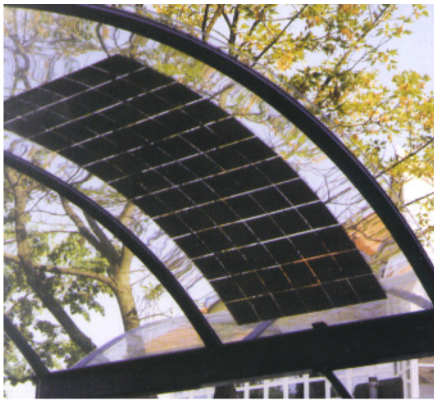
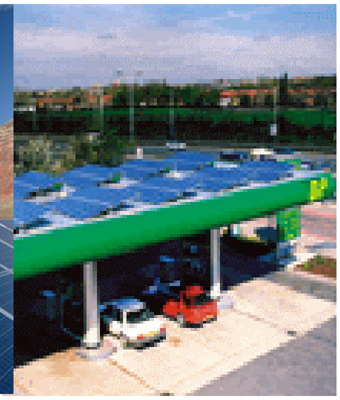
2.3.2 SOLAR PHOTOVOLTAIC POWER

Technology Description



Semi-transparent PV canopy

PV solar arrays for larger-scale electricity.



PV panels on rooftop.

Solar photovoltaic (PV) arrays convert sunlight to electricity without moving parts and without producing fuel wastes, air pollution, or greenhouse gases. Using solar PV for electricity – and eventually using solar PV for transportation in electric vehicles or by producing hydrogen from water – will help reduce carbon dioxide emissions worldwide.

System Concepts

- Flat-plate PV arrays use global sunlight; concentrators use direct sunlight. Modules are mounted on a stationary array or on single- or dual-axis sun trackers. Arrays can be ground-mounted or on all types of buildings and structures (e.g., see semi-transparent solar canopy, right). The DC output from PV can be conditioned into grid-quality AC electricity, or DC can be used to charge batteries or to split water to produce hydrogen.
- PV systems are expected to be used in the United States for residential and commercial buildings, peak power shaving, and intermediate daytime load following. With energy storage, PV can provide dispatchable electricity and/or produce hydrogen.
- Almost all locations in the United States and worldwide have enough sunlight for PV. For example, U.S. sunlight in the contiguous states varies by only about 25% from an average in Kansas. Land area is not a problem for PV. Not only can PV be more easily sited in a distributed fashion than almost all alternatives (for example, on roofs or above parking lots), a PV-generating station 140 km by 140 km sited at a high solar location in the United States (such as the desert Southwest) could generate all of the electricity needed in the country (2.5×10^6 GWh/year, assuming a system efficiency of 10% and an area packing factor of 50% to avoid self-shading).

Representative Technologies and Status

- Wafers of single-crystal or polycrystalline silicon – best cells: 25% efficiency; commercial modules: 13%-17%. Silicon modules dominate the PV market and currently cost about \$2/W_p to manufacture.
- Thin-film semiconductors (e.g., amorphous silicon, copper indium diselenide, cadmium telluride, and dye-sensitized cells) – best cells: 12%-19%; commercial modules: 5%-11%. A new generation of thin-film PV modules is going through the high-risk transition to first-time and large-scale manufacturing. If successful, market share could increase rapidly.
- High-efficiency, single-crystal silicon and multijunction gallium-arsenide-alloy cells for concentrators – best cells: 25%-37% efficient; commercial modules: 15%-24%; prototype systems are being tested in high solar areas in the southwest United States.
- Grid-connected PV systems currently sell for about \$5-\$8/W_p (20¢-32¢/kWh), including support structures, power conditioning, and land.

Current Research, Development, and Demonstration

RD&D Challenges and Goals

- Improve fundamental understanding of materials, processes, and devices to provide a technology base for advanced PV options.
- Optimize PV cell materials, cell designs, and modules; scale up laboratory cell results to product size (10^4 increase in area).
- Validate new module technologies outdoors and in accelerated testing to achieve 30-year outdoor lifetimes.
- Improve and invent new low-cost processes and technologies; reduce module and balance-of-systems manufacturing costs.
- Address substantial technical issues associated with high-yield, first-time, and large-scale (>100 MW/yr) manufacturing for advanced technologies.
- Develop and validate new, lower-cost systems hardware and integrated applications.
- Meet long-term, cost-competitive goal of manufacturing and installing PV systems under $\$1/W_p$.

RD&D Activities

- Capabilities at national labs and university centers of excellence have been developed, both in expertise and unique facilities. Funding is split 50-50 between national labs and external contracts with universities and industry. Public/private R&D partnerships, including extensive national R&D teams, have been the favored approach. All subcontracts have been awarded via competitive solicitations to select the best and most committed research partners.
- DOE and the National Center for Photovoltaics have worked with state regulatory agencies and influenced the direction of state programs.
- The Department of Defense (DOD) has some funding through special programs in which PV has a role supplying power for military systems.
- The National Aeronautics and Space Administration (NASA) has some research funds for PV. Though this effort has decreased during the past decade, advanced PV has become even more important for space missions (e.g., the high-performance cells on the Sojourner probe on Mars).
- Japan and Europe have significant funding for PV research.
- States have individual subsidy and utility portfolio programs related to PV; for example, California has a buy-down program for residential and commercial PV systems.
- U.S. PV businesses are marginally or not yet profitable and are unable to fund their own advanced research for low-cost PV.

Recent Progress

- Because of public/private partnerships, such as the Thin-Film Partnership with its national research teams, U.S. PV technology leads the world in measurable results such as record efficiencies for cells and modules. Another partnership, the PV Advanced Manufacturing R&D program, has resulted in industry cost reductions of more than 60% and facilitated a sixteen-fold increase of manufacturing capacity during the past 12 years.
- A new generation of potentially lower-cost technologies (thin films) is entering the marketplace. A 25-megawatt amorphous silicon thin-film plant by United Solar is reaching full production in 2005. Two plants (First Solar and Shell Solar) using even newer thin films (cadmium telluride and copper indium diselenide alloys) are in first-time manufacturing at the MW-scale. Thin-film PV has been a focus of the Federal R&D efforts of the past decade because it holds considerable promise for module cost reductions.
- During the past two years, record sunlight-to-electricity conversion efficiencies for solar cells were set by federally funded universities, national labs, or industry in copper indium gallium diselenide (19%-efficient cells and 13%-efficient modules) and cadmium telluride (16%-efficient cells and 11%-efficient modules). Cell and module efficiencies for these technologies have increased more than 50% in the past decade.
- A unique multijunction gallium-arsenide-alloy cell was spun off to the space power industry, leading to a record cell efficiency (35%) and an R&D 100 Award in 2001. This device configuration is expected to dominate future space power for commercial and military satellites.

Commercialization and Deployment Activities
• Worldwide, more than 510 MW of PV were sold in 2002, with systems valued at more than $5 billion; total installed PV is about 2 GW. The U.S. world market share is about 20%. • Worldwide, market growth for PV has averaged 25%/year for the past decade as a result of reduced prices and successful global marketing. In 2001, sales grew 36%, and in 2002, 31%. About two-thirds of U.S.-manufactured PV is exported. • Hundreds of applications are cost effective for off-grid needs. However, the fastest growing segment of the market is grid-connected PV, such as roof-mounted arrays on homes and commercial buildings in the United States. California is subsidizing PV systems to reduce their dependence on natural gas, especially for peak daytime loads which match PV output, such as air-conditioning. **Market Context** • Electricity for remote locations, especially for billions of people worldwide who do not have electricity. • U.S. markets: retail electricity for residential and commercial buildings; distributed utility systems for grid support, peak-shaving, and other daytime uses. • Future electricity and hydrogen storage for dispatchable electricity, electric car-charging stations, and hydrogen production for portable fuel.