The use of solar energy has not been opened up because the oil industry does not own the sun.

—Ralph Nader
LEARNING OBJECTIVES

■ Define photovoltaics.
■ Explain stand-alone (off-grid) and on-grid PV systems.
■ Identify the major components of a PV system.
■ Describe the chief concerns regarding the use of photovoltaics.
■ Explain how PV roof installations can make firefighter access and egress more difficult during fire and emergency operations.
■ Explain how solar thermal systems work.
■ Describe the chief concerns regarding the use of solar thermal systems.

INTRODUCTION

Even Larry Hagman, the actor who played J. R. Ewing, the calculating oil executive on the popular long-running show *Dallas*, has been won over by solar energy. In a recent television commercial to promote solar power and SolarWorld, a German photovoltaic (PV) module (panel) maker, Hagman states, “In the past it was always about the oil. The oil was flowing and so was the money. Too dirty. I quit years ago.” He then puts on a 10-gallon hat and walks outside his house. It’s a bright, sunny day and as Hagman looks up at the roof of the house, he gazes upon a PV array. “But I’m still in the energy business,” he says. “There’s always a better alternative.” Hagman ends the advertisement saying, “Shine, baby, shine.”

PV ENERGY

Photovoltaics is the direct conversion of light into electricity at the atomic level. Silicon materials (monocrystalline silicon, polycrystalline silicon, microcrystalline silicon, and amorphous silicon) as well as thin-film (Figure 4-1) semiconductors (cadmium telluride, gallium arsenide, and copper indium diselenide) used in this technology exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. These electrons are then harnessed and an electric current results that can be used as electricity.

In 1905, Albert Einstein described the nature of light and the photoelectric effect on which PV technology is based. He won a Nobel Prize in physics for his work in this area. The first PV module was built by Bell Laboratories in 1954. In the 1960s, the space program began to use photovoltaics to provide power aboard spacecraft. During the energy crisis in the 1970s, PV technology gained recognition as a source of power for non-space program applications. Solar panels were installed on the *Stardust* spacecraft that was launched on February 7, 1999, by the National Aeronautics and Space Administration (NASA). It travelled nearly 3 billion miles and returned to Earth on January 15, 2006, to release a sample material capsule.

Advantages of PV Solar Power

■ Generates free, renewable energy from the sun
■ No direct impact on the environment (nonpolluting/no exhaust)
Quiet (makes no noise)
Long life and durability
No moving parts to break down, thereby requiring minimal maintenance
Modular design allows for expansion as electrical needs increase
On-grid systems allow consumer to sell excess electricity back to the utility
Electrical power during blackouts
Allows the use of electricity in remote areas
Rebates as well as federal, state, and local incentives available

Fire service applications are also being implemented. PV panels are being installed on firehouse and fire department facility roofs throughout the country. They are also being placed on fire apparatus and ambulances to operate turn signals and radios, for example, when the engine is off, thereby conserving fuel. PV panels atop the Lawrence-Douglas County, Kansas, response fleet (Figure 4-2) keep the batteries charged without the use of an alternator.

**PV Cell Operation**

Figure 4-3 depicts the operation of a basic PV cell, which is also called a solar cell. PV cells consist of a specially treated thin semiconductor material that is designed to form an electric field. The cell has a positive contact on one side and negative contact on the other. Both contact sides have electrical conductors attached, forming an electrical circuit. When light energy strikes the solar cell, electrons are freed from the atoms in the semiconductor material and captured in the form of an electric current. This electric current (electricity) can then be used to power a light bulb.

**PV SYSTEMS**

Photovoltaics can be categorized into stand-alone (off-grid) and on-grid systems.

**Stand-Alone**

Stand-alone PV systems (Figure 4-4) operate independent of the utility grid. Most systems are composed of PV arrays, a charge controller, and storage batteries to supply power to direct current (DC) loads (lighting, appliances, and equipment). If the system has to supply power to alternating current (AC) loads, an inverter is required to convert the DC power into AC power. Storage batteries are needed due to the intermittent nature of sunshine. The batteries store some of the electricity generated by the PV panels, so that when sunshine is insufficient or at
night, the system can still supply power to the loads. The storage batteries will also provide emergency power during utility brownouts, blackouts, and outages. The system may also be enhanced by a diesel generator to supply peak demands or during periods of poor light conditions.

An independent PV energy system might be used at remote locations in rural properties as well as for mobile (boats and recreational vehicles) energy applications. These systems can also be used to provide electricity for isolated equipment used in communications and instrumentation, broadcasting, navigation aids, and environmental monitors. Many stand-alone inverters also incorporate charge controllers that regulate the input from the PV array and the batteries, regulate the battery output, and handle charging the batteries. Stand-alone systems generally provide 12 or 24 volts DC. An inverter will convert this voltage to 220 volts AC.

### On-Grid

**On-grid PV systems** utilize grid-tie inverters that are integrated with the public utility grid. These inverters synchronize the solar energy from the PV array that it converts from DC to AC to the primary electrical panel of the building. The power may then be used by loads within the building or it may flow out to the utility grid. Grid-tie inverters can feed energy back into the distribution network because they contain special circuitry to precisely match the voltage and frequency of the public distribution system. For safety reasons, grid-tie inverters should shut off automatically and cease operation during a fault (blackout) situation to eliminate the hazard of back-feeding into a fault and creating a hazardous condition for utility workers coming into contact with electric lines while working to restore power in an emergency.

On cloudy days or at night, the utility provides power to supply the loads for the building. During very sunny days or when the power demand is modest, it is possible for the grid-tie inverter to produce more electricity than what is being used (the bidirectional meter will spin backward). The occupant, depending upon regional area, may be able to sell this excessive energy back to the local public distribution supplier. In this case, the consumer pays only the net bill, which is known as **net metering**. On-grid systems may not include a battery backup. Power is obtained from the

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**FIGURE 4-4** Stand-alone photovoltaic system.

**NOTE**

Specific performance requirements for inverters defined in the Institute of Electrical and Electronics Engineers (IEEE) Standard 1547 require that they do not operate to serve load in an "island" separated from the rest of the grid. In a scenario whereby PV panels continue to power a building during a power outage, the building becomes an "island" with power surrounded by a "sea" of unpowered buildings. Islanding can be dangerous to first responders who may not realize that the building is still powered even though there’s no power from the grid. For this reason, inverters are designed to detect power outages and immediately stop producing power, which is called anti-islanding protection.
distribution supplier when the system is not producing enough electricity. Missoula (Montana) Fire Station No. 4, shown in Figure 4-5, is a PV solar-powered structure. The PV system (a mix of roof and ground arrays) produces approximately 6,500 kwh of electricity each year. The system is on-grid with battery backup.

On-grid equipment can be integrated into a system that replenishes or supplements batteries when power is not available from the distribution supplier, or to help the batteries support the building’s load. Battery backup inverters are special devices that are designed to draw energy from a battery, regulate the battery charge, and export excess energy to the utility grid. These inverters are capable of supplying AC power to selected loads during a utility brownout or blackout. An on-grid system with battery backup (Figure 4-6) has all the same features of the on-grid system mentioned earlier but with the addition of a battery.

Legend
- Sunlight is absorbed by the roof-mounted PV array creating DC electricity.
- Inverter takes the DC output from the PV array and converts it to AC. The AC output is then usable either inside the building or outside on the utility grid.
- AC output is used to power lighting fixtures and appliances on-site.
- Any excess power can be fed from the inverter to a battery backup system (optional, not shown).
- During times when the grid-tie inverter is producing more energy than is being used, AC power flows back out to the utility grid as indicated by the meter spinning backward.
- In net metering, the utility grid acts as a bank.

MAJOR COMPONENTS

Depending upon the type of solar system (stand-alone or on-grid), PV systems consist of photovoltaics (cells, modules, and arrays), combiner box, isolation switches, inverter, solar charge controller, and battery bank.

Photovoltaics

Figure 4-7 depicts the components of the solar panel. PV cells are clustered to build a module. Individual modules are then connected together to form a PV array. The size of the array will depend upon the dimensions of the roof as well as many other factors.
Cell

The PV cell is the device that converts the sun’s light energy into electricity. The cells convert solar energy into DC electricity. They are typically 12%–20% efficient. Some new technologies are striving for 50% efficiency. An individual PV cell typically produces between 1 and 2 watts of electrical energy. The average life of a PV cell is 25 to 30 years. It is the fundamental component of a PV (solar) energy system. To increase the power output, cells are commonly connected to form larger PV modules (panels) and PV arrays.

Module

A PV module, also commonly called a solar panel, is an interconnected assembly of PV cells. The cells are arranged in a grid-like pattern on the surface of the solar panel. Generally, modules are usually rigid, but there are some flexible modules composed of thin-film cells. Most modules have sealed junction boxes to protect the connections. A typical PV module consists of a protective weatherproof enclosure for the semiconductor materials and the electric wiring needed to connect the module with the rest of the system. Modules range in power output from 10 to 300 watts for residential and business power applications. Since the power that one module can produce rarely is enough to meet the requirements of a home or business, the PV module is used as a component in a larger PV system. The modules are, therefore, linked together to form a PV array.

Array

The modules in a PV array are usually first connected in series to obtain the correct voltage for the system; individual leads are then connected in parallel to allow the system to add more current (amperage). PV arrays are typically measured by the peak electrical power they produce, in watts, kilowatts, or megawatts. Most PV arrays use an inverter to convert the DC power produced by the modules into AC that can tie into the existing infrastructure to power lights and other loads.

Roof-Mounting Options

A traditional means of capturing solar energy has been to place PV arrays in fixed aluminum frames atop the roofs, setbacks, and patios of buildings, which are of most concern to firefighters. There are several ways to install a rooftop PV array based on a variety of different technologies. Consideration should be given for access to the system for repairs and maintenance as well as for firefighters during fire and emergency operations.

Stand-Mounted

The stand-mounted equipment (Figure 4-8) is also known as a universal mounting because it can be installed both on rooftops and on the ground. Angled solar panel arrays can easily be arranged on flat roofs to face directly into the sun. This type of PV equipment can also be adjusted as the seasons change. It will allow the array to produce more electricity than a standard unit. Stand-mounts are bulky and constructed with a grid-like system of supports (prefabricated lightweight aluminum or steel racks and legs)
that are affixed directly to roof joists using metal hardware. If necessary, firefighters may be able to remove these fasteners using hand and small power tools. Stand-mount systems may be difficult to install on rooftops due to heavy wind resistance. They are typically used with larger solar panel systems.

NOTE

PV arrays that are ground-mounted should be erected in areas clear of combustible materials and vegetation. Generally, a minimum perimeter of 10 feet should be maintained.

Flush-Mounted

Flush-mounted PV arrays (Figure 4-9) are achieved by placing a metal end bracket on each side of the solar panel and elevating it just several inches from the surface to allow for cooling air circulation. The bracket is then attached to the roof. These arrays are commonly used with small solar arrays on rooftops because the structural design cannot support large solar panels. They do not allow for adjusting the elevation or angle of the solar panel in order to maximize sunlight absorption.

Integrated Design

An integrated PV module allows the array to serve as a structural element (roof, wall, canopy, and skylight). It thereby reduces concentrations of added weight and avoids penetrations required for mountings and wiring. It also reduces the vulnerability of the equipment to high winds. The solar shingle, also called PV shingle, is one such technology. Solar shingles are PV cells designed to look like conventional asphalt shingles. There are a variety of styles that match conventional shingles in both size and flexibility. The development of thin-film PV technology (lighter and more flexible composite module materials) has also led to the increased use of integrated design. The 60,000-square-foot integrated PV canopy array over the Stillwell Avenue Subway Terminal (Coney Island—Stillwell Avenue Station, Brooklyn, New York) produces 250 kilowatts of electrical energy (Figures 4-10 and 4-11).

Combiner Box

Another major component of a PV system is the combiner box. The PV modules all feed into it. Modules are normally connected into an electrical string to produce the desired voltage and amperage. The resulting wires are then routed to the combiner box. The combiner box contains protective fuses and gets its name by allowing for one electrical output to be fed to the inverter. Normally located atop the roof, it consolidates all the energy and sends it to an isolation switch (disconnect box).

The combiner box has fuses or circuit breakers to protect the wiring coming from the solar panels themselves. Opening the combiner box to access the fuses/breakers will isolate all electricity after the combiner. Pulling fuses is not a recommended action to perform when the system is under load. Injury as well as the potential for starting a fire could result. It must also be noted that even with the fuses removed/circuit breaker tripped, the PV array and the electrical line leading to the combiner box will still be live.
Isolation Switches

NOTE

A PV array is unusual in that it cannot be turned off. Terminals will remain live at all times during daylight hours. It is important that all junction boxes and electrical conduit are suitably labeled.

Direct Current

A **DC isolation switch** is used between the PV arrays generating DC current and the inverter. Installation requirements dictate that it is located adjacent to the inverter. This disconnect device will provide a means of manually isolating the PV array. The switch must be rated for system voltage and current. It is important to note, however, that if you isolate the electrical energy at the DC disconnect switch, anything up to that point is still energized (solar panels, the combiner box, and the electrical wiring running from the combiner box into the structure and into the isolation switch [DC disconnect box]).

Alternating Current

The **AC isolation switch** disconnects the inverter from the building wiring and from the utility service. It provides a means of manually isolating the AC electrical supply to the inverter. Two AC isolation switches may be required if the inverter is located on the roof or remote from the primary electrical panel for the building. In this case, one AC disconnect switch will be adjacent to the inverter and one next to the primary electrical panel board. The one adjacent to the primary electrical panel must be readily accessible and capable of being locked in the off position. Switches must be suitably labeled.

NOTE

The inverter needs AC power to operate. Shutting down the building’s main circuit breakers at the primary electrical panel will shut off the inverter. This action also keeps AC from entering the building. Figure 4-12 reveals AC and DC isolation (disconnect) switches on both sides of the inverter. The AC isolation switch disconnects the inverter from the utility while the DC isolation switch separates battery backup power.

Inverter

**Inverters** invert one type of power source to another type, ranging from 100 watts to 4 kilowatts. The inverter must be carefully selected to ensure proper operation with other system components. Small inverters may be mounted right on the back of a PV module while larger ones are often wall mounted in a

FIGURE 4-12 Photovoltaic system showing combiner box as well as AC and DC isolation (disconnect) switches located on both sides of the inverter.
basement or garage. Stand-alone PV systems that need to convert the DC electrical energy produced by PV arrays (stored in the battery bank) to AC in order to supply AC-powered lighting fixtures and appliances require an inverter. On-grid PV systems also utilize an inverter to change PV energy from DC to AC for building use as well as match the electrical energy to the utility grid. Inverters specially designed to complement storage battery equipment contain built-in battery chargers allowing them to feed batteries when power is available from another AC source such as the utility grid or a generator.

**Solar Charge Controller**

Generally, PV systems having battery storage equipment utilize a solar charge controller, which regulates the amount of current the PV modules deliver into the battery bank. Its primary function is to prevent overcharging of the batteries. Charge controllers can also inhibit battery DC current from leaking back into the PV array during the night or on very cloudy days. This would prevent the accidental draining of the battery bank. Solar charge controllers are specified by both amperage and voltage to match the specifications of common PV arrays and battery banks.

**Battery Bank**

Several batteries linked together comprise a battery bank, which collects and stores energy produced by the PV array for nighttime application and for periods when clouds blot out the sun. Battery storage systems may be found in both stand-alone and on-grid PV systems. They come in several voltages, but the most common varieties are 6 and 12 volt. Three common types of batteries are flooded lead-acid (FLA), sealed absorbed glass mat (AGM) lead-acid, and sealed gel cell lead-acid.

- FLA batteries require maintenance that involves monitoring voltage and adding water. They must be stored in a vented enclosure since they vent hydrogen under heavy charging. FLA batteries have the longest track record in solar electric use and are used in the majority of stand-alone AC systems.

- Sealed AGM batteries are more sensitive to overcharging than FLA batteries. They do not, however, require watering nor do they generally vent flammable and corrosive fumes. AGM batteries are ideally suited for use in on-grid solar systems with battery backup. The electrolyte will not stratify, and no equalization charging is required.

- Sealed gel cell lead-acid batteries predate the AGM type. Like AGM batteries, they require little maintenance. They have many of the same advantages over FLA batteries as the AGM type, except the gelled electrolyte in these batteries is extremely thick and recombination of the gases generated while charging occurs at a much slower rate. They typically have to be charged slower than either FLA or AGM batteries. This can be a disadvantage when dealing with PV technology where there is a fixed amount of sunshine hours. Sealed gel cell batteries are commonly used in on-grid PV systems.

**NOTE**

The standard technique for installation of a battery bank uses series/parallel wiring. It allows for the combining of batteries to get the correct voltage and storage capacities (ampere-hours) to match the rest of the components in a PV system. Wiring batteries (or modules) in series will increase the voltage of the batteries that are wired together while keeping the capacity the same as the individual batteries. Series wiring connects the positive terminal of one battery to the negative terminal of the next battery. This technique multiplies the voltage of the individual batteries by the number of batteries interconnected until you reach the desired voltage. Parallel wiring multiplies the capacity of the batteries (or modules) while the voltage remains unchanged. Wiring in parallel connects the positive terminal of one battery to the positive terminal of the next battery.

**CHIEF CONCERNS REGARDING PV SYSTEMS**

Currently, there is a lack of statistical data from the U.S. Fire Administration’s National Fire Incident Reporting System concerning the fire hazard of PV systems as well as firefighter injuries while operating at incidents in buildings having PV systems. As PV systems become more commonplace, more comprehensive information will become available. This does not lessen the obligation of the fire service to evaluate standard operating procedures should these systems be encountered during fire and emergency situations. The following is a list of challenges that chief officers may encounter when confronted with PV systems.

**Electric Shock**

Electrical accidents related to PV systems may result in shocks, burns, muscle contractions, and injuries associated with falls after the shock. These injuries
can occur anytime electric current flows through a firefighter. The amount of current that will flow is determined by the difference in potential (voltage) and the resistance in the current path. The human body acts like a resistor at low frequencies, but the value of resistance varies with conditions. It is difficult to estimate when current will flow or the severity of the injury that might occur because the resistivity of human skin varies. A firefighter is in grave danger if a current greater than 0.02 amperes flows through his/her body. The firefighter may not be able to break free of the current-carrying wire. This small amount of current can be forced through moist hands with a voltage as low as 20 volts. Voltages greater than 400 volts can burn away the protective layer of outer skin at the entry and exit points. When this happens, the body’s resistance is lowered and lethal currents may ensue.

NFPA Codes Relating to Solar PV Systems

Article 690, entitled “Solar Photovoltaic Systems,” of NFPA 70 (2008 National Electrical Code) provides designers and electrical installers with the requirements to provide a safe PV system. A warning label “Warning—Electric Shock Hazard. If a Ground Fault Is Indicated, Normally Grounded Conductors May Be Ungrounded and Energized” is required to be placed upon the on-grid inverter or be applied near the ground fault indicator at a visible location. Ground fault protection for PV systems and components is specified in the National Electrical Code. A PV system having a battery bank also requires this warning label in a visible location at the batteries.

A 2009 draft of the proposed NFPA 70 (2011 edition) stresses identification of PV system conductors by separate color-coding, marking tape, tagging, or other approved means. PV source circuits and the conductors of PV output circuits and inverter input/output circuits shall be identified at all points of termination, connection, and splices. Wiring and enclosures that contain PV power source conductors (exposed raceways and cable trays; covers/enclosures of pull boxes and junction boxes; and conduit bodies in which any of the available conduit openings are unused) shall be permanently marked/labeled with the wording “Photovoltaic Power Source.” PV power circuit labels shall appear on every section of the wiring system that is separated by enclosures, walls, partitions, ceilings, or floors. Spacing between the labels/markings shall not be more than 10 feet.

NFPA 1 (2006 Uniform Fire Code) requires warning signs on rooms and cabinets that contain lead-acid battery storage. The International Code Council is incorporating NFPA 70 requirements pertaining to the installation and identification of PV systems into its own building and fire codes. Roof access, pathways, and spacing requirements to facilitate firefighting ventilation operations are also being addressed.

The following information can be helpful to the fire service in avoiding the perils of electric shock:

- Preplanning is extremely important. Chief officers must identify buildings with PV systems and familiarize all personnel under their command with the location and utilization of all key components.
- PV installers often leave 24/7 contact number information on-site so first responders can utilize their expertise to safely disconnect the system in an emergency.
- PV panels produce DC power. If sunlight strikes them, they will produce electricity. Unless there is a disconnect switch on the PV array itself, the wires running from the panels to the power distribution system should always be considered live.
- Even though the electrical power from the utility grid can be isolated at the main distribution panel, electrical energy is still present as long as the PV array is connected.
- All PV modules are not alike. Different modules will produce different levels of voltage.
- Utilizing isolation switches/disconnects ahead of or after the inverter still does not eliminate the electric current coming from the PV array.
- The amount of sunlight that PV arrays are exposed to directly influences their power output. Time of year, time of day, and climatic conditions all affect the amount electrical energy being produced. Lightning can create power surges in PV systems during both daytime and nighttime hours.
- Beware of redundant power (battery, generator, wind turbine) equipment installed to “kick-in” when the PV arrays are shut down and are not producing electrical energy.
- Do not attempt to breach PV arrays with hand or power tools. A firefighter cutting into a PV array can be electrocuted.
- Top floor and attic fire and overhaul operations must be supervised and controlled to avoid breaching through roofing material and penetrating PV modules.
- Opaque tarps can be used to cover PV arrays in order to reduce sunlight during the daytime to facilitate safe overhaul operations, but there is no
guarantee that the tarps will completely eliminate all electrical power.

- Hot sticks carried by many ladder and rescue companies are not designed to detect live DC voltage.
- Auxiliary lighting equipment and apparatus head-lights are not powerful enough to generate dangerous voltage from a PV array.
- Battery banks store solar-generated electricity. Do not cut into these batteries.
- Remember that firefighting and emergency operations at roof level can accidentally cause damage to PV equipment and wiring under the best of conditions. This situation can create hidden electrical shock hazards to unsuspecting members.

Roof Collapse

Roofs containing PV systems will limit the area available to firefighters for vertical ventilation. This can lead to several situations such as delayed vertical ventilation; no vertical ventilation being performed; an inadequate vertical ventilation hole being cut; or a primary ventilation hole being placed in other than an ideal location. Any one of these options could intensify the fire inside the structure as well as inhibit aggressive interior hoseline attack. PV arrays can lead to several situations such as delayed vertical ventilation; no vertical ventilation being performed; an inadequate vertical ventilation hole being cut; or a primary ventilation hole being placed in other than an ideal location. Any one of these options could intensify the fire inside the structure as well as inhibit aggressive interior hoseline attack. PV arrays can lead to several situations such as delayed vertical ventilation; no vertical ventilation being performed; an inadequate vertical ventilation hole being cut; or a primary ventilation hole being placed in other than an ideal location. Any one of these options could intensify the fire inside the structure as well as inhibit aggressive interior hoseline attack. PV arrays may also limit firefighters’ ability to evaluate the roof. This important analysis information of roof structural stability is a critical element in a chief officer’s decision-making process regarding safety of members operating on the roof. Hot spots, bubbling/deformation of roofing materials, and dry areas on a wet roof are just a few of the indicators of fire impinging upon roof-supporting members that might be missed during the roof size-up process. The potential for roof collapse is increased when heavy fire conditions reach the top floor of a building and/or impinge upon load-bearing walls. Heavy fire conditions tend to make Incident Commanders change strategy from an interior attack to an exterior attack. The interrelation of these conditions can and will cause roof collapse events.

The additional weight (load) imposed on a roof, even if designed to carry the load, will affect the roof’s performance under fire conditions and play a role in roof collapse. Depending upon the mounting option selected, size of array, and type of materials used, PV systems can add thousands of pounds to the roof surface. Spread across a wide area, this can be more than 10 pounds per square foot. Additionally, flush-mounted arrays may be subjected to both uplift and downforce wind loadings. PV systems installed on existing roofs may be performed along with reroofing. Covering over up to two layers of old shingles is a common practice. It is assumed that the safety factor for the roof structure allows for the extra load of the existent roof, but can it also be taken for granted that the roof can support the new PV array as well?

Fire

Over the years, electrical code officials and standard developers have worked hard to keep abreast of ever-growing renewable energy technology. Addressing safety concerns has always been their number one priority. Manufacturers have also improved their PV products for the greater good. Fires can and do occur, however, owing to the high DC voltage being generated by the arrays. The disconnection in a current-carrying wire can cause an arc. Human error, natural environmental forces, and rodents are a few other reasons leading to arc generation. An arc is the continuation of current flow through the air. The temperature of an electrical arc can exceed 10,000°F, or roughly the same temperature as the sun’s outer visible layer. PV components, roofing materials, construction supplies, windblown leaves, and paper are all candidates to ignite from this high-powered ignition source.

The application of water by firefighters at a fire on a roof having a PV installation is not an inherently dangerous action. Wide-angle fog streams (in short bursts) are safe to use on PV arrays (no shock hazard) and will not dislodge modules from their attachments. Residual water pooling in areas where electrical components and wiring are exposed, however, can be dangerous. Incipient fires should be extinguished using Class C extinguishing agents (carbon dioxide or dry chemical). Chief officers should utilize the minimum number of firefighters required to extinguish the fire and ensure that all members are wearing the appropriate personal protective equipment (PPE) throughout the fire operation.

Battery Storage

Overcharged conventional batteries will off-gas both oxygen and hydrogen. This is a dangerous combination in the presence of a spark or open flame. A fire located in or spreading into a battery storage area will cause batteries to generate an abundance of explosive, flammable, and corrosive gases. Spilled electrolyte (sulfuric acid) will release toxic fumes during evaporation. Sulfuric acid is not inherently flammable, but it can cause and support a fire by reacting with other chemicals and liberating enough
heat to ignite ordinary combustibles. The release of oxygen by sulfuric acid can also feed a fire. Sulfuric acid will dissolve many metals, releasing flammable hydrogen. Heat generated during this chemical reaction can ignite the hydrogen, creating an explosive environment.

Chemical burns can occur if sulfuric acid contacts an unprotected part of a firefighter’s body. The eyes are particularly vulnerable. When sulfuric acid comes in contact with the skin, it withdraws water, leaving a black charred carbon residue in the place of living tissue. If sulfuric acid comes in contact with large areas of the body, death can occur. If acid fumes are inhaled, serious lung damage may result. Firefighters must use self-contained breathing apparatus (SCBA) and full PPE.

Dry chemical is the extinguishing agent of choice for use on incipient fires. Water should not be used due to shock hazard and the water reactive nature of sulfuric acid. Batteries in storage areas should be positioned at least 2 feet off the floor. Protect battery storage areas from flooding during fire operations. Be aware that batteries for ground-mounted arrays may be located in makeshift containers that can be found anywhere on the surrounding property. Figure 4-13 reveals a 45-gallon plastic cooler being utilized for battery storage with jerry-rigged electrical components attached. The PV system services a community garden.

**Inhalation and Absorption**

PV systems, with their combination of plastics, semiconductors, metals, fiberglass, and chemicals that degrade during a fire, are a legitimate health concern. The products of combustion of these various materials are emitted into the atmosphere. Firefighters standing in the direction of smoke travel and not protected by SCBA and PPE will inhale and absorb through exposed skin many toxins. They may experience one or more of the following symptoms: dry mouth, sleepiness, nausea, coughing, sweating, chills, shortness of breath, weakness, and chest pain. Subsequent medical conditions can include pulmonary edema, kidney dysfunction, and cancer.

**Falls, Slips, Sprains, and Strains**

Firefighting on roofs containing PV equipment, especially during nighttime, can result in fall, slip, sprain, and strain injuries. Stepping onto flush-mounted and integrated PV arrays is both a fall and a slipping hazard.

**Cuts**

PV systems may contain metal framing and stands, brackets, anchor bolts, nuts, guy wires, junction boxes, and so on. Many of these exposed components have sharp edges that can injure firefighters.

**Insects, Snakes, and Vermin**

Spiders, bees, wasps, fire ants, poisonous snakes, and rats have all been guilty of making various components of PV systems their home. Common locations are inside array framing, junction boxes, and battery storage containers. Snakes like to use the shade provided by the array on a sunny day.

**Roof Access and Egress**

PV roof installations can make it more difficult for firefighters to access and egress the roof of a structure during fire and emergency operations. California (the nation’s leader in rooftop PV installations), as well as other states throughout the country, has developed roof access and egress guidelines pertaining to PV systems through the joint effort of the fire service in conjunction with code officials and state fire marshal office. Figures 4-14 through 4-21 are typical of minimum California fire department requirements for its personnel to safely and effectively access and egress building (both residential and commercial) roofs having PV arrays and equipment.8
Private Dwellings

Private dwellings are defined as one- and two-family homes.

Building with a Single Ridge Modules are located to provide two 3-foot-wide access pathways from the eave to the ridge on each slope where panels are located. The access pathway clear width shall not include any eaves overhang.

Building with Cross Gable Roof Modules are located in a manner to provide one 3-foot-wide clear access pathway from the eave to the ridge on each roof slope where modules are located.

Building with Cross Gable and Valley Modules are located no closer than 1.5 feet to a valley if modules are placed on both sides of the valley. If the modules are located on only one side of a valley that is of equal length, then the modules may be placed directly adjacent to the valley.

Building with Full Hip Roof Modules are located in a manner to provide one 3-foot-wide clear access pathway from the eave to the ridge on each roof slope where modules are located. Modules are located no closer than 1.5 feet to a hip if placed on both sides of the hip. If the modules are located on only one side of a hip, then the modules may be placed directly adjacent to the hip.
The access pathway shall be located at a structurally strong location on the building, such as a bearing wall.

**Dead Ends**

Concerning dead ends, for residential building roofs where there are two or more access pathways, it is required that clear pathways are arranged so there are no dead ends greater than 25 feet in length.9

If any access pathway leading to a dead end is greater than 25 feet in distance, it should continue on to the next access pathway. At no time shall any access pathway cause a firefighter’s travel distance to exceed 150 feet before arriving at another required access pathway.10

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**NOTE**

Roof-mount array layouts are required to provide a minimum 3-foot clearance from the ridgeline to array edge. This will allow firefighters to cut a ventilation hole over the fire at the roof high point parallel to the ridge. An uninterrupted section of PV array shall not exceed 150 ft. × 150 ft. in dimension in either axis.

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**Commercial Buildings and Multiple-Dwelling Residences (Three or More Families)**

A minimum of 6-foot perimeter is required around the edges of a large dimensional (either axis is
greater than 250 feet) building roof. If either axis of the building is 250 feet or less, there shall be a minimum of 4-foot wide clear perimeter around the edges of the roof. The pathways shall be located over structurally supported members. Centerline axes pathways shall be provided in both axes of the roof. A minimum of 4-foot clear straight-line pathway shall be installed from the access path to skylights and/or ventilation hatches, and it is required from the access path to roof standpipes. Not less than 4-foot clear around roof access hatches with a minimum of one pathway that is straight and not less than 4-foot clear to the parapet or roof edge is yet another requirement.

**FIGURE 4-18** Required access pathway not exceeding 25 feet.

**FIGURE 4-19** Required access pathway exceeding 25 feet.

Array sections shall be no greater than 150 ft. × 150 ft. in dimension in either axes (some jurisdictions may be considerably stricter regarding the maximum size of arrays). Ventilation options between array sections shall be one of the following:

1. An access pathway shall be 8 feet or greater in width. (Figure 4-20 illustrates the positioning of 8-foot pathways over structurally supported members in both axes of the roof on a large dimensional commercial building.) Additionally, it denotes a 6-foot clear perimeter around the edges of the roof. Access pathways 4-foot wide can also be
seen leading to skylights and ventilation hatches. Dimensions of PV array sections are restricted to no greater than 150 ft. × 150 ft. in dimension.

2. An access pathway shall be 4 feet or greater in width and bordering on the existing roof skylights or ventilation hatches.

3. An access pathway shall be 4 feet or greater in width with bordering 8 ft. × 4 ft. venting cutouts every 20 feet on alternating sides of the pathway. (Figure 4-21 illustrates the positioning of 4-foot pathways over structurally supported members in both axes of the roof on a small dimensional commercial building.) Additionally, it denotes a 4-foot clear perimeter around the edges of the roof. Venting cutouts can also be seen located every 20 feet on alternating sides of the pathways.

**FIGURE 4-20** Large commercial solar array.

**FIGURE 4-21** Small commercial solar array.
Fire-Resistance Classifications

ANSI/UL 790, “Tests for Fire Resistance of Roof Covering Materials,” and ASTM E 108, “Standard Test Methods for Fire Tests of Roof Coverings,” are the two nationally recognized fire-resistance tests used to determine a product’s or roof assembly’s classification. The test methods for the two standards are virtually identical; therefore, products and roof assemblies successfully tested in accordance with either standard result in Class A, B, or C ratings. A product or roof assembly is assigned a classification based on the fire-resistance tests it successfully completes. Building codes cite these rating classifications to establish minimum fire-resistance requirements. The standards are used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled laboratory conditions. They do not incorporate all factors required for fire hazard or fire risk assessment under actual fire conditions. Class A, B, or C ratings have no direct bearing on hourly fire ratings. Hourly fire ratings are for a roof/ceiling assembly’s integrity when a fire occurs inside a building.

Fire-resistance classifications A, B, and C are intended to represent different levels of fire-resistance performance. They are described by ANSI/UL 790 and ASTM E 108 as follows:

- **Class A** roof coverings are not readily flammable, are effective against severe fire exposures, and do not carry or spread fire. Class A tests are applicable to roof coverings that afford a high degree of fire protection to the roof deck, do not slip from position, and do not present a flying-brand hazard.

- **Class B** roof coverings are not readily flammable, are effective against moderate fire exposures, and do not readily carry or communicate fire. Class B tests are applicable to roof coverings that afford a moderate degree of fire protection to the roof deck, do not slip from position, and do not present a flying-brand hazard.

- **Class C** roof coverings are not readily flammable, are effective against light fire exposures, and do not readily carry or communicate fire. Class C tests are applicable to roof coverings that afford a light degree of fire protection to the roof deck, do not slip from position, and do not present a flying-brand hazard.

Fire-resistance classifications measure a roof assembly’s resistances to external fire exposures. It is applicable to roof coverings installed on either combustible or noncombustible decks in the assembly intended for use. Both ANSI/UL 790 and ASTM E 108 include an intermittent-flame exposure test, spread-of-flame test, burning-brand test, flying-brand test, and rain test.

The test or combination of tests required to determine classification, however, varies for each product or roof assembly. Noncombustible decks, for example, require only the spread-of-flame test while a product or roof system that can be used on a combustible deck must be subjected to not only the spread-of-flame test but the intermittent-flame and burning-brand tests as well.

Generally, fire-resistance classifications are required for all products or roof assemblies used on industrial, commercial, and residential buildings. Most rooftop PV systems qualify for a Class C fire rating, while most of the roof coverings over which these systems are installed are fire-rated Class A or B. Fire officials should confirm with local code officials that the required fire classification is installed regarding rooftop-mounted and integrated PV systems. The addition of gypsum board, for example, into the array assembly may be needed to obtain the appropriate fire rating.

**SOLAR THERMAL SYSTEMS**

Figure 4-22 reveals a stand-mounted, evacuated-tube solar thermal array atop a roof of a high-rise,
residential building. The history of solar heating dates back at least to Archimedes, one of the leading scientists in classical antiquity. During the Siege of Syracuse (214–212 BC), at the height of the Second Punic War, he used concave, bronze mirrors to focus sunlight on Roman ships and set them on fire.\(^{13}\)

How Solar Thermal Systems Work

**Figure 4-23** shows a solar thermal hot water storage system operation depicting the cyclic process of collection, conveyance, heat exchange, and recirculation. It can also indirectly generate electricity. The steam it makes from the heated fluid can power generators that produce electricity.

**Legend**

1. The sun heats water flowing inside a collector placed on roof.
2. The water leaving the collector is hotter than the water entering it and carries its heat toward the water tank.
3. Water enters heat exchanger and gives up its heat on the way through it. This action increases the water temperature inside the water tank.
4. Hot water from the tank can be utilized by the building occupants at any time. Since the collector doesn’t generate heat at all times during the day, another heat source (boiler) is generally required.
5. The cold water from the heat exchanger returns to the collector to absorb more heat.
6. An electric pump keeps water flowing through the circuit between the collector and the water tank.

**PV Systems Compared to Solar Thermal Systems**

PV systems should not be mistaken for solar thermal systems, which also use roof-mounted arrays (called collectors) fitted to a roof in much the same way as photovoltaics. The collectors look different than PV modules; they are generally smaller in size; and there are normally less of them in an array than you would find for a PV system. Also, solar thermal systems have piping (as shown in **Figure 4-24**), valves (pressure relief, drain, freeze prevention), and gauges (temperature, pressure) that will not be found on PV systems. These components may be clearly visible on the roof or at other areas inside and around the building.

Solar thermal systems may also include a rooftop water storage tank weighing well over a thousand pounds depending on the number of collectors. This would be a significant additional load on the roof support system. This information must be conveyed to the Incident Commander at all fire incidents and emergencies. An important question to ask when discovered during routine building inspection or...
familiarization drill is. Has this weight been addressed by the installer by incorporating added structural support?

A solar thermal system cycle provides both hot water and space heating to a group of buildings. Collector tubes heat water using the sun’s radiation. Heated water then flows to a central storage water tank where heat is absorbed from the water via a heat exchanger. Hot water is pumped into buildings to provide space heating and hot water. Cold water at the bottom of the central storage water tank is pumped up to the collector for reheating to begin a new cycle.

Solar Collectors

Similar to PV systems, solar collectors are most efficient, in the northern hemisphere, when installed on south-facing roofs that have an unblocked view of the sun. These collectors use the sun’s rays to generate heat. For identification purposes, there are two major types of solar water-heating collectors: flat-plate and evacuated-tube.

Flat-Plate

Flat-plates are the simplest and most common thermal collectors. A flat-plate contains copper tubes running parallel through a metal or plastic enclosure covered with thick tempered glass. The glass captures sunshine for absorption by a metal or non-metallic absorber plate that converts the sunlight to heat and transfers it to the water running through the tubes in or adjacent to it. The heated water then flows to a water tank. A boiler may be used as a backup to heat the water further to reach the desired temperature. Flat-plate collectors can be roof mounted in all the same ways that PV modules can. The flat-plate collector principle is shown in Figure 4-25.

![Flat-plate collector principle.](image)

NOTE

Solar swimming pool heating also uses flat-plate collector technology, but the collectors are typically unglazed.

Evacuated-Tube

Evacuated-tube thermal collectors are a little more complex than the flat-plate. They are more efficient and therefore require a smaller collector area than the flat-plate type. High temperatures (up to 350°F) can be obtained, making them more appropriate for commercial and industrial heating as well as cooling applications. The collector enclosure contains parallel rows of transparent, closed glass tubes similar to large diameter fluorescent strip light bulbs. Each tube contains a metal absorber sheet with a heat pipe in the middle of the sheet. The heat pipe contains a temperature-sensitive fluid (methanol). Sunlight heats up and vaporizes the fluid, which then flows into the condenser and heat exchanger located at the end of the pipe. At this end, the vapor
condenses and transfers heat to a collecting manifold situated at the top or end of the collector through which water with antifreeze flows, carrying the fluid to the hot water storage tank. Meanwhile, condensed fluid flows back to the bottom of the heat pipe to be reheated by the sun.\textsuperscript{15} To perform properly (vapor to rise and condensed fluid to flow back), evacuated-tube collectors must have a minimum angle of inclination and, therefore, cannot be directly integrated into a roof. The evacuated-tube collector principle is shown in Figure 4-26.

Chief Concerns Regarding Solar Thermal Systems

It is important for chief officers to be aware of all types of solar panel installations on and around the buildings that they respond to for fires and emergencies. Solar thermal systems do not pose the electric shock or fire hazards that PV systems do, but they still can affect firefighter fire and emergency operations. Potential flame spread involving combustible materials making up the solar thermal equipment must always be considered. The weight of the collectors on the roof must be evaluated, especially for large systems found on multiple-dwelling residences and commercial/industrial buildings. A water storage tank on the roof is yet another factor to be considered by Incident Commanders during top floor fires. A roof failure would be catastrophic to both the entire structure and members in and around the building.

Leaky systems over the years can slowly damage roofing materials as well as roof support systems. Wet roofs during subfreezing weather are dangerous slip hazards. The water/antifreeze solution involving these systems may be hot (approximately 180°F), so it is important that all PPE is properly worn and utilized. Shutting off the water and electrical power (water pump) to the structure will eliminate built-up pressures in the water-heating system.

Collectors should not be stepped on and piping components should be identified to avoid cut and trauma injuries during firefighting maneuvers on the roof. The inhalation hazard must be addressed during fire situations on the roof with the use of SCBA. Insects, vermin, and reptiles, similar to what you can expect to find in and around PV roof systems, are another hidden danger for firefighters.

During nighttime operations, the Incident Commander must provide adequate roof illumination to enhance safety. Solar thermal collectors, like PV modules, should not be breached to provide vertical roof ventilation. In most cases, the limited roof area that solar thermal collectors occupy should allow firefighters enough roof space to successfully perform vertical ventilation operations. As with PV systems, preplanning ventilation strategy and participation in code enactment/enforcement are important steps to be taken by fire officials. Both types of technology should be installed only in areas of the roof that will not hinder firefighting operations. Interference with roof access and vertical ventilation are two primary fire service concerns regarding this issue.
CASE STUDY: CITY OF BAKERSFIELD TARGET STORE
TWO-ALARM FIRE

On a sunny afternoon in April 2009, a Bakersfield, California, Target store with a large rooftop PV array experienced a roof fire, which engulfed PV array as well as the roof surface below. A second smaller independent fire on the same roof was also encountered approximately 200 feet away. This two-alarm fire required the joint response of Kern County and Bakersfield fire departments to extinguish. Firefighters were unable to isolate the PV electrical current during extinguishment operations. The postfire investigation determined that the fires were caused by electrical arcing within the PV wiring system itself. Providing DC disconnects at combiner boxes located on the roof for firefighter use was among the recommendations listed in a memorandum from Pete Jackson (electrical specialist, City of Bakersfield Development Services/Building Department) to the building director.16

CASE STUDY: CHINATOWN
SEVEN-ALARM FIRE

The fire building and the B-side exposure (two New York City old-law tenements) had solar thermal arrays spanning their shared, enclosed, interior air and light shafts. The multiple-alarm fire spread via voids from its origin in a ground floor commercial occupancy through and above the roof. Many of the potential hazards mentioned earlier in this chapter confronted the Incident Commander. Figure 4-27 visually demonstrates the magnitude of this fire.

Firefighters bravely battled the blaze throughout the two buildings as well as on the roofs. Hoselines were stretched and operated from the roof of the fire building and neighboring buildings to help control fire spread across the interior, enclosed shafts.

Operating on a roof with solar arrays especially at night under heavy fire and smoke conditions will be difficult at best. Both engine and ladder firefighters worked on the roof throughout this fire. Heavy smoke conditions at roof level mandated the use of SCBA. Firefighters had to use extreme caution maneuvering tools and equipment on the roof.

Fire rising up through the shafts between the fire building and exposure endangered the structural stability of the thermal solar arrays. Chief officers had to ensure that firefighters were not positioned inside the potential collapse zone. An impact load imposed on the roof as a result of the failure of this stand-mounted solar thermal array could have caused a local or general roof collapse.

FIGURE 4-27 Fire above the solar thermal arrays at the Chinatown (NYC) seven-alarm fire.
SUMMARY

PV and thermal arrays pose great concerns for the fire service. Administrators must ensure that their fire departments participate in code and standard enactments pertaining to this growing green technology. Chief officers should preplan strategy and tactics to facilitate the work needed to be performed when confronted with these systems during fire and emergency conditions. Firefighters must be educated and trained in the workings and hazards of this equipment too. This will help ensure safe and successful operations.

REVIEW QUESTIONS

1. When did PV technology gain recognition as a source of power for nonspace program applications?
2. List five advantages of PV solar power.
3. What is meant by a stand-alone PV system?
4. How do grid-tie inverters used with on-grid connected PV systems work?
5. What is meant by net metering?
6. What are the major components of a PV system?
7. What are the advantages to integrating PV modules into the building envelope?
8. Generally, fire-resistance classifications are required for all products or roof assemblies used on industrial, commercial, and residential buildings. Most rooftop PV systems qualify for what type of fire rating?
9. Why is it not recommended to pull the fuses in the combiner box to isolate all electricity after it?
10. The standard technique for installation of a battery bank uses series/parallel wiring. Explain the difference between series wiring and parallel wiring.
11. Electrical accidents related to a PV system may result in shock. These injuries can occur anytime electric current flows through a firefighter. Generally, what effect would 1 milliampere (1/1000 of an ampere) have when flowing through the human body?
12. Analysis information of roof structural stability is a critical element in a chief officer’s decision-making process at a fire. Name the three indicators, noted in the text, of roof-supporting members weakening that may be missed by firefighters on a roof with PV arrays.
13. Name three hazards to firefighters pertaining to storage batteries utilizing sulfuric acid electrolyte.
14. The history of solar heating dates back at least to Archimedes, one of the leading scientists in classical antiquity. How did he use this technology?
15. Visually, how do rooftop solar thermal systems differ from PV systems?
16. What are the two major types of solar water-heating collectors and how do they differ?

REFERENCES


10. Ibid.


12. Ibid.


