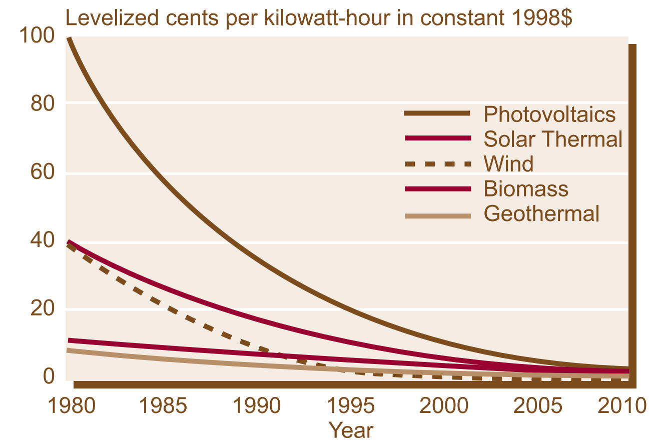
The Renewable Electric Technology Portfolio

A robust energy future for the United States requires a diverse portfolio of technologies and options that allow us to modify our current energy supply system — Science and Technology: Shaping the 21st Century, Office of Science Technology Policy, April 1997

A portfolio of renewable electricity generation technologies is available today to produce electricity for both grid and non-grid applications. The cost, performance, and reliability of these technologies have improved dramatically over the past 20 years due to extensive government and industry R&D investments. The cost of electricity from several of these technologies is now comparable to that from fossil-based plants. In particular, certain types of geothermal and biomass plants can compete with new fossil plants, when both construction and operating costs are considered. Generation from wind plants is approaching competitiveness with the variable operating costs of existing power plants, and the economic competitiveness of solar thermal and photovoltaic systems is also improving. Already cost-effective in many off-grid applications, photovoltaics are being installed in distributed grid-connected applications to provide benefits such as electric transmission and distribution system support. In addition, a market is emerging for photovoltaics for building rooftop and building-integrated systems. With continued R&D progress, the entire portfolio of renewable technologies will contribute significantly to U.S. and global electricity supplies over the coming decades.

Because the quality and availability of renewable resources vary across the country, having a portfolio of renewable technologies permits the selection of the most appropriate resource in a particular region and for a specific application. In electric grid systems, a renewable technology portfolio supports the entire range of power services. For example, renewables such as biomass and geothermal power technologies provide dispatchable, load-following service comparable to that of conventional, central station fossil-fuel technologies. Intermittent technologies such as wind and solar systems have value as determined primarily by the time of day and year during which electricity is produced. In some regions, solar power output tends to follow the summer peak. Because power delivered during peak periods is more valuable to the utility system, these solar technologies can provide high-value electricity and be significant contributors to a reliable power supply system at critical times in those regions. Combining intermittent resources with storage technology extends their daily operating hours and enhances their value as dispatchable electricity generators.

Renewable electricity technologies can be built in a capacity appropriate to electric system demand or to local



Source: Department of Energy

The cost of producing electricity (levelized cost of energy) from non-hydropower renewable sources, where costs have been traditionally high, has declined significantly. In a growing number of applications, the value to the utility system of a renewable energy plant is equivalent to, or greater than, that of a conventional power plant.

needs. This technology characteristic, which is called modularity, significantly reduces the lead time required for construction of a new electric generation facility. These smaller-sized facilities can also be placed closer to the local load center, reducing the cost of developing or upgrading transmission and distribution systems and improving reliability and power quality.

The following discussion provides an introduction to the electric supply technologies that constitute the nation's renewable supply portfolio. It describes their uses, discusses the availability of the resource, and illustrates their current technology configurations.

Hydropower

Hydropower is the most mature and largest source of renewable power, producing about 10 percent of the nation's electricity. Existing U.S. hydropower capacity is about 77,000 megawatts (not counting pumped storage) — enough electricity to meet the needs of 35 million households. This represents the energy equivalent of 140 million tons of bituminous coal and the avoided emissions of roughly 400 million tons of carbon dioxide. Hydropower plants produce no air emissions and are an important part of a strategy to minimize global climate change.

Hydropower plants convert the kinetic energy in flowing water into electricity. The quantity of electricity generated is proportional to the volume of water flow and the height of the water above the turbines. The most common form of hydropower uses a dam on a river to retain a large reservoir of water. Water is released through turbines to generate power. Other hydropower facilities, "run-of-the-river" plants, do not use large impoundments, but divert water from a stream and direct it through a pipeline to a hydraulic turbine.

Hydropower projects can affect water quality and fish and wildlife habitats. As existing hydropower plants are evaluated during relicensing, these concerns are often raised. To mitigate these impacts, many hydropower projects are diverting a portion of the flow around the dams to encourage downstream migration and maintain downstream wildlife habitats. While beneficial for wildlife, reduced water flow through the turbine lowers the power plant's output. This reduced output must be replaced by other generating resources to meet system needs. An advanced, environmentally friendly hydroelectric turbine, considerably more efficient than today's turbines but significantly less harmful to fish and other aquatic life, is now being developed for installation at existing and new sites.

Potential sources of hydropower capacity include many flowing rivers and streams on which low-head hydroelectric systems could be installed. These small, run-of-the-river facilities could use existing earthen impoundments, flood control or water-supply structures. Such plants, in the 1-10 megawatt range, can supply enough electricity to power a small town or village.

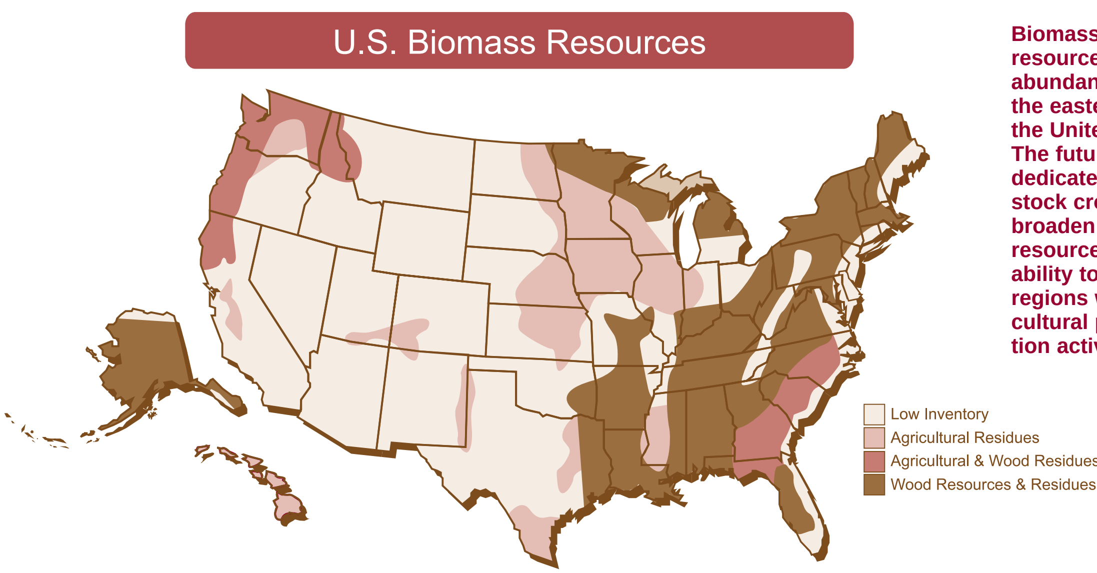
Biomass Power

Biomass power is a proven electricity-generating option that currently accounts for about 11,000 megawatts, or slightly more than 1 percent of the installed generating capacity in the United States. At approximately 11 percent of the renewable-based generation, biomass ranks second only to hydroelectric power. Biomass is unique in that it represents stored solar energy that can be converted into solid, gaseous, or liquid fuels. It is the only form of carbon that is replenished on short time scales. The biomass resource base capable of being converted into biopower (biomass-to-electricity power generation) includes various agricultural and industrial residues and processing wastes, municipal solid waste, and landfill gas. This resource base can also be augmented to include various feedstocks grown specifically as a fuel source.

Warren Gretz, NREL

The growth and harvesting of trees can, in the future, provide a replenishable source of fuel for electricity generation. The 50-megawatt McNeil station in Burlington, Vermont (shown here) currently burns wood chips prepared from wood waste directly. A gasifier that will use the fuel more cleanly and more efficiently is presently being tested at the site.

Direct-combustion steam turbine technology is the principal process currently used to convert biomass into electricity. One form of direct-combustion technology, co-firing of biomass in pulverized coal boilers, is currently being practiced in a number of electric utility-scale boilers, where it offers benefits in fossil fuel savings and reduced sulfur oxide, nitrogen oxide, and carbon dioxide emissions. Other conver-



Biomass resources are abundant across the eastern half of the United States. The future use of dedicated feedstock crops can broaden the resource availability to all regions with agricultural production activity.

Source: NREL Center for Renewable Energy Resources sion technologies that are available and/or currently under development to produce biopower include pyrolysis and gasification. Biomass gasification (using high-efficiency combined cycle and, in later years, steam-injected gas turbines) represents the most promising approach to large-scale biopower development.

Biomass-fueled electric generation facilities have several attractive commercial applications, including cogeneration (production of both steam/heat and electricity in industrial facilities), and central station generation. At the end of 1998, nearly 1,900 megawatts of wood-fired, biomass-fueled utility power plants were operating in the United States. Another 5,500 megawatts of wood-fired cogeneration plants were operating, primarily in the pulp and paper industry. Similar to pulverized coal-fired plants, biomass-fired plants produce dispatchable, baseload and load-following power. Additionally, a packaged, modular power plant that can be specifically tailored to meet domestic and international market requirements for smaller-scale, grid-connected and off-grid power systems is under development.

The future direction of biomass power is to create a new energy industry in which farms would cultivate dedicated energy crops including fast-growing trees (such as poplar or willow), switchgrass, and alfalfa. This trend will convert the biomass power industry from one that depends on transport of forest and agricultural residues to the power plant to one that grows its own dedicated fuel supply, thereby greatly expanding the size of this domestic renewable resource.

Geothermal

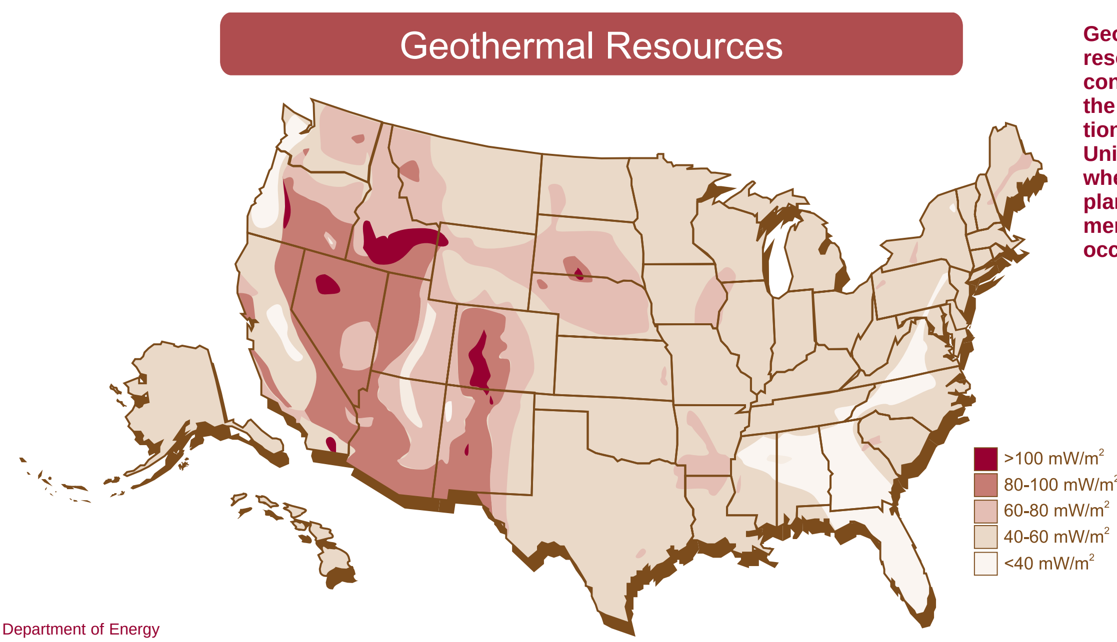
Geothermal power is a proven renewable technology with 70 plants in the United States (all in California, Nevada, Utah, and Hawaii) representing about 2,800 megawatts of installed electric generating capacity. The earliest domestic geothermal power plants were installed in the early 1960s at The Geysers geothermal field. Located north of San Francisco, California, The Geysers remains the most significant developed domestic geothermal resource.

Geothermal Resources Council

The Mammoth geothermal plant, located in the eastern Sierra Nevada mountain range in California, showcases the environmentally friendly nature of geothermal power. Three air-cooled binary units generate a total of 28 megawatts of electricity, and release essentially no emissions into the atmosphere or land surface.

Today, geothermal electricity production supplies the residential electricity needs of more than 5 million people. With continued improvements in technology, geothermal energy has the potential to supply as much as 50 percent of the nation's electrical power needs. Although the present industry is based solely on hydrothermal resources (those containing hot water and/or steam), the long-term future of geothermal energy lies in developing technology that uses the full range of the geothermal resource, including those that tap into hot rock that contains no natural water.

Geothermal energy is heat from the earth. The earth's



Geothermal resources are concentrated in the western portions of the United States where most of the plant development has occurred to-date.

Source: Department of Energy

center reaches temperatures greater than 4,000° C, and an immense amount of heat flows continuously to the surface. This flow of heat drives many global geologic processes. Some of these processes concentrate heat in shallow areas of the earth's crust, where they can be more easily accessed.

A few high-temperature resources produce dry steam, rather than hot water, which is fed straight to a turbine (dry-steam geothermal power plants). In the more usual case of flashed-steam geothermal power plants, however, hot water is brought from underground hydrothermal reservoirs to the surface through production wells. As the pressure is reduced, much of the hot water flashes to steam, which is then separated from the liquid and fed into a turbine. The remaining geothermal fluid is recycled by pumping it back into the reservoir.

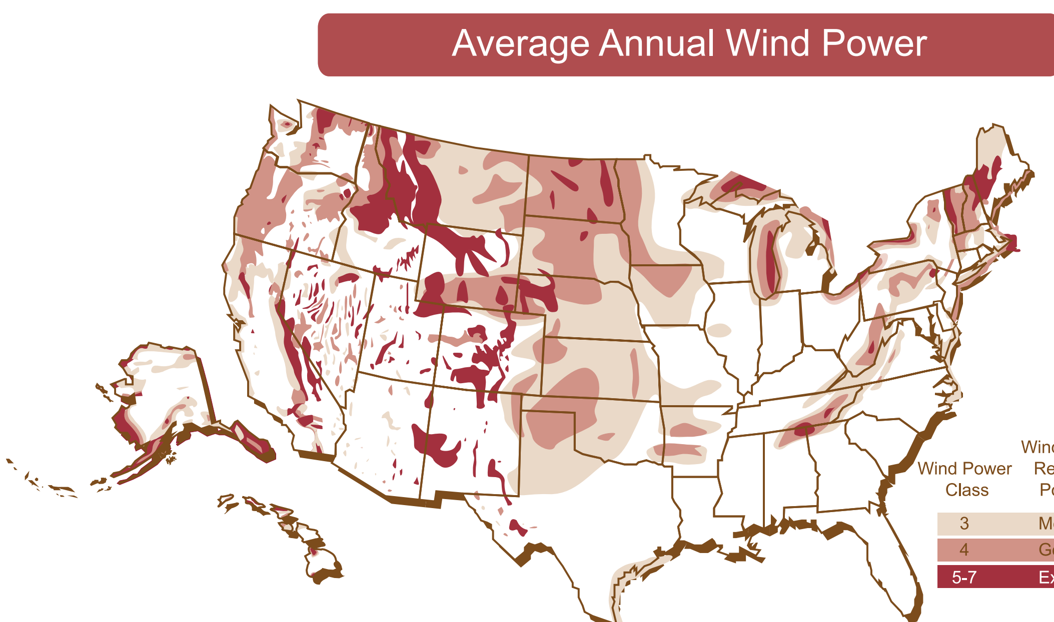
Advanced technologies offer the promise of allowing use of presently non-economic geothermal resources. For example, variations in binary cycles are extending the commercial use of geothermal power to hydrothermal reservoirs with moderate temperatures (100° to 160° C). Binary power plants use a secondary working fluid, evaporated by the geothermal fluid, to drive the turbine. Current research in enhanced geothermal systems — extracting heat from underground rock by injecting and circulating water through man-made fissures — has the potential to supply a significant portion of the nation's electricity and to bring geothermal power to every state.

Since no combustion process is involved in producing electricity, a geothermal power plant has no nitrogen oxide emissions. However, dry and flashed-steam plants do release some hydrogen sulfide and dissolved carbon dioxide, but these emission rates are usually a small percentage of those from a fossil-fueled power plant. Abatement systems are commonly used to limit hydrogen sulfide emissions to legally permissible levels. Emissions from a binary geothermal power plant are minimal because the geothermal fluid is never exposed to the atmosphere.

Traditionally, geothermal power systems have been operated to provide baseload electricity. Feasibility tests indicate that most of the installed systems can be cycled to follow the system load, thereby increasing their value in certain grid-connected and/or stand-alone applications. There is also interest in building small geothermal power plants, taking advantage of the modular nature of these units (from 200 to 3,500 kilowatts) to supply mini-grid power in remote locations with geothermal resources.

Wind Power

Wind power generation is a commercially available and competitively viable renewable technology option for producing electricity. Extracting energy from the wind is a centuries-old practice, however, modern turbines use aerodynamic designs that are far more efficient. The installed wind electric generation capacity of approximately 1,800 megawatts is about 2 percent of the total U.S. renewable electric capacity. Although California has the most installed wind electric capacity (1,600 megawatts), wind resources are broadly available across the United States. A Department of Energy study looked at the wind resources associated with land available for wind development in the continental United States. Excluding urban areas, much of the forest and agricultural land, and land that is environmentally sensitive, the study found that the new fleet of wind turbines could generate more than one and one-half times as much electricity as is now being used in the entire country. Moreover, future design improvements will make it cost effective to generate power in regions with lower average



Wind Power Class	Wind Energy Resource Potential	Average Wind Speed (mph) at 10m height
3	Moderate	12.5
4	Good	13.4
5-7	Excellent	14.3

Source: National Renewable Energy Laboratory

Moderate to excellent wind resources are found in most regions of the country. The majority of the usable wind resource is found in class 4 sites.

Lower Colorado River Authority

The Louisville Gas and Electric Company operates a 35-megawatt wind farm in west Texas. The local utility, Lower Colorado River Authority, purchases its electricity production, and land lease payments go to the Texas school systems.

wind speeds than the study considered. These advances could boost the potential for wind-generated electricity to more than four times as much electricity as the nation is now using.

Most wind facilities installed to date use propeller-like blades to capture the wind's energy. The rotating blades are connected through a shaft to a generator to produce electricity. Wind turbines are currently available in sizes from tens of watts up to the megawatt range. In the United States, the bulk of the installations is in windfarms where tens to hundreds of turbines are interconnected to the utility transmission grid through dedicated substations. However, there is growing interest in distributed wind facilities with individual or a small number of turbines connected directly to the local utility distribution system.

Wind power is a clean source of electric power with no air, water, or solid waste emissions. Development of windfarms, however, does carry with it potential localized environmental impacts associated with avian interactions, aesthetics, and acoustic emissions. The degree of these impacts can vary from none in some areas to levels of concern in others, depending on the site-specific characteristics of the project. Ongoing research, particularly avian studies, is seeking to identify ways to mitigate impacts at current installations and to minimize impacts from future developments.

Stand-alone or off-grid uses include power production for rural villages, communication stations, and use in conjunction with diesel systems. In a wind/diesel hybrid system, such as those being investigated in remote areas such as Alaska, the wind turbine can enhance reliability, reduce fuel costs, and provide local environmental benefits through emissions reductions.

Solar Thermal Power

Three solar thermal electric technologies are now in use or under development in the United States: parabolic trough systems, parabolic dish/engine systems, and central power towers. There are more than 350 megawatts of parabolic trough systems operating in southern California, which account for most of the world's grid-connected solar energy capacity. A number of parabolic dish/engine systems, which are in limited commercial production, are also operating in various locations in the United States and abroad. Finally, a 10-megawatt demonstration power tower has been tested in southern California.

Solar thermal systems use the sun's heat to generate electricity. Sunlight is focused with mirrors or lenses onto a thermal receiver/heat exchanger. The heat generated is used either to produce steam for electric power production or to drive a heat engine directly. Since solar power systems rely on the sun for energy, there are virtually no air, water, or solid waste emissions. Further, solar thermal plants can be built in modules and thus can be easily adapted to meet a variety of power needs and requirements. For example, small solar thermal systems can be used in applications ranging from electrification of remote villages, to distributed generation applications on existing power systems. Large solar thermal systems are suitable for central station applications to provide peaking power and, if integrated energy storage is incorporated, dispatchable power at other times of the day. In a hybrid configuration (solar and gas-fired combustion turbines), these plants can run continuously throughout the day and night, resulting in significant natural gas savings and emissions displacement.

Warren Gretz, NREL

Parabolic trough systems reflect and concentrate sunlight onto a receiver pipe located along the focal line of a curved, trough-shaped reflector. The heat generates steam to drive a turbine. This trough system is located at Kramer Junction, California, and has been operating since 1980.

Warren Gretz, NREL

Parabolic dishes are similar to trough systems except that they use a dish-shaped reflector. A heat engine (Stirling engine) mounted on the receiver drives a generator to produce electricity.

Dish/Stirling systems in the 5 kilowatt to 50 kilowatt range are being developed for grid-connected and remote power applications.

Photovoltaics

The total grid-connected photovoltaic generating capacity in the United States currently stands at about 25 megawatts, spread across 36 states. This grid-connected capacity is small compared to the total capacity of photovoltaic systems installed for non-grid-connected uses. Because the systems can be configured for a large variety of applications, they are finding their way into specialized markets where their relative economics are more favorable than those of the bulk power market. One such market that may grow rapidly is photovoltaic systems for buildings. The Clinton Administration's Million Solar Roofs Initiative will add about 3,000 megawatts to the United States' installed base of grid-connected photovoltaic systems by 2010. More importantly, with an increased volume of photovoltaic sales, the per unit cost of manufacturing will drive down photovoltaic system prices — following the "learning/experience curve."

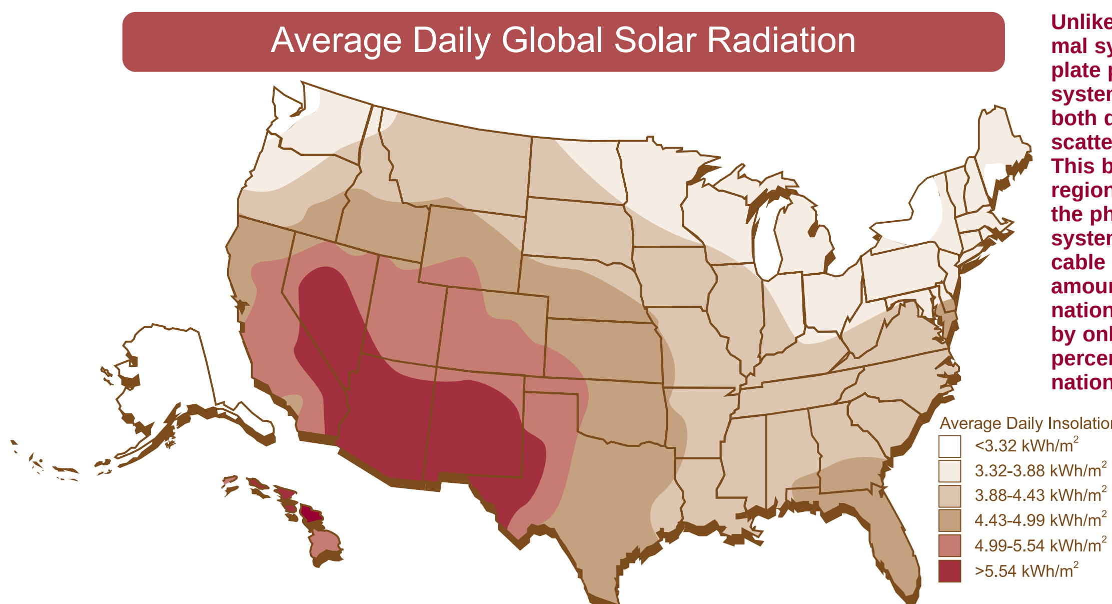
The basic unit in a photovoltaic system is the photovoltaic cell, which is made of semiconductor materials similar to those used in computer chips. Incoming sunlight is absorbed by these materials, freeing electrons from their atoms, and allowing the electrons to flow through an external circuit to generate electricity. The greater the intensity of the light, the more power is generated in the cell. Photovoltaic cells, which produce DC electricity, are usually connected together and enclosed in protective casings called modules. These in turn may be connected to an inverter to supply AC electricity.

Since photovoltaic systems use no moving parts to produce electricity, they are durable power systems with low maintenance, high reliability, and low environmental impacts. Because their basic building block, the module, is small, photovoltaic systems are suitable for both large and small electricity supply applications. For example, systems of several hundred kilowatts in size have been built in a number of locations. Some of these have been installed to supply electricity to the system owner, and others have been installed to provide operational support to the local utility distribution system.

Terry O'Rourke

Pacific Gas and Electric Company (PG&E) installed a 500-kilowatt photovoltaic system at its Kerman substation in 1993 to reinforce a weak feeder. PG&E found that distributed systems like this have measurable benefits such as increased system reliability and peak-shaving capabilities.

As described earlier, most systems installed to-date have been in off-grid or in customer-sited applications. Manufacturers are beginning to make photovoltaic arrays that not only produce power but also serve as an integral part of a building. These may take the form of photovoltaic shingles, light-filtering skylights, or overhangs. In off-grid or stand-alone applications, markets for photovoltaic systems include individual homes, campsites, and village power (providing lighting, refrigeration, and electricity for remote villages). They can also be used as fuel savers in hybrid systems, particularly those using diesel fuel and propane. Currently, the largest market for rural electrification is in developing countries.



Unlike solar thermal systems, flat-plate photovoltaic systems can use both direct and scattered sunlight. This broadens the regions in which the photovoltaic systems are applicable — the amount of sunlight nationwide varies by only about 30 percent from the national average.

Source: NREL Center for Renewable Energy Resources