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Solar Electric Buildings

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An Overview of Today's Applications

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Solar Electric Buildings

This brochure presents a broad look at photovoltaic-powered buildings. It includes residential and commercial systems, both stand-alone and connected to utility power, that are located in urban, near-urban, and rural settings around the world. As photovoltaic (PV) technology continues to improve and costs drop, opportunities for PV will multiply. PV systems for buildings, such as those shown here, represent one of the strongest near-term markets.

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Development of Photovoltaics

Often called "solar electricity," photovoltaics (PV) is the direct conversion of sunlight to electricity. It is an attractive alternative to conventional sources of electricity for many reasons: it is silent, nonpolluting, and renewable; it requires no special training to operate; it is modular and versatile; with no moving parts, it is extremely reliable and virtually maintenance free; it can be installed almost anywhere; and it can be manufactured as a building product. As you will see in this brochure, you can power virtually anything that requires electricity with PV—there are few limits to this technology.

The photoelectric effect was first observed by French scientist Edmond Becquerel in 1839. More than 100 years went by before researchers at Bell Labs developed the first modern PV cell in 1954. Four years later, PV was used to power a satellite and has provided extremely reliable electric power for space exploration ever since.

The 1960s brought the first terrestrial applications for PV. At that time, the technology was extremely expensive, with PV collectors (called modules) costing upwards of \$1,000 per peak watt (Wp). Yet, PV was still desirable in places where no other form of power production was feasible. Over the past three decades, steady advances in technology and manufacturing have brought the price of modules down nearly 200-fold, to \$5–\$6 per peak watt.

As a result of this price drop, PV applications are multiplying rapidly. Today, in fact, PV is cost-effective even when other forms of electricity are available. Experts predict that within the next 5–10 years, PV should become competitive with utility-grid power for widespread distributed applications.

Typical Applications for Photovoltaics Today

- Lighting and security
- Water pumping and irrigation
- Communications
- Remote monitoring equipment
- Aids to navigation
- Remote refrigeration
- Village power
- Electricity for individual buildings or entire communities
- Supplementing the utility grid for distribution support

Distributed Systems vs. Central-Station Electricity

When electricity is introduced into developing countries, either a centralized or a distributed system can be built. In a

centralized system, power is typically produced at large central power plants and transmitted long distances to end users across a vast network of transmission and distribution lines. In a distributed system, power is produced at or close to the point of use. Distributed systems create system diversity while avoiding the costs and losses of transmission and distribution.

Engine generators have historically provided electricity for distributed power in remote applications. However, recent system advances and cost reductions have made PV or PV/generator hybrid systems very attractive in life-cycle costing when compared with engine generators alone.

Even in countries with extensive utility grids already in place, distributed PV systems are becoming increasingly attractive to provide support for and add diversity to the power grid. Among the most promising of these distributed applications are PV systems for individual buildings.

Photovoltaics On and Integrated Into Buildings

For many years now, PV systems have been the preferred power sources for buildings in remote areas not served by the utility grid. As the cost continues to decline, distributed PV systems on buildings may be the first application to reach widespread commercialization on the utility grid. PV systems on buildings avoid the cost of land required for ground-mounted systems, as well as the cost of site development, foundations, structural support systems, underground electrical distribution, and the utility connection. The building provides the PV aperture area and support structure, and the building's utility service becomes the PV system's grid interface. In addition, PV

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systems on buildings can displace electricity on the customer's side of the meter at the retail rate, whereas centrally located PV plants displace conventional fuels at the utility's avoided cost.

Interest in building integration, where the PV modules actually become an integral part of the building and often serve as the exterior weathering skin, is growing worldwide. PV specialists from 15 countries are working within the International Energy Agency's PV program on a 5-year effort to optimize these systems. In addition, the U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) have recently implemented a 5-year cost-shared program called PV: BONUS (Building Opportunities in the United States for PV) to encourage the commercial development of building-integrated PV components.

Building-integrated PV (BIPV) systems have the potential to be architecturally attractive, which adds to the commercial acceptance of the technology on the part of design professionals, building owners, and the general public. In addition, BIPV components replace conventional building materials and labor, thus further reducing the installed cost of the PV system.

With reduced installation costs, improved aesthetics, and all the benefits of distributed generation, building-integrated PV systems will become an attractive option for residential and commercial buildings. At present, product development is proceeding in three general areas: integral roof modules, roofing tiles and shingles, and integral modules for vertical facades and sloped glazing.

Many BIPV systems have been integrated into roofs because these have the highest solar exposure and so provide the highest power output. Recent innovations have also made vertical curtain walls and awnings practical because integrated PV modules can replace facade materials such as granite and architectural glass. New semitransparent thin-film modules are also being developed, so PV can even function as a skylight or a window.

With all its advantages and promise of continued cost reductions, the potential for PV-powered buildings is very great indeed. In a best-case scenario, Arthur D. Little, Inc., has projected that the annual U.S. market for PV on buildings could top \$2.5 billion in the next 10 years. Japanese and European markets, already under development, hold similar potential.

Two Types of Systems

Photovoltaic systems for buildings can be either stand-alone or grid-connected. In a stand-alone system, the building has no

connection to the utility grid and often relies on a bank of batteries to store power for use at night and during periods of limited sun. In a grid-connected or utility-interactive (UI) system, the building receives electricity from both the PV array and the utility grid. Some PV systems are capable of both stand-alone and UI modes of operation.

In many UI systems, surplus electricity from the PV array is exported to the utility grid and "bought back" when the PV is not producing. Many states require that the utility meter spin backward under what is known as a "net metering" connection. With net metering, the utility grid becomes the storage medium, in place of on-site batteries. Owners benefit from lower system costs and reduced maintenance. The utility benefits because the PV system produces its surplus at or near the peak of the utility's demand.

Cells, Modules, and Arrays

Photovoltaic electricity is produced by an array of individual PV modules electrically connected in series and parallel to deliver the desired voltage and current. Each PV module, in turn, is constructed of individual solar cells also connected in series and parallel. A typical crystalline silicon solar cell is 100 cm² and produces about 1.75 Wp at 0.5 volt and 3.5 amps under full sun at standard test conditions (STC: 1,000 W/m² and 25°C cell temperature).

Dozens of solar cells are connected together to produce a PV module. The number of cells determines a module's size and power. Cells and modules connected electrically in series build voltage; cells and modules wired in parallel build current. Modules are typically available in ratings from less than 50 Wp to greater than 250 Wp.

There are two basic types of PV modules commercially available today: those made from crystalline silicon and those made from amorphous silicon (a-Si). Crystalline silicon modules are presently the dominant commercial product and deliver approximately 100–120 W/m² at STC. Amorphous silicon thin-film modules, which are beginning to enter the market, require less material to produce than the thick crystalline products and so can be made less expensively. Today's commercial a-Si modules deliver 40–50 W/m² under full sun at STC.

Other thin-film PV materials such as copper-indium-diselenide and cadmium telluride are currently under development and hold the promise of lower costs in the future.

When designing a PV system, the array size is determined by one or more of the following parameters: available aperture area, available resources (both solar and financial), and the load requirements. The array's operating voltage will determine, or be determined by, the direct current (DC) input voltage requirement of the inverter and, in stand-alone systems, the battery bank. Sources listed in the appendix provide detailed information on PV system sizing and component specification.

Balance of Systems

Photovoltaic systems require other components in addition to the PV modules. Often called the "balance of systems," this equipment generally includes system wiring, support structures, inverters, batteries, charge regulators, string combiners, lightning protection, overcurrent protection, disconnect switches, and ground-fault protection. A brief introduction to these components follows, with additional detailed information available from sources listed in the appendix.

Inverters are electronic devices employed in stand-alone and UI PV systems to convert the DC electricity produced by the PV array to alternating current (AC) common to the utility grid and required by most appliances and electronic devices. Inverters are specified in terms of their capacity (in watts or kilowatts), their output voltage (e.g., 120 VAC) and their power quality. All UI PV systems require an inverter, as do stand-alone systems supplying AC loads. Stand-alone systems supplying only DC loads do not need inverters.

Quality inverters provide sine-wave electrical output that conforms to utility power quality standards in terms of harmonic content and voltage and frequency stability established for the power grid. All UI inverters must meet minimum power quality standards set by the American National Standards Institute (see appendix for reference sources). Often, individual utilities impose supplemental requirements. Power quality is also important in stand-alone systems, to ensure that all appliances and electronic equipment operate properly.

In addition to DC-to-AC conversion, most stand-alone and all UI inverters incorporate some level of system control. A quality stand-alone inverter will include a low-voltage disconnect and other system controls and will often serve as a battery charger. UI inverters incorporate precise control circuitry to ensure power quality and quick disconnect of the PV system from the grid in the event of a utility outage to protect service personnel. And some inverters now include DC ground-fault protection, which disables the PV array in the event of a short to ground.

Batteries are needed in stand-alone systems to store electricity for use at night and during periods of low sun. Liquid-electrolyte, lead-acid storage batteries are by far the most widely used. Deep-cycle batteries are required for long-term service. Batteries are connected in series to provide the necessary system voltage, and in parallel to provide the required amount of storage rated in amp-hours at the system's voltage.

Captive-electrolyte or "gel-cell" batteries are available for applications in which liquid electrolyte is undesirable, but their initial cost is typically greater than for those with liquid electrolyte. Many new battery technologies are being investigated for use in electric vehicles. When commercialized, these new batteries will benefit PV systems as well.

Charge regulators manage the flow of electricity into and out of the storage batteries. These electronic devices prevent damage to the batteries by protecting against both overcharging by the PV array and over-discharging by the load. A number of models are available, from basic to sophisticated. Desirable features include low-voltage load disconnect, field adjustability, and provisions for a finishing charge. Because battery charging characteristics change with temperature, battery-temperature compensation is recommended when selecting a charge regulator in all but the most basic systems.

String combiners are prefabricated junction boxes that are useful to facilitate the parallel connection of the series strings of PV modules, called source circuits, which make up the PV array. String combiners often have integral lightning protection devices, such as silicon-oxide varistors, which shunt damaging high-voltage transients to ground. Article 690 of the National Electrical Code (NEC), which governs PV systems, requires overcurrent protection and a disconnect means for PV array source circuits, and most string combiners include overcurrent protection in the form of pull-out fuses or DC-rated circuit breakers, which also can serve as string disconnects for array testing and service.

Disconnect switches are needed for system servicing and personnel safety, as set forth in NEC Article 690. They are typically installed on the inverter's input and output, at the array output, and on the battery bank's output. Most disconnect switches also include overcurrent protection, either as fuses or as circuit breakers. A fuse or other means of "catastrophic" overcurrent protection is also necessary at the battery bank, and large battery banks even have fuses internal to their string wiring to isolate portions of the bank in the event of a fault. DC-rated components should be used in all DC circuits.

Ananda power center

Advanced Energy Systems 250-W UI microinverter

24-V Battery bank with protective enclosure

Omnicron 6-kW UI inverter

Grid-Connected Installations

Since its commercialization, electricity has been supplied to residential and commercial customers by means of central-station generation and a complex transmission and distribution system. All conventional power plants have inherent problems, such as pollution, dependence on fuel supply stability, or widespread public opposition to their use. In addition, central-station generation makes large numbers of people vulnerable to electrical blackouts. PV eliminates many of these problems. With the widespread commercialization of PV and other distributed sustainable energy resources, such as wind and biomass, our society will become less dependent on conventional central-station generation.

Although PV is capable of powering houses and businesses without any connection to electrical infrastructure, such arrangements are not always the most practical. In many states, when PV system owners connect to the grid, the utility and the customer enter into a new kind of relationship, often called "net metering." With net-metering, surplus electricity produced by the PV system can be exported back to the utility grid, effectively spinning the electric meter backward. The home or office then gets this power back at an even exchange at night and during periods of low sun. The electric utility helps the building owners by becoming the storage medium for their PV system, thus eliminating the need for batteries or other

storage devices. The PV owners benefit the utilities by providing surplus power to the grid during daytime peak periods when many utilities tend to need the electricity the most.

Today, utilities have started to encourage, and even sponsor, the installation of grid-connected PV systems. In 1985, New England Electric installed 100 kWp of distributed, rooftop PV systems, including the world's first PV-powered neighborhood, in the central Massachusetts town of Gardner. Other farsighted utilities, such as the Sacramento Municipal Utility District in California, are now installing distributed PV systems on customers' buildings. These systems will support the grid, helping meet peak demand while reducing dependence on traditional sources of power and improving the environment. Recently, a group of roughly 90 North American electric utilities formed the Utility PhotoVoltaic Group to promote and sponsor the installation of distributed PV systems across the country.

As many of the following examples demonstrate, costs can be shaved from PV installations not only by tying them into the utility grid, but also by means of design features that lower construction costs. Using the PV system as the building's weathering skin, for example, eliminates the need for an additional roof, thus displacing conventional building materials and labor costs.

Lord House

Coastal Maine

Bill and Debbi Lord dreamed of building a solar house for more than 20 years. They also wanted to retire to the coast of Maine. Their house, designed by Solar Design Associates of Harvard, MA, is approximately 250 m² and produces its own heat, hot water, and electricity from the sun. The south roof incorporates an integrated array of solar thermal collectors and large-area PV modules to form a single, uniform glass plane.

Through a net-metering relationship with Central Maine Power, surplus solar electricity is exported to the utility grid, effectively spinning the utility meter backward. The Lords get this power back in an even exchange at night and during periods of low sun when it's needed. Both homeowner and utility benefit from this relationship, and on-site electrical storage is unnecessary.

Space heating and domestic hot water are provided by the solar thermal system with space heating distributed in a multizone radiant floor system. The house also incorporates passive solar heating and cooling, super insulation, advanced R-8 windows, monolithic air and vapor barriers, air-lock vestibules, and a heat-recovery ventilation system. A woodstove provides the option for wood-fired supplemental heat, if desired.

The main living spaces are arranged along a stepped facade, giving each room a corner window to take maximum advantage of the views and passive solar gain while providing generous south-facing roof area for the solar harvest. The integral PV array is passively cooled from behind by a thermosyphon air flow that enters at the eaves and exits at the full-width north-facing louvre.

Bill Lord is so enamored of his solar house that he has put up an information page on the Internet's World Wide Web, describing the home's technical features and performance and spreading his enthusiasm about solar living.

The address is <http://solstice.crest.org/renewables/wlord/index.html>

Owner:	Bill and Debbi Lord
PV Array:	4.25 kWp, 16 ASE Americas 265-Wp modules
Installer:	Solar Design Associates, Inc.
Inverter:	4-kW Pacific
Batteries:	None, with provisions to add in the future
Heat and DHW:	Solar with radiant floor heat distribution
Mounting:	Roof integrated

Installing the roof-integrated PV array

4-kW UI inverter

Olympic Natatorium

Atlanta, Georgia

The new swimming complex, built on the campus of the Georgia Institute of Technology for the 1996 Summer Olympic Games, features a large-scale solar electric system. A 340-kWp rooftop PV array was installed on the main structure, and a custom arched glass PV canopy was designed for the entrance to the complex.

The rooftop PV system employs 2,832 Solarex 120-W PV modules mounted above the steel roof deck to allow for the free flow of cooling air below the array. A central, Kenetech 300-kW DC-to-AC inverter feeds three-phase power into the campus utility grid. The total array has an area of some 3,043 m² and is the largest system of its kind in the world.

The new entry canopy of the natatorium features special large-area 250-W Solarex AC PV modules that have a clear back skin, to allow light transmission between the individual crystalline cells. The PV modules form the canopy and are integrated in a special arched aluminum support structure custom-fabricated by the Kawneer Company. Each PV module has its own integrated DC-to-AC micro inverter, developed by Advanced Energy Systems, to deliver 60-Hz AC power directly to the building complex.

Owner:	Georgia Institute of Technology
Funding:	U.S. DOE, Georgia Power, Georgia Institute of Tech.
PV Array:	340 kWp, 2,832 Solarex 120-Wp modules
Supplier:	Solarex
Installer:	Beacon Sales Corp.
Inverter:	300-kW Kenetech
Mounting:	Stand-off

Entry Canopy

PV Pioneers

Sacramento, California

The Sacramento Municipal Utility District plans to obtain at least half its energy from energy efficiency and renewables by the end of the decade. By early 1996, 4.3 MW of distributed PV systems had been installed, much of it on customers' buildings. Homeowners participating in the program pay a monthly surcharge for the privilege of having grid-interactive PV arrays on their roofs. The array belongs to the utility and produces more than 20 kWh per day. When asked why he would pay to let the utility use his roof, one PV Pioneer explained, "Having the satisfaction of generating clean, renewable energy on my rooftop is worth it."

The house pictured here has two 4-kW systems; one faces south and the other faces west to offset late afternoon air conditioning demand on the utility grid.

Over the life of the system, the power generated by each PV home displaces the equivalent of 127 tons of coal that would otherwise be burned to produce electricity at a conventional central power plant. Based on the current national generating mix, this keeps 218 tons of carbon dioxide, a primary "greenhouse" gas, from entering the atmosphere.

Owner:	Private residences
Funding:	Sacramento Municipal Utility District
PV Array:	Two 4-kWp, Solec single-crystal modules
Supplier:	Solec International, Inc.
Installer:	Solar Electrical Systems, and Placer Electric
Inverter:	Two 4-kW Omnion
Mounting:	Stand-off

Owner:	National Renewable Energy Laboratory
Funding:	U.S. Department of Energy
PV Arrays:	Two 6-kWp AC, each with 140 Siemens M-55 modules
Installer:	Bechtel
Inverter:	Two 4-kWp Omnion, each array
Mounting:	Roof-mounted on custom support structure

Solar Energy Research Facility

Golden, Colorado

NREL's Solar Energy Research Facility (SERF) is a state-of-the-art research facility developing renewable energy and energy efficiency technologies. Completed in 1993, SERF houses 42 laboratories and accommodates nearly 200 employees. The facility faces 15° east of due south to take advantage of solar gain and is built into the site slope to take advantage of earth sheltering.

The SERF incorporates numerous energy-saving features including energy-efficient lighting, daylighting, and window shades controlled by PV sensors, evaporative cooling to control air temperature, and heat recovery systems. Annual energy costs are 30%–40% lower than for a similar building designed to meet federal standards. And it cost less than half of what a typical research facility costs to construct.

Photovoltaic arrays have been installed on the roof of the east and west wings of the SERF. Together the two systems generate as much as 12 kW AC of electricity which offsets building loads. Any surplus is fed into the Public Service Company of Colorado's power grid.

Owner/Installer:	Solarex
PV Array:	200 kWp, 3,120 Solarex 65-Wp modules
Inverter:	DC-AC motor generators and Omnion 3-phase
Batteries:	2.7-MWh Exide Industrial deep-cycle lead-acid
Mounting:	Building-integrated, roof-mounted
Electrical Loads:	Manufacturing equipment and UPS for critical process control

Solarex Technology Center

Frederick, Maryland

In 1982, Solarex unveiled an innovative way to demonstrate the benefits and reliability of PV. It constructed the world's first PV-powered PV manufacturing plant.

The 10,000-m² complex's 45° sloped south roof is covered with the company's PV modules. The 200-kWp PV array covers 2,500 m² and provides electricity for the manufacturing equipment and other building needs, and provides an uninterruptible power supply for critical manufacturing process control systems, using the 2.7-MWh battery bank.

When the system's batteries are fully charged, surplus solar-generated electricity is fed into the utility grid to offset other loads in the complex.

Several features contribute to the energy efficiency of the building. It is super-insulated, with an average rating of R-35. It also captures the heat generated in the manufacturing area and recirculates it throughout the building for space heating during the winter. During the summer, the heat is exhausted to the outside. A high-efficiency heat pump provides supplemental heating and cooling as needed.

Energy Resource Center

Atlanta, Georgia

The Southface Energy Institute is a nonprofit organization whose mission is to promote the development of sustainable, environmentally sound energy technologies through education, research, and technical outreach.

The Institute built this energy-efficient residence as a technology demonstration and to provide office and meeting space. The rooftop array of PV roof shingles was developed by United Solar Systems and Energy Conversion Devices under the DOE PV:BONUS program. The PV shingles are designed as a direct replacement for standard asphalt roof shingles and are nailed in place to the wooden roof deck.

Each PV shingle is 10 feet long, contains 10 thin-film solar cells, and produces a total of 18 Wp. Electrical connections are made with wire pigtailed into the attic through the roof deck. The system is UI, with excess power sold to the local utility, Georgia Power.

Mounting Detail

Owner:	Southface Energy Institute
Funding:	U.S. Department of Energy, PV:BONUS Program
PV Array:	2 kWp, Uni-Solar 18-Wp a-Si shingle modules
Supplier:	United Solar Systems Corp.
Inverter:	4-kW Trace 4048
Mounting:	Nailed to roof deck

Recycling Center

Rikers Island, New York

The New York Department of Sanitation installed this 40-kWp roof-integrated PV system on its new recycling center on Rikers Island, near LaGuardia Airport. The system, which incorporates 216 translucent PV modules, each rated at 186 Wp, displaces the building's conventional metal sheet roofing to provide clean electricity and daylighting to the work area below.

Each 48-in. by 60-in. module incorporates 81 5-in. Sharp monocrystalline silicon solar cells evenly spaced within the aperture to allow a 17% light transmission. The modules are installed like shingles, successively overlapping, to allow natural water shedding.

Electricity generated by the PV system will directly offset power provided by an on-site diesel generator. In 1998, the local utility, Con Edison, will provide service to the facility, replacing the generator and the PV system will become utility-interactive.

Array Installation

Owner:	New York City Department of Sanitation
Funding:	U.S. DOE, USA PV, and New York Power Authority
PV Array:	40 kWp, Solar Building Systems 186-Wp modules
Supplier:	Atlantis Energy, Inc.
Installer:	Varick Mechanical
Inverter:	Six 6-kW Omnion
Mounting:	Roof-integrated, displacing metal roofing

Georgetown University Washington, DC

Like most institutions of higher learning, Georgetown University, in Washington, DC, is dedicated to innovation and an openness to new ideas and technologies. Its impressive Intercultural Center makes a dramatic statement of those ideals. With a 337-kWp PV array integrated into the sweeping south roof, this large, modern facility sets a shining example, showcasing distributed, UI PV as the preferred power source for the future.

The array provides as much as 50% of the building's electrical needs, with the rest supplied by the utility. It interfaces with the campus grid, which also has contributions from other distributed power systems on campus. This project was funded by DOE to demonstrate the viability of large-scale building-integrated PV systems for commercial and institutional facilities.

Owner:	Georgetown University
Funding:	U.S. Department of Energy
PV Array:	337 kWp, 4,464 Solarex modules
Supplier:	Solarex
Installer:	Hughes Aircraft
Mounting:	Roof integrated, using Kawneer framing system

APS Factory Fairfield, California

Advanced Photovoltaic Systems (APS) developed a line of large-area, thin-film PV modules appropriate for use in building facades. Because they transmit some light, these thin-film modules can also be used as skylights and awnings, becoming a part of the building's architectural design. To demonstrate the potential of thin films and learn more about their efficiency in building-integrated applications, APS installed its modules in three systems on its factory in Fairfield, CA.

A 4.8-kWp awning system faces due south for maximum energy generation. The awning also shades the south-facing windows, thus reducing solar gain during times of greatest air conditioning demand.

The vertical facades of the "entry cube" are clad with a 3.2-kWp PV curtain wall, installed on all four sides for research purposes. The PV curtain wall replaces conventional facade material, such as glass or granite, which reduces construction costs while contributing a visually striking element and electricity.

Atop the entry cube is a PV skylight, sloped at 10° east and west. The modules transmit 4% of the incident light, casting a soft, diffused light on interior spaces while the shading coefficient of the modules minimizes thermal gain in the interior.

A data acquisition system monitors the performance of the PV arrays in terms of application, orientation, and insolation. The APS facility was designed by Kiss Cathcart Anders Architects of New York.

Owner/Installer:	APS
Awning PV Array:	4.8 kWp, 96 50-Wp a-Si modules at 22.5° tilt
Facade PV Array:	3.2 kWp, 47 50-Wp and 34 25-Wp a-Si modules at 90° tilt
Skylight PV Array:	400 Wp, 8 50-Wp a-Si modules at 10° tilt
Mounting:	Building-integrated a-Si modules in place of architectural glass

EII Student Center

Boston, Massachusetts

Boston Edison joined Northeastern University to use solar electricity to power the EII Student Center on the university's Boston campus. The rooftop PV system incorporates ninety 285-Wp modules installed on innovative, ballasted mounting trays that require no roof penetrations.

The project is part of a nationwide research effort to use clean technology to improve air quality, reduce peak electric demand, lower energy costs, and reduce the need for additional power plants. It is funded by the U.S. Environmental Protection Agency, the Electric Power Research Institute, and Boston Edison, one of 11 participating electric utilities.

Owner:	Northeastern University
Funding:	U.S. EPA, EPRI, Boston Edison
PV Array:	18-kWp AC, 90 ASE Americas 285-Wp modules
Output:	Monthly average 2,375.5 kWh
Supplier:	Ascension Technology
Installer:	Sontz Roofing and Northeastern Physical Plant
Inverter:	Three 6-kW Omnion 2200
Mounting:	Ballasted flat-roof jacks at 25° tilt

String combiner box

Ökotec Office Building

Berlin, Germany

A high level of design was achieved by architects Schuler Jatzlau Partners MBH in the integrated PV facade for the Ökotec office building in Kruzberg-Berlin, Germany. The building's facade consists of granite and glass panels that were installed using a structural glazing technique. The custom PV modules, produced by Flachglas Solartechnik, GmbH, are partially reflective to share the same appearance as the building's architectural glass.

Virtually all the power produced is used within the 8,100-m² building. Any surplus energy is sold to the utility grid. The investment in the PV facade paid back very quickly because the building received a great deal of attention and, as a result, was the first new speculative office building in Berlin to be fully rented.

Detail of custom module

Owner:	Ökotec 3, Berlin
Funding:	German Ministry for Research and Technology (BMFT)
PV Array:	4.2 kWp, 44 custom 96-Wp Flagsol modules
Supplier:	Pilkington Solar International
Inverter:	Two 1,800-W SMA in master/slave configuration
Mounting:	Building-integrated facade

Owner: Dilger Metallbau GmbH
 PV Arrays: 4.2 kWp, 34 Flagsol modules covering 48 m²
 Supplier: Pilkington Solar International
 Inverter: Two 1,800-W SMA
 Mounting: Building-integrated sloped glazing and skylights

Dilger Metallbau GmbH

Schluchsee, Germany

Dilger Metallbau GmbH is a small, family-owned business that designs and manufactures custom architectural glazing systems for commercial buildings. When it came time to expand facilities near Freiburg on the edge of the Black Forest of southern Germany, the family wanted to create a building that would best present their business capabilities.

Architect Walter Müller designed a dynamic glazed structure to showcase Dilger products and systems, integrating custom PV modules into the design in the sloped glazing and skylight applications. In all, 48 m² of modules were employed to deliver 4.2 kWp. The owners report that their new building is a sun-filled delight to work in. It has also brought the firm new recognition in the marketplace, opening up additional sources of revenue and providing an early return on their investment.

PV skylight spine

Owner: Union of Concerned Scientists
 Funding: UCS, COM Electric, Cambridge Electric, and EPRI
 PV Array: 2.1 kWp, 16 ASE Americas 265-Wp modules
 Installer: Solar Design Associates, Inc.
 Inverter: 4-kW Pacific PI- 4000
 Mounting: Ballasted flat-roof jacks at 25° tilt

Union of Concerned Scientists

Cambridge, Massachusetts

The Union of Concerned Scientists (UCS) is an internationally known nonprofit organization recognized for its work in policy and technology development on renewable energy use and the environment. The UCS headquarters in Cambridge, MA, is a showcase of energy-efficient design and solar utilization. The building features a UI rooftop PV system.

The PV array is installed with an innovative ballasted support system that requires no roof penetrations. The solar-generated electricity offsets the electrical demand of the office lighting, computers, and climate conditioning equipment. The project incorporates a host of other innovative energy-efficient features such as a control system that automatically adjusts the office lighting levels for the amount of daylighting available and turns lights off when rooms are unoccupied. The building's chiller features a variable-speed motor drive.

The local utility, Cambridge Electric, together with the Electric Power Research Institute and COM Electric, were sponsors of the project, along with several foundations.

Solarzentrum Freiburg

Freiburg, Germany

Solarzentrum Freiburg is a speculative office building in southern Germany that features the first application of "structural glazing with PV" in Europe. The innovative system, developed by Greschbach Industrie- und Verwaltungsbau GmbH (Karlsruhe, Germany), relies on structural silicone adhesive for the fastening and weather seal of the facade elements and requires no clamping hardware.

PV modules were integrated into prefabricated wall sections for the south and east facades. These sections were assembled in the factory and set in place, using a crane fitted with glass-handling equipment, complete in 5 hours. The south and east roof also received integrated PV arrays, for a total capacity of 18.5 kWp, split evenly between the roof and facade.

Detail of structural glazing facade

Owner:	SST GmbH
Funding:	EU Thermie Programme
PV Array:	18.5 kWp, custom glass-on-glass modules from DASA (now ASE)
Engineering:	Solar Systemtechnik GmbH
Inverters:	One 20-kW SKN 402, and one 2.5-kW SKN 301
Mounting:	Building-integrated as structural glazing using silicone adhesive

Solar Townhouse

Bowie, Maryland

This townhouse employs a number of energy-efficient features, including a 1.5-kWp PV roof and was constructed by the National Association of Home Builders at its research park near Washington, DC, as part of its 21st Century Townhouse project.

The solar roofing system, developed by United Solar Systems and Energy Conversion Devices, is designed to serve as a direct replacement for standard architectural metal roofing panels and is fastened in place to the wooden roof deck using metal roofing hardware.

Flexible, thin-film solar cells are laminated to roofing panels 15 inches wide by 19 feet long from ATAS International and produce 5- to 6-Wp power per ft². Electrical connections are made from module terminations under the ridge cap, which are fed down into the attic space. This UI system incorporates 16 kWh of battery storage to provide up to 1 day autonomous operation without utility power.

Ridge detail

Owner:	National Association of Home Builders
Funding:	U.S. Department of Energy, PV: BONUS Program
PV Array:	1.5 kWp, Uni-Solar a-Si standing-seam modules
Supplier:	United Solar Systems Corp.
Inverter:	4-kW Trace 4048
Mounting:	Fastened to roof deck, as metal roofing

Owner: New York Transit Authority
 Funding: National Renewable Energy Laboratory,
 New York Transit Authority
 PV Array: 17 kWp, Uni-Solar a-Si modules
 Supplier: United Solar Systems Corp.
 Inverter: 20-kW Omnion three phase
 Mounting: Ballasted flat-roof, mounted at 10° tilt

New York City Transit Warehouse

Maspeth, New York

On top of a warehouse operated by the New York City Transit Authority, in Queens, NY, is one of the country's first large arrays of thin-film a-Si modules. Many believe that thin-film technology may hold the key to making PV affordable in the larger marketplace of the future because of its inherent materials efficiency. The technology, however, is still in its infancy and has not yet undergone long-term performance evaluation in large-scale applications. With funding from NREL, the New York Transit Authority has installed a 17-kW array of thin-film modules to provide an average of 18,500 kWh a year for the operation of the warehouse.

The Maspeth PV array has an innovative ballasted mounting system designed by Integrated Power Corporation. The PV modules are bolted to low-cost pre-cast concrete parking curbs that hold the array down by force of gravity rather than by fastening the array through the flat roof to the structure.

Owner: Village of Tuckahoe, NY
 Funding: New York Power Authority, U.S. DOE, UPVG Program
 PV Array: 18 kWp, 120 PowerGuard PV roof tiles
 Supplier: PowerLight Corporation
 Inverter: three 6-kW Omnion
 Mounting: Set in place over conventional flat roof membrane

Community Center

Tuckahoe, New York

When the village of Tuckahoe, NY, needed to re-roof its 18-year-old community center, it partnered with the New York Power Authority to install an 1,800-ft² rooftop PV system that functions as both a roof paver and a solar electric power plant.

The PowerLight system employs conventional glass-superstrate PV modules adhered to a 2-in. base of Styrofoam roof insulation. The PV array is installed over the conventional roof membrane to provide insulation and protect the roof surface. In the Tuckahoe application, the PowerGuard roof tiles weigh about 4 pounds per ft² and provide R-10 insulation, reducing air conditioning requirements while extending the life of the conventional roof.

Quick-connect couplings provide module-to-module electrical connections, and array strings are run to a perimeter raceway where they are then fed to the inverters within the building. Roof areas without PV receive standard cementitious insulating roof pavers. The Tuckahoe system will provide approximately 30% of the building's annual requirements, much of it generated during the utility's summer peak.

Shawnee Mission County Park Ranger Station

Shawnee, Kansas

Owner: Kansas City Power and Light
 PV Array: 1.2 kWp, Uni-Solar a-Si modules
 Installer: United Solar Systems Corp.
 Inverter: 2-kW Omnion 2000
 Mounting: Building-integrated batten seam roof module

Marine Officer's Residence

Barstow, California

Owner: U.S. Government
 Funding: U.S. Environmental Protection Agency,
 Southern California Edison
 PV Array: 4.45 kWp, 84 Siemens M-55 modules
 Installer: Ascension Technology
 Inverter: 4-kW Omnion 2200
 Mounting: Stand-off on sloping roof jacks

Smith House

McElhattan, Pennsylvania

Owner: Kurtes Smith
 Funding: U.S. Department of Energy, Avis America
 PV Array: 2.2 kWp, Solarex modules
 Installer: FIRST, Inc., and Bradley Builders
 Inverter: 3-kW Pacific
 Mounting: Stand-off on sloping roof jacks

New York State Gas and Electric Service Center

Plattsburgh, New York

Owner: New York State Gas and Electric
 Funding: U.S. Environmental Protection Agency, NYSGE
 PV Array: Three arrays, each 4.45 kWp, 84 Siemens M-55 modules
 Installer: Ascension Technology
 Inverter: Three 4-kW Omnion
 Mounting: Ballasted, flat roof jacks at 25° tilt

Westchester County Laboratories

Valhalla, New York

Owner: Westchester County
 Funding: New York Power Authority
 PV array: 43 kWp @ 360 V, 360 Solarex MSX-120
 Supplier: Solarex
 Inverter: Omnion 3200 three-phase
 Mounting: Ballasted flat roof jacks at 20° tilt

Western Area Power Administration

Sacramento, California

Owner: Western Area Power Administration
 Funding: Sacramento Municipal Utility District
 PV Array: 3 kWp, 60 50-Wp APS a-Si modules
 Supplier/Installer: PowerLight Corporation
 Inverter: 4-kW Omnion 2200
 Mounting: Building-integrated roofing "paver" with insulation base

Nantucket Elementary School

Nantucket Island, Massachusetts

Owner: Nantucket Schools
 Funding: Massachusetts Division of Energy Resources
 PV Array: 7.2 kWp, two arrays, 60 Solarex MSX-60 modules each
 Installer: Ascension Technology
 Inverter: Two 4-kW Omnion 2200
 Mounting: Stand-off on sloped roof jacks

Mataro Library

Mataro, Catalonia, Spain

Owner: City of Mataro
 Funded by: EC JOULE II R&D program, Mataro City Hall, Institut Catala de Barcelona, ENHER, project partners
 PV Array: 53 kWp Flagsol translucent modules
 Supplier: Pilkington Solar International
 Installer: Toulades I Facanes Multifuncionals SA
 Mounting: Facade and roof integration

Stand-Alone Installations

In most cases, buildings powered by stand-alone PV systems are located too far from power lines to make a line extension economically feasible. In other cases, the building owner simply decides to be self-sufficient. However, even when power lines are nearby, a stand-alone system can be the best economic choice—for example, an urban bus shelter that only needs power for a simple light.

To a large degree, real estate prices encourage the use of PV for stand-alone residences because property is much less expensive if it is not served by the utility grid. There are only two practical options for providing electricity to a remote home or business: pay for a utility line extension or generate electricity on site. Utility line extensions can be \$20,000 or more per km, so most remote buildings easily make on-site generation cost-effective.

In the past, remote buildings used generators to provide electric power; now PV is a practical option. PV replaces the headaches of fuel costs, supply and storage, noise, pollution, and constant maintenance; it is reliable, sustainable, quiet, and clean. It is the most reliable source of electric power ever invented, and it is easily transported, easily installed, and virtually maintenance free. All these reasons make PV the ideal power source for remote homes and businesses.

Although the initial capital investment is higher, PV provides electrical power at less than the cost of electric-

ity from a generator, based on life-cycle costing. PV systems can deliver a positive cash flow in as little as 4 to 5 years of operation by displacing generator fuel, maintenance, and replacement costs. Even in stand-alone systems that include a generator for back-up power, the savings with PV are very dramatic over the life of the system.

Because remote power is expensive, it is good practice to make PV-powered buildings highly energy efficient, employing the most energy-saving appliances and equipment available. PV dealers and distributors experienced in the remote home market say a good rule of thumb is each dollar spent on efficient appliances saves at least three dollars in PV system components.

Remote PV systems are usually less expensive than utility line extensions from the outset. A typical home for a family of four, complete with refrigerator, freezer, microwave oven, washer, TV, VCR, stereo, kitchen appliances, and lighting, can be powered for less than \$7,500. This does not include space heating, cooking, clothes drying, or domestic hot water loads, which are typically supplied by propane in most remote PV-powered residences. That \$7,500 system is equivalent to about 400 meters of utility line extension, or the cost of buying and operating a generator for about 3 years; and, PV requires virtually no maintenance and has no monthly bill for fuel.

Hammond House

Prescott, Arizona

The 1.4-kW array powering this 240-m² house in the high desert near Prescott, AZ, provides an average 2,400 kWh per year of power. However, the owner, Bob Hammond, uses only 855 kWh a year. The low energy consumption results from the many energy-saving features and the occupants' commitment to energy conservation. Passive solar heating and cooling, roof overhangs, thermal mass, earth sheltering, and heavy insulation, keep the interior a comfortable temperature year round without air conditioning, fans, or any heat other than the sun and a woodstove. The house has no access to public water. The house collects rainwater runoff in a cistern, and uses a recirculating hot water system to reduce waste while waiting for hot water. A 400-ft well provides water when rainwater collection is insufficient.

The automatic ignition "glow-plug" in the gas oven is one of the many "hidden" energy users. The telephone, clocks, ground-fault interrupters (required by building code), remote control devices for television, VCR, and security systems, all consume power even when the appliances themselves are off. Together with the expected losses from the power inverters and regulators, these continuous loads account for 35% of the electrical consumption. With a design that takes advantage of the abundant natural lighting, and with the use of high-efficiency fluorescent lights, lighting accounts for only 4% of the total electricity use.

The PV system has operated flawlessly since its construction in 1988. Twice a year, in March and September, the owner manually adjusts the tilt angle of the array to maximize electrical output. This biannual adjustment achieves 98% of the power that a daily adjustment would achieve.

Battery bank

String combiner

Inverter

Owner:	Bob Hammond
PV Array:	1.4 kWp, Mobil Solar Ra-155
Output:	2,409 kWh annually
Inverter:	2.5-kW Trace 2524
Batteries:	20 Delco 2000, 1,040 Ah @ 24 V
Electrical Loads:	Lights, 0.45-m ³ Sun Frost refrigerator, shop, TV, VCR, microwave, computer, answering machine
Heat and DHW:	Wood stove, gas oven-range and water heater, with solar hot water

Amtrak Station

Normal, Illinois

The Amtrak passenger station at Normal/Bloomington, IL, incorporates a number of energy conservation technologies while providing efficient railroad operation, passenger comfort, and a pleasing atmosphere. A 2.4-kW rooftop array supplies energy for a portion of the building's electrical requirements: two vending machines, lighting for the ticket booth area and lobby, and emergency lighting.

The use of natural light, high-efficiency fluorescent and high-pressure sodium lighting, and electronic load management have reduced energy needed for lighting by more than 70%. Passive solar heating and shading, as well as the building's thermal mass, reduce the energy required for space conditioning. Overall, this station uses 75% less energy than a typical station of similar size located in a similar climate.

Owner:	Amtrak
Funded by:	Amtrak, Illinois Dept. of Transportation, Dept. of Energy Resources
PV Array:	2.4 kWp, 40 Solarex MSX-60 modules
Supplier:	SunWize Energy Systems
Installer:	Wannemacher Electric, Inc.
Inverter:	2.2-kW Trace
Batteries:	Eight IBE, 750 Ah @ 48V

Sunelco Office

Hamilton, Montana

Dan and Becky Brandborg operate Sunelco, Inc., the Sun Electric Company, in a small town in Montana. Their 2.4-kWp PV system is sized for year-round use, with a 24-V battery bank, Ananda power center, and a Trace 4024 sine-wave inverter. The utility grid functions as a backup power source, kicking in only when battery voltage is low. The PV system powers compact fluorescent lights and computers for the 10-person office.

In addition, the Brandborgs power their home with a 1.4-kWp array. This year-round dwelling uses energy-efficient appliances and compact fluorescent lights. Domestic water is heated by a solar-thermal water heater.

Owner:	Dan and Becky Brandborg
PV Array:	2.4 kW, 40 Solarex 60-Wp modules
Supplier/Installer:	Sunelco, Inc.
Inverter:	4-kW Trace sine-wave
Batteries:	1476 Ah @ 24V
Electrical Loads:	Office equipment and lighting

Balance of systems

Farmhouse and Ostrich Ranch

Santa Ynez, California

Nestled in California's Santa Ynez Valley lies an off-grid 18th century New England-style farmhouse and an ostrich ranch. Two buildings were disassembled in New England, combined, and updated to provide modern convenience without altering the authenticity. Most electrical appliances are unobtrusive: the large-screen TV is concealed inside an antique cabinet, and the energy-efficient refrigerator is paneled with the same distressed wood as the kitchen walls.

A hybrid PV and propane generator system, housed in a shed-like "power house" away from the main house, provides power for the house and ranch. This PV array is mounted on the roof of the power house, with an additional ground-mounted array nearby. Inside the power house are the generator, battery bank, and system control equipment. The PV array provides about 80% of the power for the main house, barn with living quarters, and ostrich ranch.

PV "power house"

Owner:	Private Residence
PV Array:	2.1 kWp, Siemens M-55 modules
Supplier:	Solar Electric Specialties Co.
Installer:	Glidden Construction Co.
Inverter:	Two 4-kW Trace SW 4024 stacked for 120/240V
Batteries:	70 kWh, C&D lead-calcium, 1,680 Ah @ 24 V
Backup:	12.5-kW propane generator
Electrical Loads:	Satellite dish/receiver, wide-screen TV, stereo, lighting, Sun Frost refrigerator, alarm system, convection oven, submersible pump, egg incubator

Joy Green Visitor Center

Rupert, Vermont

The Joy Green Visitor Center was constructed in 1989 by Merck Forest and Farmland, a private, nonprofit organization dedicated to sustainable forestry and agricultural practices and general environmental education. The Visitor Center is built on a 2,280-acre tract of forest and farmland, and is more than 0.9 km and \$20,000 away from the utility grid. The decision to power it with solar electricity was very easy, as the total cost of the PV system, including the backup generator, was only \$15,000.

The Center houses the organization's offices and hosts educational programs for school children and the general public. Designed by North Bennington, VT, architect Tom Keefe, the energy-efficient building employs passive solar and superinsulation. The building is heated by wood. More than 10,000 people visit Merck Forest and Farmland each year.

Owner:	Merck Forest and Farmland
PV Array:	1.12 kW, 20 Solarex MSX-56 modules
Supplier/Installer:	Solar Works, Inc.
Inverter:	2.5-kW Trace
Batteries:	880 Ah @ 24 V DC
Backup:	LPG Generator
Mounting:	Adjustable stand-off

Owner/Installer:	Ed Witkin
PV Array:	1.0 kWp, 20 Siemens M-75 48-Wp modules
Output:	1,500 kWh annually
Inverter:	2.5-kW Trace
Batteries:	24 Trojan T-105 deep-cycle lead-acid batteries
Electrical Loads:	Submersible pump, Sun Frost refrigerator, stereo, computer, shop vacuum, power tools, compact fluorescent lights, kitchen appliances (no dishwasher), washing machine
Heat and DHW:	Wood stoves; solar collectors and backup propane

Witkin House

Bridgewater, Connecticut

When Ed Witkin built his house on a remote, wooded lot near Bridgewater, CT, in 1991, his goal was to build a solar-powered house that would be functional, comfortable for his family of four, and aesthetically pleasing. Everything about this two-story (three-level) clapboard house, with four bedrooms and three baths, is conventional except the solar array.

Producing about 1 kW in full sunshine, the PV array first provided power for the construction of the house, and it has since provided all the power for the residents. The house uses wood heat with no backup, and eventually, Witkin plans to connect a radiant floor heating system to the stove. The house has R-19 insulation in the walls, and R-30 in the attic.

Balance-of-systems equipment

Owner:	Sandy Lawrence and Barbara Schickler
PV Array:	2.7 kWp, 56 Siemens M-75 48-Wp modules
Supplier:	Real Goods Trading Corporation
Installer:	Real Goods with Doug Pratt and Howard Claire
Inverter:	Two 2.6-kW Trace 2624 SB
Batteries:	3,800 Ah, @ 24 VDC (5 days storage)
Additional Power:	Two wind generators
Electrical Loads:	Two households with compact fluorescent lights, 0.45-m ³ Sun Frost refrigerators, submersible well pumps, pool pump
Heat and DHW:	Passive heating and cooling, solar DHW, gas backup

Lawrence/Schickler House

Calistoga, California

Dr. Sandy Lawrence and his wife Barbara Schickler bought a 5-acre parcel of land in Napa Valley with their retirement in mind—30 years away. They wanted rental income and no energy bills, so they bought a house and pool with enough land for a second house. Then they designed and built a 260-m² passive-solar, energy-efficient house with PV and wind generators, which produce enough power for both households and the pool. They will rent both houses until they retire, then they will live in the new house and continue to rent the old one.

They chose efficient appliances and lighting fixtures to reduce electrical demand. All appliances with continuous loads are activated by wall switches, so they can be completely turned off when not in use. Six of the modules in the PV array can be switched so they run the pool pump in the summer and charge the battery in the winter. This switch uses a custom power controller, because the pool pump requires 36 volts and the battery bank is charged at 24 volts.

Sandy and Barbara have now paid for their electricity for the next 30 to 50 years in 1994 dollars. When they retire, they will save thousands of dollars a year on energy at a time in their lives when this saving will be most welcome.

Owner:	Pacific Gas and Electric
Funding:	Pacific Gas and Electric
PV Array:	6 kWp, 96 Solarex 60-Wp modules
Installer:	Applied Power Corporation
Batteries:	87.6-kWh maintenance free
Backup:	Propane generator
Electrical Loads:	Emergency communications, gate activation controls, emergency shut-off valve

Helms Gatehouse

Courtright Lake, California

The T1 Gatehouse at the Helms Hydroelectric Facility is located on Courtright Lake (elevation 2,500 m) in the Sierra Nevada Mountains. It contains the emergency shut-off valve and gate activation controls used to stop the flow from the lake to the hydroelectric plant, located 450 vertical meters below. The reliability, safety, cost, and environmental impacts of the engine generators that previously powered this essential outpost were problematic.

The remote location made fuel deliveries and maintenance difficult, especially during the winter when average snow accumulation exceeds 3 m. At one point, a fuel leak caused a catastrophic fire, with extensive damage to the gatehouse. Pacific Gas and Electric, which operates the gatehouse, switched to PV because it requires no fuel deliveries, no maintenance, reduces expenses, and increases safety and reliability. The 6-kW PV array is mounted on the steep roof of the gatehouse and meets the requirements of severe snow, seismic loads, and wind loads that are dictated by the site.

Owner:	Anoosh and Kija Mizany
PV Array:	3 kWp, 50 60-Wp Solarex MSX-60 modules
Supplier:	Solar Depot
Inverter:	Two 4-kW Trace Sine-wave
Batteries:	Two 1,050-Ah 24-V Pacific Chloride lead-acid
Heat and DHW:	Solar thermal system with lp boiler back-up

Solectrogen House

Nicasio, California

The Solectrogen House is the residence of Anoosh and Kija Mizany. It was designed to use active and passive solar energy, serve as a live-in laboratory for energy conservation and alternative energy products, and be a comfortable, traditionally attractive home with all the conveniences of modern living.

The 420-m² house is built on a hillside overlooking the Nicasio reservoir and was completed in September of 1992. The house features a PV system as well as passive solar design, a solar thermal system with an liquid propane (lp) boiler backup, and a wind generator backed up by an lp-fueled engine generator. The Mizanys have incorporated many energy conservation features, including energy-efficient lighting and refrigeration.

Balance-of-systems equipment

Hitney Solar Products

Chino Valley, Arizona

Gene and Carol Hitney's business, Hitney Solar Products, in Chino Valley, AZ, demonstrates how PV can provide 100% of a commercial building's needs. On the lower level, the building has 75 m² of retail showroom and 75 m² of warehouse and shop space; 55 m² of office space fills the upper level. A 600-Wp solar electric system produces all the electricity the building needs (about 3 kWh daily). Because the business operates only during daytime hours, the PV system needs only a small battery bank. A separate 200-Wp array provides electricity for the sign lighting—and attracts the attention of passers-by.

A wind generator mounted on a tower in front of the building also attracts attention and provides backup power on rare cloudy days. Chino Valley architect Mike Freking included energy-efficient features in the building, such as the use of natural lighting from skylights and passive heating and cooling through massive rammed-earth construction. In the summer, the PV system powers an evaporative cooler on the roof. A small propane wall heater provides supplemental heat, using about 400 liters of fuel per year. Together, the price of fuel and replacement batteries costs just \$225 per year.

Owner:	Gene and Carol Hitney
PV Array:	600 Wp, 12 Siemens M-75 48 Wp 200-Wp array powers sign lights
Supplier/Installer:	Hitney Solar Products
Inverter:	Two 2-kW Trace 2012
Batteries:	1,100 Ah @ 12V
Electrical Loads:	Fluorescent and halogen lights, 3/4 hp, deep well pump, tools, office equipment
Heat and DHW:	Solar with propane backup

Daley-Haas House

Westminster, Vermont

In 1984, authors Michael Daley and Jessie Haas moved to the Vermont woods to live simply and to write. When they first built their 24-m² home, they had no electricity or running water. Since then, they have added a greenhouse, tower, bedroom, winery, office space, and PV.

They still haul water by hand, heat with wood, and use propane for cooking and refrigeration, but they welcome the electricity for lighting. Most of the other electrical loads are related to writing. They are reluctant to cut down trees to improve their solar exposure. Nevertheless, they only use about 20 liters of gasoline per year in their supplemental generator.

Jessie Haas at her computer

Owner:	Michael Daley and Jessie Haas
PV Array:	24-Wp module made by Michael, 50-Wp ARCO Solar M-75 module; 40-Wp ARCO Solar M-53 module
Installer:	Michael Daley
Backup:	Small generator
Batteries:	Two Trojan 6 V, 105 Ah @ 12V
Electrical Loads:	Five 9-W 12-VDC compact fluorescent lights, 10-W tape deck/radio, 12-W answering machine; two 9-W laptop computers, 20-W jet printer, electric shaver, ceiling fan

Harmony, U.S. Virgin Islands

St. John, Virgin Islands

Harmony, located adjacent to the U.S. Virgin Islands National Park on St. John, was built using recycled materials and uses only renewable energy. Owner Stanley Selengut built this retreat as a prototype for environmentally sustainable resorts in sensitive ecosystems and landscapes.

From each of Harmony's twelve units, visitors have a private view of an unspoiled environment. Each house has a small footprint that required no trees to be cut, and in return, their shade provides cooling and perches for exotic birds and hanging orchids. Elevated wooden walkways connect the beaches and buildings, leaving the soil and vegetation undisturbed.

Each house has its own PV array. Passive solar cooling is created by a wind scoop, cross-ventilation, overhangs, landscaping, and heat-rejecting glazings. Water is solar heated, and each unit has a solar oven on the deck. Electrical appliances are few, and lighting fixtures are energy efficient. Cisterns in each basement collect rainwater from runoff, which is filtered before use; Harmony uses no groundwater. Gray water is captured and used for flushing and for watering plants. All the waste is composted and returned to the soil.

In addition to serving vacationers, Harmony serves as a "living laboratory" about how an "off-the-grid" resort functions within a pristine natural setting. Local school children also visit Harmony to learn about sustainable development, renewable energy resources, and recycling.

Owner:	Stanley Selengut
Planning Support:	U.S. National Park Service, U.S.V.I. Energy Office, Sandia National Labs
PV Array:	240 Wp, 4 Siemens PC-4 polyframed modules for each unit
Supplier:	Real Goods Trading Corporation
General Contractor:	Nelson Uzzell
Inverter:	1,500 Powerstar UPG
Electrical Loads:	Low-voltage refrigerator, lights, computer
DHW:	Solar thermal

Palumbo House

Hyde Park, Vermont

Mary Val and David Palumbo, along with their three children, live comfortably in their large, traditionally styled but unconventionally powered home. Their neighborhood, consisting of three homes and a barn/shop, is entirely off the power grid. They make their own electricity using renewable energy available on their hillside. PV arrays on or near each building charge the batteries when the sun shines, and a micro-hydro turbine charges the batteries when it's cloudy.

The Palumbos are fortunate to have two good sources of renewable electric power available, but they still use electricity wisely by investing in efficient appliances and lighting. Their home is tucked back into the dense woods of the northern Green Mountains. They built their home using wood harvested from this land, and 90% of their heating needs are satisfied by efficiently burning wood.

Owner:	David and Mary Val Palumbo
PV Array:	1.15 kWp, 24 Kyocera 48-W modules
Output:	3.0 kWh/day annual average
Supplier/Installer:	Independent Power and Light
Inverter:	Trace 4-kW Sine-wave
Batteries:	Trojan 1200 Ah @ 24 V
Other Power:	Micro hydro

Epstein House

Ashland, Oregon

Located on the southeastern side of 2285-m Mt. Ashland, the Epsteins' home is on a 400-acre site in a heavily wooded area prone to forest fires. Although they had originally wanted to build a true stand-alone solar home, the Epsteins needed to install utility power to pump enough water from their 150-m well to satisfy the water supply requirements for fighting forest fires. In addition to the well, the Epsteins use the grid for high-power appliances, including the electric oven, hydronic heating, central vacuum, and an irrigation system.

The other electrical loads in the house are powered by the stand-alone PV system. It uses a battery bank for 2 days of energy storage and the grid as a backup system. The PV system could be modified to be utility interactive when the utility's buyback rates become more attractive or net metering is enacted.

The building's stone construction provides excellent thermal mass for passive heating, supplemented by conventional hydronic heating and three wood-burning stoves. Solar thermal collectors supply domestic hot water.

Owner:	Bill and Sara Epstein
PV Array:	2 kWp, 36 Solarex 60-Wp modules
Installer:	Bob-O Schultz, Electron Connection
Inverter:	4-kW Trace Sine-wave
Batteries:	1,400 Ah @ 24 V
Electrical Loads:	Lighting, entertainment, communications, and alarm systems
DHW:	Solar thermal

Liss House

Fairbanks, Alaska

Geologist Shirley Liss lives with her 10 sled dogs near Fairbanks, AK. Although her home is only 20 km from downtown Fairbanks, utility power would have cost more than \$16,000. Therefore, Ms. Liss installed a PV system.

The system supplies more power than she needs during the summer. During that time she has her refrigerator on a timer so it runs only about 3 hours a day. In the fall, only the freezer runs, for freezing fresh vegetables.

During the winter she often unplugs the refrigerator and freezer and uses ice in 20-liter containers to keep them cool. There is enough power during the winter to keep the heater going when she is away for days or weeks at a time doing geology field work or mushing with her sled dogs, but she has oil heat for days that drop below -35°C. Because it would take too much power to keep water pipes unfrozen in the Alaskan winter, she has no indoor plumbing. She melts snow and ice for the dogs, hauls water for herself, and showers at work.

Owner/Installer:	Shirley Liss
PV Array:	576 Wp, 12 Kyocera 48-Wp modules
Inverter:	2-kW Trace
Batteries:	16 12-V automotive type
Backup:	Generator
Electrical Loads:	Refrigerator, microwave, toaster, iron, radio, lights, fan, answering machine, sewing machine, ham radio, oil furnace (starter), vehicle (winter starter), and sauna
Heat and DHW:	Wood and oil heat; solar hot water

Owner:	Massachusetts Metropolitan District Commission
Funded by:	Massachusetts Div. of Environmental Resources
PV Array:	3.2 kWp, 32 Solec100-Wp non-glass marine modules
Installer:	Sunnyside Solar, Inc.
Inverter:	Two 2.6-kW Trace
Batteries:	2,400 Ah, 24 2-V gel cells
Backup:	Diesel generator
Electrical Loads:	Lighting, smoke alarms, refrigeration, computers

Photovoltaic Power Station

Peddock's Island, Boston, Massachusetts

One of many Boston Harbor Island Parks, Peddock's Island is a historical site that once served as a WWI military station. Now operated as a historical and environmental park by Boston's Metropolitan District Commission (MDC), the island has a visitor's center, church, fire house, "stable residence" for the rangers, and a woodworking shop.

For several years, power came from a small PV lighting system. The MDC decided to install a larger PV system to power the island facilities as they expand for tourism and educational groups. To preserve the character of the buildings, a separate power station was constructed. The 3.2-kW PV array was installed on the new building that also houses the power conditioning equipment, storage batteries, and the generator. Electricity from the PV Power Station is fed to the other buildings through underground distribution cables. None of the buildings has air conditioning, and heat is not needed because the facilities are open only in the summer season.

The PV Power Station faces due south, and the roof has a 35° tilt angle biased toward summer harvest. The array extends beyond the building in two wings that are supported by posts and concrete footings.

Owner/Installer:	FIRST, Inc.
Funding:	New Jersey Office of Energy
PV Array:	1.8 kWp, 36 APS 50-Wp a-Si modules
Inverter:	4-kW Trace Sine-wave
Batteries:	16.6 kWh, 12 Trojan T-145, 690 Ah @ 24 V

FIRST House

Hopewell, New Jersey

Lyle Rawlings runs a business called FIRST (Fully Integrated Residential Solar Technology), which designs and installs PV systems for homes in urban and suburban areas. The FIRST demonstration home was built to show that a home integrating advanced passive solar design, PV power, solar hot water, highly efficient construction, and highly efficient loads could be built economically in the Northeast. The State of New Jersey awarded FIRST a grant for building this stand-alone PV home in Hopewell, NJ, near Princeton.

Lyle designed and built the house and lives there with his wife, Cheryl and their two sons. The home serves as the offices for FIRST and classroom space for educational programs conducted there. The off-grid lifestyle has proved to be very enjoyable and rewarding for the family.

Balance-of-systems equipment

Nelson House

Norwich, Connecticut

Berta Nelson's two-story frame colonial house in Norwich, CT, was built in 1840. It has 100 m² of living space and is connected to city water, sewer, natural gas, and electric service. The main electrical loads are lighting and refrigeration. In 1990, she invested in energy-efficiency improvements, changing all lights to 28-W compact fluorescent bulbs and replacing her refrigerator with a Sun Frost, which consumes only 23 kWh per month—about 20% of an average refrigerator's consumption.

These improvements cut her electrical use 80%—from 300 kWh to 80 kWh per month. In 1991, she installed a 347-W PV array in her back yard. As the house now uses electricity from the array as well as from the utility, the \$6 per month hookup charge sometimes exceeds the total electrical usage. "The best payback," according to Ms. Nelson, "is to be using a pollution-free, quiet, safe energy source."

Owner:	Berta Nelson
Installer:	Sunnyside Solar, Inc.
PV Array:	360 Wp with 8 Hoxan 45-Wp modules
Inverter:	2-kW Trace 2012
Batteries:	Eight 6-V deep-cycle, 880 Ah @ 12V
Backup:	Utility power
Electrical Loads:	Compact fluorescent lights and refrigerator
Heat and DHW:	Gas-fired hot water system, gas range

DeVoe House

Fairbanks, Alaska

David and Carol DeVoe built this house outside of Fairbanks, on the edge of the Alaska wilderness. The Golden Valley Electric Company has no service near this location, so the DeVoes installed PV to power lighting, entertainment, water pumping, and an oil-fired heating system.

Six of the eight PV modules are mounted on a rack that can be adjusted to follow the seasons, while two pole-mounted modules can be moved manually to track the sun throughout the day. The DeVoes eventually plan to install a tracker for all eight modules. From March to October, the house requires no additional electricity. Their backup generator operates only about 5 hours per week in mid-winter.

In addition to the PV system, the DeVoes capture and filter 12,000 liters of snowmelt and rainwater for their non-potable water uses. They heat primarily with wood, burning only two to three cords per year.

Owner:	David and Carol DeVoe
Installer:	Taiga Woodcraft
PV Array:	480 Wp, 8 Kyocera 51-Wp modules
Inverter:	2-kW 2012 Trace
Batteries:	Two nickel-iron, 580 Ah @ 12V
Backup:	Diesel generator
Heat and DHW:	Wood stove supplemented by oil-fired hydronic system
Electrical Loads:	Fluorescent lights, hot-water boiler and circulator pump, heat-recovery ventilation, stereo, TV, tools, vacuum, mixer, sewing machine, kitchen fan, microwave, battery charger

Douville House

No Name Key, Florida

Owner:	Hallett and Linda Douville
PV Array:	1.2 kWp, 24 Kyocera 51-Wp modules
Supplier:	Photocomm, Inc.
Installer:	Andrews Electric Shop
Inverter:	2.6-kW Trace
Batteries:	1,000 Ah @ 24 V
Electrical Loads:	24-V Sun Frost refrigerator, 24-V flowlight pump, lights
DHW:	160-liter batch solar hot water heater

Patz Cabin

Bitterroot Mountains, Montana

Owner:	Jon and Jean Patz
PV Array:	200 Wp, 4 Solarex 50-Wp modules
Installer:	Sunelco
Inverter:	600 W
Batteries:	Six 80 Ah @ 6 V
Electrical Loads:	DC water pump for remote livestock watering

Tern Island Research Station

French Frigate Shoals

Owner:	U.S. Fish and Wildlife Service
PV Array:	2.8 kWp, 54 Solarex 52-W modules
Installer:	Applied Power Corporation
Inverter:	4 kW
Batteries:	57.6 kWh @ 24 V
Backup:	3.8-kW diesel generator
Electrical Loads:	12-Vdc fluorescent lights, five Sun Frost refrigerators, 24-Vdc centrifugal jet-pump, radios, dehumidifier, computers, office and entertainment equipment

South Cardiff Beach Park

San Diego, California

Owner:	South Cardiff Beach Park
Funding:	San Diego Gas & Electric
PV Array:	2.4 kWp, Uni-Solar a-Si batten-seam roof modules
Supplier:	United Solar Systems Corp.
Installer:	Alternative Solar Products
Inverter:	4-kW Trace 4024 Sine-wave
Batteries:	24-V lead-acid
Electrical Loads:	Street lamps, lighting for restrooms, and guard station

Foster House

Eastport, Maine

Owner: John Foster
PV Array: 1.12 kWp, 20 Solarex MSX-56 modules
Installer: Solar Works, Inc.
Inverter: 2.5-kW Trace
Batteries: 880 Ah @ 24 V DC
Backup: LPG generator (slow speed 1800 RPM)

Black Canyon Trailhead

Prescott, Arizona

Owner: Arizona State Bureau of Land Management
PV Array: 192 Wp, three 64-Wp Solarex modules
Architect: Jones Studio Inc.
Installer: Krueger Contracting
Batteries: Four deep-discharge lead-acid batteries
Electrical Loads: Three compact fluorescent lights, light beacon, two exhaust fans

Selway Lodge

Bitterroot Wilderness Area, Picabo, Idaho

Owner: Pat Millington
PV Array: 2.88 kWp, 48 Solarex MSX-60 modules
Supplier/Installer: Sunelco
Inverter: 4-kW Trace
Batteries: 2,600 Ah @ 24 V
Backup: 8-kW propane generator
Electrical Loads: Lights for each of the guest cabins, two 0.54-m³ Sun Frost refrigerators, kitchen appliances, a computer, wheat grinder, and washing machine

Ke Ea O Ka La

Honolulu, Oahu, Hawaii

Owner: Cully Judd residence
PV Array: 3 kWp, ARCO Solar modules
Supplier/Installer: Inter-Island Solar Supply
Inverter: Two 2.5-kW Heart Interface
Batteries: 200-amp Industrial Battery Engineering 24V
Backup: Utility
Electrical Loads: DC lighting, refrigeration, AC for kitchen and entertainment appliances, washer, and power tools

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A Guide to the Photovoltaic Revolution
P.D. Maycock, E.N. Stirewalt,
PV Energy Systems
4539 Old Auburn Rd.
Warrenton, VA 20187
(540) 788-9626
pvenergy@crosslink.net

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John Schaeffer, Ed.
Real Goods, Ukiah, CA 95482
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(800) 762-7325

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Quincy, MA 02269
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American Solar Energy Society
Solar Today Magazine
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ases@ases.org
http://www.ases.org/solar

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Merrifield, VA 22116
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doe.erec@nciinc.com
http://www.eren.doe.gov

*Florida Solar Energy Center,
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1679 Clear Lake Rd.
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(407) 638-1015
http://www.fsec.ucs.edu

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PO Box 520
Ashland, OR 97520
(916) 475-3179
http://www.homepower.com

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Laboratory (NREL)*
Technical Publications
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*National Technical Information
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http://www.fedworld.gov

*Northeast Sustainable Energy
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Greenfield, MA 01301
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buildings@nesea.org
http://solstice.crest.org/
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www.sandia.gov/renewable_
Energy/photovoltaic/pv.html

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122 C Street NW, 4th Fl
Washington, DC 20001-2109
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71263,377@compuserve.com
http://solstice.crest.org

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<http://www.asepv.com>

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Solar Park
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(302) 366-0400

Atlantis Energy, Inc.
14790 Mosswood
Grass Valley, CA 94710
scoonen@interserve.com

Energy Conversion Devices
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Troy, MI 48084
(810) 280-1900
michelle@ovonic.com
<http://ovonic.com/OVONIC>

Golden Photon
PO Box 4040
Golden, CO 80402
(303) 271-7150

Pilkington Solar International
1615 L Street NW
Washington, DC 20036
(202) 463-4698

PowerLight Corporation
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Berkeley, CA 94710
(510) 540-0550
shugar@powerlight.com

Siemens Solar Industries
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4650 Adohr Lane
Camarillo, CA 93011
(805) 482-6800
<http://www.solarpv.com>

Solar Cells, Inc.
6702 Westwood Ave.
Toledo, OH 43607
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United Solar Systems Corporation
1100 West Maple Road
Troy, MI 48084
(810) 362-4170/3120

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(410) 686-2500

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econet@snowcrest.net

Hitney Solar Products
2655 Hwy 89
Chino Valley, AZ 86323
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Independent Power & Light
RR 1 Box 3054
Hyde Park, VT 05655
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Inter-Island Solar Supply
345 N Nimitz Highway
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Kyocera America
Solar Systems Division
8611 Balboa Ave.
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(800) 537-0294

Photocomm Inc.
7681 East Gray Road
Scottsdale, AZ 85260
(602) 948-8003
<http://www.photocomm.com>

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1220 Blosser Ave.
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Real Goods Trading Company
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<http://www.solardepot.com>

Solar Electric Engineering, Inc.
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Solar Electric Specialties Co.
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<http://www.traceengineering.com>

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