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 current from sunlight. Only 1.8% of U.S. electricity was generated with solar technologies in 2019.\(^1\)

**Solar Resource and Potential**

- On average, \(1.73 \times 10^5\) terawatts (TW) of solar radiation continuously strike the Earth, while global electricity demand averages 2.6 TW.\(^3,4\)
- Electricity demand peaks around mid-day, leading to energy surplus and deficits. Energy storage and demand forecasting will help to match PV generation with demand.\(^5\)
- If co-located with load centers, solar PV can be used to reduce stress on electricity distribution networks, especially during peak demand.\(^6\)
- PV conversion efficiency is the percentage of incident solar energy that is converted 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.\(^10\)
- In 2011, the U.S. Department of Energy (DOE) 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, cheaper than electricity from fossil fuel energy resources.\(^11\)

**PV Technology and Impacts**

**PV Cells**

- PV cells are made from semiconductor materials that eject electrons when photons strike the surface, producing an electrical current.\(^15\)
- Most PV cells are small, rectangular, and produce a few watts of direct current (DC) electricity.\(^16\)
- PV cells also include electrical contacts that allow electrons to flow to the load and surface coatings that reduce light reflection.\(^15\)
- A variety of semiconductor materials can be used for PVs, including silicon, copper indium gallium diselenide (CIGS), cadmium telluride (CdTe), and even some organic compounds (OPV).\(^15\)
- Although PV conversion efficiency is an important metric, cost efficiency—the cost per watt of power—is more important for most applications.

**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 structural back surface. They usually have metal frames 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 addition to the actual PV panels, such as wires that connect modules, 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, which themselves can be BOS components.\(^18\)
- In contrast to a rack-mounted PV array, Building Integrated PV (BIPV) replaces building materials (e.g., shingles) to improve PV aesthetics and costs.\(^19\)
- Some ground-mount PV arrays employ a solar tracker. This technology can increase energy output by as much as 100%.\(^20\)
PV Installation, Manufacturing, and Cost

- In 2019, global PV power capacity grew by over 115 GW and reached 633.7 GW. Solar PV capacity has grown by nearly 400 times since 2000.\(^{23}\)
- Top installers in 2019 were China (30.1 GW), the U.S. (13.3 GW), and India (8.9 GW).\(^ {23}\)
- New PV installations grew by 13% in 2019 and accounted for 48% of global power plant capacity additions. Even with this growth, solar power only accounts for 2.6% of global power generation.\(^ {43}\)
- The cost of solar power has dropped nearly 89% since 2009. Various contracts have been signed around the world with solar power prices as low as 1.22¢/kWh; this is much cheaper than conventional power sources.\(^ {23}\) In comparison, U.S. retail electricity averaged 10.60¢/kWh for all sectors and 13.04¢/kWh for residential consumers in 2019.\(^ {7}\)
- In 2019, global investment in solar power dropped to $131.1 billion. This is partially a result of declining capital costs of PV systems.\(^ {45}\)
- PV system/component manufacturing employed 34,000 people in the U.S. in 2018.\(^ {46}\)

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 showed that amorphous silicon PVs generate 3 to 6 times more energy than are required to produce them.\(^ {7}\)
- Recycling multi-crystalline cells can reduce manufacturing energy by over 50%.\(^ {48}\)
- 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 CO₂e per kWh delivered, far below electricity sources such as coal (1,001 g CO₂e/kWh).\(^ {29,20}\)
- PVs can have lower environmental impacts than fossil fuel electricity generation; for example, thermoelectric plants use an average of 15 gallons of water per kWh generated.\(^ {31}\)

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.\(^ {26}\) Property assessed clean energy (PACE) programs allow property owners to finance the upfront costs of a solar installation through a voluntary assessment on annual property taxes.\(^ {33}\) Green banks and other lending institutions are being developed to specifically fund and support clean energy projects on local, regional, and national scales.\(^ {24}\)
- Carbon cap-and-trade policies would work in favor of PVs by increasing the cost of fossil fuel energy generation.\(^ {25}\)
- PV policy incentives include renewable portfolio standards (RPS), feed-in tariffs (FIT), capacity rebates, and net metering.\(^ {26}\)
- An RPS requires electricity providers to obtain a minimum fraction of their energy from renewable resources by a certain date.
- A 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) for energy returned to the grid.

What You Can Do

- “Green pricing” allows customers to pay a premium for electricity that supports investment in renewable technologies. Renewable Energy Certificates (RECs) can be purchased to “offset” commodity electricity usage and help renewable energy become more competitive.\(^ {37,38}\)

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.\(^ {36,39}\)

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34. Clean Energy Credit Union (2020) “Our Story.”