Independent Statistics & Analysis
U.S. Energy Information Administration

March 2022

# Cost and Performance Characteristics of New Generating Technologies, *Annual Energy Outlook 2022*

The tables presented below are also published in the Electricity Market Module chapter of the U.S. Energy Information Administration's (EIA) *Annual Energy Outlook 2022* (AEO2022) Assumptions document. Table 1 represents our assessment of the cost to develop and install various generating technologies used in the electric power sector. Generating technologies typically found in end-use applications, such as combined heat and power or roof-top solar photovoltaics (PV), will be described elsewhere in the Assumptions document. The costs shown in Table 1, except as noted below, are the costs for a typical facility for each generating technology before adjusting for regional cost factors. Overnight costs exclude interest accrued during plant construction and development. Technologies with limited commercial experience may include a technological optimism factor to account for the tendency to underestimate the full engineering and development costs for new technologies during technology research and development.

All technologies demonstrate some degree of variability in cost, based on project size, location, and access to key infrastructure (such as grid interconnections, fuel supply, and transportation). For wind and solar PV, in particular, the cost favorability of the lowest-cost regions compound the underlying variability in regional cost and create a significant differential between the unadjusted costs and the capacity-weighted average national costs as observed from recent market experience. To reflect this difference, we report a weighted average cost for both wind and solar PV, based on the regional cost factors assumed for these technologies in AEO2022 and the actual regional distribution of the builds that occurred in 2020 (Table 1).

Table 2 shows a full listing of the overnight costs for each technology and electricity region, if the resource or technology is available to be built in the given region. The regional costs reflect the impact of locality adjustments, including one to address ambient air conditions for technologies that include a combustion turbine and one to adjust for additional costs associated with accessing remote wind resources. Temperature, humidity, and air pressure can affect the available capacity of a combustion turbine, and our modeling addresses these possible effects through an additional cost multiplier by region. Unlike most other generation technologies where fuel can be transported to the plant, wind generators must be located in areas with the best wind resources. Sites that are located near existing transmission with access to a road network or are located on lower development-cost lands are generally built up first, after which additional costs may be incurred to access sites with less favorable characteristics. We represent this trend through a multiplier applied to the wind plant capital costs that increases as the best sites in a region are developed.

## Table 1. Cost and performance characteristics of new central station electricity generating technologies

| Technology | First available year[a] | Size (MW) | Lead time (years) | Base overnight cost[b] (2021$/kW) | Techno-logical optimism factor[c] | Total overnight cost[d,e] (2021$/kW) | Variable O&M[f] (2021 $/MWh) | Fixed O&M (2021$/ kW-y) | Heat rate[g] (Btu/kWh) |
|---|---|---|---|---|---|---|---|---|---|
| Ultra-supercritical coal (USC) | 2025 | 650 | 4 | $4,074 | 1.00 | $4,074 | $4.71 | $42.49 | 8,638 |
| USC with 30% carbon capture and sequestration (CCS) | 2025 | 650 | 4 | $5,045 | 1.01 | $5,096 | $7.41 | $56.84 | 9,751 |
| USC with 90% CCS | 2025 | 650 | 4 | $6,495 | 1.02 | $6,625 | $11.49 | $62.34 | 12,507 |
| Combined-cycle—single-shaft | 2024 | 418 | 3 | $1,201 | 1.00 | $1,201 | $2.67 | $14.76 | 6,431 |
| Combined-cycle—multi-shaft | 2024 | 1,083 | 3 | $1,062 | 1.00 | $1,062 | $1.96 | $12.77 | 6,370 |
| Combined-cycle with 90% CCS | 2024 | 377 | 3 | $2,736 | 1.04 | $2,845 | $6.11 | $28.89 | 7,124 |
| Internal combustion engine | 2023 | 21 | 2 | $2,018 | 1.00 | $2,018 | $5.96 | $36.81 | 8,295 |
| Combustion turbine—aeroderivative[h] | 2023 | 105 | 2 | $1,294 | 1.00 | $1,294 | $4.92 | $17.06 | 9,124 |
| Combustion turbine—industrial frame | 2023 | 237 | 2 | $785 | 1.00 | $785 | $4.71 | $7.33 | 9,905 |
| Fuel cells | 2024 | 10 | 3 | $6,639 | 1.09 | $7,224 | $0.62 | $32.23 | 6,469 |
| Nuclear—light water reactor | 2027 | 2,156 | 6 | $6,695 | 1.05 | $7,030 | $2.48 | $127.35 | 10,443 |
| Nuclear—small modular reactor | 2028 | 600 | 6 | $6,861 | 1.10 | $7,547 | $3.14 | $99.46 | 10,443 |
| Distributed generation—base | 2024 | 2 | 3 | $1,731 | 1.00 | $1,731 | $9.01 | $20.27 | 8,923 |
| Distributed generation—peak | 2023 | 1 | 2 | $2,079 | 1.00 | $2,079 | $9.01 | $20.27 | 9,907 |
| Battery storage | 2022 | 50 | 1 | $1,316 | 1.00 | $1,316 | $0.00 | $25.96 | NA |
| Biomass | 2025 | 50 | 4 | $4,524 | 1.00 | $4,525 | $5.06 | $131.62 | 13,500 |
| Geothermal[i, j] | 2025 | 50 | 4 | $3,076 | 1.00 | $3,076 | $1.21 | $143.22 | 8,813 |
| Conventional hydropower[j] | 2025 | 100 | 4 | $3,083 | 1.00 | $3,083 | $1.46 | $43.78 | NA |
| Wind[e] | 2024 | 200 | 3 | $1,718 | 1.00 | $1,718 | $0.00 | $27.57 | NA |
| Wind offshore[i] | 2025 | 400 | 4 | $4,833 | 1.25 | $6,041 | $0.00 | $115.16 | NA |
| Solar thermal[i] | 2024 | 115 | 3 | $7,895 | 1.00 | $7,895 | $0.00 | $89.39 | NA |
| Solar photovoltaic (PV) with tracking[e, i, k] | 2023 | 150 | 2 | $1,327 | 1.00 | $1,327 | $0.00 | $15.97 | NA |
| Solar PV with storage[i, k] | 2023 | 150 | 2 | $1,748 | 1.00 | $1,748 | $0.00 | $33.67 | NA |

Source: We primarily base input costs on a report provided by external consultants: Sargent & Lundy, December 2019. We most recently updated hydropower site costs for non-powered dams for AEO2018 using data from Oak Ridge National Lab

Note: MW=megawatt, kW=kilowatt, MWh=megawatthour, kW-y=kilowatt-year, kWh=kilowatthour; Btu=British thermal unit

[a] The first year that a new unit could become operational.

[b] Base cost includes project contingency costs.

[c] We apply the technological optimism factor to the first four units of a new, unproven design; it reflects the demonstrated tendency to underestimate actual costs for a first-of-a-kind unit.

[d] Overnight capital cost includes contingency factors and excludes regional multipliers (except as noted for wind and solar PV) and learning effects. Interest charges are also excluded. The capital costs represent current costs for plants that would come online in 2022.

[e] Total overnight cost for wind and solar PV technologies in the table are the average input value across all 25 electricity market regions, as weighted by the respective capacity of that type installed during 2020 in each region to account for the substantial regional variation in wind and solar costs (Table 4). The input value used for onshore wind in AEO2022 was $1,411 per kilowatt (kW), and for solar PV with tracking, it was $1,323/kW, which represents the cost of building a plant excluding regional factors. Region-specific factors contributing to the substantial regional variation in cost include differences in typical project size across regions, accessibility of resources, and variation in labor and other construction costs throughout the country.

[f] O&M = Operations and maintenance.

[g] The nuclear average heat rate is the weighted average tested heat rate for nuclear units as reported on the Form EIA-860, *Annual Electric Generator Report*. No heat rate is reported for battery storage because it is not a primary conversion technology; conversion losses are accounted for when the electricity is first generated; electricity-to-storage losses are accounted for through the additional demand for electricity required to meet load. For hydropower, wind, solar, and geothermal technologies, no heat rate is reported because the power is generated without fuel combustion, and no set British thermal unit conversion factors exist. The module calculates the average heat rate for fossil-fuel generation in each year to report primary energy consumption displaced for these resources.

[h] Combustion turbine aeroderivative units can be built by the module before 2023, if necessary, to meet a region's reserve margin.

[i] Capital costs are shown before investment tax credits are applied.

[j] Because geothermal and hydropower cost and performance characteristics are specific for each site, the table entries show the cost of the least expensive plant that could be built in the Northwest region for hydro and the Great Basin region for geothermal, where most of the proposed sites are located.

[k] Costs and capacities are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

## Table 2. Total overnight capital costs of new electricity generating technologies by region

2021 dollars per kilowatt

| Technology | 1<br>TRE | 2<br>FRCC | 3<br>MISW | 4<br>MISC | 5<br>MISE | 6<br>MISS | 7<br>ISNE | 8<br>NYCW | 9<br>NYUP | 10<br>PJME | 11<br>PJMW | 12<br>PJMC | 13<br>PJMD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ultra-supercritical coal (USC) | $3,786 | $3,897 | $4,259 | $4,371 | $4,422 | $3,918 | $4,721 | NA | $4,614 | $4,763 | $4,064 | $5,120 | $4,385 |
| USC with 30% CCS | $4,777 | $4,903 | $5,294 | $5,437 | $5,480 | $4,935 | $5,846 | NA | $5,729 | $5,883 | $5,094 | $6,254 | $5,477 |
| USC with 90% CCS | $6,252 | $6,411 | $6,841 | $7,072 | $7,078 | $6,473 | $7,495 | NA | $7,303 | $7,508 | $6,601 | $7,994 | $7,015 |
| CC—single-shaft | $1,085 | $1,107 | $1,235 | $1,246 | $1,277 | $1,117 | $1,441 | $1,912 | $1,445 | $1,443 | $1,197 | $1,446 | $1,377 |
| CC—multi-shaft | $944 | $968 | $1,098 | $1,117 | $1,146 | $979 | $1,259 | $1,725 | $1,238 | $1,266 | $1,037 | $1,327 | $1,170 |
| CC with 90% CCS | $2,668 | $2,693 | $2,877 | $2,884 | $2,928 | $2,718 | $3,021 | $3,422 | $2,953 | $2,996 | $2,756 | $3,124 | $2,871 |
| Internal combustion engine | $1,898 | $1,940 | $2,073 | $2,155 | $2,131 | $1,966 | $2,209 | $2,769 | $2,125 | $2,209 | $1,980 | $2,408 | $2,056 |
| CT—aeroderivative | $1,145 | $1,168 | $1,354 | $1,357 | $1,398 | $1,193 | $1,456 | $1,864 | $1,405 | $1,448 | $1,242 | $1,591 | $1,317 |
| CT—industrial frame | $692 | $707 | $822 | $826 | $851 | $723 | $886 | $1,144 | $854 | $882 | $753 | $971 | $800 |
| Fuel cells | $6,933 | $7,041 | $7,362 | $7,680 | $7,534 | $7,159 | $7,815 | $9,201 | $7,498 | $7,748 | $7,138 | $8,261 | $7,358 |
| Nuclear—light water reactor | $6,636 | $6,779 | $7,157 | $7,807 | $7,530 | $7,000 | $7,964 | NA | $7,430 | $7,781 | $6,878 | $8,556 | $7,158 |
| Nuclear—small modular reactor | $7,032 | $7,197 | $7,841 | $8,176 | $8,173 | $7,287 | $8,441 | NA | $8,040 | $8,459 | $7,376 | $9,438 | $7,660 |
| Distributed generation—base | $1,563 | $1,595 | $1,779 | $1,795 | $1,840 | $1,609 | $2,076 | $2,754 | $2,081 | $2,079 | $1,724 | $2,083 | $1,984 |
| Distributed generation—peak | $1,839 | $1,877 | $2,174 | $2,180 | $2,246 | $1,916 | $2,339 | $2,994 | $2,257 | $2,326 | $1,995 | $2,555 | $2,116 |
| Battery storage | $1,316 | $1,320 | $1,301 | $1,364 | $1,319 | $1,347 | $1,357 | $1,351 | $1,321 | $1,325 | $1,313 | $1,329 | $1,325 |
| Biomass | $4,198 | $4,313 | $4,669 | $4,824 | $4,835 | $4,348 | $5,372 | $7,292 | $5,389 | $5,483 | $4,611 | $5,493 | $5,255 |
| Geothermal | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Conventional hydropower | $4,498 | $5,495 | $2,186 | $1,453 | $2,959 | $4,378 | $2,025 | NA | $4,144 | $4,305 | $3,752 | NA | $3,808 |
| Wind | $2,757 | NA | $1,552 | $1,411 | $1,690 | $1,411 | $1,870 | NA | $2,281 | $1,870 | $1,411 | $2,055 | $1,948 |
| Wind offshore | $5,901 | $7,080 | $6,984 | NA | $7,234 | NA | $7,047 | $6,079 | $7,370 | $6,755 | $5,524 | $7,999 | $6,293 |
| Solar thermal | $7,616 | $7,731 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Solar PV with tracking | $1,304 | $1,279 | $1,323 | $1,372 | $1,357 | $1,290 | $1,370 | $1,612 | $1,357 | $1,397 | $1,320 | $1,440 | $1,317 |
| Solar PV with storage | $1,692 | $1,710 | $1,761 | $1,817 | $1,792 | $1,727 | $1,828 | $2,078 | $1,796 | $1,832 | $1,721 | $1,905 | $1,781 |

| Technology | 14<br>SRCA | 15<br>SRSE | 16<br>SRCE | 17<br>SPPS | 18<br>SPPC | 19<br>SPPN | 20<br>SRSG | 21<br>CANO | 22<br>CASO | 23<br>NWPP | 24<br>RMRG | 25<br>BASN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ultra-supercritical coal (USC) | $3,920 | $3,979 | $4,032 | $3,947 | $4,193 | $3,991 | $4,159 | NA | NA | $4,406 | $4,119 | $4,297 |
| USC with 30% CCS | $4,939 | $4,985 | $5,059 | $4,952 | $5,226 | $4,999 | $5,215 | NA | NA | $5,480 | $5,159 | $5,353 |
| USC with 90% CCS | $6,485 | $6,542 | $6,620 | $6,451 | $6,778 | $6,497 | $6,758 | NA | NA | $7,090 | $6,658 | $6,967 |
| CC—single-shaft | $1,103 | $1,116 | $1,150 | $1,115 | $1,183 | $1,104 | $1,085 | $1,590 | $1,553 | $1,264 | $1,023 | $1,106 |
| CC—multi-shaft | $968 | $980 | $1,016 | $979 | $1,051 | $971 | $934 | $1,398 | $1,359 | $1,096 | $880 | $987 |
| CC with 90% CCS | $2,684 | $2,698 | $2,759 | $2,688 | $2,777 | $2,647 | $2,448 | $3,071 | $3,036 | $2,833 | $2,303 | $2,586 |
| Internal combustion engine | $1,977 | $1,982 | $2,017 | $1,962 | $2,068 | $1,982 | $2,001 | $2,398 | $2,355 | $2,133 | $1,975 | $2,114 |
| CT—aeroderivative | $1,186 | $1,196 | $1,241 | $1,194 | $1,279 | $1,203 | $1,086 | $1,529 | $1,491 | $1,341 | $1,051 | $1,198 |
| CT— industrial frame | $718 | $726 | $753 | $724 | $777 | $729 | $658 | $934 | $910 | $816 | $637 | $728 |
| Fuel cells | $7,211 | $7,205 | $7,304 | $7,080 | $7,376 | $7,143 | $7,243 | $8,299 | $8,203 | $7,585 | $7,104 | $7,567 |
| Nuclear—light water reactor | $7,090 | $7,035 | $7,263 | $6,807 | $7,198 | $6,805 | $7,058 | NA | NA | $7,640 | $6,837 | $7,648 |
| Nuclear—small modular reactor | $7,323 | $7,380 | $7,547 | $7,306 | $7,759 | $7,368 | $7,465 | NA | NA | $8,083 | $7,386 | $8,028 |
| Distributed generation—base | $1,589 | $1,608 | $1,657 | $1,606 | $1,705 | $1,591 | $1,563 | $2,290 | $2,238 | $1,821 | $1,474 | $1,593 |
| Distributed generation—peak | $1,905 | $1,922 | $1,994 | $1,919 | $2,055 | $1,932 | $1,744 | $2,456 | $2,394 | $2,154 | $1,688 | $1,924 |
| Battery storage | $1,359 | $1,340 | $1,357 | $1,310 | $1,318 | $1,302 | $1,333 | $1,371 | $1,373 | $1,348 | $1,305 | $1,357 |
| Biomass | $4,364 | $4,397 | $4,455 | $4,368 | $4,641 | $4,460 | $4,777 | $6,119 | $5,981 | $4,939 | $4,732 | $4,731 |
| Geothermal | NA | NA | NA | NA | NA | NA | $3,135 | $3,109 | $2,517 | $3,043 | NA | $3,076 |
| Conventional hydropower | $2,120 | $4,599 | $2,377 | $4,550 | $1,917 | $1,802 | $3,655 | $3,867 | $3,723 | $3,083 | $3,681 | $4,023 |
| Wind | $1,683 | $1,907 | $1,411 | $1,411 | $1,552 | $1,552 | $1,411 | $3,116 | $2,447 | $2,057 | $1,411 | $1,411 |
| Wind offshore | $5,437 | NA | NA | NA | NA | NA | NA | $9,112 | $9,560 | $6,836 | NA | NA |
| Solar thermal | NA | NA | NA | $7,693 | $7,991 | $7,614 | $7,980 | $9,400 | $9,282 | $8,493 | $7,668 | $8,510 |
| Solar PV with tracking | $1,343 | $1,276 | $1,318 | $1,278 | $1,328 | $1,287 | $1,300 | $1,447 | $1,440 | $1,332 | $1,315 | $1,327 |
| Solar PV with storage | $1,739 | $1,721 | $1,742 | $1,709 | $1,765 | $1,727 | $1,736 | $1,903 | $1,898 | $1,795 | $1,729 | $1,791 |

Source: U.S. Energy Information Administration, Office of Electricity, Coal, Nuclear and Renewables Analysis

Notes: Costs include contingency factors, regional cost multipliers, and ambient condition multipliers. Interest charges are excluded. The costs are shown before investment tax credits are applied.

NA = not available; plant type cannot be built in the region because of a lack of resources, sites, or specific state legislation.

USC = ultra-supercritical, CCS = carbon capture and sequestration, CC = combined cycle, CT = combustion turbine, PV = photovoltaic

Electricity Market Module region map