Independent Statistics & Analysis
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Cost and Performance Characteristics of New Generating Technologies, *Annual Energy Outlook 2021*

The tables presented below will be incorporated into the Electricity Market Module chapter of the U.S. Energy Information Administration's (EIA) *Annual Energy Outlook 2021* (AEO2021) Assumptions document. Table 1 represents EIA's assessment of the cost to develop and install various generating technologies used in the electric power sector. Generating technologies typically found in end-use applications, such as combined heat and power or roof-top solar photovoltaics (PV), will be described elsewhere in the Assumptions document. The costs shown in Table 1, except as noted below, are the costs for a typical facility for each generating technology before adjusting for regional cost factors. Overnight costs exclude interest accrued during plant construction and development. Technologies with limited commercial experience may include a technological optimism factor to account for the tendency to underestimate the full engineering and development costs for new technologies during technology research and development.

All technologies demonstrate some degree of variability in cost, based on project size, location, and access to key infrastructure (such as grid interconnections, fuel supply, and transportation). For wind and solar PV, in particular, the cost favorability of the lowest-cost regions compound the underlying variability in regional cost and create a significant differential between the unadjusted costs and the capacity-weighted average national costs as observed from recent market experience. To account for this difference, Table 1 shows a weighted average cost for both wind and solar PV, based on the regional cost factors assumed for these technologies in AEO2021 and the actual regional distribution of the builds that occurred in 2019.

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

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

Technology	First available year[1]	Size (MW)	Lead time (years)	Base overnight cost[2] (2020 $/kW)	Techno-logical optimism factor[3]	Total overnight cost[4,5] (2020 $/kW)	Variable O&M[6] (2020 $/MWh)	Fixed O&M (2020$/ kW-yr)	Heat rate[7] (Btu/kWh)
Ultra-supercritical coal (USC)	2024	650	4	3,672	1.00	3,672	4.52	40.79	8,638
USC with 30% carbon capture and sequestration (CCS)	2024	650	4	4,550	1.01	4,595	7.11	54.57	9,751
USC with 90% CCS	2024	650	4	5,861	1.02	5,978	11.03	59.85	12,507
Combined-cycle—single shaft	2023	418	3	1,082	1.00	1,082	2.56	14.17	6,431
Combined-cycle—multi shaft	2023	1,083	3	957	1.00	957	1.88	12.26	6,370
Combined-cycle with 90% CCS	2023	377	3	2,471	1.04	2,570	5.87	27.74	7,124
Internal combustion engine	2022	21	2	1,813	1.00	1,813	5.72	35.34	8,295
Combustion turbine—aeroderivative[8]	2022	105	2	1,169	1.00	1,169	4.72	16.38	9,124
Combustion turbine—industrial frame	2022	237	2	709	1.00	709	4.52	7.04	9,905
Fuel cells	2023	10	3	6,277	1.09	6,866	0.59	30.94	6,469
Nuclear—light water reactor	2026	2,156	6	6,034	1.05	6,336	2.38	122.26	10,455
Nuclear—small modular reactor	2028	600	6	6,183	1.10	6,802	3.02	95.48	10,455
Distributed generation—base	2023	2	3	1,560	1.00	1,560	8.65	19.46	8,935
Distributed generation—peak	2022	1	2	1,874	1.00	1,874	8.65	19.46	9,921
Battery storage	2021	50	1	1,165	1.00	1,165	0.00	24.93	NA
Biomass	2024	50	4	4,077	1.00	4,078	4.85	126.36	13,500
Geothermal[9,10]	2024	50	4	2,772	1.00	2,772	1.17	137.50	8,946
Municipal solid waste—landfill gas	2023	36	3	1,566	1.00	1,566	6.23	20.20	8,513
Conventional hydropower[10]	2024	100	4	2,769	1.00	2,769	1.40	42.01	NA
Wind[5]	2023	200	3	1,846	1.00	1,846	0.00	26.47	NA
Wind offshore[9]	2024	400	4	4,362	1.25	5,453	0.00	110.56	NA
Solar thermal[9]	2023	115	3	7,116	1.00	7,116	0.00	85.82	NA
Solar photovoltaic (PV) with tracking[5,9,11]	2022	150	2	1,248	1.00	1,248	0.00	15.33	NA
Solar PV with storage[9,11]	2022	150	2	1,612	1.00	1,612	0.00	32.33	NA

[1] Represents the first year that a new unit could become operational.

[2] Base cost includes project contingency costs.

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

[4] Overnight capital cost includes contingency factors and excludes regional multipliers (except as noted for wind and solar PV) and learning effects. Interest charges are also excluded. The capital costs represent current costs for plants that would come online in 2021.

[5] Total overnight cost for ind and solar PV technologies in the table are the average input value across all 25 electricity market regions, as weighted by the respective capacity of that type installed during 2019 in each region to account for the substantial regional variation in wind and solar costs (as shown in Table 4). The input value used for onshore wind in AEO2021 was $1,268 per kilowatt (kW), and for solar PV with tracking it was $1,232/kW, which represents the cost of building a plant excluding regional factors. Region-specific factors contributing to the substantial regional variation in cost include differences in typical project size across regions, accessibility of resources, and variation in labor and other construction costs throughout the country.

[6] O&M = Operations and maintenance.

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

[8] Combustion turbine aeroderivative units can be built by the model before 2022, if necessary, to meet a region's reserve margin.

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

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

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

Sources: Input costs are primarily based on a report provided by external consultants: Sargent & Lundy, December 2019. Hydropower site costs for non-powered dams were most recently updated for AEO2018 using data from Oak Ridge National Lab

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

2020 dollars per kilowatt

Technology	1 TRE	2 FRCC	3 MISW	4 MISC	5 MISE	6 MISS	7 ISNE	8 NYCW	9 NYUP	10 PJME	11 PJMW	12 PJMC	13 PJMD
Ultra-supercritical coal (USC)	3,412	3,512	3,838	3,939	3,985	3,531	4,255	NA	4,159	4,293	3,662	4,614	3,952
USC with 30% CCS	4,308	4,422	4,774	4,903	4,942	4,450	5,272	NA	5,167	5,306	4,594	5,640	4,939
USC with 90% CCS	5,642	5,786	6,173	6,381	6,387	5,841	6,764	NA	6,590	6,775	5,956	7,214	6,331
CC—single shaft	977	997	1,112	1,122	1,151	1,006	1,298	1,722	1,301	1,300	1,078	1,302	1,241
CC—multi shaft	851	872	989	1,006	1,032	882	1,134	1,554	1,115	1,140	934	1,196	1,054
CC with 90% CCS	2,410	2,432	2,599	2,605	2,645	2,455	2,729	3,091	2,667	2,707	2,489	2,822	2,593
Internal combustion engine	1,705	1,743	1,862	1,936	1,915	1,766	1,984	2,487	1,909	1,985	1,778	2,164	1,847
CT—aeroderivative	1,034	1,056	1,223	1,226	1,263	1,077	1,315	1,684	1,269	1,308	1,122	1,437	1,190
CT—industrial frame	626	639	742	746	768	653	801	1,033	771	797	680	877	723
Fuel cells	6,589	6,691	6,997	7,299	7,160	6,804	7,428	8,745	7,126	7,364	6,784	7,851	6,993
Nuclear—light water reactor	5,981	6,110	6,450	7,036	6,786	6,309	7,177	NA	6,696	7,013	6,199	7,711	6,451
Nuclear—small modular reactor	6,338	6,486	7,066	7,369	7,366	6,567	7,608	NA	7,246	7,623	6,648	8,506	6,904
Dist. generation—base	1,408	1,437	1,603	1,618	1,659	1,450	1,871	2,482	1,876	1,874	1,554	1,877	1,788
Dist. Generation—peak	1,657	1,692	1,959	1,965	2,024	1,727	2,108	2,698	2,034	2,096	1,798	2,303	1,907
Battery storage	1,165	1,168	1,151	1,207	1,168	1,192	1,201	1,196	1,169	1,173	1,162	1,177	1,173
Biomass	3,784	3,887	4,208	4,348	4,358	3,919	4,842	6,572	4,857	4,942	4,156	4,951	4,736
Geothermal	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MSW—landfill gas	1,476	1,508	1,606	1,673	1,652	1,530	1,713	2,133	1,647	1,711	1,538	1,861	1,596
Conventional hydropower	4,040	4,935	1,963	1,305	2,657	3,932	1,819	NA	3,722	3,866	3,370	NA	3,420
Wind	2,477	NA	1,395	1,268	1,518	1,268	1,680	NA	2,049	1,680	1,268	1,846	1,750
Wind offshore	5,325	6,390	6,304	NA	6,529	NA	6,360	5,486	6,652	6,097	4,985	7,219	5,679
Solar thermal	6,865	6,969	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Solar PV with tracking	1,214	1,191	1,232	1,278	1,264	1,202	1,276	1,501	1,264	1,301	1,229	1,341	1,226
Solar PV with storage	1,561	1,577	1,624	1,677	1,653	1,593	1,687	1,917	1,656	1,690	1,588	1,757	1,643

Technology	14 SRCA	15 SRSE	16 SRCE	17 SPPS	18 SPPC	19 SPPN	20 SRSG	21 CANO	22 CASO	23 NWPP	24 RMRG	25 BASN
Ultra-supercritical coal (USC)	3,533	3,586	3,634	3,557	3,779	3,597	3,748	NA	NA	3,971	3,712	3,873
USC with 30% CCS	4,454	4,496	4,563	4,466	4,713	4,508	4,703	NA	NA	4,942	4,653	4,828
USC with 90% CCS	5,852	5,904	5,974	5,821	6,117	5,863	6,098	NA	NA	6,398	6,008	6,287
CC—single shaft	993	1,005	1,036	1,004	1,066	995	978	1,432	1,399	1,138	922	996
CC—multi shaft	872	883	915	882	947	874	842	1,259	1,225	987	793	889
CC with 90% CCS	2,424	2,437	2,492	2,428	2,509	2,391	2,212	2,774	2,743	2,559	2,080	2,336
Internal combustion engine	1,776	1,781	1,812	1,763	1,858	1,781	1,798	2,155	2,116	1,916	1,775	1,900
CT—aeroderivative	1,071	1,081	1,121	1,079	1,155	1,087	981	1,381	1,347	1,211	949	1,082
CT— industrial frame	649	655	680	654	701	658	594	844	822	737	575	657
Fuel cells	6,853	6,848	6,942	6,728	7,010	6,789	6,884	7,887	7,796	7,209	6,751	7,191
Nuclear—light water reactor	6,390	6,340	6,546	6,135	6,487	6,133	6,361	NA	NA	6,885	6,162	6,893
Nuclear—small modular reactor	6,600	6,651	6,802	6,584	6,993	6,640	6,728	NA	NA	7,285	6,656	7,235
Dist. Generation—base	1,432	1,449	1,493	1,448	1,536	1,434	1,409	2,064	2,017	1,641	1,328	1,436
Dist. Generation—peak	1,717	1,732	1,797	1,729	1,852	1,741	1,572	2,213	2,158	1,941	1,521	1,734
Battery storage	1,203	1,186	1,201	1,159	1,167	1,153	1,180	1,213	1,216	1,193	1,155	1,201
Biomass	3,934	3,963	4,016	3,937	4,183	4,020	4,305	5,515	5,390	4,451	4,265	4,265
Geothermal	NA	NA	NA	NA	NA	NA	2,825	2,802	2,269	2,742	NA	2,772
MSW—landfill gas	1,539	1,541	1,568	1,525	1,605	1,539	1,555	1,857	1,825	1,655	1,534	1,642
Conventional hydropower	1,904	4,130	2,135	4,086	1,722	1,619	3,282	3,473	3,344	2,769	3,306	3,613
Wind	1,512	1,713	1,268	1,395	1,395	1,395	1,395	2,799	2,418	1,848	1,395	1,395
Wind offshore	4,907	NA	NA	NA	NA	NA	NA	8,224	8,628	6,170	NA	NA
Solar thermal	NA	NA	NA	6,934	7,203	6,864	7,193	8,473	8,367	7,656	6,912	7,671
Solar PV with tracking	1,251	1,188	1,228	1,190	1,237	1,199	1,211	1,348	1,341	1,241	1,225	1,236
Solar PV with storage	1,604	1,588	1,607	1,577	1,628	1,594	1,602	1,756	1,751	1,656	1,595	1,653

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

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

Electricity Market Module region map

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

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