United States
Environmental Protection
Agency

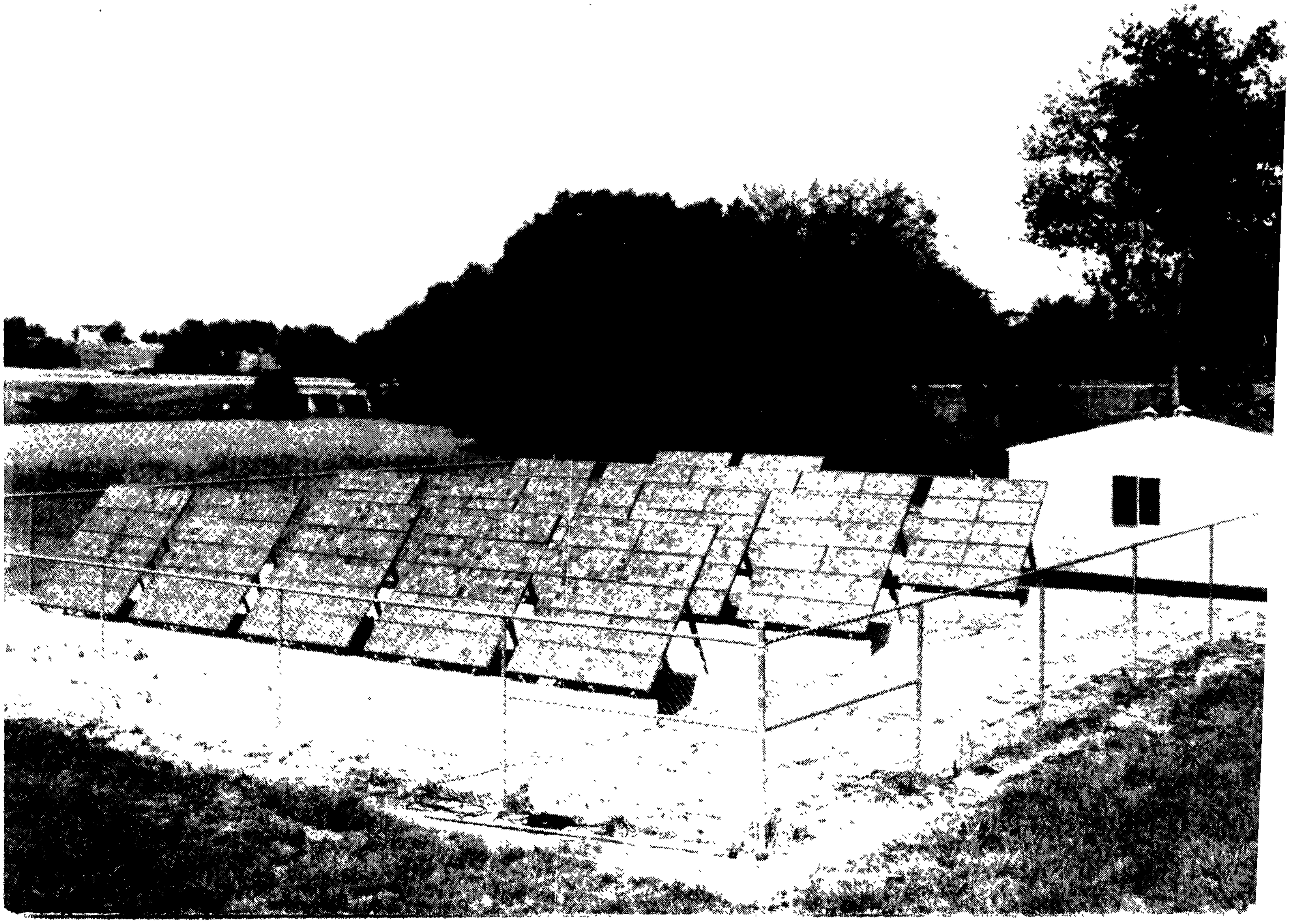
Office of Research and
Development
Washington, DC 20460

EPA/625/5-87/021

Research and Development

EPA

Solar-Powered Environmental Monitoring



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Solar-Powered Environmental Monitoring

November 1986

This report was prepared jointly by:

Office of Environmental Engineering and Technology
Office of Research and Development
U.S. Environmental Protection Agency
Washington, D.C. 20460

and

Office of Renewable Energy
Office of Conservation and Renewable Energy
Department of Energy
Washington, D.C. 20585

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1. Overview

In 1978 the Department of Energy created the Federal Photovoltaic Utilization Program (FPUP) to commercialize the use of PV systems within the Federal and private sectors. The program also sought to improve Federal agencies' technical knowledge, stimulate their use of PV power, and increase their application of life cycle cost analysis for energy investments. The U.S. Environmental Protection Agency (EPA) received funding under the program to design and demonstrate PV systems to power envionmental monitoring equipment.

EPA completed the assembly, deployment, and evaluation of 39 PV systems in 1985. This document summarizes what EPA learned in the FPUP program. It includes a history of EPA's experience, an analysis of how best to use PV for environmental applications, and technical descriptions of EPA's FPUP systems to help in the design of future systems.

The systems described in this document were built between 1980 and 1982. They are working, but some of the equipment is no longer commercially available because manufacturers have introduced improved models. In fact, PV power has become even more competitively priced and several PV manufacturers have begun offering improved 10-year warranties on their cells. Anyone building a system should therefore look at the newest technology, rather than building exact copies of the equipment described here.

Since researchers produced the first PV cell at Bell Laboratories in 1954, the cells have steadily increased in efficiency and decreased in price. First used to power orbiting satellites, PV cells have found their way into applications ranging from tiny cells that run watches to multi-megawatt arrays that provide power to electric utilities.

PV cells convert sunlight directly into electricity. They are silent, emission-free, long-lived, and virtually maintenance-free, qualities which make them an ideal power source for certain environmental monitoring activities.

The economics of PV cells also make them attractive under many conditions. The first PV cells used on a satellite in 1958 cost about $600 per Wp. They are now available for $6 to $10 per Wp. As prices fell during the 1970s PV cells became a common source of power for railroad switches, navigation buoys, electric fences, desalination devices, microwave repeaters and other communications equipment, cathodic rust protection for bridges, and scientific research stations. Individuals began using PV power on sailboats and remote vacation homes. In developing countries PV systems began replacing diesel engines for pumping water. The 1980s saw the introduction of tiny PV cells to power calculators, watches, radios and small battery chargers, and the construction of giant centralized PV systems capable of providing power to hundreds of homes.

PV power is still too expensive to compete with conventional coal or nuclear plants for centralized electricity generation, or to be used for homes that are already connected to the utility grid. But it is practical and economical for many specialized applications, particularly those with small power needs in remote locations away from the power lines. PV power is then competitive with batteries and diesel generators. For these special uses, PV power can offer advantages in reliability, cost, and convenience. It may also make feasible projects, that could not have been done in the past, such as certain remote monitoring projects.

This document is designed for several audiences: environmental managers and decision makers who might consider PV systems for environmental monitoring, technical professionals who manage or design PV systems, and the scientific public who may have future uses for PV technology. Section 2 gives basic terminology and principles necessary for an understanding of PV systems. Section 3 describes EPA's experience with PV-powered environmental monitoring. Section 4 analyzes the EPA experience and should help managers decide if solar-powered monitoring meets their needs. Section 5 contains detailed technical descriptions of the systems used by EPA and will be of interest primarily to technical professionals. Appendix A discusses several types of PV cells. Appendix B has information about PV equipment that can be borrowed from EPA, as well as a list of contacts for further information.

2. Terminology and Principles of Operation

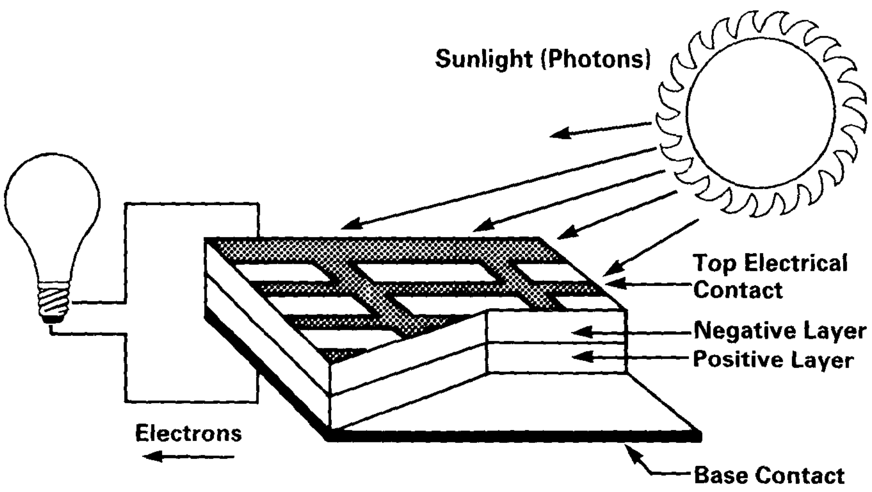
The photovoltaic (PV) *cell* is the basic unit of a photovoltaic system. The typical cell measures about 4 in wide and can be round or square. Each cell is capable of generating about 1.25 watts of electricity. Cells are mounted on a panel, wired together, and covered with glass to produce a *module*. A typical module contains 32 cells, produces 40 watts of electricity, and measures 1 ft by 4 ft.

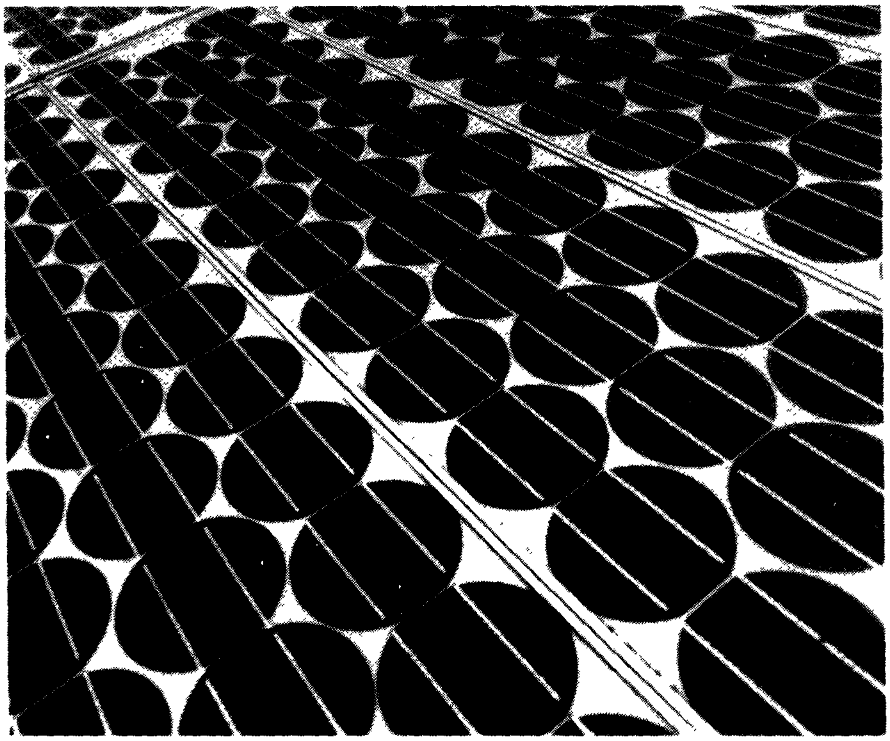
Modules must be mounted on a supporting structure that faces them toward the sun at the optimum angle. Each supporting structure with its modules is called a *subarray*, and the entire configuration of subarrays is the *array*. The complete photovoltaic *system* also includes batteries to store the electricity, electronic components to control the flow of electricity and, in some cases, components to convert direct current to alternating current.

The size of a photovoltaic module or system is expressed in *watts peak* (Wp), approximately equal to the amount of power produced at noon on a sunny day with the panel directly facing the sun.

All these systems work on the same general principle. As shown in Figure 1, the PV cell has two layers of conductor silicon. The top layer is treated to have a negative charge, the bottom layer to have a positive charge. The sun's rays excite and dislodge the electrons in the negative layer, causing them to move toward the positive layer. When they cross the barrier between the layers to the positive layer, an electric current is created. A grid of metal contacts embedded in the PV cell collects the electron flow and delivers useable current from the cell.

Figure 1. The Photovoltaic Process





Close-up view of solar panels showing individual cells of single-crystal silicon.

3. EPA Experience

Under the Department of Energy's FPUP program, EPA conducted 12 projects to design, construct, and use 39 PV systems to power a variety of environmental monitors. The emphasis was on remote applications, which required portability and maintenance-free operation. Some involved emergencies requiring the quick response possible with a mobile system. Some applications entailed hazards that limited human access. The systems included backpack, trailer-mounted, and large stationary systems.

Visibility Monitoring

The National Park Service measures visibility in remote areas of national parks as an indicator of overall air quality. The first solar-powered visibility monitoring system, installed at Lava Point in Zion National Park in 1980, used a 1,400 Wp system. The PV system has since been moved to provide electricity for a ranger's cabin elsewhere in Zion. The National Park Service now uses a visibility monitoring system in Zion that requires only 120 watts of peak PV power.

EPA developed a prototype 120 Wp visibility monitoring station for use in the U.S. National Forest Flattops Wilderness Area in Colorado. This system, like the system in Zion, measures visibility and transmits the data via satellite to a computer in Washington, D.C. After one year of successful operation, the system was removed because of changes in the requirements of the national visibility monitoring program. The PV system served as a model for an additional 10 systems built by the Environmental Monitoring Systems Laboratory-Las Vegas (EMSL-LV) and used by the National Park Service throughout the West in places like Grand Canyon and Bryce National Parks. Similar systems could be used to develop baseline environmental data before the construction of large facilities such as power plants or mines in rural areas.

The visibility monitoring systems are ideally suited for use in remote areas of the national parks. They are small enough to be unobtrusive and reliable enough to require only quarterly inspections to check the monitoring equipment. Batteries alone are not an alternative because they can supply power for only a few days before they must be replaced or recharged. Without photovoltaic power, visibility monitoring would be feasible only near power lines.

Ozone Monitoring

Photochemical smog from California cities is transported east and can be trapped by the Sierra Nevada Mountains. Researchers believe that the smog may interfere with reproduction in giant sequoias, among the world's oldest and largest trees. Therefore, officials at Sequoia National Park and the California Air Resources Board wanted to monitor ozone levels at remote sites within Sequoia National Park. EPA staff at EMSL-LV adapted a commercial alternating current (AC) ozone monitor to run on direct current (DC) power and built a 540 Wp PV system to provide the power. Data from the monitor are relayed via satellite and telephone lines to the California Air Resources Board for analysis. The accuracy of the ozone monitor must be checked every two weeks.

To support the study of potential adverse effects of smog on saguaro cacti, the National Park Service is borrowing a PV trailer from EMSL-LV to power ozone monitoring equipment in Saguaro National Monument near Tucson, Arizona. The National Park Service is also using a PV-powered ozone monitor in Great Smoky Mountain National Park.

High-Volume Air Sampling for Particulates

The Ute Indian Reservation at Fort Duchesne, Utah, is surrounded by a variety of energy development projects that could degrade air quality in that region. EPA provided a 480 Wp PV-powered high-volume air sampler to monitor particulate pollution at the reservation. The system meets the specifications established for conventional samplers, and the Ute Indians continue to use it.

Air samplers pump air through a filter to trap particles or through an absorbent to trap gases. The filter is replaced by a new filter every week, and taken to a lab for analysis of particulates and gases in the air. The high-volume air sampler is often specified by EPA for routine monitoring of particulates, but a small sampler that can operate with a 40 Wp PV power supply may be adequate for many applications.

Water Quality Monitoring

EPA's lab in Montgomery, Alabama, designed and built several trailer-mounted mobile PV systems. The 320 Wp trailer powered a water sampler at the Chattahoochee River, and a 720 Wp trailer powered a water sampler at the Alabama River.

Water samplers operate on the same principle as air samplers. They pump water through a filter, recording the total volume of water. The filter is removed periodically so that it can be studied in a laboratory.

Hazardous Waste Monitoring

Monitoring air and water quality near hazardous waste sites or at the scene of accidents is essential to public safety. EPA is understandably concerned, however, about the exposure of its personnel involved in monitoring. Reliable PV-powered monitoring equipment makes monitoring feasible with a minimum of human intervention. When the Weldon Spring Chemical Plant in Missouri was identified as a hazard, EPA brought in one of the PV trailers to power air sampling equipment in the area.

Radiation Monitoring

Radiation is among the most potent environmental hazards and is impossible to detect without specialized equipment. EPA has used PV-powered systems to monitor radiation in a variety of settings. In 1981 EPA installed a 4,000 watt stationary PV system at the Farley Nuclear Plant in Alabama to monitor radiation levels at the fence that surrounds the plant more than a mile away. EPA found that using PV power was less costly than extending a power line from the plant. The independent PV-powered system would also operate no matter what was happening in the plant, potentially providing life-saving information in the event of an accident. EPA has a similar 6,000 Wp PV system powering radiation and other monitoring equipment in Montgomery, Alabama.

EPA also installed three radiation monitors powered by 37 Wp backpack systems at the Nevada Nuclear Weapons Test Site. The monitors are linked to strip chart recorders that can store 30 days of monitoring data. These small systems are operating reliably and could be useful around nuclear power plants as well.

Additional Projects

A number of institutions have borrowed the EPA equipment for other projects. Dartmouth College is using a backpack system to monitor acid rain in the Northeast; a University of California researcher is doing the same in Gothic, Colorado. Carnegie-Mellon University has used a backpack system to power an air sampler in Nepal as part of the United Nations Biosphere Reserve Monitoring Program. The National Park Service has monitored sulfur dioxide levels at Volcanoes National Park in Hawaii with five backpacks. It also plans to use one of the trailers for ozone or sulfur dioxide monitoring in the Southwest.

4. Lessons Learned

Best Uses

PV systems can be used successfully to monitor radiation, visibility, particulates, gases and water quality. They can also be used to power satellite telemetry equipment to transmit data immediately.

For many remote environmental monitoring applications, PV power is not only the most practical and economic power source, it is the only feasible power source. Photovoltaic power is usually the first choice in remote areas where power lines are not available, maintenance is impractical, and monitoring is needed for more than a few days. Batteries alone must be replaced or recharged frequently. Diesel generators require frequent refueling and produce exhaust fumes that can distort measurements. In national parks, wilderness areas, and other areas where environmental concerns are particularly important, silent, exhaust-free, long-lasting PV systems are ideal.

PV systems can provide either continuous or periodic power. Air samplers, for example, do not require continuous operation and so a backpack system which has energy storage capacity for only one day may be adequate. (See Section 5 for a description of EPA's backpack system.) Ozone monitoring, on the other hand, must be continuous. EPA found that PV systems with 5 to 6 days of energy storage capacity—such as the trailer-mounted systems described in Section 5—could reliably power an ozone monitor.

Finally, the PV backpacks and trailers are well suited to emergencies. Easily moved and completely self-contained, they can be called into action when the need arises. For example, the radiation monitoring equipment that measured the impact of the Chernobyl nuclear accident was powered by PV systems.

The appropriateness of using PV power is specific to the site and monitoring application. Sufficient sun must reach the PV panels. Shading by trees, mountains, or heavy snow will obviously prevent the system from producing power. Storage capacity must also match the application. If continuous environmental monitoring is needed, 5 to 6 days of energy storage capacity is usually enough to provide reliable operation. However it may not be sufficient in areas with prolonged periods of precipitation or heavily overcast skies. Seasonal variations in daylight also must be considered. For example, PV power will be of little use in winter in northern Alaska.

The suitability of using PV power is also a function of the monitoring equipment specifications. Most environmental monitoring equipment runs on AC while PV cells provide DC. PV trailers and the stationary systems therefore include DC to AC inverters, but backpack systems have none. Using a DC to AC inverter is possible, but it results in as much as a 40 percent energy loss. A better solution is either to find DC monitoring equipment or to convert AC equipment to DC operation. The conversion requires a one-time change in hardware (wiring, transformer, etc.) but there is no continuing cost or energy drain on the system. The EMSL-LV staff was able to adapt a commercially available AC ozone analyzer to run on DC power for a project in Sequoia National Park.

Sizing Systems and Storage

Sizing the PV system involves not only considering site conditions and the need for continuous or interruptable power, but also whether AC or DC power will be used and the size of the storage batteries. Personal computer software is now commercially available for calculating the specifications for PV systems; this is helpful because the specifications depend on so many variables. A list of solar power design software and where to obtain them is available from the Conservation and Renewable Energy Information and Referral Service. (See Appendix B, which also lists other sources of technical information.)

The amount of energy produced by a PV system will depend on the power rating of the PV array, the time of year, and the location. For example, in the United States only about half as much sunlight is available in December as in June, and Phoenix receives about twice as much sunlight as Cleveland in an average year.

The orientation of the PV cells is also a factor. In the northern hemisphere, the modules should face due south. Because the sun travels high in the sky in summer and low in winter, the tilt angle of the array from the horizontal must be determined. For maximum annual power production in one position, a rule of thumb is that the tilt angle of the array should equal the latitude of the system. In Washington, D.C., for example, the panel should be tilted 39 degrees from horizontal. If one wanted to optimize annual output, the panel could be raised an additional 15 degrees for midwinter operation and lowered 15 degrees for midsummer operation. However, seasonal adjustment is not essential since a 15 degree shift increases annual power production by only 5 percent. In practice, optimizing power production on short winter days is often more important than achieving the highest annual output. Systems are therefore often set at a "winter" angle, i.e., an angle equal to the latitude plus 10 to 15 degrees.

The ratio of PV peak wattage to load demand is also important in sizing a system. A low ratio is possible for the interrupted operation of a DC load; a high ratio is needed for continuous operation with an AC load. A backpack system producing 18 Wp can power a 6 watt DC air sampler (a 3:1 ratio) while providing 24 hours of storage. This will not provide continuous operation, but is usually acceptable for a small air sampler. A 320 Wp trailer system supplies 30 watts of continuous AC power (a 10:1 ratio) with 5 to 6 days of storage.

Reliability

EPA's PV systems have enjoyed virtually problem-free operation. The only significant problem was the almost immediate failure of the DC to AC inverter on one of the trailers and on one of the large stationary systems. The problem was with the inverter itself, and the manufacturer repaired it under warranty. Nevertheless, it is worth shopping around for a rugged inverter. With the exception of one of the backpack systems which was destroyed by lava in Volcanoes National Park, the systems have performed consistently and provided power at levels acceptably close to specifications.

In fact, for virtually all applications, the monitoring equipment itself will be the limiting factor for durability and maintenance. In general, the PV systems are far more durable and maintenance-free than the monitoring equipment they power. An ozone monitor, for example, must be checked for accuracy every 2 weeks, while quarterly inspection is adequate for the PV system.

Economics

Simple calculations of the value of PV-powered environmental monitoring are impossible. The price of PV cells has dropped significantly since 1980-82 when these systems were built, and the price seems likely to continue to drop. In addition, PV power is most often used in applications where other power sources are not feasible so that one has no standard for direct cost comparison. In these cases one must compare the cost of the PV system with the value of the monitoring information, which may be difficult to quantify.

PV power can also be the most economical option even when interconnection with the grid is possible, as at the Farley nuclear power plant. Here, building a PV system was less expensive than extending the powerline a mile from the plant to the fence where the monitoring equipment was needed.

One particularly cost-effective option when considering whether to use a PV system is to borrow the equipment that EPA already owns. (See Appendix B for more information.) With no equipment cost, many remote monitoring applications will be economically attractive, and some monitoring which has been done partially or not at all may now become feasible.

5. System Design and Specification

Three PV systems have been developed: backpack systems, trailer-mounted systems, and stationary systems. The basic components of the systems are shown in Figure 2.

Backpack Systems

Environmental monitoring is often needed in very remote areas, accessible only on foot. To make monitoring possible in such areas, EMSL-LV with assistance from Lockheed Engineering Management Services Company designed a PV power system that could be carried into a remote site on a backpack frame. The 64 lb solar backpack includes a 37 watt PV panel, a nickel cadmium aircraft battery, electrical control equipment, a housing to protect the battery and controls, an adjustable frame for mounting the PV panel at the proper angle to the sun, and tools for setting up the system at the site.

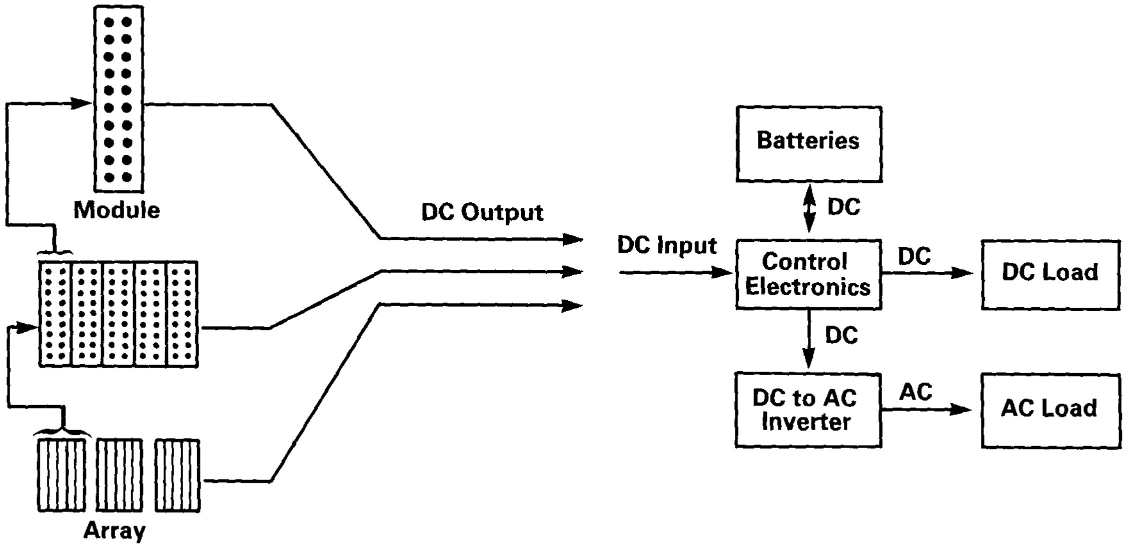
The PV panel can be wired in series to produce 37 watts of power at 28 volts or in parallel to produce 14 volts. With its battery providing backup power, this single backpack system can provide 6 watts of continuous power in most areas of the country. However, the battery stores only enough power to last through a night and a cloudy day. This small storage capacity limits the use of a single backpack to interruptable monitoring applications. One can, however, wire several backpacks together to increase storage capacity and provide continuous operation. This flexibility makes it possible to use the backpacks with various types of monitoring equipment.

EPA chose a Solarex HE60 single crystal silicon panel for use in the backpack. The square cells make for a high-density panel that provided the most power for its surface area of any panel on the market at the time. The panel was also designed for easy switching between 18 watt and 37 watt output. (The panel is no longer commercially available.) The battery was a General Electric 2-AC02 nickel cadmium aircraft battery chosen for its compactness, light weight, and high-density storage capacity.

Rather than designing a custom case for protecting the battery and controls, EPA used a commercially available aluminum suitcase. Rugged and waterproof, the case has proven reliable in field tests. The PV panel is mounted on a frame that is permanently attached to the case. The hinged frame makes it possible to adjust the panel angle in 5 degree increments between 15 and 60 degrees from the horizontal. Adjustable legs on the underside of the case make it possible to level the case on south-facing slopes of up to 25 degrees. The individually adjusting legs also allow for leveling in the lateral direction.

A waterproof junction box mounted on the back of the panel houses a terminal strip for connecting the panel to the battery. A Motorola Schottky diode allows current to charge the battery during the day and prevents the battery from discharging through the panel at night.

Figure 2. PV Systems Components



The backpack frame is a commercially available model to which EPA added an adjustable shelf to locate the load in the best position for the individual. Metal rings with locking Allen screws position the shelf on the vertical rods of the backpack frame. Two pegs protrude upward from the shelf and fit into holes in the bottom of the PV panel to secure its position. The case and panel are mounted on the frame with the panel facing toward the frame. A foam pad protects the face of the panel, and the load is secured with two nylon webbing straps.

Enclosed in the case with the battery is the electronic equipment. An LM-117 voltage regulator insures that power is delivered at a constant voltage, typically 6 or 12 volts. A 5k ohm potentiometer is used to select the level of the output voltage. The solar pack can provide up to 1.5 amps at regulated voltage for short intervals. A 0.5 amp load is more appropriate for long-term operation.

An LM-193 voltage comparator protects the battery from complete discharge. It controls a relay to disconnect the load from the battery when the battery's charge falls below a preset level, usually 10.5 volts for a 12 volt battery, and reconnects it when the voltage rises to 12 volts. The addition of 100k resistors and 50 microfarad capacitors minimizes the transients that occur as the load is picked up by the solar pack circuitry. The circuitry for the LM-193 includes two 0.68k ohm resistors to provide 1 volt of hysteresis to prevent premature reconnection with the battery that would result in rapid oscillations. A Curtis CP3E Incachron elapsed time meter records how long power is flowing to the load.

Matching load to power output is important. The PV panel produces 2.56 amps of current under standard sunlight conditions. With a 500 milliamp load, the panel sends 2 amps to the battery, which could lead to overcharging on consistently sunny summer days. Moderate overcharging will not damage the battery, but will increase water loss and require more frequent replenishment. The angle of the panel can be adjusted to decrease power production and avoid overcharging. Too large a load causes the more serious problem of insufficient operating time for the monitoring equipment. As a rule of thumb, the battery stores enough power to feed a load through a night and a cloudy day. Prolonged cloudy periods or stormy weather cause the system to disconnect itself from the load. EPA found that during the summer in the Pacific Northwest the system could provide 6 watts of continuous power.

The solar backpack is used to power radiation monitoring equipment where small amounts of power are quickly needed in remote locations.

Trailer-Mounted Systems

The need for environmental monitoring information seldom requires that a site be monitored perpetually. Data from a few years or even a few weeks is often sufficient for short-term monitoring projects and for emergencies. Building a permanent support structure for a PV array makes little sense for these short-term projects. A trailer-mounted PV system fills a vital niche for remote power supply.

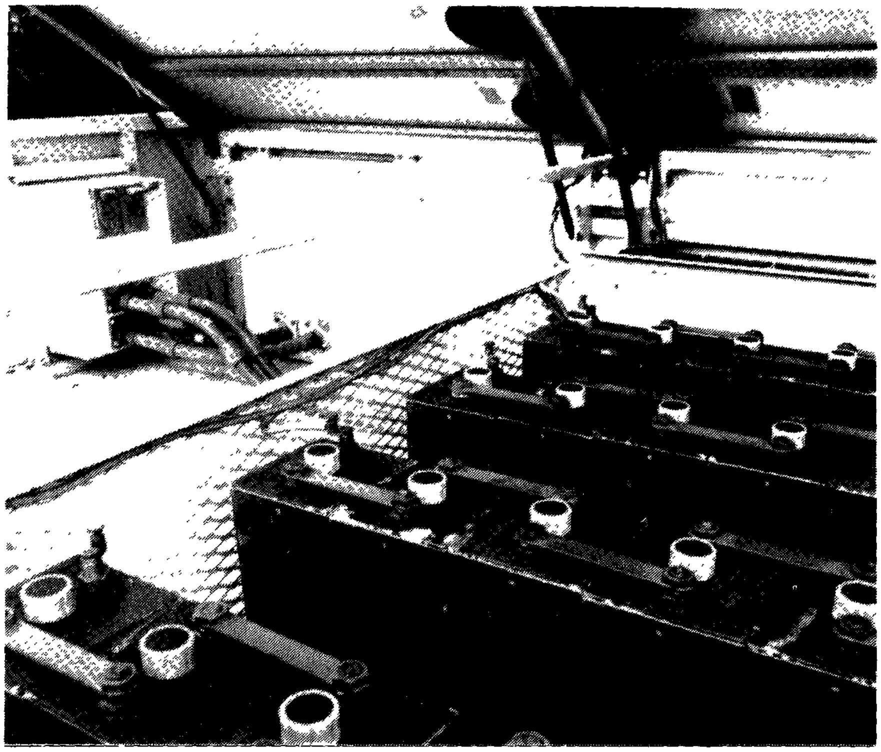
EPA designed two trailer-mounted PV systems that would contain storage batteries and all necessary electronics as well as the PV array. One of the two systems is a 720 watt trailer that supplies 80 watts of continuous power, and the other is a 320 watt trailer that supplies 30 watts of continuous power. Both trailers can store enough power to get through 5 or 6 cloudy days. Each also has room for storing up to 1,000 lb of monitoring equipment.

As Table 1 illustrates, the trailers are almost identical in design, differing only in their power and storage capacity. The PV modules are attached to unistruts with telescopic tubing for adjusting the angle of the PV array. The small system has two subarrays, and the large system has three. Each subarray has gas springs to facilitate raising the panels into position and to protect the panels from damage while lowering them. Nickel cadmium batteries provide storage.

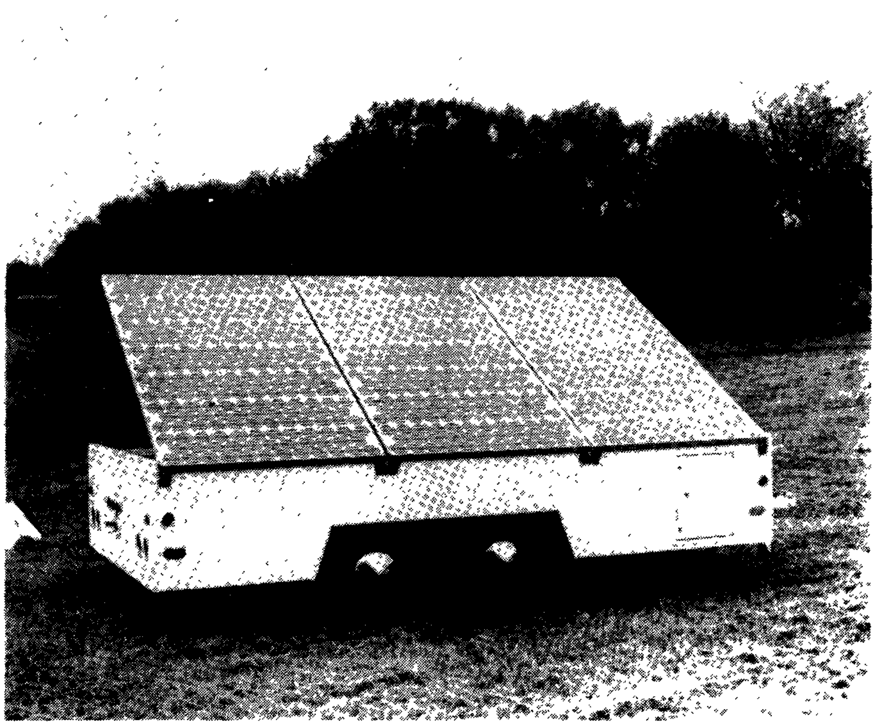
Table 1.

Technical Characteristics of PV Trailers

Characteristic	320 Wp Unit	720 Wp Unit
PV cells	Eight 40 Wp modules	Eighteen 40 Wp modules
Configuration	2 subarrays	3 subarrays
Nominal output power	30 watts AC continuous	80 watts AC continuous
System voltage	120 volts	120 volts
Power demand capability	6 times nominal	4 times nominal
Energy storage	20 McGraw-Edison CED-120 nickel cadmium batteries	40 McGraw-Edison CED-250 nickel cadmium batteries
Storage capacity	300 amp hrs	1,000 amp hrs
Tilt range	0-65°	0-65°
Dimensions when packed for transport	4'9" x 8'3" x 3'	7' x 12' x 3'
Weight	2,500 lb	4,000 lb
Additional storage capacity for monitoring equipment	1,000 lb	1,000 lb



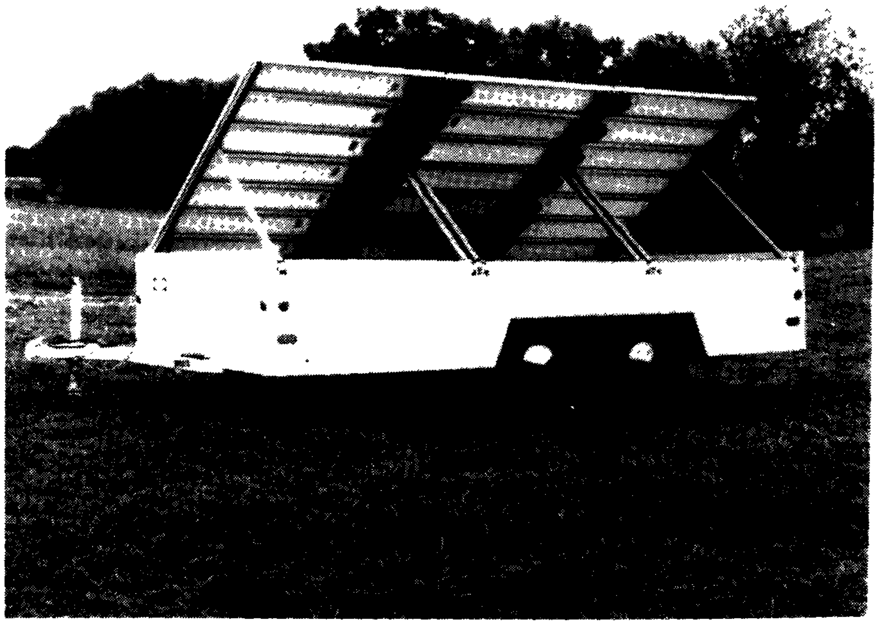
Interior view of trailer-mounted power supply with dual 12 VDC power outlets shown in upper left, gas springs supporting subassemblies shown in upper left and right, and nickel-cadmium batteries shown in foreground.



Curbside view of mobile 720 Wp solar power supply which is used to provide power to a variety of remote locations.

Each trailer includes instrumentation for monitoring array current, load current, and system voltage. The array ammeter makes it possible to measure current while the array is being erected to optimize the tilt angle of the array. All the control mechanisms, instruments, and terminal points are housed in weathertight enclosures.

When the PV array is stored for travel, the 720 Wp trailer measures 12 ft long, 7 ft wide, 3 ft high and weighs 4,000 lb. The smaller trailer is 8 ft 3 in long, 9 ft 3 in wide, 3 ft high, and weighs 2,500 lb. Each trailer includes springs, shock absorbers, and 10 in electric brakes operated by a self-actuating electrical controller. Each design includes three jacks to level and stabilize the trailer: a removable caster jack mounted on the tongue, and screw-type folding jacks under each corner.



Roadside view of mobile 720 Wp solar power supply showing panel junction boxes and support structures.

Stationary Systems

Two stationary PV systems were constructed by the EPA laboratory in Montgomery, Alabama, to power radiation monitoring equipment. A 4.08 kilowatt system is on the grounds of the Farley nuclear power plant in Alabama, and a 6.8 kilowatt system is at the EPA Eastern Environmental Radiation Facility in Montgomery, Alabama. As shown in Table 2, the systems are very similar in design.

Both systems use Solarex semicrystalline silicon PV modules. Ten modules are connected in series to produce a string that operates at 120 volts DC; the strings are then connected in parallel. Each module has a bypass diode installed in parallel to prevent the batteries from discharging through the panels at night.

An anodized aluminum frame supports the module. Adjustable legs make it possible to achieve the optimum panel tilt—in this case, 50 degrees from horizontal. The frame is strapped to a concrete foundation and anchored with ground augurs to make it secure even in 100 mph winds. Each subarray is 7 ft wide and 7 ft 3 in high. The rows are 12 ft apart to prevent shadows on the back rows.

Lead cadmium batteries from the C&D Company provide storage so that the system can run for five sunless days. A Solarex controller protects the batteries from overcharging and complete discharge. When the batteries near capacity, the controller automatically reduces the number of modules in series in each string. The controller allows for pump charging of the batteries by adjusting the power supply in small increments. This also prevents electrolyte stratification which can ruin the battery. The controller panel indicates the status of the system, and a voltmeter and two ammeters monitor the performance of the array, battery bank, and load.

Table 2.

Technical Characteristics of Stationary Systems

Characteristic	4.08 Kilowatt	6.8 Kilowatt
PV cells	120 Solarex HE51JG single crystal silicon 34 watt modules	170 Solarex SX-120 semicrystalline silicon 40 watt modules
Configuration	12 parallel strings of 10 modules connected in series	17 parallel strings of 10 modules connected in series
Array area	40′ wide x 40′ deep	40′ wide x 60′ deep
Nominal continous output power	400 watts AC	600 watts AC
System voltage	120 volts	120 volts
Storage capacity	60 kilowatt hrs - 5 days without sun	123 kilowatt hrs - 5 days without sun
Energy storage	60 C&D Company KCPSA-9 lead cadmium batteries	60 C&D Company KCPSA-9 lead cadmium batteries
Controller	Solarex ACR-6	Solarex ACR-6
Inverter	Abacus 413-3-120	Nova 2KVA
voltage	120 V DC to AC	120 V DC to AC
power	1,000 W, 60 Hz	2,000 W, 60 Hz
efficiency	85%	85%
sine wave output	less than 4% THD	less than 4% THD
Angle from horizontal	50°	50°
Storage building dimensions	10′ x 12′	10′ x 16′
Support structure	Solarex A-1266 galvanized aluminum frame with telescoping legs	Standard galvanized aluminum frame (no telescoping legs)
Ground	4′ long x ⅜" diameter galvanized rod at center of each row of modules	

Solar energy is used to power a high volume air sampler where measurements of particulates in the air are required to assess pollution in remote areas.

When the batteries discharge to a preset level, the controller disconnects low-priority components of the load. As the battery charge continues to drop, other loads are disconnected until finally the most critical functions are cut off. Loads are reconnected in order as the batteries recharge. Class R, 60 amp fuses protect the battery bank from a direct short. The PV array is protected from a direct short by Class R, 20 amp fuses. Blocking diodes, mounted in the bottom of the controller enclosure, are connected electronically in series between each subarray of PV modules and the array disconnect switch to prevent the batteries from discharging through the PV array at night. The controller is grounded and has a built-in lightning protection device to protect against surges.

Because most monitoring equipment runs on AC current, the DC current from the PV system is converted to AC by a 120 volt DC to AC inverter. This will shut down automatically to protect against insufficient or excessive voltage and restart when the voltage returns to the proper level. The inverter is also automatically protected from high temperatures and short circuits. Because the unit is convection cooled, there are at least two inches of clearance above and below the unit.

An insulated storage building houses the batteries, inverter, and controller. Adjustable vents allow airflow and temperature to be regulated.

Appendix A: Types of Cells

Photovoltaic cells are made with a variety of materials which differ in their conversion efficiency, durability, cost, and weight. Understanding these differences is essential for choosing the best type of PV cell for a particular application.

The most common PV cells are made from single crystal silicon, the same material used in semiconductor chips in computers. The wafers of silicon are sliced from ingots of very pure silicon. Single crystal silicon cells were the first PV cells developed and have proven their durability and reliability since the 1950s. They are the standard against which other cells are measured.

Polycrystalline silicon is similar to single crystal silicon except that it is not as pure and its crystal structure not as regular. Ingots can be produced less expensively, but conversion efficiency is somewhat lower. Although polycrystalline silicon cells have been in use for only a few years, they seem to be as reliable as single crystal cells. Polycrystalline silicon cells also can be made by a process that produces thin films of silicon that do not have to be sliced from an ingot. These cells are commercially available but have not had much market success. Their performance is acceptable, but the manufacturers have not succeeded in scaling up production economically.

Amorphous silicon has an irregular crystal pattern and is always produced as a thin film. Amorphous silicon cells are the least expensive and are lighter than those sliced from ingots. Amorphous silicon's efficiency is lower, and the durability of the cell in outdoor applications has yet to be proven. Because the cells are light and easily cut, they have been used extensively in calculators and other small consumer products where efficiency and durability are not critical. Amorphous silicon cells are often referred to as the cells of the future, and several companies began producing large amorphous silicon panels for outdoor use in 1985.

Some photovoltaic modules come equipped with concentrating lenses, but these have not been used for remote, untended applications. PV cells made with other materials are also appearing on the market, but they are either unproven or unsuitable for environmental monitoring. Gallium arsenide cells, for example, are used for space applications because they are more efficient than silicon cells. They are too expensive, however, to be competitive for nonspace applications.

For remote environmental monitoring there are only two serious contenders—single crystal and polycrystalline silicon. Both are durable and reliable, and are available from a number of manufacturers. The choice between the two depends on the cost and efficiency requirements of the particular panel. Efficiency is improving and cost decreasing for both, and neither has emerged as clearly superior. Amorphous silicon has the potential to significantly lower costs in the next few years and could become a viable option in the late 1980s if it proves its durability in outdoor applications.

Appendix B: Sources of Equipment and Further Information

The equipment developed for this EPA program is still in use by EPA, the National Park Service, universities, and others. EPA is eager to have these PV systems used. If you have a need for one of the portable systems described here, contact Jon Broadway or Jeffrey van Ee to find out if the equipment is available.

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Technical monitor for the EPA-FPUP projects in Mongtomery, AL

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Technical monitor for the EPA-FPUP projects in Las Vegas, NV

Other sources of information include:

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Photovoltaic Energy Technology Division (CE 352)
1000 Independence Avenue, SW
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(202) 252-6264
Manages the Department of Energy Federal Photovaltaic Utilization Program (FPUP)

David Berg
U.S. Environmental Protection Agency
Office of Research and Development (RD-681)
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(202) 382-5735
EPA program director for the EPA-FPUP projects

Dr. G. J. Jones
Sandia National Laboratory
Division 6223
P.O. Box 5800
Albuquerque, NM 87185
(505) 844-2433

Conservation and Renewable Energy Inquiry and Referral Service (CAREIRS)
P.O. Box 8900
Silver Spring, MD 20907
(800) 523-2929
Federal program that provides introductory information and suggestions for finding more specific or technical data

National Appropriate Technology Assistance Service (NATAS)
U.S. Department of Energy
P.O. Box 2525
Butte, MT 59702
(800) 428-2525
(800) 428-1718; in Montana only,
Federal program that can provide design assistance

Office of Scientific and Technical Information (OSTI)
Department of Energy
P.O. Box 62
Oak Ridge, TN 37831
(615) 576-6837
Technical information

Technical Inquiry Service
Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401
(303) 231-7303
Leading Federal research facility for photovoltaics

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