RENEWABLE ENERGY

A NONTECHNICAL GUIDE

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BOOKS

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A TALE OF TWO DECADES

Since the first edition of this book was published in 2004, many aspects of renewable energy have changed markedly, while others are just as remarkably the same.

Take wind turbines, for example. Over the two decades since 2004, wind turbines have steadily grown larger in size and power. The average size, or capacity, of newly installed wind turbines in 2021 in the United States was 3.0 megawatts (MW), an increase of more than 300% since the early 2000s. Those larger, higher-capacity machines mean that fewer turbines in total are needed to generate the same amount of energy across a wind farm, helping to control project costs.[1]

When it comes to solar, the core photovoltaic (PV) cell technology was developed in the mid-1950s and largely has remained unchanged over the decades. Notably, however, PV cells today are more efficient in converting the sun's rays into electricity. And, although cell technology was pioneered in the U.S., solar equipment supply chains over the past 20 years have shifted to China, which now ranks as the world's dominant manufacturer. That shift drove down the cost of deploying large amounts of solar generating capacity. Ongoing human rights and trade disputes between governments in Western countries and Beijing, however, have put solar at the center of increasingly worrisome geopolitical tensions.

Back in 2004, a Nevada business was set to play host to a 214.5-kilowatt (kW) solar PV installation, at the time the state's largest. Two decades later, the Silver State counted nearly 100 solar installations in total, with a combined generating capacity of more than 5.3 gigawatts (equal to 5,300 MW or 5,300,000 kW). That installed capacity was on track to grow larger still with the expected completion in 2023 of the 690-MW Gemini solar project not far from the electricity-powered glitter and glam of the Las Vegas Strip. With a price tag of around $1.3 billion, the project in the Nevada desert would join the ranks of the world's largest.

Solar deployment over the decades has not been limited to the U.S. by any means. The German town of Neustadt, south of Frankfurt, was the site in 2004 of the world's largest solar power plant. Rated at 2 MW of capacity, the solar farm occupied 17 acres of land, roughly the size of seven soccer fields. Developers said its power output on sunny days could power 700 houses.

U.S. renewable energy consumption

During 2019, energy consumption from renewable sources—wind, solar, hydro, biomass, and geothermal—surpassed coal-fired sources for the first time in the U.S. since the 19th century. A year earlier, renewable generation passed nuclear generation for the first time.

As shown in Figure 3-1, new electric generating capacity in the U.S. during 2023 was expected to come largely from solar (52%) and wind (13%). Natural gas was expected to be the only fossil fuel type to add new capacity. In contrast, nearly all the capacity being retired during the year was fossil fuel-based, led by coal (62%) and older, less efficient natural gas units (36%). In total, some 56.1 GW of new capacity was on track to be added in 2023 while 14.5 GW of capacity was being retired. That was expected to result in a net gain of 41.6 GW of capacity.[21]

The EIA said that the total amount of utility-scale solar capacity rose from 61 GW in 2021 to 71 GW in 2022. Wind capacity, meanwhile, grew from 133 GW to 141 GW in 2022.

Wind was a particularly big energy resource in Texas, which produced more wind-generated power than any other state. The Lone Star State accounted for 26% of total U.S. wind generation in 2022, followed by Iowa (10%) and Oklahoma (9%). One of the largest wind farms in the United States (with a capacity of nearly 1,000 MW) came online in Oklahoma in 2022.

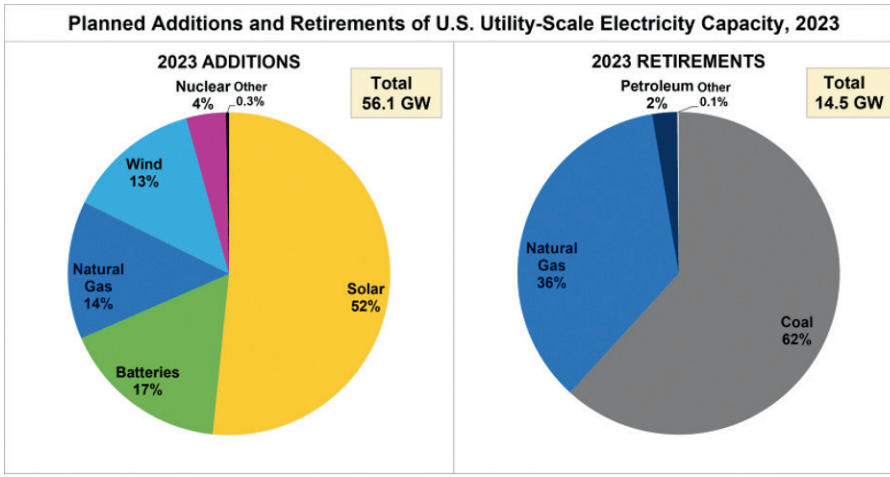

Figure 3-1: Data from the Energy Information Administration showed that planned new capacity additions in 2023 were primarily solar and wind. Nearly all planned generating plant retirements were based on fossil fuels. Credit: U.S. Energy Information Administration[22].

laws have been in place since the 1930s that prohibit the importation of goods made by forced labor. The recent allegations tied to solar production have led to action in the United States and the European Union to ban the import of solar cells and other manufactured goods whose supply chains are suspected of including forced labor.

And, although pioneering work on silicon-based solar cell technology took place in the U.S., efforts in the early 2000s to drive down production costs resulted in most manufacturing being relocated to China, which offered low-cost labor and efficient manufacturing. A relative handful of Chinese companies now hold a dominant market share of silicon-based solar cell production. Those manufacturers now wield significant power over supply chains and module availability. Thus, in the global push to decarbonize electricity production, energy from the sun—free and available everywhere to everyone—has become a geopolitical point of contention.

Then, in mid-August 2023, a year-long U.S. Department of Commerce investigation ended with a finding that a handful of producers based in China had been using production facilities in Cambodia, Malaysia, Thailand, and Vietnam to avoid paying what are known as antidumping and countervailing duties (AD/CVD) on solar cells.[39] The federal government's finding upheld a finding from late 2022 that concluded multiple Chinese companies used the four Southeast Asian countries to perform only minor work at best on solar modules. Arrangements were put in place, federal Commerce officials determined, to enable the companies to dodge paying import duties imposed in 2012 after it was first determined that U.S. companies were at a competitive disadvantage because of unfair trade practices. Table 4-1 highlights a decade's worth of trade rulings affecting crystalline silicon photovoltaics imported to the U.S.

The Commerce Department's finding, which was made final in August 2023, was not expected to have an immediate impact on solar imports. Under pressure to deliver an aggressive domestic clean energy agenda, President Joseph R. Biden in June 2022 ordered that duties not be collected on any solar module or cell imports from the four Asian countries until June 2024 at the earliest. The delay was intended to give U.S. solar importers time to shift their supply chains.

One long-overlooked aspect of solar modules is what happens to them at the end of their useful life. Solar module recycling is just getting underway. At present, most panels—along with reusable materials such as aluminum, glass, and silver—end up in landfills. The topic of recycling is covered in more detail in Chapter 14.

An emerging criticism centers on the amount of land that large-scale solar PV projects require, raising questions over whether solar farms should occupy what in many cases is prime agricultural land. In Nebraska, for example, an 81-MW project was slated to enter service in 2024 and supply power to the Omaha Public Power District using solar panels sited across 500 acres. Another half-dozen large-scale projects also were in the works, but a lawsuit filed by landowners aimed to stop the projects entirely.

Such cracking is not unique to the wind industry but can be found in automotive, rail, and even washing machine bearings. In 2020, a group of researchers working at Department of Energy laboratories outfitted a 1.5-MW wind turbine with instrumentation to gather experimental data at scale. They found that bearing slip occurs during wind turbine operations because of bearing design, load, speed, lubrication, and temperature.

Another problem, fretting corrosion, is caused by contacting gear tooth surface deterioration caused by tiny vibrations. The corrosion occurs between surfaces that are pressed together and subject to cyclic, albeit small, motions. Lubricants can't protect against this friction, so ruts form along the gear teeth.

A third problem is bending fatigue within the gearbox that can move from crack propagation to expansion to an outright, sudden failure. That failure may be ductile, brittle, or mixed mode depending on the type of material and amount of stress that is applied.

Production challenges also have emerged for wind turbine manufacturers. In mid-2023, wind turbine manufacturer Siemens Gamesa found multiple design and operational flaws with some of its turbines. The problems were blamed on unacceptable vibrations within some turbines and led the company to say it might cost $2 billion to remedy.

Wind power competes head-on with other low-cost energy sources. When comparing the cost of energy associated with new power plants, wind and solar projects are now more economically competitive than gas, geothermal, coal, or nuclear facilities. However, wind projects may not be cost competitive in some locations where wind speeds (either too little or too much) limit the turbine's ability to make money for its owner. Next-generation technology, manufacturing improvements, and a better understanding of wind plant physics may help bring costs down.

Ideal wind sites are often in remote locations. Installation challenges must be overcome to bring electricity from wind farms to urban areas, where it can be used to meet demand. Upgrading the nation's transmission network to connect areas with abundant wind resources to population centers could significantly reduce the costs of expanding land-based wind energy. In addition, offshore wind energy transmission and grid interconnection capabilities are improving.

Wind turbines can be noisy and affect viewsheds, particularly in rural places where tall structures are not usually found. Wind plants also can affect local wildlife. Fatalities of birds and bats have been recorded at virtually all wind energy facilities for which records are publicly available.[65] For birds, mean estimated fatality rates range from 3 to 6 birds per megawatt per year. In one data set, 75% of studies reported 2.3 or fewer fatalities per megawatt per year, with a median fatality estimate of 1.3 birds per megawatt per year.[66]

Estimated bat fatality rates tend to be higher and more variable, generally ranging from around 4 to as many as 7 bats per megawatt per year. Some individual

A second turbine design that was fed directly with natural steam (referred to as a "direct cycle" process) had a capacity of 23 kW and was installed at Serrazzano, Italy, in 1923. Due to the plants' strategic importance, they were targeted for destruction by the Allies during the Second World War. In the spring of 1944, the geothermal power stations and nearby chemical plants all were destroyed in air raids, and almost all the production wells were blown up.[84]

Meanwhile, in the U.S., an entrepreneur named John D. Grant drilled a well in 1921 at The Geysers in northern California with the intention of generating electricity. His initial effort proved unsuccessful, but the following year he succeeded at another site, and the country's first geothermal power plant entered service. Grant continued to drill and complete wells, so that the entire operation had a generating capacity of 250 kW. The geothermal plant, however, proved to be non-competitive against other sources of power, and it fell into disuse.

The Geysers, however, continued to attract attention, and in 1960 the country's first large-scale geothermal electricity-generating plant began operating there. Investor-owned utility Pacific Gas and Electric operated the plant, whose turbine had an initial generating capacity of 11 MW. Today, The Geysers ranks as one the world's largest geothermal fields and plays host to 18 geothermal power plants with a combined capacity of around 1,500 MW, drawing steam from more than 350 wells. In 2019 it accounted for almost 20% of all the renewable energy produced in California.

Figure 8-1: The Geysers geothermal complex in northern California. The geothermal resource is excellent at the location, but the topography presents challenges for electric power generation and transmission infrastructure. Credit: National Renewable Energy Laboratory/David Parsons.

As with other geothermal power plants, The Geysers (a portion of which is depicted in Figure 8-1) has experienced both pressure and production declines