Renewable Energy Systems

4

Buchla, Kissell, Floyd

Chapter Outline

Solar Power Systems 4

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4-1 Stand-Alone Solar Power Systems

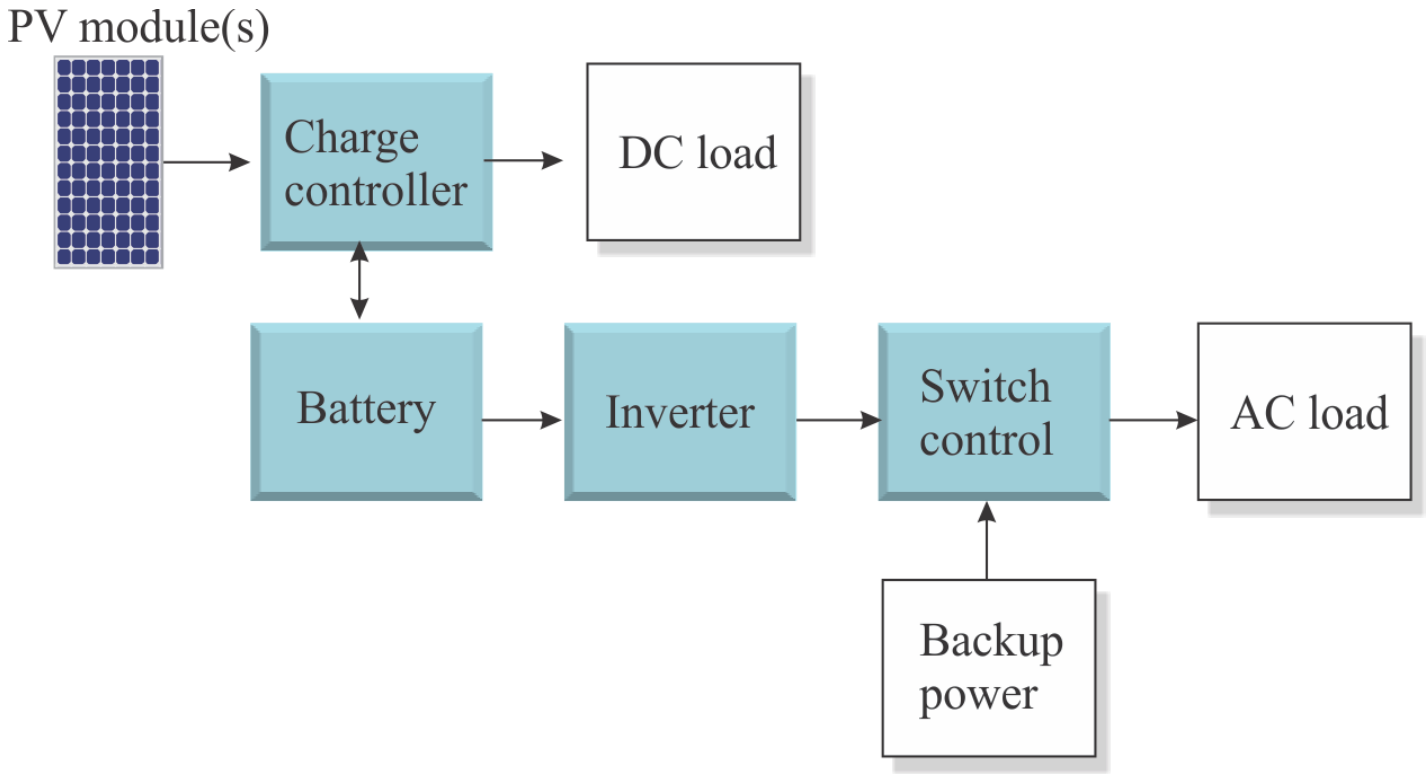
Stand-alone solar electric systems do not connect to the grid but in general supply electricity for smaller or remote applications or to supplement the grid. Many are strictly dc systems, running 12 V, 24 V or 48 V.

This stand-alone traffic signal is an example of a low voltage application, in which the PV module keeps a battery charged using a charge controller to regulate and limit charging current to prevent overcharging the batteries.

Source: David Buchla

4-1 Stand-Alone Solar Power Systems

Larger stand-alone solar electric systems include ac as an output. In this case an inverter to convert dc to ac is used. A representative system is shown:



4-1 Stand-Alone Solar Power Systems

The cost for a solar electrical system is done as a "life-cycle" cost that includes purchase price, operating, maintenance, energy costs, and recycling costs.

To understand the life-cycle costs, the expected life and long-term reliability has to be understood. Some countries (all of Europe, Japan, and parts of Asia require testing for product reliability and safety.

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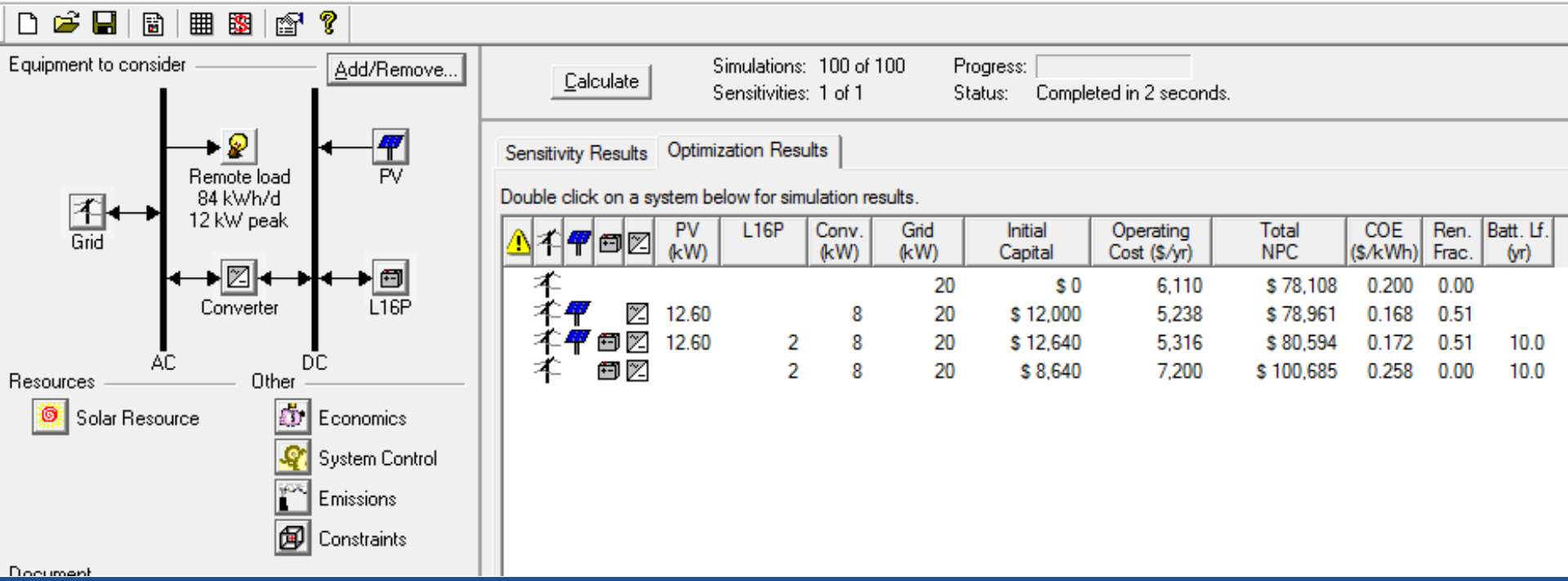
4-1 Stand-Alone Solar Power Systems

Costs including capital and operating expenses can be evaluated with the help of software such as HOMER, a computer simulation tool for designing and analyzing power systems that have various resources (PV, wind, generators, etc.)



4-1 Stand-Alone Solar Power Systems

HOMER, simplifies the task of evaluating designs for both stand alone and grid-tied systems for a variety of applications. Some of the issues HOMER can address are:

- the components to include in the design
- quantity and sizes of components
- variations of the resource
- costs including capital cost and operating cost
- sensitivity of variables to changes (for example, how does a change in fuel cost affect the system choice?)

4-1 Stand-Alone Solar Power Systems

Many developing countries do not have power in remote villages. Important projects for solar electricity include projects for hospitals and health centers, pumping clean water, and providing power for schools.

Another application in developing countries is solar-driven refrigeration systems based on a solid-absorption ($CaCl_2/NH_3$) cycle. The benefit include food and vaccine storage.

Source: David Buchla

4-1 Stand-Alone Solar Power Systems

Codes are standards for the building industry and include the International Building code (IBC) and the National Electric Code (NEC) in the U.S. The NEC has standards for electrical design, installation, and inspection of electrical installations including solar electric systems.

There are NEC standards for wiring (sunlight, moisture, etc.) as well as protection circuits, grounding, surge arresters, conduit, boxes, and more.

Source: NREL

4-2 Sizing the Stand-Alone System

Steps:

Source: NREL

4-2 Sizing the Stand-Alone System

AC Load description	Quantity	Power rating (W)	Time on per da (h/da)	Energy used (Wh/da)
Refrigerator	1	450	8	3600
Washing machine	1	500	0.5	250
TV	2	100	3	600
Lights (incandescent)	4	60	6	1440
Lights (fluorescent)	5	30	10	1500
Toaster oven	1	1500	0.5	750
Microwave oven	1	1000	0.4	400
Ceiling fans (medium speed)	3	25	10	750
Computer	2	125	4	1000
Printer	1	400	0.25	100
Miscellaneous loads	1	200	2	400
			TOTAL=	10790

4-2 Sizing the Stand-Alone System

Site evaluation includes insolation data for the site and other installations issues such as snow or wind loading, support requirements, shading issues, steep ground, etc.

Shading problems can be investigated with a device like the Solar Pathfinder™. The Solar Pathfinder™ uses a polished transparent, dome that shows a reflected panoramic view of the site.

Courtesy of The Solar Pathfinder Company

4-2 Sizing the Stand-Alone System

The size of an array can be determined starting with the energy audit. The power, in watts, is estimated for each month by:

$$P_{array} = \frac{W}{t_{solar}\eta_{sys}}$$

Example

A site has 6 hours of peak sunlight per day in March. If 15 kWh is required on an average March day from a grid-free system, what power is required from the array for this month? (Assume 65% efficiency.)

Solution

$$P_{array} = \frac{W}{t_{solar}\eta_{sys}}$$

$$P_{array} = \frac{15{,}000 \text{ Wh}}{(6 \text{ h})(0.65)} = 3846 \text{ W} = 3.85 \text{ kW}$$

4-2 Sizing the Stand-Alone System

Most stand-alone systems require a battery backup. Battery voltage gradually decreases as the battery discharges, so there is a minimum voltage that is useable.

The ampere hour requirement can be estimated with the following formula:

$$\text{Ah} = \frac{W_{day} \cdot t_{store}}{VB_{dod}\eta_{inv}}$$

Courtesy of Solar Direct

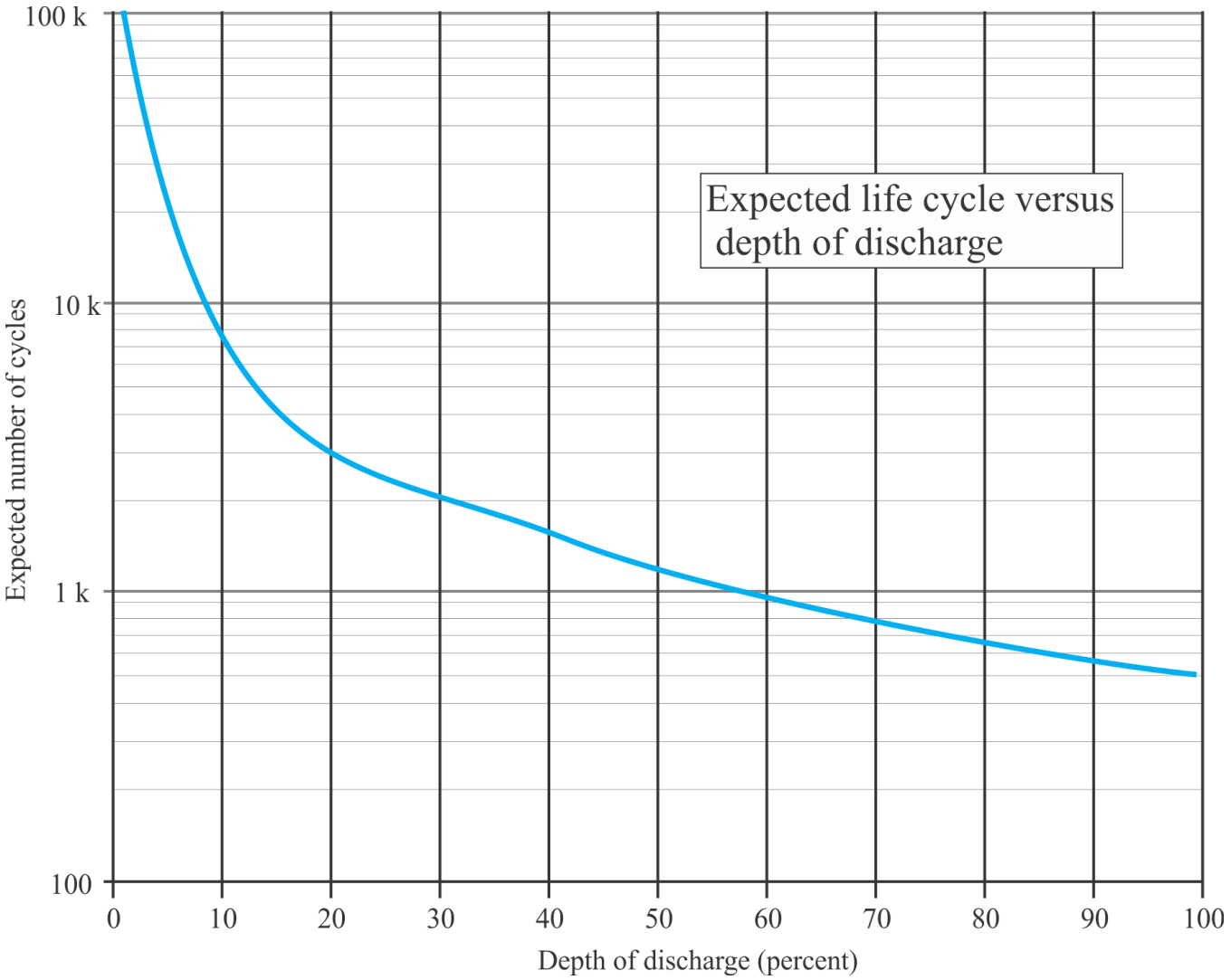
4-2 Sizing the Stand-Alone System

Batteries in solar electric systems should be deep-cycle types. They must be checked regularly for fluid level and any potential problem like corrosion or sulfation (lead sulfate crystals on the positive terminal).

Each day that is sunny, there is daily charging period and a discharge period. Because of variations in weather and rate of energy use, the depth of discharge will vary seasonally but having ample battery backup will extend the life of the batteries.

The graph on the next slide illustrates the expected number of cycles versus depth of discharge.

4-2 Sizing the Stand-Alone System



4-3 Grid-tie PV Solar Power Systems

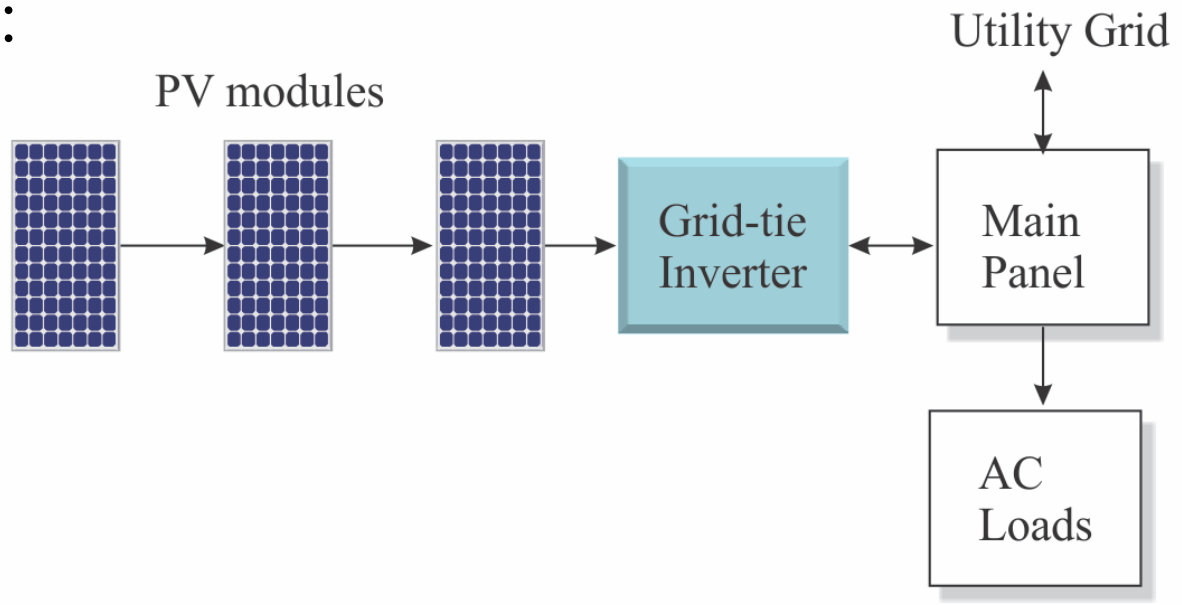
Grid-tied systems can be set up with or without a battery backup. The simplest grid-tied system supplements some fraction of the utility power with solar power. The major components in this system are the PV modules and an inverter.

For systems that are set up to send excess power to the grid, a special inverter is required that includes a transfer switch.

(Source: NREL)

4-3 Grid-tie PV Solar Power Systems

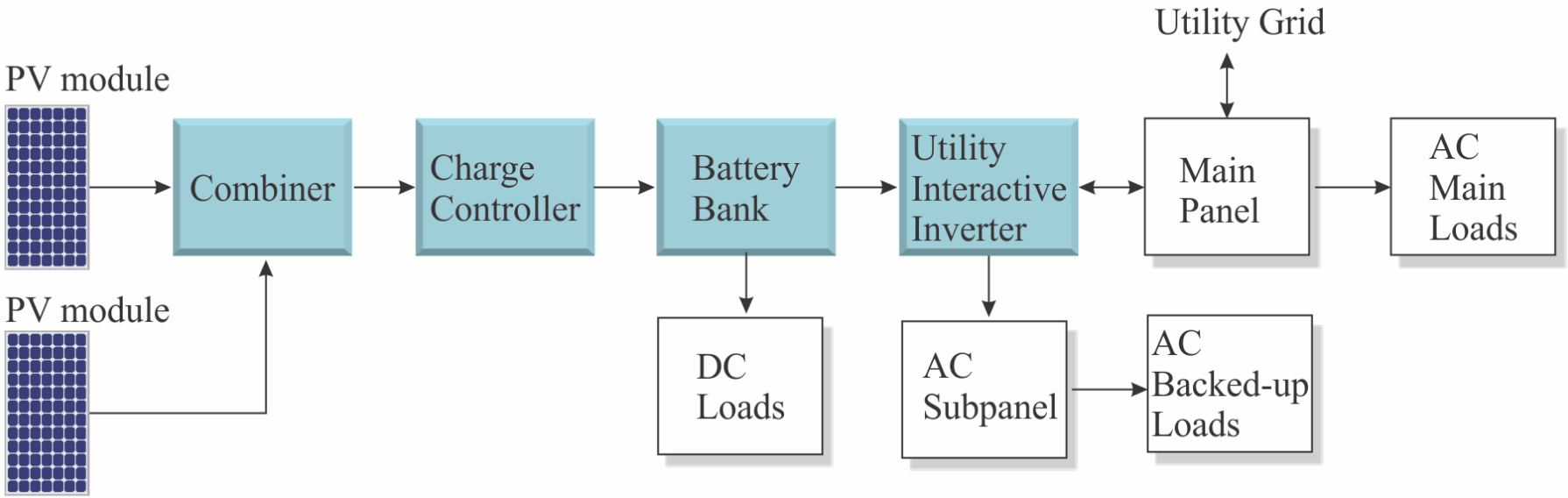
The block diagram for a basic grid-tied system is shown:



A battery-free system is less expensive and easier to install and virtually maintenance-free. It can offset any fraction of the utility power and have the utility make up the difference

4-3 Grid-tie PV Solar Power Systems

The block diagram for a basic grid-tied system is shown:



Some loads are backed-up; others are not. This saves the number of batteries required for backup, reducing capital and maintenance cost as well as space.

Grid-tie PV Solar Power Systems

Parking shelters with PV panels on the roof offer an excellent match of the need to the resource and provide power for electric vehicles and for offices during the day.

Parking shelters can be grid-tied systems for the charging stations to provide reliable power on cloudy days.

(Source: NREL)

Grid-tie PV Solar Power Systems

A number of power companies have implemented solar farms using large PV arrays. An advantage for utilities is that the rest of their system can act as backup for when solar power is not available.

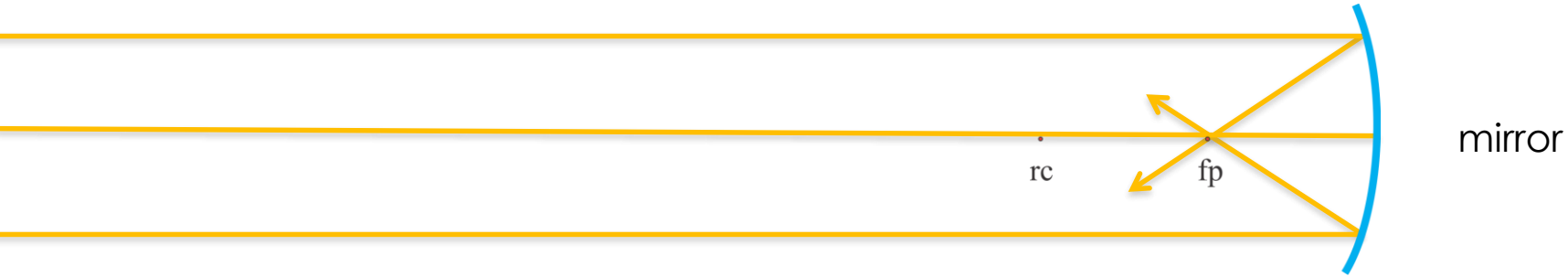
Utilities must consider load balancing, equipment loading, and power quality issues, transmission system, distribution requirements, and the impact on existing facilities.

(Source: NREL)

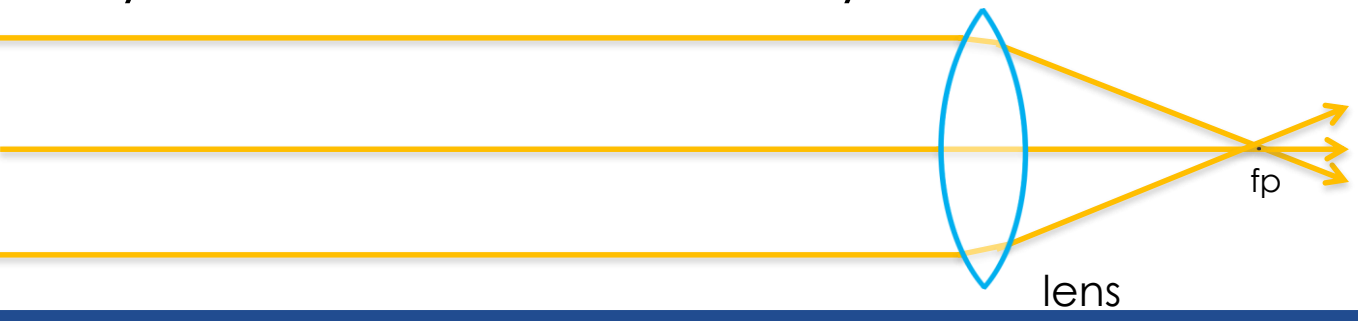
Florida Power and Light's Company's DeSoto plant

4-4 Solar Concentrators

A solar concentrator uses either a mirror or lens to focus light. With a mirror, on-axis light from infinity reflects to the focal point(fp), which is ½ the radius of curvature (rc).



With a lens, on-axis light from infinity passes through the lens to the focal point. Because of costs, lens systems are not as widely used as mirror systems.



4-4 Solar Concentrators

The are a number of variations on mirror systems. Three types are illustrated here:

(Source: NREL)

Parabolic troughs used for heating a fluid

(SolFocus, Inc.)

Parabolic mirrors to focus light to a PV cell

(Source: NREL)

Parabolic mirrors to focus light to Stirling engine.

In each of these cases, the collector is at the focal point of a concave mirror. These collectors all work best with direct sunlight, so use tracking to keep the sun on the target.

4-4 Solar Concentrators

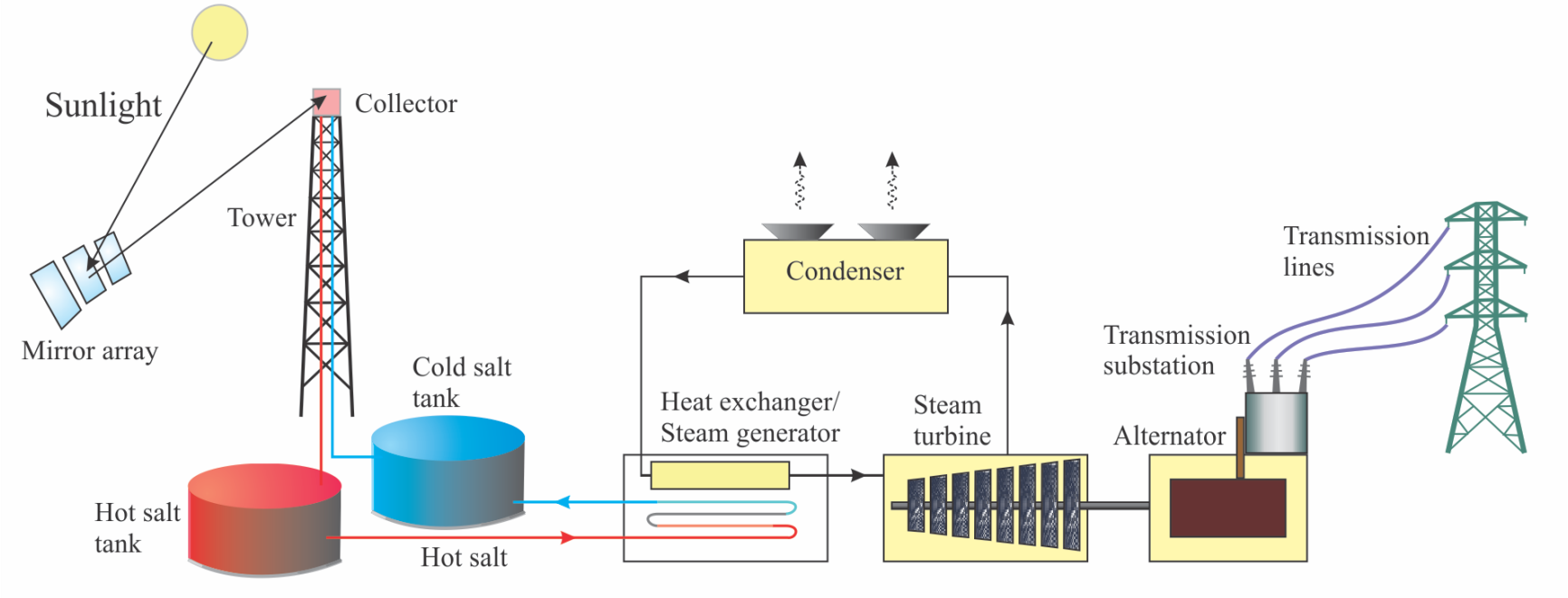
The world's largest solar plant uses a large bank of heliostats to focus the sun on a tower. The plant is the Ivanpah Solar Electric Generating System (ISEGS) in California's Mojave Desert.

ISESGS is a 370 MW solar complex of three towers that receive energy and use the heat to drive turbines. The towers are the same as this one, photographed in Israel.

Source: NREL

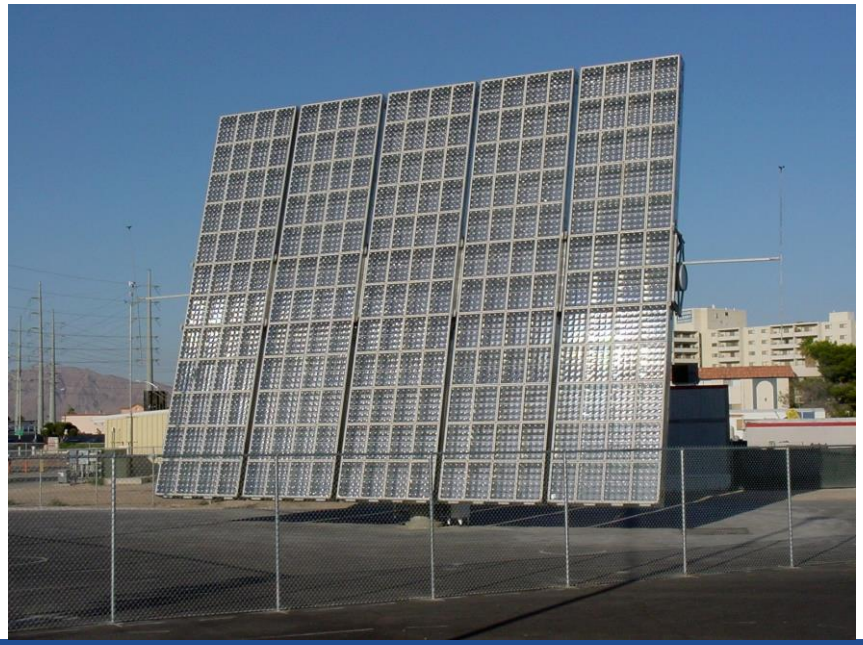
4-4 Solar Concentrators

The basic idea of tower power is summarized in the block diagram:



4-4 Solar Concentrators

An experimental PV system with circular plastic Fresnel lenses has been constructed at the University of Nevada in Las Vegas to focus light onto cells in each small square. This system is rated at 25 kW for a solar flux of 850 W/m^2.



(Source: NREL)

4-5 Solar Hot Water Systems

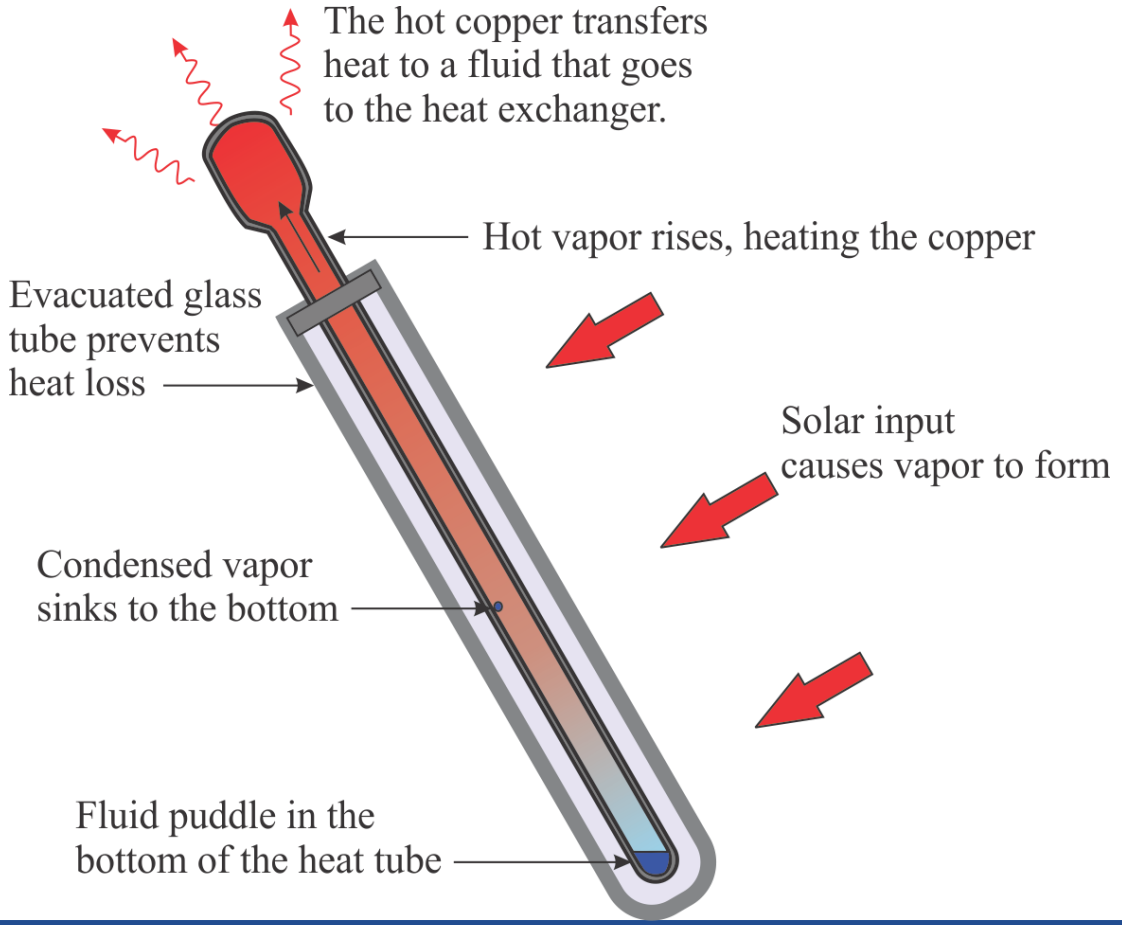
Water heating is a way to significantly reduce energy consumption and is a proven technology that is a good match of a resource to a need.

Flat plate collectors circulate water or fluid in a manifold. Heat from the sun is transferred to the fluid. Normally, pipes are coated with a material that has high absorptance and low emittance.

(Source: David Buchla)

4-5 Solar Hot Water Systems

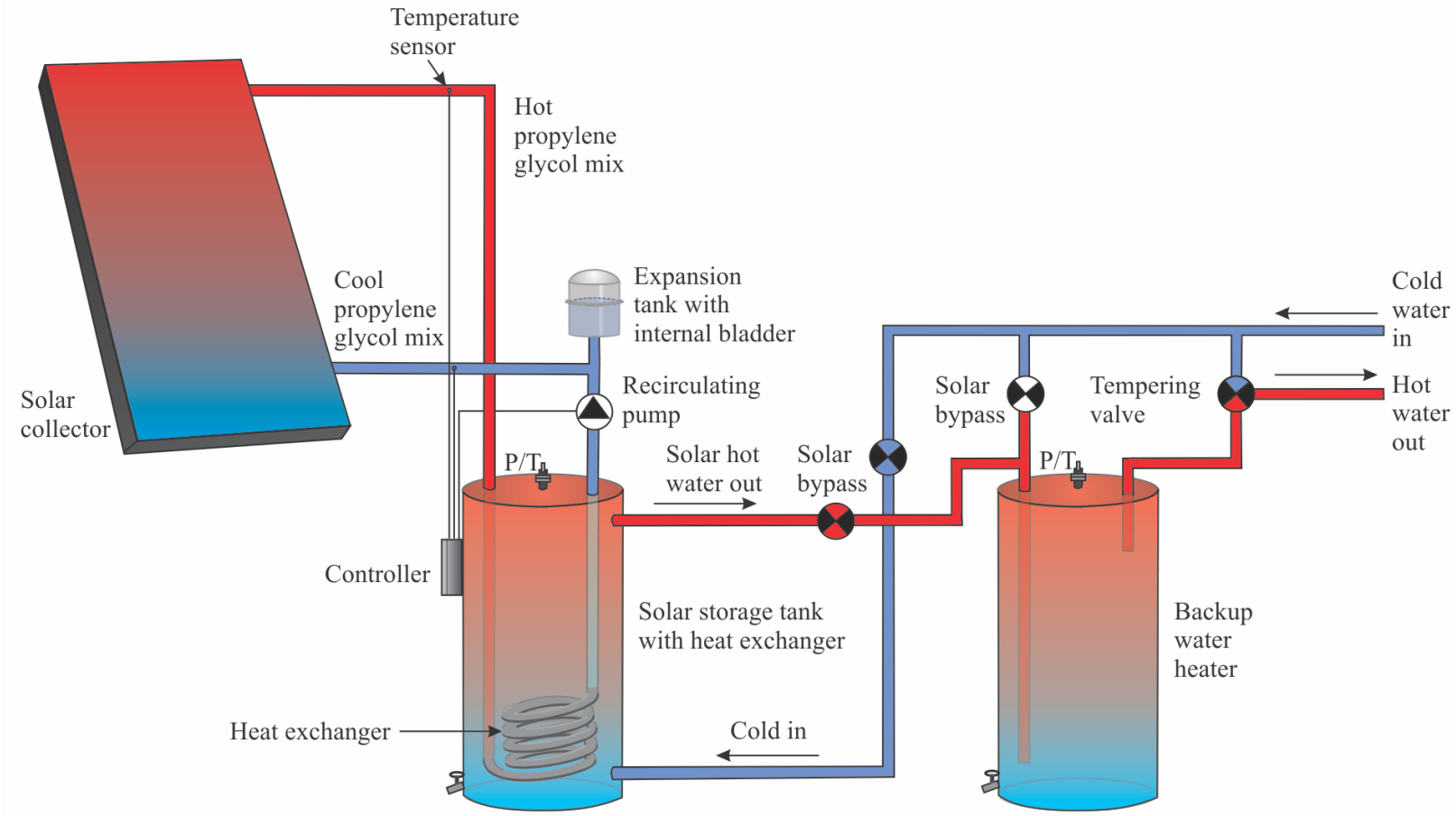
Solar heat pipes function on an evaporation and condensation cycle using a non-toxic fluid in the tube.



(Source: David Buchla)

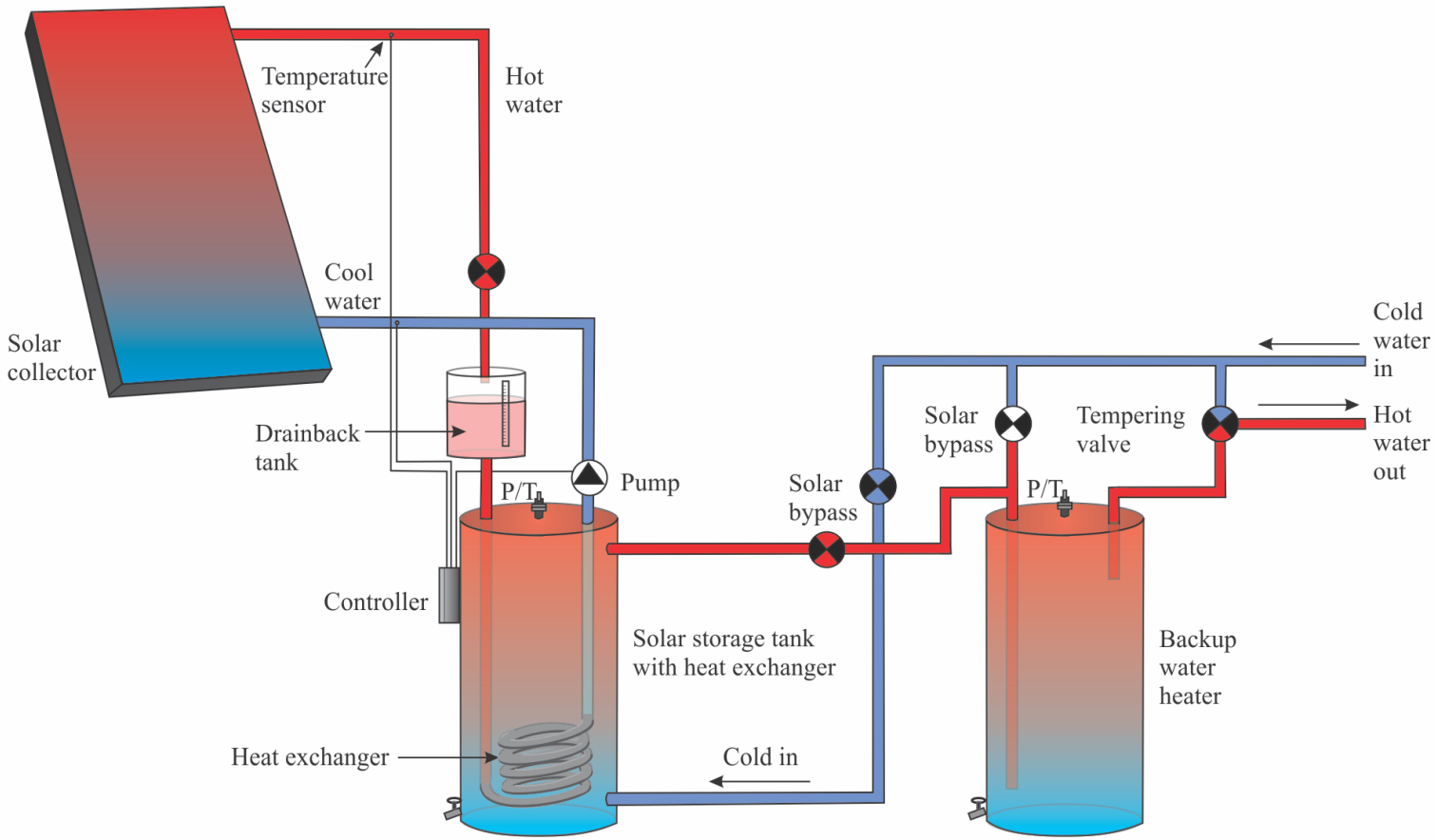
4-5 Solar Hot Water Systems

In areas subject to freezing, a closed-loop pressurized glycol-water system can be used.



4-5 Solar Hot Water Systems

Another option is a drain-back system, in which water is drained from the cold areas when temperatures drop.



Selected Key Terms

Absorptance	A dimensionless number that the ratio of absorbed to incident radiation.
Charge controller	A device that regulates and limits charging current to prevent overcharging batteries.
Combiner box	A double-insulated box that allows several strings from modules to be connected together in parallel; it also houses fuses for the strings and will include surge and overvoltage protection from potential lightning strikes.
Depth of discharge (DOD)	The ratio, expressed as a percentage, of the quantity of charge (usually in ampere-hours) removed from a battery to its rated capacity.

Selected Key Terms

Drainback system	A solar water heating system in which the circulating fluid is only circulated when heat is available at the collector – otherwise the collector and exposed plumbing is drained.
Emittance	The total flux emitted per unit area from a material; it is related to the ability of the material to give off radiant heat.
Ground fault protection device (GFPD)	A device that has the following functions: 1) detect a ground fault, 2) interrupt the current in the line, 3) indicate a fault has occurred with a visible warning, and 4) disconnect the faulty module.
Insolation	The word insolation is from "**in**cident **sol**ar radi**ation**" and is a measure of the energy received on a surface in a specific amount of time; it can be measured in units of W/m^2.

Selected Key Terms

Latent heat of vaporization	The heat absorbed or released during a change of state from a liquid to a gas.
Solar concentrator	A type of solar collector that collects light over a certain area and focuses it onto smaller area.
Stirling engine	A type of heat engine that cools and compresses a gas in one portion of the engine and expands it in a hotter portion to obtain mechanical work.
Transfer switch	A switch that can switch loads between alternate power sources without interrupting the current.

true/false quiz

1. A stand-alone PV system always includes an inverter.

true/false quiz

2. HOMER is a computer program that can show sensitivity of variables.

true/false quiz

3. The NEC includes solar energy standards.

true/false quiz

4. The first step in sizing a stand-alone system is to determine the array size needed.

true/false quiz

5. To extend battery life, it should be cycled frequently.

true/false quiz

6. When a large PV system is added by a utility, distribution requirements need to be considered.

true/false quiz

7. A power utility will normally back-up a large PV system with batteries.

true/false quiz

8. On-axis light from infinity that strikes a curved mirror will reflect to the radius of curvature.

true/false quiz

9. A closed loop pressurized hot water system is drained when there is a possibility of freezing temperatures.

true/false quiz

10. Solar heat pipes use a fluid that changes to a vapor in the tube.

true/false quiz

Answers:

1.F
2.T
3.T
4.F
5.F
6.T
7.F
8.F
9.F
10. T