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Levelized Costs of New Generation Resources in the *Annual Energy Outlook 2022*

Every year, the U.S. Energy Information Administration (EIA) publishes updates to its *Annual Energy Outlook* (AEO), which provides long-term projections of energy production and consumption in the United States using EIA's National Energy Modeling System (NEMS). The AEO update for 2022 (AEO2022) includes projections through 2050 given certain specified assumptions and methodologies.

Investment in the expansion of electric generation capacity requires an assessment of the competitive value of generation technologies in the future that is determined as part of a complex set of modeling systems. To better understand investment decisions in NEMS, we use specialized measures that simplify those modeled decisions. Levelized cost of electricity (LCOE) refers to the estimated revenue required to build and operate a generator over a specified cost recovery period. Levelized avoided cost of electricity (LACE) is the revenue available to that generator during the same period. Beginning with AEO2021, we include estimates for the levelized cost of storage (LCOS). Although LCOE, LCOS, and LACE do not fully capture all the factors considered in NEMS, when used together as a value-cost ratio (the ratio of LACE-to-LCOE or LACE-to-LCOS), they provide a reasonable comparison of first-order economic competitiveness among a wider variety of technologies than is possible using LCOE, LCOS, or LACE individually.

In this paper, we present average values of LCOE, LCOS, and LACE for electric generating technologies entering service in 2024, 2027,[1] and 2040 as represented in NEMS for the AEO2022 Reference case. We present the costs for electric generating facilities entering service in 2027 in the body of this report, and we include the costs for 2024[2] and 2040 in Appendixes A and B, respectively. We provide both a capacity-weighted average based on projected capacity additions and a simple average (unweighted) of the regional values across the 25 U.S. supply regions of the NEMS Electricity Market Module (EMM), together with the range of regional values.

Levelized cost of electricity and levelized cost of storage

Levelized cost of electricity (LCOE) and levelized cost of storage (LCOS) represent the average revenue per unit of electricity generated or discharged that would be required to recover the costs of building and operating a generating plant and a battery storage facility, respectively, during an assumed financial life and duty cycle.[3] LCOE is often cited as a convenient summary measure of the overall competiveness of different generating technologies. Although the concept is similar to LCOE, LCOS is different in that it represents an energy storage technology that contributes to electricity generation when discharging and

[1] Given the long lead time and licensing requirements for some technologies, the first feasible year that all technologies are available is 2027.

[2] Appendix A shows LCOE, LCOS, and LACE for the subset of technologies available to be built in 2024.

[3] *Duty cycle* refers to the typical utilization or dispatch of a plant to serve base, intermediate, or peak load. Wind, solar, or other intermittently available resources are not dispatched and do not necessarily follow a duty cycle based on load conditions.

consumes electricity from the grid when charging. Furthermore, LCOS is calculated differently depending on whether it is supplying electricity generation to the grid or providing generation capacity reliability.

In NEMS, we model battery storage in energy arbitrage applications where the storage technology provides energy to the grid during periods of high-cost generation and recharges during periods of lower cost generation, not as providing generation capacity reliability.

AEO2022 representation of tax incentives for renewable generation

Federal tax credits for certain renewable generation facilities can substantially reduce the realized cost of these facilities. Cost estimates in this report are for generators owned by the electric power sector, which are generally eligible for federal tax credits. These estimates are not for systems owned by the residential or commercial sectors. Where applicable, we show LCOE both with and without tax credits that we assume, based on the following representation, that they would be available in the year in which the plant enters service.

Production Tax Credit (PTC): As of 2021, new electric power sector wind, geothermal, and closed-loop biomass plants receive a tax credit of $25 per megawatthour (MWh) of generation; other PTC-eligible technologies receive $13/MWh. We adjust PTC values for inflation and apply them during the plant's first 10 years of service. Plants that were under construction before the end of 2016 received the full PTC. After 2016, wind continues to be eligible for the PTC but at a declining dollars-per-megawatthour rate. We assume that wind plants have five years after beginning construction to come online and claim the PTC.[4] As a result, we assume that wind plants entering service before January 1, 2026 will receive 60% of the full PTC value (inflation adjusted), and no PTC for any projects placed in service in 2026 and beyond.

Investment Tax Credit (ITC): We assume all electric power sector solar projects coming online before January 1, 2024 will receive the full 30% ITC.[4] The available ITC is then phased down to 26% for solar projects entering commercial service in 2024 and 2025 and 10% for those placed in service after December 31, 2025. Because we assume that battery storage is a standalone, grid-connected system, it is not eligible for the ITC. However, we assume that battery storage in the solar photovolataic (PV) hybrid system recharges exclusively from the co-located solar facility, and so it is eligible for the ITC with the same phaseout schedule as for standalone solar PV systems.

Both onshore and offshore wind projects are eligible to claim the ITC instead of the PTC. Although we expect that onshore wind projects will choose the PTC, we assume offshore wind projects will claim the ITC because of the relatively higher capital costs for those projects. We assume offshore wind projects are eligible for a 30% ITC if placed in service by December 31, 2035.[5]

[4] Based on Division EE (Taxpayer Certainty and Disaster Tax Relief Act of 2020) of the Consolidated Appropriations Act of 2021, signed into law in December 2020, and Notice 2021-41 released by the Internal Revenue Service (IRS) in June 2021.
[5] Based on Division EE of the Consolidated Appropriations Act of 2021 and IRS Notice 2021-05 released in December 2020.

Key inputs to calculating LCOE and LCOS include capital costs, fixed operations and maintenance (O&M) costs, variable costs that include O&M and fuel costs, financing costs, and an assumed utilization rate for each plant type.[6] For LCOS, in lieu of fuel cost, the levelized variable cost includes the cost of purchasing electricity from the electric power grid for charging. The importance of each of these factors varies across technologies. For technologies with no fuel costs and relatively small variable costs, such as solar and wind electric-generating technologies, LCOE changes nearly in proportion to the estimated capital cost of the technology. For technologies with significant fuel cost, both fuel cost and capital cost estimates significantly affect LCOE. Incentives, including state or federal tax credits (see text box *AEO2022 representation of tax incentives for renewable generation*), also affect the calculation of LCOE. As with any projection, these factors are uncertain because their values can vary regionally and temporally as technologies evolve and as fuel prices change. Solar photovoltaic (PV) hybrid technology is represented by LCOE and not LCOS because we assume it operates as an integrated unit supplying electricity to the grid.

Actual plant investment decisions consider the specific technological and regional characteristics of a project, which involve many other factors not reflected in LCOE (or LCOS) values. One factor is the projected utilization rate, which depends on the varying amount of electricity required over time and the existing resource mix in an area where additional capacity is needed. A related factor is the capacity value, which depends on both the existing capacity mix and load characteristics in a region. Because load must be continuously balanced, generating units with the capability to vary output to follow demand (dispatchable technologies) generally have more value to a system than less flexible units that use intermittent resources to operate (resource-constrained technologies). We list the LCOE values for dispatchable and resource-constrained technologies separately because they require a careful comparison. We include the solar PV hybrid LCOE under resource-constrained technologies because, much like hydroelectric generators, solar PV hybrid generators are energy-constrained and so are more limited in dispatch capability than generators with essentially continuous fuel supply. For combustion turbine and battery storage technologies, capacity might be added in regions with higher renewables penetration, particularly solar, to meet regional capacity reserve requirements for when intermittent resources are not available for generation during evening peak demand, and we show them as capacity resource technologies.

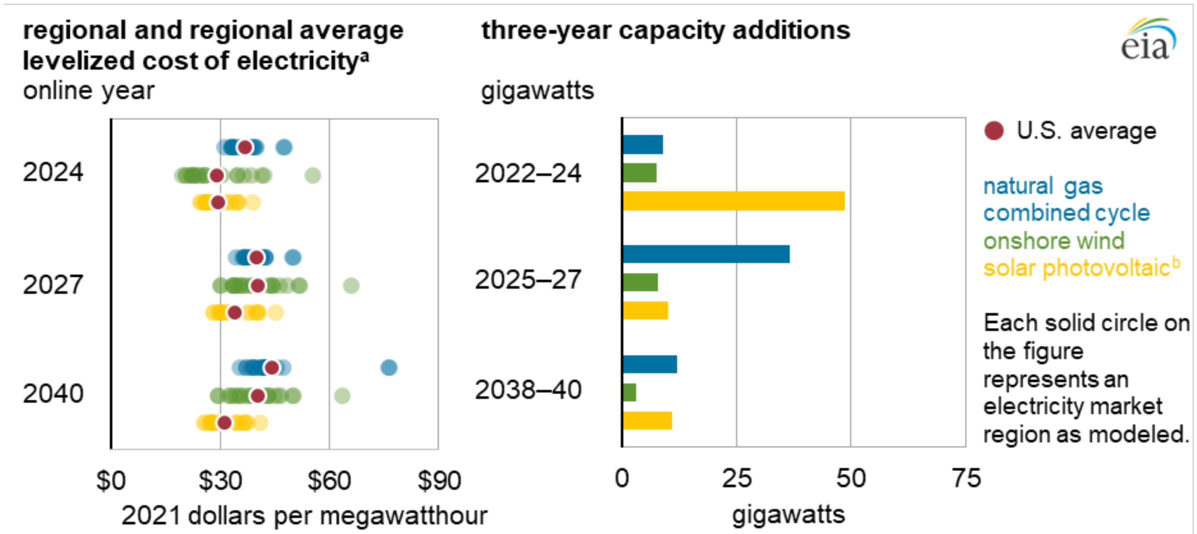
Levelized avoided cost of electricity

LCOE and LCOS by themselves do not capture all of the factors that contribute to actual investment decisions, making direct comparisons of LCOE and LCOS across technologies problematic and misleading as a method to assess the economic competitiveness of various generation alternatives. Figure 1 illustrates the limitations of using LCOE alone. In AEO2022, solar LCOE, on average, is lower than natural gas-fired combined-cycle (CC) LCOE in 2027. However, more CC generating capacity is installed than solar PV between 2025 and 2027. We project more CC capacity to be installed than solar PV capacity because the relative value of adding CC to the system is greater than for solar PV, which LCOE does not capture.

[6] The specific assumptions for each of these factors are provided in the *Assumptions to the Annual Energy Outlook*.

Along with LCOE and LCOS, we compare economic competitiveness between generation technologies by considering the value of the plant in serving the electric grid. This value provides a proxy measure for potential revenues from the sale of electricity generated from a candidate project displacing (or the cost of avoiding) another marginal asset. We sum this value over a project's financial life and convert that sum into an annualized value (that is, divided by the average annual output of the project) to develop the levelized avoided cost of electricity (LACE).[7] Using LACE along with LCOE and LCOS provides a more intuitive indication of economic competitiveness for each technology than either metric separately when several technologies are available to meet load. We calculate LACE-to-LCOE and LACE-to-LCOS ratios (or value-cost ratios) for each technology to determine which project provides the most value relative to its cost. Projects with a value-cost ratio greater than one (that is, LACE is greater than LCOE or LCOS) are more economically attractive as new builds than those with a value-cost ratio less than one (that is, LACE is less than LCOE or LCOS).

Figure 1. Levelized cost of electricity (with applicable tax subsidies) by region and total incremental capacity additions for selected generating technologies entering into service in 2024, 2027, and 2040



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

[a] Levelized cost includes tax credits available for plants entering service during the projection period.
[b] Technology is assumed to be photovoltaic with single-axis tracking. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

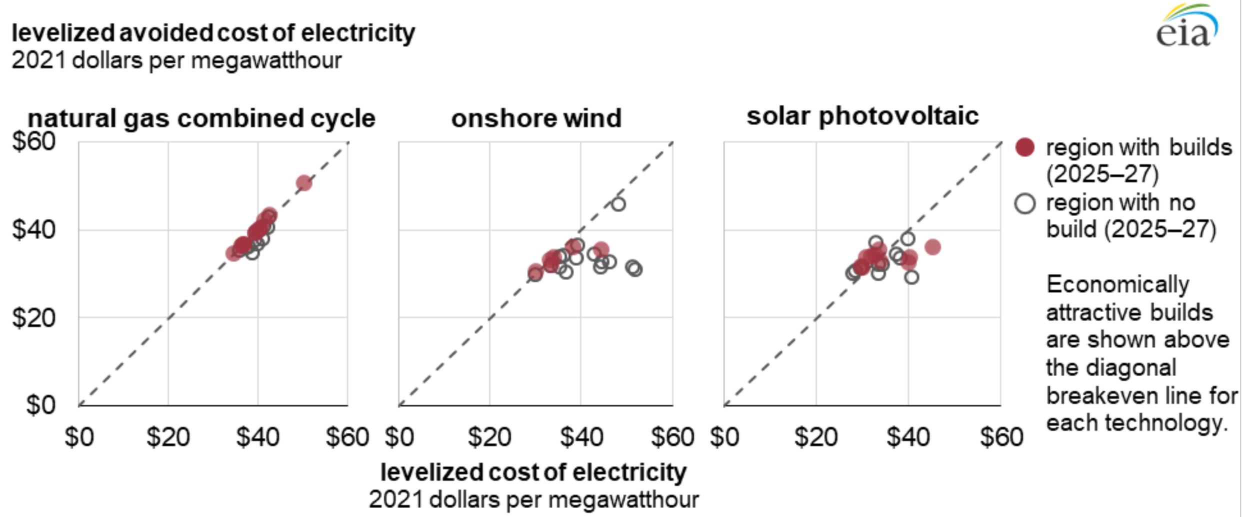
Estimating LACE is more complex than estimating LCOE or LCOS because it requires information about how the grid would operate without the new power plant or storage facility entering service. We calculate LACE based on the marginal value of energy and capacity that would result from adding a unit of a given technology to the grid as it exists or as we project it to exist at a specific future date. LACE accounts for both the variation in daily and seasonal electricity demand and the characteristics of the existing generation fleet to which new capacity will be added. Therefore, LACE compares the prospective new generation resource against the mix of new and existing generation and capacity that it would displace. For example, a wind resource that would primarily displace generation from a relatively

[7] Our website provides further discussion of the levelized avoided cost concept and its use in assessing economic competitiveness.

expensive natural gas-fired peaking unit will usually have a different value than one that would displace generation from a more efficient natural gas-fired combined-cycle unit or coal-fired unit with low fuel costs.

Although the modeled economic decisions for capacity additions in our long-term projections do not use the LACE, LCOE, or LCOS concepts, the LACE and value-cost ratio presented in this report is generally more representative of the factors contributing to the build decisions in our long-term projections than looking at LCOE or LCOS alone. Figure 2 shows selected generating technologies that could come online in 2027. CC and PV are the most economically attractive technologies to build because the value (or LACE) is greater than the cost (or LCOE). Onshore wind and PV add capacity in some less economically attractive regions. This outcome is partly because capacity additions are from the preceding three years, which reflect the years where onshore wind was subject to greater tax incentives than in 2027 alone. In addition, some regions are adding uneconomical capacity builds to fulfill state-level renewable portfolio standards (RPS) that require that a certain percentage of generation come from renewables. Even so, looking at both LCOE and LACE together (Figure 2) indicates more of the full analysis from the AEO2022 model than LCOE alone (Figure 1).

Figure 2. Levelized cost of electricity and levelized avoided cost of electricity by region for selected generation technologies, 2027 online year



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

Note: Each solid circle on the figure represents an electricity market region as modeled. Projects tend to be built in regions where revenue (levelized avoided cost of electricity, or LACE) exceeds costs (levelized cost of electricity, or LCOE).

Nonetheless, the LACE, LCOE, and LCOS estimates simplify modeled decisions, and these estimates may not fully capture all of the factors considered in NEMS or match modeled results. We calculate levelized costs using an assumed set of capital and operating costs, but investment decisions may be affected by factors other than the project’s value relative to its costs. For example, the inherent uncertainty about future fuel prices, future policies, or local considerations for system reliability may lead plant owners or investors who finance plants to place a value on portfolio diversification or other risk-related concerns. We consider many of these factors in our analysis of technology choice in the electricity sector in NEMS, but not all of these concepts are included in LCOE, LCOS, or LACE calculations. Future policy-related factors, such as new environmental regulations or tax credits for specific generation sources, can also affect investment decisions. We derive the LCOE, LCOS, and LACE values presented here from the AEO2022 Reference case, which includes state-level renewable electricity requirements as of November 2021 and a phaseout of federal tax credits for renewable generation.

LCOE, LCOS, and LACE calculations

We calculate all levelized costs and values based on a 30-year cost recovery period, using a nominal after-tax weighted average cost of capital (WACC) of 6.2%.[8] In reality, a plant's cost recovery period and cost of capital can vary by technology and project type. The represented technologies are selected from available electric power sector technologies modeled in NEMS's Electricity Market Module (EMM) and not from distributed residential and commercial applications.[9] Starting in AEO2020, we model an ultra-supercritical[10] (USC) coal generation technology without carbon capture and sequestration (CCS), and we continue to model USC with 30% and 90% CCS. In December 2018, the U.S. Environmental Protection Agency (EPA) amended earlier 2015 findings that partial CCS was the *best system of emissions reductions* (BSER) for greenhouse gas reductions and proposed to replace it with the most efficient demonstrated steam cycle, which we assume is represented by USC technology.

The levelized capital component reflects costs calculated using tax depreciation schedules consistent with tax laws without an end date, which vary by technology. For AEO2022, we assume a corporate tax rate of 21%, as specified in the Tax Cuts and Jobs Act of 2017. For technologies eligible for the Investment Tax Credit (ITC) or Production Tax Credit (PTC), we report LCOE both with and without tax credits, which phase out and expire based on current laws and regulations in AEO2022 cases. Costs are expressed in terms of net alternating current (AC) power available to the grid for the installed capacity.

We evaluate LCOE, LCOS, and LACE for each technology based on assumed capacity factors, which generally correspond to the high end of their likely utilization range. This convention is consistent with using LCOE and LCOS to evaluate competing technologies in baseload operation such as coal and nuclear plants. Although sometimes used in baseload operation, some technologies, such as CC plants, are also built to serve load-following or other intermediate dispatch duty cycles. We evaluate combustion turbines that are typically used for peak-load duty cycles at a 10% capacity factor, which reflects the historical average utilization rate. We also evaluate battery storage at a 10% capacity factor, reflecting an expected use for energy arbitrage, especially in conjunction with intermittent renewable generation such as solar generation. The duty cycle for intermittent resources is not operator controlled, but rather, it depends on the weather, which does not necessarily correspond to operator-dispatched duty cycles. As a result, LCOE values for wind and solar technologies are not directly comparable with the LCOE values for other technologies that may have a similar average annual capacity factor, and we show them

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[8] We use this WACC for plants entering service in 2027. The nominal WACCs used to calculate LCOE for plants entering service in 2024 and 2040 are 5.6% and 6.5%, respectively. An overview of the WACC assumptions and methodology is available in the *Electricity Market Module of the National Energy Modeling System: Model Documentation 2020*.

[9] The list of all technologies modeled in EMM is available in the *Electricity Market Module of the National Energy Modeling System: Model Documentation 2020*.

[10] USC coal plants are compatible with CCS technologies because they use boilers that heat coal to higher temperatures, which increases the pressure of steam to improve efficiency and results in less coal use and fewer carbon emissions than other boiler technologies.

separately as resource-constrained technologies. Hydroelectric resources, including facilities where storage reservoirs allow for more flexible day-to-day operation, and hybrid solar PV generally have signifcant seasonal and daily variation, respectively, in availability. We label them as resource-constrained to discourage comparison with technologies that have more consistent seasonal and diurnal availability. The capacity factors for solar, wind, and hydroelectric resources are the average of the capacity factors (weighted or unweighted) for the marginal site in each region, which can vary significantly by region, and will not necessarily correspond to the cumulative projected capacity factors for both new and existing units for resources in AEO2022 or our other analyses.

The LCOE and LCOS values we show in Tables 1a and 1b are averages of region-specific values weighted by the projected regional capacity builds in AEO2022 (Table 1a) and unweighted averages (simple average, Table 1b) for new plants coming online in 2027. We develop the weights based on the cumulative capacity additions during three years, reflecting the two years preceding the online year and the online year (for example, the capacity weight for a 2027 online year represents the cumulative capacity additions from 2025 through 2027).

Table 1a. Estimated capacity-weighted[a] levelized cost of electricity (LCOE) and levelized cost of storage (LCOS) for new resources entering service in 2027 (2021 dollars per megawatthour)

Plant type	Capacity factor (percent)	Levelized capital cost	Levelized fixed O&M[b]	Levelized variable cost	Levelized transmis-sion cost	Total system LCOE or LCOS	Levelized tax credit[c]	Total LCOE or LCOS including tax credit
Dispatchable technologies								
Ultra-supercritical coal	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*
Combined cycle	87%	$8.56	$1.68	$25.80	$1.01	$37.05	*NA*	$37.05
Advanced nuclear	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*
Geothermal	90%	$21.80	$15.20	$1.21	$1.40	$39.61	-$2.18	$37.43
Biomass	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*
Resource-constrained technologies								
Wind, onshore	43%	$27.45	$7.44	$0.00	$2.91	$37.80	*NA*	$37.80
Wind, offshore	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*
Solar, standalone[d]	29%	$26.35	$6.34	$0.00	$3.41	$36.09	-$2.64	$33.46
Solar, hybrid[d,e]	26%	$39.12	$15.00	$0.00	$4.51	$58.62	-$3.91	$54.71
Hydroelectric[e]	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*
Capacity resource technologies								
Combustion turbine	10%	$55.55	$8.37	$49.93	$10.00	$123.84	*NA*	$123.84
Battery storage	10%	$64.74	$29.64	$18.92	$11.54	$124.84	$0.00	$124.84

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

[a] The capacity-weighted average is the average levelized cost per technology, weighted by the new capacity coming online in each region. We base the capacity additions for each region on additions from 2025 to 2027. Technologies for which capacity additions are not expected do not have a capacity-weighted average and are marked as *NB*, or *not built*.

[b] O&M = operations and maintenance

[c] The tax credit component is based on targeted federal tax credits such as the Production Tax Credit (PTC) or Investment Tax Credit (ITC) available for some technologies. It reflects tax credits available only for plants entering service in 2027 and the substantial phaseout of both the PTC and ITC as scheduled under current law. Technologies not eligible for PTC or ITC are indicated as *NA,* or *not available*. The results are based on a regional model, and state or local incentives are not included in LCOE and LCOS calculations. See text box on page 2 for details on how the tax credits are represented in the model.

[d] Technology is assumed to be photovoltaic (PV) with single-axis tracking. The solar hybrid system is a single-axis PV system coupled with a four-hour battery storage system. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

[e] As modeled, we assume that hydroelectric and hybrid solar PV generating assets have seasonal and diurnal storage, respectively, so that they can be dispatched within a season or a day, but overall operation is limited by resource availablility by site and season for hydroelectric and by daytime for hybrid solar PV.

Table 1b. Estimated unweighted levelized cost of electricity (LCOE) and levelized cost of storage (LCOS) for new resources entering service in 2027 (2021 dollars per megawatthour)

Plant type	Capacity factor (percent)	Levelized capital cost	Levelized fixed O&M[a]	Levelized variable cost	Levelized transmis-sion cost	Total system LCOE or LCOS	Levelized tax credit[b]	Total LCOE or LCOS including tax credit
Dispatchable technologies								
Ultra-supercritical coal	85%	$52.11	$5.71	$23.67	$1.12	$82.61	*NA*	$82.61
Combined cycle	87%	$9.36	$1.68	$27.77	$1.14	$39.94	*NA*	$39.94
Advanced nuclear	90%	$60.71	$16.15	$10.30	$1.08	$88.24	-$6.52	$81.71
Geothermal	90%	$22.04	$15.18	$1.21	$1.40	$39.82	-$2.20	$37.62
Biomass	83%	$40.80	$18.10	$30.07	$1.19	$90.17	*NA*	$90.17
Resource-constrained technologies								
Wind, onshore	41%	$29.90	$7.70	$0.00	$2.63	$40.23	*NA*	$40.23
Wind, offshore	44%	$103.77	$30.17	$0.00	$2.57	$136.51	-$31.13	$105.38
Solar, standalone[c]	29%	$26.60	$6.38	$0.00	$3.52	$36.49	-$2.66	$33.83
Solar, hybrid[c,d]	28%	$34.98	$13.92	$0.00	$3.63	$52.53	-$3.50	$49.03
Hydroelectric[d]	54%	$46.58	$11.48	$4.13	$2.08	$64.27	*NA*	$64.27
Capacity resource technologies								
Combustion turbine	10%	$53.78	$8.37	$45.83	$9.89	$117.86	*NA*	$117.86
Battery storage	10%	$64.03	$29.64	$24.83	$10.05	$128.55	*NA*	$128.55

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

[a] O&M = operations and maintenance

[b] The tax credit component is based on targeted federal tax credits such as the Production Tax Credit (PTC) or Investment Tax Credit (ITC) available for some technologies. It reflects tax credits available only for plants entering service in 2027 and the substantial phaseout of both the PTC and ITC as scheduled under current law. Technologies not eligible for PTC or ITC are indicated as *NA,* or *not available*. The results are based on a regional model, and state or local incentives are not included in LCOE and LCOS calculations. See text box on page 2 for details on how the tax credits are represented in the model.

[c] Technology is assumed to be photovoltaic (PV) with single-axis tracking. The solar hybrid system is a single-axis PV system coupled with a four-hour battery storage system. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

[d] As modeled, we assume that hydroelectric and hybrid solar PV generating assets have seasonal and diurnal storage, respectively, so that they can be dispatched within a season or a day, but overall operation is limited by resource availablility by site and season for hydroelectric and by daytime for hybrid solar PV.

Table 2 shows a range of LCOE and LCOS values, which represent the significant regional variation attributed to local labor markets and the cost and availability of fuel or energy resources (such as windy sites). For example, the LCOE for incremental onshore wind capacity ranges from $30.01 per megawatthour (MWh) in the region with the highest-quality wind resources to $65.65/MWh in the region with the lowest-quality wind resources and/or higher capital costs for the best sites. Because onshore wind plants will most likely be built in regions that offer low cost and high value, the weighted average cost across regions is closer to the low end of the range at $37.80/MWh. Costs for wind generators may include additional expenses associated with transmission upgrades needed to access remote resources, as well as other factors that markets may not internalize into the market price for wind power.

Table 2. Regional variation in levelized cost of electricity (LCOE) and levelized cost of storage (LCOS) for new resources entering service in 2027 (2021 dollars per megawatthour)

	Without tax credits				With tax credits[a]			
Plant type	**Minimum**	**Simple average**	**Capacity-weighted average[b]**	**Maximum**	**Minimum**	**Simple average**	**Capacity-weighted average[b]**	**Maximum**
Dispatchable technologies								
Ultra-supercritical coal	$73.86	$82.61	*NB*	$101.25	$73.86	$82.61	*NB*	$101.25
Combined cycle	$34.30	$39.94	$37.05	$50.09	$34.30	$39.94	$37.05	$50.09
Advanced nuclear	$82.76	$88.24	*NB*	$98.78	$76.23	$81.71	*NB*	$92.25
Geothermal	$36.86	$39.82	$39.61	$41.57	$34.98	$37.62	$37.43	$39.25
Biomass	$79.87	$90.17	*NB*	$141.03	$79.87	$90.17	*NB*	$141.03
Resource-constrained technologies								
Wind, onshore	$30.01	$40.23	$37.80	$65.65	$30.01	$40.23	$37.80	$65.65
Wind, offshore	$109.88	$136.51	*NB*	$170.31	$86.34	$105.38	*NB*	$128.93
Solar, standalone[c]	$30.13	$36.49	$36.09	$48.58	$27.93	$33.83	$33.46	$44.95
Solar, hybrid[c,d]	$43.15	$52.53	$58.62	$67.97	$40.30	$49.03	$54.71	$63.30
Hydroelectric[e]	$48.96	$64.27	*NB*	$82.65	$48.96	$64.27	*NB*	$82.65
Capacity resource technologies								
Combustion turbine	$106.02	$117.86	$123.84	$145.46	$106.02	$117.86	$123.84	$145.46
Battery storage	$114.70	$128.55	$124.84	$141.06	$114.70	$128.55	$124.84	$141.06

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

Note: We calculate the levelized costs for non-dispatchable technologies based on the capacity factor for the marginal site modeled in each region, which can vary significantly by region. The capacity factor ranges for these technologies are 38%–47% for onshore wind, 41%–50% for offshore wind, 25%–33% for standalone solar PV, 24%–32% for hybrid solar PV, and 25%–80% for hydroelectric. Regional variations in construction labor rates and capital costs as well as resource availability also affect levelized costs.

[a] Levelized cost with tax credits reflects targeted federal tax credits such as the Production Tax Credit (PTC) or Investment Tax Credit (ITC) available for plants entering service in 2027 and the substantial phaseout of both the PTC and ITC as scheduled under current law.

[b] The capacity-weighted average is the average levelized cost per technology, weighted by the new capacity coming online in each region. The capacity additions for each region are based on additions from 2025 to 2027. Technologies for which capacity additions are not expected do not have a capacity-weighted average and are marked as *NB,* or *not built*.

[c] Technology is assumed to be photovoltaic (PV) with single-axis tracking. The solar hybrid system is a single-axis PV system coupled with a four-hour battery storage system. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

[d] As modeled, we assume that hydroelectric and hybrid solar PV generating assets have seasonal and diurnal storage, respectively, so that they can be dispatched within a season or a day, but overall operation is limited by resource availablility by site and season for hydroelectric and by daytime for hybrid solar PV.

LACE accounts for the differences in the grid services that each technology provides, and it recognizes that intermittent resources, such as wind or solar, have substantially different duty cycles than the baseload, intermediate, and peaking duty cycles of conventional generators. Table 3 provides the range of LACE estimates for different capacity types. We calculate the LACE in this table by assuming the same maximum capacity factor that we used for the LCOE and LCOS calculations.

Table 3. Regional variation in levelized avoided cost of electricity (LACE) for new resources entering service in 2027 (2021 dollars per megawatthour)

Plant type	Minimum	Simple average	Capacity-weighted average[a]	Maximum
Dispatchable technologies				
Ultra-supercritical coal	$34.87	$38.69	*NB*	$43.82
Combined cycle	$34.71	$39.54	$37.45	$50.77
Advanced nuclear	$34.63	$38.42	*NB*	$43.44
Geothermal	$40.38	$45.11	$46.52	$50.40
Biomass	$34.97	$39.84	*NB*	$51.25
Resource-constrained technologies				
Wind, onshore	$29.84	$34.54	$34.37	$53.53
Wind, offshore	$30.90	$36.00	*NB*	$47.64
Solar, standalone[b]	$29.21	$32.85	$33.82	$38.02
Solar, hybrid[b,c]	$30.48	$45.53	$50.82	$57.14
Hydroelectric[c]	$31.48	$37.87	*NB*	$48.71
Capacity resource technologies				
Combustion turbine	$68.35	$101.74	$107.82	$132.10
Battery storage	$68.35	$101.01	$106.08	$126.39

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

[a] The capacity-weighted average is the average levelized cost per technology, weighted by the new capacity coming online in each region. The capacity additions for each region are based on additions from 2025 to 2027. Technologies for which capacity additions are not expected do not have a capacity-weighted average and are marked as *NB*, or *not built*.

[b] Technology is assumed to be photovoltaic (PV) with single-axis tracking. The solar hybrid system is a single-axis PV system coupled with a four-hour battery storage system. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

[c] As modeled, we assume that hydroelectric and hybrid solar PV generating assets have seasonal and diurnal storage, respectively, so that they can be dispatched within a season or a day, but overall operation is limited by resource availablility by site and season for hydroelectric and by daytime for hybrid solar PV.

When the LACE of a particular technology exceeds its LCOE or LCOS, that technology would generally be economically attractive to build. The build decisions in actuality (and as we model in AEO2022), however, are more complex than a simple LACE-to-LCOE or LACE-to-LCOS comparison because they include factors such as policy and non-economic drivers. Nevertheless, the value-cost ratio (the ratio of LACE-to-LCOE or LACE-to-LCOS) provides a reasonable point of comparison of first-order economic competitiveness among a wider variety of technologies than is possible using LCOE, LCOS, or LACE tables individually. In Tables 4a and 4b, a value index of less than one indicates that the cost of the marginal new unit of capacity exceeds its value to the system, and a value-cost ratio greater than one indicates that the marginal new unit brings in value higher than its cost by displacing more expensive generation and capacity options. The *average value-cost ratio* is an average of 25 regional LACE-to-LCOE or LACE-to-LCOS ratios. The range of the LACE-to-LCOE or LACE-to-LCOS ratios represents the lower and upper bounds of the regional LACE-to-LCOE and LACE-to-LCOS ratios, and it is not based on the ratio between the minimum and maximum values shown in Tables 2 and 3.

As shown in Table 4a, the capacity-weighted average value-cost ratio is greater than one for standalone solar PV and geothermal in 2027, suggesting that these technologies will be built in regions where they are economically viable. Furthermore, the capacity-weighted average value-cost ratio for CC is above one, suggesting that the technology is an attractive marginal capacity addition and that the market has developed the technology to an equilibrium point where the net economic value is close to breakeven after having met load growth or displaced higher cost generation.[11]

Table 4a. Value-cost ratio (capacity-weighted) for new resources entering service in 2027

Plant type	Average capacity-weighted[a] LCOE[b] or LCOS[b] with tax credits (2021 dollars per megawatthour)	Average capacity-weighted[a] LACE[b] (2021 dollars per megawatthour)	Average value-cost ratio[c]
Dispatchable technologies			
Ultra-supercritical coal	*NB*	*NB*	*NB*
Combined cycle	$37.05	$37.45	1.01
Advanced nuclear	*NB*	*NB*	*NB*
Geothermal	$37.43	$46.52	1.25
Biomass	*NB*	*NB*	*NB*
Resource-constrained technologies			
Wind, onshore	$37.80	$34.37	0.92
Wind, offshore	*NB*	*NB*	*NB*
Solar, standalone[d]	$33.46	$33.82	1.02
Solar, hybrid[d,e]	$54.71	$50.82	0.94
Hydroelectric[e]	*NB*	*NB*	*NB*
Capacity resource technologies			
Combustion turbine	$123.84	$107.82	0.87
Battery storage	$124.84	$106.08	0.85

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

[a] The capacity-weighted average is the average levelized cost per technology, weighted by the new capacity coming online in each region. The capacity additions for each region are based on additions from 2025 to 2027. Technologies for which capacity additions are not expected do not have a capacity-weighted average and are marked as *NB*, or *not built*.

[b] LCOE = levelized cost of electricity, LCOS = levelized cost of storage, and LACE = levelized avoided cost of electricity.

[c] The *average value-cost ratio* is an average of 25 regional value-cost ratios based on the cost with tax credits for each technology, as available.

[d] Technology is assumed to be photovoltaic (PV) with single-axis tracking. The solar hybrid system is a single-axis PV system coupled with a four-hour battery storage system. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

[e] As modeled, we assume that hydroelectric and hybrid solar PV generating assets have seasonal and diurnal storage, respectively, so that they can be dispatched within a season or a day, but overall operation is limited by resource availablility by site and season for hydroelectric and by daytime for hybrid solar PV.

[11] For a more detailed discussion of the LACE versus LCOE measures, see *Assessing the Economic Value of New Utility-Scale Electricity Generation Projects*.

Table 4b. Value-cost ratio (unweighted) for new resources entering service in 2027

Plant type	Average unweighted LCOE[a] or LCOS[a] with tax credits (2021 dollars per megawatthour)	Average unweighted LACE[a] (2021 dollars per megawatthour)	Average value-cost ratio[b]	Minimum[c]	Maximum[c]
Dispatchable technologies					
Ultra-supercritical coal	$82.61	$38.69	0.47	0.40	0.52
Combined cycle	$39.94	$39.54	0.99	0.91	1.03
Advanced nuclear	$81.71	$38.42	0.47	0.41	0.55
Geothermal	$37.62	$45.11	1.20	1.08	1.41
Biomass	$90.17	$39.84	0.45	0.28	0.52
Resource-constrained technologies					
Wind, onshore	$40.23	$34.54	0.88	0.60	1.03
Wind, offshore	$105.38	$36.00	0.34	0.27	0.43
Solar, standalone[d]	$33.83	$32.85	0.98	0.72	1.14
Solar, hybrid[d,e]	$49.03	$45.53	0.93	0.64	1.07
Hydroelectric[e]	$64.27	$37.87	0.60	0.45	0.80
Capacity resource technologies					
Combustion turbine	$117.86	$101.74	0.86	0.61	1.00
Battery storage	$128.55	$101.01	0.79	0.52	0.97

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

[a] LCOE = levelized cost of electricity, LCOS = levelized cost of storage, and LACE = levelized avoided cost of electricity

[b] The *average value-cost ratio* is an average of 25 regional value-cost ratios based on the cost with tax credits for each technology, as available.

[c] The range of unweighted value-cost ratio represents the lower and upper bounds resulting from the ratio of LACE-to-LCOE or LACE-to-LCOS calculations for each of the 25 regions.

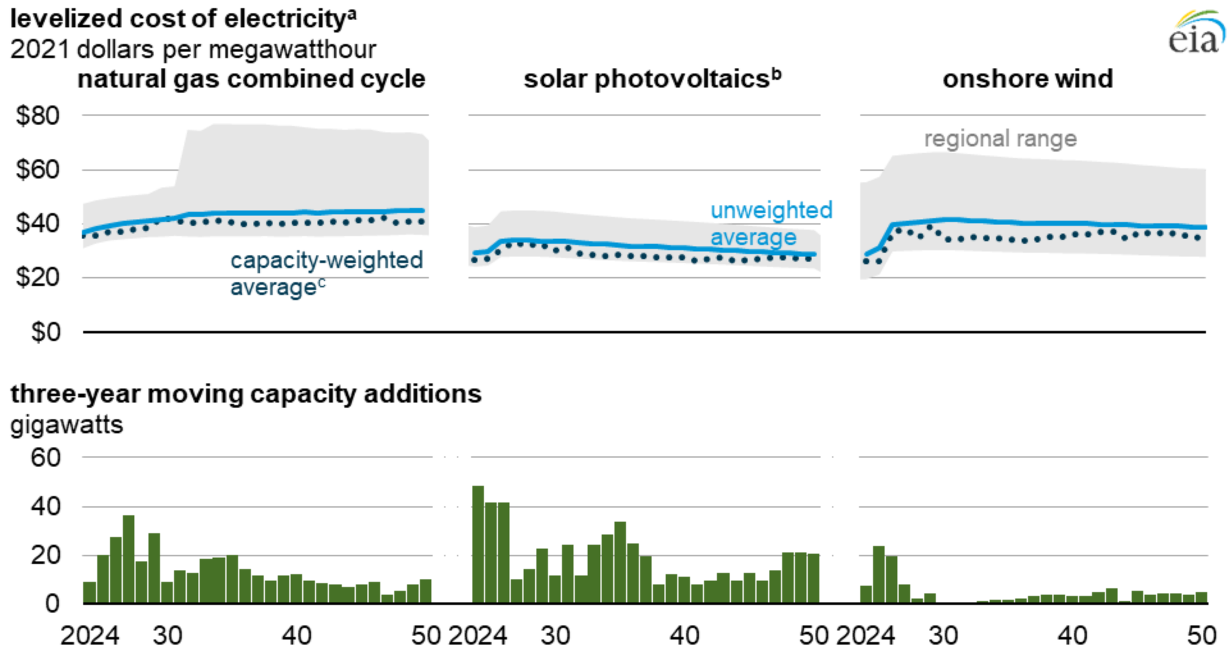
[d] Technology is assumed to be photovoltaic (PV) with single-axis tracking. The solar hybrid system is a single-axis PV system coupled with a four-hour battery storage system. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

[e] As modeled, we assume that hydroelectric and hybrid solar PV generating assets have seasonal and diurnal storage, respectively, so that they can be dispatched within a season or a day, but overall operation is limited by resource availablility by site and season for hydroelectric and by daytime for hybrid solar PV.

LCOE and LACE projections

In Figure 3, we show capacity-weighted and unweighted LCOE for CC, solar PV (standalone), and onshore wind plants entering service from 2024 to 2050 in the AEO2022 Reference case. Changes in costs over time reflect a number of different model factors, sometimes working in different directions. For both solar PV and onshore wind, LCOE increases in the near term with the phasedown and expiration of the ITC and PTC, respectively. However, LCOE eventually declines over time because of technology improvement that tends to reduce LCOE through lower capital costs or improved performance (as measured by capacity factor for onshore wind or solar PV plants), offsetting some or all of the loss of the tax credits. The availability of high-quality resources may also be a factor. As the best, least-cost resources are used first, future development will occur in less favorable areas, potentially resulting in lower-performing resources, higher project development costs, and higher costs to access transmission lines. For CC, changing fuel prices also factors into the change in LCOE, as well as any environmental regulations that affect capital or operating costs.

Figure 3. Capacity-weighted and unweighted levelized cost of electricity (LCOE) projections and three-year moving capacity additions for selected generating technologies, 2024–50



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

[a] Levelized cost includes tax credits available for plants entering service during the projection period.

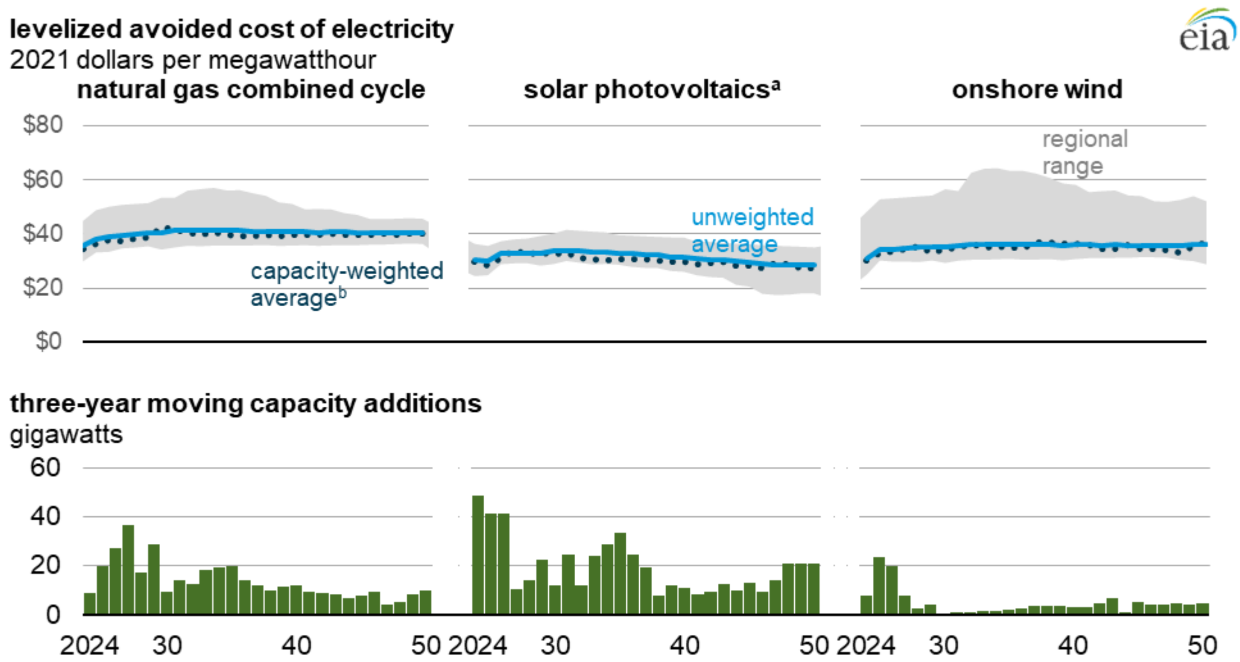
[b] Technology is assumed to be photovoltaic with single-axis tracking. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

[c] Capacity-weighted average is the average levelized cost per technology, weighted by the new capacity coming online in the previous three years in each region. For example, plants coming online in 2027 are based on additions from 2025 to 2027.

For all three technologies, the capacity-weighted average LCOE and unweighted average LCOE are not far apart from each other. In addition, all three technologies continue to be installed throughout the projection period so the capacity-weighted average LCOE stays lower than the unweighted LCOE, reflecting the build-out in low-cost regions. The capacity-weighted average LCOE and unweighted average LCOE for solar PV are closer to each other because we expect new builds across many regions throughout the projection period. The projected regional range for CC is generally narrow in the early years, but this range widens in later years because of the increase in variable costs for plants in California as a result of California's phaseout of fossil fuel-fired generation starting in 2030.

In Figure 4 we show capacity-weighted and unweighted average LACE over time. Changes in the value of generation, represented by LACE, are primarily a function of load growth. The LACE for onshore wind increases throughout the projection period as load increases. On the other hand, the LACE value for solar significantly decreases as generation from solar resources become more saturated with similar hourly operation patterns from strong daily or seasonal generation patterns within any given region. As this saturation occurs, generation from new facilities must compete with lower-cost options in the dispatch merit order. However, lower marginal electricity prices during daylight hours leads to declining LCOS for battery storage over the projection period, as it can take advantage of charging during the periods of lower electricity prices and discharges during evening peak-demand periods with higher electricity prices.

Figure 4. Capacity-weighted[1] and unweighted levelized avoided cost of electricity (LACE) projections and three-year moving capacity additions for selected generating technologies, 2024–50

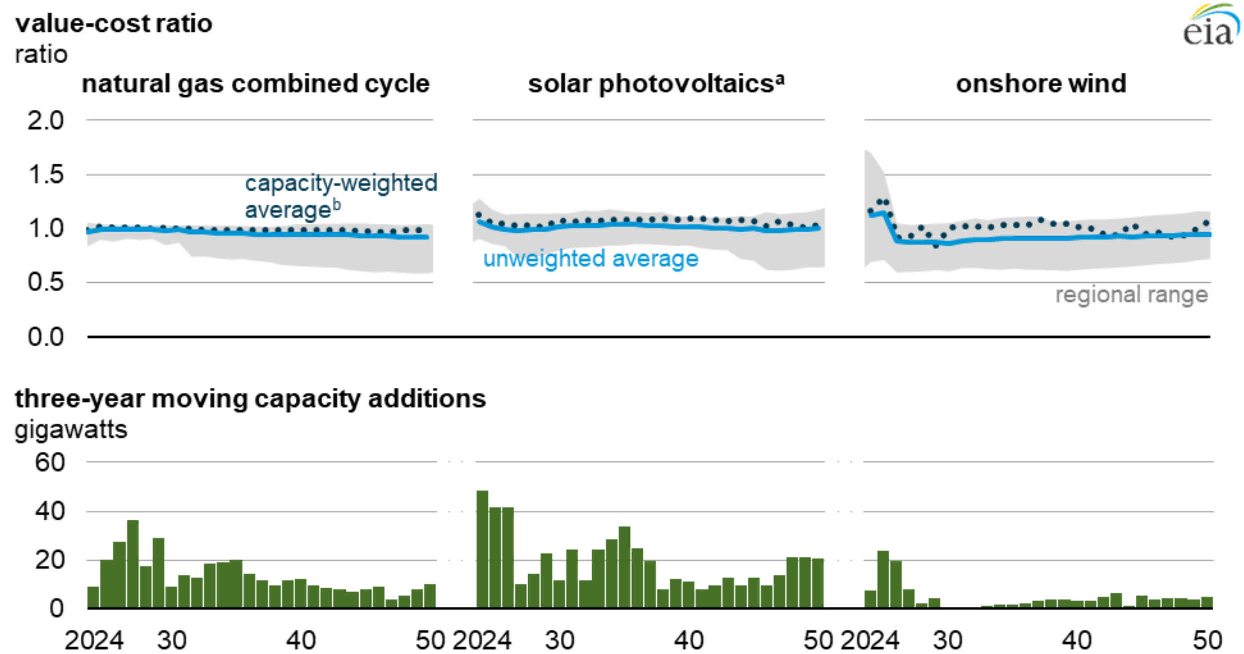


Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*
[a] Technology is assumed to be photovoltaic with single-axis tracking. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.
[b] Capacity-weighted average is the average levelized cost per technology, weighted by the new capacity coming online in the previous three years in each region. For example, plants coming online in 2027 are based on additions from 2025 to 2027.

Similar behaviors and patterns emerge with LACE as with LCOE; the capacity-weighted and the unweighted LACE stay close to each other throughout the projection period while the capacity-weighted LACE generally remains lower than the unweighted LACE.

When considering both the value and cost of building and operating a power plant, CC, solar PV, and onshore wind all reach market equilibrium or a break-even point (Figure 5). The break-even point represents a stable solution point where LACE equals LCOE. Once a technology achieves a value-cost ratio greater than one, its value-cost ratio tends to remain close to one, as seen with CC and solar PV. If the value-cost ratio is less than one, as seen with onshore wind in the near to mid-term, continued load growth, technology cost declines, or perhaps escalation in the fuel cost of a competing resource will tend to reduce the technology costs or increase the technology value to the grid over time. Similarly, if the value-cost ratio becomes significantly greater than one, the market will quickly build-out the technology until it meets the demand growth or displaces the higher cost incumbent generation. In all technologies, the capacity-weighted value-cost ratio stays mostly above the unweighted value-cost ratio, indicating that the capacity is being added in regions where it is most economical.

Figure 5. Value-cost ratio and three-year moving capacity additions for selected generating technologies, 2024–50



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*
[a] Technology is assumed to be photovoltaic with single-axis tracking. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.
[b] Capacity-weighted average is the average levelized cost per technology, weighted by the new capacity coming online in the previous three years in each region. For example, plants coming online in 2027 are based on additions from 2025 to 2027.

Market shocks may cause a divergence between LACE and LCOE and, therefore, disturb the market equilibrium. These market shocks include technology change, policy developments, or fuel price volatility that can increase or decrease the value-cost ratio of any given technology. However, we expect the market to reverse the divergence by either building the high-value resource (if the value-cost ratio increased) or waiting for slow-acting factors such as load growth to increase the value (if the value-cost ratio decreased) as seen for the capacity-weighted average value-cost ratios of both wind and solar PV.

Appendix A: LCOE tables for new generation resources entering service in 2024

Table A1a. Estimated capacity-weighted[a] levelized cost of electricity (LCOE) and levelized cost of storage (LCOS) for new resources entering service in 2024 (2021 dollars per megawatthour)

Plant type	Capacity factor (percent)	Levelized capital cost	Levelized fixed O&M[b]	Levelized variable cost	Levelized transmis-sion cost	Total system LCOE or LCOS	Levelized tax credit[c]	Total LCOE or LCOS including tax credit
Dispatchable technologies								
Combined cycle	87%	$7.72	$1.68	$25.10	$1.03	$35.53	*NA*	$35.53
Resource-constrained technologies								
Wind, onshore	41%	$24.71	$7.65	$0.00	$2.56	$34.92	-$8.77	$26.15
Solar, standalone[d]	30%	$24.53	$6.03	$0.00	$2.51	$33.07	-$6.38	$26.69
Solar, hybrid[d,e]	30%	$32.35	$12.94	$0.00	$3.08	$48.37	-$8.41	$39.96
Capacity resource technologies								
Combustion turbine	10%	$46.75	$8.37	$40.64	$8.32	$104.07	*NA*	$104.07
Battery storage	10%	$64.08	$29.64	$36.25	$10.15	$140.11	*NA*	$140.11

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

[a] The capacity-weighted average is the average levelized cost per technology, weighted by the new capacity coming online in each region. We base the capacity additions for each region on additions from 2022 to 2024.

[b] O&M = operations and maintenance

[c] The tax credit component is based on targeted federal tax credits such as the Production Tax Credit (PTC) or Investment Tax Credit (ITC) available for some technologies. It reflects tax credits available only for plants entering service in 2024 and the substantial phaseout of both the PTC and ITC as scheduled under current law. Technologies not eligible for PTC or ITC are indicated as *NA,* or *not available*. The results are based on a regional model, and state or local incentives are not included in LCOE and LCOS calculations. See text box on page 2 for details on how the tax credits are represented in the model.

[d] Technology is assumed to be photovoltaic (PV) with single-axis tracking. The solar hybrid system is a single-axis PV system coupled with a four-hour battery storage system. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

[e] As modeled, we assume that hybrid solar PV generating assets have diurnal storage so that they can be dispatched within a day, but overall operation is limited by resource availablility during daytime.

Table A1b. Estimated unweighted levelized cost of electricity (LCOE) and levelized cost of storage (LCOS) for new resources entering service in 2024 (2021 dollars per megawatthour)

Plant type	Capacity factor (percent)	Levelized capital cost	Levelized fixed O&M[a]	Levelized variable cost	Levelized transmis-sion cost	Total system LCOE or LCOS	Levelized tax credit[b]	Total LCOE or LCOS including tax credit
Dispatchable technologies								
Combined cycle	87%	$8.03	$1.68	$26.07	$1.03	$36.81	*NA*	$36.81
Resource-constrained technologies								
Wind, onshore	41%	$27.79	$7.65	$0.00	$2.36	$37.80	-$8.77	$29.03
Solar, standalone[c]	29%	$26.56	$6.34	$0.00	$3.16	$36.07	-$6.91	$29.16
Solar, hybrid[c,d]	28%	$35.57	$13.85	$0.00	$3.26	$52.68	-$9.25	$43.43
Capacity resource technologies								
Combustion turbine	10%	$47.70	$8.37	$42.41	$8.94	$107.42	*NA*	$107.42
Battery storage	10%	$63.85	$29.64	$29.39	$9.09	$131.98	*NA*	$131.98

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

[a] O&M = operations and maintenance

[b] The tax credit component is based on targeted federal tax credits such as the Production Tax Credit (PTC) or Investment Tax Credit (ITC) available for some technologies. It reflects tax credits available only for plants entering service in 2024 and the substantial phaseout of both the PTC and ITC as scheduled under current law. Technologies not eligible for PTC or ITC are indicated as *NA*, or *not available*. The results are based on a regional model, and state or local incentives are not included in LCOE and LCOS calculations. See text box on page 2 for details on how the tax credits are represented in the model.

[c] Technology is assumed to be photovoltaic (PV) with single-axis tracking. The solar hybrid system is a single-axis PV system coupled with a four-hour battery storage system. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

[d] As modeled, we assume that hybrid solar PV generating assets have diurnal storage so that they can be dispatched within a day, but overall operation is limited by resource availablility during daytime.

Table A2. Regional variation in levelized cost of electricity (LCOE) and levelized cost of storage (LCOS) for new resources entering service in 2024 (2021 dollars per megawatthour)

	Without tax credits				With tax credits[a]			
Plant type	Minimum	Simple average	Capacity-weighted average[b]	Maximum	Minimum	Simple average	Capacity-weighted average[b]	Maximum
Dispatchable technologies								
Combined cycle	$30.99	$36.81	$35.53	$47.40	$30.99	$36.81	$35.53	$47.40
Resource-constrained technologies								
Wind, onshore	$28.36	$37.80	$34.92	$64.14	$19.59	$29.03	$26.15	$55.37
Solar, standalone[c]	$29.96	$36.07	$33.07	$48.23	$24.22	$29.16	$26.69	$38.77
Solar, hybrid[c,d]	$43.54	$52.68	$48.37	$68.51	$35.96	$43.43	$39.96	$56.09
Capacity resource technologies								
Combustion turbine	$95.83	$107.42	$104.07	$132.85	$95.83	$107.42	$104.07	$132.85
Battery storage	$105.50	$131.98	$140.11	$148.49	$105.50	$131.98	$140.11	$148.49

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

Note: We calculate the levelized costs for non-dispatchable technologies based on the capacity factor for the marginal site modeled in each region, which can vary significantly by region. The capacity factor ranges for these technologies are 37%–51% for onshore wind, 25%–33% for standalone solar PV, and 24%–32% for hybrid solar PV. Regional variations in construction labor rates and capital costs as well as resource availability also affect levelized costs.

[a] Levelized cost with tax credits reflects targeted federal tax credits such as the Production Tax Credit (PTC) or Investment Tax Credit (ITC) available for plants entering service in 2024 and the substantial phaseout of both the PTC and ITC as scheduled under current law.

[b] The capacity-weighted average is the average levelized cost per technology, weighted by the new capacity coming online in each region. The capacity additions for each region are based on additions from 2022 to 2024.

[c] Technology is assumed to be photovoltaic (PV) with single-axis tracking. The solar hybrid system is a single-axis PV system coupled with a four-hour battery storage system. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

[d] As modeled, we assume that hybrid solar PV generating assets have diurnal storage so that they can be dispatched within a day, but overall operation is limited by resource availablility during daytime.

Table A3. Regional variation in levelized avoided cost of electricity (LACE) for new resources entering service in 2024 (2021 dollars per megawatthour)

Plant type	Minimum	Simple average	Capacity-weighted average[a]	Maximum
Dispatchable technologies				
Combined cycle	$29.92	$35.48	$34.73	$44.82
Resource-constrained technologies				
Wind, onshore	$25.07	$30.95	$30.30	$48.24
Solar, standalone[b]	$24.45	$30.65	$29.96	$36.36
Solar, hybrid[b,c]	$28.02	$41.28	$40.93	$53.73
Capacity resource technologies				
Combustion turbine	$58.44	$90.11	$92.19	$120.32
Battery storage	$58.44	$89.82	$102.69	$119.52

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

[1]The capacity-weighted average is the average levelized cost per technology, weighted by the new capacity coming online in each region. The capacity additions for each region are based on additions from 2022 to 2024.

[b] Technology is assumed to be photovoltaic (PV) with single-axis tracking. The solar hybrid system is a single-axis PV system coupled with a four-hour battery storage system. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

[c] As modeled, we assume that hybrid solar PV generating assets have diurnal storage so that they can be dispatched within a day, but overall operation is limited by resource availablility during daytime.

Table A4a. Value-cost ratio (capacity-weighted) for new resources entering service in 2024

Plant type	Average capacity-weighted[a] LCOE[b] or LCOS[b] with tax credits (2021 dollars per megawatthour)	Average capacity-weighted[a] LACE[b] (2021 dollars per megawatthour)	Average value-cost ratio[c]
Dispatchable technologies			
Combined cycle	$35.53	$34.73	0.98
Resource-constrained technologies			
Wind, onshore	$26.15	$30.30	1.17
Solar, standalone[d]	$26.69	$29.96	1.12
Solar, hybrid[d,e]	$39.96	$40.93	1.03
Capacity resource technologies			
Combustion turbine	$104.07	$92.19	0.89
Battery storage	$140.11	$102.69	0.73

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

[a] The capacity-weighted average is the average levelized cost per technology, weighted by the new capacity coming online in each region. The capacity additions for each region are based on additions from 2022 to 2024.

[b] LCOE = levelized cost of electricity, LCOS = levelized cost of storage, and LACE = levelized avoided cost of electricity.

[c] The *average value-cost ratio* is an average of 25 regional value-cost ratios based on the cost with tax credits for each technology, as available.

[d] Technology is assumed to be photovoltaic (PV) with single-axis tracking. The solar hybrid system is a single-axis PV system coupled with a four-hour battery storage system. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

[e] As modeled, we assume that hybrid solar PV generating assets have diurnal storage so that they can be dispatched within a day, but overall operation is limited by resource availablility during daytime.

Table A4b. Value-cost ratio (unweighted) for new resources entering service in 2024

Plant type	Average unweighted LCOE[a] or LCOS[a] with tax credits (2021 dollars per megawatthour)	Average unweighted LACE[a] (2021 dollars per megawatthour)	Average value-cost ratio[b]	Minimum[c]	Maximum[c]
Dispatchable technologies					
Combined cycle	$36.81	$35.48	0.97	0.84	1.06
Resource-constrained technologies					
Wind, onshore	$29.03	$30.95	1.12	0.69	1.70
Solar, standalone[d]	$29.16	$30.65	1.06	0.91	1.28
Solar, hybrid[d,e]	$43.43	$41.28	0.95	0.66	1.06
Capacity resource technologies					
Combustion turbine	$107.42	$90.11	0.84	0.57	1.04
Battery storage	$131.98	$89.82	0.68	0.43	0.95

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

[a] LCOE = levelized cost of electricity, LCOS = levelized cost of storage, and LACE = levelized avoided cost of electricity.

[b] The *average value-cost ratio* is an average of 25 regional value-cost ratios based on the cost with tax credits for each technology, as available.

[c] The range of unweighted value-cost ratio represents the lower and upper bounds resulting from the ratio of LACE-to-LCOE or LACE-to-LCOS calculations for each of the 25 regions.

[d] Technology is assumed to be photovoltaic (PV) with single-axis tracking. The solar hybrid system is a single-axis PV system coupled with a four-hour battery storage system. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

[e] As modeled, we assume that hybrid solar PV generating assets have diurnal storage so that they can be dispatched within a day, but overall operation is limited by resource availablility during daytime.

Appendix B: LCOE and LACE tables for new resources entering service in 2040

Table B1a. Estimated capacity-weighted[a] levelized cost of electricity (LCOE) and levelized cost of storage (LCOS) for new resources entering service in 2040 (2021 dollars per megawatthour)

Plant type	Capacity factor (percent)	Levelized capital cost	Levelized fixed O&M[b]	Levelized variable cost	Levelized transmis-sion cost	Total system LCOE or LCOS	Levelized tax credit[c]	Total LCOE or LCOS including tax credit
Dispatchable technologies								
Ultra-supercritical coal	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*
Combined cycle	87%	$8.07	$1.68	$29.43	$1.12	$40.29	*NA*	$40.29
Advanced nuclear	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*
Geothermal	90%	$23.09	$15.92	$1.21	$1.42	$41.64	-$2.31	$39.34
Biomass	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*
Resource-constrained technologies								
Wind, onshore	41%	$25.24	$7.78	$0.00	$3.06	$36.08	*NA*	$36.08
Wind, offshore	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*
Solar, standalone[d]	31%	$20.80	$5.86	$0.00	$2.82	$29.48	-$2.08	$27.40
Solar, hybrid[d,e]	30%	$27.95	$13.07	$0.00	$3.19	$44.21	-$2.80	$41.41
Hydroelectric[e]	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*
Capacity resource technologies								
Combustion turbine	10%	$50.53	$8.37	$48.19	$9.66	$116.75	*NA*	$116.75
Battery storage	10%	$57.84	$29.64	$8.31	$8.53	$104.33	*NA*	$104.33

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

[a] The capacity-weighted average is the average levelized cost per technology, weighted by the new capacity coming online in each region. We base the capacity additions for each region on additions from 2038 to 2040. Technologies for which capacity additions are not expected do not have a capacity-weighted average and are marked as *NB*, or *not built*.

[b] O&M = operations and maintenance

[c] The tax credit component is based on targeted federal tax credits such as the Production Tax Credit (PTC) or Investment Tax Credit (ITC) available for some technologies. It reflects tax credits available only for plants entering service in 2040 and the substantial phaseout of both the PTC and ITC as scheduled under current law. Technologies not eligible for PTC or ITC are indicated as *NA*, or *not available*. The results are based on a regional model, and state or local incentives are not included in LCOE and LCOS calculations. See text box on page 2 for details on how the tax credits are represented in the model.

[d] Technology is assumed to be photovoltaic (PV) with single-axis tracking. The solar hybrid system is a single-axis PV system coupled with a four-hour battery storage system. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

[e] As modeled, we assume that hydroelectric and hybrid solar PV generating assets have seasonal and diurnal storage, respectively, so that they can be dispatched within a season or a day, but overall operation is limited by resource availablility by site and season for hydroelectric and by daytime for hybrid solar PV.

Table B1b. Estimated unweighted levelized cost of electricity (LCOE) and levelized cost of storage (LCOS) for new resources entering service in 2040 (2021 dollars per megawatthour)

Plant type	Capacity factor (percent)	Levelized capital cost	Levelized fixed O&M[a]	Levelized variable cost	Levelized transmis-sion cost	Total system LCOE or LCOS	Levelized tax credit[b]	Total LCOE or LCOS including tax credit
Dispatchable technologies								
Ultra-supercritical coal	85%	$48.97	$5.71	$23.64	$1.14	$79.46	*NA*	$79.46
Combined cycle	87%	$9.10	$1.68	$32.11	$1.16	$44.05	*NA*	$44.05
Advanced nuclear	90%	$57.31	$16.15	$10.71	$1.10	$85.28	-$5.07	$80.20
Geothermal	90%	$22.84	$16.44	$1.21	$1.42	$41.91	-$2.28	$39.63
Biomass	83%	$37.86	$18.10	$29.36	$1.21	$86.53	*NA*	$86.53
Resource-constrained technologies								
Wind, onshore	40%	$29.45	$7.89	$0.00	$2.74	$40.08	*NA*	$40.08
Wind, offshore	43%	$64.77	$30.58	$0.00	$2.66	$98.01	*NA*	$98.01
Solar, standalone[c]	29%	$23.42	$6.41	$0.00	$3.59	$33.42	-$2.34	$31.07
Solar, hybrid[c,d]	28%	$30.93	$13.99	$0.00	$3.71	$48.63	-$3.09	$45.54
Hydroelectric[d]	56%	$46.11	$11.85	$3.86	$2.02	$63.83	*NA*	$63.83
Capacity resource technologies								
Combustion turbine	10%	$50.84	$8.37	$52.59	$10.07	$121.87	*NA*	$121.87
Battery storage	10%	$58.93	$29.64	$21.66	$10.24	$120.47	*NA*	$120.47

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

[a] O&M = operations and maintenance

[b] The tax credit component is based on targeted federal tax credits such as the Production Tax Credit (PTC) or Investment Tax Credit (ITC) available for some technologies. It reflects tax credits available only for plants entering service in 2040 and the substantial phaseout of both the PTC and ITC as scheduled under current law. Technologies not eligible for PTC or ITC are indicated as *NA*, or *not available*. The results are based on a regional model, and state or local incentives are not included in LCOE and LCOS calculations. See text box on page 2 for details on how the tax credits are represented in the model.

[c] Technology is assumed to be photovoltaic (PV) with single-axis tracking. The solar hybrid system is a single-axis PV system coupled with a four-hour battery storage system. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

[d] As modeled, we assume that hydroelectric and hybrid solar PV generating assets have seasonal and diurnal storage, respectively, so that they can be dispatched within a season or a day, but overall operation is limited by resource availablility by site and season for hydroelectric and by daytime for hybrid solar PV.

Table B2. Regional variation in levelized cost of electricity (LCOE) and levelized cost of storage (LCOS) for new resources entering service in 2040 (2021 dollars per megawatthour)

	Without tax credits				With tax credits[a]			
Plant type	**Minimum**	**Simple average**	**Capacity-weighted average[b]**	**Maximum**	**Minimum**	**Simple average**	**Capacity-weighted average[b]**	**Maximum**
Dispatchable technologies								
Ultra-supercritical coal	$70.43	$79.46	*NB*	$97.93	$70.43	$79.46	*NB*	$97.93
Combined cycle	$35.35	$44.05	$40.29	$76.22	$35.35	$44.05	$40.29	$76.22
Advanced nuclear	$80.09	$85.28	*NB*	$95.22	$75.02	$80.20	*NB*	$90.14
Geothermal	$33.74	$41.91	$41.64	$48.18	$32.15	$39.63	$39.34	$45.41
Biomass	$77.25	$86.53	*NB*	$138.23	$77.25	$86.53	*NB*	$138.23
Resource-constrained technologies								
Wind, onshore	$29.13	$40.08	$36.08	$63.46	$29.13	$40.08	$36.08	$63.46
Wind, offshore	$79.79	$98.01	*NB*	$117.39	$79.79	$98.01	*NB*	$117.39
Solar, standalone[c]	$27.45	$33.42	$29.48	$44.18	$25.52	$31.07	$27.40	$41.00
Solar, hybrid[c,d]	$39.77	$48.63	$44.21	$62.45	$37.26	$45.54	$41.41	$58.34
Hydroelectric[d]	$48.66	$63.83	*NB*	$82.08	$48.66	$63.83	*NB*	$82.08
Capacity resource technologies								
Combustion turbine	$105.50	$121.87	$116.75	$174.35	$105.50	$121.87	$116.75	$174.35
Battery storage	$104.33	$120.47	$104.33	$144.04	$104.33	$120.47	$104.33	$144.04

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

Note: We calculate the levelized costs for non-dispatchable technologies based on the capacity factor for the marginal site modeled in each region, which can vary significantly by region. The capacity factor ranges for these technologies are 38%–47% for onshore wind, 41%–50% for offshore wind, 25%–33% for standalone solar PV, 24%–32% for hybrid solar PV, and 25%–80% for hydroelectric. Regional variations in construction labor rates and capital costs as well as resource availability also affect levelized costs.

[a] Levelized cost with tax credits reflects targeted federal tax credits such as the Production Tax Credit (PTC) or Investment Tax Credit (ITC) available for plants entering service in 2040 and the substantial phaseout of both the PTC and ITC as scheduled under current law.

[b] The capacity-weighted average is the average levelized cost per technology, weighted by the new capacity coming online in each region. The capacity additions for each region are based on additions from 2038 to 2040. Technologies for which capacity additions are not expected do not have a capacity-weighted average and are marked as *NB*, or *not built*.

[c] Technology is assumed to be photovoltaic (PV) with single-axis tracking. The solar hybrid system is a single-axis PV system coupled with a four-hour battery storage system. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

[d] As modeled, we assume that hydroelectric and hybrid solar PV generating assets have seasonal and diurnal storage, respectively, so that they can be dispatched within a season or a day, but overall operation is limited by resource availablility by site and season for hydroelectric and by daytime for hybrid solar PV.

Table B3. Regional variation in levelized avoided cost of electricity (LACE) for new resources entering service in 2040 (2021 dollars per megawatthour)

Plant type	Minimum	Simple average	Capacity-weighted average[a]	Maximum
Dispatchable technologies				
Ultra-supercritical coal	$35.92	$40.21	*NB*	$44.63
Combined cycle	$35.75	$40.86	$39.52	$51.13
Advanced nuclear	$35.68	$39.99	*NB*	$44.43
Geothermal	$43.09	$46.14	$46.36	$50.71
Biomass	$36.04	$41.17	*NB*	$51.45
Resource-constrained technologies				
Wind, onshore	$30.77	$36.06	$36.41	$58.14
Wind, offshore	$30.88	$36.13	*NB*	$47.53
Solar, standalone[b]	$26.09	$31.42	$29.82	$38.71
Solar, hybrid[b,c]	$36.33	$45.50	$43.18	$57.68
Hydroelectric[c]	$32.16	$39.19	*NB*	$49.40
Capacity resource technologies				
Combustion turbine	$88.27	$101.73	$102.54	$130.18
Battery storage	$87.00	$100.64	$89.21	$129.98

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

[a] The capacity-weighted average is the average levelized cost per technology, weighted by the new capacity coming online in each region. The capacity additions for each region are based on additions from 2038 to 2040. Technologies for which capacity additions are not expected do not have a capacity-weighted average and are marked as *NB*, or *not built*.

[b] Technology is assumed to be photovoltaic (PV) with single-axis tracking. The solar hybrid system is a single-axis PV system coupled with a four-hour battery storage system. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

[c] As modeled, we assume that hydroelectric and hybrid solar PV generating assets have seasonal and diurnal storage, respectively, so that they can be dispatched within a season or a day, but overall operation is limited by resource availablility by site and season for hydroelectric and by daytime for hybrid solar PV.

Table B4a. Value-cost ratio (capacity-weighted) for new resources entering service in 2040

Plant type	Average capacity-weighted[a] LCOE[b] or LCOS[b] with tax credits (2021 dollars per megawatthour)	Average capacity-weighted[a] LACE[b] (2021 dollars per megawatthour)	Average value-cost ratio[c]
Dispatchable technologies			
Ultra-supercritical coal	*NB*	*NB*	*NB*
Combined cycle	$40.29	$39.52	0.98
Advanced nuclear	*NB*	*NB*	*NB*
Geothermal	$39.34	$46.36	1.20
Biomass	*NB*	*NB*	*NB*
Resource-constrained technologies			
Wind, onshore	$36.08	$36.41	1.01
Wind, offshore	*NB*	*NB*	*NB*
Solar, standalone[d]	$27.40	$29.82	1.09
Solar, hybrid[d,e]	$41.41	$43.18	1.04
Hydroelectric[e]	*NB*	*NB*	*NB*
Capacity resource technologies			
Combustion turbine	$116.75	$102.54	0.88
Battery storage	$104.33	$89.21	0.86

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

[a] The capacity-weighted average is the average levelized cost per technology, weighted by the new capacity coming online in each region. The capacity additions for each region are based on additions from 2038 to 2040. Technologies for which capacity additions are not expected do not have a capacity-weighted average and are marked as *NB*, or *not built*.

[b] LCOE = levelized cost of electricity, LCOS = levelized cost of storage, and LACE = levelized avoided cost of electricity.

[c] The *average value-cost ratio* is an average of 25 regional value-cost ratios based on the cost with tax credits for each technology, as available.

[d] Technology is assumed to be photovoltaic (PV) with single-axis tracking. The solar hybrid system is a single-axis PV system coupled with a four-hour battery storage system. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

[e] As modeled, we assume that hydroelectric and hybrid solar PV generating assets have seasonal and diurnal storage, respectively, so that they can be dispatched within a season or a day, but overall operation is limited by resource availablility by site and season for hydroelectric and by daytime for hybrid solar PV.

Table B4b. Value-cost ratio (unweighted) for new resources entering service in 2040

Plant type	Average unweighted LCOE[a] or LCOS[a] with tax credits (2021 dollars per megawatthour)	Average unweighted LACE[a] (2021 dollars per megawatthour)	Average value-cost ratio[b]	Minimum[c]	Maximum[c]
Dispatchable technologies					
Ultra-supercritical coal	$79.46	$40.21	0.51	0.42	0.57
Combined cycle	$44.05	$40.86	0.95	0.65	1.04
Advanced nuclear	$80.20	$39.99	0.50	0.44	0.58
Geothermal	$39.63	$46.14	1.19	0.99	1.53
Biomass	$86.53	$41.17	0.48	0.31	0.56
Resource-constrained technologies					
Wind, onshore	$40.08	$36.06	0.92	0.62	1.08
Wind, offshore	$98.01	$36.13	0.37	0.29	0.48
Solar, standalone[d]	$31.07	$31.42	1.02	0.84	1.11
Solar, hybrid[d,e]	$45.54	$45.50	1.00	0.87	1.09
Hydroelectric[e]	$63.83	$39.19	0.63	0.47	0.82
Capacity resource technologies					
Combustion turbine	$121.87	$101.73	0.84	0.60	1.05
Battery storage	$120.47	$100.64	0.84	0.71	1.04

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2022*

[a] LCOE = levelized cost of electricity, LCOS = levelized cost of storage, and LACE = levelized avoided cost of electricity

[b] The *average value-cost ratio* is an average of 25 regional value-cost ratios based on the cost with tax credits for each technology, as available.

[c] The range of unweighted value-cost ratio represents the lower and upper bounds resulting from the ratio of LACE-to-LCOE or LACE-to-LCOS calculations for each of the 25 regions.

[d] Technology is assumed to be photovoltaic (PV) with single-axis tracking. The solar hybrid system is a single-axis PV system coupled with a four-hour battery storage system. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

[e] As modeled, we assume that hydroelectric and hybrid solar PV generating assets have seasonal and diurnal storage, respectively, so that they can be dispatched within a season or a day, but overall operation is limited by resource availablility by site and season for hydroelectric and by daytime for hybrid solar PV.