

# 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 electricity directly from sunlight. Solar technologies generated 3.4% of U.S. electricity in 2022.<sup>1</sup>

## 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 2.9 TW.<sup>3,4</sup>
- Electricity demand varies throughout the day. Energy storage and demand forecasting will help to match PV generation with demand.<sup>5</sup>
- If co-located with demand, solar PV can be used to reduce stress on electricity distribution networks, especially during demand peaks.<sup>6</sup>
- PV conversion efficiency is the percentage of incident solar energy that is converted to electricity.<sup>7</sup>
- Though most commercial panels have efficiencies from 17% to 20%, researchers have developed PV cells with efficiencies approaching 50%.<sup>8,9</sup>
- Assuming intermediate efficiency, PV covering 0.6% of U.S. land area would generate enough electricity to meet national demand.<sup>10</sup>
- 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 early. The 2030 goal includes reducing utility-scale solar energy to \$0.03/kWh, cheaper than electricity from fossil fuel energy resources.<sup>11</sup>

## PV Technology and Impacts

### PV Cells

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

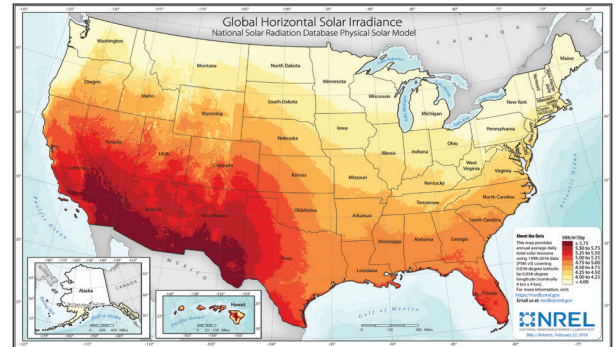
### PV Modules and Balance of System (BOS)

- PV modules typically comprise a rectangular grid of 60 to 72 cells, laminated between a transparent front surface and a structural back surface. They usually have metal frames and weigh 34 to 62 pounds.<sup>17</sup>
- A PV array is a group of modules, connected electrically and fastened to a rigid structure.<sup>18</sup>
- 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.<sup>18</sup>
- An inverter is a power electronic device that converts electricity generated by PV systems from DC to alternating current (AC).<sup>18</sup>
- A charge controller is a power electronic device used to manage energy storage in batteries, which themselves are BOS components.<sup>18</sup>
- In contrast to a rack-mounted PV array, Building Integrated PV (BIPV) replaces building materials such as shingles and improves PV aesthetics.<sup>19</sup>
- Some ground-mount PV arrays employ a solar tracker. This technology can increase energy output by up to 100%.<sup>20</sup>

### PV Installation, Manufacturing, and Cost

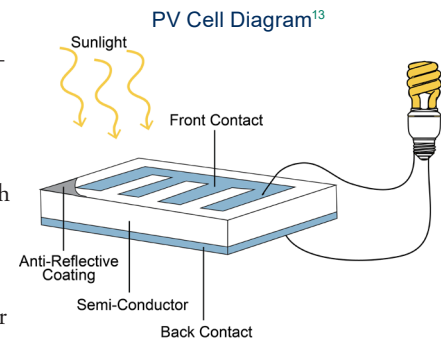
- In 2022, global PV power capacity grew by 239 GW and reached almost 1,200 GW, or 1.2 Terawatt (TW). Solar PV capacity has grown by nearly 750 times since 2000.<sup>23</sup>
- Top installers in 2022 were China (94.7 GW), the U.S. (21.9 GW), and India (17.4 GW).<sup>23</sup>
- New PV installations grew by 45% in 2022 and accounted for 66% of global renewable capacity

Annual Average Solar Radiation<sup>2</sup>



PV Technology Types and Efficiencies<sup>9,12</sup>

	PV Technology	Conversion Efficiency	
		Cell	Module
Crystalline	Monocrystalline silicon (Si)	27.6%	24.4%
	Multicrystalline Si	23.3%	20.4%
	Multi-junction Gallium arsenide (GaAs)	47.6%	38.9%
Thin film	Cadmium telluride (CdTe)	22.3%	19.5%
	CIGS	23.6%	19.2%
Emerging	Perovskite/Si tandem	33.7%	-
	Perovskite	26.0%	17.9%
	Organic	19.2%	13.1%



Residential PV System<sup>14</sup>



additions. Even with this significant growth, solar power only accounts for 4.5% of global power generation.<sup>23</sup>

- The cost of solar power has dropped over 80% since 2009. Various contracts have been signed around the world with solar power prices as low as 1-2¢/kWh; this is much cheaper than conventional power sources.<sup>24</sup> In comparison, U.S. retail electricity averaged 12.49¢/kWh for all sectors and 15.12¢/kWh for residential users in 2022.<sup>1</sup>
- In 2023, global investment in solar power is estimated to be \$380 billion. This accounts for 14% of the total amount invested in energy worldwide.<sup>25</sup>
- Including sectors such as manufacturing, sales, distribution, and installation, there are over 231,000 U.S. solar jobs.<sup>16</sup>

## 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.<sup>26</sup>
- Reusing multi-crystalline cells can reduce manufacturing energy by over 50%.<sup>27</sup>
- 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<sub>2</sub>e per kWh delivered, far below electricity sources such as coal (1,001 g CO<sub>2</sub>e/kWh).<sup>28,29</sup>
- PVs on average consume less water to generate electricity (26 gallons per MWh), compared to non-renewable technologies such as coal (687 gallons per MWh).<sup>30</sup>

## Solutions, Sustainable Actions, and Future Technology Policies Promoting Renewables

- Consumers that do not have roof space for PV panels can join community solar programs, which are local solar projects that community members can share and receive credit on their electricity bills.<sup>31</sup> 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.<sup>32</sup> Green banks and other lending institutions are being developed to specifically fund and support clean energy projects on local, regional, and national scales.<sup>33</sup>
- Carbon cap-and-trade policies would work in favor of PVs by increasing the cost of fossil fuel energy generation.<sup>34</sup>
- The Inflation Reduction Act of 2022 expanded the federal Investment Tax Credit (ITC) to 30% until 2032 for the installation of a solar PV system, a savings of over \$7,500 for an average system.<sup>35</sup>
- PV policy incentives include renewable portfolio standards (RPS), feed-in tariffs (FIT), capacity rebates, and net metering.
  - An RPS requires electricity providers to obtain a minimum fraction of energy from renewable resources.<sup>36</sup>
  - A FIT sets a minimum per kWh price that retail electricity providers must pay renewable electricity generators.<sup>37</sup>
  - Capacity rebates are one-time, up-front payments for building renewable energy projects, based on installed capacity (in watts).<sup>37</sup>
  - With net metering, PV owners get credit from the utility (up to their annual energy use) for energy returned to the grid.<sup>37</sup>

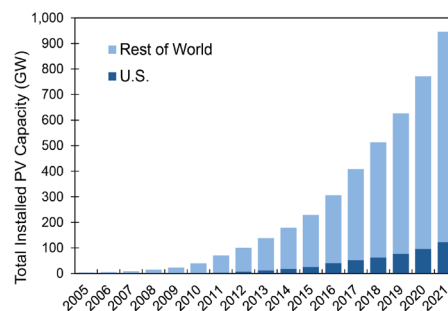
## What You Can Do

- “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.<sup>38</sup>

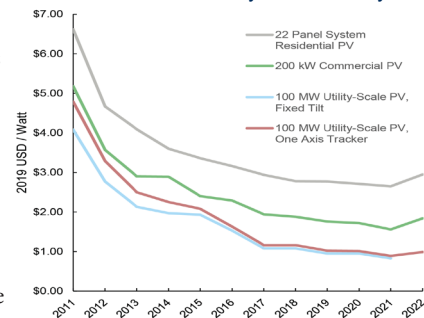
## Future Technology

- Emerging PV technologies include perovskites, bifacial PV modules, and concentrator PV (CPV) technology. Perovskite solar cells have a high conversion efficiency (over 25%) and low production cost. Bifacial modules are able to collect light on both sides of the PV cells. CPV utilizes low-cost optics to concentrate light onto a small solar cell.<sup>39,40,41</sup>
- Designing for end-of-life could improve the current 10% rate of PV module recycling.<sup>42</sup>

World Cumulative Installed PV Capacity<sup>21</sup>



Median Installed Price, Residential, Commercial, and Utility-Scale PV Systems<sup>22</sup>



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