

THE SOLAR ELECTRIC OPTION

(INSTEAD OF A POWER LINE EXTENSION)

A JOINT PUBLICATION OF THE ARIZONA CORPORATION COMMISSION
AND THE ARIZONA DEPARTMENT OF COMMERCE ENERGY OFFICE

I. INTRODUCTION

PURPOSE

This brochure is designed for the Arizonan who is contemplating the need for electric power at a remote cabin, home, ranch, farm, or other facility that is currently not served by utility grid power lines. In many cases, extending the power lines to the site would be prohibitively expensive. One alternative to extending the power lines is to purchase and operate a solar electric system (also called photovoltaics or PV). Your utility may offer PV systems on a special rate or lease basis and may offer a maintenance contract for service and repair. Also, these services are available from private contractors.

This brochure provides an introduction to PV systems and a method to evaluate this option.

LINE EXTENSIONS

The cost of a utility power line extension depends on the type of customer (e.g., residential, commercial, irrigation) and economic feasibility. For a residential customer, the utility typically provides a certain number of feet (e.g., 1000') of line extension (overhead) at no cost to the customer. Beyond that, any additional power line footage is paid for by the customer - normally at \$2-4 per foot for above-ground lines. Regulations governing line extensions are defined by the Arizona Corporation Commission. Each regulated utility has an approved line extension policy on file at the Corporation Commission.

The cost of line extensions can be obtained by calling the customer service representative for the utility that serves your area.

WHY YOU SHOULD CONSIDER PV

Line extensions typically cost from \$10,000 to \$21,000 per mile, depending on the terrain and other conditions. It may be to the utility's benefit and the customer's benefit to find an alternative to a power line extension.

The economic decision to choose either a power line extension or PV may require careful analysis. A line extension may include a one-time major expense, plus monthly electric bills that are expected to increase. A PV system, however, will include a one-time major expense, followed by years of free electricity from the sun. The PV option will require the replacement of storage batteries every three to 10 years, plus minimal maintenance during the 30 year life expectancy of the system. There may be additional costs for a back-up generator, its fuel, and maintenance.

The balance of this brochure will provide an introduction to the PV option and discuss the pros and cons of this option.



*Nestled into the hills 18 miles north of Prescott is this PV and passive solar home.
Photo by Bob Hammond.*

II. PHOTOVOLTAIC OPTION

OVERVIEW

You are probably familiar with PV (solar) powered calculators and watches. Although less familiar, PV systems have been providing electric power for remote sites for over twenty years. It is estimated that in 1992, 30,000 remote homes, farms and ranches in the United States received some or all of their electricity from PV (most of these systems use a generator for back-up power). Of these 30,000 remote systems, about 3,500 are in Arizona. **PV systems are a simple, field-proven and cost-effective power option in many remote applications.**

The advantages of PV:

- free energy - sunlight is renewable and plentiful in every region of Arizona
- minimal maintenance
- non-polluting; environmentally pristine
- no noise
- modular and easily expanded
- energy independence
- the cost of electricity (cents per kWh) is known for the life of the system
- reliable power (when properly designed and installed)
- energy can be stored in batteries

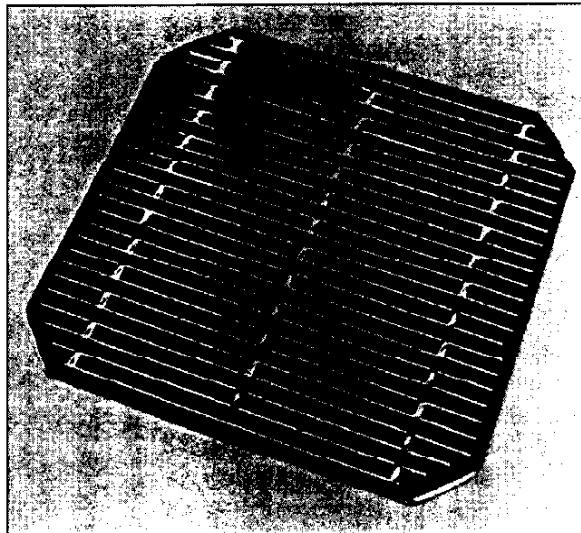
The disadvantages of PV:

- high initial system cost (initial system cost can range from \$1,000 to more than \$20,000, but a typical residence will fall in the \$3,000-\$10,000 range)
- average cost of electricity generated over the expected 30 year system life is typically higher than urban grid power
- energy is produced only when the sun shines (but can be stored in batteries)
- may require a somewhat different lifestyle than a grid-connected lifestyle
- use of a generator as a back-up will be noisy and polluting
- a certain amount of space (inside a building or outside) will have to be dedicated for the batteries and other equipment
- batteries must be replaced periodically
- the manufacture and disposal of some PV modules and batteries may have environmental impacts
- vandalism

PHOTOVOLTAIC TECHNOLOGY

Photovoltaic devices (i.e., solar cells) are part of the semiconductor technology, which includes diodes, transistors and integrated circuits; they are all solid state devices. The first practical solar cell was developed about the same time as the first practical transistor - during the mid-1950s. Both were developed by Bell Laboratories.

PV is a descriptive name for a technology in which radiant energy from the sun is converted to direct current (dc) electrical energy. Solar cells are made of semi-conducting materials, typically silicon, doped with special additives. When sunlight hits the surface of the solar cell, electricity is generated. Desired power, voltage and current can be obtained by connecting individual solar cells in series and/or in parallel, in much the same fashion as batteries.

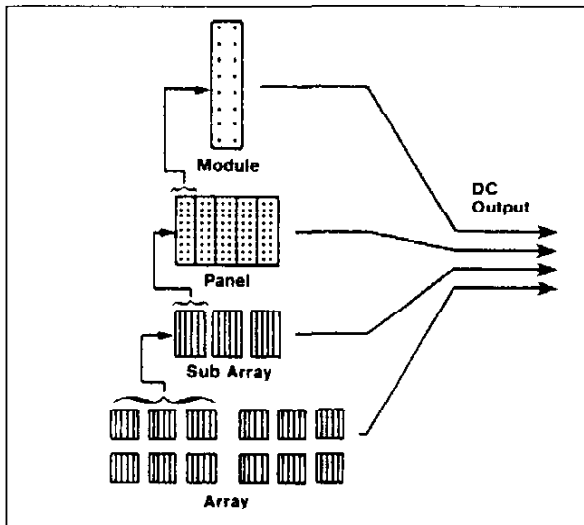


SOLAR CELL

HOW PHOTOVOLTAIC SYSTEMS WORK

Groups of interconnected solar cells are packaged into standard modules (sometimes called panels or collectors). Modules are readily available from at least eight major manufacturers.

Modules are connected together to form a unit called an array. The number of modules and the interconnection pattern will determine the system voltage and maximum current output of the array.



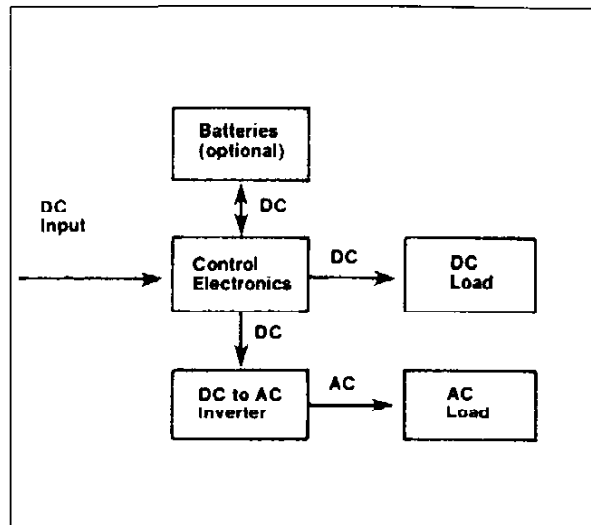
PV NOMENCLATURE

The amount of electric current generated by a solar cell is directly proportional to sunlight intensity. If there is no sunlight, there is no electricity generated. Because electricity is often needed when the sun is not shining, storage is generally required. PV electricity for water pumping is sometimes an exception. By pumping one or more days worth of water needs during sunlight hours, there is no need to store electricity — the water itself is stored for future use.

Batteries are the most common form of PV energy storage. These batteries are typically the same physical size as an automobile battery, but have deep cycle characteristics similar to golf cart batteries; automobile type batteries are generally not suitable for PV systems.

Just as an automobile uses a voltage regulator to control the charging voltage to the battery, a similar type of voltage regulator is used in PV systems to prevent overcharge of the batteries. PV voltage regulators (sometimes called charge controllers) often incorporate an additional feature - load disconnect. The load disconnect feature disconnects the load from the battery when the battery reaches a low state of charge and prevents further discharge of the battery.

The dc system voltage is generally 12 Vdc, 24 Vdc, or 48 Vdc. In residential systems, 120 Vac (alternating current) is desirable to power conventional appliances, motors, and lights. The conversion from dc to ac is achieved with an inverter. With an inverter, you can use all of the normal appliances in a home, such as hair dryer, curling iron, coffee pot, microwave oven, dishwasher, clothes washer, power tools or



BLOCK DIAGRAM OF A PV SYSTEM

water pump. Inverters can also power office equipment such as computers and facsimile machines. Laser printers, however, may require a power line conditioner to prevent damage to the printer.

In general, PV systems are not used to generate heat for hot water, space heating or electric cook stoves and ovens. Propane is a more cost-effective energy source for these high-power applications. However, a solar thermal water heater with propane as a back-up may be the most cost-effective source of hot water.

III. PV SYSTEM DESIGN

Designing a reliable, safe, cost-effective PV system requires a thorough knowledge of electrical load characteristics, photovoltaic components and system characteristics, local ambient temperature and sunlight intensity data, electrical wiring practices, and local electrical codes. For those inexperienced in these areas, it is strongly recommended that professional help be obtained to assist in (or provide) system design and installation. The system design process is sufficiently complex that a computer program is often used to develop an optimized design, predict system performance, and produce cost estimates. Many Arizona PV companies will provide the design service (including a computer optimized design) at little or no cost. See page 16 for a source of such companies.

The following five steps provide an overview of the design process:

Step 1. Define Electrical Loads

PV system design starts with a definition of the electrical loads. The initial system cost will be directly proportional to the amount of energy that the system is designed to provide. For residential systems, initial installed PV system costs will typically be \$3,000 to \$10,000. Small systems, used to power a few appliances in small homes or cabins, can be installed for as little as \$1,000. Much larger PV systems that provide virtually all electricity for a large home can cost \$20,000, or more, installed.

Energy conservation and efficient loads are essential if system costs are going to be minimized and affordable. Reducing the load requirements (kWh) by 50 percent will reduce the initial system cost by 50 percent - which could save thousands of dollars.

The size, and subsequently the cost, of a photovoltaic system depends upon two factors: the electrical requirements of the devices relying on the system (commonly referred to as the daily load and based on the average number of hours per day of usage) and the amount of sunshine available to power the system. These factors determine the quantity and size of modules, batteries, and other components.

The load is usually measured as the amount of electric power being used at any given moment. For the purposes herein, the term "average daily load" will refer to the wattage of the electrical device multiplied by the average daily use in hours per day. To determine the load, it is necessary to identify the devices that will rely on the system for power. If the system is used to power a home, the load might consist of lights, coffee pot, microwave oven, hair dryer, vacuum cleaner, radio, TV, power tools, water pump, and other common household items.

The general strategy in planning electrical loads includes: a) avoiding electrical devices requiring high power, such as a hot water heater, kitchen stove, and space heaters (use propane or natural gas instead of electricity); b) avoiding conventional refrigerators (use high efficiency electric refrigerators or propane fueled refrigerators); c) avoiding unnecessary electrical loads; d) using high efficiency appliances and e) minimizing the use of loads that are on twenty-four hours per day (e.g., LED clocks, appliances with controls using lighted displays, and remotely controlled TVs, VCRs, and stereos).

Many new energy efficient products have been developed for use with PV powered homes. A designer of PV systems can now choose low voltage dc appliances and lights, standard 115 Vac loads, or a combination of both to meet the owner's specific needs. Arizona companies can supply high efficiency and special electrical items for use in remote homes (see page 16 for a source of these companies). These items include: fluorescent lights, TVs, refrigerators, pumps, evaporative coolers, and radio telephones.

Step 2. Determine load wattage

Once the individual electrical loads have been identified, determine the wattage of each item. The wattage of a device is usually stamped or printed on a nameplate or identification plate on the rear of the unit. If the unit lists VA (volts x amps), that may approximate the wattage. If only amps are listed, multiply the amps by the volts listed to find the approximate wattage. Name plate ratings are generally maximum design limits of the device, which could be two to four times the actual power consumed. If possible, measure (or have a technician measure), the actual power of every electrical load to be used.

A chart of wattage for typical appliances is provided for reference on page 5.

Step 3. Estimate Usage of Individual Loads

Next, decide how many hours per day (average) each item is to be used. The load estimate must be as precise as possible to avoid oversizing or undersizing the systems. If system design is oversized, money is wasted on excess capacity. If it is undersized, power shortages during operation may result.

The average daily load then, is:

$$\text{Daily load} = \text{watts} \times \text{time in use} \quad (\text{DL} = \text{W} \times \text{T})$$

For example, if a fluorescent light consumes 15 watts and is on four hours per day, then:

$$\begin{aligned} \text{DL} &= 15 \text{ watts} \times 4 \text{ hours (per day)} \\ &= 60 \text{ watt-hours (per day)} \end{aligned}$$

APPLIANCE WATTAGE CHART

APPLIANCE	RATED WATT	MEASURED WATTS	APPLIANCE	RATED WATT	MEASURED WATTS
BATHROOM			MISCELLANEOUS		
Hair dryer - Clairol CH-12			Clock; LED, Alarm, Cosmo E-803	5	2
High	1200	1176	Evaporative Cooler, Sears, Room	396	-
Medium	650	710	Evaporative Cooler, 1/2 hp	875	897
Low	300	282	Fan; 18" Portable, KMART	660	586
Curling iron			Ground fault circuit interrupter (7)	-	5
Vidal Sasson VS 171	150	140	Security system; Radio Shack 49-470	1	1
Windmere C6-E-5	18	15	Telephone, Cordless, Uniden EX30008	10	4.2
ENTERTAINMENT			Vacuum; Canister, Eureka 3125	1080	818
TV, 19" Portable			Vacuum; Upright, Hoover U400	-	297
Off (w/ remote control)	-	6	Vacuum; Shop, Craftsman 758.17881	660	586
On	95	58	Washing Machine, GE	920	-
VCR			Water Pump; 1/2 hp centrifugal jet	1495	1280
Off (w/ remote control)	-	10	OFFICE EQUIPMENT		
Play	27	25	Computer, Micro I, LCD-286	150	61
Radio, Portable, Toshiba RT8578	15	3.6	Computer, 486 P CU Tower	220	83
KITCHEN			Computer; 14" Color Monitor	120	76
Coffee Pot; Salton 10 Cup	825	798	Computer, 386 Notebook (120 Vac)	144	-
Coffee Pot; Mr. Coffee 4 Cup	625	620	Off (charging battery)	-	16
Gas Range; Magic Chef			On, idle	-	31
Clock /Controller	-	3	On; hard drive on	-	41
Ignitor	-	1	Printer, Panasonic Dot Matrix	180	11
Glow Plug	400	398	Printer, hp LaserJet IIIP	576	-
Microwave; Sharp, 600 Watt			Warm-up	-	408
Off (Clock controller on)	-	4	On, idle	-	28
On	1200	1243	Printing	-	456
Toaster; Proctor Silex	1050	1110	Printer, hp DeskJet 500	48	-
Refrigerator, Sun Frost -16 ft ³			Off	-	13
Refrigerator section	64	68	On, idle	-	16
Freezer section	64	66	On, printing	-	31
Refrigerator; GE-18 ft ³	600	432	Facsimile, Sharp FO-220, idle	140	13
LIGHTS			SHOP TOOLS		
7 Watt Fluorescent (25 Watt equiv.)	7	5	Saw, Radial Arm, 10" Craftsman	1200	583
13 Watt Fluorescent (60 Watt equiv.)	15	11	Saw, Circular, 7", Craftsman	1200	841
18 Watt Fluorescent (75 Watt equiv.)	20	20	Saw, Miter, 10" Makita	1440	751
40 Watt Incandescent	40	36	Planer, 3.5" Makita 1900B	480	355
60 Watt Incandescent	60	59	Drill, 3/8" VSR, B&D 7-144	246	151
			Drill, 1/2" VSR, Skil	408	214
			Router, Craftsman, 1 hp	746	490
			Sander, Belt, B&D 7450	624	445

Step 4. Total Daily Loads

The average total daily load is the sum of the individual device average daily loads. A budgetary estimate for the equipment cost of a PV system can be developed knowing the total daily load and the geographic location of the system (geographic location will define available sunlight - see page 14.)

An example showing the calculation of the average daily load is provided on page 6 along with a blank worksheet.

Step 5. Estimate System Costs

For a rough approximation of the equipment cost of a PV system to power the total daily load, multiply the total daily load by three if the PV system is simple; by four if the PV system is "typical"; or by five if the system has all the "bells and whistles."

For example, if a small simple system supplied 500 Watt-hours per day, then the approximate PV system cost would be \$1,500.

¹ Professional installation of the system may cost an additional 10-25 percent, depending on the complexity and the distance from the installer.

EXAMPLE - CALCULATING THE DAILY LOAD (Remote Home)

For a more accurate cost estimate, additional design questions must be answered, such as: Will a backup generator be used? A backup generator often results in a lower initial system cost, a lower cost of energy over the life of the system, a system which can accommodate changes in energy demand, and a more reliable system. The disadvantages of a backup generator are: fuel must be stored; fuel costs may increase with time; maintenance; and noise when the generator is running. About 80 percent of remote homeowners elect to use a back-up generator which supplies, on average, about 2 percent of the total electrical energy consumed.²

Other questions which impact the cost of a PV system are: will the tilt angle of the PV array be seasonally adjustable; will the PV array track the sun; will the system require an inverter to provide 110 volts ac; and what is the maximum power required from the system at any time?

Developing answers to the above questions is not always a straight forward process. **You may wish to employ the assistance of a company that specializes in PV system design and installation to answer these questions, select the optimum system configuration, and define the system cost** (see page 16 for a source of such companies.) This service is available at little or no cost.

For those desiring a more detailed understanding of the PV system design process, an excellent document - *Stand-Alone System Design Handbook* - is available from Sandia National Laboratories. A bimonthly magazine is also available which is devoted to the remote homeowner - *HOME POWER-The Hands-On Journal Of Home-Made Power*. (see Bibliography, page 16, for ordering information for these two documents).

SYSTEM EXPANSION

Most PV system components are modular and system expansion is relatively easy, especially if one plans for future expansion. Systems evolve and grow as the needs grow or are better defined.

² Hammond, B., D. Shugar, A Profile of Stand-Alone Residential Power Systems, Solar 90, Austin, Texas, March 1990.

System operating voltage (of the array and batteries) needs to be defined with possible future expansion in mind. A 12 volt dc inverter, for example, will not work on a 24 volt dc system. The initial system should be designed for the highest dc system voltage anticipated in the future.

For systems requiring an inverter, the size of the inverter should be large enough to handle anticipated increases in loads.

IMPACT ON LIFESTYLE (Remote Home)

PV systems can be (and often are) designed such that minimal lifestyle changes are required to live comfortably with the system. The lifestyle changes due to PV can range from very little to very significant, depending on system design, system configuration, climate and cost; it is generally a matter of balance between system cost and lifestyle changes.

The occupants of a typical remote PV home are the owners and operators of their own electric "utility." They have a great deal of freedom in how they manage this system and the degree of lifestyle changes that they are willing to make.

For the typical Arizona remote home with a 500 watt PV array, an inverter to power 110 Vac loads, and a back-up generator, typical lifestyle changes would be turning off lights and other appliances when they are not needed and using high energy consuming appliances (c.g., clothes washer, shop tools, microwave oven) during sunlight hours to minimize the use of the batteries (and extend battery life). This may mean waiting a few days for an overcast sky to clear before doing laundry. An alternative would be to turn on the back-up generator to avoid a deep discharge of the batteries while using these appliances.

A survey³ of 321 stand-alone homeowners showed that changes in lifestyle are not a significant issue. The average system size in this survey was 312 Watts of PV array and a 4.4kW generator.

**A COMPARISON OF A 1.5 MILE LINE EXTENSION VS A PV SYSTEM
(CALCULATED OVER A 30 YEAR LIFE)**

	Energy Efficient Home		Normal Home
	Line Ext.	PV System w/ Back-up	Line Ext.
Grid extension	\$22,500	—	\$22,500
30-yr. electric bills	\$7,242	—	\$40,270
Energy efficient appliances	\$1,800	\$1,800	—
PV system, installed	—	\$8,699	—
Back-up generator	—	\$600	—
Fuel for generator	—	\$1,780	—
Maintenance	—	\$3,711	—
Replacement batteries	—	\$6,556	—
Additional property tax	—	\$1,827	—
TOTALS:	\$31,542	\$24,973	\$62,770

Note: This is a rough cost analysis. A more accurate calculation would require a "present value analysis", which, by using an appropriate discount rate, brings future costs back to an equivalent current-day dollar value for comparison of options. An inflation rate of 3%/year is assumed.

Assumptions for an energy efficient home:

1. Line extension of 1.5 miles at \$2.50 per foot plus \$2,700 fixed cost.
2. Monthly utility basic service charges are \$8 in 1993 and increase at 1.7% per year.
3. Price of grid electricity is \$0.10 per kWh in 1993, increasing at 3% per year.

4. Taxes on the entire utility bill are equal to 5% of the bill.
5. 1891 Watt-hours (average daily load)
6. PV system cost: \$8699:
Hardware: 1891 Wh/d x 4 = \$7564
Installation: \$7,564 x 0.15 = \$1,135
7. Batteries: 1320 Wh, 5 no sun days, initial cost \$650, replace every five years.
8. Generator: 4 kW (operating at 2 kW); 4 kWh per gallon of gasoline at \$1.30/gallon; \$0.33/kWh; 113.4 kWh/year.
9. Maintenance: water batteries and clean terminals twice per year; change generator oil twice per year, spark plugs once per year. Parts and labor, \$78/yr.
10. Property tax on PV system: Assessed value is 10% of full cash value. Property tax is 7% of assessed value.

Assumptions for a home with typical energy consumption and a line extension:

1. The home uses electricity for space conditioning, cooking, and conventional appliances. Average daily load: 20 kWh.
2. The monthly utility basic service charges are the same as an energy efficient home (\$3,620 over 30 years).
3. Cost of purchased electricity over 30 years is \$34,732. Utility bill taxes/assessments, \$1,918.

IV. SAFETY ISSUES

PV systems can (and should) be designed and installed so that they provide decades of safe, reliable service. Systems not installed in a safe manner could result in fire, personal injury, or even death.

The National Electrical Code (NEC) was developed to ensure safe electrical systems. In addition to complying with the NEC, local or regional codes may also require that a licensed electrician or technician install the PV system.

General guidelines for a safe installation are:

- use proper gauge wires
- use appropriate fuses, circuit-breakers, and circuit disconnects
- use proper grounding techniques
- eliminate exposed wires and connections
- vent battery gasses

V. DESIGN EXAMPLES

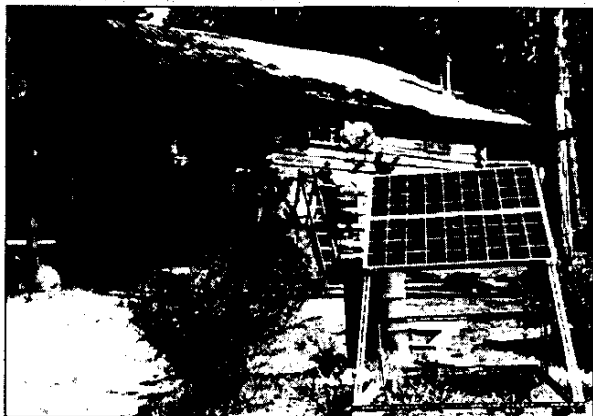
Three residential design examples are provided on pages 9, 10, and 11. Loads and energy consumption are defined, as well as the cost of the PV system.

The first example is a cabin with a small PV system. This is a "bare bones" PV system without a voltage regulator. Example number two is a medium size PV system for a 2000 square foot home.

The third example is a remote home with 1,900 square feet of floor area in the living space plus an additional 1,200 square feet in the basement. The cost of the back-up generator was not specified for this system, but, depending on the quality of the generator, it would add from \$500 to \$3,500 to the cost of the system.

REMOTE HOME - SMALL

(Source: Home Power Magazine, Issue #13, October/November 1989, *Big Uns and Lil Uns*, Richard Perez, pp. 5-6. Edited and printed with permission.)©



One of the greatest advantages to using sunshine to make electricity is freedom — freedom to live where we want and how we want. All we have to do is lightly tap Mother Nature for a smidgen of her endless energy. Our system's size depends on us, our needs and desires. If you don't need the power, then you don't have to produce it or pay for it. Here's an article about a small system that meets small needs. It is cost effective and points out the freedom and flexibility built into photovoltaic systems.

When Bill and Jean Andrews moved to their mountain home, they were ready to leave many conveniences behind. Bill and Jean's home is on a south facing slope surrounded by tall Douglas fir and ponderosa pine trees. There is a spring that flows into a small pond in their front yard, home to at least a million frogs and tadpoles.

Their 80 year-old log cabin is about 2.5 airline miles from commercial electricity. The nearest paved highway is over five long, rough, muddy, and deeply rutted miles away. Electrical alternatives, other than running the commercial grid at \$70,600, included an engine generator and/or photovoltaics (PVs). They choose to use a stand-alone PV system (without a back-up generator) for essential electrical chores like communications and lighting.

ENERGY CONSUMPTION

Every system starts with a thorough survey of the appliances. Bill and Jean's system was no exception. They sought help from Electron Connection in specifying and installing their system. In Bill and Jean's

case the list of appliances was very short. They only needed electricity for two functions, communications and lighting. The table below details the appliances and their consumption:

Appliance	Watt-hrs/day	%
Radio Telephone; Receive	216	43%
Incandescent Lights (2)	144	28%
Fluorescent Light	52	10%
CB Radio; Receive	34	7%
Radio Telephone; Transmit	25	5%
Stereo Radio/Cassette	24	5%
CB Radio; Transmit	10	2%
Total	505	100%

They decided right off to put all the electrical appliances on 12 Vdc and not to use an inverter in this system. Twelve volt lighting is readily available in either fluorescent or incandescent models. Just about all two-way radios, either CB or radio-telephone, are available in 12 Vdc powered models.

This system has only two major components, PV panels and batteries. The PVs produce the power and the batteries store it. The two Trojan L-16Ws form a battery that will store about six sunless days of power for Bill and Jean. The cost of the system was:

Item	Cost	%
Kyocera 48W PV Panels (2)	\$712	52%
Trojan L-16W Batteries (2)	\$550	40%
PV Mounting Rack (4 panels)	\$100	7%
Battery Cables	\$15	1%
Total	\$1,377	100%

Professional installation might add an additional cost of \$150 to \$350 to this cost.

Stand-alone PV system cost is directly proportional to the amount of energy required from the system. Note that Bill and Jean installed a rack for four PV panels even though they now use only two panels. In stand-alone PV systems this is a very good idea. As the system's electrical consumption grows (and it always seems to), then adding more panels is simple.

REMOTE HOME - MEDIUM

(Source: Home Power Magazine, Issue # 31, October/November 1992, *A Clean Solar Life*, George B. Chase - 813-993-0391, pp. 6-9. Edited and printed with permission)©



Photo by George B. Chase

When we decided to build a home big enough to live in and leave the city for good, our first step was to check with the local electric company. They told us it would cost about \$15,000 to bring power to our site! Our budget forced us to find more cost-effective power.

Over the last six years we had been doing research on solar power. We were familiar with the products and had a fairly good idea of what was necessary to go stand-alone solar. I did my own architectural and electrical plans and had them OK'd by the building inspector prior to building. I had great luck with local building inspectors by going to them early. I told them what I planned to do and asked for help. They knew I was not trying to cut corners on safety and actually asked my opinion on many items.

ASSESSING POWER NEEDS

Our next step was to establish our power needs. We knew we wanted to have a normal electrical lifestyle. We first decided what we must have, and what we could do without and still live comfortably. We chose a standard 30-inch gas range and a Sun Frost RF-16 (16 cubic foot) refrigerator/freezer. A regular automatic washer is used for clothes and is powered by our inverter. A 10-gallon RV gas water heater provides our hot water needs. Once we estimated our total electrical needs, we could then start the design of our power system.

ENERGY CONSUMPTION

Appliances	Watt-hrs/day	%
12 Vdc Loads		
Sun Frost refrigerator	720	52%
Mac Donald water pump	175	13%
Lights	36	3%
Ceiling Fans	25	2%
Radio/tape player	1	-
120 Vac Loads		
Washing Machine	252	18
13" B&W TV	44	3
Microwave	56	4
Vacuum cleaner	42	3
19 inch color TV	16	1%
Ceiling fans	12	1%
Total	1,379	100%

System Costs

Item	Cost	%
Arco 47 watt modules (14)	\$3,990	58%
Heart inverter, 2000W	\$1,800	26%
Exide 6 volt batteries (8)	\$520	8%
Centrix voltage reg. (60A)	\$290	4%
Support Structure	\$200	3%
Meters (5)	\$100	1%
Total	\$6,900	100%

Professional installation might add an additional \$700 to \$1,400 to this cost.

You can easily start with a small system and add to it later. If you chose this route, make sure that you buy components that will allow you to expand. We decided a back-up battery charger would come in handy and got a used 12 volt alternator, which is driven by our tractor.

STANDARD AND SOLAR!

If you visit our 2,000 square foot stand-alone solar home, you would not think that it was any different from a standard utility connected house. Most people we've spoken to think that PV-powered homes are just "cabins" without any creature comforts. All our fixtures and appliances are standard, although some have been modified to run more efficiently.

REMOTE HOME - LARGE

(Source: Home Power Magazine, Issue #27, February/March 1992, *Rook's Castle*, Bob-O Schultze, pp. 6-13. Edited and printed with permission).©



Photo by Richard Perez

The Rook's home is four miles and \$24,000 from the nearest power grid. Their log home has 1,900 square feet of floor area in the living space and an additional 1,200 square feet in the basement. With the aid of some subcontractors, they built their own solar-powered log home.

THE ELECTRICAL SYSTEM

They had pretty much resigned themselves to life with a diesel generator when a neighbor handed Mike an old copy of Home Power. So much for the diesel! They read as many HPs and everything else they could find on the subject. They saw the technology develop and decided on solar electricity as their primary power source. Electrical appliances used by the Rooks are:

Appliances	Watt-hrs/day	%
12 Vdc Loads		
Sun Frost refrigerator	660	21%
27 inch Color TV	600	20%
Washing machine	343	12%
Power tools	321	11%
Satellite TV System	300	10%
Fluorescent lights (3)	264	9%
Vacuum Cleaner	114	4%
Microwave oven	107	4%
Jacuzzi Pump	107	4%
Fluorescent shop lights (2)	69	2%
Video cassette recorder	39	1%
Incandescent light (1)	21	1%
Stereo	14	1%
Food processor	11	~0%
Blender	5	~0%
Misc.	11	~0%
Total	2,986	100%

The Rooks opted for a 24 Vdc system because they planned to invert all of their power to 110 Vac. Not only are wire resistance losses reduced four times compared to a 12 Vdc system, but 24 Vdc inverters are more efficient and deliver more power.

The Rooks also use their 120 Vac generator to supply power during sunless periods. Mike says they run the generator about five hours weekly during the winter, to pump their water, run the washer, and fully charge the batteries. The batteries contain enough energy to power the log home for four days (without sunshine). The PV system costs (not including the generator) were:

Item	Cost	%
Kyocera 51W modules (14)	\$4,480	40%
ED-160 Ni-cad batteries (60)	\$3,990	36%
Trace 2524SB inverter	\$1,411	13%
Cable, wire, disconnect	\$475	4%
Ample Power meter	\$299	3%
PV mounting rack	\$240	2%
Heliotrope CC-60 controller	\$225	2%
Total	\$11,120	100%

Professional installation might add an additional \$1,100 to \$2,200 to this cost.

LIVING WITH RENEWABLE ENERGY

"A lot of people still think that living with solar electricity means reading by car taillight bulbs and doing without," Mike Rook told us. "Folks that come over are amazed at our totally 110 Vac house, complete with the big microwave and the 27" color TV and satellite receiver. We've given up nothing by using the sun for our electricity, we've just learned to use it efficiently," explained Mike.

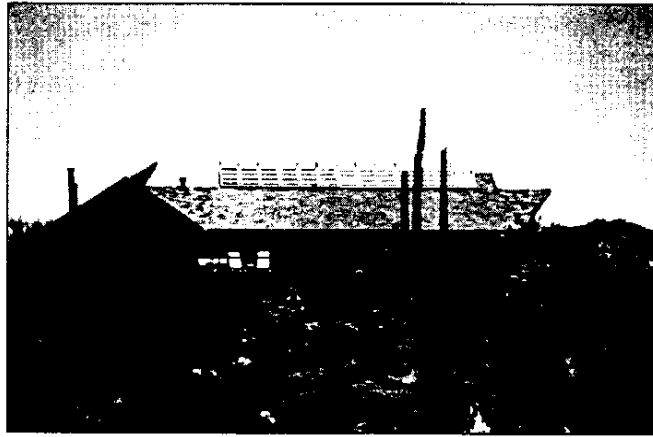
We asked if the Rooks had any regrets with their system. Mike volunteered that if he had it to do over, he'd have purchased the inverter and the batteries first and used them to substantially reduce the time spent feeding and listening to their noisy generator during construction!

VI. MORE "LIVING WITH SOLAR" TESTIMONIALS

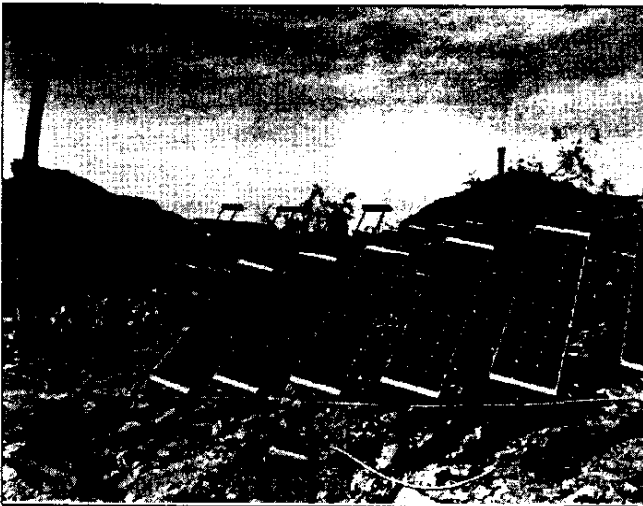
THE ROSS AND SUSAN DEAN HOME (SCOTTSDALE)

Today, the Deans relax in their 3700 square-foot house surrounded by the Arizona desert. Photovoltaic modules capture sunlight and furnish nearly all their electricity.

Solar-generated electricity powers their evaporative coolers, a microwave, refrigerator, dishwasher, several color television sets, all the lights, an intercom and sound system, washing machine, and video recorder. Even the water pump for their well and an outdoor baseball pitching machine run on solar energy.



The Ross and Susan Dean Home in Scottsdale



The Gary and Marti Ross Home in Tucson

THE GARY AND MARTI ROSS HOME (TUCSON)

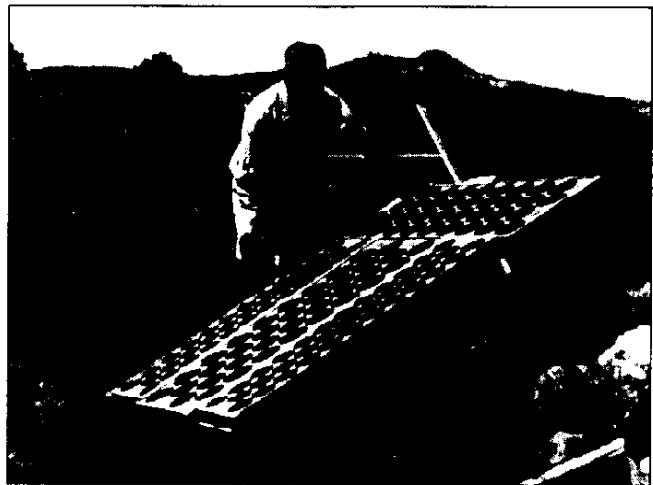
In 1988, Gary and Marti Ross moved into their new home beyond the Tucson city limits, and beyond the power lines. "We built this house from the ground up to be the most energy efficient it could be, with energy efficient appliances and with the photovoltaics," Gary says.

Marti remembers her friends' reaction to their building a solar house, "when I told them that we were going to be living in a solar house, their main concern was how was I going to be able to do anything at night because I would have to burn candles. They thought that when the sun went down, our power went out."

THE GERRY AND ANN CUNNINGHAM HOME (PATAGONIA)

Gerry and Ann Cunningham haven't paid a utility bill in 11 years. Their modest 500 square-foot home near Patagonia runs off a small solar array that furnishes their electricity, a wind generator that pumps their water, and a small propane tank that provides fuel for the stove. The earth-bermed house is a comfortable 72 degrees without benefit of any active cooling system. No back-up generator or power line stand ready in case they run out of energy.

"If we run out of energy it's because we've done something stupid," said Gerry. "The house design is important, but your energy consumption depends on you."



Gerry Cunningham stands near his PV powered home.

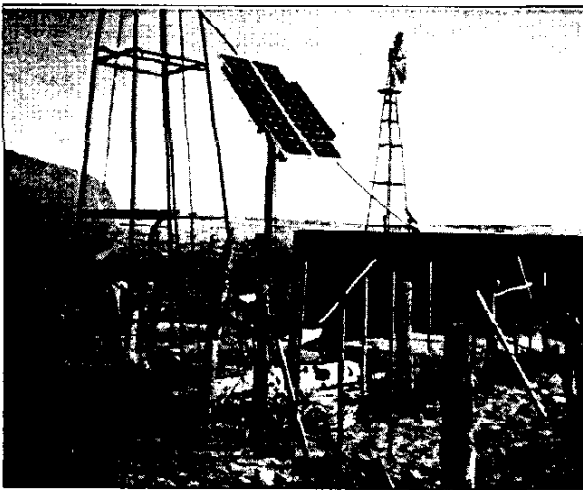
VII. PV AND WATER PUMPING

Photovoltaics provide a simple and reliable means to power remote water pumps for remote homes, ranches, and game preserves. Many of these systems do not require batteries for energy storage; water can be pumped during daylight hours and stored in holding tanks.



One of three PV water pumps at the Quarter Circle U Ranch that support a family of four and about 250 head of cattle and horses.

Photo by Chuck Backus



This stock watering system produces 1500 gallons per day for 90-100 head of cattle. It was installed for Arizona Public Service Company near Holbrook.

Photo by Lee Tanner, ElectriSol Ltd.

The size of the PV system and the type of water pump required for a given water pumping application will depend primarily on the gallons per day (gpd) required, the total dynamic head (TDH), the efficiency of the pump, and the available sunlight.¹

The following are two examples of PV pumping systems:

EXAMPLE 1. STOCK WATERING, DEEP WELL, JACK PUMP

Requirements: 2200 gallons per day with a total dynamic head of 400 feet.

Installed cost:	
Array (765 Watts of PV)	\$5,168
Jack pump	3,000
Pipe, piston, sucker rod	2,000
Mounting and foundation	1,500
Other hardware	300
Maximum power tracker	200
Installation	500
Total	\$12,668

(Mounting includes a single axis tracker)

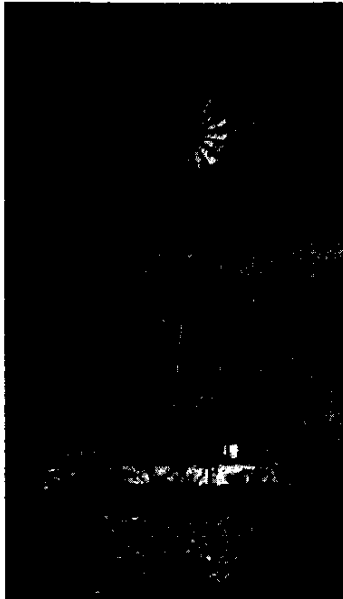
EXAMPLE 2. STOCK WATERING, SHALLOW WELL, SURFACE PUMP

Requirements: 1200 gallons per day with a total dynamic head of 15 feet.

Installed Costs:	
Site preparation	\$100
Array (64 Watts of PV)	448
Surface Pump	515
Misc. hardware	200
Installation	150
TOTAL	\$1,413

¹Alternative Energy Sourcebook, Real Goods

VIII. OTHER CONSIDERATIONS



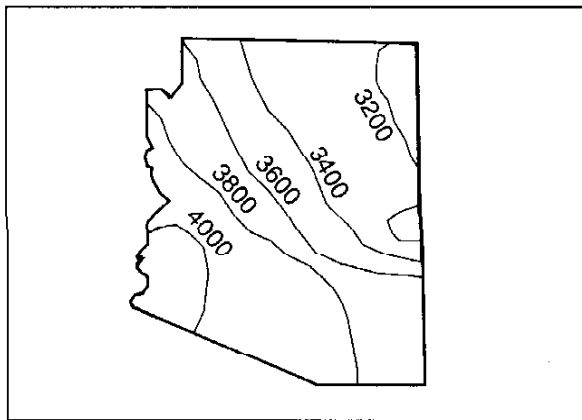
Photovoltaic power is now replacing wind power for water pumping.

Photo by Jim Arwood

THE SOLAR RESOURCE

The amount of sunlight available at a given location is called the "solar resource" or insolation. The energy produced by a PV array is proportional to the value of insolation.

Arizona has more sunlight available than any other state, and it is fairly evenly distributed across the state.



Annual Mean Total Hours of Sunshine

These annual values of insolation provide an overview of the sunlight available for a given area; monthly values of insolation⁴ should be used for PV system design — not annual mean values.

⁴ Stand-Alone Photovoltaic Systems - A Hand-book of Recommended Design Practices - see page 16.

MAINTENANCE AND REPLACEMENT

There is virtually no maintenance required for PV modules. Expected life is 20 to 30 years for a typical commercial power module.

The batteries will require water every six to 12 months and the battery terminals should be cleaned annually. If properly used and maintained, lead-acid batteries will need to be replaced every three to 10 years. Owners can extend the life of batteries by limiting the daily discharge.

Back-up generator oil must be replaced twice per year, or more often if the generator is used frequently. Other generator repair and maintenance will depend upon the hours of use. The useful life of a "stand-by" generator is approximately 500 hours, while a "prime power" generator will operate for 10,000 hours before requiring an overhaul.

COOLING USING PV AND GENERATORS

Conventional air conditioners use a great deal of electricity. **The use of room or central air conditioners is not recommended with PV/generator systems, since the generator will have to be used extensively during the cooling season.** Evaporative coolers may provide an effective means of cooling.

FUTURE OPTIONS

With time and population growth, the grid may gradually extend within economic reach of a PV powered home, such that a utility connection becomes a viable option for the homeowners. A residential PV system can be installed in a manner to easily accommodate future connection to the utility grid. If the PV homeowners opt for a grid connection, they can then sell their PV system to someone who is not as close to the power line.

IX. ANSWERS TO FREQUENTLY ASKED QUESTIONS

INVERTERS

Q. What determines the size of the inverter?

A. Generally, the load with the highest starting current will determine inverter size. These loads are typically radial-arm saws, air compressors, deep well pumps, and washing machines. Also, if these or other large loads, such as hair dryer, toaster, or coffee pot, are used at the same time, the inverter must be capable of handling the total power requirements of these loads.

Q. What is the difference between an inverter and a converter?

A. An inverter changes dc to ac (e.g., 12 Vdc to 120 Vac) and a converter changes a dc voltage to a different voltage level (e.g., 24 Vdc to 12 Vdc).

Q. Why invert to ac?

A. The majority of readily available appliances are 120 Vac. Because these appliances are mass produced, they are readily available, low cost, and generally reliable. They usually operate more efficiently than low voltage dc appliances.

PV MODULES AND ARRAY

Q. How many PV modules are required to power a house?

A. A "typical" house uses 150 Watts to 1,500 Watts of modules (3 to 30 50-Watt modules). The number depends on the loads used, how long they are used, how much sunlight is available, and whether or not a back-up generator is used.

Q. Can a PV module be repaired if the glass is broken?

A. No. There is no practical means to repair the broken glass.

Q. Do modules need to be cleaned?

A. In general, no. The loss in power due to dust and dirt on a module is generally less than 10%. This dust and dirt will wash off during rain and output will return to 100%.

Q. Will modules be damaged by hail?

A. In general, no. Most modules are made of tempered glass and are designed to withstand the impact of a 1" hail stone at 52 mph.

Q. Can Plexiglas or screens be placed over the modules to prevent vandalism?

A. Yes, but both approaches reduce the amount of sunlight reaching the solar cells and thus reduce module output. In most situations, the benefits of these protective devices are not cost-effective.

LOADS/APPLIANCES

Q. Can I use a hair dryer or curling iron or microwave oven with a PV system?

A. Yes. An inverter which can supply 1,200 Watts can power these loads.

Q. Where can I find 12 Vdc appliances?

A. Twelve volt dc appliances are available from companies that specialize in PV systems, auto and RV retail stores, and mail order catalogs that specialize in renewable energy products.

Q. Is computer equipment available that operates on 12 Vdc?

A. Yes, both computers and printers are available which operate on 12 Vdc. Portable computers with LCD screens typically operate from low voltage batteries (e.g., 9-18 Vdc).

BATTERIES

Q. How many batteries are required?

A. As a rule of thumb, one 100 amp-hour 12 Vdc battery (or equivalent) is required for each 50 watts of PV. The number required depends on the number of continuous days of cloudy weather and whether or not a back-up generator is available.

Q. How long will the batteries last?

A. Typical battery life for lead-acid batteries is three to 10 years, but actual life will depend on the construction of the battery, the average daily cycle depth, and the battery charging technique.

Q. Can car batteries be used?

A. Auto batteries are **not recommended** for use in PV systems. Daily cycling in a PV system can shorten a car battery's life to one year or less. Deep-cycle batteries, such as marine, RV, or industrial grade batteries are recommended.

If you have additional questions about photovoltaics, please call the Arizona Department of Commerce Energy Office at 280-1440 (in the Phoenix Area) or 1-800-352-5499.

X. GLOSSARY OF TERMS

Alternating current (ac): Electric current in which the direction of flow is reversed at a constant rate (e.g., 60 cycles per second in the U.S.). This is the normal form of electricity provided by U.S. utilities.

Ampere (A): A measure of electric current; the rate of flow of electrons (analogous to the flow of water - gallons per minute, for example).

Battery (rechargeable): A storage device that operates on the principle of changing electrical energy into chemical energy and also back to electricity.

Direct current (dc): Electric current that always flows in the same direction (positive to negative). Batteries and photovoltaic cells are dc devices.

Efficiency (pump): The shaft output power of the pump divided by the input power to the pump motor.

Energy (electrical): Power measured in watts for a period of time (e.g., Watt-hours).

Insolation: The solar radiation incident on an area over time. Usually expressed in kilowatt-hours per square meter or Langleys.

Inverter: In a PV system, an inverter converts dc voltage from the PV array or batteries to ac voltage (e.g., from 12 Vdc to 120 Vac).

Load (Electrical): Devices such as lights or appliances that consume electricity.

Kilowatt (kW): One thousand Watts.

Kilowatt Hour (kWh): The power level measured in kilowatts multiplied by the hours that it is used.

Lift: The vertical distance that water is raised.

Off-grid: See Stand-alone.

Photovoltaic: The generation of a voltage at the junction of two different materials in response to light or other radiation.

Photovoltaic array: A group of photovoltaic modules electrically wired together.

Photovoltaic cell (solar cell): The basic building block in photovoltaic systems.

Power (Watts): The rate at which work is being done; equal to the product of voltage and current.

Semiconductor: Any material, such as silicon or germanium, that has limited capacity for conducting an electric current.

Stand-alone: A photovoltaic system that is not connected to the utility power grid.

Solar resource: See insolation.

Total Dynamic Head (TDH): The maximum vertical lift plus pipe friction, generally measured in feet.

Voltage (V): A measure of the force or "push" given the electrons in an electric circuit; a measure of electric potential (analogous to water pressure - pounds per square inch).

Voltage regulator (charge controller): An electrical device used to prevent overcharge of batteries by limiting the maximum voltage applied (similar to an automobile voltage regulator).

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XII. FOR A LIST OF ARIZONA PV SUPPLIERS, INSTALLERS AND DESIGNERS, CONTACT:

The Arizona Department of Commerce Energy Office, 3800 North Central Avenue, Suite 1200, Phoenix, AZ 85012; 1-800-352-5499 (outside Phoenix), or 280-1402 in the Phoenix area.