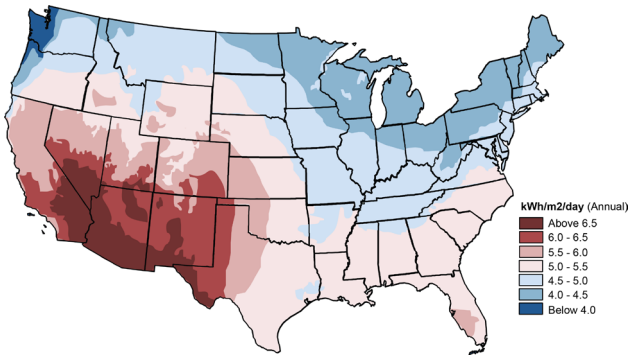
Photovoltaic Energy

Solar energy can be harnessed in two basic ways. First, solar thermal technologies utilize sunlight to heat water for domestic uses, warm building spaces, or heat fluids to drive electricity-generating turbines. Second, photovoltaics (PVs) are semiconductors that generate electrical currents from sunlight. Only 1.6% of U.S. electricity was generated with solar technologies in 2018, in part because direct costs are high.[1]

Solar Resource and Potential

- On average, 1.05 x 10^5 terawatts (TW) of solar radiation reach the Earth's surface, while global electricity demand averages 2.5 TW.[3,4]
- Electricity demand peaks in the morning and evening, while PV generation peaks around mid-day. This is often referred to as the "duck curve" and leads to either energy surplus or deficits. Energy storage, and demand forecasting may play roles in eliminating these surpluses and deficeits.[5]
- PVs can be installed where electricity is used to reduce stress on electricity distribution networks, especially during peak demand.[6]
- PV conversion efficiency is the percentage of incident solar energy that a PV converts to electricity.[7]
- Though most commercial panels have efficiencies from 15% to 20%, some researchers have developed PV cells with efficiencies approaching 50%.[8,9]
- Assuming intermediate efficiency, PVs covering 0.6% of U.S. land area would generate enough electricity to meet national demand.[7]
- In 2011, the Department of Energy announced the SunShot Initiative. Its aim was to reduce the cost of solar energy by 75%, making it cost competitive with other energy options. In 2017, DOE announced that the 2020 goal of utility scale solar for $0.06/kWh had been achieved three years earlier than expected. The 2030 goal includes reducing utility scale solar energy to $0.03/kWh, allowing it to out compete traditional fossil fuel energy resources.[10]

Annual Average Solar Radiation[2]



PV Technology Types and Efficiencies[9,11]

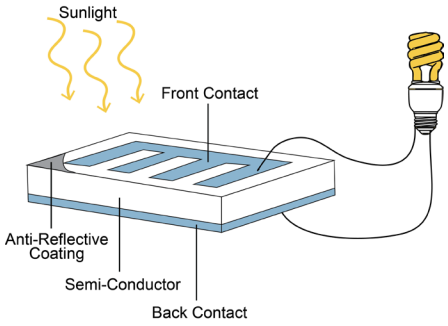
PV Technology		Cell Conversion Efficiency	Module Conversion Efficiency
Crystalline	monocrystalline silicon (Si)	26.1%	22.7% - 24.4%
	polycrystalline Si	22.3%	19.9%
	Gallium arsenide (GaAs)	27.8 - 30.5%	25.1%
Thin film	amorphous Si (a-Si)	14.0%	8.2%
	Cadmium telluride (CdTe)	22.1%	18.6%
	CIS / CIGS	23.4%	16.6% - 19.2%

PV Technology and Impacts

PV Cells

- PV cells are made from semiconductor materials that eject electrons when photons strike the surface, which produce an electrical current.[14]
- Most PV cells are small and rectangular, and produce a few watts of direct current (DC) electricity.[15]
- PV cells also include electrical conductors called contacts, which allow for the flow of electrons to the external load, and surface coatings to reduce light reflection.[16]
- A variety of semiconductor materials can be used for PVs, including silicon, copper indium diselenide (CIS), and cadmium telluride (CdTe).[17] Although PV conversion efficiency is an important metric, cost efficiency—the cost per watt of power—is more important for most power applications. Some very cost efficient cells do not have high conversion efficiencies.

PV Cell Diagram[12]



PV Modules and Balance of System (BOS)

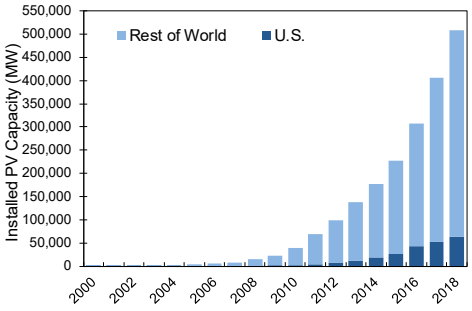
- PV modules typically comprise a rectangular grid of 60 to 72 cells, connected in several parallel circuits and laminated between a transparent front surface and a protective back surface. They usually have metal frames for strength and weigh 34 to 62 pounds.[17]
- A PV array is a group of modules, connected electrically and fastened to a rigid structure.[18]
- BOS components include any elements necessary in PV systems in addition to the actual PV panels, such as wires that connect modules in series, junction boxes to merge the circuits, mounting hardware, and power electronics that manage the PV array's output.[18]
- An inverter is a power electronic device that converts electricity generated by PV systems from DC to alternating current (AC).[18]
- A charge controller is a power electronic device used to manage energy storage in batteries.[18]
- In contrast to a rack-mounted PV array, Building Integrated PV (BIPV) replaces building materials to improve PV aesthetics and costs.[19]
- Some PV arrays employ a solar tracker. This technology can increase energy output by as much as 100%.[20]

2.2 kW Residential BIPV System[13]

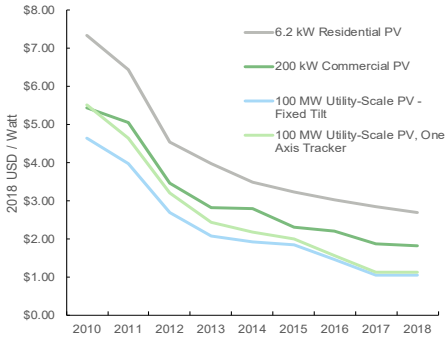
PV Installation, Manufacturing, and Cost

- In 2018, global PV power capacity grew by over 100 GW and reached 509.3 GW, it has increased by more than 30-fold since 2008.[24]
- The top installers in 2018 were China (44.4 GW), the U.S. (10.6 GW) and India(8.3 GW).[24]
- Though installed PV capacity in 2018 was only 4% higher than 2017, compared to double-digit growth in previous years, more solar capacity was installed than all fossil fuels and nuclear energy capacity combined. Even with this significant growth, solar power only accounts for 2.2% of global power generation.[24]
- The cost of solar electricity has dropped over 85% since 2008. Certain analyses have shown solar power prices in the range of 2 cents/kWh.[24] In comparison, retail electricity averaged 10.58¢/kWh for all sectors and 12.89¢/kWh for residential consumers in 2018.[1]
- In 2018, global investments in solar power dropped significantly to $130.8 billion. This is likely partially due to declining capital costs of PV systems.[26]
- PV systems or components are manufactured in over 100 factories across 30 states.[17]

World Cumulative Installed PV Capacity[21,22,23,24]



Median Installed Price, Residential & Commercial PV Systems[25]



Energy Performance and Environmental Impacts

- Net energy ratio compares the life cycle energy output of a PV system to its life cycle primary energy input. One study shows that amorphous silicon PVs generate 3 to 6 times more energy than are required to produce them.[27]
- Recycling multi-crystalline cells can reduce manufacturing energy over 50%.[28]
- Although pollutants and toxic substances are emitted during PV manufacturing, life cycle emissions are low. For example, the life cycle emissions of thin-film CdTe are roughly 14 g CO_2e per kWh delivered, far below electricity sources such as coal (1,001 g CO_2e/kWh).[29,30]
- PVs can reduce environmental impacts associated with fossil fuel electricity generation; for example, thermoelectric plants use an average of 15 gallons of water to produce one kWh of electricity.[31]

Solutions, Sustainable Actions, and Future Technology

Policies Promoting Renewables

- The price consumers pay for electricity does not cover externalities such as the cost of health effects from air pollution, environmental damage from resource extraction, or long-term nuclear waste storage.[32] For instance, in 2011, Harvard Medical School estimated the external costs of coal to be around $345 billion annually.[32] Policies that support PVs can address these externalities to make PV energy more cost-competitive.[32]
- Proposed carbon cap-and-trade policies would work in favor of PVs by increasing the cost of fossil fuel energy generation.[34]
- PV policy incentives include renewable portfolio standards (RPS), feed-in tariffs (FIT), capacity rebates, and net metering.[35]
  - An RPS requires electricity providers to obtain a minimum fraction of their energy from renewable resources by a certain date.
  - An FIT sets a minimum per kWh price that retail electricity providers must pay renewable electricity generators.
  - Capacity rebates are one-time, up-front payments for building renewable energy projects, based on installed capacity (in watts).
  - With net metering, PV owners get credit from the utility (up to their annual energy use) if their system supplies power to the grid.

What You Can Do

- "Green pricing" allows customers to pay a premium for electricity that supports investment in renewable technologies. At least 850 utilities in nearly all 50 states offer some version of this green pricing. Renewable Energy Certificates (RECs) can be purchased in addition to commodity electricity to "offset" electricity usage and help renewable energy become more competitive.[36,37]

Future Technology

- Two emerging PV technologies are bifacial PV modules and concentrator PV (CPV) technology. Bifacial modules are able to collect light on both sides of the PV cells, which can improve electricity generation depending on environmental conditions. CPV utilizes low-cost optics to concentrate light onto a small solar cell. By reducing the area of PV cell needed, more resources can be focused on high efficiency cells.[38,39]

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Cite as: Center for Sustainable Systems, University of Michigan. 2019. "Photovoltaic Energy Factsheet." Pub. No. CSS07-08. **August 2019**