5.1.1. Most states limit the amount of the credit or deduction, and some states give you the option of a credit or a deduction. (An example of this will be shown later.) Currently, 28 states have an income tax incentive for purchasers of PV systems. Table 5.3 lists these states.

The least common type of state solar tax incentive available to a PV system buyer is an exemption or refund of the state sales tax on the purchase. The states that offer a sales tax exemption or refund are listed in Table 5.4.

Table 5.5 describes the state solar tax incentives currently available in California and Arizona. California and Arizona were chosen because more solar panels are sold in California than anywhere else, and because the system examples in Chapter 6.0 assume that the PV systems are installed in Arizona residences. The table lists in detail the qualifications, limits, and eligibility requirements for the corresponding state solar income tax incentives available in each state.

TABLE 5.2
State Property Tax Exemption

Exemption (statewide or local option)				No Exemption or Not Applicable	
Arizona	Iowa	Montana	Oregon	Alabama	Missouri
Colorado	Kansas	Nevada	Rhode Island	Alaska	Nebraska
Connecticut	Louisiana	New Hampshire	South Dakota	Arkansas	New Mexico
Florida	Maine	New Jersey	Tennessee	California	Oklahoma
Georgia	Maryland	New York	Texas	Delaware	Pennsylvania
Hawaii	Massachusetts	North Carolina	Vermont	Idaho	South Carolina
Illinois	Michigan	North Dakota	Virginia	Kentucky	Utah
Indiana	Minnesota	Ohio	Washington	Mississippi	West Virginia
			Wisconsin		Wyoming

Source: Conservation and Renewable Energy Inquiry and Referral Service.

TABLE 5.3
State Income Tax Incentives

Credit or Deduction				No Incentive or Not Applicable	
Alabama	Indiana	Nebraska	Oregon	Alaska	Missouri
Arizona	Kansas	New Mexico	Rhode Island	Connecticut	Nevada
Arkansas	Maine	New York	South Carolina	Delaware	New Hampshire
California	Massachusetts	North Carolina	Utah	Florida	New Jersey
Colorado	Michigan	North Dakota	Vermont	Georgia	Pennsylvania
Hawaii	Minnesota	Ohio	Virginia	Illinois	South Dakota
Idaho	Montana	Oklahoma	Wisconsin	Iowa	Tennessee
				Kentucky	Texas
				Louisiana	Washington
				Maryland	West Virginia
				Mississippi	Wyoming

Source: *Solar Age* (March 15, 1983).

TABLE 5.4
State Sales Tax Exemption or Refund

Exemption or Refund		No Incentive or Not Applicable			
Arizona	Michigan	Alabama	Iowa	New Hampshire	South Dakota
Connecticut	Nebraska	Alaska	Kansas	New Mexico	Tennessee
Florida	New Jersey	Arkansas	Kentucky	New York	Utah
Georgia	Ohio	California	Louisiana	North Carolina	Vermont
Maine	Rhode Island	Colorado	Maryland	North Dakota	Virginia
Massachusetts	Texas	Delaware	Minnesota	Oklahoma	Washington
		Hawaii	Mississippi	Oregon	West Virginia
		Idaho	Missouri	Pennsylvania	Wisconsin
		Illinois	Montana	South Carolina	Wyoming
		Indiana	Nevada		

Source: Conservation and Renewable Energy Inquiry and Referral Service.

Chapter 6.0 lists several system examples that include both estimated system costs and tax credits. These examples assume that the appropriate income tax credits are taken. For consistency, it was assumed in all cases that the taxpayer elected to take the state solar income tax credit instead of the optional deduction as explained in the Arizona State Solar Tax Incentives, Section 1.A.5 of Table 5.5.

In many cases it would be more advantageous to the taxpayer to take the deduction rather than the credit. If you ignore the time value of money and assume that the taxpayer is in the maximum marginal Arizona state income tax bracket of 8%, one would elect to take the deduction rather than the credit if the PV system cost exceeds $12,500 (8% of $12,500 is $1,000).

5.2 Energy Conservation Tax Incentives

Generally, the largest energy-consuming device in a home is the space heating and cooling unit. Heating and cooling can account for two-thirds or more of a home's annual energy consumption. Reducing the size and operating time of a space conditioning device in a PV-powered home saves money in two ways. First, a smaller unit will cost less to purchase. Secondly, a smaller unit that operates less often will require a smaller and less expensive PV system to power it. Clearly, one would want to continue adding energy-saving measures until their cost exceeds the savings from downsizing the conditioning and PV systems.

This section discusses the various types of tax incentives available to taxpayers at the federal and state level for residential energy conservation measures.

TABLE 5.5
California and Arizona State Tax Incentives

CALIFORNIA STATE SOLAR INCOME TAX CREDIT

1. An income tax credit of up to 50% of the cost of purchasing and installing a PV system is available to the purchaser.
2. Residential PV systems are eligible whether grid connected or not.
3. The maximum credit per dwelling is $3,000.
4. The federal credit must be taken first, and the state credit must be reduced so that the combined total credit does not exceed 50% of the eligible system costs.
5. The credit must be taken in the year of installation.
6. Unused credits (i.e., the credit is greater than the net tax owed) may be carried forward until exhausted.
7. The credit expires at the end of 1986.
8. For more information, contact the California Energy Commission solar and conservation tax credit hot line (telephone: 800-952-5670 or 916-324-3522).

ARIZONA STATE SOLAR TAX INCENTIVES

1. The followng tax breaks are available for purchasers of residential solar systems in the state of Arizona.
   - A. An Arizona homeowner is eligible for an income tax credit in lieu of the optional standard deduction. The credit is based on the cost of purchasing and installing a solar system.
     1. The credit is 35% in 1983; thereafter the credit is reduced by 5% per year.
     2. This credit may be taken in addition to the credit in the renewable energy source portion of the Federal Residential Energy Credit.
     3. The maximum credit for a given residence is $1,000, and this may be accumulated over different tax years.
     4. Unused credits may be carried over for a period not to exceed 5 years.
     5. In lieu of the above credit, a homeowner may elect to amortize or deduct the cost of solar energy devices over 36 months.
     6. These credits and deductions expire after 1987.
   - B. Solar systems are exempt from property taxes.
   - C. Purchases of solar systems are exempt from state sales taxes.
2. For more information, contact the Taxpayer Service Section of the Arizona Department of Revenue (telephone: 602-255-3381 in Phoenix or 602-352-5407 in Tucson).

5.2.1 Federal Tax Incentives for Energy Conservation Devices

The Federal Residential Energy Credit has two parts. The Renewable Energy Source portion of this credit was described in Section 5.1.1. The qualifications, limits, and eligibility requirements of the Energy Conservation portion are listed in Table 5.6.

5.2.2 State Tax Incentives for Energy Conservation Devices

Energy conservation tax incentives available at the state level vary widely from state to state. They are not as common as the state solar tax incentives, but in the states that do offer them, the cost of energy saving devices can be reduced significantly. Generally, there are three possible types of state energy conservation tax incentives depending on the tax structure in the particular state: state property tax exemptions, state income tax incentives, and state sales tax exemptions or refunds. Table 5.7 lists the states that offer some type of energy conservation tax incentive.

Tables 5.8 and 5.9 describe the state energy conservation income tax credits available currently in California and Arizona, respectively. Listed in detail are the qualifications, limits, and eligibility requirements for the energy conservation tax credits in each state.

TABLE 5.6
Federal Residential Energy Credit
(energy conservation)

1. The cost of purchasing and installing energy-saving components is eligible for the Federal Residential Energy Credit if the following three conditions are met:
   A. They are installed in an individual's principal residence located in the U.S. and are substantially completed before April 20, 1977.
   B. The energy-saving components are new when installed.
   C. The components are reasonably expected to remain in operation for three years.
2. The following limits apply to the energy conservation portion of the federal residential energy credit.
   A. The credits are available for expenditures made through 1985 (currently there is legislation pending to extend these credits for several years).
   B. The credit is retroactive to April 20, 1977.
   C. The credit is 15% of expenditures up to $2,000, for a maximum credit of $300.
   D. The maximum amount of $300 is applied on a cumulative basis, not yearly.
   E. If the amount of the credit exceeds the tax liability of the individual in a particular year, the unused portion of the credit may be carried over until it is used up. Credits may be carried over only until they are used up and/or only until the end of 1987.
3. The federal residential energy credit may be taken for qualified expenditures made by an individual, for that individual's principal residence, whether they are the homeowner or tenant.
   A. A proportion of the qualified expenditures for multiple unit (separate owners) housing may be taken by the owner/resident (e.g., condominiums or town houses). Each owner/resident is eligible for the full credit.
   B. Multiple owners of a single dwelling are treated as a single taxpayer and must divide the available credit amounts among themselves.
4. Qualifying expenditures include:
   A. insulation
   B. storm (or thermal) windows or doors
   C. caulking or weatherstripping
   D. a replacement burner for your existing furnace that is more efficient
   E. flue opening modifications that make a heating system more efficient
   F. an electrical or mechanical furnace ignition system that replaces a gas pilot light
   G. a thermostat with an automatic setback
   H. a meter that shows the cost of energy used
5. For more information, contact the Conservation and Renewable Energy Information and Referral Service (telephone 800-523-2929), or contact the IRS and request income tax form 5695.

TABLE 5.7
States With Energy Conservation Tax Incentives

Alabama	Colorado	Kansas	North Carolina
Alaska	Florida	Massachusetts	Oklahoma
Arizona	Hawaii	Michigan	Oregon
Arkansas	Idaho	Montana	Rhode Island
California	Indiana	Nevada	Washington
			Wisconsin

TABLE 5.8
California State Conservation Tax Credit

1. An income tax credit is available to California taxpayers who install eligible energy conservation measures on a dwelling owned by the taxpayer at the time of installation.
   A. The credit is 35% of the cost incurred or $1,500, whichever is less.
   B. The credit must be reduced by the amount of any grant or nonreimbursable financial assistance (other than interest charges) provided by a utility or a public entity.
   C. The energy conservation measure must be installed before the end of 1985 when California State Conservation Tax Credit expires.
   D. If the state tax credit exceeds your state tax liability for the year, then the unused portion of the credit may be carried forward and used in future years until it is exhausted.
2. The credit is available for new and existing residences.
   A. For new dwellings, conservation measures are eligible only to the extent that they exceed the amount necessary to meet the Residential Building Standards.
   B. For existing residences, only the cost of conservation measures that exceed the code requirements, at the time of original construction, is eligible for the credit.
3. The taxpayers can reduce their state taxes by a portion of the costs spent on energy audits, engineering feasibility studies, permit fees, installation, materials, design, and the principal recovery of monthly lease payments.
4. Listed below are some of the energy conservation measures that are eligible[a] for tax credit:
   A. electrical or mechanical furnace ignition systems
   B. storm or thermal windows or doors
   C. evaporative coolers
   D. insulation
   E. weatherstripping
   F. caulking and sealing
   G. ventilation cooling fans, attic ventilators, economizer systems
   H. load management devices
   I. daylighting devices
5. For more information, contact the California Energy Commission solar and conservation tax credit hot line (telephone: 800-952-5670, or 916-324-3522).

(a) Some of these items require a Residential Conservation Service audit to be eligible for the tax credit. All items must have a useful life of at least 3 years.

Source: California Energy Commission Publications No. P-200-83-002.

TABLE 5.9
Arizona State Conservation Tax Credits

1. An income tax credit is available to Arizona homeowners who install certain energy-saving devices on their personal residences.
   A. The credit is 25% of the cost incurred for purchase and installation.
   B. The credit is used to reduce state income taxes and cannot exceed $100.
   C. The credit must be taken in the year of installation, cannot be refunded, and no carry forward is allowed.
   D. After 1989 the credit expires.

2. To qualify for credit, the devices must meet the following criteria:
   A. They must be in addition to what currently exists in the residence, or
   B. They must be in addition to what is normally installed in a new home.

3. Listed below are some of the energy-saving devices that qualify for the credit:
   A. insulation (roll, loose fill, rigid or foam)
   B. insulating windows (storm and/or multiple glazed)
   C. thermal insulating doors
   D. attic ventilators (mechanically driven or wind turbine)
   E. passive roof vents
   F. water heater insulation jackets.

4. For more information, contact the Taxpayer Service Section of the Arizona Department of Revenue (telephone 602-255-3381 in Phoenix or 602-352-5407 in Tucson).

6.0 WHEN TO CHOOSE PHOTOVOLTAICS

The purpose of this chapter is to help you decide when to buy a PV-powered system. In several types of applications, PV has proven to be reliable and cost effective, whereas in other applications PV may require more development. In some cases, the decision depends on the uniqueness of the location and/or on individual circumstances. Because individual circumstances require a more difficult decision, we emphasize it in this chapter.

PV systems are not yet cost effective for people who are connected to a utility grid and who use a large amount of electrical power, if they do not plan to adjust their lifestyles and their electricity use. Because the concept of a large roof-top array generating electricity for household needs with some extra to sell to the utility is an exciting prospect, a program involving private and government funding is working to make it a reality. Although many believe it may soon become practicable, right now the before-tax cost of such a PV system would be about $100,000 per home. Using current federal and state tax credits would reduce the cost by $7,000 in California and $5,000 in Arizona.

In cases where individuals are willing to reduce their energy use, currently available PV systems may be a viable energy resource. Besides cost, other factors to consider include the unique benefits of PV systems, such as reliability, security, self-sufficiency, environmental compatibility, modularity, and privacy. For those considering building a vacation or retirement home in a remote area, PV power supplies are well worth serious consideration. For farmers or outdoorsmen, the portability and freedom of PV-powered systems from utility hook-ups make them valuable for applications from lighting, to water pumping, to security systems.

In more and more applications, PV systems are clearly preferable to alternative power sources. For example, when utility power is not conveniently available, a PV system can provide power requirements for such applications as communications repeaters, navigational aids, and remote sensing equipment. In some cases, the cost of connecting equipment to locally available utility supply may be more than the cost of PV power supplies. For example, PV power supplies are cheaper than connecting to a utility for aircraft warning lights atop high tension electrical transmission towers. PV systems are also clearly appropriate in cases where power needs occur when the sun shines.

In deciding whether to use PV supplies, you should compare the cost and performance of PV-powered systems with other available systems. The word "system" is important here because various types of equipment may meet your energy needs. For example, both a mechanical system that directly uses wind and a PV system that converts sunlight into electricity and then uses electricity will provide pumping.

In the rest of the chapter, we compare the performance of PV systems with other systems. The alternatives to be considered include the following:

- utility power available from the power grid

- wind power for pumping water or generating electricity
- gasoline or diesel generators for providing electricity
- manual labor.

To make any of these power supplies cost effective requires certain levels of energy efficiency. The best system to fit your needs may be a combination of two or more of these energy supplies, along with energy conservation. Section 6.1 discusses applications where currently available PV systems are the best choice, and Section 6.2 discusses cases where PV may be the best power source, depending on your specific needs.

6.1 Cost-Effective Photovoltaic Systems

PV energy systems are being used in more and more applications where utility power is either not available or relatively expensive to access. We say relatively expensive, because in some applications the cost of installing a PV-powered system is cheaper than connecting a conventional appliance to the utility supply. The applications where PV clearly makes sense can be classified into three categories:

- where power is needed in remote or difficult-to-access areas
- where PV net installation costs are lower
- where there is a unique timing of needs.

The following discussions highlight examples of these applications and the benefits of PV applications compared to alternative measures.

6.1.1 Photovoltaics for Remote Areas

PV systems have been shown to be cost effective in industrial applications that are away from utility grids where average power requirements are less than two kilowatts. Tens of thousands of remote PV applications have been installed to power such equipment as warning beacons on oil drilling platforms, telephones and repeater stations, and radio transmitters on mountain tops. In these applications, PV systems have proven to be very economical and reliable compared to other systems. At first these applications were used for power requirements of only a few watts per installation. However, with the increasing cost of fossil fuels and the availability of larger PV systems, even larger electrical loads are using PV supplies.

Each installation has unique features that should be considered when selecting the best power source. A few of the key attributes of PV power systems are as follows:

1. **Reliability** - Properly sized PV systems demonstrate excellent reliability in very hostile environments.
2. **High-Altitude Performance** - PV is favored at high altitudes because the air is thinner and the sun is brighter. For example, at high altitudes a typical diesel generator has about only half of its sea-level capacity and is less efficient as well.
3. **Maintenance Cost** - Transporting materials and qualified personnel to remote areas for periodic maintenance is very expensive. Because PV systems require only periodic inspection and occasional replacement of storage batteries, maintenance costs are usually much less when compared to alternatives.
4. **Cost of Fuel** - PV energy supplies have no costs for obtaining, storing, and transporting fuel.

Because most remote industrial applications have firm or essential power requirements, only those power sources that can perform consistently are acceptable. Consequently, alternative energy sources such as wind or hydro are seldom acceptable by themselves. However, some currently generating hybrid systems combine the reliability of a PV system with the economy of a wind generator. Typically, the wind power is used for optional or intermittent loads, while the PV system assures a minimum level of power availability for essential needs.

For power needs in excess of 2 kilowatts continuous, the current major alternative is diesel for liquid propane gas-powered generators. Although the purchase costs of diesel are fairly low, the cost and availability of fuel in remote areas is of such significance that PV arrays are becoming the preferred power source for many applications of up to 15 kilowatts. The economics and reliability uncertainties of diesel equipment compared to the security of PV systems are primary influences that are increasing the use of PV power sources.

In addition to the energy needs for remote industrial equipment, PV systems can be used in less remote agricultural, residential, and recreational applications. A survey of several electric utilities indicated that the cost for extending utility lines averages over $20,000 per mile. The cost and accessibility of such extensions will vary according to the servicing utility, but the cost will more likely be higher than lower. If soil conditions are less than ideal (marshy or rocky lands) or if right-of-way for the power lines must be secured, the costs can rise rapidly. Therefore, PV supply systems should definitely be considered where utility connection costs are significant. Rather than putting one's money into power lines that must be paid for in addition to the ever increasing price of the power delivered, one can invest in a PV system that has higher reliability and lower operating cost. The farmer who needs to pump water for his livestock may best be served by a PV system that pumps water according to the intensity of sunlight. Historically, wind systems have been used for this application, and where sufficient wind is available for year-round needs it is usually the cheapest alternative. However, in cases where wind systems are not enough, adding a PV-powered pump for a hybrid system may be ideal.

Another example of a remote application would be a vacation home in the wilderness. The alternative sources of power available include wind power if sufficiently reliable, hydro power if sufficient and legally useable, a gasoline or diesel generator set if cost effective and environmentally acceptable, or a silent, reliable, and cost-effective PV system. Once again, if conditions permit, a hybrid system may be the best approach. The reliability of a PV system could be combined with potential economies of alternatives. One of the great benefits of hybrid systems where battery storage is necessary is that several types of electrical generation can use the battery storage to its fullest extent at a low incremental cost.

6.1.2 Photovoltaics for Lower Net Installation Costs

PV clearly makes sense when the power needs are low. Although utility power may be available, local costs for wiring are sometimes high enough to justify the cost of a PV panel. For example, retrofitting an attic fan or driveway light can be expensive; however, a PV attic fan can be easily installed by the handyman without shock hazard. Also, it is very expensive to run a conduit up the side of a petroleum tank for a level indicator or a light. Using a small PV array close to the power need for installations such as this may be more cost efficient.

To help the reader compare the costs of using a PV system to supply power where connection costs to utility power are significant, we have listed typical costs for common wiring tasks in Table 6.1. Actual costs for your installation will vary depending upon the local costs and availability of materials and skilled labor. Although many jobs can be done by "handyman" types, the use of licensed electricians is advised because of the liability risks of safety hazards from improperly installing the appliance.

6.1.3 Photovoltaics for Unique Timing of Needs

PV power supplies also clearly make sense when the energy needs are proportional to the sun's intensity. Such conditions exist in many heating or cooling applications. One example is water circulation pumps in solar heating systems. A circulating pump connected to a PV panel will circulate the water at a rate proportional to the rate of hot water production. It will circulate fastest when the sun is at its hottest.

In such applications, PV offsets the cost of controls normally used and is generally more reliable. The benefits of PV as motive power for solar collection systems include a) improved reliability, b) improved system efficiency because of proportional control, c) improved protection against freezing because water is not pumped until the sun warms the panel and, d) simplified installation and maintenance. These considerations often times outweigh initial cost differences between PV-powered and standard controls.

Another example is powering an evaporative cooler with PV panels. In the hottest weather, the sun shines much more than the yearly average, and the PV array produces additional power for the cooling unit. Because demands on utilities are often the

TABLE 6.1
Typical Local Costs of Supplying Remote Branch Circuits

Cost Item	Example Ft.	Total Cost of Wiring
Cost of controls and wiring 120 V AC attic fan	75' of Romex	$ 123(a)
Same except use 1/2" standard conduit	75' of Conduit	160(a)
Cost of wiring & installing a driveway light	100' of Conduit	260
Cost of wiring and connecting auto. gate opener on a ranch	500' of Conduit	878
Cost of wiring a stock watering pump. 1/4 HP 230 V	1500' of #8 3 Conductor Cable	2,271
Cost of supplying power to a level indicator on petroleum storage tanks	500' to tank, 75' vertical run up tank, 20' horizontal all in Conduit	about 5,000

(a) For retrofit installations, these figures most likely are low.

greatest during the hottest periods, a growing number of utilities are adopting pricing systems that charge more for power during these hours. Under these conditions PV-powered coolers will have improved cost effectiveness.

The sun-synchronous watering needs of livestock and agricultural areas also offer unique opportunities for PV power supplies. Here again, the need for pumping typically occurs when the sun shines the hottest. Because water storage can replace the need for electrical storage in batteries, the costs of purchasing and upkeeping the PV system are minimized.

The key factor in these types of applications is timing. If energy needs coincide with the sun's intensity, PV systems have inherent benefits that often make them the least expensive and most practical form of energy supply. Because these applications use power as it is generated, electrical storage systems usually are not necessary. Therefore, these systems are among the simplest, most easily maintained, and most cost-effective PV applications currently available.

6.2 Possible Photovoltaic Applications

Depending upon the buyer's specific concerns, needs, and preferences, PV **may** be the most sensible power source in many applications. As mentioned earlier in this chapter, many of these factors can only be assessed by the buyer. The purpose of this section is to suggest some applications where PV offers particular advantages that may be of value to you.

Although cost is often the most important consideration in selecting power supplies, many other factors may influence the decision. These factors include impacts on the environment, the national economy, world security, and feelings of personal well being from self-sufficiency, to name a few. Given the uncertainties of the cost and availability of future energy supplies and the stability of the world economy, many of you may place a premium on the certainty that a PV energy supply can provide. The fact that PV systems are silent and otherwise environmentally harmless, simple and easy to maintain, reliable, and essentially free of inflationary pressures may make them attractive at present prices.

Surveys indicate that more people than ever are concerned about our energy future. Since 1975, a significant change has occurred in the way people look at the energy question. According to one study (Sumichrast, December 1980, published by National Association of Home Builders), 80% of home purchasers in 1980 considered energy a serious problem, whereas in 1975 only about 25% considered energy a problem. Only 7% rated the energy problem in 1975 "extremely serious", but this increased to about 36% by 1980 and is indicated to increase to about 74% by 1985. Consequently, a growing number of people are finding that it may be acceptable and even advantageous to reduce their energy dependence through conservation, lifestyle changes, and/or use of renewable energy resources.

Clearly, many people today are concerned about the future supply and cost of energy. Building a dream home could become a nightmare if utility bills (heating and electrical) aren't controlled. As a result, interest in energy-efficient homes and passive solar designs has increased dramatically in recent years, although surprisingly little attention has been given to the possibility of markedly reducing electrical consumption in the home. If people would be willing to significantly reduce their electricity requirements, as we suggest later in this chapter, PV power systems may prove to be an appropriate and affordable power supply.

Will people continue to buy homes that face an uncertain future of higher fuel bills? Most believe that they will if actions are taken to minimize the cost of energy supplies. This is done first by reducing energy needs through conservation features and lifestyle changes, and then by obtaining dependable and economic fuels.

The cost of energy from the PV array over its expected 25-year life is constant and even reduces in real cost compared to the other commodities required for living. The cost of electricity for most utility companies will increase at a rate significantly higher than inflation. On the other hand, if a PV system is purchased as part of a 30-year home mortgage, the real burden of those fixed payments typically decreases as time goes by. If a purchaser's income increases as inflation rises and the house payment remains the same, the cost of the system will be a smaller percentage of total income. This cash flow situation will depend upon your particular situation, but it is an important consideration for those nearing retirement or those particularly concerned about their future income potential.

If you have decided to buy or build a home or start a business where utility power is not readily available, PV may be your best alternative. You must consider the costs to run a utility line out to your property (typically in excess of $20,000 per mile), the cost of metering and connection, and finally the cost of the power bills.

If a PV system is to be used to power a building, extensive measures should be taken to reduce the building's energy needs. As in other solar systems, it does not make sense to use relatively expensive collectors to replace energy that could be more cheaply conserved. The money that can be saved by conserving energy and using PV power supplies depends on site conditions, such as climate and energy costs. The example residential installations below will show how energy conservation and lifestyle changes can affect the size and cost of PV systems.

We conducted the analysis using climatic data for Phoenix, Arizona. We selected Phoenix for several reasons:

1. The amount of solar insolation (sunshine) is among the highest in the country.
2. The main electricity requirement is for space cooling, which is mainly needed at the same time that PV power is available.
3. The cost of grid-supplied electricity is among the highest in the nation.
4. Statistics on population growth indicate that home construction will continue at a high rate.
5. The climatic information was accurate and detailed enough to allow sophisticated energy analysis tools to be used.

Because of these conditions, the following examples may represent a "best-case" for PV use in the residential sector.

Four cases were analyzed. For the first three cases, we assumed that only the homes' design and appliances were changed, with no significant lifestyle changes. In the fourth case, we assumed that significant changes were made in lifestyle also to reduce the cost and to increase the PV system's effectiveness.

In each case the living area was 1,400 square feet, although the design and construction of each home was quite different. The amount of energy needed in the first three cases was figured to meet the typical needs of an average family of three and changed only because of improvements in appliance efficiency and energy conservation measures. Only the last case assumes that the occupants significantly altered their energy-use habits as well.

It was assumed that the homes **were not** connected to the utility grid, so the PV system is sized to supply all the electricity necessary to do the following:

- keep internal temperatures below 80°F 98% of the time
- maintain adequate lighting levels
- provide power for a refrigerator
- provide enough power for commonly used home appliances.

Because some of the energy requirements occur when the sun is not shining, electrical storage was required. The size and cost of the storage system varied with the size of the array, percentage of daily energy consumption occurring during non-sunlight periods, type of batteries used, the existence of backup generation, and many other factors (see Section 4.4).

Fuel for cooking, as well as backup for space heating, was assumed to be supplied by other means such as liquid propane gas, wood, or gasoline-powered electric generators. However, a large part of these needs can be met by the PV power supply when excess power is available, particularly if appropriate appliances were selected. Water heating was assumed to be supplied by either electrical or solar energy for the sake of consistency, although a fossil-fueled water heater or back-up system could probably be more cost effective considering current PV system and fossil fuel prices. Other groundrules of the energy-use comparisons are listed in Table 6.2.

The energy required for space heating and cooling depends on the building's char-

TABLE 6.2
Groundrules of Energy-Use Consumption

Design and Lifestyle Changes in Applying 1984 PV Technology in Residences

PURPOSE

To assess the trade-offs of energy efficiency, PV system size, and lifestyle adjustment.

MEASURES CONSIDERED

Insulation of walls, ceilings, windows passive solar, earth sheltering, window glazings, areas, and orientation, vapor barriers, air-to-air heat exchangers, heat pump, solar water heating, and energy-efficient appliances and lighting.

METHODOLOGY

Compare PV system size and cost with conventional energy cost for three levels of energy conservation holding use and amenity level constant and one additional case where some lifestyle and comfort adjustments are made.

ASSUMPTIONS

Family size	3
Internal load	53,100 Btu/day
Infiltration	Coblentz-Achenbach normalized
Peak sun-hours	6
Solar hot water fraction	80% (when used)
Cooling COP	3.0
Energy cost	Current rate schedule for Arizona Public Service Co.
Battery life	5 years
Battery discharge depth	15% daily average
Battery salvage value	$5 per battery
Time value of money	15%/year
Solar tax credits	40% federal up to $4,000, 30% state up to $1,000
Location	Phoenix

acteristics and climate and the occupants' comfort requirements. To calculate these requirements, we used the DOE 2.1 computer program developed by the DOE. The program uses information about the building's construction and use, along with weather data for each hour of the typical meterological year to generate estimates of energy needs. The program has been validated against actual building performance in several studies and has been found to yield estimates within about plus or minus 10%.

In cases where the PV system is the primary source of home electricity, a backup fossil-fueled generator is very useful to provide additional power when very low levels of sun and very high levels of need occur at the same time. For example, you may occasionally have several/many overnight visitors, which will increase energy needs dramatically. It would probably not be cost effective to size the PV array for such short periods of higher-than-normal need, when a relatively inexpensive fossil-fueled generator could be used. The cost of this backup system has not been included, however, since the need and value of it vary significantly depending upon the user.

Each of the four sample homes is discussed separately below.

6.2.1 Case I — Typical All-Electric Home

To minimize the cost of new homes, energy conservation features are often installed only to the level required by current building codes. Typically, the code is based upon historical rather than projected fuel costs, and therefore the amount and cost of energy for heating and cooling is exceedingly high. The ranch-style home selected to represent such construction is shown and described in Table 6.3.

As the table shows, the typical peak electricity needs were found to be about 60 kWh per day. The major portion (67%) was for summer cooling, and because solar water heating is not usually used, a full 10 kWh per day is required for water heating unless alternative fuels are used. To meet the energy requirements, a full 10 kW of PV capacity is needed, which would cover nearly one half of the total roof area. Because the major portion of electrical needs occur during the sunlight hours, it was assumed that the battery storage system would provide for 20% of daily power use during non-sunlight hours. The annual estimated battery cost for this systems is $643.

Even after using the renewable energy tax credits to its fullest extent, the cost of such a large system would be $88,000, well above the realm of affordability by most of us. Therefore, there is some validity to the widespread public perception that at least at present, PV is too expensive. However, as you read on, you may realize that this perception is not always justified.

TABLE 6.3
Typical All-Electric Home

CHARACTERISTICS

Insulation	R-11 walls, R-19 ceilings
Windows	Area 15% of floor, single glazing, evenly distributed
Infiltration	1.0 air change/hour, average

ELECTRICAL SYSTEM

		Average Daily Energy Use (kWh)
Space heating	15 kW forced air furnace	35-40*
Space cooling	2½ ton fan coil	40
Water heating	4.5 kW electric resistance	10
Lighting	700 watts incandescent	3
Refrigeration	Frost free	3
Other appliances	4 kWh/day	4
Total		60 kWh

ENERGY COST IF GRID CONNECTED

$133.54/month

CONSERVATION MEASURE COSTS

$0

PV SYSTEM SIZE AND COST

233 43W modules
64 105 Amp-hour batteries
1 Control panel
1 Inverter
$93,000

NET SYSTEM COST

The Maximum Tax Credit Would Be $5,000
$93,000 - $5,000 → $88,000 or $8.80/W

*Summer design is more severe load.

6.2.2 Case II - The Energy-Efficient Home

Because many buyers realize that energy costs are expected to continue to escalate, they are demanding and builders are including additional energy conservation measures in new homes. By incorporating measures that cost no more than $3,140 after tax credits, the average peak energy requirements can be reduced by 40% to approximately 35 kWh per day, as shown in Table 6.4.

Conservation measures that reduce power consumption at significant additional cost include the following:

- thicker insulation
- double-glazed windows
- complete vapor barrier
- vestibule entry
- use of efficient fluorescent lighting
- solar water heating.

The example uses a one-story design. A two-story design, which reduces exposed surface area and concentrates windows on the south to maximize solar heating in the winter and minimize it in the summer, are features that would reduce energy costs but were not used in this case.

The cooling system required to condition this home is smaller than typical because of the energy conservation measures, and the electricity needs are reduced to 35 kWh on the design day. Because solar water heating is used, which is adequate to meet 80% of the hot water needs, only 2 kWh per day of electricity is needed to heat hot water. The energy needed for the refrigerator was reduced by selecting a more energy-efficient model that did not cost more than the typical model. Because the major portion of the electrical needs (summer cooling) occurs during sunlight hours, it was assumed that the battery storage system would provide 20% of power used daily during the non-sunlight hours. The annul estimated battery cost of this system is $431. Although the size of the PV systems needed in this case has been reduced to 5.83 kW, the net system cost after maximum use of tax credits would be $53,640, which is still too expensive for most of us.

TABLE 6.4
Energy-Efficient Home

CHARACTERISTICS

Insulation	R-19 walls, R-38 ceilings
Windows	Area 15% of floor area, double glazed, predominantly on south face
Infiltration	0.5 air change/hour, vestibule entry

ELECTRICAL LOADS

		Average Daily Energy Use (kWh)
Space heating	10 kW forced air	25
Space cooling	1½ ton fan coil	
Water heating	80% solar	2
Lighting	50% fluorescent-task lighting	2
Refrigeration	Energy efficient	2
Other appliances		4
Total		35 kWh

ENERGY COST IF GRID CONNECTED

$78.31/month

CONSERVATION MEASURE COSTS

Insulation	$440
Windows	$300
Vapor barrier	$200
Solar hot water	$2,500
	3,440

CREDITS

System Downsizing	$200
Tax Credit	$100
	$300

NET

$3,140

PV SYSTEM SIZE AND COST

136 43W modules
40 105 Amp-hour batteries
1 Control panel
1 Inverter
$55,500

NET PV SYSTEM COST

The Maximum Tax Credit Would Be $5,000
$55,500 - $5,000 → $50,500
or $8.66/W

NET SYSTEM COST

$50,000 + $3,140 → $53,640

6.2.3 The Earth-Sheltered Home

Many home buyers and builders are experimenting with unconventional construction techniques that offer the promise of dramatically reducing energy needs. The "earth-sheltered" home depicted in Table 6.5 is an example that has shown that significant energy savings can be had, if you can accept what many consider to be radical architectural practices. Earth sheltering reduces energy needs by using the earth as a buffer between the home and the surrounding environment, thereby reducing both heating and cooling energy needs. In addition, the installation of a continuous vapor barrier is simplified because earth-sheltered walls are adequately sealed.

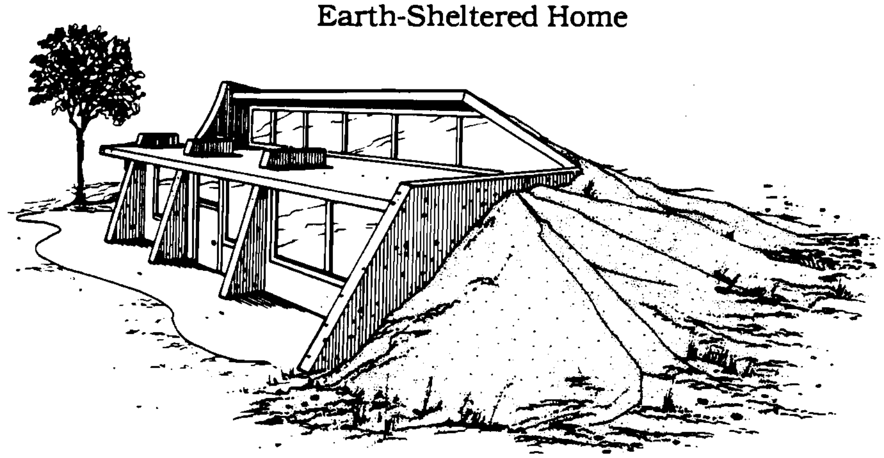
In addition to the features of the home described in Case II, this home also includes the following:

- Windows are triple-glazed and total window area is reduced to 10% of floor area.
- Air infiltration has been reduced to a net of .1 air change/hour by using an air-to-air heat exchanger for ventilation.

This house uses about one-half of the electrical energy of the "energy-efficient" example (Case II) mainly because the cooling energy requirements are reduced from the earth sheltering and from the reduced air infiltration.

The PV system size needed for this home is about 3 kW, which would fit nicely on the lower level of the exposed roof. Because the energy needs were reduced by decreasing the cooling energy requirements, the battery storage system could have to be the same size as in Case II. Thus, the battery storage system would provide for 40% of daily power use during non-sunlight hours, and the annual estimated battery cost for this system would also be $431. When tax credits are used to their full advantage, they cover about 15% of the total system costs. Although the cost after tax credits is still $29,150, such a system may be affordable by some, especially when independence, privacy, or self-sufficiency is desired.

TABLE 6.5
Earth-Sheltered Home



CHARACTERISTICS

Insulation	R-38 ceilings, earth sheltered walls
Windows	Triple glazed south facing @ 10% of floor area or single glazed with photoelectric moveable insulation
Infiltration	0.1 air change/hour net (0.5 ach. with 75% efficient heat exchange) vestibule entry

ELECTRICAL LOADS

	Average Daily Energy Use (kWh)
Space heating	1
Space cooling	8
Water heating	2
Lighting	2
Refrigeration	2
Other appliances	4
Total	19 kWh

ENERGY COST IF GRID CONNECTED

$43.70/month

CONSERVATION MEASURE COSTS

Earth berming	$1,000
Solar hot water	$2,500
Air-to-Air heat exchanger	$500
	4,000

CREDITS

System Downsizing	$600
Insulation	$400
Tax Credit	$100
	$1100

NET

$2,900

PV SYSTEM SIZE AND COST

70 43W modules
40 105 Amp-hour batteries
1 Control panel
1 Inverter
$31,250

Net PV SYSTEM COST

The Maximum Tax Credit Would Be $5,000
$31,250 - $5,000 → $26,250
or $8.75/W

NET SYSTEM COST

$26,250 + $2,900 → $29,150

6.2.4 Case IV - The Energy-Independent Home

For some, the desire for energy independence and protection from the uncertainties of our energy future may make significant changes in lifestyle and energy-use habits acceptable. We have prepared this example (Table 6.6) for those who may be willing to implement such changes. Because PV systems are modular, you can start with a small system and add capacity as your needs increase and finances allow.

It is possible to eliminate 90% of the electrical consumption of a typical home. Naturally, it raises the question of whether it would be pleasant to live in such a home. Judge for yourself. Newly developed types of lighting now give four times as much light per watt as an incandescent bulb. You can buy refrigerators that are smaller than we are use to but that operate on one-fourth of the power a standard refrigerator uses. The list goes on.

Besides efficient appliances, you may consider stopping unnecessary appliance use such as dishwashers, electric can openers, electric knives, etc. and substituting manual methods. Of even greater potential impact is the proper scheduling of energy-use activities to use power efficiently **when it is available in abundance.** For example, cooking later in the evening reduces the load on the air conditioner, or washing with full loads only on sunny afternoons when solar heated water is available in abundance and PV power supply is great minimizes the size of battery storage.

Whether life could be fun with 90% reduction in electricity use is always debatable because for you it may be different than for your friend next door. If you could be happy with this kind of situation, you might be able to move toward energy independence. If you could equip your new home with a PV power supply for about $10,000, you would get substantial tax credit and wouldn't have to worry ever again about high electric utility bills ruining the enjoyment of your dream home. Is it a good economic investment? No one can give you the answer to that question because they don't know how high utility bills will go. How much is your peace of mind worth? No one else can decide that for you!

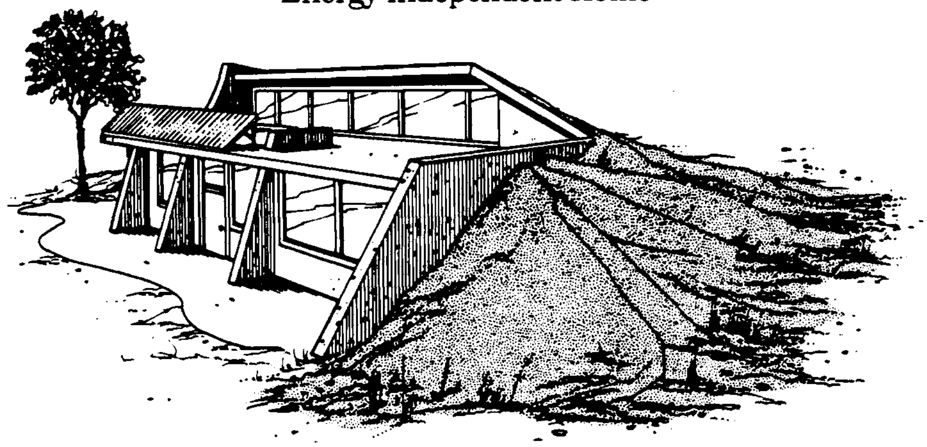
The features and appearance of the house in this case are identical to the earth-sheltered example. However, the use and comfort level of the home are altered somewhat. Specifically this example assumes the following:

- Evaporative cooling alone is acceptable (the result of this assumption is that occasionally the home may be uncomfortably warm for some).
- Efficient fluorescent lights are used for only 8 fixture hrs per day.
- Energy-efficient DC appliances are used.
- Manual dishwashing and refrigerator defrosting are acceptable.
- A smaller 4 cu ft energy-efficient refrigerator is used.
- Back-up for water heating is not provided electrically.

The example used here is similar to the one that is displayed in Chapter 4.0, Section 4.6.2. In that example some uses were curtailed. Energy for cooling will not be required at all times and this capacity is made available for other uses when possible.

In Case IV the cooling load in summer is assumed to be supplied by two evaporative coolers operated by PV panels, requiring 0.8 kWh/day. Hot water is supplied by solar panels with a PV-powered circulating pump, requiring 0.2 kWh/day. Lighting uses 12-V DC very high-efficiency fluorescent lights

TABLE 6.6
Energy Independent Home



CHARACTERISTICS

Insulation	R-38 ceilings, earth sheltered walls
Windows	Triple glazed south facing @ 10% of floor area or single glazed with photoelectric moveable insulation
Infiltration	0.1 air change/hour net (0.5 ach. with 75% efficient heat exchange) vestibule entry

ELECTRICAL LOADS

	Average Daily Energy Use (kWh)
Space heating	0
Space cooling	0.8
Water heating	0.2
Lighting	0.16
Refrigeration	0.5
Other applicances	1.3
Total	2.96 kWh

ENERGY COST IF GRID CONNECTED

$15.84/month

CONSERVATION MEASURE COSTS

Earth berming	$1,000
Solar hot water	$2,500
Air-Air heat exchanger	$500
	4,000

CREDITS

System Downsizing	$600
Insulation	$400
Tax Credit	$100
	$1100

NET

$2,900

PV SYSTEM SIZE AND COST

12 43W modules
12 105 Amp-hour batteries
1 Control panel
$5,750

NET PV SYSTEM COST

The Maximum Tax Credit Would Be $3,300
$5,750 - $3,300 → $2,450
or $4.90/W

NET SYSTEM COST

$2,450 + $2,900 → $5,350

and uses 0.16 kWh/day. Refrigeration uses a small, high-efficiency 12-V DC refrigerator, 0.5 kWh/day. Other DC appliances use a total up to 1.3 kWh/day, for a total of 2.96 kWh/day, used in the earth-sheltered home without energy management and lifestyle adjustment. Because much of the power used in the energy-dependent home can occur at any time of day, the battery storage system was sized so that as much as 75% of daily power use could occur during non-sunlight hours. The annual estimated battery cost for this system is $146.

The starter system to provide for the requirements listed in Table 6.6 has a capacity of approximately .5 kW. This size PV system for the Phoenix area has a system cost of about $5,750 using current prices. Tax incentives (Federal and State of Arizona) reduce the net PV cost to less than $2,500. Adding to this the cost of the specified conservation measures of about $3,000 brings the net concept cost of this residence to less than $5,500. This is a very affordable level of expense. If the system were found to be restrictive of lifestyle, additional capacity could easily be installed later.

The concept may be too restrictive for permanent use but it appears livable for the first year. A major advantage of the energy-independent concept is that it lets you get started with PV at a modest cost and then you can expand the system at a later date. Also, it should be noted that the system shown does not take maximum advantage of the available tax credits. The federal residential energy credit of 40% is limited to $4,000 but a credit of only $2,300 was taken here. Thus a tax credit of $1,700 is still available to be taken if the system is expanded before 1985.

6.2.5 Summary of Case Studies

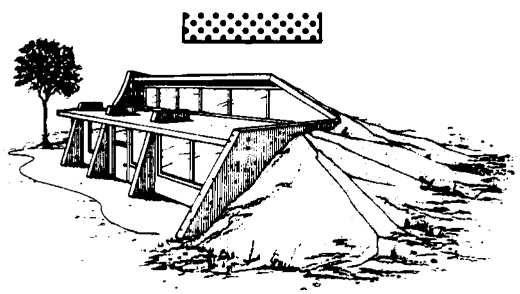
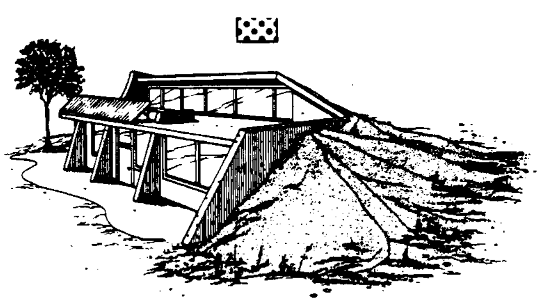
A review of the four case studies is helpful to gain an appreciation of the impact of home energy requirements on PV system size and cost. Table 6.7 depicts each of the homes with a scaled drawing of the relative size of PV arrays needed to supply the calculated energy needs. As the annual and peak daily energy use diminishes, the size of the required array drops proportionally.

The typical all-electric home (Case I) consumes about 20,000 kWh per year and requires 60 kWh on the peak day, thereby requiring a 10-kW array costing about $88,000 even after tax credits. By using conventional conservation measures and passive solar design (Case II), the energy needs are reduced by about 45%. Only 11,700 kWh per year are needed, and the peak requirement is reduced to 35 kWh per day, thereby making a 6-kW array sufficient. Although the conservation features increase the cost of the home by $3,140, the cost of the PV system required is reduced by $37,500.

Clearly one would want to continue adding energy-savings measures until their cost exceeds the savings to be had from downsizing the conditioning and PV systems. Using earth-sheltering principles (Case III) can cut the energy needs of the energy-efficient home again in half, requiring 6,000 kWh per year and only 18 kWh on the peak day. As a result, a 3-kW array is adequate, costing $26,250 after tax credits.

These first three cases required only insignificant changes in lifestyle resulting soley from incorporating energy conservation features on the building and appliances. The final case (IV), called the energy-independent home concept, suggests that by wisely altering lifestyle to minimize energy

TABLE 6.7
Comparison of PV Requirements

SCALED ARRAY SITE	Annual Energy Use (kWh)	Peak Daily Use (kWh)	PV System Size (kW)	PV System Net Cost (1984 $)
	ALL-ELECTRIC HOME			
 (incremental cost $0)	20,000	60	10	88,000
	ENERGY-EFFICIENT HOME*			
 (incremental cost $3,140)	11,700	35	6	50,500
	EARTH-SHELTERED HOME*			
 (incremental cost $2,900)	6,000	18	3	26,250
	ENERGY-INDEPENDENT HOME (Lifestyle Adjustment)			
 (incremental cost $2,900)	1,080	3	0.5	2,450

*No lifestyle or comfort adjustments required.

needs and to maximize the effectiveness of the PV array, the size of the PV array can be drastically reduced. The energy needs of this home are approximately 1000 kWh per year and the peak daily load is limited to 3 kWh. A .5 kW array is adequate to supply this level of energy need and would cost less than $2,500 after tax credits.

Tax advantages of purchasing PV systems should be considered in system selection to maximize the systems' cost-effectiveness. We summarize the federal and state tax credits in Chapter 5.0. We recommend that you contact your state energy office for more comprehensive and specific guidance in taking advantage of available tax credits.

As mentioned previously, the system size can be easily increased in subsequent years because the modular nature of PV energy systems. Thus, a system can be built over a period of years as your needs increase or your finances permit, and tax credits will assist you at least until 1985. Because the future of tax credits is uncertain past this period, you should use them now while they are available.

In Table 6.8 we list some preliminary findings of this case study which you may want to take into account if you are considering the purchase of a home-electric system. Although these findings are based upon weather data and tax credits of Phoenix, Arizona, they are generally applicable to other areas, although optimal system size will likely be different. However, by raising these issues with a local PV supplier, you will be well on your way towards the purchase of the most cost-effective system to meet your particular needs.

TABLE 6.8
Preliminary Findings

The effects of energy conservation approaches on the electricity requirements and the potential for electrical energy independence.

1. PV systems are most cost effective when used on more energy-efficient homes.
2. Under current federal tax regulations, one can claim $4,000 cumulatively for the period 1981-1985.
3. Under Arizona state tax regulations, one can claim $1,000 cumulatively for the period 1981-1987. Other states have different tax & incentive regulations, which may apply.
4. Consequently, the earth-sheltered style home, which requires 3 kW capacity, is optimal for PV development without change of lifestyle.
5. Assuming grid extensions cost $20,000 mile, the earth-sheltered building is cost effective more than 1 mile from the grid.
6. With appropriate lifestyle adjustment, necessary residential electrical requirements can be satisfied with a .5 kW system costing less than $2,500 (after tax credits). This system can be upgraded in subsequent years, if desired, taking full advantage of unused tax credits.

6.3 Purchasing a Photovoltaic System

PV systems have been demonstrated to provide a reliable and cost-effective power-supply in many situations. We have tried to highlight some of them in this directory, and as this goes to press, many more are emerging. Because of this rapid expansion of the types and sources of PV products reaching the marketplace, some words of advice to potential buyers are needed.

Once you have identified a potential application for a PV energy system, contact several vendors to compare the available products. Take the time to explain your needs to the vendor and tell him that you are contacting other suppliers to compare products, services, and warranties. You may want to ask for references from satisfied customers or for copies of product brochures and warranties. Most reputable vendors will have little trouble satisfying these requests.

If you expect to take advantage of tax credits available for renewable energy systems, contact your state energy office to get the details on their requirements and limitations. They may also maintain lists of licensed vendors or installers as well as individuals using PV energy supplies. Also, the energy office may be able to refer you to associations of individuals sharing information on solar energy and energy conservation for more information.

Industry and government have worked hard to bring this space age technology down to earth so it can be used to meet our energy needs. The products are available; significant financial incentives are in place; and the risks of failure are very low.

7.0 USER EXPERIENCES WITH PHOTOVOLTAICS

In addition to reviewing the literature on the design and performance of PV power systems, prospective PV buyers can gain invaluable insight into PV performance from current users. In this chapter various installations are described and their performances are appraised by the owners. The discussions are based upon information received from personal interviews conducted by the authors.

The PV users interviewed are as diverse as the types of systems described. We interviewed young entrepeneurs, middle-aged businessmen, and elderly retirees who use photovoltaics to power mountain retreats, vacation cabins, or year-round residences. We talked to wealthy PV users in upper class neighborhoods and exclusive farms as well as young families or retirees using PV to power their modest cabins in remote areas.

This exploration takes you from the sunny beaches of Southern California to the occasionally shadowed hills of Northern California as well as to the relatively severe and clouded climate of eastern Washington State just south of the Canadian border. Our intent is to provide information on a sampling of diverse installations in unique locations, purchased by different people for different reasons. The representative samples were chosen from over 1,000 installations on the west coast. We hope that these interviews will encourage you to contact PV dealers in your area to view local installations.

In our interviews, we discovered that some people have had problems with their systems. We candidly describe these problems to help the prospective buyer to avoid them or at least to be prepared to deal with them. Overall, we are impressed with the apparent satisfaction of PV owners, whether they have a simple system comprised of one module and a battery and some lights, or a much larger and elaborate system to provide for most domestic needs.

7.1 Southern California Installations

The interviews with southern California homeowners were conducted in June 1981 through contacts provided by Solarwest Electric Company of Santa Barbara, California, and Wm. Lamb Company of Hollywood, California. PV power systems have proven to be cost effective in many situations where utility power is within 500 yards of the site. In a growing number of areas, overhead powerlines can no longer be installed and because of the required easements and funds, sometimes underground power connections cannot be installed.

Currently available PV power systems now make it practical to build homes on excellent view lots regardless of closeness to utility lines. Because PV power supplies are simple and reliable, installation is easy, the surroundings are not disturbed, and the energy supply is secure and long-lasting. Although the initial costs of such systems are significant, the freedom from ongoing regulatory and financial requirements of being connected to a utility frequently overrides PV system costs.

Doug and Nancy Ingolsby live in the Santa Barbara area with two small children.

Their PV system has eight 35-W panels storing energy in about 300 Ah of storage batteries at 24 V DC. They operate lights at 24 V DC using special ballasts and a 2500-W inverter, which supplies power for a stereo system, a television, a vacuum cleaner, a washing machine and a gas-heated clothes dryer. They have enough power to do a load of wash daily and to meet other typical daily electrical needs. They use gas to power their refrigerator and range.

Because of the Ingolsby's remote location, Southern California Edison determined that it was "impossible" to provide power to them. Originally, the Ingolsby's only electric supply was a Honda gasoline generator. As they became increasingly concerned about fuel costs and the noise from their generator, they began to actively investigate alternative power systems. They ruled out a wind system "because it is mechanical". Although information on PV was hard to find, they eventually decided on a PV system.

They report that they are very satisfied with their PV system's performance over the past year and feel that a major influence slowing the acceptance of PV power supples is a lack of helpful information. They were quite pleased to contribute to this effort, particularly considering some of the misinformation being published. They expressed their incredulity when while reading a popular magazine with PV powered light, they came upon a full page advertisment by America's Electric Energy Companies stating that "technology to generate electricity from the sun on a large scale is still a long way from being practical and economical."

John Beaman is a young professional living in a house overlooking the Santa Barbara harbor. His home has been equipped with a four-module packaged system obtained from SolarWest Electric Company in 1978. The system provides power for lights, stereo system, television, power tools and an air circulation fan. A 500-W Tripplite inverter provides AC power for the stereo and television. Although he has no back-up system, John reports that he has never been short of power. In the future he plans to power a hot tub pump with the PV power system.

At a year-round residence in the foothills of northeast Santa Barbara, Rob and Grace Robinson present a convincing example of PV power as a viable alternative energy source (see Figure 7.1). Although the site is only 600 feet from the utililty grid, the high cost of using utility power prompted the Robinsons to install a solar electric system. Not only does their PV system provide the electricity for their daily needs, it supplied all of the electrical power needed for the home's construction!

Their system has twelve 35-W modules and a battery bank comprised of 12 Delco 1150 storage batteries connected to store power at 24 V DC. This power is used directly to provide fluorescent lighting and television reception or is converted either to 12-V DC through a power convertor or to 120-V AC through a 2500-W inverter before delivery to

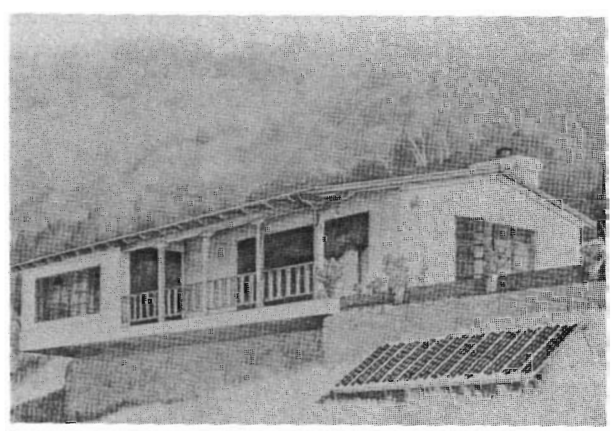


FIGURE 7.1. The Robinson Home

other electrical loads. The house is wired for both DC and AC, with each outlet having both an AC and DC socket. This allows for the use of efficient DC lights and the convenience of AC appliances. The inverter is manually controlled by switches located close to the outlets.

The system presently powers 17 interior lights, 3 outside lights, stereo, TV, toaster, blender, juicer, fans, power tools, the washer and dryer motors, vacuum cleaner, and a Jacuzzi pump for an average daily electrical requirement of 1500 watt hours. At this level of consumption, the system's storage capacity of 13,000 watt hours could power the home for 5 to 7 days without sunlight. In addition to the PV electricity, the home's other energy sources include propane for cooking, refrigeration, and hot water as well as passive solar features and a convection fireplace for space heating.

The home has been occupied full time by two adults since it was completed in August of 1980. The Robinsons report that they've always had ample power and have had no major problems with the system except for repairing the inverter in March. This repair was done at no cost under the manufacturer's warranty. The payback on the $10,000 system was immediate considering the tax credit (combined federal and state) and the $4,000 cost of connecting the home to a utility line if the system had not been installed.

Rick and Lynn Scott and their two small children live in a beautiful adobe home in the foothills overlooking Santa Barbara (Figure 7.2). When the system was installed in 1978, it became one of the very first homes to use AC from PV power. When the Scott's learned that it would cost $7,500 to bring utility power up to 1000 feet to their home, they reasoned that the $13,000 cost of a PV system (less than 55% tax credit) made solar electricity a cost-effective alternative.

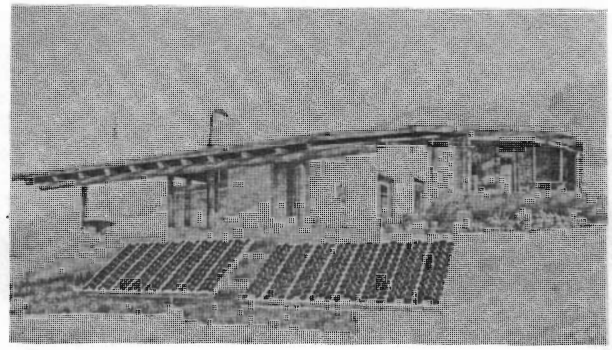


FIGURE 7.2. The Scott Home

Their 16-panel system charges 12 Delco 1150 batteries at 48 DC. Before the power is used, it is converted to 120 V AC with a 5000-W load-demand start inverter. The power is used for 12 interior lights, toaster, stereo, blender, vacuum cleaner, table saw, skill saw, and a juicer for an average of 2500 watt hours daily. The system provides an average of 3,000 watt hours daily and the storage system of approximately 13,000 watt hours can sustain standard building operation for 4 to 5 days without sunshine.

The Scott home is similar to the Robinson home in that propane is used for cooking, refrigeration and hot water; and passive solar and wood are used for space heating. The PV system has proven to be a reliable and easily maintained power supply whose overall operation has been very satisfactory. One annoyance that the Scotts revealed is that the load-demand start on the inverter does not work for very small loads such as a nightlight or stereo. Therefore, they have to turn on some other appliance or light to start the inverter.

Jim and Donna Christensen have a 3300-square-foot home in Solvang, California (see Figure 7.3), that was built entirely by

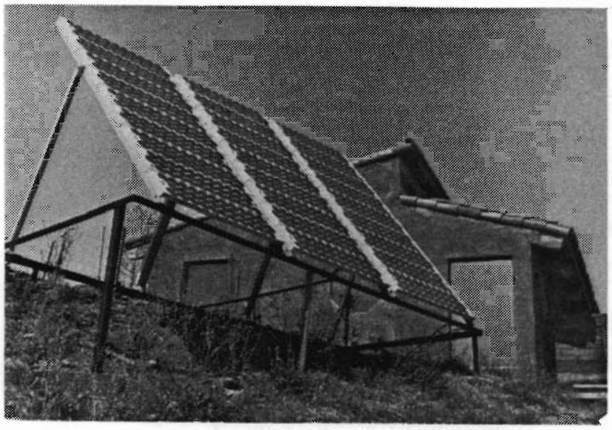
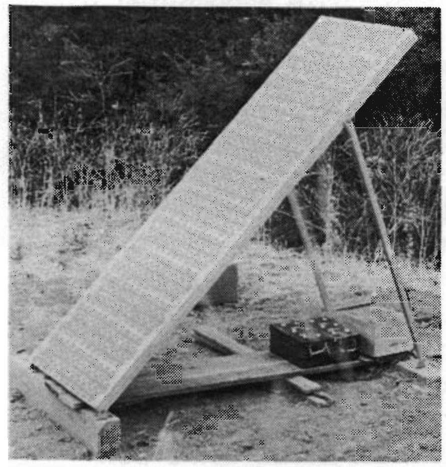


FIGURE 7.3. The Christensen Home



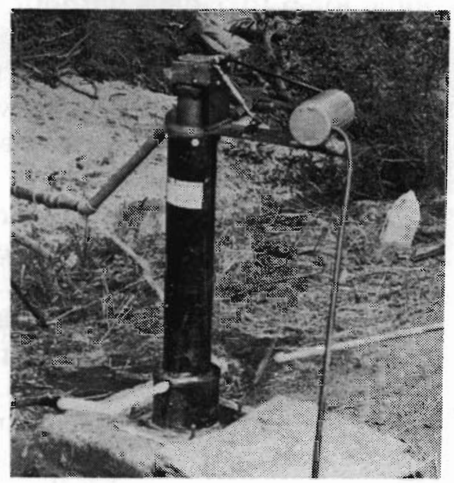


FIGURE 7.4. PV-Powered Drip Irrigation System

PV-powered equipment. Although they could now connect to the utility grid, the Christensens choose to enjoy the independence their private electric system provides. They report that "the beautiful part of the PV system is that we are not connected to the utility."

They have twenty-seven 35-W modules connected to charge 30 Delco 2000 batteries at 120 V DC. A 6-kilovolt ampere (about 6000 W) inverter is used to provide 120-V AC power for all electrical appliances except for cooking and water heating. As far as we know, this installation is the largest one done without government assistance. Except for a few problems that are being corrected, they are very pleased with their system.

The Brisa Del Mar Ranch is one of several in an exclusive, limited-entry area of the coast near Santa Barbara. Dodd Geiger and Gebb Turpin have recently installed a PV-powered drip irrigation system (see Figure 7.4) supplying water for 200 avocado trees and 100 citrus trees as well as a large garden. A 4 kW Jacobs wind generator supplies electricity for a barn on their ranch, with backup supplied by a 6-kW propane-powered Wisconsin generator. Although the wind system performs well, periodically, they have to call in outside help to replace the wind turbine brushes because the owners "don't want to climb any 40-foot tower!"

Their irrigation system is powered by twelve 35-W modules connected for 24-V DC. They use about 250 Ah of storage battery to store the early morning sun while the power is too low to operate the progressive cavity pump. The pump, located at 120' depth, is driven by a permanent magnet DC motor on the surface. The pump system, by Blue Sky Water Supply Company, is rated at 2000 gallons per day. The system is currently in a debugging stage, but promises to be a dependable and easily maintained water supply.

William and Sandy Merrill are moving onto a ranch east of Los Angeles where they have installed PV power to pump water and plan to add capacity for domestic lighting and appliance use. Part of their ranch is almost directly under three high-voltage power lines (see Figure 7.5). To connect the utility they would have to spend about $4000 for underground cable, many hours of labor to install it, and obtain an easement from a neighbor who is not cooperating with power companies at this time. They say that PV is an excellent solution to their problem, and they like its quietness and lack of maintenance.

The water pumping system, installed by William Lamb Company, provides water for livestock, gardening, and domestic use. The installation is termed sun-synchronous because no batteries are used and the water is pumped in direct relation to the available sunlight. The power for the jack pump, which lifts 250 gallons per hour from a 230-foot deep well is provided by twelve 35-W PV modules. Watching their pumping system may not be exciting ("it just keeps on pumping"), but without it the land is scorched brown most of the year rather than being a productive growth area for produce and livestock.

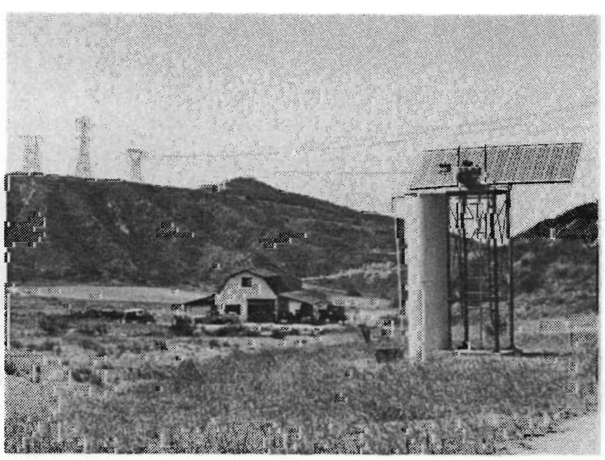


FIGURE 7.5. The Merrill's Pumping System

Although the water system is working perfectly now, startup problems had to be worked out. Initially, the counterweight was insufficient and the pulleys weren't correctly matched to the motor and pump. Having a knowledgeable dealer to help with system debugging is extremely helpful in achieving maximum performance quickly.

The installations discussed above are representative of actitivy in Southern California. If you live in a climate similar to that of the sunny southwestern U.S., these experiences should give some insight into the performance of PV power supplies. We now travel northward so that you can see the uses of PV in climates with less sunshine.

7.2 Northern California Installations

The installations described in this section were inspected in June 1981 and resulted from contacts provided by Jim Cullen Enterprises, Inc. of Laytonville, California; Solar General Store of Yarberville, California; and Jim Padulla of Padulla Lumber and Co. in Willits, California.

A wide spectrum of PV system users was encountered in northern California, ranging from business and professional people to those espousing an "avante guarde" lifestyle. Some of the PV owners contacted were hesitant to speak with us because they value privacy very highly; often, this was a motivating factor in their decision to purchase their systems. We have used pseudonyms to protect those who expressed a concern about revealing their identity.

Linda McVarish and Travis Kock live in the Laytonville, California area (see Figure 7.6). They have a hybrid system with four 35-W panels and a wind generator charging a 500 Ah 12-V battery bank. They power 3 fluorescent lights and a dozen incandescent lights at 12 V and small appliances at 120-V AC using a Tripplite 550-W inverter.

They report that the weakest links in the system are the wind generator ("we may relocate it") and the inverters. Overall, they like the PV system very much and plan to add to it when "the price comes down". They started the backup gas generators about 4 times last winter to charge the batteries during extended cloudy periods, but they expect the generator to "last forever" with the PV and wind system carrying most of the load. Their Servel refrigerator uses 20 gallons of propane in 6 weeks, and they are using a gas motor to pump water 100' up a hill to a redwood storage tank. In the future, they plan to use PV to operate the refrigerator and pump water.

FIGURE 7.6. The McVarish Home

Suzanne Rick, Laytonville, California, uses four 35-W solar modules to power 2 B&W TVs, a stereo, 6 fluorescent and 2 incandescent lights, as well as to operate a "cottage industry" (Figure 7.7). She makes original ceramic dolls and sews authentic costumes for them. The system exceeds her expectations and she would like two more panels ("I use a lot of light"). The system could also use an elevated adjustable mount for the two-panels that are mounted on the rafters. The site is less than ideal with trees located all around. Many installations are less than ideally located, but owners are realistic and very pleased with the performance actually obtained.

The James P. Lowary family (Laytonville, California) has ten 18-W panels charging 500 Ah of batteries (Figure 7.8). They operate a color TV, radio, lights, a tape deck, and other 12-V appliances. They have no inverter and operate the AC appliances such as vacuum cleaners from a Honda AC generator powered by propane. They are delighted to eliminate most of the noise and expect that the Honda will last indefinitely with the PV system carrying the major load.

The Lowarys are retired and appreciate controlling their expenses. They have no desire for utility power even if it could be had for less than the $100,000 estimated to extend the power line. They believe their PV system is not delivering its rated output, but they haven't experienced power shortages. They charge the batteries while operating the washing machine, vacuum, etc. with the excess power from the generator. They enjoy the simplicity of PV.

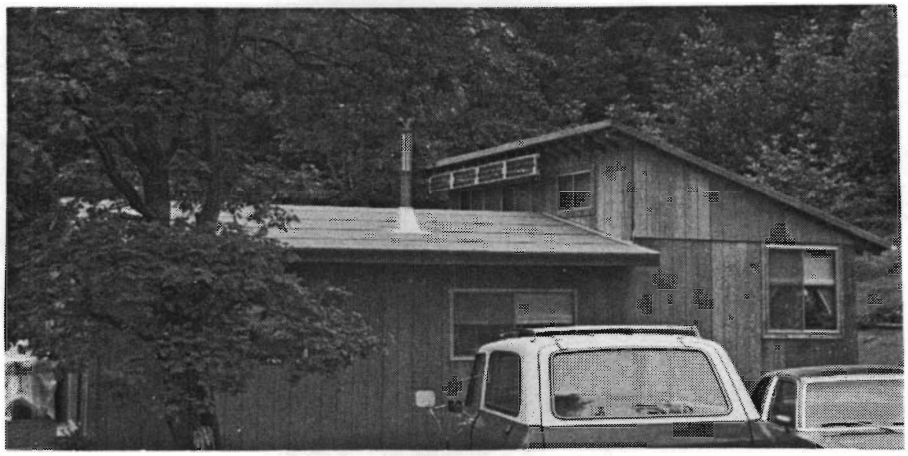


FIGURE 7.7. The Rick Home

FIGURE 7.8. The Lowary Home

Jerry Martin (Laytonville, California) has six 18-W panels charging 500 Ah of battery storage. He uses a 500-W inverter to power light hand tools. Also, he powers a TV, stereo, radio, and several fluorescent and incandescent lights. He is absolutely sold on PV and planned to add five 35-W panels in July and five more in September 1981. He does not have a regulator on the system and uses a hydrometer to check the batteries once a week. He cleans the battery terminals every two to three months.

Mr. Martin uses the system to provide power to both the trailer and the cabin (see Figure 7.9). He plans to power the refrigerator from PV and perhaps pump the water with it as he enlarges the system.

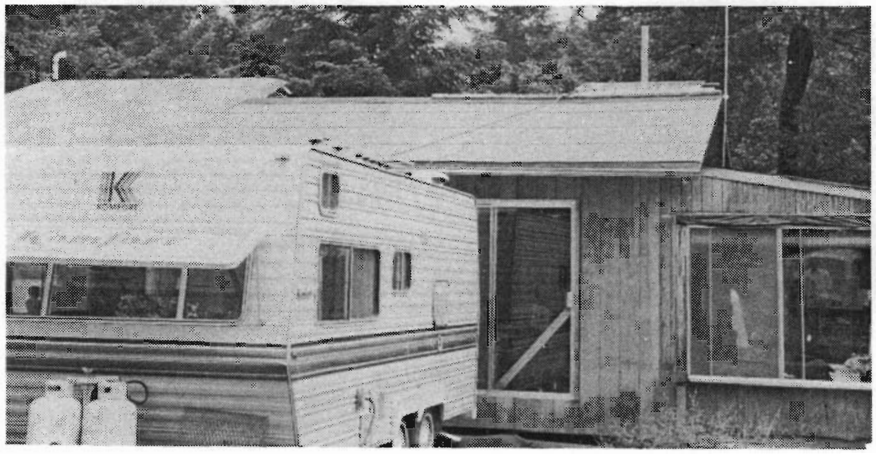


FIGURE 7.9. The Martin Home

In the Garberville, California area, several PV systems are operating for owners who prefer the solitude of the countryside and would not allow their names or pictures of their installation to be published. One of these, whom we shall call John Doe, has sixteen 35-W panels connected to a 3500 Ah battery bank that drives a Best 2500-W inverter to supply 120-V AC. A propane generator was used previously and the noise-free PV system is most appreciated. He is satisfied with the PV system and would like to enlarge it soon to offset the $20/mo propane cost required to fuel his Servel refrigerator.

John Doe II has installed six 35-W modules with 700 Ah of battery storage that is protected by a Specialty Concepts regulator. This system is used to power two stereo/radios, a TV set, and numerous fluorescent and incandescent lights in the main cabin as well as a 14' RV. A special application of note is the powering of a DC fan to enhance the effectiveness of a wood stove. He plans to add about 8 more panels and an inverter to power a refrigerator and other AC appliances. He was pleased to have less generator noise and looks forward to the larger system that will further reduce propane generator operation.

Other than the replacement of a defective controller in November of 1980, the system has proven to be a 100% reliable power source—even during the cloudy winter months. The owner feels that such reliable power could not be provided by the utility grid even at the estimated cost of $50,000 for the necessary line extension.

John Doe III built a 1100 square-foot home in a remote area more than 10 miles from the nearest power line. He installed four 35-W PV modules to power various 12-V appliances providing music, entertainment, and light. Mr. Doe III is totally satisfied with the system, although the regulator failed and had to be replaced soon after installation. He plans to add 4 additional panels to power a refrigerator.

We spoke with a customer selecting a module and a 95 Ah battery to power a fluorescent light and a stereo radio. He was pleased to be able to avoid both filling the kerosene light in the cabin (particularly during inclement weather) and the kerosene odor that dominated his environment. Furthermore, without the convenience of a PV power supply, the enjoyment of radio broadcasts would be limited by continuous replacement of batteries.

The northern California homeowners we talked to are pleased with their PV systems and confirm that performance is as expected. Most plan to buy more panels "when they can afford it". This allows them to have the immediate convenience that a small system can provide usually for lighting and entertainment systems and the opportunity to gain first-hand knowledge of system performance before making a large investment.

7.3 Northeastern Washington Installations

The installations discussed in this section were inspected in July of 1981 as a result of contacts with the Northeast Washington Appropriate & Creative Technology Organization (NEW ACT). In recognition of the potential value of PV systems to bring the benefits of electrical power to remote residences in the region, the organization sponsored public discussions of photovoltaics and arranged a quantity purchase in December of 1980 and again in July of 1981. All but one of the systems described below resulted directly from these efforts.

The earliest installation in the region went into operation in 1978 and has provided reliable power for a stereo sound system in a remote mountain retreat (Figure 7.10). One 24-W Solarex panel is connected to a small aircraft "gel cel" to power the DC tape player and amplifier. The builder and resident of the retreat home plans to add some small incandescent lights in the near future and comments that her desire for privacy and independence lead her to use photovoltaics. Because the only access to the home is by a steep 500-yard trail, lugging batteries, gas generators and fuel, or a wind machine would be difficult. The lightweight PV panel has proven to be a reliable and trouble-free power supply that preserves the silence and pristine naturalness of the site.

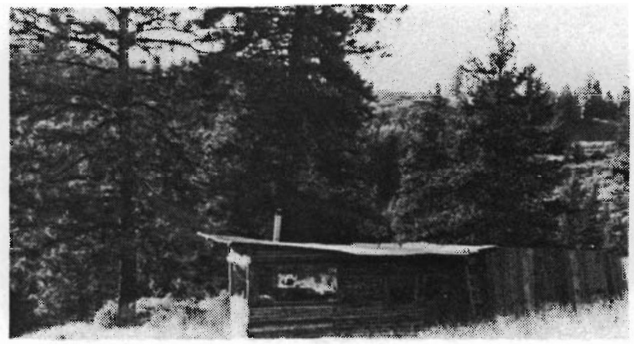


FIGURE 7.10. PV-Powered Mountain Retreat

The home of Mike Nelson, his wife and teen-aged daughter is an interesting and effective mix of alternative and creative technologies to provide for independent living (Figure 7.11). The passive solar, partly earth-sheltered home uses a small wind generator, two PV panels, and a 380-Ah battery storage system to provide power for lighting, home entertainment, and ventilation. Although the cost of connecting the house to nearby power lines is only about $500, Mr. Nelson enjoys the freedom from the requirements and ever-escalating costs that utility interconnection would invite.

A look at the history of the home's energy systems provides insight into the appropriateness of the current system. During construction, a 1500-W gasoline generator was purchased to provide the electricity

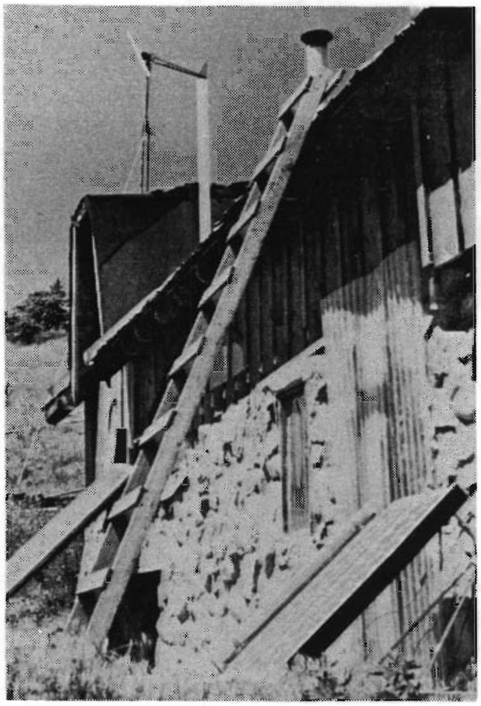


FIGURE 7.11. The Nelson Home

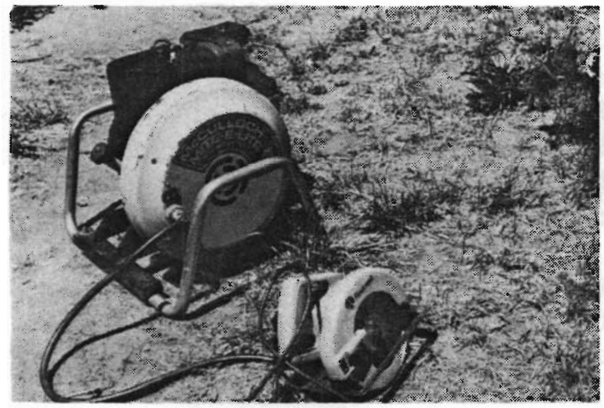


FIGURE 7.12. 1500-W Gas Generator

for power tools (Figure 7.12). This same generator now provides the large amounts of power for clothes washing and power tools but is not required for other typical needs. A 200-W Winco wind turbine mounted atop a 28-ft mast was erected soon after the shell of the house was completed and provided intermittent charging for the 12-V batteries. The latest addition of two ArcoSolar 35-W panels in December of 1980 and an inexpensive diode has made the system 100% reliable. Soon Mr. Nelson plans to install a home-built 1000-W wind generator on a 65-foot tower, as well as additional PV modules.

The system powers four 15-W fluorescent fixtures, two 25-W incandescent lights, one 25-W stereo, and a one amp vent fan on a composting toilet. An 50-W invertor purchased from the J.C. Whitney catalog for $19.95 provides occasional AC needs such as a turntable. Mr. Nelson states that system maintenance is minimal, only occasional inspection with the hydrometer and topping off of the battery fluid with distilled water. He is completely satisfied with the PV's performance and plans to add more capacity as finances permit to power a small refrigerator.

Dean and Anne Fischer/Lawson have installed a 35-W panel to provide power for sound and lighting systems. Presently, the panel is connected to a 100-Ah hour storage battery, which in turn energizes a DC tape deck and amplifier. The home, depicted in Figure 7.13, is more than three miles from the nearest power lines and the only other source of electricity is a rather large 6000-W Honda gas generator. It would not be cost effective to run this large unit to provide the energy needed for the stereo and small lights. Apparently another panel is planned for the near future since the support frame is already installed.

A local carpenter known as Boone installed a 35-W panel on his remote residence in January of 1981. The home, which is well insulated and includes an attached greenhouse with rock storage to provide both heat and nourishment, is depicted in Figure 7.14. Before he installed the PV panel,

FIGURE 7.13. The Fischer/Lawson Home

FIGURE 7.14. The Boone Home

the only electricity available was from storage batteries or a gasoline generator, neither of which was convenient to provide power for lighting and entertainment systems.

The panel is connected to a 100-Ah snowmobile battery without a voltage regulator. Boone insists that all that is necessary is an occasional topping off of the battery fluid, and that anyone capable of installing an automotive back up light should have no problems with system installation or maintenance. His wife is glad to be free from the inconvenience and danger of kerosene lighting and enjoys the home sound system. Boone plans to add more panels to power a refrigerator in the future.

The PV users in this northern climate receive an average of 2 to 4 peak sun hours per day and report that they are completely satisfied with system performance. Although their systems are modest, they provide a substantial improvement in their lifestyle. No longer must odorous and expensive kerosene be burned for lighting, and enjoyment of stereos can be had without the noise of gas generators or the inconvenience and expense of transporting batteries. It is surprising that so much convenience can be had at such a modest cost.

7.4 Northeastern Installations

In Hudson Valley, New York, a nonutility connected, PV-powered home has been designed and built by Steven Strong, president of Solar Design Associates, and David Sleeper of Brooks Farm, Inc. (Figure 7.15). This home uses twenty-four 4' x 6' Mobile Solar PV modules, 140 storage batteries, 2 Best inverters, and one small inverter for the security system and garage door opener. The

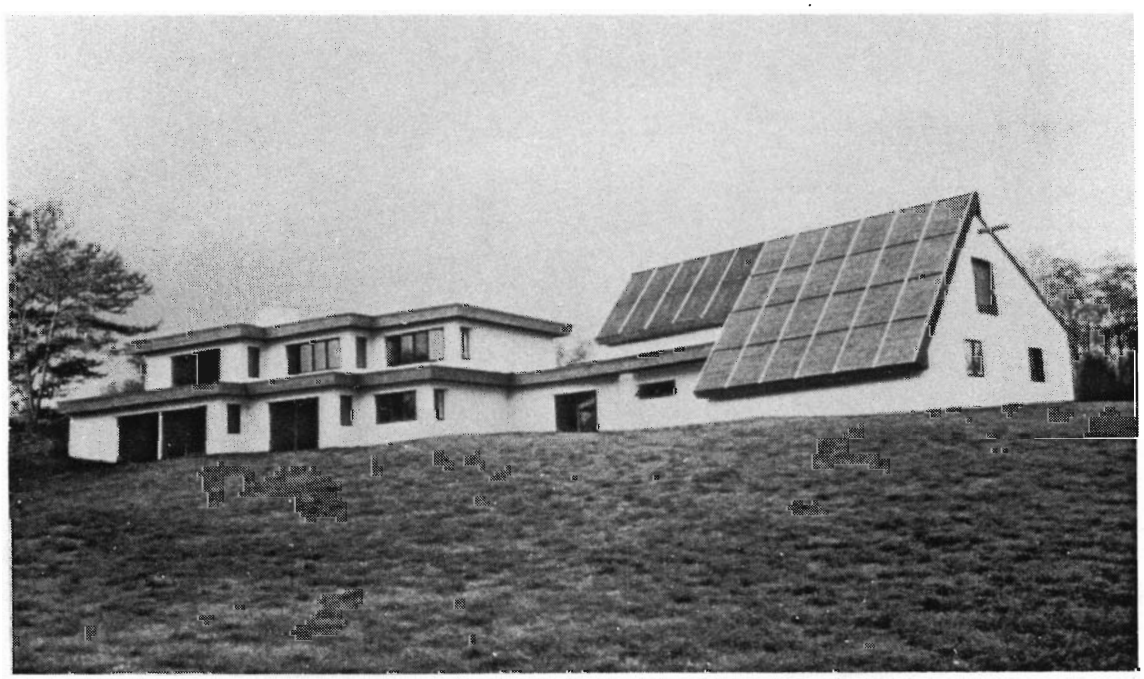


FIGURE 7.15. The Hudson Valley New York House

PV system provides 18 kWh/day, which is similiar to the electrical requirements of many nonsolar homes.

A fairly sophisticated PV monitoring and control system has also been installed. This system will provide operating data of the PV system that will be used by architects in designing future PV-powered homes.

Other solar technologies are also used in the house, including passive solar for space heating and solar thermal for water heating. The ceiling and walls have additional insulation, and the north side of the house is earth-bermed. Energy-efficient appliances are used throughout.

The Boston Edison Impact 2000 house (Figure 7.16) located in Brookline, Massachusetts, was featured on the PBS series *This Old House*. The home, also designed by Solar Design Associates, featured a 4.0-kW PV array, passive solar for space heating, and solar thermal for water heating. An additional feature of this home is that it will be connected to the Boston Edison utility grid when completed.

Unfortunately, both of these northeastern installations are fairly new and we do not have information on the homeowners' experiences.

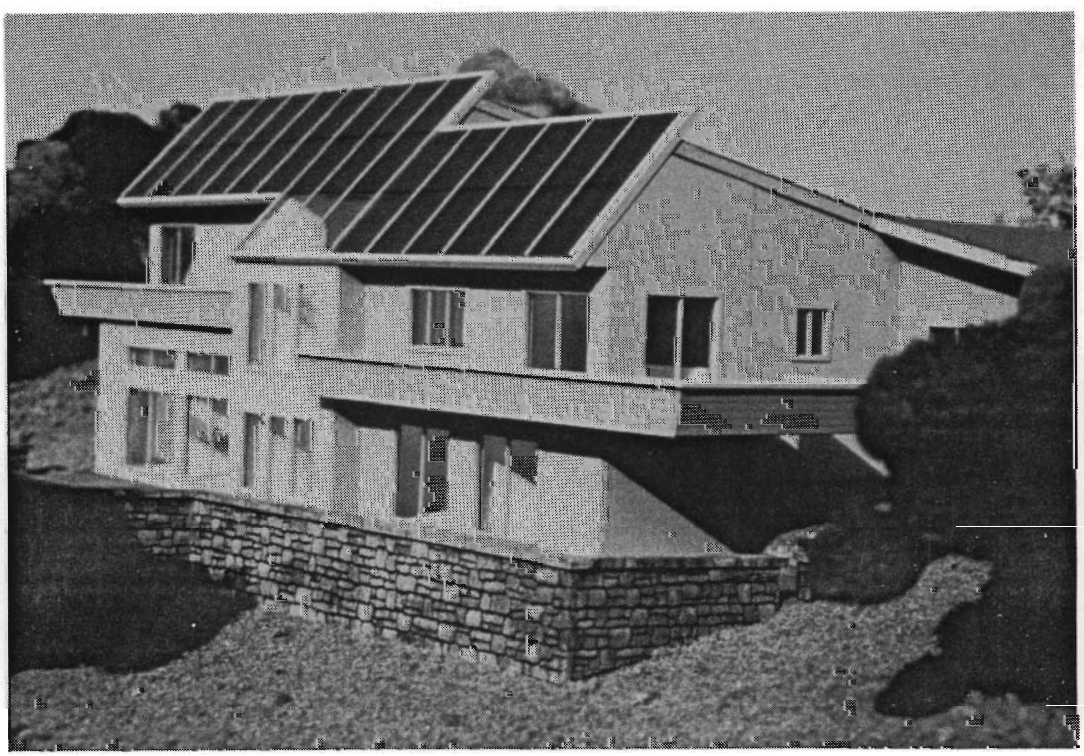


FIGURE 7.16. The Boston Edison Impact 2000 House

7.5 Summary of User Experiences with Photovoltaics

The PV owners whom we interviewed in California and Washington were quite pleased with the performance of their PV systems. Occasionally, minor problems did arise; however, these were not significant enough to prevent owners from expanding their systems.

Our interviews revealed a fairly consistent pattern of PV system expansion. Most owners begin with one to six 35-W PV modules and a few automobile or golf cart storage batteries. These small systems can be purchased for as little as $500 and will provide power for high-priority needs such as music and lighting. Of course, man cannot survive on music and light alone, so many users supplement their PV system with a 1750-W Kohler or similar gas generator ($500). This allows the owner to operate vacuum cleaners and other appliances and provide back-up to the PV system. Back-up lighting is also provided by candles or kerosene.

Once an owner has built up confidence in a PV system, he enlarges the system by adding a few more panels, batteries, a charge controller and an inverter. This larger system will provide enough power to operate most household appliances intermittently, except for heating and cooling units and sizeable induction motors. These systems have performed well, and owners seldom use propane or gas generators except in the northern climates.

Some PV owners have enlarged their systems to 16 or more 35-W modules and have added more batteries and a larger inverter. A system of this size is capable of operating all typical AC appliances (except heating and cooling units), which would minimize lifestyle changes.

The particular size system that you should purchase depends upon your energy needs, income, location and willingness to accept lifestyle changes. The authors strongly recommend that anyone who is considering a PV system visit a few installations in their area.

APPENDIX I

STATE ENERGY OFFICES

APPENDIX I
STATE ENERGY OFFICES

State Energy Offices	Address	Telephone
Alabama Department of Energy	25 Washington Ave. Montgomery, AL 36130	205 832-5010
Alaska Division of Energy and Power Development	McKay Building 338 Denali St., 7th Floor Anchorage, AK 99501-2681	907 276-0508
American Samoa Energy Office	Rainmaker Hotel, Rm 137 Pago, Pago A.S. 96799	Overseas Op. 633-1306
Arizona Energy Office	1700 W. Washington St., 5th Floor Phoenix, AZ 85007	602 255-3303
Arkansas Energy Office	#1 Capital Mall, Rm 2C105 Little Rock, AR 72201	501 371-1370
California Energy Commission	1111 Howe Avenue Sacramento, CA 95825	916 920-6811
Colorado Office of Energy Conservation	1525 Sherman St., 4th Floor Denver, CO 80203	303 866-2507
Connecticut Energy Division	80 Washington Street Hartford, CT 06115	203 566-2800
Delaware Energy Office	PO Box 1401, 56 The Green Dover, DE 19901	302 736-5644
District of Columbia Office of Planning & Development, Energy Unit	Avon and R. Street N.W. Jackson School Washington, D.C. 20007	202 727-1800
Florida State Energy Office	301 Bryant Bldg. Tallahassee, FL 32301	904 488-6764
Georgia Office of Energy Resources Office of Planning & Budget	270 Washington St., S.W. Atlanta, GA 30334	404 656-3874
Guam Energy Office	PO Box 2950 Agana, Guam 96910	Overseas Op. 477-9845
Hawaii State Energy Office Dept. of Planning & Economic Development	PO Box 2359 Honolulu, HI 96804	808 548-3033
Idaho Office of Energy	State House Boise, ID 83720	208 334-3800

State Energy Offices	Address	Telephone
Illinois Institute of Natural Resources	325 West Adams, 3rd Floor Springfield, IL 62706	217 785-2800
Indiana Economic Development Planning Division	440 N. Meridian Street Indianapolis, IN 46204	317 232-8910
Iowa Energy Policy Council	Lucas Bldg., 6th Floor Des Moines, IA 50319	515 281-4420
Kansas Energy Office	214 W. 6th Street Topeka, KS 66603	913 296-2496
Kentucky Department of Energy	Iron Works Pike PO Box 11888 Lexington, KY 40578	606 252-5535
Louisiana Dept. of Natural Resources	PO Box 44156 Baton Rouge, LA 79804	504 342-4594
Maine Office of Energy Resources	295 Water Street, Sta. 53 State Office Building Augusta, ME 04333	207 289-3811
Maryland Energy Policy Office	301 W. Preston, #90 Baltimore, MD 21201	301 383-6810
Massachusetts Executive Office of Energy Resources	72 Tremont Street #700 Boston, MA 02108	617 727-4732
Michigan Department of Commerce	PO Box 30228 Lansing, MI 02108	517 373-9090
Minnesota Energy Agency	980 Amer. Ctr. Bldg. St. Paul, MN 55010	612 296-1564
Mississippi Dept. of Energy and Transportation	510 George St. Jackson, MS 39202	601 961-4733
Missouri Division of Energy	PO Box 1309 Jefferson City, MO 65102	314 751-4000
Montana Energy Division	32 South Ewing Helena, MT 59601	406 449-3780
Nebraska Energy Office	PO Box 95085 Lincoln, NE 68509	402 471-2867
Nevada Dept. of Energy	400 W. King St., Ste. 106 Carson City, NV 89710	705 885-5157
New Hampshire Governor's Council on Energy	2 1/2 Beacon Street Concord, NH 03301	603 271-2711
New Jersey Dept. of Energy	101 Commerce Street Newark, NJ 07102	201 648-2744

State Energy Offices	Address	Telephone
New Mexico Dept. of Energy and Minerals	PO Box 2770 Santa Fe, NM 87501	505 827-2471
New York State Energy Office	Agency Bldg., No. 2, 10th Fl. Empire State Plaza Albany, NY 12223	518 473-4376
North Carolina Energy Div., Department of Commerce	PO Box 25249 Raleigh, NC 27611	919 733-2230
North Dakota Energy Office	State Capital Bismark, ND 58501	701 224-2250
North Mariana Island	Government of North Mariana Islands Saipan, Mariana Islands 96950	Overseas Op. Saipan 6407
Ohio Department of Energy	State Office Tower, 34th Fl. 30 East Broad Street Columbus, OH 43215	614 466-1805
Oklahoma Department of Energy	4400 North Lincoln Blvd. Suite 251 Oklahoma City, OK 73105	405 521-3941
Oregon Department of Energy	Labor & Industries Bldg. Room 102 Salem, OR 97310	503 378-4128
Pennsylvania Governor's Energy Council	PO Box 8010 Harrisburg, PA 17105	717 783-8610
Puerto Rico Office of the Governor	Minnillas Gov't Center North Bldg., Stop 22 PO Box 41089, Minnillas Sta. Santerce, Puerto Rico 00940	809 726-4740
Rhode Island Governor's Energy Office	80 Dean Street Providence, RI 02903	401 277-3374
South Carolina Governor's Division of Energy Resources	1122 Lady St., #1130 Columbia, SC 29201	803 758-7502
South Dakota Office of Energy Policy	Capital Lake Plaza Pierre, SD 57501	605 773-3603
Tennessee Energy Authority	226 Capital Blvd., #707 Nashville, TN 37219	615 741-2994
Texas Energy & Natural Resources Adv. Council	200 E. 18th Street 5th Floor Austin, TX 78701	512 475-0773
Trust Territory of the Pacific Islands	Office of Planning & Statistics Mariana Islands 96950	Overseas Op. Saipan 9411

State Energy Offices	Address	Telephone
Utah Energy Office	825 N. 3rd W. #150 Salt Lake City, UT 84013	801 533-5424
Vermont State Energy Office	State Office Building Montpelier, VT 05602	802 828-2393
Virgin Islands Office of Energy	PO Box 2996 St. Thomas Virgin Islands 00801	809 774-6726
Virginia State Office of Emerg. & Energy Services	310 Turner Road Richmond, VA 23225	804 745-3245
Washington State Energy Office	400 E. Union Avenue Olympia, WA 98504	206 754-0728
West Virginia Energy Dev. Division	State Capital Charleston, WV 25311	304 348-0400
Wisconsin Division of State Energy	101 S. Webster Madison, WI 53702	608 266-9861
Wyoming Energy Conservation Office	Capital Hill Office Bldg. Cheyenne, WY 82002	307 777-7131

APPENDIX II

ADDITIONAL SOURCES OF INFORMATION

APPENDIX II
ADDITIONAL SOURCES OF INFORMATION

In this directory, we have tried to give you an idea of the PV systems/ products that are currently available, and how they can help you meet your energy needs. Although we've raised many questions that you should consider when choosing a system, we haven't raised or answered them all.

Appendix II contains information on organizations and literature sources that may be helpful to you in answering your questions. The books listed should be available through your local public library.

RESEARCH ORGANIZATIONS

Aerospace Corporation
Stanley Leonard
P.O. Box 92957
Los Angeles, CA 95081
(213) 648-7040

Battelle Pacific Northwest Laboratory
Raymond L. Watts
Sigma-4
Box 999
Richland, WA 99352
(509) 376-4348

Jet Propulsion Laboratory
Elmer Christensen
4800 Oak Grove Dr.
Psadena, CA 91103
(213) 577-9077

Massachusetts Institute of Technology
Energy Laboratory
Ed Kern
711 Virginia Rd.
Concord, MA 01742
(617) 863-5770

NASA/Lewis Research Center
Bill Brainard
21000 Brookpark Rd.
Cleveland, OH 44135
(216) 433-6840

Sandia National Laboratory
Don Schueler
Division 4719
P. O. Box 5800
Albuquerque, NM 87185
(505) 844-4041

Solar Energy Research Institute
Don Ritchie
1617 Cole Blvd.
Golden, CO 80401
(303) 231-1373

Florida Solar Energy Center
Jerry Ventre
300 State Rd. 401
Cape Canaveral, FL 32920

New Mexico Solar Energy Institute
Vernon Risser
New Mexico State University
Box 3 SOL
Los Cruces, NM 88003
(505) 646-3948

OTHER HELPFUL ORGANIZATIO

American Solar Energy Society
1230 Grandview Ave.
Boulder, CO 80302
(303) 492-6017

Solar Energy Industries Association
David Gorin
1156 15th St. N.W.
Washington, D.C. 20005
(202) 293-2981

Photovoltaics Division, SEIA
Charles Gay
ARCO Solar
20554 Plummer St.
Chatsworth, CA 91311
(818) 700-7152

LITERATURE SOURCES

Bechtel National Inc. 1979. *Handbook for Battery Energy Storage in Photovoltaic Power Systems.* SAND 80-7022, San Francisco, CA. The purpose of this handbook is to provide the photovoltaic system designer with a source of interface design considerations, as well as performance, cost and other necessary information involved with the development and design of photovoltaic systems.

Caskey, D. L., B. C. Caskey and E. A. Aronson. 1980. *Parametric Analysis of Residential Grid Connected Photovoltaic Systems with Storage.* SAND 79-2331, Sandia National Laboratories, Albuquerque, New Mexico. This report investigates the cost of using battery storage in residential grid-connected PV applications.

Cullen, J. 1980. *How to be Your Own Power Company.* Van Nostrand Reinhold Co., New York, New York. This book provides a simple method for designing and installing your own power system.

Davidson, J. and R. Komp. *The Solar Electric Home.* aatec Publications, Ann Arbor Michigan. This book provides information on selecting and sizing a PV system, and the operation of various PV components.

Intermediate Technology Development Group. 1980. *The Power Guide: A Catalog of Small Scale Power Equipment.* ed. P. Fraenkel, Charles Scribner's Son, New York, New York. This guide is to help people who want to purchase small scale power equipment for use in remote and underdeveloped areas. It lists the pros and cons of choosing various power sources and the availability of these products internationally.

Jacobson, E., G. Fletcher and G. Hein. 1980. *Photovoltaic System Costs Using Local Labor and Materials in Developing Countries.* Prepared for NASA Lewis Research Center by the Engineering Extension Laboratory of the Georgia Institute of Technology, Atlanta, Georgia. This study addresses the costs of using photovoltaics in countries that do not presently have high technology industrial capacity.

Matlin, R. W. and M. T. Katzman. 1977. *The Economics of Adopting Solar Photovoltaic Energy Systems in Irrigation.* C0014094-2, Massachusetts Institute of Technology Lincoln Laboratory, Lexington, Massachusetts. This study compares the costs of PV and conventional fossil fuels as energy sources for irrigation. Also, an estimate is made of the time to initial profitability, and the time of optimal investment.

Maycock, P., David E. Stirewalt, 1981. *Photovoltaics, Sunlight to Electricity in One Step.* Brick House Publishing Co., Andover, MA. This book covers the story of PV from the unique perspective of a DOE Division Director. Autographed copies from author, $10, paper, $20, cloth.

NASA Lewis Research Center. 1980. *Photovoltaic Stand Alone Systems: Preliminary Engineering Design Handbook.* DOE/NASA/0195-8111, Cleveland, OH.

PRC Energy Analysis Company. 1980. *Solar Photovoltaic Applications Seminar.* McLean, VA. This report provided technical information on photovoltaic components and systems.

Paule, T. D. 1981. *How to Design an Independent Power System.* Best Energy Systems for Tomorrow Inc., Necedah Wisconsin.

Richter, H. P. 1983. *Wiring Simplified.* Park Publishing, Inc., St. Paul, MN. This book has been written for people who want to learn how to install electrical wiring, so that the finished job will be safe and practical. The installation will comply with the National Electrical Code.

Rosenblum, L. 1982. *Practical Aspects of Photovoltaics Technology, Applications, and Cost.* NASA CR-168025, Prepared for U.S. Agency for International Development by NASA Lewis Research Center, Cleveland, Ohio. Provides information on the operation of flat plat PV systems and components the types of PV applications, the procedure for sizing a system, and the present and estimated future costs of PV.

Sandia National Laboratory. 1981. *Simplified Design Guide for Estimating Photovoltaic Flat Array and System Performance.* SAND 80-7185, Albuquerque, NM. Provides a methodology for estimating PV array and system performance. This report also contains a solar weather data base for 97 U.S. locations.

Solarex Corp. 1980. *Guide to Solar Electricity.* Washington, D.C. Provides basic information on the operation and use of photovoltaic systems and components. About $7.95 plus handling and postage from Solarex Corp.

Stewart, J. W. 1979. *How to Make Your Own Solar Electricity.* Tab Books, Blue Ridge Summit, PA. Discusses how PV cells work, the various applications of PV and the future of PV.

APPENDIX III

DOT MATRIX OF MANUFACTURERS

	PV-Powered Vent Fans	Evaporative Coolers	PV-Powered Pumps	PV-Powered Battery Chargers	DC Power Packages	AC Power Packages	Home Electric Systems	Specialty PV Appliances	Custom-Built PV Systems	DC Appliances	PV Modules & Concentrators	Batteries	Voltage Regulators	Inverters/ Converters
A. Y. McDonald			•						•					
AAI									•					
Abacus									•					•
American Power Conversion														•
Applied Solar Energy									•					
ARCO Solar	•			•	•	•					•		•	
Arctic Cold										•				
ARTU									•					
Best														•
BOSS													•	
Braden Metal Products								•						
C&D Batteries												•		
Chronar											•			
Delco Remy												•		
Dynamote														•
Exide												•		
Free Energy Systems				•			•		•					
Gates												•		
General Electric									•					
Globe									•					
Heart														•
Helionetics									•					•
Hydrocap												•		
Intersol											•			
Iota Engineering									•	•				
Jim Cullen									•					
March Manufacturing									•					
Marvel										•				
Milton Roy			•						•					
Mobil Solar									•		•			

	PV-Powered Vent Fans	Evaporative Coolers	PV-Powered Pumps	PV-Powered Battery Chargers	DC Power Packages	AC Power Packages	Home Electric Systems	Specialty PV Appliances	Custom-Built PV Systems	DC Appliances	PV Modules & Concentrators	Batteries	Voltage Regulators	Inverters/ Converters
Newmar														*
Norcold										*				
Nova														*
Parker McCrory	*							*						
Photovoltaics Inc.									*					
Polar Products							*							
Power Sonic Corp.												*		
Pulstar Corp.			*											
REC										*				
Roger Ethier									*					
Silicon Sensors									*		*		*	
Solar Contractors									*					
Solar Power Corp											*		*	
Solar Usage Now									*					
Solarex Corp.	*			*	*		*	*	*		*		*	
Solarwest Elec			*	*			*		*					
Solavolt							*		*		*			
Solec				*							*		*	
Solenergy Corp									*		*			
Specialty Concepts													*	
Spire Corp									*					
Sun Frost										*				
Surrette												*		
Teledyne Inet									*					
Tideland Signal				*	*				*		*			
Topaz														*
Tripp Lite														*
TrisolarCorp.			*						*					
United Energy Corp									*		*			
Wilmore Elec.														*
Windworks									*					
Wm. Lamb	*	*												
Zomeworks									*					

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