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Cost and Performance Characteristics of New Generating Technologies, Annual Energy Outlook 2019

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 2019* (AEO2019) Assumptions document. Table 2 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* photovoltaics (PV), will be described elsewhere in the Assumptions document. The costs shown in Table 2, 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 during technology research and development to underestimate the full engineering and development costs for new technologies.

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 2 shows a weighted average cost for both wind and solar PV, based on the regional cost factors assumed for these technologies in AEO2019 and the actual regional distribution of the builds that occurred in 2017. For AEO2019, the electricity model includes two solar PV technologies: one using single-axis tracking technology and the other using fixed-tilt arrays.

Table 3 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 locational 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 2. Cost and performance characteristics of new central station electricity generating technologies

Technology	First available year[1]	Size (MW)	Lead time (years)	Base overnight cost (2018 $/kW)	Project contin-gency factor[2]	Techno-logical optimism factor[3]	Total overnight cost[4,10] (2018 $/kW)	Variable O&M[5] (2018 $/MWh)	Fixed O&M (2018$/ kW/yr)	Heat rate[6] (Btu/kWh)	Final heat rate (Btu/kWh)
Coal with 30% carbon sequestration (CCS)	2022	650	4	4,713	1.07	1.03	5,169	7.31	72.12	9,750	9,221
Coal with 90% CCS	2022	650	4	5,212	1.07	1.03	5,716	9.89	83.75	11,650	9,257
Conv gas/oil combined cycle (CC)	2021	702	3	952	1.05	1.00	999	3.61	11.33	6,600	6,350
Adv gas/oil CC	2021	1,100	3	736	1.08	1.00	794	2.06	10.30	6,300	6,200
Adv CC with CCS	2021	340	3	1,963	1.08	1.04	2,205	7.34	34.43	7,525	7,493
Internal combustion engine	2020	85	2	1,306	1.05	1.00	1,371	6.03	7.11	8,500	8,160
Conv combustion turbine[7]	2020	100	2	1,072	1.05	1.00	1,126	3.61	18.03	9,840	9,600
Adv combustion turbine	2020	237	2	658	1.05	1.00	691	11.02	7.01	9,800	8,550
Fuel cells	2021	10	3	6,250	1.05	1.10	7,197	46.56	0.00	9,500	6,960
Adv nuclear	2022	2,234	6	5,224	1.10	1.05	6,034	2.37	103.31	10,461	10,461
Distributed generation – base	2021	2	3	1,501	1.05	1.00	1,576	8.40	18.90	8,958	8,900
Distributed generation – peak	2020	1	2	1,804	1.05	1.00	1,894	8.40	18.90	9,948	9,880
Battery storage	2019	30	1	1,857	1.05	1.00	1,950	7.26	36.32	NA	NA
Biomass	2022	50	4	3,642	1.07	1.00	3,900	5.70	114.39	13,500	13,500
Geothermal[8,9]	2022	50	4	2,654	1.05	1.00	2,787	0.00	122.28	NA	NA
MSW - landfill gas	2021	50	3	8,313	1.07	1.00	8,895	9.47	425.38	18,000	18,000
Conventional hydropower[9]	2022	500	4	2,680	1.10	1.00	2,948	1.36	40.85	NA	NA
Wind[10]	2021	100	3	1,518	1.07	1.00	1,624	0.00	48.42	NA	NA
Wind offshore[8]	2022	400	4	4,758	1.10	1.25	6,542	0.00	80.14	NA	NA
Solar thermal[8]	2021	100	3	4,011	1.07	1.00	4,291	0.00	72.84	NA	NA
Solar PV - tracking[8, 10, 11]	2020	150	2	1,876	1.05	1.00	1,969	0.00	22.46	NA	NA
Solar PV – fixed tilt[8,10,11]	2020	150	2	1,698	1.05	1.00	1,783	0.00	22.46	NA	NA

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

[2] AACE International (the Association for the Advancement of Cost Engineering) has defined contingency as, "An amount added to an estimate to allow for items, conditions, or events for which the state, occurrence, or effect is uncertain and that experience shows will likely result, in aggregate, in additional 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 2019.

[5] O&M = Operations and maintenance.

[6] 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 Btu conversion factors exist. The model calculates the average heat rate for fossil generation in each year for purposes of reporting primary energy consumption displaced for these resources.

[7] Conventional combustion turbine units can be built by the model before 2020, if necessary, to meet a region's reserve margin.

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

[9] 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 Power Pool region, where most of the proposed sites are located.

[10] Wind and both solar PV technologies' total overnight cost shown in the table shows the average input value across all 22 electricity market regions, as weighted by the respective capacity of that type installed during 2017 in each region to account for the substantial regional variation in wind and solar costs (as shown in Table 3). The input value used for wind in AEO2019 was $1,920 per kilowatt (kW), solar PV with tracking was $2,160/kW, and solar PV fixed tilt was $2,024, representing 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 through the country.

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

Source: Input costs other than Advanced Combined Cycle are consistent with those used in AEO2018, and they are primarily based on a report provided by external consultants. The base costs shown above reflect calculated learning cost reductions based on recent builds that occurred since the cost report was provided. The cost differential between the two PV technologies was based on Lawrence Berkeley National Lab's *Utility-Scale Solar Report*. Hydropower site costs for non-powered dams were updated for AEO2018 using data from Oak Ridge National Lab. Costs for advanced CC were updated for AEO2019 based on a PJM Interconnection *Cost of New Entry* report and EIA analysis of reported costs.

Table 3. Total overnight capital costs of new electricity generating technologies by region

2018 $/kW

Technology	1 (ERCT)	2 (FRCC)	3 (MROE)	4 (MROW)	5 (NEWE)	6 (NYCW)	7 (NYLI)	8 (NYUP)	9 (RFCE)	10 (RFCM)	11 (RFCW)
Coal with 30% CCS	4,631	4,838	5,112	4,969	5,417	NA	NA	5,045	5,649	5,138	5,220
Coal with 90% CCS	5,121	5,350	5,636	5,493	5,959	NA	NA	5,579	6,207	5,681	5,756
Conv gas/oil combined cycle (CC)	914	945	954	975	1,110	1,611	1,611	1,128	1,182	998	1,023
Adv gas/oil CC	761	777	754	785	882	1,209	1,209	896	932	788	821
Adv CC with CCS	2,058	2,135	2,144	2,121	2,258	3,217	3,217	2,270	2,412	2,161	2,220
Internal combustion engine	1,233	1,267	1,343	1,346	1,468	1,969	1,969	1,429	1,510	1,383	1,382
Conv combustion turbine	1,082	1,123	1,070	1,114	1,169	1,586	1,586	1,154	1,239	1,116	1,142
Adv combustion turbine	671	694	666	694	749	1,071	1,071	744	806	693	714
Fuel cells	6,744	6,909	7,233	7,016	7,262	8,723	8,723	7,161	7,392	7,190	7,176
Adv nuclear	5,787	5,871	6,077	5,947	6,288	NA	NA	6,384	6,451	6,028	6,149
Distributed generation - base	1,403	1,444	1,547	1,542	1,802	2,574	2,574	1,824	1,887	1,600	1,617
Distributed generation - peak	1,819	1,889	1,800	1,873	1,967	2,667	2,667	1,941	2,083	1,876	1,920
Battery storage	1,910	1,926	1,948	1,944	1,978	2,286	2,286	1,943	1,996	1,949	1,953
Biomass	3,595	3,697	3,974	3,774	4,017	4,785	4,785	4,032	4,153	3,880	3,939
Geothermal	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MSW - landfill gas	8,183	8,441	8,966	8,613	8,975	11,207	11,207	8,886	9,188	8,868	8,841
Conventional hydropower	NA	5,255	NA	1,723	1,937	NA	NA	3,963	4,116	NA	3,588
Wind	1,455	NA	2,413	1,483	2,554	NA	2,773	2,286	2,169	2,518	1,849
Wind offshore	5,973	6,542	6,581	6,613	6,712	8,380	8,380	6,483	6,712	6,509	6,581
Solar thermal	3,656	3,888	NA	NA	NA	NA	NA	NA	NA	NA	NA
Solar PV - tracking	2,173	1,759	2,069	1,876	2,419	3,212	2,058	1,946	2,283	2,986	1,977
Solar PV – fixed tilt	2,037	1,649	1,939	1,758	2,267	3,010	1,928	1,824	2,139	2,798	1,853

Technology	12 (SRDA)	13 (SRGW)	14 (SRSE)	15 (SRCE)	16 (SRVC)	17 (SPNO)	18 (SPSO)	19 (AZNM)	20 (CAMX)	21 (NWPP)	22 (RMPA)
Coal with 30% CCS	4,714	5,251	4,672	4,724	4,559	4,972	4,833	5,019	5,753	5,086	4,952
Coal with 90% CCS	5,219	5,802	5,167	5,224	5,036	5,493	5,344	5,544	6,327	5,613	5,459
Conv gas/oil combined cycle (CC)	912	1,035	939	916	889	990	954	1,090	1,258	1,039	1,169
Adv gas/oil CC	759	830	780	774	745	805	788	941	1,014	864	971
Adv CC with CCS	2,075	2,282	2,090	2,045	2,001	2,194	2,129	2,495	2,575	2,281	2,477
Internal combustion engine	1,271	1,406	1,259	1,255	1,212	1,338	1,293	1,330	1,534	1,360	1,328
Conv combustion turbine	1,096	1,163	1,126	1,076	1,065	1,138	1,115	1,300	1,293	1,179	1,353
Adv combustion turbine	681	724	711	669	666	708	696	820	832	739	993
Fuel cells	6,809	7,320	6,780	6,823	6,708	7,046	6,924	7,097	7,521	7,118	6,895
Adv nuclear	5,823	6,125	5,805	5,835	5,769	5,962	5,889	5,992	NA	6,052	6,034
Distributed generation - base	1,409	1,628	1,438	1,428	1,376	1,535	1,480	1,576	1,960	1,591	1,660
Distributed generation - peak	1,843	1,957	1,894	1,810	1,791	1,914	1,875	2,186	2,175	1,983	2,276
Battery storage	1,923	1,969	1,918	1,920	1,911	1,940	1,929	1,941	2,025	1,957	1,931
Biomass	3,627	3,966	3,607	3,642	3,560	3,794	3,728	3,900	4,196	3,907	3,650
Geothermal	NA	NA	NA	NA	NA	NA	NA	4,130	2,844	2,787	NA
MSW - landfill gas	8,299	9,064	8,228	8,299	8,103	8,672	8,468	8,735	9,384	8,735	8,423
Conventional hydropower	NA	NA	4,398	1,389	2,027	1,833	NA	3,495	3,560	2,948	3,520
Wind	2,256	1,653	2,256	2,256	2,082	1,413	1,450	2,654	2,243	1,687	1,539
Wind offshore	6,542	NA	6,012	NA	5,907	NA	NA	NA	6,823	6,647	NA
Solar thermal	NA	NA	NA	NA	NA	NA	3,935	4,214	4,798	4,240	3,952
Solar PV - tracking	1,877	1,637	1,648	1,392	1,724	1,442	1,864	2,218	2,332	1,461	1,915
Solar PV – fixed tilt	1,759	1,534	1,545	1,305	1,616	1,351	1,747	2,078	2,185	1,369	1,795

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

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

CCS = carbon capture and sequestration, CC = combined cycle, 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.