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Levelized Costs of New Generation Resources in the *Annual Energy Outlook 2021*

Levelized cost of electricity (LCOE) refers to the estimates of the 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 the *Annual Energy Outlook 2021* (AEO2021), the U.S. Energy Information Administration (EIA) includes estimates for the levelized cost of storage (LCOS) in addition to LCOE and LACE. This paper presents average values of LCOE, LCOS, and LACE for electric generating technologies entering service in 2023, 2026,[1] and 2040 as represented in the National Energy Modeling System (NEMS) for the AEO2021 Reference case.[2] The costs for electric generating facilities entering service in 2026 are presented in the body of this report, and the costs for 2023[3] and 2040 are included in Appendices A and B, respectively. 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) are provided, together with the range of regional values.

LCOE, LCOS, and LACE are simplifications of modeled decisions, and do not not fully capture all the factors considered in NEMS. Nevertheless, when used together, the cost and revenue metrics provide a more intuitive framework for understanding economic competitiveness between generation technologies in the capacity expansion decisions than considering either metric alone.

Levelized Cost of Electricity and Levelized Cost of Storage

Levelized cost of electricity and levelized cost of storage represent the average revenue per unit of electricity generated 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.[4] 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 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, EIA models 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.

[1] Given the long lead-time and licensing requirements for some technologies, the first feasible year that all technologies are available is 2026.
[2] AEO2021 is available on EIA's website.
[3] Appendix A shows LCOE, LCOS, and LACE for the subset of technologies available to be built in 2023.
[4] *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.

AEO2021 representation of tax incentives for renewable generation

Federal tax credits for certain renewable generation facilities can substantially reduce the realized cost of these facilities. Where applicable, LCOE is shown both with and without tax credits that EIA assumed would be available in the year in which the plant enters service based on the following representation.

Production Tax Credit (PTC): New wind, geothermal, and closed-loop biomass plants receive $25 per megawatthour (MWh) of generation; other PTC-eligible technologies receive $13/MWh. The PTC values are adjusted for inflation and are applied 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. EIA assumes that wind plants have five years after beginning construction to come online and claim the PTC (based on Division Q [Taxpayer Certainty and Disaster Tax Relief Act of 2019] of the Further Consolidated Appropriation Act, 2020 signed into law in December 2019 and Notice 2020-41 released by the Internal Revenue Service [IRS] in May 2020). As a result, wind plants entering service before 2025 will receive 60% of the full PTC value (inflation adjusted).

Investment Tax Credit (ITC): In June 2018, the IRS issued Notice 2018-59, which was beginning-of-construction guidance for the ITC. Based on these guidelines, EIA assumes all solar projects coming online before January 1, 2024 will receive the full 30% ITC. Solar projects include both utility-scale solar plants—those with a capacity rating of 1 megawatt (MW) or greater—and small-scale systems—those systems with a capacity rating of less than 1 MW. All commercial and utility-scale plants with a construction start date on or after January 1, 2022, or those plants placed in service after December 31, 2023, receive a 10% ITC. The ITC expires completely, however, for residential-owned systems starting in 2022. Results in this levelized cost report only include utility-scale solar facilities and do not include small-scale solar facilities. Because battery storage is assumed to be a standalone, grid-connected system, it is not eligible for the ITC. However, battery storage in the solar PV hybrid system is modeled as a co-located system, and is therefore 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 in lieu of the PTC. Although EIA expects that onshore wind projects will choose the PTC, EIA assumes offshore wind projects will claim the ITC because of the relatively higher capital costs for those projects.

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.[5] 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 *AEO2021 representation of tax incentives for renewable generation*), also affect the calculation of LCOE.

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

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 EIA assumes 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 such 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 (non-dispatchable technologies) that use intermittent resources to operate. The LCOE values for dispatchable and non-dispatchable technologies are listed separately in the following tables because comparing them must be done carefully. The solar PV hybrid LCOE is included under non-dispatchable 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 battery storage, capacity might be added in regions with higher renewables penetration, particularly solar, to capture any curtailments that would otherwise occur during the daytime, allowing for higher levels of capacity additions in those regions.

Levelized Avoided Cost of Electricity

LCOE and LCOS 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 AEO2021, solar LCOE on average is lower than natural gas-fired combined-cycle (CC) LCOE in 2023. More solar generating capacity is installed than CC between 2021 and 2023. Solar LCOE remains lower than CC LCOE on average in 2040, but EIA projects much more CC capacity to be installed than solar capacity between 2038 and 2040.

Along with LCOE and LCOS, EIA compares 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 sale of electricity generated from a candidate project displacing (or the cost of avoiding) another marginal asset. EIA sums this value over a project's financial life and converts 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).[6] 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. EIA calculates 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

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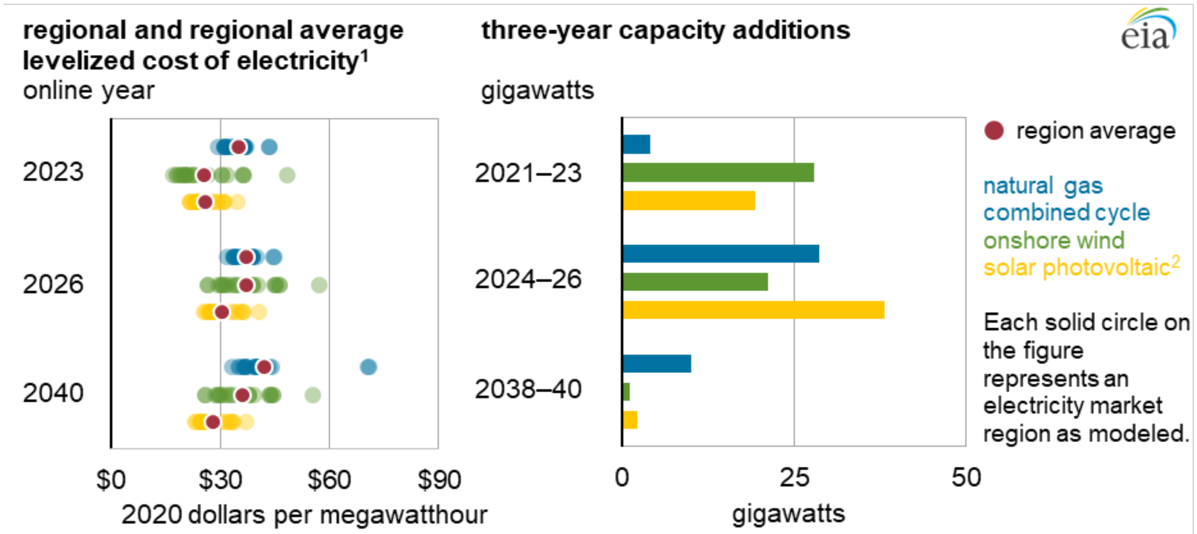
[6] EIA's website provides further discussion of the levelized avoided cost concept and its use in assessing economic competitiveness.

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 2023, 2026, and 2040



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*

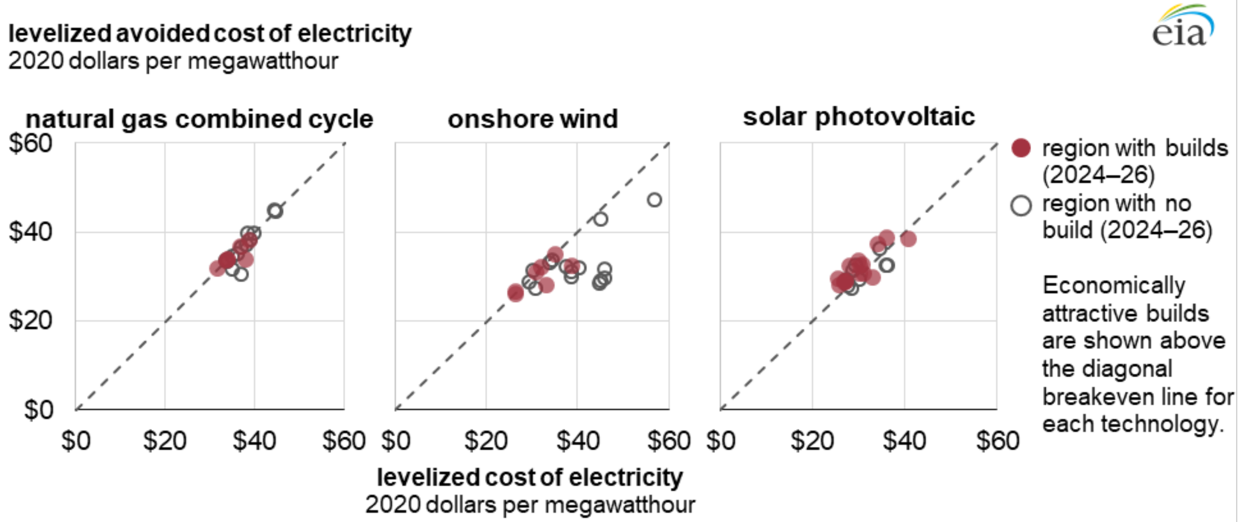
[1]Levelized cost includes tax credits available for plants entering service during the projection period.
[2]Technology is assumed to be photovoltaic with single-axis tracking. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

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. EIA calculates 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 is projected 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 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 EIA's 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 EIA's long-term projections than looking at LCOE or LCOS alone. Figure 2 shows selected generating technologies that are feasible to come online in 2026. CC and PV are shown to be mostly economically attractive to build because the value (or LACE) is higher than the cost (or LCOE). Onshore wind is shown to be adding capacity when it's less economically attractive. This 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 2026

alone. In addition, some regions are adding uneconomic 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 as shown in Figure 2 is more indicative of the full analysis from the AEO2021 model than LCOE alone as established in Figure 1.

Figure 2. Levelized cost of electricity and levelized avoided cost of electricity by region for selected generation technologies, 2026 online year



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*

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 are simplifications of modeled decisions, and may not fully capture all of the factors considered in NEMS or match modeled results. EIA calculates 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. EIA considers many of these factors in its 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. The LCOE, LCOS, and LACE values presented here are derived from the AEO2021 Reference case, which includes state-level renewable electricity requirements as of October 2020 and a phaseout of federal tax credits for renewable generation.

LCOE, LCOS, and LACE calculations

EIA calculates all levelized costs and values based on a 30-year cost recovery period, using a real after-tax weighted average cost of capital (WACC) of 5.4%.[7] 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 utility-scale technologies modeled in EMM and not from distributed residential and commercial applications.[8] Starting in AEO2020, EIA represents an ultra-supercritical[9] (USC) coal generation technology without carbon capture and sequestration (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 EIA assumes is represented by ultra-supercritical coal technology. Regulatory or court actions related to power plant emissions taken after September 2020 are not accounted for in AEO2021.

The levelized capital component reflects costs calculated using tax depreciation schedules consistent with tax laws without an end date, which vary by technology. For AEO2021, EIA assumes 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), EIA reports LCOE both with and without tax credits, which phase out and expire based on current laws and regulations in AEO2021 cases. Costs are expressed in terms of net alternating current (AC) power available to the grid for the installed capacity.

EIA evaluated 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. Combustion turbines that are typically used for peak-load duty cycles are evaluated at a 10% capacity factor, which reflects the historical average utilization rate. Battery storage is also evaluated 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. As a result, wind and solar technologies are shown separately as non-dispatchable 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. EIA shows them as non-dispatchable to discourage comparison with technologies that have more consistent

[7]EIA uses this WACC for plants entering service in 2026. The real WACCs used to calculate LCOE for plants entering service in 2023 and 2040 are 4.8% and 6.3%, 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*.

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

[9] 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.

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 AEO2021 or in other EIA analyses.

The LCOE and LCOS values shown in Tables 1a and 1b are averages of region-specific values weighted by the projected regional capacity builds in AEO2021 (Table 1a) and unweighted averages (simple average, Table 1b) for new plants coming online in 2026. EIA developed 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 2026 online year represents the cumulative capacity additions from 2024 through 2026).

Table 1a. Estimated capacity-weighted[1] levelized cost of electricity (LCOE) and levelized cost of storage (LCOS) for new resources entering service in 2026 (2020 dollars per megawatthour)

Plant type	Capacity factor (percent)	Levelized capital cost	Levelized fixed O&M[2]	Levelized variable cost	Levelized transmis-sion cost	Total system LCOE or LCOS	Levelized tax credit[3]	Total LCOE or LCOS including tax credit
Dispatchable technologies								
Ultra-supercritical coal	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*
Combined cycle	87%	$7.00	$1.61	$24.97	$0.93	$34.51	*NA*	$34.51
Combustion turbine	10%	$45.65	$8.03	$45.59	$8.57	$107.83	*NA*	$107.83
Advanced nuclear	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*
Geothermal	90%	$18.60	$14.97	$1.17	$1.28	$36.02	-$1.86	$34.16
Biomass	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*
Battery storage	10%	$57.51	$28.48	$23.93	$11.92	$121.84	*NA*	$121.84
Non-dispatchable technologies								
Wind, onshore	41%	$21.42	$7.43	$0.00	$2.61	$31.45	$0.00	$31.45
Wind, offshore	45%	$84.00	$27.89	$0.00	$3.15	$115.04	*NA*	$115.04
Solar, standalone[4]	30%	$22.60	$5.92	$0.00	$2.78	$31.30	-$2.26	$29.04
Solar, hybrid[4, 5]	30%	$29.55	$12.35	$0.00	$3.23	$45.13	-$2.96	$42.18
Hydroelectric[5]	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*

[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 2024 to 2026. Technologies for which capacity additions are not expected do not have a capacity-weighted average and are marked as *NB*, or *not built*.

[2]O&M = operations and maintenance

[3]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 2026 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.

[4]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.

[5]As modeled, EIA assumes 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 2026 (2020 dollars per megawatthour)

Plant type	Capacity factor (percent)	Levelized capital cost	Levelized fixed O&M[1]	Levelized variable cost	Levelized transmis-sion cost	Total system LCOE or LCOS	Levelized tax credit[2]	Total LCOE or LCOS including tax credit
Dispatchable technologies								
Ultra-supercritical coal	85%	$43.80	$5.48	$22.48	$1.03	$72.78	*NA*	$72.78
Combined cycle	87%	$7.78	$1.61	$26.68	$1.04	$37.11	*NA*	$37.11
Combustion turbine	10%	$45.41	$8.03	$44.13	$9.05	$106.62	*NA*	$106.62
Advanced nuclear	90%	$50.51	$15.51	$2.38	$0.99	$69.39	-$6.29	$63.10
Geothermal	90%	$19.03	$14.92	$1.17	$1.28	$36.40	-$1.90	$34.49
Biomass	83%	$34.96	$17.38	$35.78	$1.09	$89.21	*NA*	$89.21
Battery storage	10%	$57.98	$28.48	$23.85	$9.53	$119.84	*NA*	$119.84
Non-dispatchable technologies								
Wind, onshore	41%	$27.01	$7.47	$0.00	$2.44	$36.93	*NA*	$36.93
Wind, offshore	44%	$89.20	$28.96	$0.00	$2.35	$120.52	*NA*	$120.52
Solar, standalone[3]	29%	$23.52	$6.07	$0.00	$3.19	$32.78	-$2.35	$30.43
Solar, hybrid[3, 4]	28%	$31.13	$13.25	$0.00	$3.29	$47.67	-$3.11	$44.56
Hydroelectric[4]	55%	$38.62	$11.23	$3.58	$1.84	$55.26	*NA*	$55.26

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*

[1]O&M = operations and maintenance

[2]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 2026 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.

[3]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.

[4]As modeled, EIA assumes 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 $26.33 per megawatthour (MWh) in the region with the highest-quality wind resources to $56.94/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 $31.45/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 2026 (2020 dollars per megawatthour)

	Without tax credits				With tax credits[1]			
Plant type	Minimum	Simple average	Capacity-weighted average[2]	Maximum	Minimum	Simple average	Capacity-weighted average[2]	Maximum
Dispatchable technologies								
Ultra-supercritical coal	$64.98	$72.78	*NB*	$88.45	$64.98	$72.78	*NB*	$88.45
Combined cycle	$31.67	$37.11	$34.51	$44.68	$31.67	$37.11	$34.51	$44.68
Combustion turbine	$94.63	$106.62	$107.83	$129.91	$94.63	$106.62	$107.83	$129.91
Advanced nuclear	$64.82	$69.39	*NB*	$78.15	$58.52	$63.10	*NB*	$71.85
Geothermal	$33.41	$36.40	$36.02	$39.55	$31.80	$34.49	$34.16	$37.59
Biomass	$70.95	$89.21	*NB*	$130.97	$70.95	$89.21	*NB*	$130.97
Battery storage	$109.53	$119.84	$121.84	$131.42	$109.53	$119.84	$121.84	$131.42
Non-dispatchable technologies								
Wind, onshore	$26.33	$36.93	$31.45	$56.94	$26.33	$36.93	$31.45	$56.94
Wind, offshore	$97.52	$120.52	$115.04	$149.53	$97.52	$120.52	*NB*	$149.53
Solar, standalone[3]	$27.28	$32.78	$31.30	$43.90	$25.32	$30.43	$29.04	$40.67
Solar, hybrid[3, 4]	$39.54	$47.67	$45.13	$62.11	$36.98	$44.56	$42.18	$57.92
Hydroelectric[4]	$41.92	$55.26	*NB*	$70.60	$41.92	$55.26	*NB*	$70.60

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*

Note: EIA calculated 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. The levelized costs are also affected by regional variations in construction labor rates and capital costs as well as resource availability.

[1]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 2023 and the substantial phaseout of both the PTC and ITC as scheduled under current law.

[2]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 2024 to 2026. Technologies for which capacity additions are not expected do not have a capacity-weighted average and are marked as *NB,* or *not built*.

[3]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.

[4]As modeled, EIA assumes 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 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. EIA calculated the LACE in this table by assuming the same maximum capacity factor as used for the LCOE and LCOS calculations. LACE values for combustion turbine and battery storage are the same since EIA assumes both technologies service the same peak-demand duty cycle.

Table 3. Regional variation in levelized avoided cost of electricity (LACE) for new resources entering service in 2026 (2020 dollars per megawatthour)

Plant type	Minimum	Simple average	Capacity-weighted average[1]	Maximum
Dispatchable technologies				
Ultra-supercritical coal	$30.82	$35.59	*NB*	$40.05
Combined cycle	$30.68	$36.35	$34.58	$44.85
Combustion turbine	$66.86	$90.95	$93.59	$119.43
Advanced nuclear	$30.75	$35.41	*NB*	$39.79
Geothermal	$37.44	$40.89	$41.48	$44.52
Biomass	$30.92	$36.60	*NB*	$45.17
Battery storage	$66.86	$90.95	$97.53	$119.43
Non-dispatchable technologies				
Wind, onshore	$26.17	$31.87	$30.71	$47.42
Wind, offshore	$28.50	$33.19	*NB*	$42.63
Solar, standalone[2]	$27.45	$31.66	$30.63	$38.78
Solar, hybrid[2, 3]	$28.74	$42.74	$44.45	$55.48
Hydroelectric[3]	$29.41	$34.74	*NB*	$43.49

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*

[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 2024 to 2026. Technologies for which capacity additions are not expected do not have a capacity-weighted average and are marked as *NB*, or *not built*.

[2]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.

[3]As modeled, EIA assumes 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 the real world and as modeled in AEO2021, 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* represents the average of the ratio of the LACE-to-LCOE or LACE-to-LCOS calculation, where the ratio is calculated for each of the 25 EMM regions. This

range of ratios is not based on the ratio between the minimum and maximum values shown in Tables 2 and 3, but rather represents the lower and upper bounds resulting from the ratio of LACE-to-LCOE and LACE-to-LCOS calculations for each of the 25 regions.

As shown in Table 4a, the capacity-weighted average value-cost ratio is greater than one for both standalone and hybrid solar PV and geothermal in 2026, 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 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.[10]

Table 4a. Value-cost ratio (capacity-weighted) for new resources entering service in 2026

Plant type	Average capacity-weighted[1] LCOE or LCOS[2] with tax credits (2020 dollars per megawatthour)	Average capacity-weighted[1] LACE[2] (2020 dollars per megawatthour)	Average value-cost ratio[3]
Dispatchable technologies			
Ultra-supercritical coal	*NB*	*NB*	*NB*
Combined cycle	$34.51	$34.58	1.00
Combined turbine	$107.83	$93.59	0.87
Advanced nuclear	*NB*	*NB*	*NB*
Geothermal	$34.16	$41.48	1.22
Biomass	*NB*	*NB*	*NB*
Battery storage	$121.84	$97.53	0.80
Non-dispatchable technologies			
Wind, onshore	$31.45	$30.71	0.98
Wind, offshore	*NB*	*NB*	*NB*
Solar, standalone[4]	$29.04	$30.63	1.06
Solar, hybrid[4, 5]	$42.18	$44.45	1.06
Hydroelectric[5]	*NB*	*NB*	*NB*

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*
[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 2024 to 2026. Technologies for which capacity additions are not expected do not have a capacity-weighted average and are marked as *NB*, or *not built*.
[2]LCOE = levelized cost of electricity, LCOS = levelized cost of storage, and LACE = levelized avoided cost of electricity
[3]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.
[4]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.
[5]As modeled, EIA assumes 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.

[10] 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 2026

Plant type	Average unweighted LCOE or LCOS[1] with tax credits (2020 dollars per megawatthour)	Average unweighted LACE[1] (2020 dollars per megawatthour)	Average value-cost ratio[2]	Minimum[3]	Maximum[3]
Dispatchable technologies					
Ultra-supercritical coal	$72.78	$35.59	0.49	0.39	0.57
Combined cycle	$37.11	$36.35	0.98	0.83	1.04
Combustion turbine	$106.62	$90.95	0.85	0.65	1.05
Advanced nuclear	$69.39	$35.41	0.56	0.49	0.67
Geothermal	$36.40	$40.89	1.19	1.03	1.40
Biomass	$89.21	$36.60	0.41	0.29	0.48
Battery storage	$119.84	$90.95	0.76	0.54	0.95
Non-dispatchable technologies					
Wind, onshore	$36.93	$31.87	0.88	0.64	1.07
Wind, offshore	$120.52	$33.19	0.28	0.21	0.36
Solar, standalone[4]	$32.78	$31.66	1.05	0.90	1.17
Solar, hybrid[4, 5]	$47.67	$42.74	0.96	0.72	1.11
Hydroelectric[5]	$55.26	$34.74	0.64	0.49	0.84

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*

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

[2]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.

[3]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.

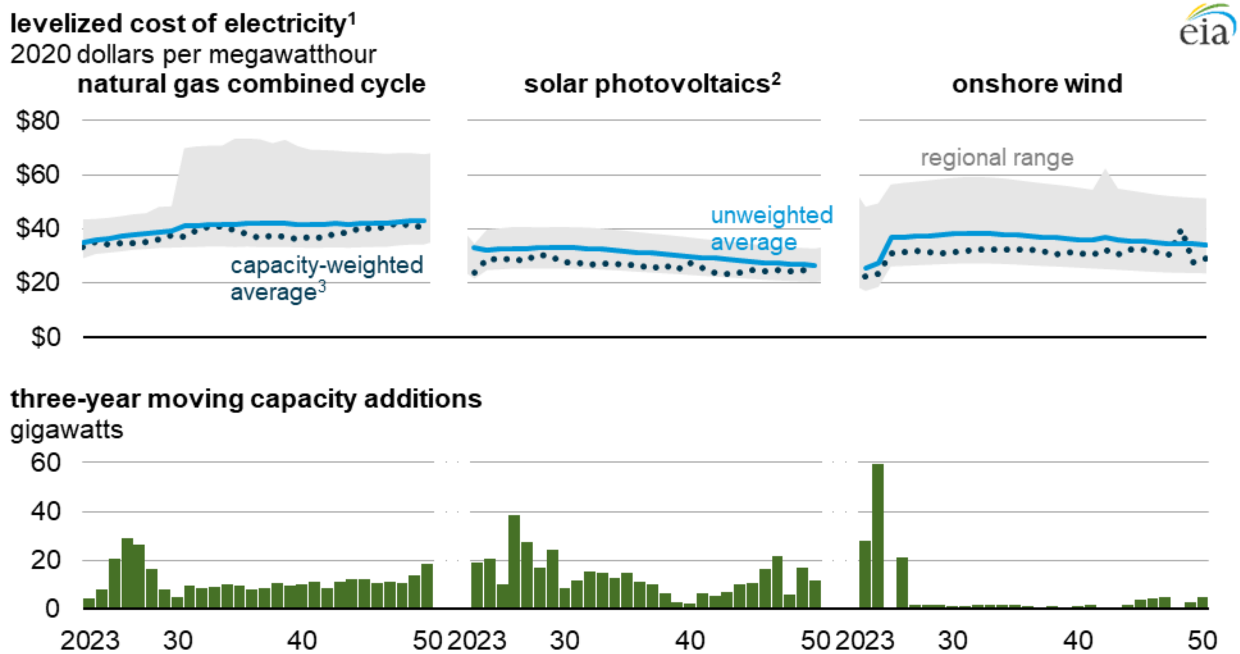
[4]Technology is assumed to be photovoltaic (PV) with single-axis tracking. The solar hybrid system is a single-axis PV system coupled with a four-hour battery storage system. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.

[5]As modeled, EIA assumes 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

Figure 3 shows capacity-weighted and unweighted LCOE for CC, solar PV, and onshore wind plants entering service from 2023 to 2050 in the AEO2021 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 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 heat rate for CC plants or capacity factor for onshore wind or solar PV plants), offsetting 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, 2023–50

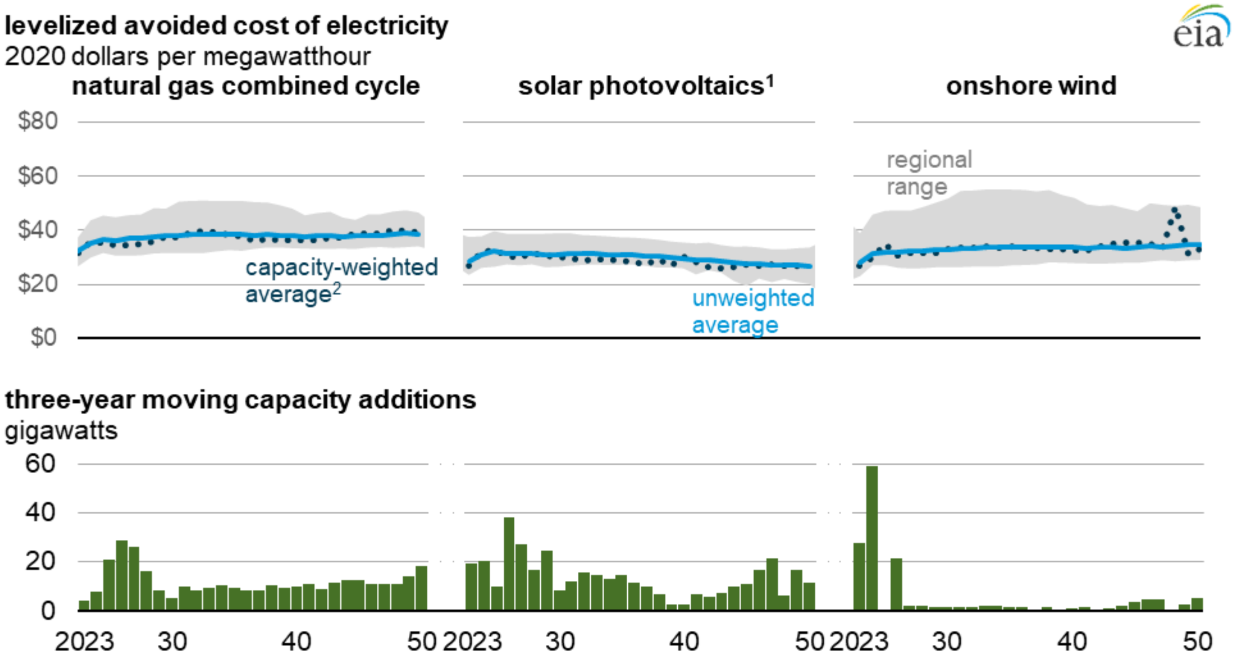


Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*
[1]Levelized cost includes tax credits available for plants entering service during the projection period.
[2]Technology is assumed to be photovoltaic with single-axis tracking. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.
[3]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 2026 are based on additions from 2024 to 2026.

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 new builds are expected 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 generation starting in 2030.

Figure 4 shows capacity-weighted and unweighted average LACE over time. Changes in the value of generation, represented by LACE, are primarily a function of load growth. Solar may show strong daily or seasonal generation patterns within any given region; as a result, the LACE value significantly decreases as these time periods become more saturated with generation from solar resources with similar hourly operation patterns. As this saturation occurs, generation from new facilities must compete with lower-cost options in the dispatch merit order. The LACE for onshore wind, on the other hand, increases throughout the projection period.

Figure 4. Capacity-weighted[1] and unweighted levelized avoided cost of electricity (LACE) projections and three-year moving capacity additions for selected generating technologies, 2023–50

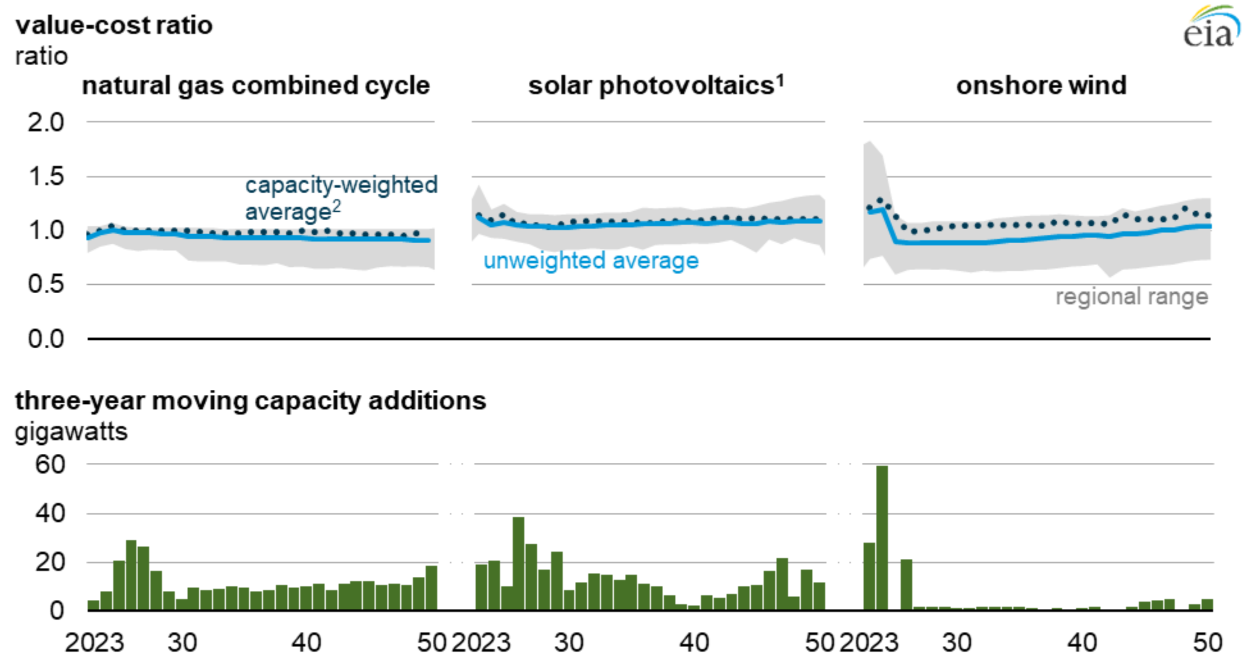


Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*
[1]Technology is assumed to be photovoltaic with single-axis tracking. Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.
[2]Capacity-weighted average is the 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 2026 are based on additions from 2024 to 2026.

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.

As illustrated in Figure 5, 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. 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, 2023–50



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*
[1]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.
[2]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 2026 are based on additions from 2024 to 2026.

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, EIA expects 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 in the case of a value-cost ratio decrease, 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 2023

Table A1a. Estimated capacity-weighted[1] levelized cost of electricity (LCOE) and levelized cost of storage (LCOS) for new resources entering service in 2023 (2020 dollars per megawatthour)

Plant type	Capacity factor (percent)	Levelized capital cost	Levelized fixed O&M[2]	Levelized variable cost	Levelized transmis-sion cost	Total system LCOE or LCOS	Levelized tax credit[3]	Total LCOE or LCOS including tax credit
Dispatchable technologies								
Combined cycle	87%	$6.77	$1.61	$23.93	$0.89	$33.21	*NA*	$33.21
Combustion turbine	10%	$42.74	$8.03	$38.89	$7.85	$97.50	*NA*	$97.50
Battery storage	10%	$54.44	$28.45	$28.19	$10.78	$121.85	*NA*	$121.85
Non-dispatchable technologies								
Wind, onshore	39%	$20.36	$7.80	$0.00	$2.28	$30.44	-$7.98	$22.46
Solar, standalone[4]	31%	$22.37	$5.77	$0.00	$2.49	$30.63	-$6.71	$23.92
Solar, hybrid[4, 5]	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*

[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 2021 to 2023. Technologies for which capacity additions are not expected do not have a capacity-weighted average and are marked as *NB,* or *not built*.

[2]O&M = operations and maintenance

[3]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 2023 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.

[4]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.

[5]As modeled, EIA assumes 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 by daytime for hybrid solar PV.

Table A1b. Estimated unweighted levelized cost of electricity (LCOE) and levelized cost of storage (LCOS) for new resources entering service in 2023 (2020 dollars per megawatthour)

Plant type	Capacity factor (percent)	Levelized capital cost	Levelized fixed O&M[1]	Levelized variable cost	Levelized transmis-sion cost	Total system LCOE or LCOS	Levelized tax credit[2]	Total LCOE or LCOS including tax credit
Dispatchable technologies								
Combined cycle	87%	$6.80	$1.61	$25.41	$0.96	$34.78	*NA*	$34.78
Combustion turbine	10%	$40.75	$8.03	$40.21	$8.33	$97.32	*NA*	$97.32
Battery storage	10%	$53.95	$28.45	$26.56	$8.64	$117.59	*NA*	$117.59
Non-dispatchable technologies								
Wind, onshore	41%	$23.94	$7.38	$0.00	$2.21	$33.53	-$7.98	$25.55
Solar, standalone[3]	29%	$24.14	$6.06	$0.00	$2.93	$33.13	-$7.24	$25.89
Solar, hybrid[3, 4]	28%	$31.95	$13.20	$0.00	$3.02	$48.16	-$9.58	$38.58

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*

[1] O&M = operations and maintenance

[2]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 2023 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.

[3]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.

[4]As modeled, EIA assumes 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 by daytime for hybrid solar PV.

Table A2. Regional variation in levelized cost of electricity (LCOE) and levelized cost of storage (LCOS) for new resources entering service in 2023 (2020 dollars per megawatthour)

	Without tax credits				With tax credits[1]			
Plant type	Minimum	Simple average	Capacity-weighted average[2]	Maximum	Minimum	Simple average	Capacity-weighted average[2]	Maximum
Dispatchable technologies								
Combined cycle	$29.17	$34.78	$33.21	$43.47	$29.17	$34.78	$33.21	$43.47
Combustion turbine	$85.11	$97.32	$97.50	$117.72	$85.11	$97.32	$97.50	$117.72
Battery storage	$106.63	$117.59	$121.85	$127.64	$106.63	$117.59	$121.85	$127.64
Non-dispatchable technologies								
Wind, onshore	$25.09	$33.53	$30.44	$56.12	$17.10	$25.55	$22.46	$48.14
Solar, standalone[3]	$27.65	$33.13	$30.63	$44.46	$21.61	$25.89	$23.92	$34.49
Solar, hybrid[3, 4]	$40.10	$48.16	*NB*	$62.97	$32.19	$38.58	*NB*	$50.02

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*

Note: EIA calculated 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. The levelized costs are also affected by regional variations in construction labor rates and capital costs as well as resource availability.

[1]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 2023 and the substantial phaseout of both the PTC and ITC as scheduled under current law.

[2]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 2021 to 2023. Technologies for which capacity additions are not expected do not have a capacity-weighted average and are marked as *NB,* or *not built*.

[3]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.

[4]As modeled, EIA assumes 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 by daytime for hybrid solar PV.

Table A3. Regional variation in levelized avoided cost of electricity (LACE) for new resources entering service in 2023 (2020 dollars per megawatthour)

Plant type	Minimum	Simple average	Capacity-weighted average[1]	Maximum
Dispatchable technologies				
Combined cycle	$26.72	$32.24	$31.83	$37.34
Combustion turbine	$50.39	$80.84	$89.84	$120.74
Battery storage	$50.39	$80.84	$88.55	$120.74
Non-dispatchable technologies				
Wind, onshore	$23.07	$28.22	$27.09	$38.98
Solar, standalone[2]	$23.57	$28.78	$27.15	$37.58
Solar, hybrid[2, 3]	$25.23	$37.57	*NB*	$52.48

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*

[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 2021 to 2023. Technologies for which capacity additions are not expected do not have a capacity-weighted average and are marked as *NB,* or *not built*.

[2]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.

[3]As modeled, EIA assumes 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 by daytime for hybrid solar PV.

Table A4a. Value-cost ratio (capacity-weighted) for new resources entering service in 2023

Plant type	Average capacity-weighted[1] LCOE or LCOS[2] with tax credits (2020 dollars per megawatthour)	Average capacity-weighted[1] LACE[2] (2020 dollars per megawatthour)	Average value-cost ratio[3]
Dispatchable technologies			
Combined cycle	$33.21	$31.83	0.96
Combustion turbine	$97.50	$89.84	0.92
Battery storage	$121.85	$88.55	0.73
Non-dispatchable technologies			
Wind, onshore	$22.46	$27.09	1.21
Solar, standalone[4]	$23.92	$27.15	1.14
Solar, hybrid[4, 5]	*NB*	*NB*	*NB*

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*

[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 2021 to 2023. Technologies for which capacity additions are not expected do not have a capacity-weighted average and are marked as *NB*, or *not built*.

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

[3]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.

[4]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.

[5]As modeled, EIA assumes 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 by daytime for hybrid solar PV.

Table A4b. Value-cost ratio (unweighted) for new resources entering service in 2023

Plant type	Average unweighted LCOE or LCOS[1] with tax credits (2020 dollars per megawatthour)	Average unweighted LACE[1] (2020 dollars per megawatthour)	Average value-cost ratio[2]	Minimum[3]	Maximum[3]
Dispatchable technologies					
Combined cycle	$34.78	$32.24	0.93	0.79	1.04
Combustion turbine	$97.32	$80.84	0.83	0.53	1.08
Battery storage	$117.59	$80.84	0.69	0.42	0.97
Non-dispatchable technologies					
Wind, onshore	$33.53	$28.22	1.17	0.74	1.83
Solar, standalone[4]	$33.13	$28.78	1.12	0.97	1.42
Solar, hybrid[4, 5]	$48.16	$37.57	0.98	0.73	1.14

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*

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

[2]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.

[3]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.

[4]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.

[5]As modeled, EIA assumes 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 by daytime for hybrid solar PV.

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

Table B1a. Estimated capacity-weighted[1] levelized cost of electricity (LCOE) and levelized cost of storage (LCOS) for new resources entering service in 2040 (2020 dollars per megawatthour)

Plant type	Capacity factor (percent)	Levelized capital cost	Levelized fixed O&M[2]	Levelized variable cost	Levelized transmis-sion cost	Total system LCOE or LCOS	Levelized tax credit[3]	Total LCOE or LCOS including tax credit
Dispatchable technologies								
Ultra-supercritical coal	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*
Combined cycle	87%	$6.95	$1.61	$26.79	$0.98	$36.33	*NA*	$36.33
Combustion turbine	10%	$42.15	$8.03	$51.28	$9.70	$111.16	*NA*	$111.16
Advanced nuclear	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*
Geothermal	90%	$19.73	$15.02	$1.17	$1.34	$37.26	-$1.97	$35.29
Biomass	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*
Battery storage	10%	$51.02	$28.44	$12.56	$12.12	$104.14	*NA*	$104.14
Non-dispatchable technologies								
Wind, onshore	40%	$20.18	$7.54	$0.00	$3.04	$30.76	*NA*	$30.76
Wind, offshore	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*
Solar, standalone[4]	28%	$20.61	$6.21	$0.00	$2.90	$29.72	-$2.06	$27.66
Solar, hybrid[4, 5]	30%	$24.53	$12.52	$0.00	$2.91	$39.95	-$2.45	$37.50
Hydroelectric[5]	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*	*NB*

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*

[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 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*.

[2]O&M = operations and maintenance

[3]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.

[4]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.

[5]As modeled, EIA assumes 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 (2020 dollars per megawatthour)

Plant type	Capacity factor (percent)	Levelized capital cost	Levelized fixed O&M[1]	Levelized variable cost	Levelized transmis-sion cost	Total system LCOE or LCOS	Levelized tax credit[2]	Total LCOE or LCOS including tax credit
Dispatchable technologies								
Ultra-supercritical coal	85%	$41.95	$5.48	$22.75	$1.08	$71.26	*NA*	$71.26
Combined cycle	87%	$7.80	$1.61	$31.26	$1.10	$41.77	*NA*	$41.77
Combustion turbine	10%	$43.69	$8.03	$50.70	$9.54	$111.97	*NA*	$111.97
Advanced nuclear	90%	$48.93	$15.51	$2.38	$1.04	$67.87	-$5.00	$62.87
Geothermal	90%	$19.49	$15.78	$1.17	$1.34	$37.78	-$1.95	$35.83
Biomass	83%	$32.32	$17.38	$35.84	$1.15	$86.69	*NA*	$86.69
Battery storage	10%	$49.67	$28.44	$23.39	$9.69	$110.26	*NA*	$110.26
Non-dispatchable technologies								
Wind, onshore	41%	$25.96	$7.46	$0.00	$2.57	$35.98	*NA*	$35.98
Wind, offshore	43%	$58.94	$29.36	$0.00	$2.52	$90.82	*NA*	$90.82
Solar, standalone[3]	29%	$20.38	$6.12	$0.00	$3.39	$29.89	-$2.04	$27.85
Solar, hybrid[3, 4]	28%	$26.83	$13.36	$0.00	$3.51	$43.70	-$2.68	$41.02
Hydroelectric[4]	54%	$39.38	$11.05	$3.97	$2.01	$56.40	*NA*	$56.40

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*

[1]O&M = operations and maintenance

[2]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.

[3]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.

[4]As modeled, EIA assumes 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 (2020 dollars per megawatthour)

	Without tax credits				With tax credits[1]			
Plant type	Minimum	Simple average	Capacity-weighted average[2]	Maximum	Minimum	Simple average	Capacity-weighted average[2]	Maximum
Dispatchable technologies								
Ultra-supercritical coal	$63.58	$71.26	*NB*	$86.66	$63.58	$71.26	*NB*	$86.66
Combined cycle	$33.15	$41.77	$36.33	$70.53	$33.15	$41.77	$36.33	$70.53
Combustion turbine	$97.11	$111.97	$111.16	$159.90	$97.11	$111.97	$111.16	$159.90
Advanced nuclear	$63.42	$67.87	*NB*	$76.34	$58.43	$62.87	*NB*	$71.34
Geothermal	$30.68	$37.78	$37.26	$43.30	$29.32	$35.83	$30.76	$40.94
Biomass	$79.61	$86.69	*NB*	$128.72	$79.61	$86.69	*NB*	$128.72
Battery storage	$90.70	$110.26	$104.14	$121.90	$90.70	$110.26	$104.14	$121.90
Non-dispatchable technologies								
Wind, onshore	$25.63	$35.98	$30.76	$55.14	$25.63	$35.98	$30.76	$55.14
Wind, offshore	$74.16	$90.82	*NB*	$108.41	$74.16	$90.82	*NB*	$108.41
Solar, standalone[3]	$24.67	$29.89	$29.72	$39.64	$22.99	$27.85	$27.66	$36.86
Solar, hybrid[3, 4]	$35.94	$43.70	$39.95	$56.26	$33.75	$41.02	$37.50	$52.68
Hydroelectric[4]	$35.94	$43.70	*NB*	$56.26	$33.75	$41.02	*NB*	$52.68

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*

Note: EIA calculated 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%–48% 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. The levelized costs are also affected by regional variations in construction labor rates and capital costs as well as resource availability.

[1]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 2023 and the substantial phaseout of both the PTC and ITC as scheduled under current law.

[2]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*.

[3]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.

[4]As modeled, EIA assumes 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 (2020 dollars per megawatthour)

Plant type	Minimum	Simple average	Capacity-weighted average[1]	Maximum
Dispatchable technologies				
Ultra-supercritical coal	$33.60	$37.35	*NB*	$43.07
Combined cycle	$33.43	$38.05	$36.29	$48.01
Combined turbine	$65.22	$87.03	$90.23	$117.32
Advanced nuclear	$33.50	$37.22	*NB*	$42.96
Geothermal	$38.55	$43.10	$43.23	$47.55
Biomass	$33.74	$38.28	*NB*	$48.15
Battery storage	$65.22	$87.03	$68.50	$117.32
Non-dispatchable technologies				
Wind, onshore	$27.89	$33.66	$32.68	$51.99
Wind, offshore	$29.53	$34.25	*NB*	$45.23
Solar, standalone[2]	$25.96	$29.69	$30.12	$35.52
Solar, hybrid[2, 3]	$34.42	$43.66	$41.18	$53.62
Hydroelectric[3]	$30.25	$36.56	*NB*	$46.15

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*

[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 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*.

[2]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.

[3]As modeled, EIA assumes 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[1] LCOE[2] or LCOS[2] with tax credits (2020 dollars per megawatthour)	Average capacity-weighted[1] LACE[2] (2020 dollars per megawatthour)	Average value-cost ratio[3]
Dispatchable technologies			
Ultra-supercritical coal	*NB*	*NB*	*NB*
Combined cycle	$36.33	$36.29	1.00
Combustion turbine	$111.16	$90.23	0.81
Advanced nuclear	*NB*	*NB*	*NB*
Geothermal	$35.29	$43.23	1.24
Biomass	*NB*	*NB*	*NB*
Battery storage	$104.14	$68.50	0.66
Non-dispatchable technologies			
Wind, onshore	$30.76	$32.68	1.06
Wind, offshore	*NB*	*NB*	*NB*
Solar, standalone[4]	$27.66	$30.12	1.09
Solar, hybrid[4, 5]	$37.50	$41.18	1.10
Hydroelectric[5]	*NB*	*NB*	*NB*

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*

[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 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*.

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

[3]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.

[4]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.

[5]As modeled, EIA assumes 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 or LCOS[1] with tax credits (2020 dollars per megawatthour)	Average unweighted LACE[1] (2020 dollars per megawatthour)	Average value-cost ratio[2]	Minimum[3]	Maximum[3]
Dispatchable technologies					
Ultra-supercritical coal	$71.26	$37.35	0.53	0.44	0.61
Combined cycle	$41.77	$38.05	0.93	0.67	1.01
Combustion turbine	$111.97	$87.03	0.78	0.41	0.99
Advanced nuclear	$67.87	$37.22	0.59	0.52	0.72
Geothermal	$37.78	$43.10	1.23	1.00	1.62
Biomass	$86.69	$38.28	0.44	0.30	0.52
Battery storage	$110.26	$87.03	0.79	0.61	1.13
Non-dispatchable technologies					
Wind, onshore	$35.98	$33.66	0.95	0.67	1.13
Wind, offshore	$90.82	$34.25	0.38	0.29	0.49
Solar, standalone[4]	$29.89	$29.69	1.07	0.88	1.19
Solar, hybrid[4, 5]	$43.70	$43.66	1.07	0.91	1.21
Hydroelectric[5]	$56.40	$36.56	0.66	0.51	0.86

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*

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

[2]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.

[3]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.

[4]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.

[5]As modeled, EIA assumes 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.